THE FIRST FEATHER

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AUSTRALIAN

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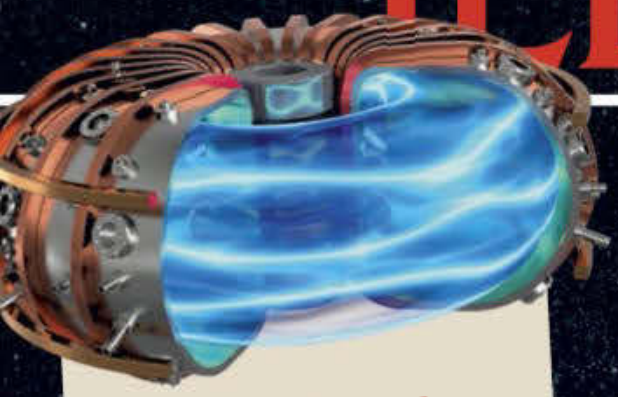

STAR POWER

Why plasma could save the world

FLY ME TO THE MOON

It's **lift-off** for space tourism

COVID-19

YOUR VACCINES ARE READY...

How they did it in under 12 months

BLACK HOLE: THE MOVIE

The bold plan to film Sagittarius A*

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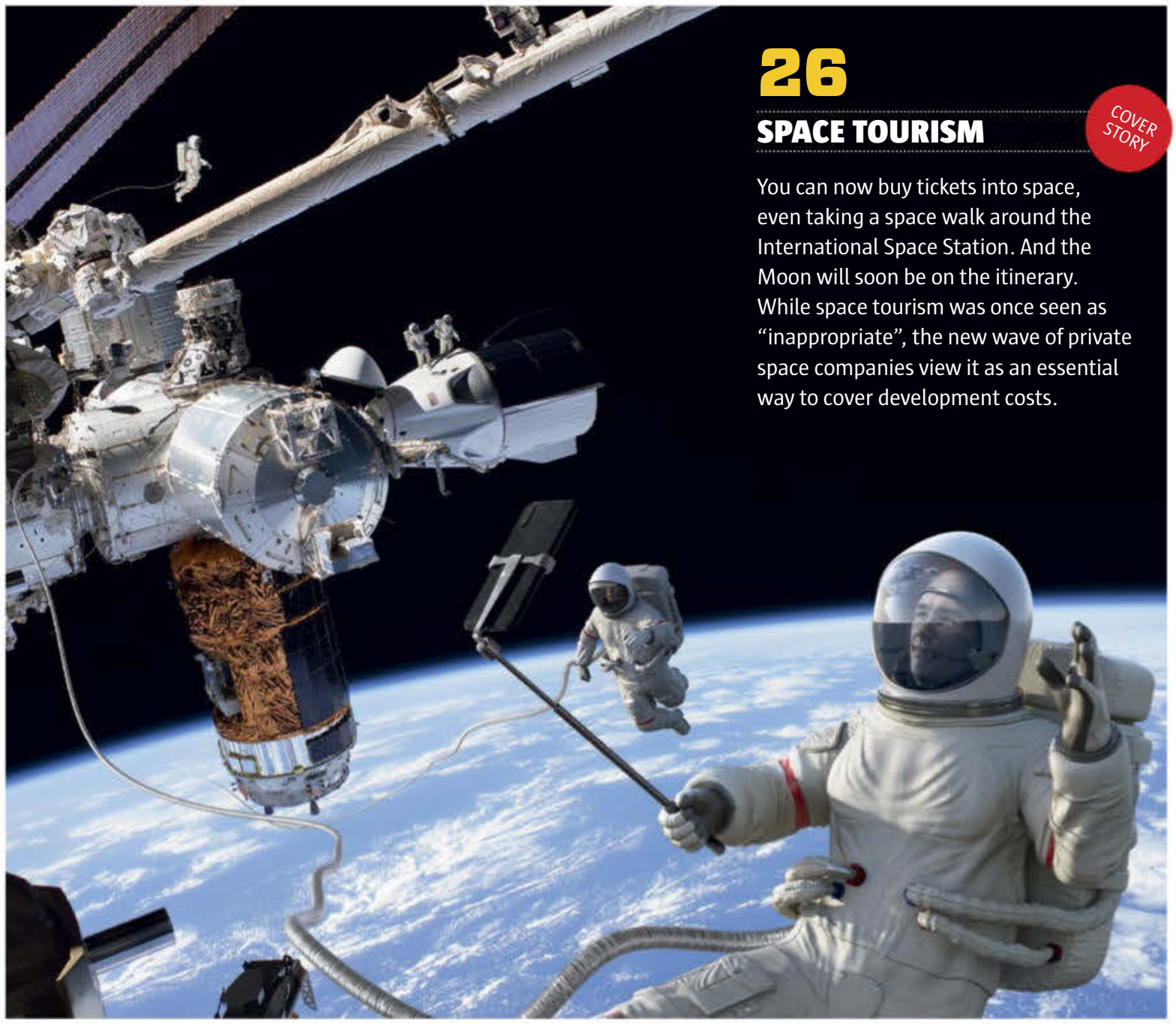
AUSTRALIAN SCIENCE ILLUSTRATED
PUBLISHED 1 APRIL 2021



REGULARS AND OTHER FEATURES

AUSTRALIAN SCIENCE ILLUSTRATED

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BONNIER INTERNATIONAL MAGAZINES
International Licensing Director: Julie Smartz
Art Director: Hanne Bo
Picture Editors: Allan Baggesø, Lisbeth Brünnich, Peter Eberhardt

SUBSCRIBE: 1300 361 146 or 9901 6111 or mymagazines.com.au

nextmedia

Science Illustrated is published 8 times a year by nextmedia Pty Ltd, a Forum Media Group Company.
ACN: 128 805 970
Level 8, 205 Pacific Highway, St Leonards NSW 2065

Proudly Printed In Australia

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.

Star quality: Chile telescope produces super-sharpness

Astronomers have captured the sharpest photo yet taken of the Carina Nebula, a birth place of new stars. Star nebulas are hard to see using the visible light spectrum, as dust blocks out the light. But the Gemini South telescope in Chile captures infrared, peering through the cloud. The telescope also corrects for the atmosphere's distortion of light, and the result is twice the sharpness of the Hubble space telescope. The image gives us an idea of the detail that the new James Webb space telescope will reveal.

Photo // International Gemini Observatory

NOIRLAB/NSF/AURA

Tiger king: tree hugger of a different stripe

Environmental campaigners are not the only ones who hug trees. The Siberian tiger embraces trunks to mark its territory, which may stretch up to 2000km within Russian forests. With a weight of up to 300kg, the Siberian tiger is the largest of the six tiger species which remain in the world. Its hugs leave hair, urine and scratch marks, while the tiger gets to smell the scents of any peers in the area. This picture won the prestigious Wildlife Photographer of the Year Grand Title award.

Photo // Sergey Gorshkov

WILDLIFE PHOTOGRAPHER OF THE YEAR 2020

Life on Earth could be observed from more than 1000 stars

The Milky Way probably includes billions of solar systems with inhabitable planets. Astronomers have now calculated how many of them have the opportunity to spot us.

ASTRONOMY Over the past few decades, astronomers have discovered more than 4000 exoplanets – those orbiting other stars – within our galaxy, the Milky Way. Some of these could harbour life, perhaps even intelligent civilisations which might, like our own, be scanning the stars for signs of life elsewhere.

But how visible would we be when viewed from the outside? Scientists from Cornell University in the United States have looked into this, and they calculate that our world – and the evidence of life on it – could be observed from 1004 known stars located within a distance of 326 light years.

The scientists used similar methods to those used in our own searches in the other direction, seeking exoplanets and evidence of life on those. In most cases, astronomers are able to discover an exoplanet when, as observed from Earth, it moves in front of its star, so the starlight is slightly dimmed. If alien civilisations are to discover our own world, they would need to be located in a direction that allows their line of sight to encounter both the Sun and Earth. Then, if they find us, that line of sight should also allow them to see evidence of life here. The sunlight that passes through Earth's atmosphere is influenced by the substances present in it, so that analyses of light wavelengths would reveal evidence of life such as oxygen and methane.

We know that 95% of these 1004 stars are so old that life on their planets has had billions of years to evolve. One particularly interesting star is K2-155, located 200 light years away and orbited by an Earth-like planet.

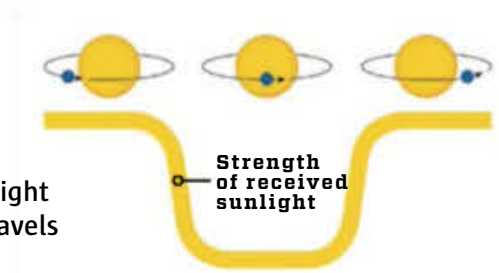
Other candidates could emerge in the decades to come, because the stars' reciprocal locations change all the time. In 2044 another star with exoplanets, this one only 12 light years away, will be in a position to spot us.

Earth and its life would be seen indirectly

Civilisations on exoplanets could only discover our world and see evidence of life by studying changes in sunlight as Earth passes in front of the Sun.

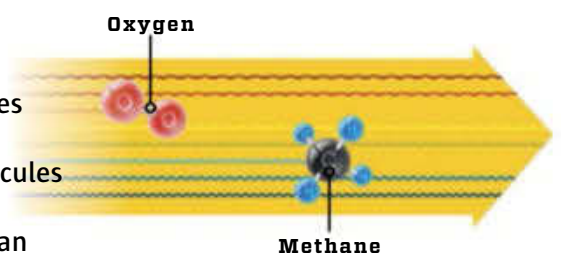
Earth is revealed by its own shadow

1 If an exoplanet is located in the right position relative to our Solar System, aliens could spot that the intensity of the sunlight dips for a period of time every year as Earth travels in front of the Sun, blocking out a little light.



Life leaves its mark on the sunlight

2 A small quantity of the sunlight passes through Earth's atmosphere, then continues on towards the exoplanet. Molecules in the atmosphere absorb specific light frequencies, so that analyses of the light can reveal signs of life such as oxygen and methane.



Test yourself Answers to p82. No peeking!

1: 5 metres. With a length of 12 metres, the field will be 5 metres wide. The answer is a Pythagorean triangle, with long side 12m, while the circle's diameter, 13m, is the length of the field's diagonal. This is a 5, 12, 13 right-angled triangle: $a^2 + 12^2 = 13^2$.

2: 5. The answer is found by multiplying each weight by its position on the lever arm. (8 × 3) + (2 × 1) = 26 on the left side., so to match this, the right side must be: (3 × 2) + (**5** × 4) = 26. Pedants using the half-point centres of gravity will reach the same result: (8 × 2.5) + (2 × 0.5) = 21 = (3 × 1.5) + (**5** × 3.5).

3: A.

4: 5046. The correct answer is found by reducing the equation:
x + (x - 512) + (x - 2513) + (x - 4814) = 12,345.
X is = 5046. The other three got 4534, 2533, and 232 votes, respectively.

5: C. See page 16.
6: A. See page 30.
7: D. See page 64.
8: C. See page 72.

ARCHAEOLOGY When scientists from the US University of California recently excavated a 9000-year-old grave in the Andes mountains of Peru, they were in for a major surprise. The grave included many well-made knives and spearheads made of flint, which is usually taken as a clear indication of the deceased being a well-respected hunter.

Apart from valuable hunting weapons, the grave also included prey. The scientists found bones from big game such as deer and llama, together with tools for butchering the animals and scraping their hides.

The surprise came from the hunter's own bones, which were slender and light, making scientists suspect that it could be a woman. This was confirmed by scrutiny of the protein amelogenin in the tooth enamel, confirming that the game hunter, estimated to have died at age 17-19, was indeed a woman.

The discovery challenges the idea of hunter-gatherer communities in which men hunted while the women took care of other chores such as collecting roots, fruit, and berries. The existing gender role idea is based on modern hunter-gatherer communities in Africa.

The scientists broadened their studies, scrutinising excavation reports from 107 Stone Age graves from 8000+ years ago across South and North America. The result showed that there were 26 graves with hunting weapons, and 10 of them probably belonged to women. This eye opener could help rewrite archaeologists' view of Stone Age gender roles and social structures.

Stone Age women hunted big game

The excavation of a 9000-year-old hunter grave is changing scientists' idea of gender roles in Stone Age hunter-gatherer communities.

Nine thousand years ago, a woman aged between 17 and 19 was buried in the mountains of Peru. Her grave included well-made spearheads, indicating that she was a respected hunter.

R. HASS ET AL., R. HASS UC DAVIS & M. VERDELIVO/UC DAVIS IET

SHUTTERSTOCK, NASA & T. PYLE/IPL_CALTECH/NASA

Super-Earth could see us

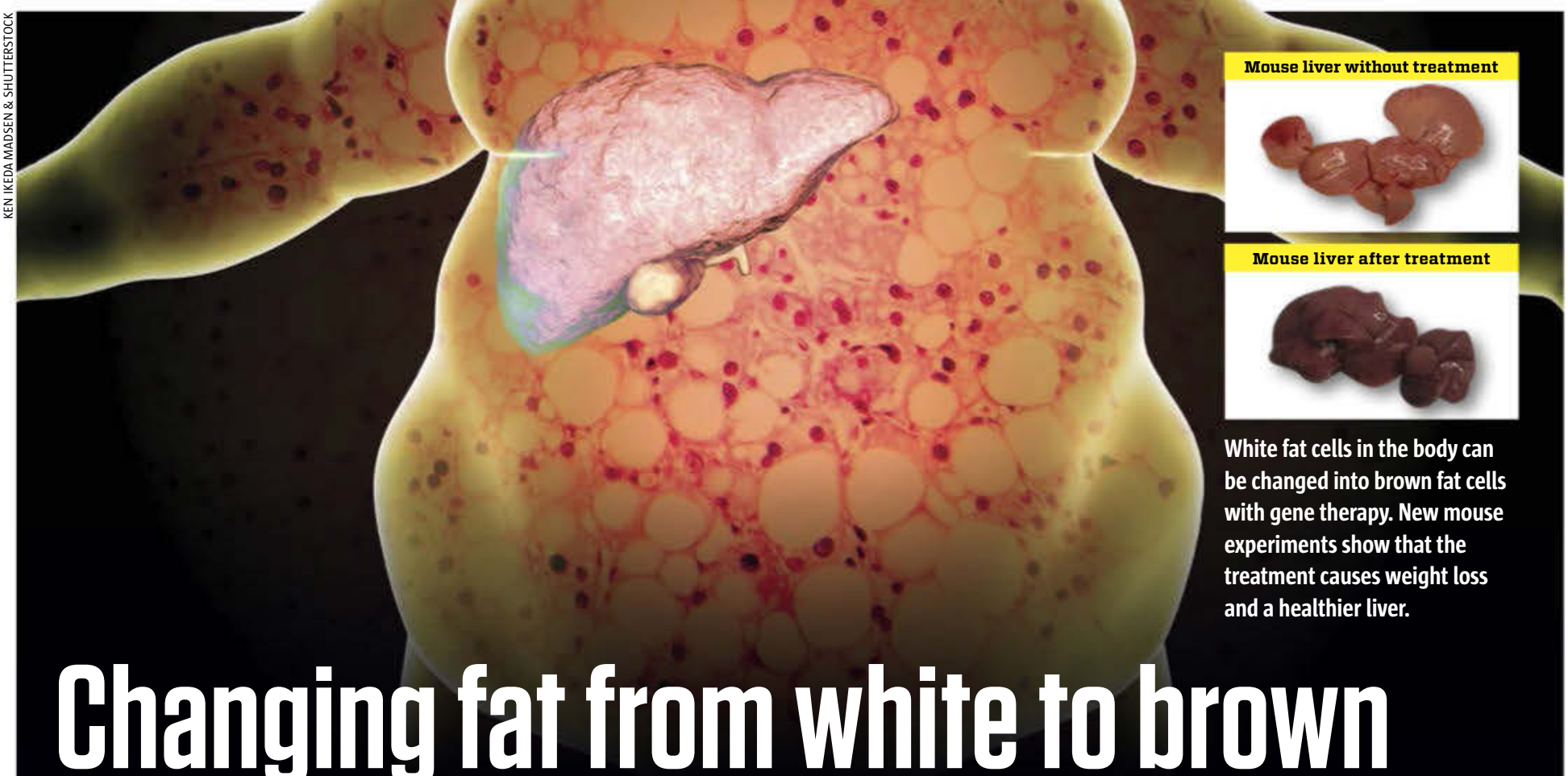
The exoplanet K2-155d orbits its star 200 light years away, and in the same way that we spotted it, any inhabitants of the planet would also be able to see us. K2-155d is a super-Earth that might include life.

- **Diameter:** 1.64 times that of Earth.
- **Orbit time around star:** 40.6 Earth days.
- **Surface temperature:** An estimated 16°C, which allows liquid water.
- **Atmosphere:** Remains unknown.

The K2-155d exoplanet and its star are obvious candidates for study using the James Webb space telescope that NASA is constructing.

Artificial light will not be directly visible to alien civilisations on planets in other solar systems. What they might spot instead would be Earth's shadow.

KEN IKEDA MADSEN & SHUTTERSTOCK



White fat cells in the body can be changed into brown fat cells with gene therapy. New mouse experiments show that the treatment causes weight loss and a healthier liver.

Changing fat from white to brown

The removal of one single gene in our fat cells could be the key to a new obesity treatment where scientists could make fat cells burn energy instead of accumulating it.

MEDICINE New experiments with mice show that it is possible to treat obesity by changing the fat cells of the body. US scientists from the University of Massachusetts used the CRISPR method that can remove specific genes from genetic material to make the discovery.

Body fat exists in two variants: white and brown. In white fat, cells function as passive energy storage, whereas brown fat cells actively boost fat burning, converting the fat into heat. Babies have plenty of brown fat cells, allowing them to quickly heat their bodies, but the number is reduced as we grow older.

The new method can change this. The scientists extracted white fat cells from people, removing a gene by the name of NRIP1. Without this gene the cells developed into brown fat cells, which the scientists subsequently injected into lab mice. The scientists put the mice on a fattening diet to see the effect compared with other mice with ordinary white fat cells.

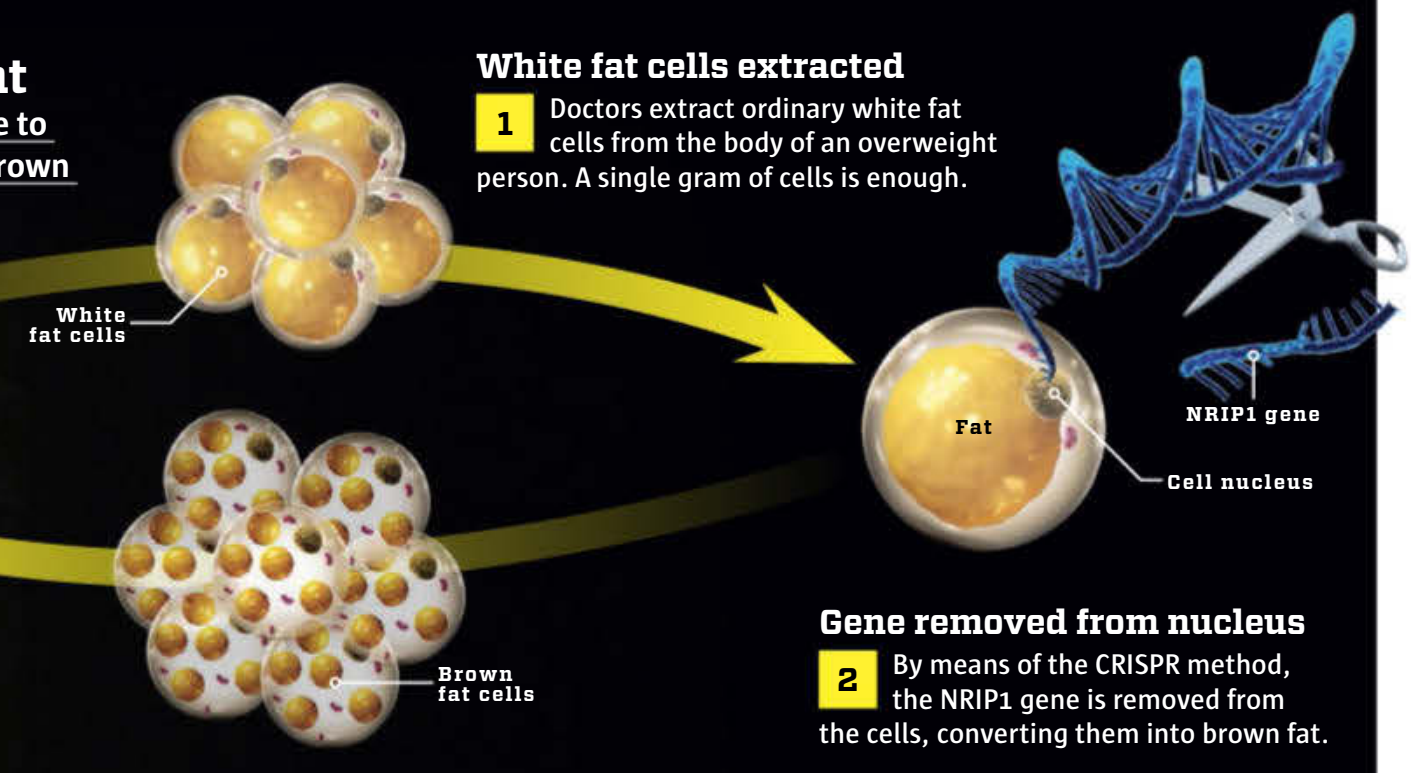
The results showed that the mice with brown fat only gained half as much weight as the mice with white fat. Moreover, the mice with brown fat continued to have normal blood sugar regulation and normal sensitivity to insulin. The mice with white fat, however, developed symptoms of diabetes with poor blood sugar regulation.

Studies of the mice livers also revealed that the mice with brown fat had normal brown livers, whereas those with white fat had developed enlarged and pale livers.

The scientists are now going to test the method on monkeys before trials involving humans can begin.

One gene converts fat

A new treatment may soon be able to change unhealthy white fat into brown fat by disabling one single gene.



White fat cells extracted

1 Doctors extract ordinary white fat cells from the body of an overweight person. A single gram of cells is enough.

Gene removed from nucleus

2 By means of the CRISPR method, the NRIP1 gene is removed from the cells, converting them into brown fat.

Brown cells inserted

3 When the brown fat cells are inserted into the body, they convert fat into heat, making the overweight person lose weight.

Wind turbine harvests power from high-speed traffic

Air pressure caused by cars could generate power for street lamps and the grid.

TECHNOLOGY Cyclists know all too well the force of air pressure which can be delivered by a vehicle overtaking at speed. Now a UK company, Alpha 311, is suggesting that this air pressure is a potential source of power, and aims to use existing motorway infrastructure to generate and carry green energy. The company wants to install cylindrical wind turbines on lamp posts, so that the air pressure from passing cars will power the turbines and charge a battery that can then power street lights. Turbines located at the centre of the road will be particularly efficient, it is suggested, because they will be activated from both sides.

Tests of a turbine prototype show that it can generate up to 70kWh a day, equivalent to 21m^2 of solar panels (sufficient to supply 10 homes with energy). The company estimates that the final version of the traffic turbine will cost around A$3500.

Cables currently supplying power to street lights could be repurposed to give surplus energy from turbines to the electricity grid as green energy for other purposes. The company is in discussion with authorities in the UK and US to field-test the idea.

ALPHA 311

Cylindrical turbines on lamp posts could be powered by air pressure from passing cars. A turbine prototype generates 70kWh from a day's traffic.

Memory without a brain? The secrets of the Venus flytrap

Genetically-modified versions of the Venus flytrap plant reveal that it uses memory in its search for insects.

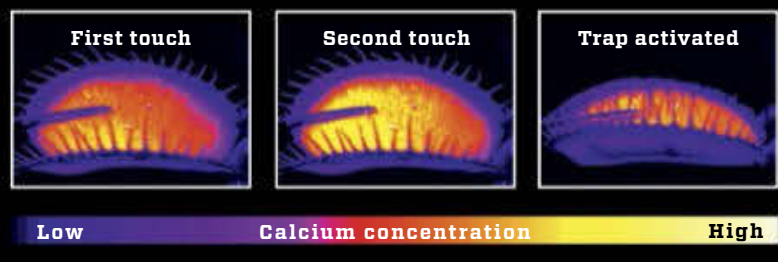
BIOLOGY Plants have no brain in the literal sense of the word, but nevertheless, the activity of the carnivorous Venus flytrap indicates that it has some kind of short-term memory.

The plant captures insects by trapping them between two leaves when they touch sensory hairs on the inside of the leaves. However the trap is not activated by the first touch. It takes several touches, so clearly the plant can 'remember' previous touches. Often two touches within 30 seconds is sufficient to activate the trap. Subsequently it takes another three touches before the plant produces the enzymes needed to break down the prey. In other words, the plant can count to five.

Scientists from the National Institute for Basic Biology in Japan have studied the process. The sensory hairs trigger cells in the leaves to secrete calcium, and only when a specific level of calcium is reached will the trap activate. The scientists used gene modification to make versions of the plant that produce a protein which lights up when subjected to calcium. It became clear that the first touch of a sensory hair made the leaves light up, but not sufficiently to activate the trap. Not until the second touch was the calcium level high enough for the trap to be activated.

According to the scientists, this strategy avoids the plant wasting energy every time a sensory hair is touched by a raindrop or other non-prey event. A visiting insect will almost certainly trigger the hairs several times, closing the trap.

The fly can touch the sensory hairs of the carnivorous plant once unharmed. But the second touch will activate the trap.



Touch of sensory hairs triggers calcium in the plant's leaves. Reaching a specific level activates the trap.

SHUTTERSTOCH & NIBB

Gene therapy could return sight to people who are blind

The eye disease glaucoma destroys the optic nerve that connects the eye to the brain's centre of vision. According to new experiments, a protein can repair the damage.

MEDICINE Scientists from the UK's University of Cambridge have demonstrated that it is possible to restore optic nerves which have been destroyed, causing blindness. In experiments with mice, the scientists have used gene therapy to activate the gene that is responsible for producing the protein protrudin. This is involved in the composition of both nerve cells' dendrites that receive signals from the eye's visual cells, and of axons, which pass the signals on. The axons run all the way from the eye's retina through the optic nerve to the centre of vision that is located at the back of the brain.

Glaucoma is one of the most common causes of blindness in older people. The disease occurs when axons are damaged and fail to regenerate because the protein is not present in fully-grown axons. By stimulating nerve cells to produce an excess quantity of the protein, the scientists managed to make the axons grow as if the nerve cells were very young. The scientists first cultured the nerve cells in culture dishes, cutting their axons in two by means of laser. Subsequently they stimulated the production of protrudin, making the axons regenerate.

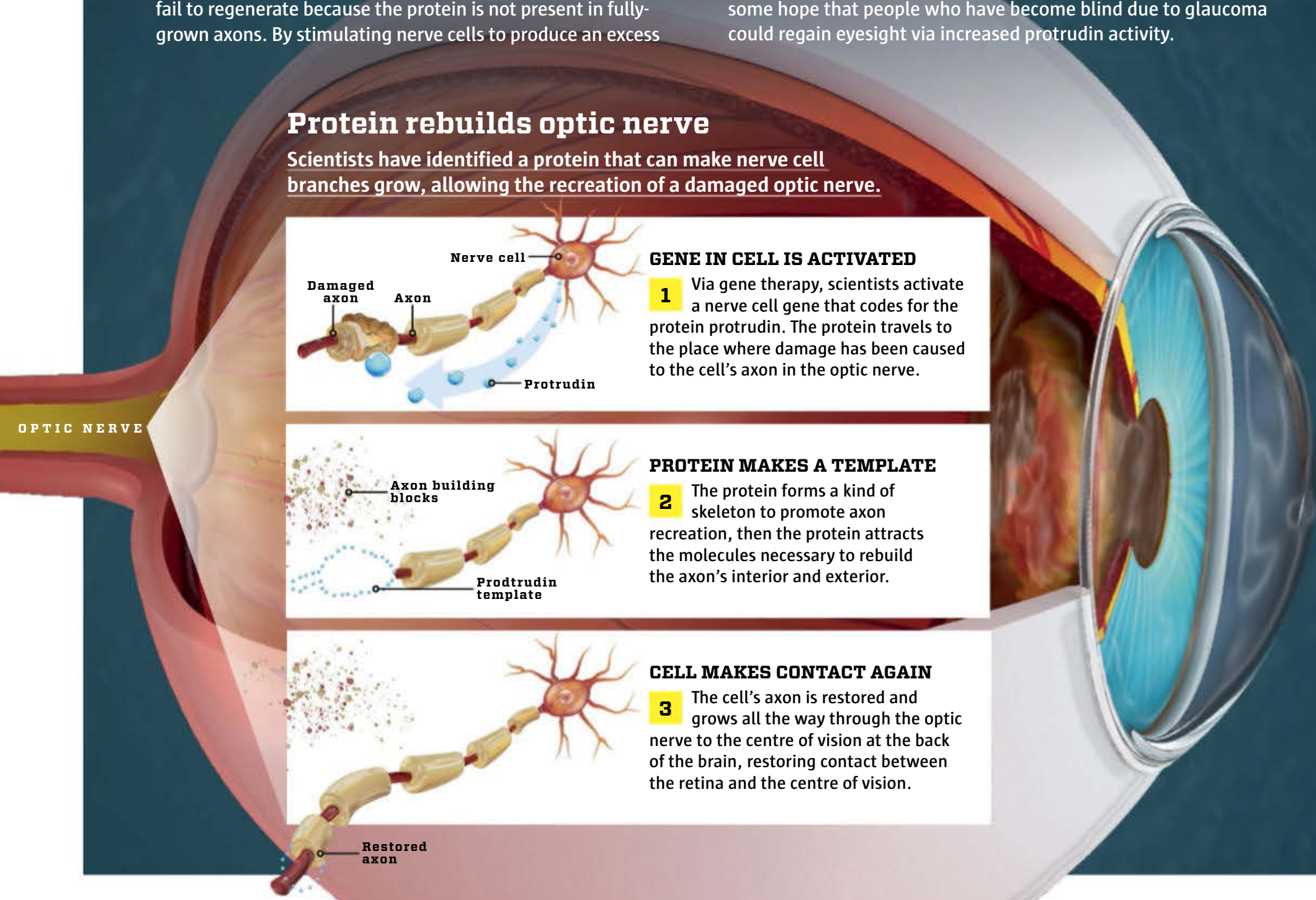
When the scientists subsequently tested the method on living mice with damaged optic nerves, the axons from the nerve cells grew considerably over the following two weeks.

The experiments showed that protrudin works in two ways. First it produces a skeleton that controls the extension of the axon. Subsequently it attracts the building blocks for reconstruction.

The new results, which will require extensive trials, hold some hope that people who have become blind due to glaucoma could regain eyesight via increased protrudin activity.

Protein rebuilds optic nerve

Scientists have identified a protein that can make nerve cell branches grow, allowing the recreation of a damaged optic nerve.



GENE IN CELL IS ACTIVATED

1 Via gene therapy, scientists activate a nerve cell gene that codes for the protein protrudin. The protein travels to the place where damage has been caused to the cell's axon in the optic nerve.

PROTEIN MAKES A TEMPLATE

2 The protein forms a kind of skeleton to promote axon recreation, then the protein attracts the molecules necessary to rebuild the axon's interior and exterior.

CELL MAKES CONTACT AGAIN

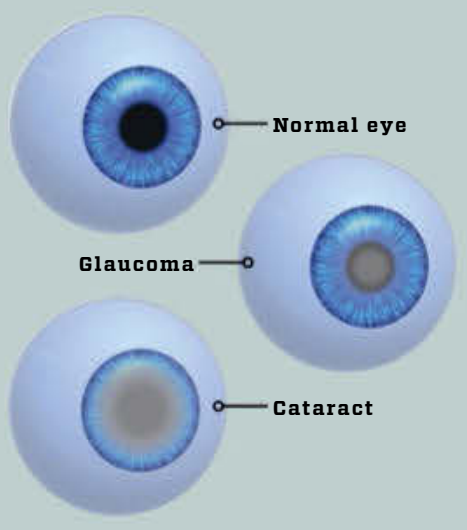
3 The cell's axon is restored and grows all the way through the optic nerve to the centre of vision at the back of the brain, restoring contact between the retina and the centre of vision.

Acute glaucoma can cause blindness in as little as a few days.

Overpressure can cause glaucoma

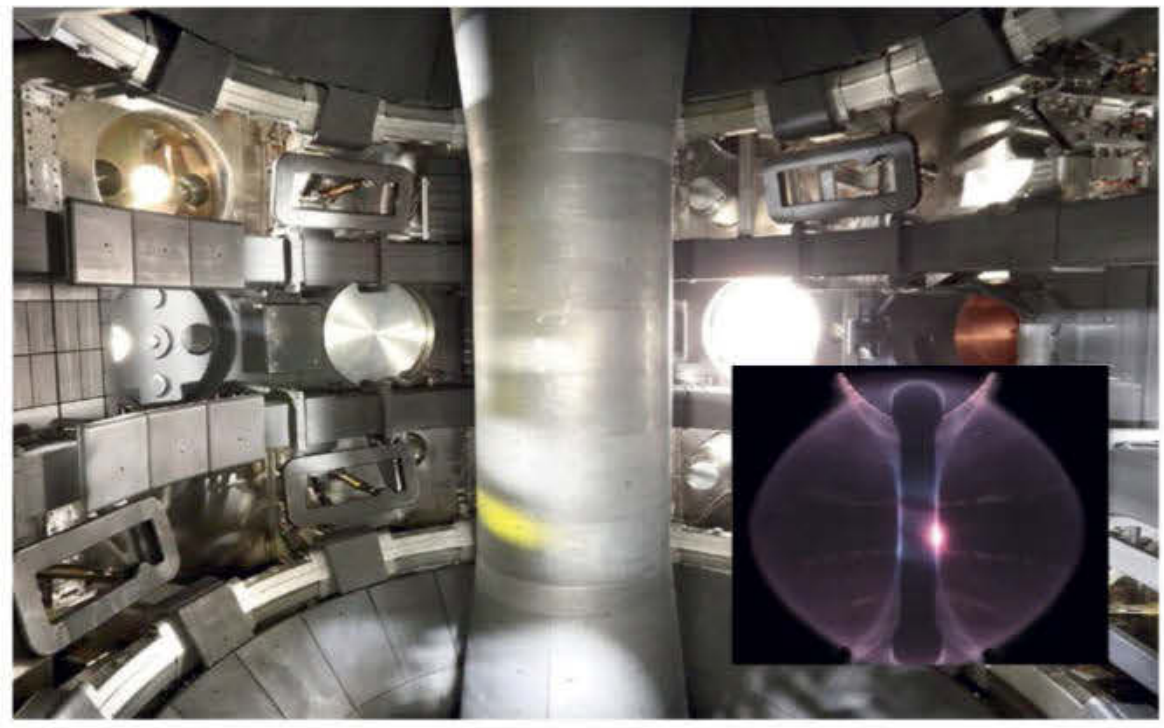
Glaucoma is caused by damage to the optic nerve between the eye and the centre of vision. The exact cause is unknown, but the disease has to do with the fluid pressure in the eyeball becoming too high. Around 2% of the world's population suffer from the disease, which comes in two versions:

- **Open-angle glaucoma:** this is age-related and can appear without any prior symptoms. When the patient discovers that vision of one eye is impaired, the damage to the optic nerve has often built up over several years.
- **Closed-angle glaucoma:** this is acute and often affects people of 40+ years with small, long-sighted eyes. The vision is periodically clouded, and patients feel pain over their eyebrows. Without treatment, the patient could go blind in a matter of a few days.



Aside from cataracts, glaucoma is the most frequent cause of blindness.

KEN IKEDA MADSEN /SHUTTERSTOCK



The MAST Upgrade test reactor heats hydrogen to red-hot plasma, which is then captured in a magnetic field (insert). This process is the first step towards fusion energy.

UK ATOMIC ENERGY AUTHORITY

New reactor paves the way to fusion energy

British scientists have built a test reactor that takes a step closer to the dream of fusion energy and its promise of an inexhaustible source of green energy.

ENERGY It has taken seven years of work and an investment of nearly A$100 million to complete the reconstruction of the MAST Upgrade test reactor, which hopes to pave the way for future fusion power plants. Located at the Culham Centre for Fusion Energy in Oxfordshire, the reactor has already given indications that it may have been worth the effort. It has been activated for the first time, producing the red-hot hydrogen plasma that is the prerequisite for fusion.

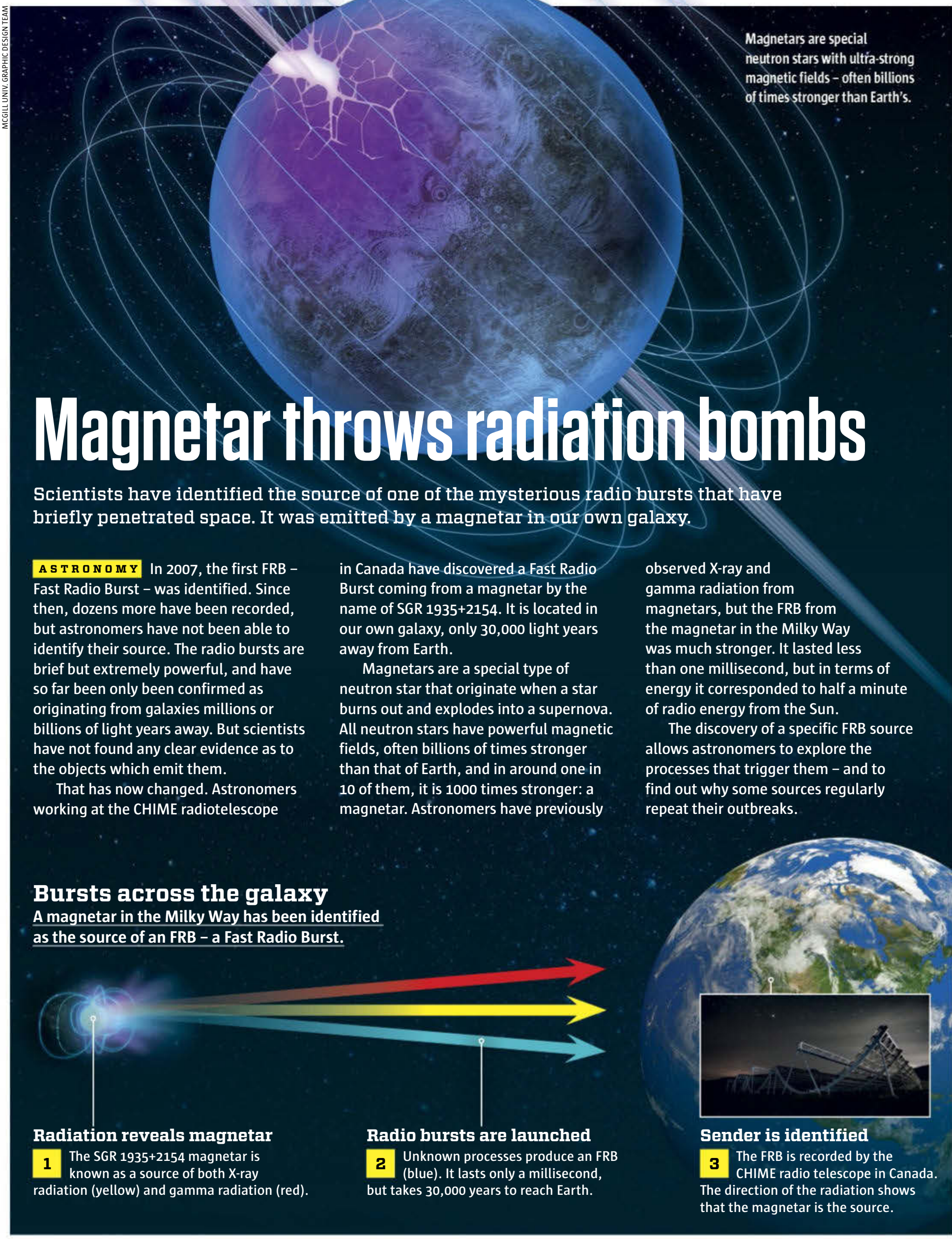
MAST Upgrade is designed to produce temperatures of 50-100 million °C. The high temperatures convert the hydrogen into plasma in which the atomic nuclei are separated from the electrons. It is then possible to make the hydrogen nuclei fuse into helium nuclei, a process which corresponds to the activity that takes place inside the Sun, and which liberates huge quantities of energy.

The potential of fusion energy is huge, but so are the challenges. The plasma cannot touch the sides of the reactor, so must be contained within a magnetic field. In most test reactors, this happens in a doughnut-shaped reactor, but MAST Upgrade's containment zone is more like a cored apple (see also p69).

The goal of MAST Upgrade is not to achieve fusion but to find solutions that can keep the plasma in check and divert surplus heat. These solutions will then be used in other test reactors that move still closer to successful fusion, such as the international ITER reactor that is under construction in France. This should be completed in 2025, and aims to achieve an autonomous fusion process at 150 million °C within 10 years. The ultimate goal is to cross the point at which fusion of the hydrogen cores releases more energy than is supplied from the outside.

2025 is the year all fusion researchers are waiting for: the inauguration of the big ITER reactor in southern France.

MCGILL UNIV. GRAPHIC DESIGN TEAM



Magnetars are special neutron stars with ultra-strong magnetic fields – often billions of times stronger than Earth's.

Magnetar throws radiation bombs

Scientists have identified the source of one of the mysterious radio bursts that have briefly penetrated space. It was emitted by a magnetar in our own galaxy.

ASTRONOMY In 2007, the first FRB – Fast Radio Burst – was identified. Since then, dozens more have been recorded, but astronomers have not been able to identify their source. The radio bursts are brief but extremely powerful, and have so far been only been confirmed as originating from galaxies millions or billions of light years away. But scientists have not found any clear evidence as to the objects which emit them.

That has now changed. Astronomers working at the CHIME radiotelescope in Canada have discovered a Fast Radio Burst coming from a magnetar by the name of SGR 1935+2154. It is located in our own galaxy, only 30,000 light years away from Earth.

Magnetars are a special type of neutron star that originate when a star burns out and explodes into a supernova. All neutron stars have powerful magnetic fields, often billions of times stronger than that of Earth, and in around one in 10 of them, it is 1000 times stronger: a magnetar. Astronomers have previously observed X-ray and gamma radiation from magnetars, but the FRB from the magnetar in the Milky Way was much stronger. It lasted less than one millisecond, but in terms of energy it corresponded to half a minute of radio energy from the Sun.

The discovery of a specific FRB source allows astronomers to explore the processes that trigger them – and to find out why some sources regularly repeat their outbreaks.

Bursts across the galaxy

A magnetar in the Milky Way has been identified as the source of an FRB – a Fast Radio Burst.

Radiation reveals magnetar

1 The SGR 1935+2154 magnetar is known as a source of both X-ray radiation (yellow) and gamma radiation (red).

Radio bursts are launched

2 Unknown processes produce an FRB (blue). It lasts only a millisecond, but takes 30,000 years to reach Earth.

Sender is identified

3 The FRB is recorded by the CHIME radio telescope in Canada. The direction of the radiation shows that the magnetar is the source.

JINGCHUAN YU, BEIJING PLANETARIUM & ANDRE RENARD/AFP/RITZAU SCANPIX

Monster gulls conquered the air after pterosaur extinction

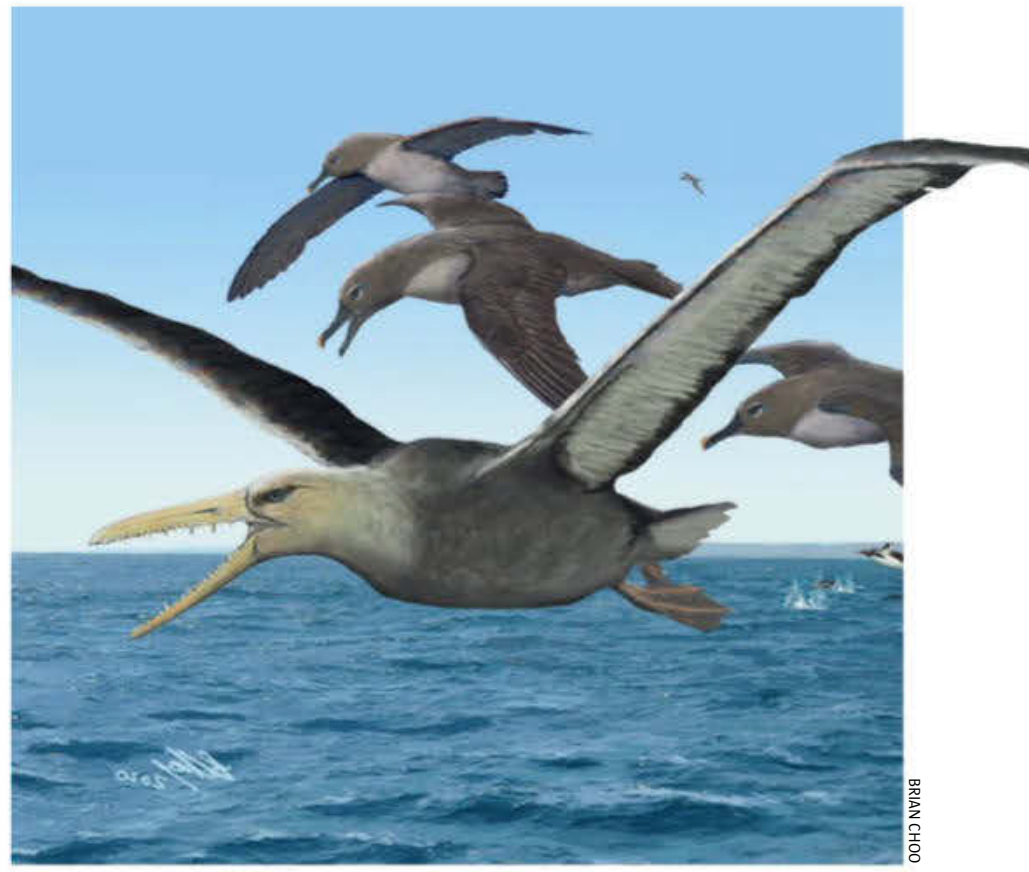
Predatory birds with six-metre wing spans were already taking flight 50 million years ago.

PALAEONTOLOGY The disaster event that wiped out the dinosaurs 66 million years ago also put an end to the pterosaurs that had ruled the air for 150+ million years.

But birds were ready to take over. By 50 million years ago, huge gull-like birds were gliding above the oceans, according to new dating of fossils from Seymour Island off Antarctica. Scientists from the University of California have studied a leg bone and a jaw fragment from a sea bird species that belonged to the family of pelagornithids. Based on the bone sizes, the scientists estimate that the species had a wing span of up to 6 metres and a skull that was at least 60cm long, making it one of the biggest flying birds that ever existed. (The modern record holder, the wandering albatross, has a wing span of up to 3.5 metres.) Other fossils have shown that big pelagonithids existed as late as seven million years ago, an aerial dominance of more than 40 million years.

Pelagornithids are also known as bony-toothed birds, because their beaks included teeth-like jawbone projections. The points helped thebids to hold on to fish that they captured.

For more on pterosaurs and the origin of feathers, see pages 34-41.



BRIAN CHOO

The king of sea birds originated 50 million years ago; it had a wing span of six metres, and a saw-toothed beak for holding on to captured fish.

New method helps patients sober up three times faster

A new method removes alcohol from the blood via the lungs far faster than leaving the liver to break it down naturally.

MEDICINE Canadian scientists have invented a method that can remove alcohol from the blood three times faster, which could assist greatly in treating patients with alcohol poisoning.

The idea is to make the patient hyperventilate under controlled conditions which avoid dizziness nor nausea. This uses a device known as a Clear-Mate, through which the intoxicated person breathes. The device ensures an ideal balance between oxygen and carbon dioxide in the inhaled air, and hence in the patient's blood.

Hyperventilation makes alcohol evaporate through the lungs, rendering the liver's work superfluous. Scientists from the University of Toronto tested the method by making five volunteers drink half a glass of vodka twice. The first time they allowed the test subjects to burn alcohol in the natural way without any help. It took 2-3 hours to halve the alcohol content of the blood in this way.

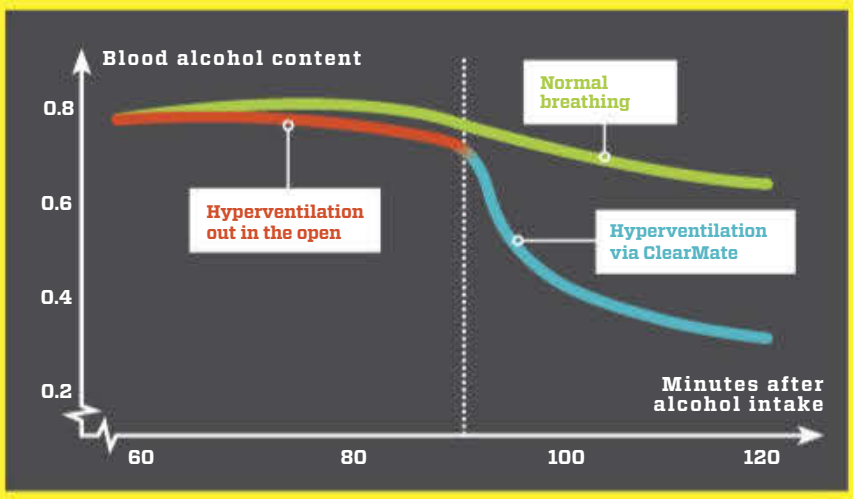
The second time they were asked to hyperventilate out in the open for a while, after which they continued rapid breathing through a ClearMate.

The experiments showed that the method reduced the alcohol level in the blood about three times faster than the liver alone.

Doctors have limited remedies against alcoholic poisoning. They can remove the alcohol from the blood via dialysis, but that is an extensive procedure. The new method is much simpler, and as the ClearMate device is only the size of a briefcase, doctors can also easily bring it to a patient.

UNIVERSITY HEALTH NETWORK

When a patient with alcoholic poisoning hyperventilates through the ClearMate device, alcohol evaporates through the lungs.



Alcohol levels normally reduce only slowly. But it happens faster if the patient hyperventilates, particularly when using a ClearMate device.

What is the lowest temperature a human being can survive?

'Is there a lower limit to temperatures our bodies can tolerate even when wrapped in clothes? Can temperatures become so low that the lungs freeze when breathing air?'

PHYSIOLOGY At a temperature of -40°C, a healthy human being should be able to go for a run for three minutes without any consequences, even without clothes. But if naked skin is subjected to temperatures below -60°C, it will immediately freeze, and the cells die. If the entire body is exposed, a person will die almost immediately. Even with a thick layer of clothing, areas around the eyes and nose will be under risk of severe frostbite.

Breathing freezing cold air can certainly harm airways and lungs: the Inuit and other people who live in very cold climates often experience lung injury. Inhaling through the nose is better than the mouth, as cold air will be warmed and moisturised as it passes through the nose, throat and upper airway. Scientists in Antarctica often breathe through a kind of snorkel that passes through their jackets so the air is heated by the body as well.

WIND MAKES COLD 'FEEL LIKE' COLDER

Although the thermometer may indicate a a temperature only a few degrees below freezing point, wind can make it feel much colder. The chill factor or cold index – often now incorporated into "feels like" temperatures on weather forecasts – occurs beause our bodies usually heat the air around us, producing a layer of insulation. But if this layer is blown away by the wind, we will cool faster, so the skin gets colder. During a storm, -20°C may thereby be just as dangerous as -40°C in calm weather. Staying dry is also important, as the body will cool much faster when clothes are wet, or if your body is wet from sweat underneath the clothes.

MAARTEN TAKENS

With an average temperature of -60°C, Vostok, Antarctica, is the world's coldest place.

NASA

Astronauts on short Mars missions will consume food from Earth and plants from NASA's 'Veggie' system which has been developed on the International Space Station.

Will any colonists on Mars have go vegan?

NUTRITION Future Martians will probably not need to be pure vegans. In 2019, two scientists from the University of Central Florida published calculations of calorie consumption, land use and potential food sources for a colony on Mars that has a million inhabitants. The scientists concluded that the nutritional requirements could be met using vegetables, insects, and cell cultures that can produce animal proteins from milk, eggs and meat, but without any animals. In the same report, the scientists concluded that it will probably take 100 years from establishment for a Mars colony to become completely self-sufficient without the need for frequent food supply from Earth.

The body will fail in severe cold

At a body temperature below 35°C, the body starts to tremble. At even lower temperatures, the skin turns blue, the cardiac rhythm is reduced, and it becomes almost impossible to move.

32-35°C

MILD SUPERCOOLING

Muscles: Tremble to generate heat.
Heart: Cardiac rhythm and blood pressure rise.
Lungs: Fast breathing.
Blood: High blood sugar level, as glucose is digested slowly.
Skin: Pale, as the blood vessels contract.

28-32°C

MODERATE SUPERCOOLING

Muscles: Tremble vigorously.
Arms and legs: Motions are slow and uncoordinated.
Brain: Becomes confused and reacts slowly.
Lips, ears, fingers, toes: Turn blue as the blood supply almost stops.

20-28°C

SEVERE SUPERCOOLING

Muscles: Stop trembling.
Arms and legs: Walking and motions are almost impossible.
Heart: Cardiac rhythm and blood pressure are reduced.
Lungs: Slow breathing.
Brain: Memory loss, very groggy.
Mouth: Very difficult to speak.
Skin: Turns blue and swollen.

SHUTTERSTOCK

SCALE · Are there more orchid or bird species?

Orchids

New orchid species are discovered every year, and the number of orchid species is now higher than 28,000. So around 10,000 more identified orchid species exist than bird species, and scientists estimate that some 5000 more orchid species are waiting to be discovered.

SHUTTERSTOCK

There are around

10,000

more orchid species than bird species.

SHUTTERSTOCK

Birds

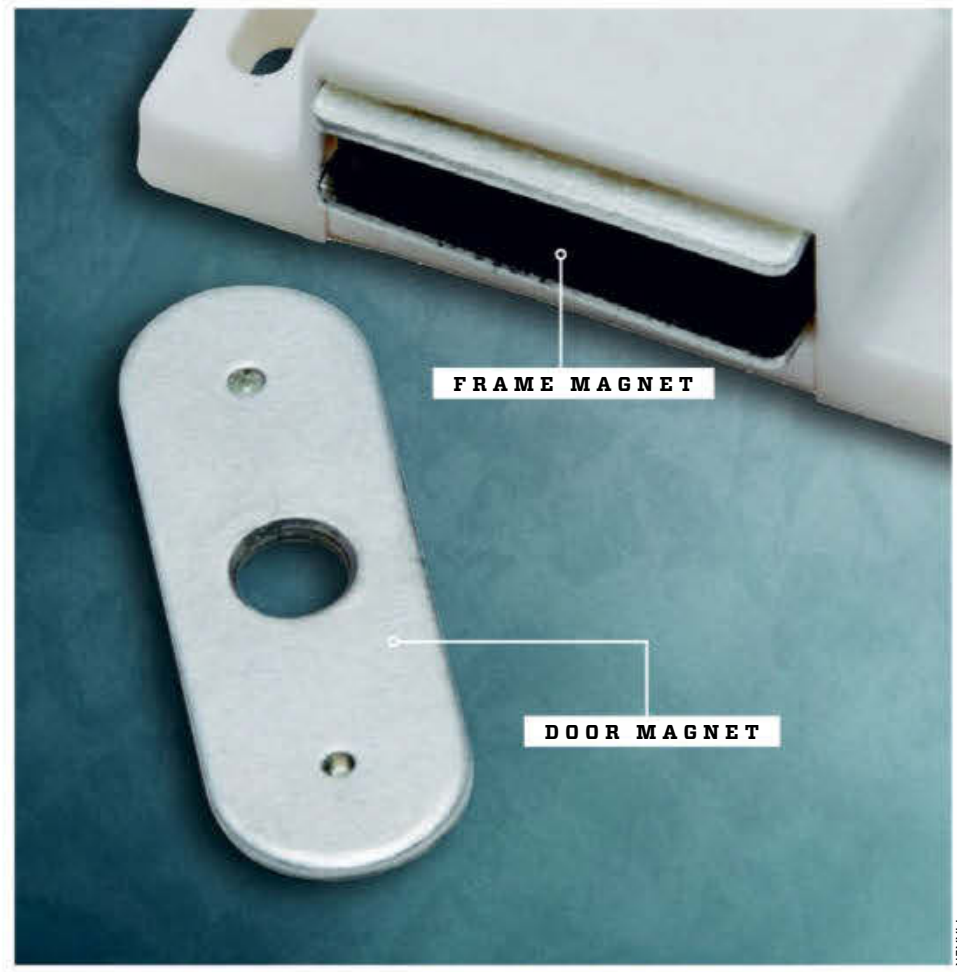
For many years, ornithologists thought that the number of bird species was 9000-10,000, but in a report from 2016 scientists used a new method to estimate the number of species based on an analysis of 200 species. The new method doubled the probable number of species to around 18,000.

How long does it take for a magnetic door catch to lose its strength?

PHYSICS The answer is 'a very long time', unless the magnet is subjected to some severe external influence, such as high temperature or physical damage. The strontium iron magnets that are typically used in fridge magnets and magnetic catches will lose no more than 1% of their strength in 100 years. The iron atoms in a magnet are organised according to the magnetic field in which they were magnetised. As long as the atoms remain organised, the magnet will retain its strength. The organisation can only be disturbed if the magnet is subjected to relatively strong external forces or fields.

A MAGNET HAS FOUR ENEMIES

- **Heat:** High temperatures could weaken the magnet.
- **Damage:** Physical damage reduces strength.
- **Magnetic fields:** A magnet can become weaker after being in contact with other magnets.
- **Blows and vibration** only have limited negative effect.



FIXXER

The atoms inside a magnetic catch are difficult to weaken unless an external force reduces the organisation of its magnetised atoms.

WHAT IS THIS? · Wave Rock in Western Australia

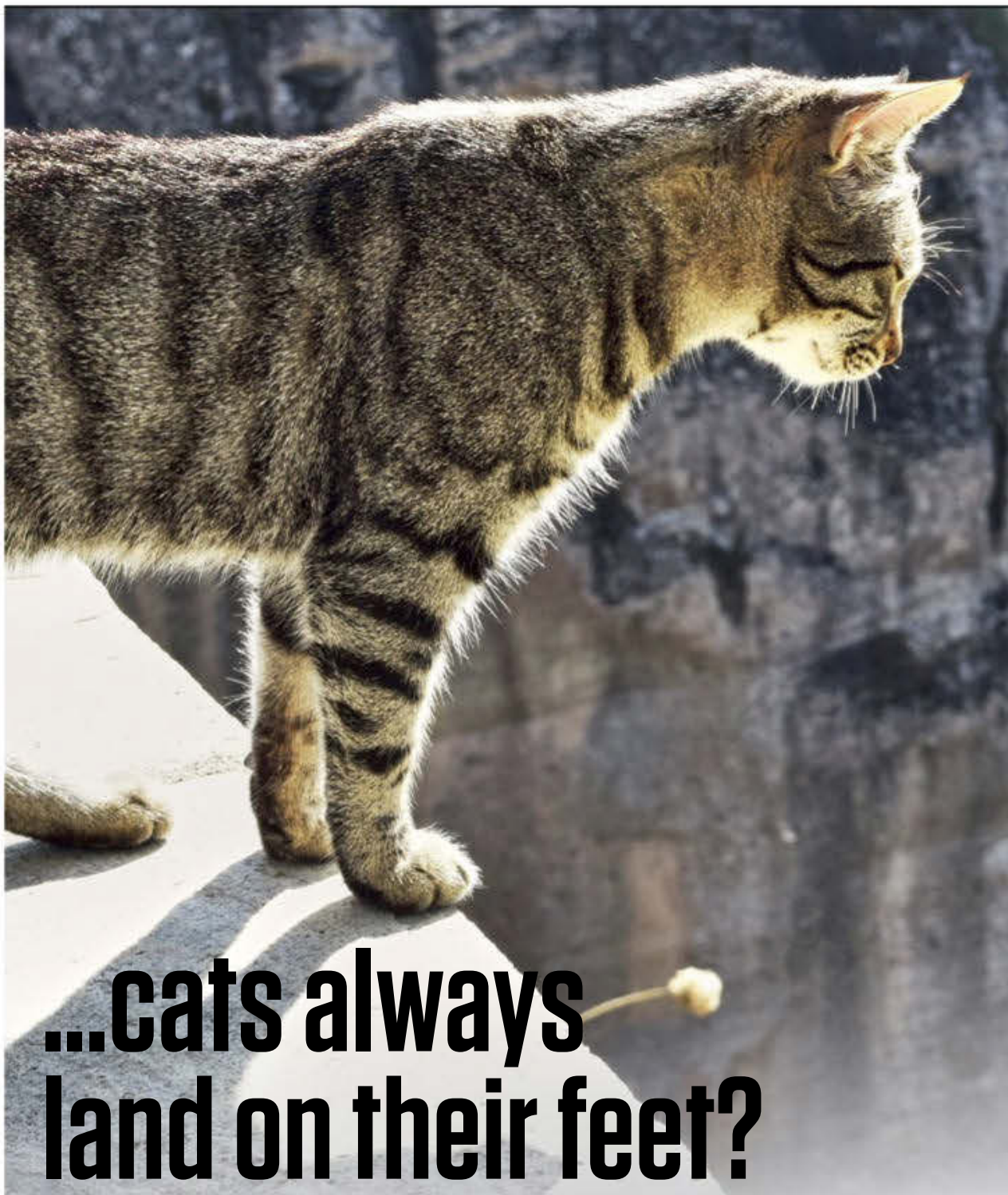
SHUTTERSTOCK

The 15-metre-high Wave Rock near the Wheatbelt town of Hyden in Western Australia is made up of 2.6-billion-year-old granite.

1 Wave Rock forms the north side of the Hyden Rock formation, a bedrock hill rising from a flat landscape – also known as an inselberg. The rock has cultural significance for indigenous Noongar people of the Ballardong region in which it is located.

2 Wave Rock consists of grey and red granite. Ground water undermined the base of the rock while it was covered in sediments. Geologists call this process chemical weathering.

3 Before COVID-19 curtailed tourism, some 100,000 tourists were visiting the 110-metre-long rock wall annually.



...cats always land on their feet?

Is it just a figure of speech that cats always land on their feet, or is it actually true? If so, why don't all animals do this?

ZOOLOGY If a cat falls more than about a metre, it will land on its feet no matter the initial position – unless it is sick or otherwise impaired. From this height the cat has time to rotate its body in the air on its way down. Biologists have named this ability a righting reflex. The ability to rotate in the air requires special adaptations of the cat body, such as a very flexible spine and a well-developed organ of balance that will quickly allow the cat to orientate itself as it falls. But even animals with a righting reflex can nevertheless suffer damage in a fall.

In 1984, American scientists studied how early cats develop the righting reflex. Their results show that kittens master the basic method by around age 3-4 weeks, and a few weeks later they will carry out perfect rotations in the air. Over the course of their evolution, the domestic cat's wild ancestors developed the ability because they caught their prey in trees, from which they risked a dangerous fall.

According to biologists, almost all the members of the cat family have the righting reflex. But in several heavier species such as the mountain lion and the tiger, they cannot endure falling very far even if they do land on their feet.

Other animals that risk falling because of their way of life have developed their own versions of the righting reflex, including guinea pigs and rabbits.

A fine-tuned physiology makes cats rotate in a fall

Cats rotate in the air by using a double axis of rotation and making fast adjustments to the moment of inertia.

1 Cats bend their backs, so their foreparts and hind parts are perpendicular, retracting their forelegs and stretching their hind legs. Their hind parts function as anchors, ensuring that they do not rotate out of control as they fall through the air.

2 Cats rotate their foreparts around an axis that is perpendicular to their hind parts. The foreparts can rotate a full 90 degrees, whereas the hind parts rotate a maximum of only 10 degrees. They subsequently make the same rotation with their hind parts.

3 Once the cats have rotated, they stretch their legs for landing. If cats fall from altitudes of 20+ metres they will spread their legs to the side, so that air resistance slows the fall. When they land, they bring their feet together, so that the head hits their paws.

SHUTTERSTOCK/ALAMY

What are stromatolites?

MICROBIOLOGY The tourists who visit the hard stromatolite features prevalent in such places as Shark Bay and the Pilbara, Western Australia, might be just a tad put off to discover that their hardness may be the result of ancient viruses. Scientists from the University of New South Wales' Australian Centre for Astrobiology have uncovered both direct and indirect viral effects, including virally-introduced genetic changes which enabled these ancient microbial ecosystems to produce carbonate, "pouring the concrete to make their stromatolite apartment blocks," says Associate Professor Brendan Burns, who co-authored a new paper on the possible causes for the hardening of the microbial mats into stromatolite form.

UNSW

Stromatolites date back some 3.7 billion years, and produced so much oxygen through photosynthesis that they contributed to changing Earth's atmosphere.

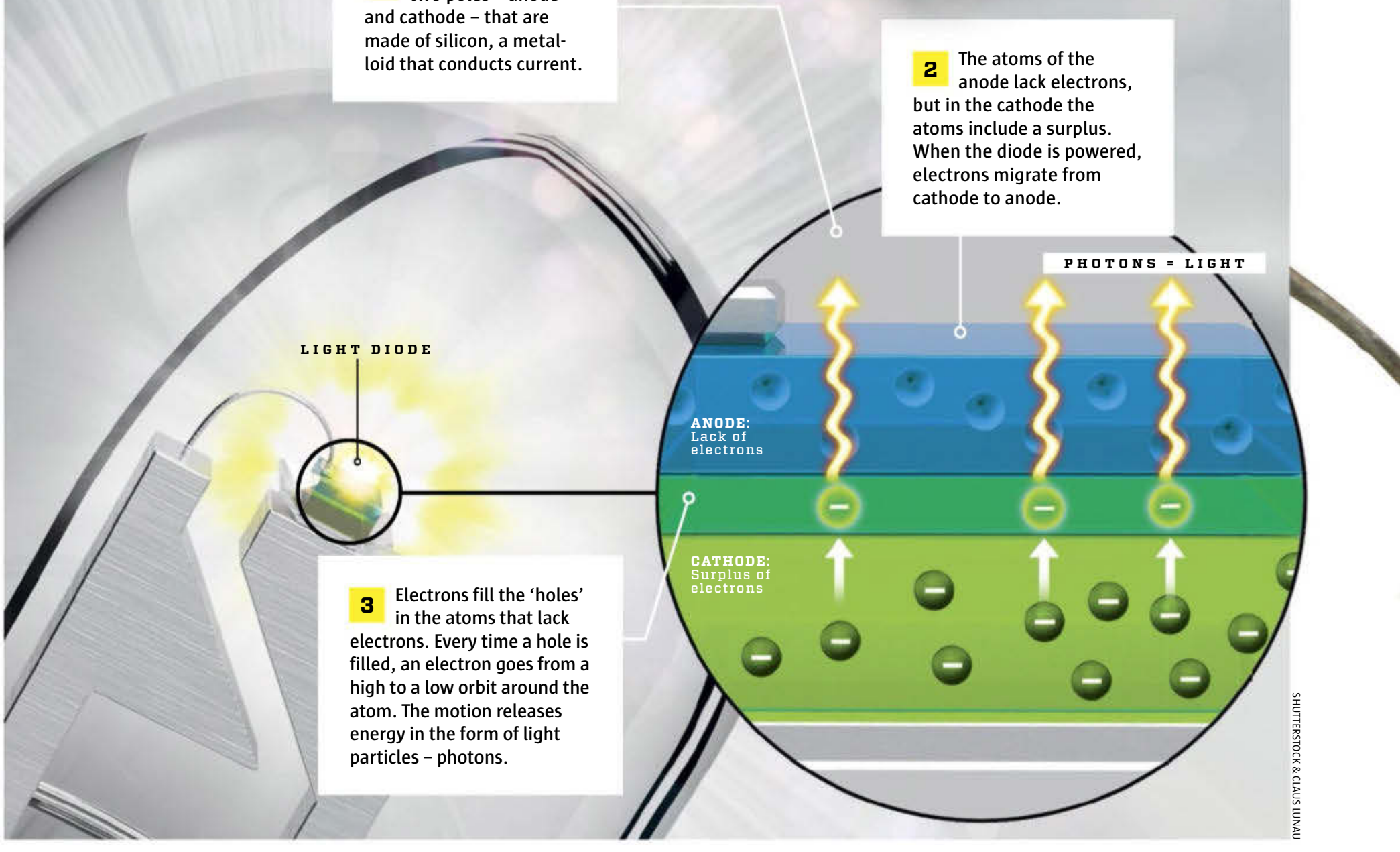
⊕ HOW THINGS WORK · How do LED bulbs work?

LED bulbs light up when electrons are in motion. A bulb includes diodes that emit energy in the form of light when electrons pass through them, relying on the fact that energy is required for an electron to move from one atom to another.

1 A light diode includes two poles – anode and cathode – that are made of silicon, a metal-loid that conducts current.

2 The atoms of the anode lack electrons, but in the cathode the atoms include a surplus. When the diode is powered, electrons migrate from cathode to anode.

3 Electrons fill the 'holes' in the atoms that lack electrons. Every time a hole is filled, an electron goes from a high to a low orbit around the atom. The motion releases energy in the form of light particles – photons.



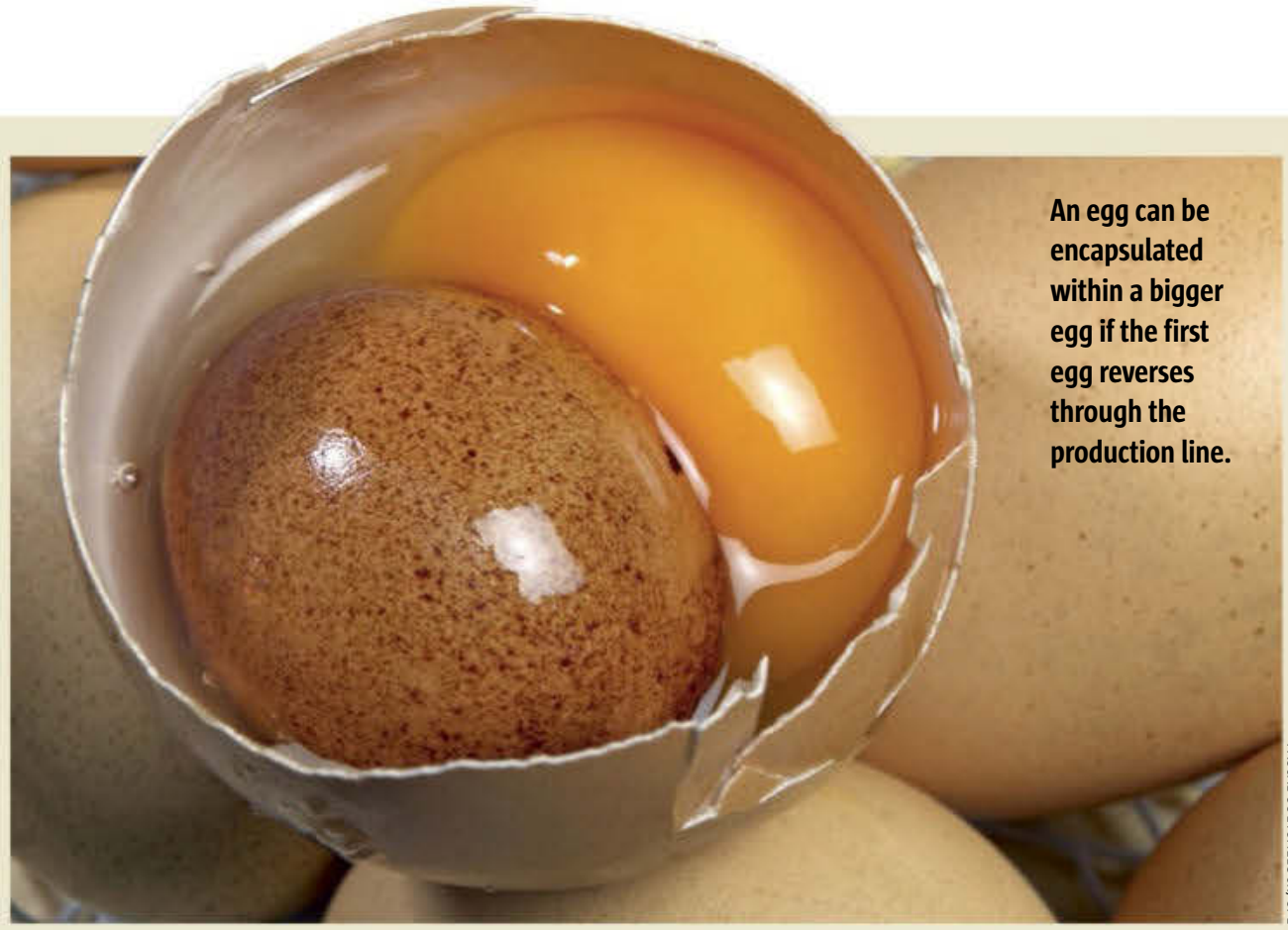
SHUTTERSTOCK & CLAUS LUNAU

WHY DO BIRDS SING?

It is usually said that male birds sing to attract a partner, or to defend territory. But recent research has uncovered many examples of highly structured duetting between bird couples. This may function as vocal negotiation over parental care, or even be used as a form of deception. Female birdsong is still significantly under-researched and in many cases the meaning of their songs and vocalisations remains unknown.

SHUTTERSTOCK

Male birds sing to attract a mate and mark territory. But the songs of females and paired birds are less understood.



An egg can be encapsulated within a bigger egg if the first egg reverses through the production line.

PASCAL GOETGHELUCK/SPL

SHUTTERSTOCK

SHUTTERSTOCK

How can a hen lay an egg inside another egg?

"I've heard stories of people finding eggs inside another egg, complete with shell and everything. Can this happen, and how?"

BIOLOGY Domestic fowl lay eggs in a kind of biological assembly line. It begins with the production of the egg yolk in the ovaries. Subsequently, the yolk passes via the oviduct through glands that secrete the white of the egg, which settles in a layer surrounding the yolk. Then the membrane forms to hold together the contents of the egg (and which later makes it harder to peel). The next step is for glands that secrete calcium to form the shell. Then finally, right before the egg is laid by the hen, a layer of colour (or colour with spots) is added.

However, errors can result during the process. Complete eggs may reverse and pass backwards through the system, where they can encounter new yolk on its way out. They then head outwards again, gaining an additional layer of white, new membranes and a new shell, so that the result is a shelled egg nestling inside another.

EGGS CAN GAIN EXTRA YOLK OR LOSE THEIR SHELLS

A The most common errors in eggs are observed in fowls whose ovaries secrete too much yolk at once, creating a 'double yolker'.

B In some chickens, the glands that secrete the shell can stop functioning correctly, so that eggs can get either battered or gnarled shells – and sometimes the fowls lay eggs that have no shells at all.

Why do our eyes water when we chop up onions?

CHEMISTRY Onions emit a sulphur-containing gas when they are chopped. The gas irritates the cells of the eye, which react by producing tears that are intended to clear away the irritation. In ordinary onions, the gas originates because the enzyme alliinase is liberated to react with a sulphur-containing amino acid, producing a sulphonic acid. Another enzyme subsequently converts the sulphonic acid into lachrymatory PTSO (propanethial-S-oxide).

Onions have evolved the ability to secrete PTSO as a survival mechanism. Onion bulbs grow underground, where they would be easy prey for small burrowing animals if they lacked any self-defence strategies.

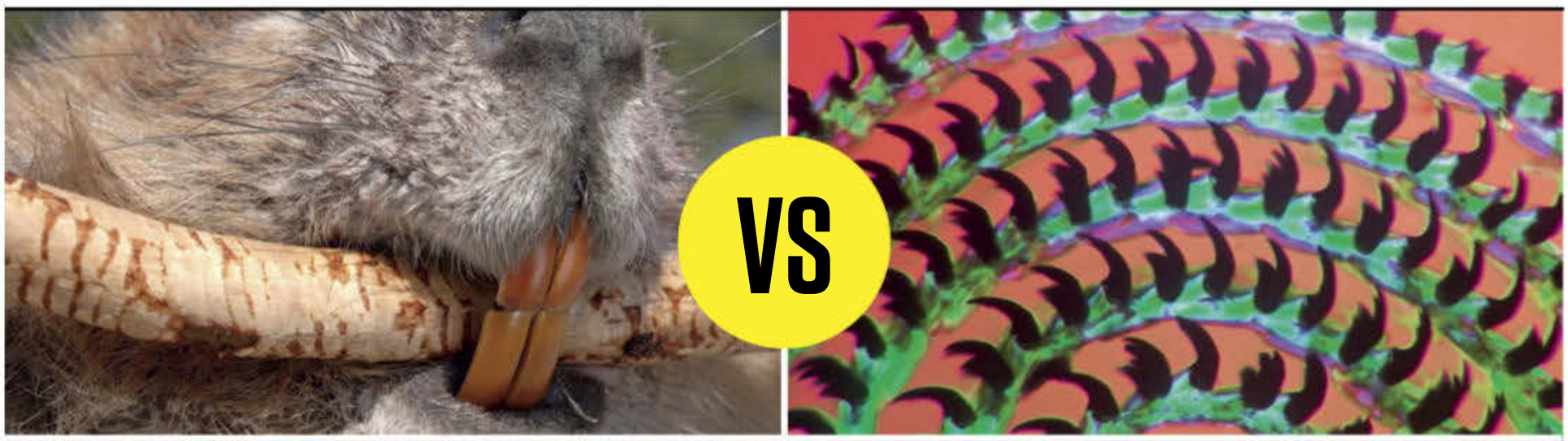
THREE WAYS TO AVOID ONION TEARS

- **1.** Use a tight diving mask or swimming goggles.
- **2.** Peel the onions. Place them in the freezer for 30 minutes, and then chop them.
- **3.** Hold a slice of bread in front of your face with your teeth (it will absorb the gas).

Onions secrete PTSO as a defence mechanism. Like tear gas, this is a lacrimator that causes 'crying'.

SHUTTERSTOCK

VERSUS · Which animal has the stronger teeth?



BEAVER		COMMON LIMPET
20	Number	1920
Iron and magnesium reinforced enamel	Material	Goethite nanofibres held together by chitin
Grow throughout life	Durability	Continously worn and cracked
25mm	Length	0.15mm

The beaver chisels through thick tree trunks with its four front teeth, also crushing its coarse diet (such as bark) with its 16 molars. Although reinforced by metal, the teeth are not the hardest in the animal kingdom.

The 6cm sea snail grates algae and crustaceans off rocks. For this purpose it has the world's strongest teeth. They can resist 4.9 gigapascals, a pressure which is sufficient to convert graphite into diamond.

MAURITIUS IMAGES/IMAGESELECT & STEVE LOWRY/SPL

Space scenes like the ones in Star Trek should not include any sound.

DIRECTORS KNOW THE FACTS

For *2001: A Space Odyssey*, director Stanley Kubrick observed the laws of physics. When an astronaut leaves a space capsule, everything is quiet until the air lock is filled with air.

ALAMY

Kubrick's 1968 movie kept space silent, and some other films, including *Gravity*, have followed suit. Others choose dramatic effect over accuracy.

Can you hear sounds in space?

"I have watched many space films, and in some of them astronauts can hear sounds, and in others they can't. Which is true?"

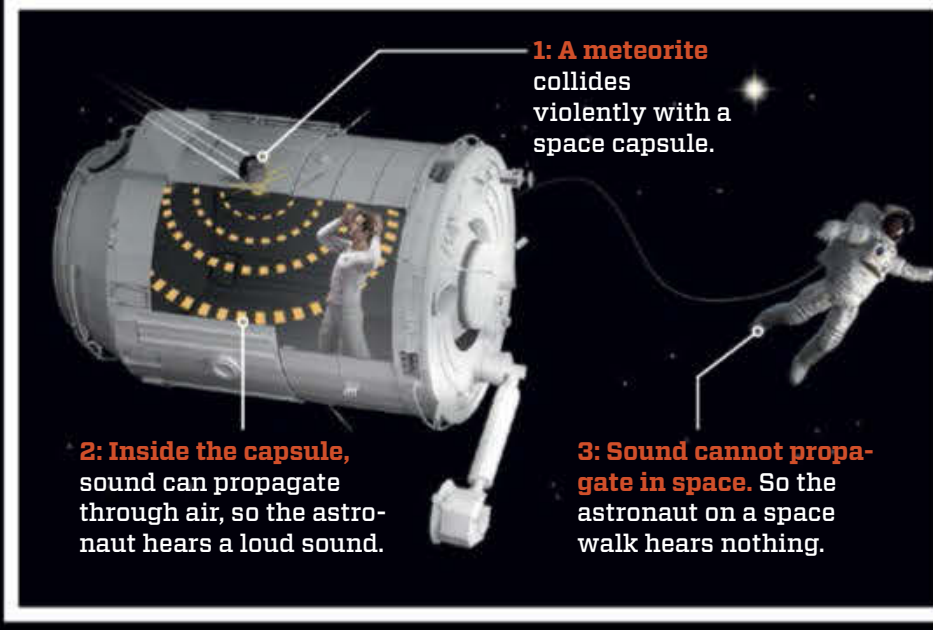
PHYSICS In science-fiction films such as the Star Trek franchise, there are often sounds in space. Even in *Alien*, which had a film poster stating that "in space, no one can hear you scream" the Nostromo craft produces a rumbling noise as it sails by, and later explodes with a loud bang.

The film poster is right – sound cannot propagate in a vacuum. Every time you see explosions surrounded by the vacuum of outer space in a film, everything ought to be quiet. Sound consists of waves that can only propagate in a medium. Sound propagates through air and other gases, liquids such as water, and solids, but not in a vacuum.

The sounds that we hear are minor changes of the air pressure caused by such waves. Without air, there is no air pressure, and so no pressure changes. In the pressurised cabin of a spacecraft, sounds can be heard normally, but the sounds do not leave the spacecraft.

Sound needs a medium

The astronaut in the spacecraft hears a meteorite hit the hull, because the air waves can propagate through the metal and the air inside the spacecraft. An astronaut on a space walk would hear nothing, as the sound cannot propagate through a vacuum. In space, sound waves have no medium through which to propagate.



ALEX THOMPSON, ALAMY & CLAUS LUNAU

By **Henrik Bendix**

Tourists to sightsee from the ISS:

2021: A SPACE ODYSSEY

Space is now finally within reach of ordinary (if wealthy) people. If you have the money and can face 15 weeks of astronaut training, you could spend your next summer holiday in a state of weightlessness inside and outside the International Space Station.

CLAUS LUNAU & NASA & SHUTTERSTOCK

The countdown has begun. Three tourists and their tour guide fasten their seat belts. They are going neither north nor south, but instead up – into space, heading for the International Space Station, ISS, which is orbiting Earth some 420km above the planet's surface.

The four passengers are seated in the Crew Dragon spacecraft on top of a 62-metre-high Falcon 9 space rocket. The rocket accelerates violently, forcing the passengers back against their seats. After one minute they are travelling faster than the speed of sound, and have reached an altitude of 9km above the Florida spaceport. After two minutes and 33 seconds, the speed is 6800km/h — and the rocket engines are switched off. For a brief moment, everything is quiet. The first rocket stage disconnects, falling back towards the Earth below.

A few seconds later, the brief peace is shattered by the ignition of the second rocket stage, and once again the passengers are forced back against their seats. Almost three minutes after launch they have reached an altitude of 100km. They are now officially in space and can call themselves astronauts. Earth's surface is getting ever more distant as the upward flight continues, and the speed increases to more than 27,000+ km/h. Only nine minutes after the rocket was launched, the Crew Dragon has entered into orbit around the Earth. Over the next few hours, the spacecraft will quietly approach the International Space Station.

The space tourists paid US$55m each for their tickets to the space station, something which could become reality as early as the end of 2021. The money was paid to the Axiom Space company, which books the trip with the American company SpaceX, and the stay at the space station with NASA. And travel agencies don't plan to stop there – the next steps could be the creation of space hotels orbiting Earth, and week-long tourist trips around the Moon.

Russia offers space walks

Space tourism will gain momentum in the years to come. After decades of approaches, American aerospace companies are now very close to sending paying guests into space. They will almost certainly offer trips from mere hours in space to longer stays.

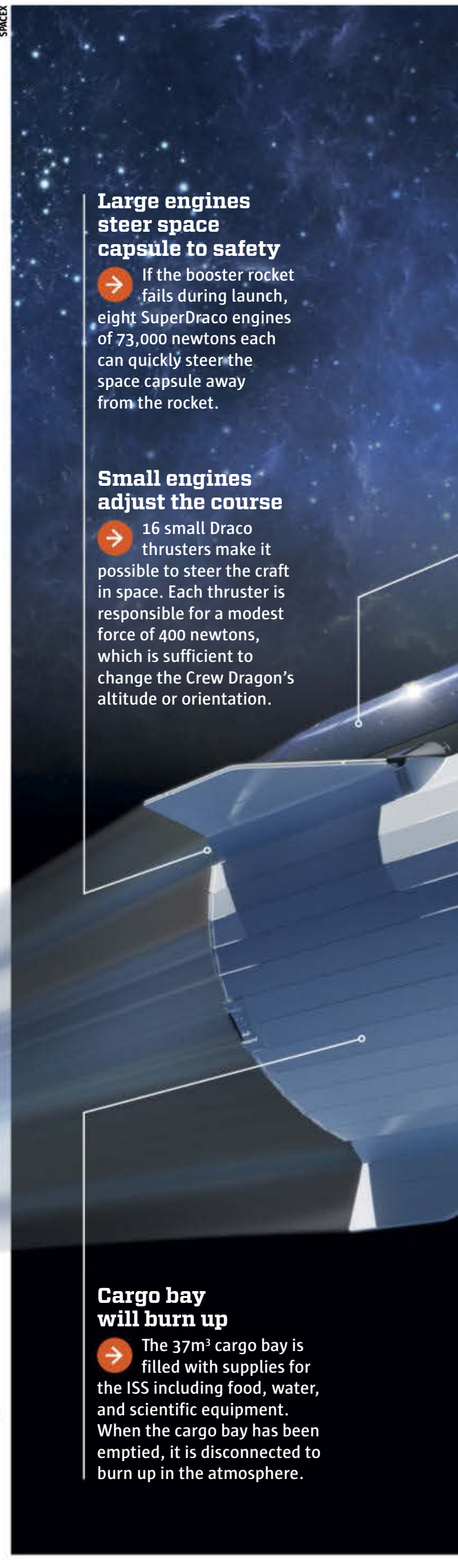
But the prize for 'first tourist in space' has already been taken, by US engineer and entrepreneur Dennis Tito. He was the first of seven private individuals – six men and one woman – who bought a trip to the International Space Station between 2001 and 2009. Those trips were organised by American space travel agency Space Adventures, and were delivered through cooperation with the Russian space agency Roscosmos, at a time when NASA considered it "inappropriate" for a tourist to take a ride into space. Yet in this way, Russia was able to earn some of the cost of its national space programme. And now, history is repeating itself.

Roscosmos has just made a new arrangement with Space Adventures, allowing the sale of two more Sojuz tickets to the ISS. One of the space tourists, to be launched in 2023, will even be allowed to take a space walk – the ultimate sightseeing experience. Wearing a Russian space suit, the tourist will exit the space station and 'walk' for up to 1.5 hours. A space suit for space walks is like a small spacecraft in itself. The suit protects against the lethal vacuum of outer space, while a backpack brings the space walker oxygen, a climate system for ventilation and temperature control, plus filters that remove carbon dioxide from expired air.

A space walk offers a splendid view, but it is also hard work. Space walks ▶

The first wave of space tourists will probably launch from Florida, Texas, and New Mexico. A few will be launched from the Russian spaceport in Kazakhstan.
SHUTTERSTOCK

SPACEX



Space in space for seven

The Crew Dragon spacecraft from SpaceX consists of two parts – a cargo bay and a space capsule for the astronauts. The capsule can carry seven people, including pilots. They share a space of 9.3m³ – rather smaller than the back of a transit van.

Solar panels power technology

One side of the cargo bay is covered in solar panels so there is no need for more fragile solar cell panels that must be unfolded after launch.

CREW DRAGON

Diameter: 4 metres
Height: 8.1 metres
Maximum load: 6000kg

ISS

Heat shield ensures safe return

Under the capsule is a heat shield of tiles made from a special carbon-fibre material known as PICA-X. The tiles can resist temperatures of 2000°C.

Windows allow a view of Earth

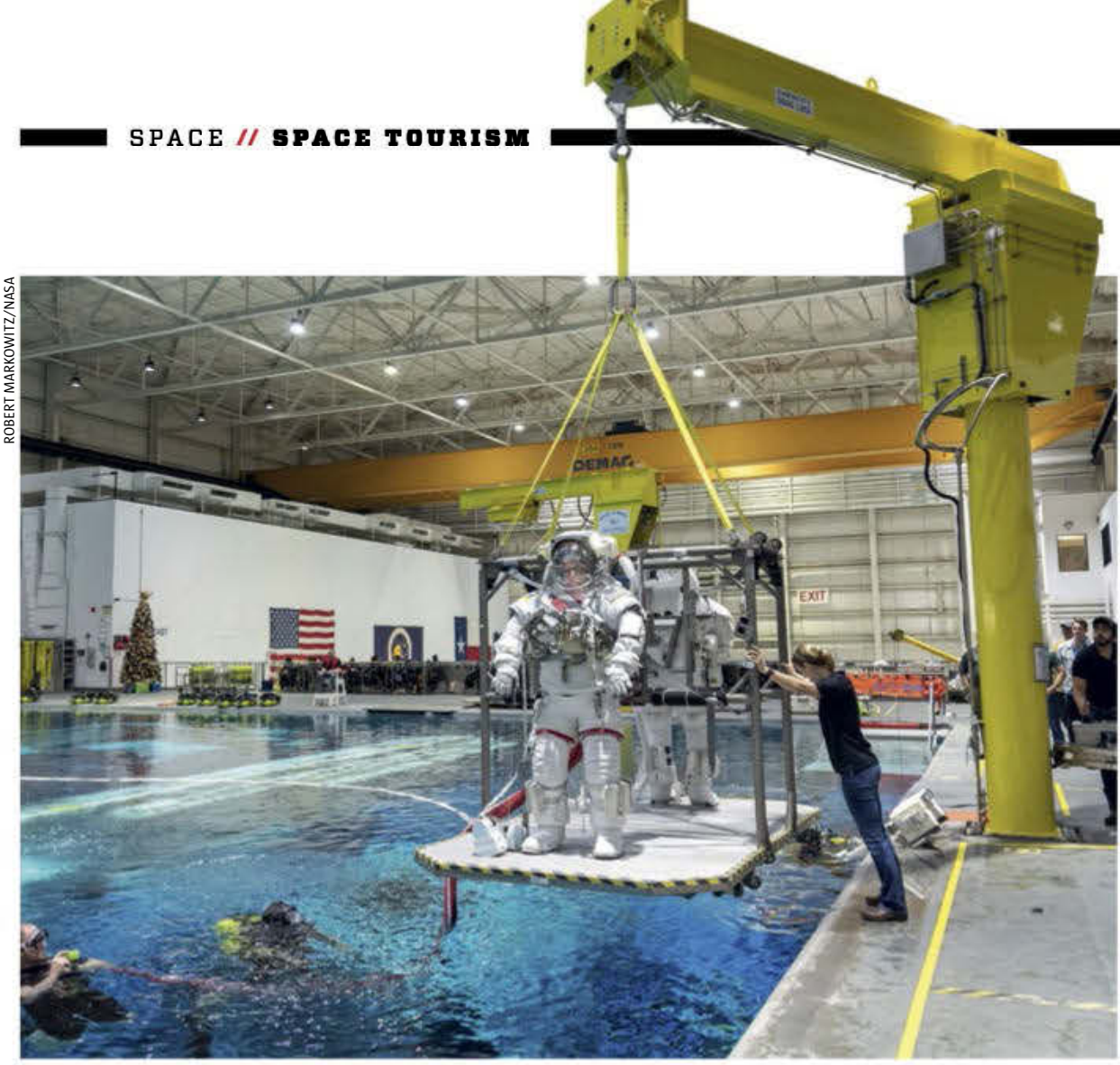
On their way to the ISS, the tourists can enjoy the view through the windows. It remains uncertain yet whether the Crew Dragon will get two, three, or four windows.

Nose docks with space station

A docking mechanism under the nose connects the Crew Dragon with the ISS. After a successful docking, the tourists can open the hatch and enter the ISS.

The Crew Dragon is fully automatic, but pilots can control the spacecraft by means of touch-sensitive displays that replace the usual confusion of buttons in more traditional spacecraft. During launch, the tourists wear space suits in case the pressure drops.

SPACEX



ROBERT MARKOWITZ/NASA

American tourists receive training at the Johnson Space Center in Houston, which includes a replica of the ISS immersed in water, so the tourists can become familiar with the space station.

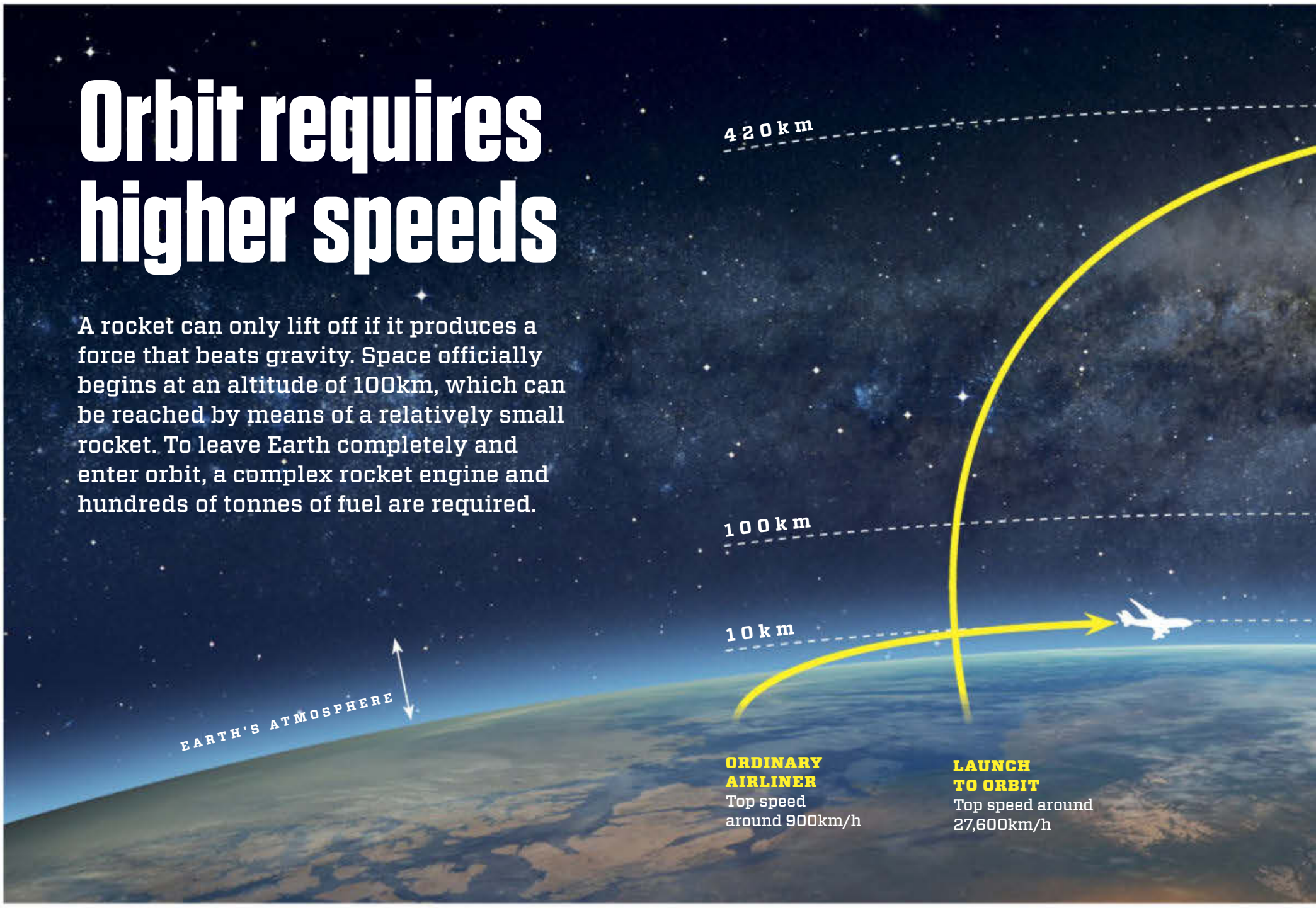
▶ are physically demanding, as the space suit is inflexible and difficult to move about in. The pressure inside the suit is only 40% of normal atmospheric pressure, and the astronaut breathes pure oxygen during the space walk. It may become essential to remain calm and to remember a long series of safety procedures even if the situation becomes stressful. So future space tourists must first spend several weeks exercising on the space walk in Star City, the Russian astronaut centre to the north-east of Moscow.

Billionaires change space travel

In the longer term, it is expected that most space tourists will be launched from the US, where manned aerospace missions are being revolutionised by commercial aerospace activities. It is so expensive to develop, build, and launch rockets that historically, such efforts have always been undertaken by governments. But a new generation of space-junkie billionaires has seen 'astronomical' amounts of private money invested in

Orbit requires higher speeds

A rocket can only lift off if it produces a force that beats gravity. Space officially begins at an altitude of 100km, which can be reached by means of a relatively small rocket. To leave Earth completely and enter orbit, a complex rocket engine and hundreds of tonnes of fuel are required.



SHUTTERSTOCK

27,000

km/h is the speed required for a rocket to escape Earth and enter into orbit.

space. The most successful private company is SpaceX, run by the world's wealthiest (as we write) man, Elon Musk. On 30 May 2020, SpaceX became the first private company to launch people into an orbit around Earth and to the International Space Station. The US company's client was NASA, the people aboard the Crew Dragon two experienced astronauts: Bob Behnken and Doug Hurley. SpaceX now has NASA's approval that the Falcon 9 rocket and the Crew Dragon meet all requirements for manned aerospace missions – a stamp of quality that paves the way for tourist flights.

Like Axiom Space, Space Adventures also plans to book the Crew Dragon for paying guests, but a stay at the ISS is not included. Instead, three or four space tourists will remain in the spacecraft as it orbits Earth. The trip can bring the tourists two to three three times deeper into space than the altitude of the space station. Nobody has been that far away from Earth since the Apollo missions to the Moon 50 years ago.

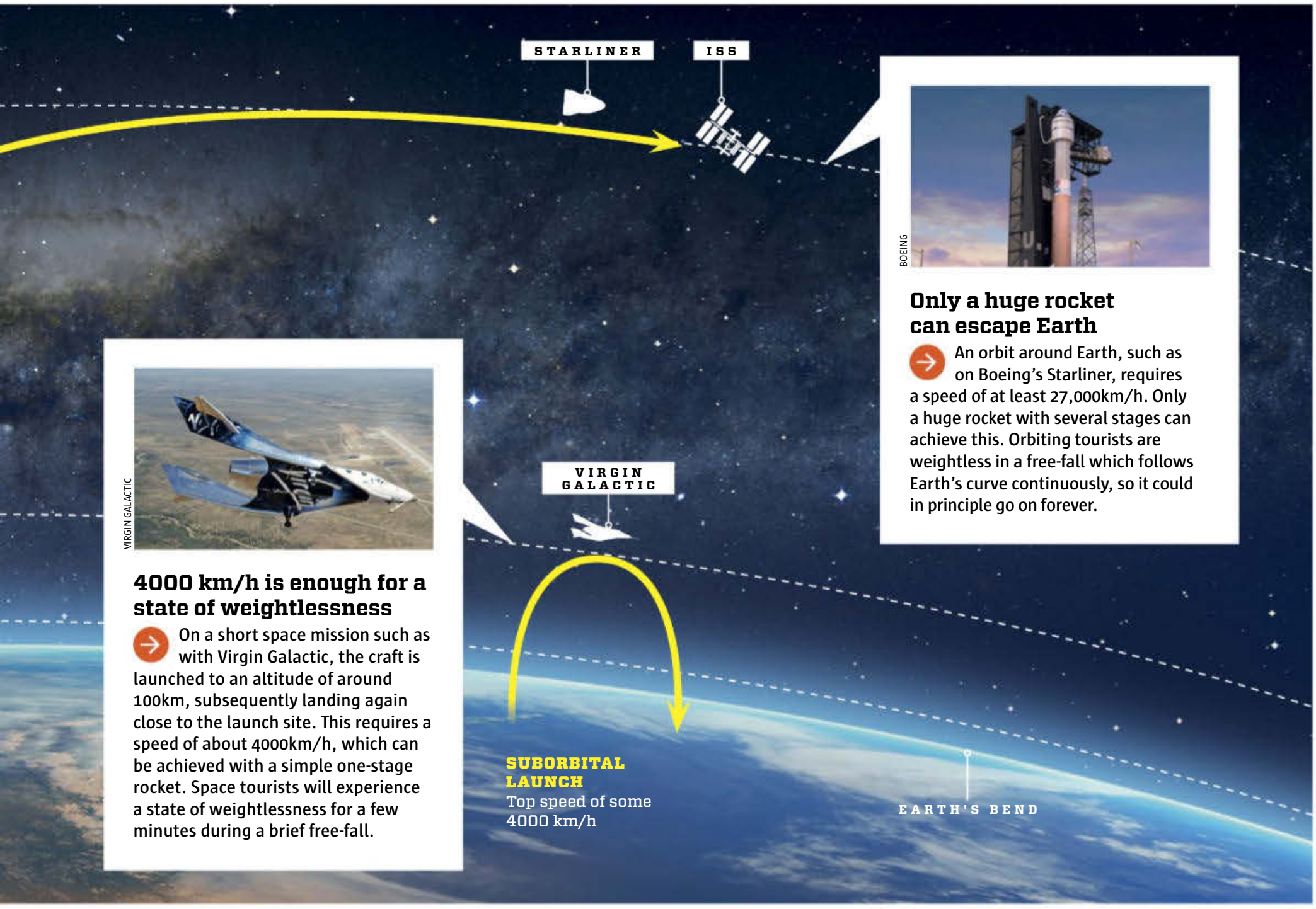
The Crew Dragon is fully automatic and can orbit Earth for up to five days. The space capsule's volume is around that of a large van, sufficient to allow passengers to float around in a state of weightlessness, though rather cramped if the mission were to last for several days. Nevertheless Space Adventures expects to be ready for launch in late 2021, at a price of around A$42 million.

Weightlessness feels like falling

SpaceX will have competition from a well-established aircraft maker and aerospace company, Boeing, which has developed a spacecraft known as Starliner. Just like SpaceX, Boeing has been hired by NASA, which prefers to send astronauts to the ISS with an American rocket from American soil instead of paying the Russians to launch them. Since the last space shuttle was pensioned off in 2011, NASA has been unable to carry astronauts to the ISS itself, but now SpaceX and soon also Boeing will be able to help the agency.

Boeing is lagging about one year behind SpaceX, and has not yet launched humans into space. But its plans for the future also include space tourism with the Starliner, to be launched with an Atlas V rocket from the United Launch Alliance, and able to carry up to seven space travellers.

The highlights of such a mission will undoubtedly be the experience of weightlessness, and the view of Earth from ▶



BOEING

Only a huge rocket can escape Earth

An orbit around Earth, such as on Boeing's Starliner, requires a speed of at least 27,000km/h. Only a huge rocket with several stages can achieve this. Orbiting tourists are weightless in a free-fall which follows Earth's curve continuously, so it could in principle go on forever.

VIRGIN GALACTIC

4000 km/h is enough for a state of weightlessness

On a short space mission such as with Virgin Galactic, the craft is launched to an altitude of around 100km, subsequently landing again close to the launch site. This requires a speed of about 4000km/h, which can be achieved with a simple one-stage rocket. Space tourists will experience a state of weightlessness for a few minutes during a brief free-fall.

A fleet of Starship spacecraft aim to conquer space. Initially they will function as tourist craft, but they might go on to colonise the Moon and Mars.

SPACEX

space. Both of these are perhaps best experienced from the ISS, which offers plenty of space and even a special observation module with seven large windows, from which there is a spectacular view of Earth. The ISS orbits Earth 16 times a day, and the landscape below the space station is constantly changing. The tourists could take photos of the Amazon river winding through South America, of the characteristic boot shape of Italy in the Mediterranean, or of the Bahamas surrounded by the clear, turquoise water of the Caribbean. Even bad weather can look spectacular from space.

When the tourists are not enjoying the view, they can float through the space station in a state of weightlessness. But that is a challenge in itself. It can be difficult for the body to get used to weightlessness, which is due to the fact that the ISS is in an eternal free-fall around Earth. Many will feel that they are constantly descending, and some astronauts suffer from space sickness, which they say feels a little like car sickness.

Space hotel is an optional extra

The ISS is not a cheap hotel, despite its spartan facilities. NASA charges US$35,000 per night, and tourists aren't even guaranteed a private room. The space station has only six small sleeping cubicles, and if these are all occupied, new arrivals will have to sleep somewhere else that their sleeping bags can be reliably attached.

$250k

is the entry price to space, buying one of the proposed short trips into space with Virgin Galactic.

In 2025, Axiom Space will provide the ISS with an extra residential module, with eight more cubicles. Once the space station has been expanded by this space hotel, which includes a large observatory module, space tourism should be able to gain momentum, and prices will fall as aerospace companies gear up and competition increases. But in the foreseeable future, a trip including an orbit around Earth will still cost millions of US dollars. Even with more reusable rockets and spacecraft, it will remain very expensive to launch people to the space station.

Short trips at a discount price

People who are less than mega-wealthy also stand a chance if they are happy with a few minutes in space, rather than a full tour. You can already book a 'discount' trip with either Virgin Galactic or Blue Origin at a price of some US$250,000. They hope to launch their first tourists into space in 2021 or 2022.

Blue Origin's tourists will travel to an altitude of slightly more than 100km, only to fall back down again, experiencing 3-5 minutes of weightlessness. Blue Origin is owned by Amazon's Jeff Bezos. Up to six people can get a seat in the space capsule at the top of his 18-metre fully reusable New Shepard space rocket. From the spaceport in Texas, the rocket will accelerate upwards for 2.5 minutes before its engine is switched off. Then the space capsule is detached from the rest of the rocket, and the passengers fly in a state of weightlessness in the 15m^3 cabin. The space capsule will land back on Earth only 11 minutes after departure.

Virgin Galactic claims it has around 600 bookings already, including Justin Bieber and Leonardo DiCaprio. Their trip aboard the SpaceShipTwo spaceplane will take a little longer, carried first to an altitude of 15km by the WhiteKnightTwo carrier aircraft, then detached so the spaceplane's rocket can be activated, launching it almost vertically upwards into space, where tourists will experience weightlessness for about five minutes before SpaceShipTwo falls back into the atmosphere and glides to the landing strip.

Once Blue Origin and Virgin Galactic have launched sufficient tourists to cover their investment, prices will be further reduced. Perhaps one day it will not only be wealthy millionaires who travel into space .

The Moon as tourist resort

For some tourists, a short trip into space or a longer stay at the space station is not enough. They would like to travel further – to se Earth reduced to a small, distant, blue world. SpaceX is constructing a huge rocket that would allow orbits around the Moon. Prototypes of the 50-metre-tall Starship craft are tested in Texas, and the Super Heavy Rocket booster is in its early development stage. Yusaku Maezawa of Japan has volunteered to be the first space tourist to fly 400,000km into space, passing by the Moon. Maezawa will be accompanied by a group of artists in the #dearMoon project.

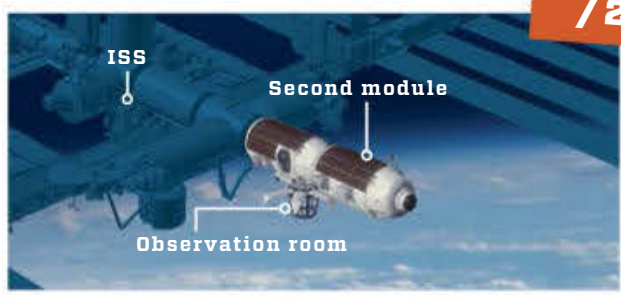
According to (perhaps optimistic) time schedules, the Moon mission will take place in 2023. But as the rocket and the spacecraft have not yet been constructed or tested, the maiden voyage is very likely to be delayed by a few years. But Starship might not send only tourists on round trips to the Moon. NASA is considering using it as the landing craft for the Artemis programme, which is to take astronauts back to the Moon in 2024, to begin building a permanent base.

Checking in at the space hotel

Axiom Space of the USA plans to spend a decade constructing a 'hotel' in the first private space station. At first Axiom's modules will be attached to the ISS, but when the space hotel is completed it will be able to detach and orbit independently.

CLAUS LUNAU & AXIOM SPACE

2024 /25



Space station with a view

1 The first module of the Axiom space hotel should be attached to the ISS in 2024. The module is an aluminium tube equipped with an observation room so space tourists can enjoy the view of Earth. In 2025, another module is planned, providing sleeping quarters for an extra eight people.

2026 /27

Spacewalking tourists

2 A research module is planned for addition in 2026, which companies can book to undertake experiments in weightless conditions. In 2027, a module with large solar panels will make the space hotel self-sufficient in energy, and also add an airlock for spacewalks.

2028 AND BEYOND

Independent tourist hotel

3 By 2028, an extra module with sleeping cubicles will make room for another eight space tourists and more labs. It is hoped that the Axiom Space Station can then leave the ISS and become the first private space station orbiting Earth. (Around then, the ISS will be pensioned off and ditched in the Pacific.)

French designer Philippe Starck will design the sleeping cubicles, which come complete with windows and touch screens.

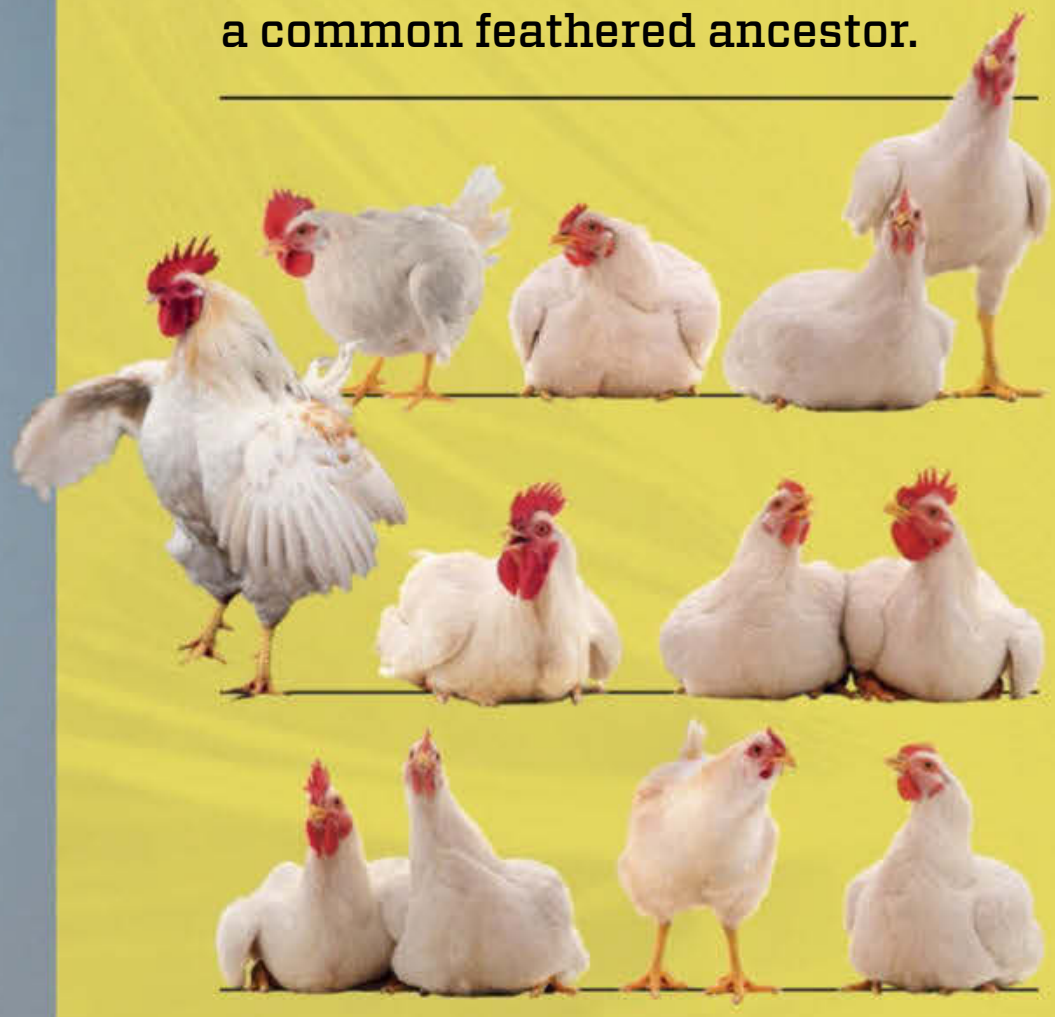
By **Antje Gerd Poulsen**

The first feathers were most likely used to keep warm, not to take flight.

SHUTTERSTOCK

1 FEATHER BECAME 26 BILLION CHICKENS

25 years after the discovery of the first plumed dinosaur, scientists still haven't found the origin of feathers. Controversial discoveries suggest that dinosaurs were not the first feathered creatures: there may have been a common feathered ancestor.



A small striped creature the size of a turkey is uncovered in a fossilised lake bed in China. The dinosaur, which has spent 125 million years on the the lake bed before being discovered in 1996, is quite a surprise to scientists – a predatory dinosaur with thick plumage and a patterned face like that of a racoon. And importantly, *Sinosauropteryx* is the first dinosaur with feather-like plumage – but without wings.

The discovery of *Sinosauropteryx* in China offered clear evidence against the theory that feathers originated to allow birds to take flight. The first plumed ancestors of today's 10,000+ modern bird species, including about 26 billion chickens, apparently had no ambitions to soar above their habitat, as palaeontologists and ornithologists had long believed. So what, then, was the purpose of feathers? The discovery of two fossil pterosaurs has now brought scientists back to a discussion of the first feather – and has shaken up the dinosaur family tree.

Predatory dinosaurs had feathers

The first fossil feather was discovered in 1861 in limestone near Solnhofen, Germany. It was 150 million years old and probably belonged to a nearby fossil of *Archaeopteryx*, a bird-like dinosaur. For more than 100 years, that feather and *Archaeopteryx* formed the basis of research into feather origins, in which feathers and flying were considered inseparable. But that was a false trail.

With the discovery of *Sinosauropteryx* in China, it became clear that feathers served other purposes. *Sinosauropteryx* had no flight feathers; it was covered in a kind of plumed fur known as 'dino fuzz'. The purpose of such protofeathers – small, primitive, hair-like feathers – was probably to function as insulation, to help the creature keep warm.

Many scientists were already becoming convinced that birds had descended from dinosaurs, and feather origin research gained momentum from many discoveries over the past 10 to 20 years, including prehistoric birds and at least five different predatory dinosaurs which appear to support a surprising variation of feathers and of feather-like outgrowths.

> **PAUL BARRETT**
> PROFESSOR AND DINOSAUR EVOLUTION EXPERT
>
> **It is still possible that feathers played an important role in the history of dinosaurs.**

The new discoveries have been made thanks to improved access to China's fossil record for young energetic palaeontologists, who bring new technology – such as LSF (laser-stimulated fluorescence), by which lasers make otherwise invisible soft tissue (such as skin and feathers) light up. The discoveries are important, because feathers do more than tell us about evolutionary connections between different animals. They are also evidence of specific physiologies, living conditions, and behaviours.

For example, thick plumage as evident on *Sinosauropteryx* could mean that the creature was able to maintain a stable body temperature, more like birds and mammals than the reptiles they are. Also, analyses of melanosomes – small pigment pockets in the feathers – reveal that *Sinosauropteryx* had a reddish colour, with light stripes on its tail. This type of camouflage, with the dark back and white abdomen, is a distinct pattern that fits life in an open landscape.

Animals that live in a open plain tend to have a clear distinction between light and dark high up the abdomen, compared with forest-dwelling animals that have a more diffuse distinction further down their bodies. The distinction high up the abdomen blurs some of the shadow that sunlight casts on the body, making the animals seem 'flat'. Predators would find it harder to spot *Sinosauropteryx* against the landscape.

The plumed *Sinosauropteryx* belonged to the same Coelurosauria sub-group of predatory dinosaurs that includes both *T. rex* and the small elegant carnivores known as 'raptors' from the Jurassic Park films. So there seemed to be every indication that feathers originated in a subgroup of predatory dinosaurs. But just as this idea found acceptance as confirming the origin of feathers, a small horned creature overturned the theory. ▶

This *Sinosauropteryx* fossil included pigment pockets known as melanosomes, which can give scientists some idea of the colour of a dinosaur.

BYLINE

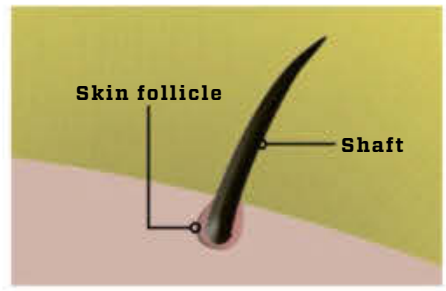
JULIUS T. CSOTONYI/SPL & SHUTTERSTOCK

Feathers helped dinosaurs keep warm

Until 1999, scientists believed that feathers developed from scales, but ornithologist Richard Prum from the University of Kansas was able to dismiss that idea. Instead it seems that feathers grew from small skin depressions, subsequently developing in stages that reflect their evolutionary history.

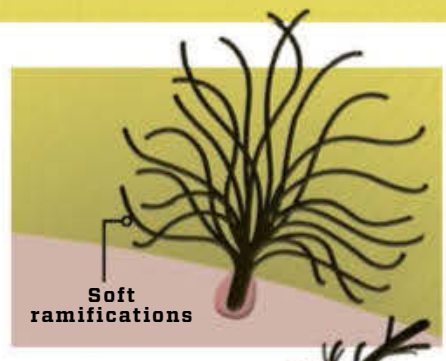
Circle of cells produces a pipe

1 A feather begins in the same way as a scale, by cell division in a follicle. A circle of cells divides to produce a pointed shaft that grows from the follicle – a protofeather. Dinosaur protofeathers look like small, coarse bristles.



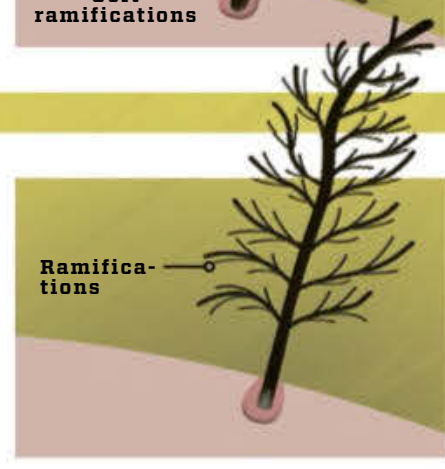
Soft protodown branches originate

2 The protofeather develops into protodown with a short shaft and long, soft ramifications. Some dinosaurs, such as the *Deinonychus* raptor, had their entire bodies covered in protodown which probably functioned as a kind of insulation.



Primitive feather branches out

3 In the next development stage, the protodown becomes a primitive feather more like the ones we know from modern birds, but without being aerodynamic. The primitive feather spreads from the shaft in ever smaller branches.



Aerodynamics allow birds to take flight

4 The final stage of a feather's development is winding branches that fit together to make a denser structure. A modern flight feather is asymmetric, so that the air is directed faster over or under the wing, to provide lift.

LOTTE FREDSLUND & SHUTTERSTOCK

Herbivores raised their bristles

Psittacosaurus is a herbivore, belonging to the group of horned dinosaurs that also includes *Triceratops*. It is located far away from the predatory dinosaurs on the family tree. Yet a *Psittacosaurus* fossil revealed that it had bristles protruding from its tail that were hollow, inflexible, and very reminiscent of primitive feathers.

In 2014, another herbivore with similar growths turned up. *Kulindadromeus* was discovered in Kulinda, in eastern Siberia. The dinosaur was the size of a medium dog, and the fossil was extremely well-preserved.

It was wearing a very special 'overcoat' which consisted of three different kinds of scales, also short feather-like fur, and clusters of fibre structures resembling small curled ribbons. Moreover, *Kulindadromeus* had a few hair-like bristles on its head, neck and body, while its upper arms and thighs included small, feather-like 'bouquets' of 5 to 7 bristles. These last bouquets are particularly interesting, as something similar had been observed in both predatory dinosaurs and modern birds. Yet here the location of the fossil dates it to some 168 million years ago, making *Kulindadromeus* the oldest dinosaur yet to include feather-like growths.

> **MIKE BENTON**
> PALAEONTOLOGIST
>
> **The structures are the same as the ones we observe in the feathers of birds and dinosaurs, moving the origin of feathers from 160 to 240 million years ago.**

Several scientists have interpreted the find as an indication that there must be a common ancestor of all plumed dinosaurs, as they consider it unlikely that such complex plumage as that of the carnivore *Sinosauropteryx* and the herbivore *Kulindadromeus* could have originated independently in each of these two main groups of dinosaurs. But the hypothesis is controversial, particularly because feathers are still very rare among herbivorous dinosaurs. Some scientists prefer to suggest that the feathers originated randomly several times on different branches of the family tree.

Four kinds of pterosaur feather

Those looking for a common ancestor have examined the pterosaurs that coexisted with dinosaurs from 230 to 66 million years ago. These pterosaurs have their own branch of the dino-family tree, so linking back to a common original form.

Scientists headed by palaeontologist Mike Benton have been taking a close look at 160-million-year-old pterosaur fossils from China, and have found structures that they think originate from four different types of head, neck, body and wing feathers.

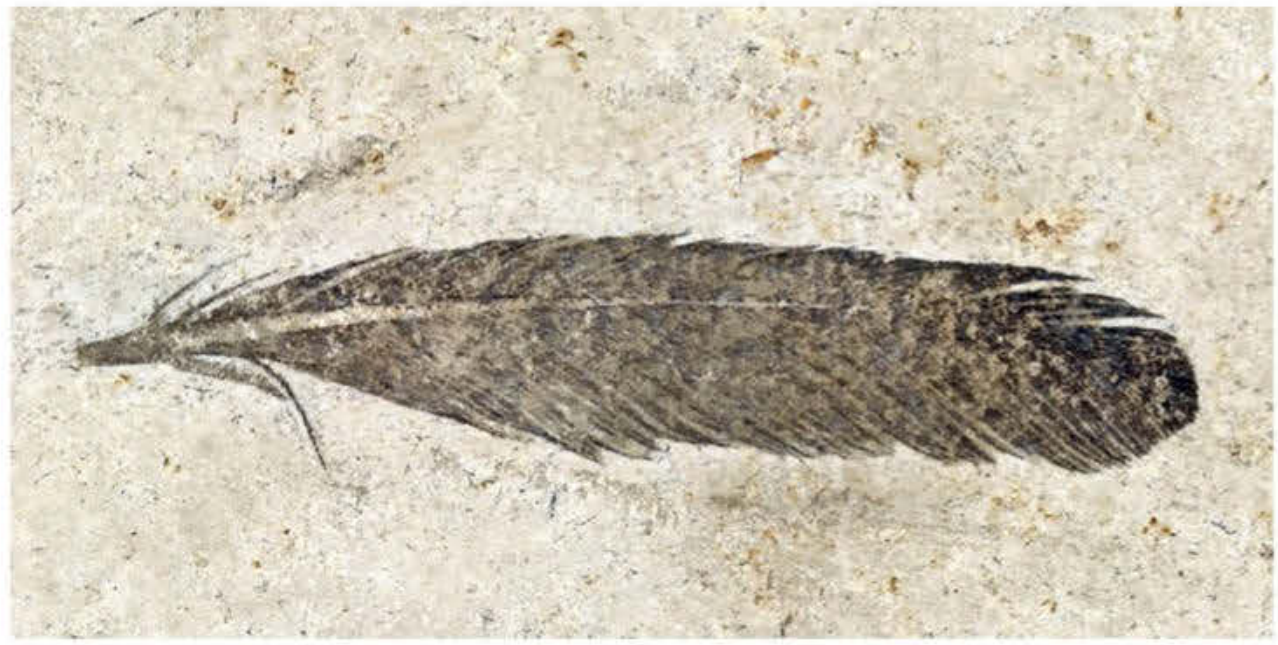
Three discoveries changed how dinosaurs look

Our visions of smooth and scaled dinosaurs – as we know them from the Jurassic Park films – is being superseded by increasing evidence of feathers being found all over the dinosaur family tree.

"The structures are the same as the ones we observe in the feathers of birds and dinosaurs, moving the origin of feathers from 160 to 240 million years ago," Mike Benton says. That dating fits into the period following the Permian-Triassic extinction, when some 95% of all animal and plant species were driven to extinction after severe volcanic eruptions.

After that, life developed new forms. The first dinosaurs and mammals arrived, while reptiles became marine animals, or developed wings to take flight. According to the scientists behind the study, a common ancestor of dinosaurs and pterosaurs developed protofeathers as insulation 240 million years ago, with the other functions of feathers not developing until much later. They cite genetic studies that indicate a common origin for scales, hair, and feathers across different species.

This means that all dinosaur species had an opportunity to develop feathers, but environmental conditions and mutations would then have determined if and how the genes found expression successful enough to carry on through the generations. Some never developed feathers; others had them for a period of time only to lose them again.

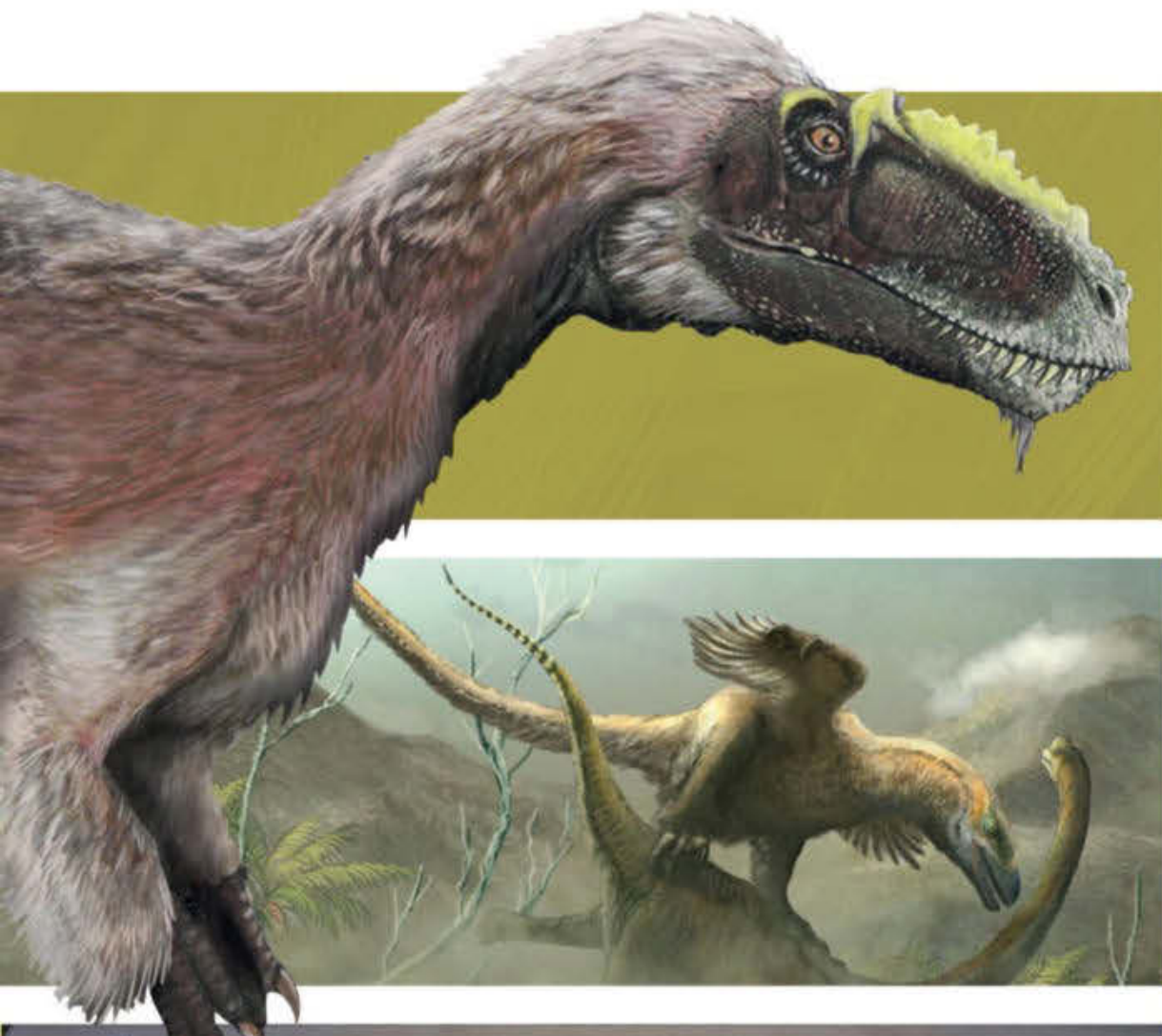


UNIVERSITY OF HONG KONG

The first fossil feather belonged to *Archaeopteryx*, which was the size of a raven and is thought to have glided between trees. The first example was found in 1860/61, and is now at the Natural History Museum of Berlin.

Just fraying and decayed fibres?

This interpretation is not, however, yet widely shared. Various palaeontologists still disagree with Benton's conclusions – and they have supercomputers on their side. ▶



B. CHOO/CAS

Tyrannosaurus rex was a fluffy killer

1 Scientists used to think that bigger dinosaurs would not have had feathers, since large animals do not lose heat as easily as small ones. Then in 2012 a 9-metre-long *T. rex* ancestor, *Yutyrannos*, which existed some 125 million years ago, was discovered in China. The big predatory dinosaur had primitive fluffy feathers, and though no feather-like structures have yet been found on any *T. rex*, there is every likelihood that it also had some kind of feathers.

MARK P. WITTON/SPL

Raptor feet were covered in feathers

2 While it turns out that feathers cannot originate from scales, the opposite is possible. Small predatory dinosaurs are often portrayed with scaly feet, but fowls (chicken, ducks and geese, the closest modern dinosaur relatives) have two types of scales on their feet: small, round, reptile scales and bigger scales that developed from feathers. Fossils from Liaoning, China, indicate that some raptors even had feathers on their toes.

SHUTTERSTOCK

Triceratops had bristles

3 Palaeontologists had long been convinced that the big horned *Triceratops* dinosaur had neither hair nor feathers. But as it is related to the much smaller *Psittacosaurus*, which we now know to have had long bristles on its tail, they are no longer so sure. An impression of the *Triceratops*' skin indicates that it might have had similar bristles. Scientists are less certain, however, whether the bristles have anything to do with feathers.

Pterosaurs belong to a special branch of the dinosaur family tree that links directly back to a common ancestor.

DAMIR G MARTIN

PTEROSAURS MAY HAVE BEEN COVERED IN UP TO 4 TYPES OF FEATHERS – BUT SOME EXPERTS HAVE THEIR DOUBTS.

Dr. David Unwin from the University of Leicester in the UK is a pterosaur expert, and he denies that pterosaur wings were covered in a type of feathers. He emphasises the discovery of some 30 pterosaurs, several of them with well-preserved wings, yet all naked and smooth. On the other hand, the wing membrane includes structures that, in a state of decay, could be misinterpreted as 'fluffy' and feather-like under a microscope. The lack of knowledge of decay processes is

RITZAU SCANPIX

According to Professor Paul Barrett, the dino ancestor probably did not have feathers.

a major current problem, according to David Unwin, as it makes palaeontologists' efforts to identify structures in the fossils prone to error. These relics have spent millions of years deep in the ground, being both compressed and heated.

Professor and dinosaur evolution expert Paul Barrett from the Natural History Museum in London has contributed to a new book about the origin of feathers. He and two other scientists have worked with computer modelling and probabilities, trying to calculate backwards towards the first feathers.

The scientists fed the computers data relating to 77 dinosaur species that have been found with well-preserved skin showing traces of scales, hair, or feather-like structures. The dinosaurs were placed on a family tree, and in the places where fossils are missing, the scientists inserted hypothetical fossils. In one model, they placed a pterosaur with protofeathers; in another model, they used a pterosaur without feathers. In this way, they could predict different lines of development and calculate the likelihood of the hypothetical lines being the true ones.

The models revealed that any common ancestor of dinosaurs and pterosaurs is highly unlikely to have had feathers.

"I had expected that models based on a pterosaur with protofeathers would result in all dinosaurs having feathers. It surprised me that that was not the case," Paul Barrett says.

Plumed piece is missing

The results of the computer models reveal that in spite of the many finds made in recent years, we still lack important information. And although the study denies a plumed common ancestor, Paul Barrett thinks that this could change.

"It is still possible that feathers played an important role in the history of dinosaurs. And just one or a few finds of early dinosaurs or dinosaur relatives with feathers would change our approach considerably," he says.

The ancestor of all dinosaurs originated in the Triassic 251-200 million years ago, and according to palaeontologist Bent Lindow from the Natural History Museum of Denmark, it would require immense luck to find a feather from such an ancient beast.

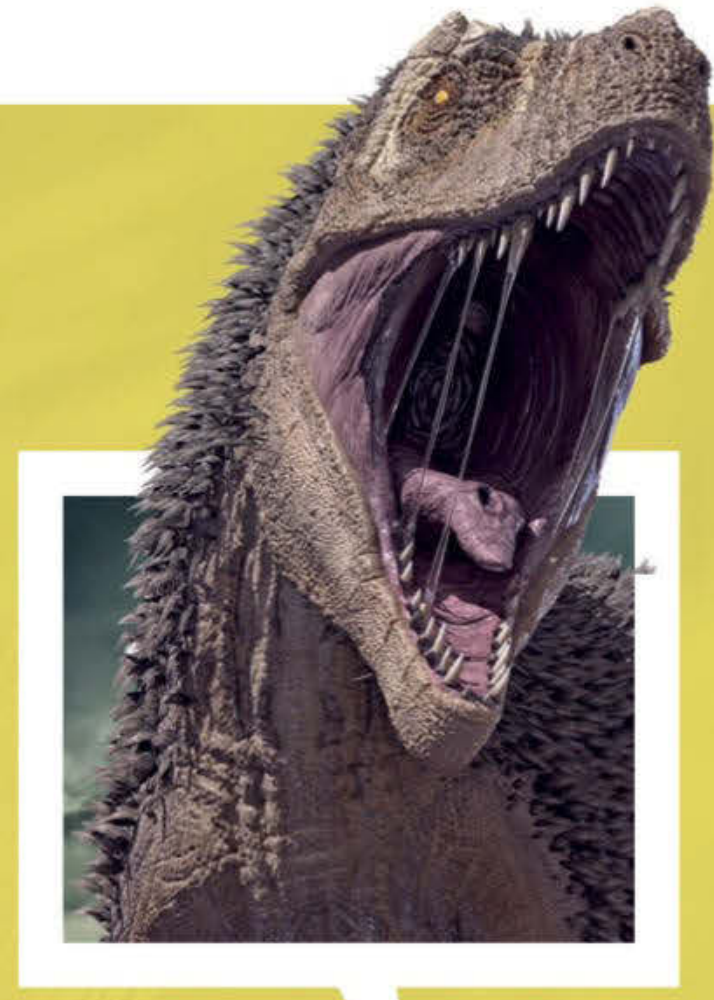
"It is difficult to find such old fossils, as very special conditions are required to preserve soft tissue," he says. "But it is not impossible – and we can begin by looking specifically for them."

The closest relatives of birds, dinosaurs, and pterosaurs are crocodiles, as they all belong to the group of archosaurs. The first crocs originated in the Triassic, and although they do not have feathers, the ability to develop plumage is in the genes of modern crocodiles.

So perhaps somewhere a fossil of some remote plumed crocodile relative is hiding in the ground, waiting to be found – just like *Sinosauropteryx* 25 years ago. Just one single feather may be all we need. SI

Dinosaur family tree is being redrawn

Based on 77 dinosaur fossils with hair, feathers, or scales, a computer model has calculated the likely features of a plumed ancestor. Not only did the model reveal that the ancestor most probably had scales, it suggests that the entire dinosaur family tree should be reconstructed.



SHUTTERSTOCK

Pterosaur

Ornitischia

Sauropodmorph

Saurischia

Theropoda

Dinosauria (ancestor)

Dinosaur ancestor unlikely to have had feathers

1 Pterosaurs have their own branch of the family tree, and are hence more closely related to the dinosaurs' common ancestor than other species. The computer simulation was based on a pterosaur which had some kind of feathers across its entire body. The simulation's conclusion was that even with a well-feathered pterosaur that is directly related to the common ancestor, the likelihood of a feathered original form is low compared to one with scales.

Feathered dinosaurs originated several times

2 The computer model was also fed the few species in the group of armoured and horned dinosaurs (to which *Triceratops* and *Stegosaurus* belong) that have been found with feather-like growths. These examples, including *Psittacusaurus* and *Kulindadromeus*, have outgrowths that are very different from other types of feathers. According to the computer model, this means either that feather-like growths originated independently several times, or that the horned dinosaurs should be repositioned with the predatory dinosaurs on the family tree.

Longnecks and T. rex must be separated

3 *Saurischia* is a group with two subgroups that are surprisingly varied: predatory dinosaurs (which include birds), and the big long-necked sauropod herbivores. Originally they were united on the family tree due to their hip structures, which share common features. But there are also distinct differences. According to the computer model, the sauropodmorphs should be a separate group, because feather-like growths have been found in predatory dinosaurs, but not in sauropodmorphs.

Scientists focus on the invisible monsters of the universe, as

BLACK HOLES GO TO THE MOVIES

In 2019, we saw the first still image of a black hole, captured using a huge telescope network. Now the same scientists aim to record video footage of the supermassive black hole at the centre of our own Milky Way. Such a film might just deliver the data required for a huge revolution in physics.

→ LOCATION

Black holes are invisible, but astronomers can observe and measure events that happen around the holes.

→ SHOOTING

Thanks to a global network of telescopes, scientists can image black holes at increasingly high resolution.

→ LEAD ROLE

The black hole at the centre of our Milky Way, Sagittarius A*, may hold answers to the mysteries of galaxy dynamics.

→ OPENING NIGHT

Data from radio waves are stored on thousands of hard drives, and supercomputers piece the movie together.

By **Jens E. Matthiesen**

A black hole is so massive that its gravity sucks up everything – even light. Nevertheless scientists intend to make a movie of these invisible giants.

SHUTTERSTOCK

In photographic terms, the image was not very impressive – a blurred circle of yellow and orange light with a round dark shadow at the centre. But it caused a sensation when it was published on 10 April 2019, because this was the first ever image taken of a black hole. Or to be more precise, it was an image of what surrounds a black hole, since the holes themselves are invisible, their immense gravity sucking in everything around them and preventing even light from escaping. Nevertheless, the image included such clear contours of the black hole that the astronomers behind the achievement could claim that they had for the first time "seen what we thought was impossible to see".

Black holes remain one of the most studied astronomical phenomena, both because they are mysterious and because, according to astrophysicists, they have been vital to the development of the universe, the formation of galaxies, stars, and planets – and to people on Earth. Astronomers are seeking more information about what happens close to black holes as their immense gravity sets the time and space of the surrounding universe into a spin. And that's why hundreds of scientists spent years observing outer space through a global network of telescopes to piece together a blurry yellow and orange circle around a dark shadow.

But those astronomers were only getting started. Now they are aiming the telescopes at the black hole located at the centre of our Milky Way – this time not to take a snapshot, but to record a movie which can show whether the laws of physics as we understand them still hold together when they come under extreme pressure.

Surroundings reveal holes

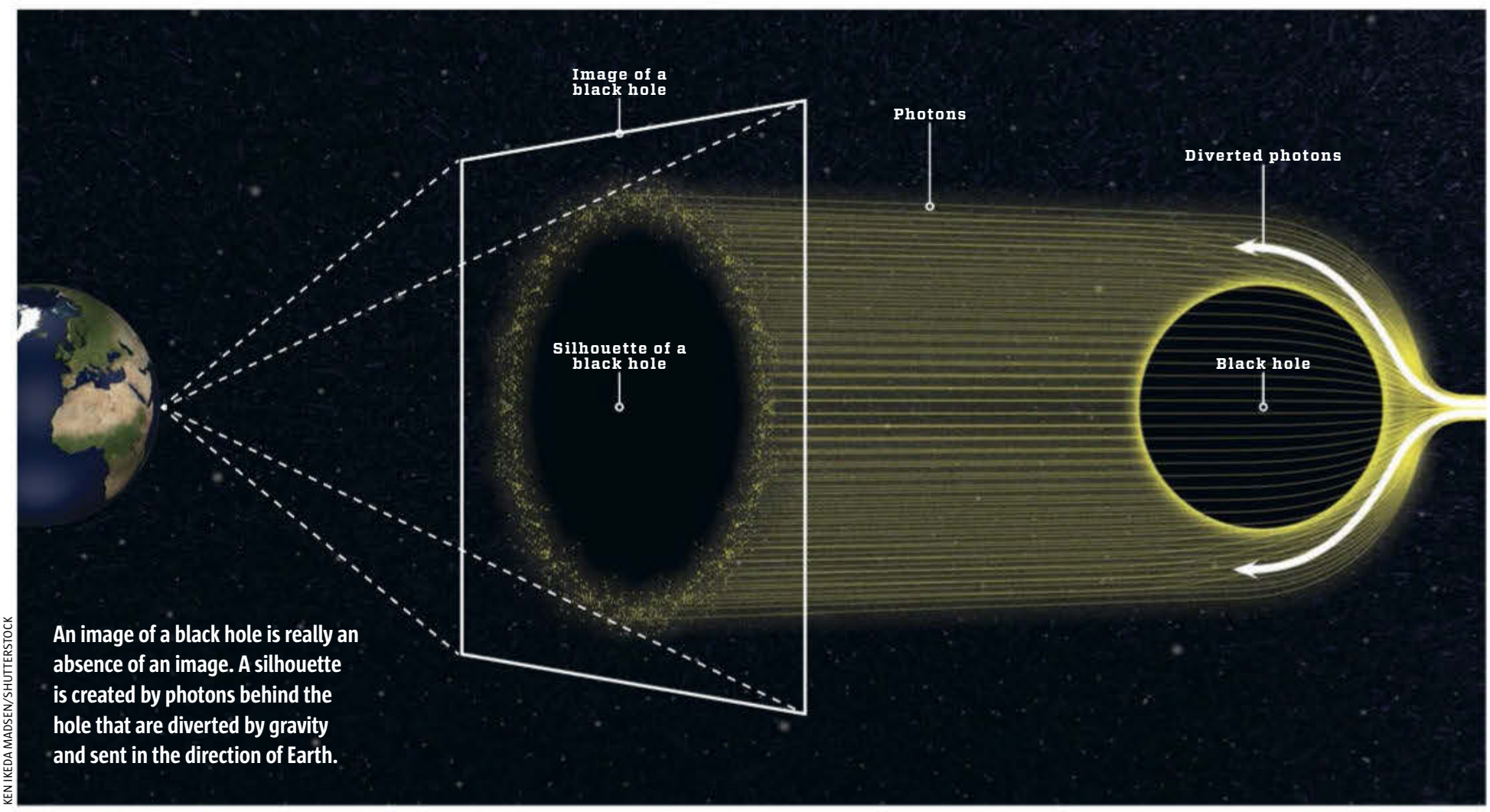
In short, a black hole is an extremely large mass compressed into a very small area.

> **SHEP DOELEMAN,** ASTROPHYSICIST
>
> **"We are delighted to report that we have seen what we thought was impossible to see!"**

Moving inwards, the gravity becomes ever stronger, and at the centre there is so much mass in such a tiny space that the force is immense – so immense that it bends space and time around it. Such a point is known as a singularity, a concept introduced by Albert Einstein in 1915 when he published his general relativity theory, which remains our best description of the nature of gravity. Einstein himself doubted that singularities would really exist, but today, they are astrophysicists' only explanation of the phenomena we can observe around black holes. The density in the holes is so extreme that scientists study their effects to put our current understanding of gravity under similarly extreme pressure.

Around a black hole, dust and gas swirl in the so-called growth disk. The inner edge of the disc is gradually sucked into the hole by gravity, and when the matter comes close enough, it passes the event horizon, which might be physics' most fascinating boundary: if an object (or light) passes it, it can never come out again. The event horizon is therefore the limit of our ability to see into a black hole, and also the boundary of our direct knowledge about them.

So astronomers study black holes by observing what happens around them. The gravity of black holes makes stars orbit them, and the masses of the holes can be calculated based on the masses and orbits of stars. Closer to the black holes, intense radiation is emitted, which we can measure from Earth. The radiation derives from extremely hot gases. Close to the event horizon, the field of gravity is so intense that the radiation's individual constituents, photons, are locked in orbits around the hole. But the orbits are unstable, and photons can either fall into the black hole or are flung away. Some of them are flung in our ▶

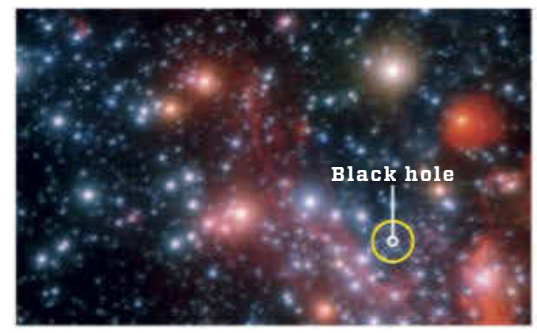


An image of a black hole is really an absence of an image. A silhouette is created by photons behind the hole that are diverted by gravity and sent in the direction of Earth.

KEN IKEDA MADSEN/SHUTTERSTOCK

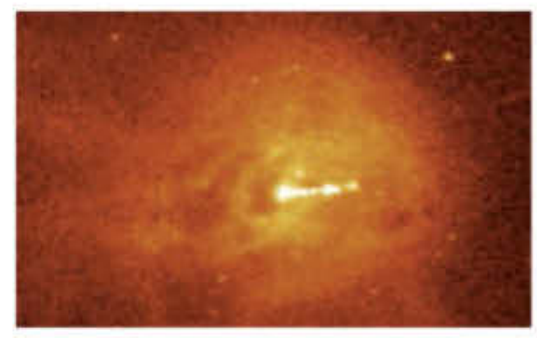
Dead stars are invisible

Not even light escapes black holes, but scientists can create images of the darkness because the intense gravitational fields of the holes influence everything around them.



Stars encircle the black hole

Astronomers usually discover a black hole because stars seem to orbit nothing – or an object that is very massive, but emits no radiation. And that can only be a black hole.



Radiation reveals intense energy

Light and other radiation cannot escape a black hole, but the disc around the hole emits intense radiation as gas and dust are heated to a temperature of millions of degrees.

Gravitational waves distort space

When two black holes merge, energy is released in the shape of gravitational waves that flow through space and distort it. The waves can be measured by extremely sensitive detectors on Earth.

Black holes are invisible, but scientists can see how the holes influence their surroundings.

NASA/JPL-CALTECH & ESO/MPE/S. GILLESSEN ET AL. & NASA/CXC/W. FORMAN ET AL. & NASA'S GODDARD SPACE FLIGHT CENTER

→ SHOOTING

Huge telescope network focuses on black holes

The Event Horizon Telescope comprises 11 telescopes that combine into one big telescope – with a 'screen' covering the whole surface of the Earth. Each telescope covers a region on the screen and contributes to the total image.

Radiation from black hole arrives at the Earth

1 Astronomers observe black holes using telescopes that capture radio waves. Unlike visible light, these waves can travel through the atmosphere to reach the surface.

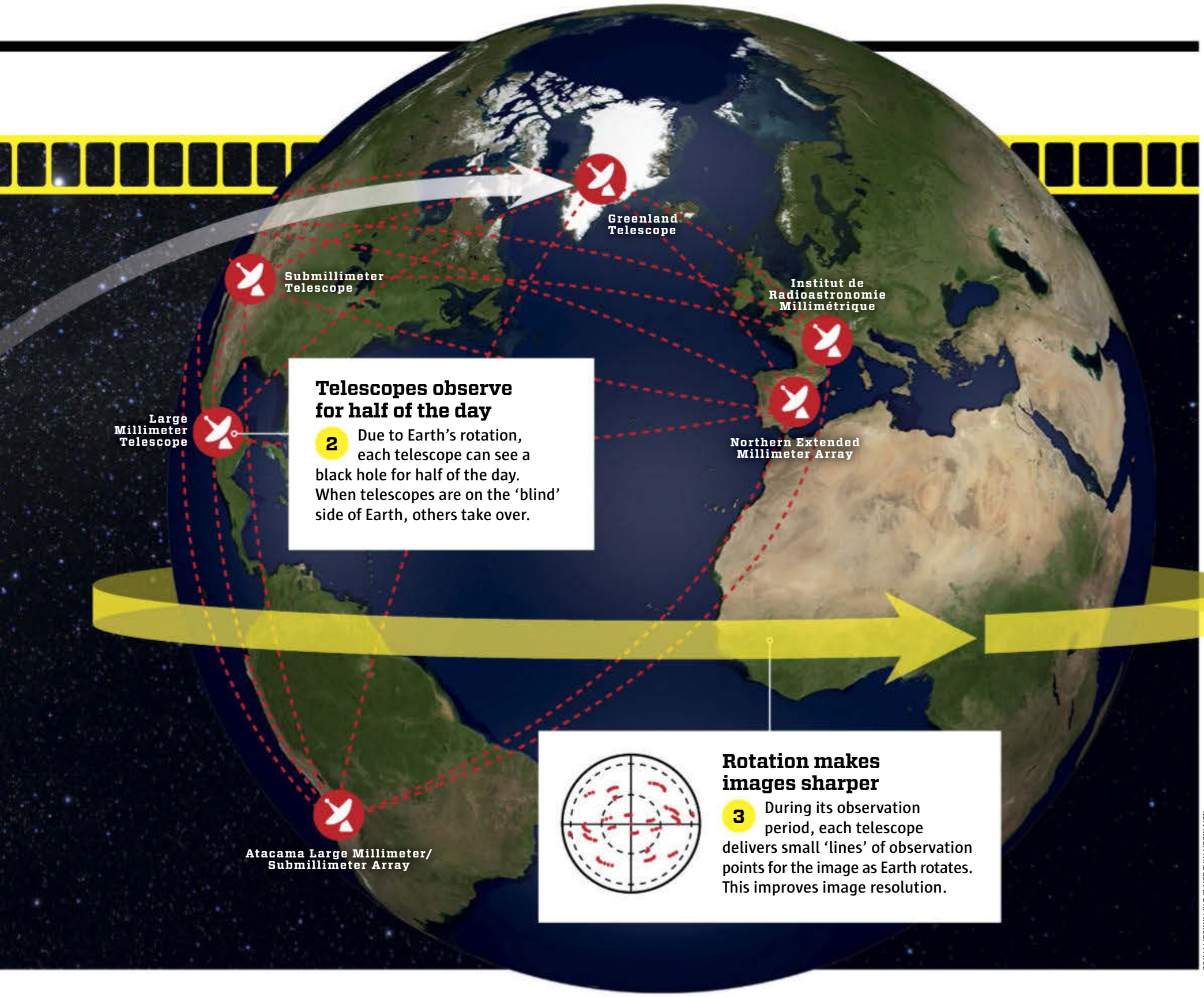
The 12-metre Greenland Telescope is a radio telescope that is one of the most recent in the Event Horizon Telescope network. It offers the network's northern-most view.

EHT COLLABORATION

In April 2019, the scientists behind the Event Horizon Telescope global telescope network published this first image ever taken of a black hole (known as M87*).

direction, arriving here millions of years later – assuming they encounter no obstacles on the way, and avoid being either diverted by other massive objects or absorbed by water vapour in Earth's atmosphere.

This radiation from black holes does not reach Earth in the form of visible light, but as radio waves. Astronomers detect the waves using a global network of radio telescopes known as the Event Horizon Telescope (EHT), which can measure radiation down to a wavelength of 1.3mm. In April 2017 the EHT radio telescopes were used to measure radiation from the black hole of M87* and, over a period of seven days, the EHT collected 5 petabytes of data about the hole (in information terms, that's equivalent to the total production of selfies by 40,000 people in their lifetimes). Such vast quantities of data are still faster to move physically than to transmit via the internet, so hard drives of data were flown to two data centres, where the observations could be combined. The scientists translated the radio waves into



KEN IKEDA MADSEN & DR. NIMESH PATEL

visible colours – yellow pixels representing the most intense radiation, then red a little weaker, and black for the places in which no radiation at all was measured.

Using this method, the EHT scientists constructed the image that was to become so famous a few years later. The image was particularly groundbreaking because it shows us the event horizon for the very first time. We can see it (left) as the round dark disc surrounded by yellow and orange light. The EHT astronomers have calculated that the event horizon of M87* has a diameter of around 39.2 billion kilometres.

Milky Way black hole is a child

As for weight, M87* weighs some 6.5 billion times the mass of our Sun, making it a supermassive black hole. The black hole at the centre of our Milky Way, around which the entire galaxy rotates, is Sagittarius A*. It is also supermassive, though M87* is around 1600 times heavier and around 2000 times further away. But these differences of mass and distance mean that, as seen from Earth, there is little apparent difference between the dimensions of the two holes.

39.2

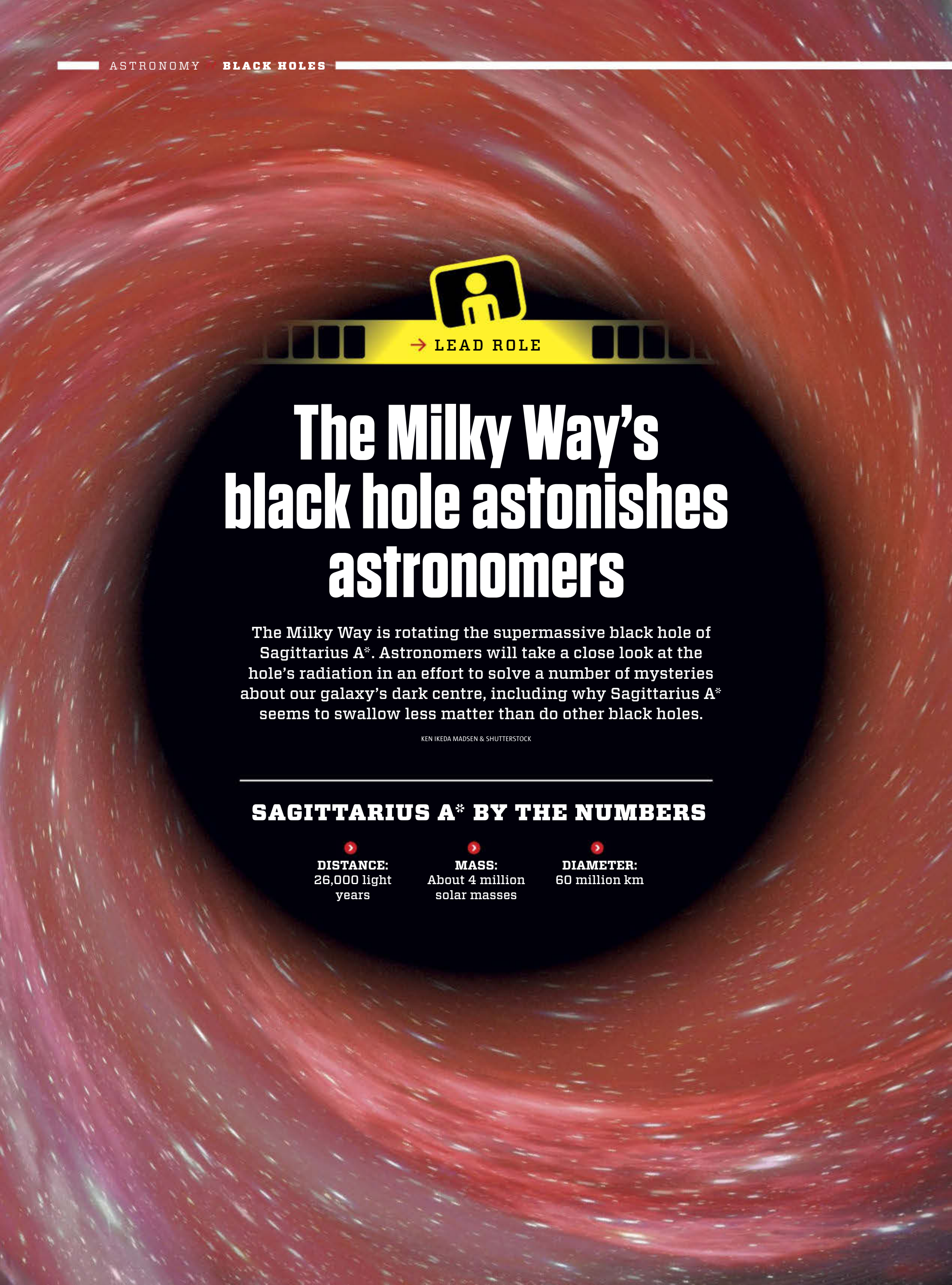
billion kilometres is the diameter of black hole M87*, 'photographed' in 2019.

However, there is another important difference – that of speed. The M87* hole is a friendly subject for photography because the radiation from the hole remains almost unchanged over many hours, the gases swirling very slowly around the hole, enabling astronomers to take 'photos' of it with a relatively slow 'shutter speed'. Its gases travel slowly because they are far away from the point around which the black hole's mass is located – its centre of mass.

With Sagittarius A* the opposite is the case – the gases are closer to the centre of mass, so travel faster around the hole. Scientists compare M87* to an adult sitting still to have his portrait taken, whereas Sagittarius A* is like a three-year-old child in constant motion. The solution is to record a movie, instead of taking a photo.

The scientists will make adjustments to the EHT network's telescopes, enabling them to record radio energy with a shorter wavelength – 0.87mm instead of the previous 1.3mm. They aim to combine recordings from additional telescopes located in Greenland, France and Arizona, a total of 11 telescopes from which the recordings must be combined. All this should improve the sharpness of the final images by 30-50%.

Finally, the scientists will use a computer program by the name of 'StarWarps' to ▶



→ LEAD ROLE

The Milky Way's black hole astonishes astronomers

The Milky Way is rotating the supermassive black hole of Sagittarius A*. Astronomers will take a close look at the hole's radiation in an effort to solve a number of mysteries about our galaxy's dark centre, including why Sagittarius A* seems to swallow less matter than do other black holes.

KEN IKEDA MADSEN & SHUTTERSTOCK

SAGITTARIUS A* BY THE NUMBERS

DISTANCE:
26,000 light years

MASS:
About 4 million solar masses

DIAMETER:
60 million km

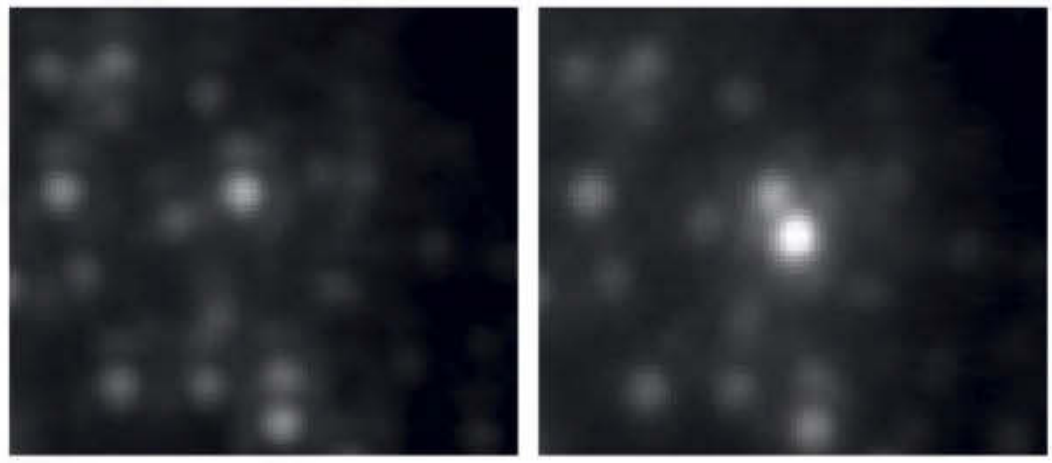
NASA

Why does our black hole swallow so little?

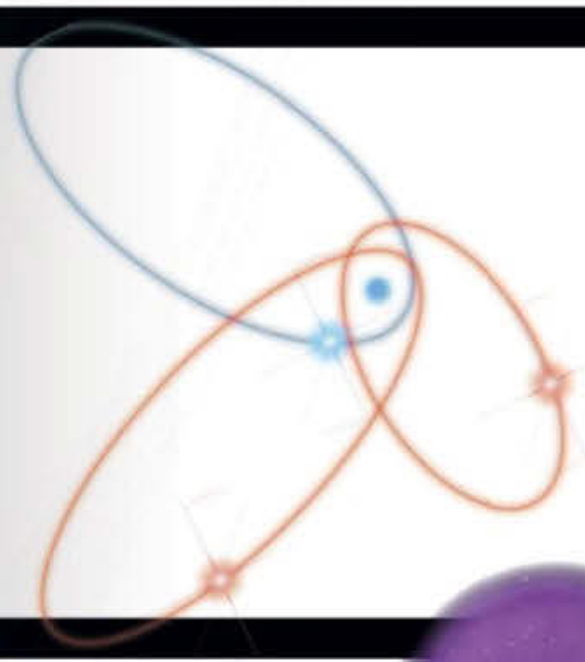
Radiation from Sagittarius A* indicates that it consumes very little gas and dust in its growth disc compared with other black holes. The explanation could be found in the hole's magnetic field, which forces the matter of the growth disc into stable orbits where it is not swallowed. The magnetic field is examined by the SOFIA telescope, located on a Boeing 747.

Why does the radiation flare up?

In May 2019, the radiation from Sagittarius A* suddenly doubled. Astronomers still do not know why, but it might be because the star SO-2 passed relatively close to the black hole, making gases around the hole huddle together and accelerate in a rush towards the black hole – causing a huge energy discharge.



TUAN DO/KECK/UCLA GALACTIC CENTER GROUP



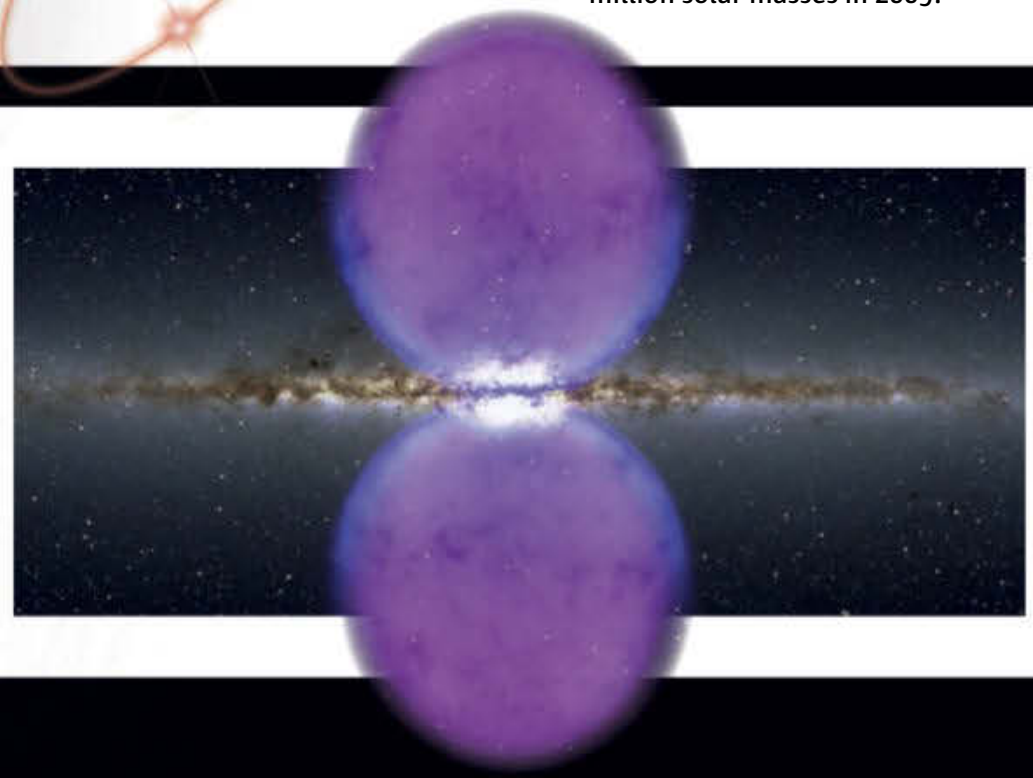
KEN IKEDA MADSEN

How much mass does the hole hold?

The mass of Sagittarius A* is often stated as 4 million solar masses, but astronomers do not know the exact 'weight'. So far, the mass has been calculated by observing stars that orbit close to the hole in elliptical orbits. In 2008, American scientists calculated a size of 3.7 million solar masses, whereas German scientists arrived at 4.3 million solar masses in 2009.

Does the black hole have jets?

Supermassive black holes often have jets that dart out perpendicularly to the inner edge of the growth disc. Astronomers from the University of Sydney have analysed two huge gas bubbles stretching from Sagittarius A*. The black hole swallowed a huge gas cloud around 3.5 million years ago, and some of the gas was ejected in opposite directions, in the same manner as jet creation.



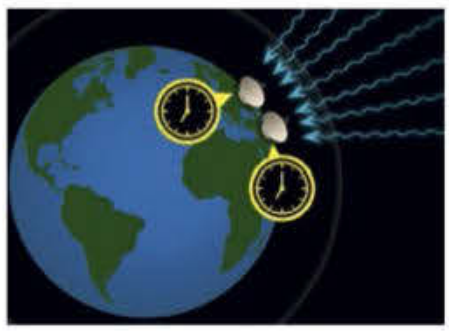
NASA'S GODDARD SPACE FLIGHT CENTER

KEN IKEDA MADSEN & SHUTTERSTOCK

→ OPENING NIGHT

Computer to combine images into a movie of the black hole

Scientists from the global Event Horizon Telescope (EHT) network aim to make video footage of the black hole at the centre of the Milky Way. They have developed a method that combines observed and computer-generated images into a film.



Telescopes record observations accurately

1 Radiation from the black hole at the centre of the Milky Way reaches EHT's 11 telescopes on Earth. The time of every observation is recorded by atomic clocks which lose only one second in 10 million years.

Data on hard drives are flown across the world

2 Half a tonne of hard drives with data are flown from the telescopes to Cambridge, USA, and Bonn, Germany, where supercomputers combine all the observations.

Observations from all over the world united

3 Each observation contributes a little slice to a total image in which scientists use different colours to indicate the strength of the measured radio waves from the black hole.

Computer fills the gaps between the images

4 Each image of the black hole is created based on several minutes of observations made by individual telescopes. The StarWarps computer program notes minor changes that take place during the 'shutter period' and generates the most likely intermediate images, rather like your TV smoothing motion judder by interpolating additional frames. The result is a continuous movie.

The Kamioka Gravitational Wave Detector (KAGRA) in Japan is a new instrument that can observe gravitational waves that could derive from collisions between black holes.

KAGRA OBSERVATORY

combine the images into a coherent film. The StarWarps program can analyse a series of images and calculate intermediate computer-generated images, so that what might otherwise look like a slide show can be presented as fluid video.

Black holes provide the answers

Such a film of the black hole at the centre of our own Milky Way could help us answer several questions. Scientists would like to know more about how the magnetic fileids of black holes are able to 'push' matter in the growth disc. According to the theory, gravity from a black hole and its rotation distorts a magnetic field to affect charged particles around the hole. Some of the particles fall into the hole while others are flung far away, but scientists do not know how much matter goes each way. Video of the activity surrounding Sagittarius A* might provide scientists with an answer. The particles can also end up in 'jets', which have been found near to many black holes, consisting of charged particles that pour out from the inner edge of the growth disc.

Another question that the video of Sagittarius A* might answer is how these supermassive black holes originated. Supermassive black holes exist at the centres of most galaxies, and were formed at the same time as the galaxies. But some supermassive black holes of up to 30 billion solar masses are further away than current theories should allow. One of these black holes is designated J2157, and the light we receive from J2157 was emitted when the universe was only 1.2 billion years old. According to current theories, black holes of more than 20 billion solar masses should not have existed so early in the history of the universe. Video of Sagittarius A* would give scientists a hint as to how the Milky Way's dark centre formed, and so how 'forbidden' black holes are born.

> **AVERY BRODERICK,** ASTROPHYSICIST
>
> **"The quantum gravity theory problem remains unsolved, and black holes are one of the places in which we can look for an answer."**

EHT astronomers also plan to film other black holes. They dream of creating a catalogue that will allow scientists to compare supermassive black holes of different ages, so they can see how they develop.

Today, the EHT telescopes are located across the world's surface, combining to collect radiation with a huge 'receiver'. But a network of satellite-based telescopes would give the EHT an even larger diameter, while also recording radiation that gets absorbed in Earth's atmosphere before it reaches ground-based telescopes. Scientists from the Netherlands' Radboud University calculate that the two improvements would allow an image resolution up to five times greater than that of the existing EHT.

A high-resolution video catalogue is only the beginning of what we might obtain if the EHT were able to expand into space. The scientists' hope to provide evidence towards the much-vaunted 'theory of everything' that might unite two fundamental theories of physics. Einstein's relativity theory explains the universe on a large scale, and is still the best explanation of how black holes behave. But it has always been incompatible with quantum mechanics, which explain the tiniest of particles. Astrophysicists have already named the theory that might unite the two as 'quantum gravity'. And the proof of this theory – which would be the biggest revolution in physics for more than 100 years – could exist around black holes.

As one of the EHT scientists, Canadian astrophysicist Avery Broderick, says: "We are looking at the universe with new eyes, more deeply and more sharply than ever before. The effects of quantum gravity might be observable at these scales. If they are, then this might be the point when, all of a sudden, the puzzle pieces click into place." SI

The **deep sea floor** teems with life

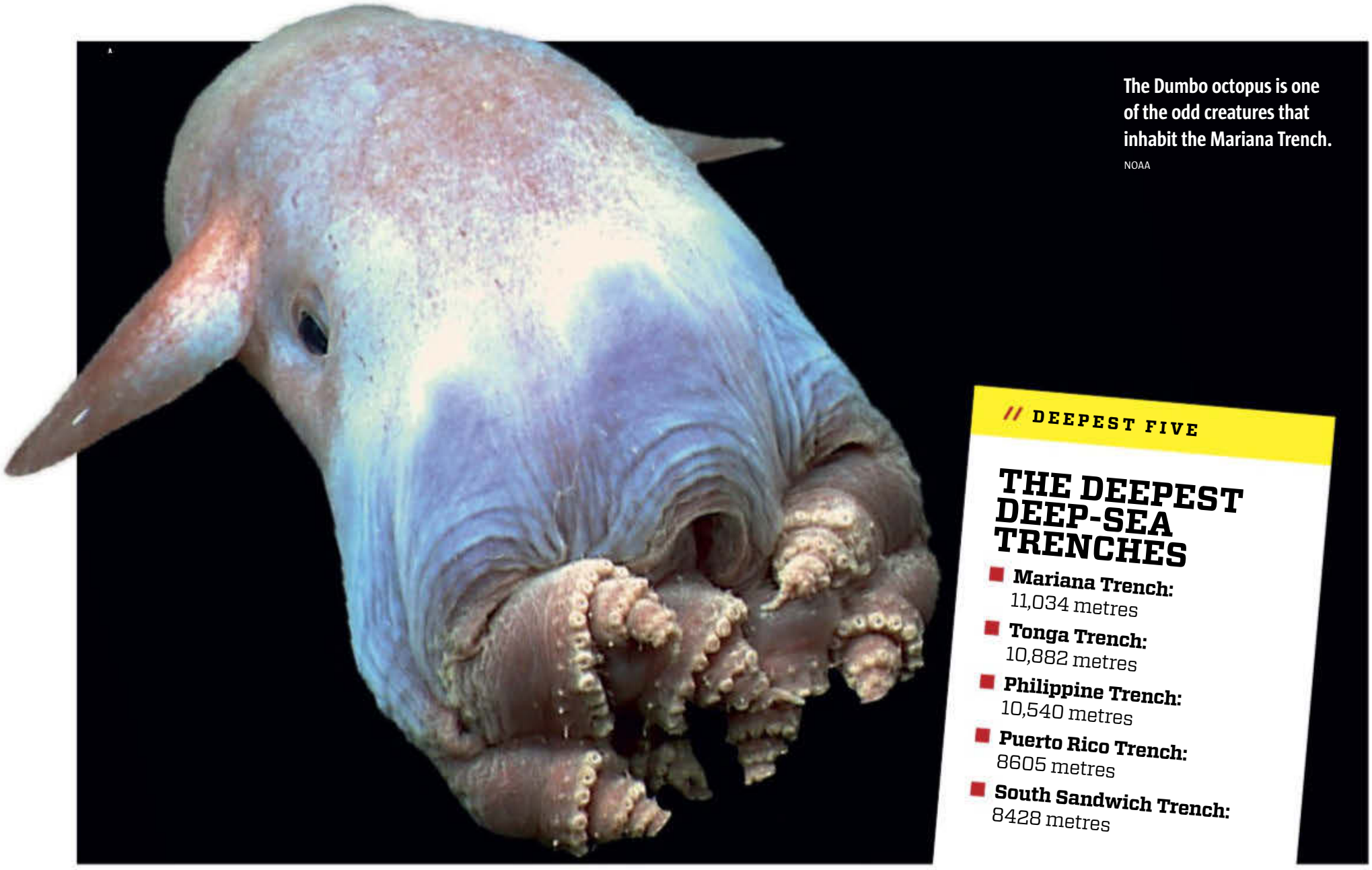
The Mariana Trench is the world's deepest place, 11 kilometres below the ocean surface. There is no light and hardly any oxygen – yet there's plenty of life to be found even in this extreme environment.

We have planted flags on the Moon, sent spacecraft to Mars, and taken samples from asteroids 300 million kilometres away. But there are still places on Earth that humans have never visited. The American National Oceanic and Atmospheric Administration estimates that more than 80% of Earth's oceans remain unexplored, with the deepest places of all being particular blank spots on the world map. Indeed scientists estimate that a mere 0.0001% of the ocean floor has been explored.

At a depth of 11,034 metres, the Pacific Ocean's Mariana Trench is the world's deepest place. Pitch darkness and immense pressure make the Mariana Trench almost impossible to explore. But those very conditions make it a fascinating place to study. Ocean drilling has revealed that the deep biosphere – as deep underground as we can reach – includes more microorganisms than there are stars in the universe. And if we can understand how life exists under such extreme conditions with neither oxygen nor sunlight, it could assist scientists in predicting whether there might be life on planets which are otherwise considered lifeless.

The Mariana Trench is the deepest sea trench that has been identified. There are 27 known deep-sea trenches in the oceans – defined as 6000 metres and below – and they cover a total area similar to that of Australia. The Mariana Trench originated approximately 180 million years ago from a collision between two of Earth's biggest tectonic plates – the Philippine Plate and the Pacific Plate. This also makes the ocean floor around the Mariana Trench the oldest on Earth. Scientists used to believe that life simply could not exist at such extreme depths, but they were wrong. Expeditions to deep-sea zones reveal that life exists in the form of starfish, sea anemones, fungi, bacteria, and other microorganisms. Indeed ocean-floor drilling near the Mariana Trench using remote-controlled robotic vessels reveal that the ground beneath contains not mere evidence of life, but so much of it that scientists now estimate that more than 90% of all the world's microorganisms exist deep in the ground, under the oceans.

The deepest point of the Mariana Trench, down at 11,034 metres, forms an area known as the Challenger Deep. There the pressure is 1000 times higher than at Earth's surface, the equivalent of carrying a blue whale on your head. When the film director James Cameron made the first ever solo dive



The Dumbo octopus is one of the odd creatures that inhabit the Mariana Trench.
NOAA

// DEEPEST FIVE

THE DEEPEST DEEP-SEA TRENCHES

- **Mariana Trench:** 11,034 metres
- **Tonga Trench:** 10,882 metres
- **Philippine Trench:** 10,540 metres
- **Puerto Rico Trench:** 8605 metres
- **South Sandwich Trench:** 8428 metres

into the Mariana Trench in 2012 to a depth of 10,898 metres in his Deepsea Challenger vessel, he felt as if he was journeying to another planet. Cameron was only the third person in history to get so deep into the Mariana Trench. The first mission had taken place more than 50 years earlier, in 1960, when Don Walsh of the USA and Jacques Piccard of Switzerland dived the Mariana Trench to reach a depth of 10,911 metres aboard the submarine Trieste.

In 2020, the Mariana Trench was visited by the first woman, in an expedition by American adventurer and businessman Victor Vescovo and former astronaut Kathryn Sullivan, who in 1984 had also become the first woman to undertake a spacewalk. The dive was undertaken in Victor Vescovo's customised submarine, and the two of them reached a depth of 10,918 metres, which was not enough to beat the existing record set the year before, when Victor Vescovo reached 10,927 metres on his own. During his record dive, Victor Vescovo discovered four new species at the floor of the Mariana Trench, and there will almost certainly be more such finds made in the world's deepest places. In November 2020, three Chinese scientists dived into the Mariana Trench aboard the submarine Fendouzhe. The first dive reached 10,909 metres, and more dives followed. According to their plan, the vessel will take samples of the ocean floor in an effort to teach us more about life under such extreme conditions – and perhaps reveal how it originated. SI

FILM DIRECTOR JAMES CAMERON ABOUT HIS SOLO DIVE IN THE MARIANA TRENCH:

I felt like I literally, in the space of one day, had gone to another planet and come back.

WATCH THE CUTE DUMBO OCTOPUS IN ACTION

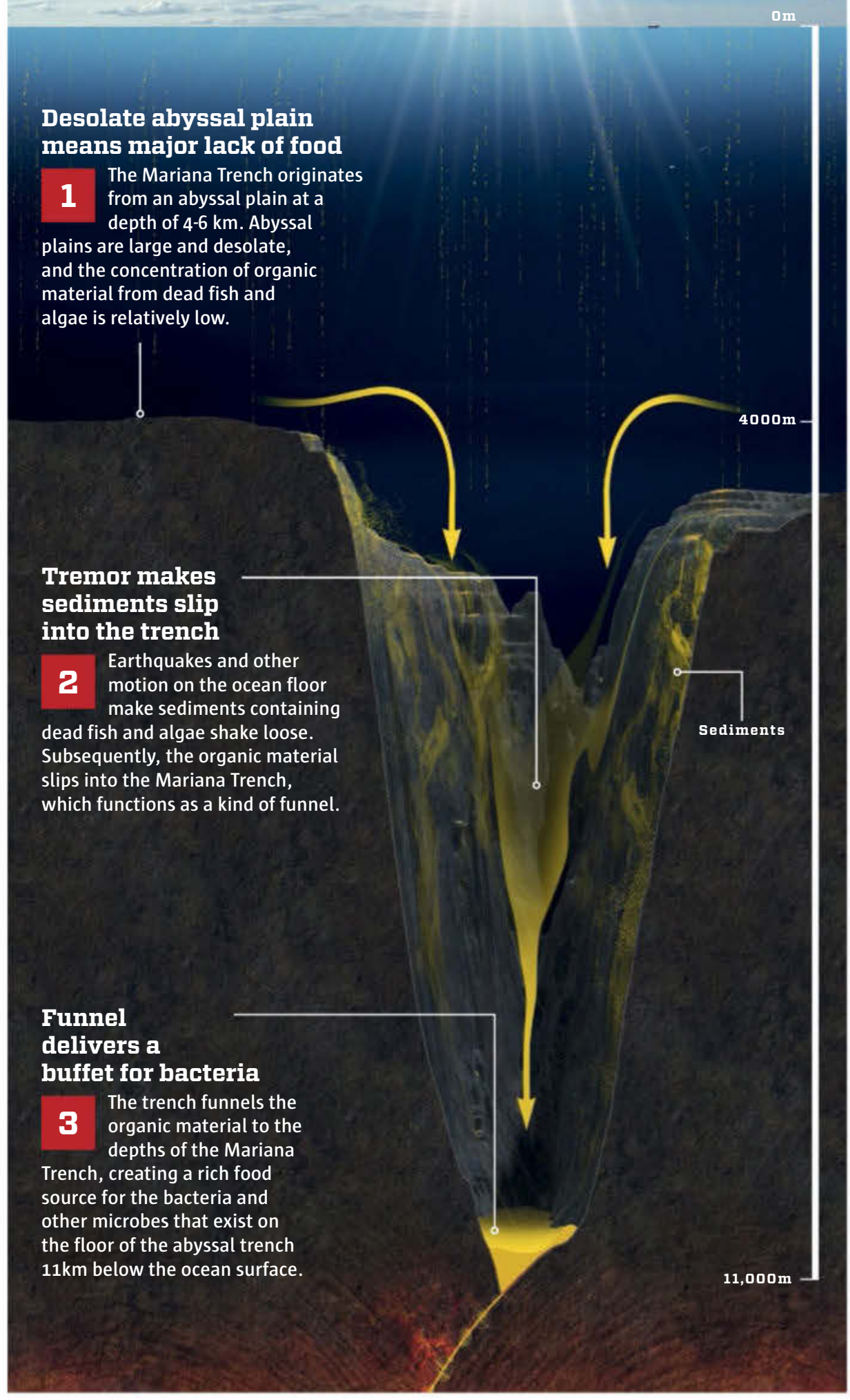
This YouTube video shows a close encounter with the Dumbo octopus – and makes clear how it got its name...

tinyurl.com/scivid82

// HOW LIFE ORIGINATES IN THE MARIANA TRENCH

Deep-sea trench is a funnel for dead animals and algae

Most bacteria live in shallow waters, where they can get nutrition from dead fish and algae, but the Mariana Trench is an exception. Food accumulates there, funnelled down from above, and life can thrive there.



CLAUS LUNAU

SHUTTERSTOCK

It has been a race which has transformed vaccines:

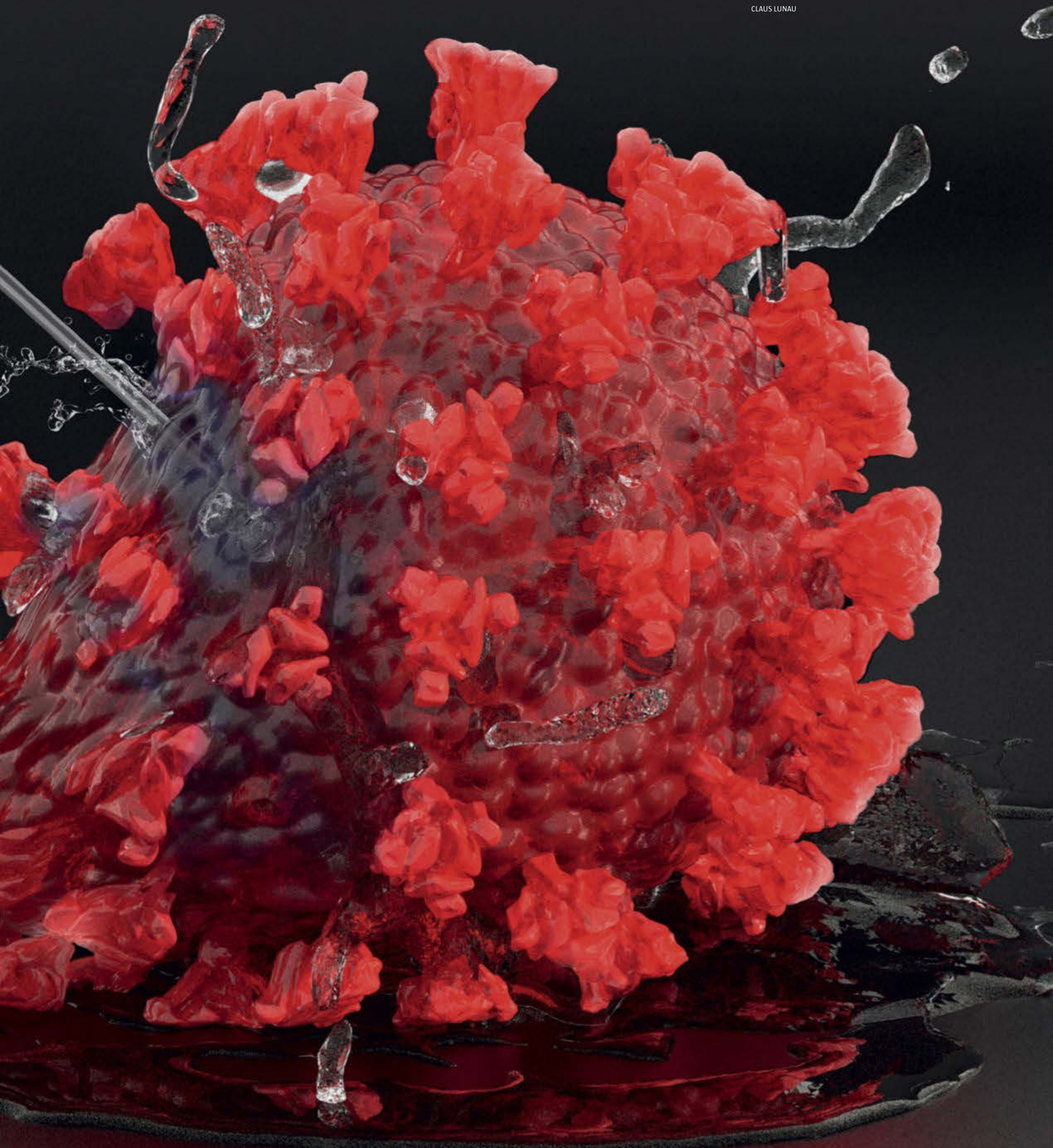
DOCTORS ARE READY TO GIVE VACCINE 2.0

In January 2020, few people even understood the danger facing the world. But only 11 months later, scientists were ready to vaccinate against the pandemic. And after the fastest race in the history of medicine, a whole new generation of vaccines may tackle diseases beyond just COVID-19.

By **Gorm Palmgren**

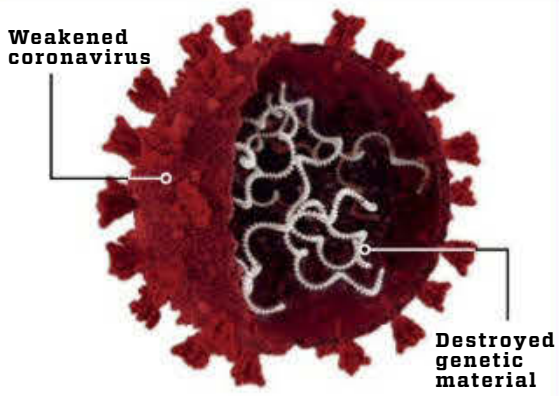
Vaccines have eliminated pandemics before. The extraordinary acceleration now achieved in vaccine production should make them more powerful than ever.

CLAUS LUNAU



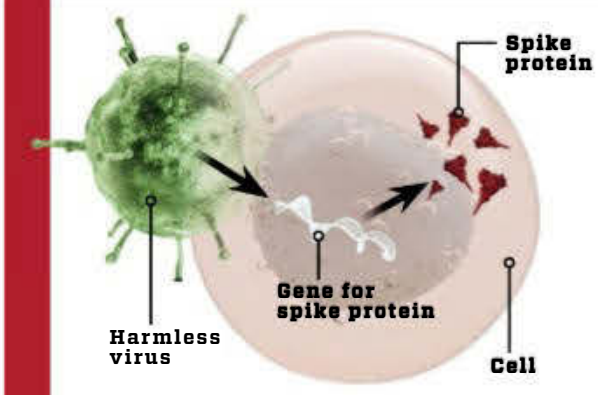
4 variants compete to win

More than 180 different COVID-19 vaccines have been in the pipeline – and the majority of them can be placed in one of four vaccine categories. One is a classic. Two are comparatively recent. And one has never before been approved for use in humans.



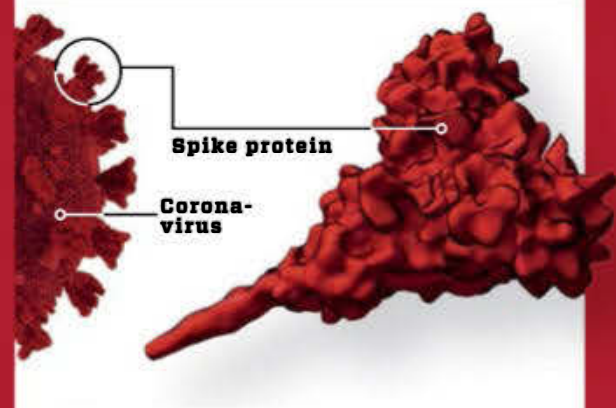
Weakened virus is a risky approach

1 SARS-CoV-2's genetic material (white) is first destroyed by high temperatures. The virus exterior remains intact and so trains the immune system to recognise the real virus. The method is familiar, but in rare cases the weakened virus could cause disease.



Harmless virus makes itself known

2 A harmless virus (white) with the gene for SARS-CoV-2's spike protein makes body cells produce the spike protein (dark triangles), so the immune system gets to know it. In some cases, the body begins to fight the harmless virus.



Virus fragments are expensive to run

3 Scientists take a protein from the surface of SARS-CoV-2 and inject it directly into the body, so the immune system is trained to recognise the virus. However, such proteins can be difficult and expensive to make in sufficient quantities.

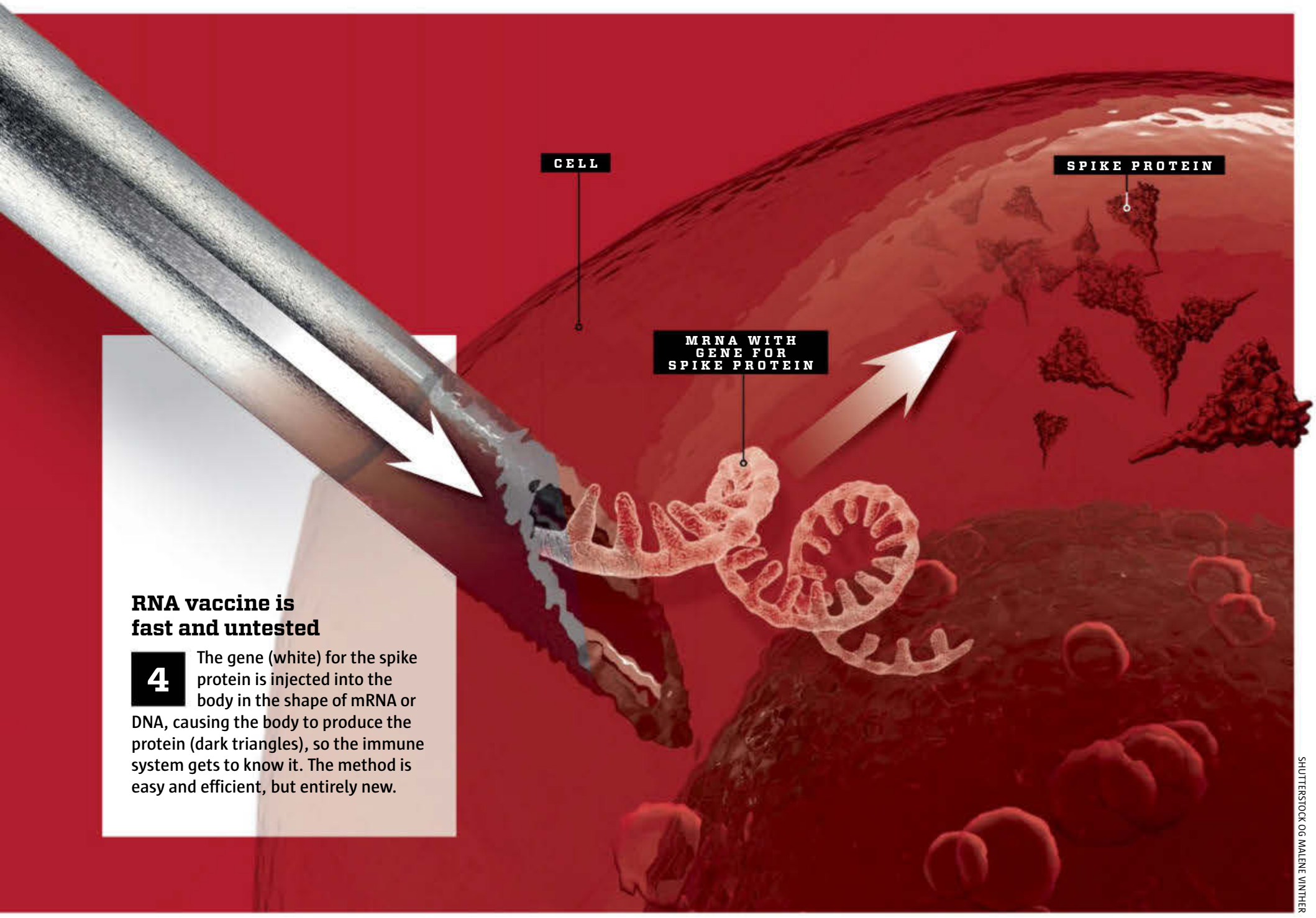
RITZAU SCANPIX

Coronavirus spread rapidly through the Chinese city of Wuhan in January 2020 – and then to the rest of the world in a matter of just a few months.

Physician Ugur Sahin received an email late one Friday night near the end of January 2020. At the time, very few people had realised that a new coronavirus was about to take the world's population in its grip. But as Sahin read the scientific article to which the email directed him, he understood what was about to happen – the beginning of a war against an enemy that had not yet demonstrated its full potential. And he decided to do something about it.

At that point in time, few knew about the new virus that had emerged in the Chinese city of Wuhan and spread to the rest of China and a handful of neigbouring countries. The virus, which was later named SARS-CoV-2, had infected a total of 1347 people, of whom 41 had died of a new type of pneumonia.

In the scientific article that Sahin read, scientists from China and Hong Kong were describing how the infection had spread in a family. By studying the time period between infection and disease symptoms in each fam-



SHUTTERSTOCK OG MALENE VINTHER

RNA vaccine is fast and untested

4 The gene (white) for the spike protein is injected into the body in the shape of mRNA or DNA, causing the body to produce the protein (dark triangles), so the immune system gets to know it. The method is easy and efficient, but entirely new.

ily member, the scientists concluded that the virus was spreading from human to human.

Sahin was the CEO of German drug maker BioNTech, and he realised immediately that the virus could sweep across the world, and that a vaccine would be the only efficient weapon against the nascent pandemic. Over that weekend, Sahin considered the possible paths of action, and on Monday, he summoned BioNTech's board of directors, asking permission to immediately launch 'Project Lightspeed'. Its aim was to develop a vaccine for COVID-19 – and to do so in record time.

Scientists find new ways

Normally, it takes 10-15 years to develop a new vaccine. The all-time record was four years. This time it was going to be achieved in under a year – and with more than 180 competitors in action.

Scientists not only had to work extremely fast, they also had to choose the most efficient method for producing their vaccine. Like all vaccines, their goal was to make the immune system produce antibodies and T cells that could combat the virus. The classic method for a vaccine is to use an inactivated or weakened version of the virus being targeted, but with this type of vaccine, scientists cannot control which parts of the virus the immune system will aim its antibodies at. Ideally, the antibodies must be aimed at a protein on the surface of the virus, one that exists only on that specific virus, so that the immune system doesn't waste energy attacking other harmless viruses. Scientists had previously solved this problem by making a vaccine consisting of that specific protein. It's a method that certainly works, but it is complex and time-consuming to develop. Ugur Sahin feared that such existing methods would be simply too slow. He decided that BioNTech needed to opt for a new approach.

1.8

million people died with SARS-CoV-2 in 2020.

Code trains the immune system

BioNTech already specialised in immune therapy against cancer – a type of treatment that is similar to vaccines. In both cases, the immune system is stimulated to combat the enemy. One of their preferred methods was the use of mRNA molecules. These are similar to DNA, and like DNA they can carry a genetic code that cells then use as a blueprint to produce a protein. By injecting mRNA with the code for a specific virus protein, the scientists could make the body's own cells produce the protein – and hence train the immune system to recognise the virus.

BioNTech's expertise with the mRNA method made Sahin believe that a COVID-19 vaccine could be developed the same way, even though other scientists had previously experimented with mRNA vaccines, and nobody had yet succeeded. However, the potential advantages were clear. An mRNA vaccine can be designed and made in the lab in less than a week, whereas it takes months to make more conventional vaccines. So by early February BioNTech had already made a series of prototypes of the vaccine that they could test on animals. Rhesus macaques and mice had a number of mRNA molecules injected into their bodies, and the scientists studied how the animals' immune systems reacted, and whether the animals became immune to coronavirus.

BioNTech lags behind

By early April, these animal trials had been completed, and a vaccine candidate with the code name of BNT162b2 looked like a winner. The vaccine's mRNA molecule made the immune system attack part of the spike protein on the surface of coronavirus, which the virus uses to enter body cells. One single injection of BNT162b2 made the treated animals produce sufficient quantities of both antibodies and T cells to attack SARS-CoV-2. And the vaccine protected the animals efficiently against pneumonia.

With these promising results, BioNTech teamed up with big American drug company Pfizer, and in late April, they were allowed to begin human trials in both Germany and the United States.

But in spite of such a rapid response, BioNTech and Pfizer were not leading the race to develop a COVID-19 vaccine. In the US, the companies Moderna and Inovio were already busy testing vaccines on humans. Like BioNTech, Moderna had used mRNA in its vaccine, whereas Inovio used DNA. In China, the company CanSino Biologics was testing another vaccine, this one consisting of a harmless cold virus that made body cells produce the coronavirus spike protein.

10%

of the world population had been infected by October 2020, according to the WHO.

Swedish-British firm AstraZeneca had also developed a vaccine – following the same methodology as CanSino Biologics' – and on 22 May 2020, its vaccine was the first to reach final phase 3 trials on humans. At that time, there were 19 different vaccines being tested in experiments on humans across the world, while 130 other vaccine candidates were being tested on animals. Only AstraZeneca had reached phase 3, in which the vaccine is tested on thousands of people.

In cooperation with the UK's University of Oxford, AstraZeneca chose to carry out its trials in Brazil, where the number of new COVID-19 cases was growing rapidly day by day. Because the 40,000 test subjects were facing a high potential infection rate, the scientists had an excellent opportunities to test the vaccine's efficiency.

Vaccines sprint towards the goal

BioNTech and Pfizer kept working. They had positive results from their phase 1 and 2 trials on humans, and in July they initiated phase 3, which involved more than 43,000 people in Germany, the USA, Brazil, Argentina, South Africa and Turkey. At the same time, they made binding agreements with authorities in the UK, the US and Japan for 250 million doses of the vaccine – although nobody yet knew if it would ultimately be approved. Australia entered into four separate agreements for the supply of vaccines once they proved effective. Meanwhile the money from the BioNTech/Pfizer sales were quickly spent on a new vaccine factory to ensure rapid deliveries of huge quantities of vaccine once approved.

By early November, BioNTech and Pfizer had taken the lead in the vaccine race, the first to publish the preliminary results of their crucial phase 3 experiments. At that time, a total of 94 of the 43,000 test subjects had tested positive for coronavirus – 86 of them from the placebo group which had not received the vaccine, and only eight from the vaccinated group. The scientists were thereby able to conclude that the vaccine offered higher than 90% protection against infec-

BIONTECH

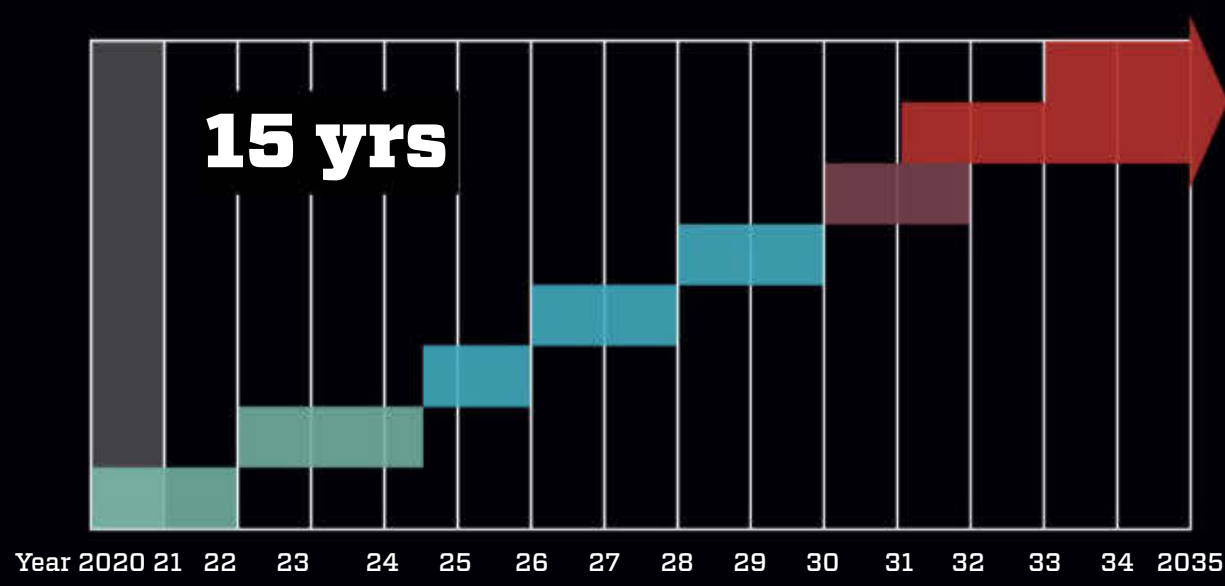
Ugur Sahin and Özlem Türeci are married; they are respectively the CEO and Chief Medical Officer of BioNTech. They headed the development of the company's vaccine against SARS-CoV-2, produced in cooperation with Pfizer.

15 years of work done in one year

Normally it would take 10-15 years to develop a new vaccine and bring it to market. But with efficient cooperation between drug makers and health authorities, the COVID-19 vaccine was developed in less than a year – without compromising safety.

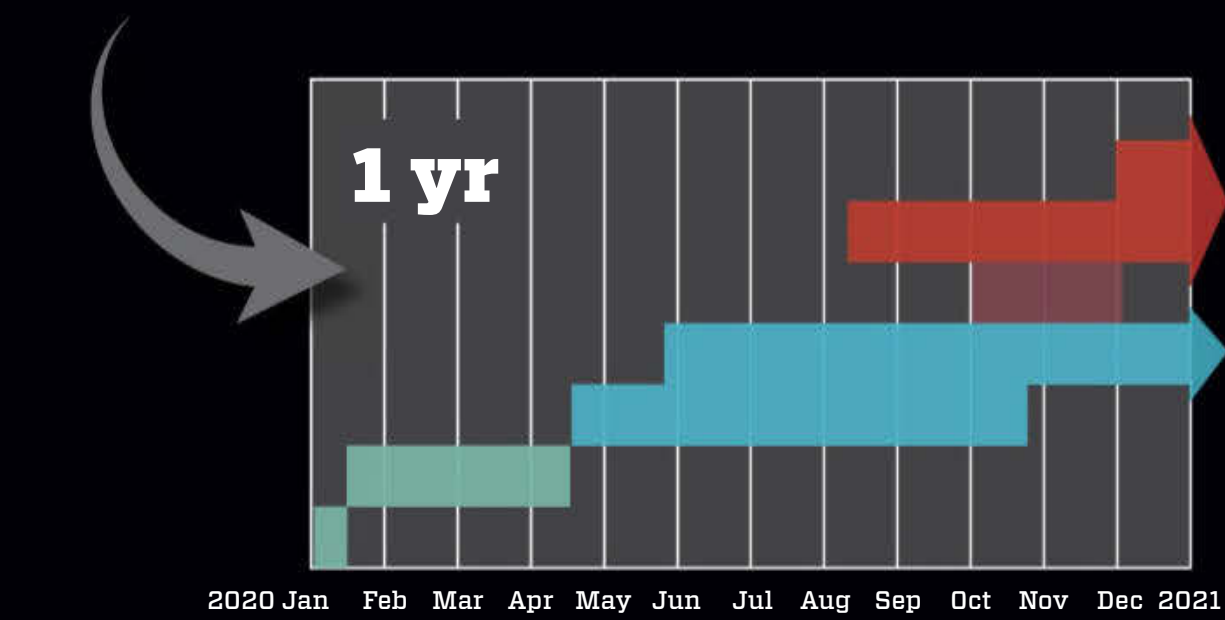
SHUTTERSTOCK & MALENE VINTHER

LABORATORY/ ANIMAL EXPERIMENTS | EXPERIMENTS ON HUMANS | AUTHORITY APPROVAL | MANUFACTURE AND DISTRIBUTION



Normal procedure takes about 15 years

1 Scientists develop the vaccine in the lab, test it on animals, and then test it on humans in three phases – on first 50, then 300, and finally 30,000 test subjects. The trials are very expensive, so under normal circumstances the company behind the vaccine takes breaks between the phases to calculate whether it is worthwhile continuing. The final result is then introduced to the authorities, who decide whether the vaccine is to be approved. Factories can then be equipped to make the vaccine, followed by global distribution.



Fast procedures speed up the process

2 Scientists quickly develop the vaccine based on knowledge of the new coronavirus, SARS and MERS. The trial phases on animals and humans are completed rapidly and with overlaps because – due to the severity of the situation – authorities contribute millions to the development, so drug makers need not fear major losses. The authorities evaluate the preliminary results and buy millions of doses so mass production can begin. The vaccine is approved before the trials are fully completed, and quickly distributed.

JACOB KING/PA

The United Kingdom's 90-year-old Margaret Keenan became the first to receive the Pfizer/BioNTech vaccine as part of the post-approval roll-out, on 8 December 2020.

tion with SARS-CoV-2. The vaccine was a success. As more test results were received the result was adjusted to 95% protection.

Only one week later, Moderna reported equally good results for its mRNA vaccine candidate. And in late November, AstraZeneca finished its vaccine trials. It scored only 70% for protection, but with the advantage that it can be stored at fridge temperatures rather than the -70°C required by its competitors.

The authorities are watching

The health authorities didn't stand idly by during the vaccine race. Whereas normally they would not begin evaluating a vaccine until after the final phase 3 trial results were available, the severity of the global situation persuaded them to follow a far more rapid strategy – though to do so without compromising on safety.

Known as a rolling review, the faster procedure involves drug makers continously submitting all preliminary results to the health authorities, which can thereby get an ongoing general idea of the vaccine's efficiency and any side effects or similar critical results – all long before the phase 3 trials are fully completed. This allows the authorities to make a qualified decision about approval only a few weeks after receiving the final results. And that is exactly what happened to BioNTech and Pfizer with their vaccine.

The companies submitted final research results on 18 November, and on 2 December the vaccine was already approved in the UK. On 11 December, it was approved in the US, and on 21 December in the EU. Australia gave it provisional approval on 25 January 2021. At the same time, preparations for vaccination were under way. Doses had already been manufactured, the authorities had ordered and paid for them, and the infrastructure behind the distribution of the vaccines was being put into place. The EU's first injections occurred only six days after their approval there; the first Australian vaccination took place on the morning of February 21st.

Competitors cooperate

In the wake of the Pfizer/BioNTech vaccine, the vaccines from Moderna and AstraZeneca were also approved. Many more vaccines are in the pipeline – which is a good thing. No single company could manufacture enough doses of vaccine to inoculate the whole world within a reasonable time frame. Also, the vaccines based on different principles may deliver separate strengths and weaknesses. Scientists expect that some vaccines will be more efficient for the elderly, others for young people. Some vaccines might offer very high

54%

of the general public is willing to get the vaccine, according to an international study.

protection that lasts for a relatively short period of time, whereas others may offer a lower level of protection over much longer periods. Scientists do not yet know which vaccines will perform best in different scenarios.

As scientists gradually answer such questions, different health authorities will be able to develop the best strategy for their struggle against coronavirus. Scientists still have much work to do, even in connection with the approved vaccines. They need to monitor who gets which vaccines when, and how many still get ill. Further research is needed on the emerging variants of SARS-CoV-2, and on how long the benefits of vaccination will last.

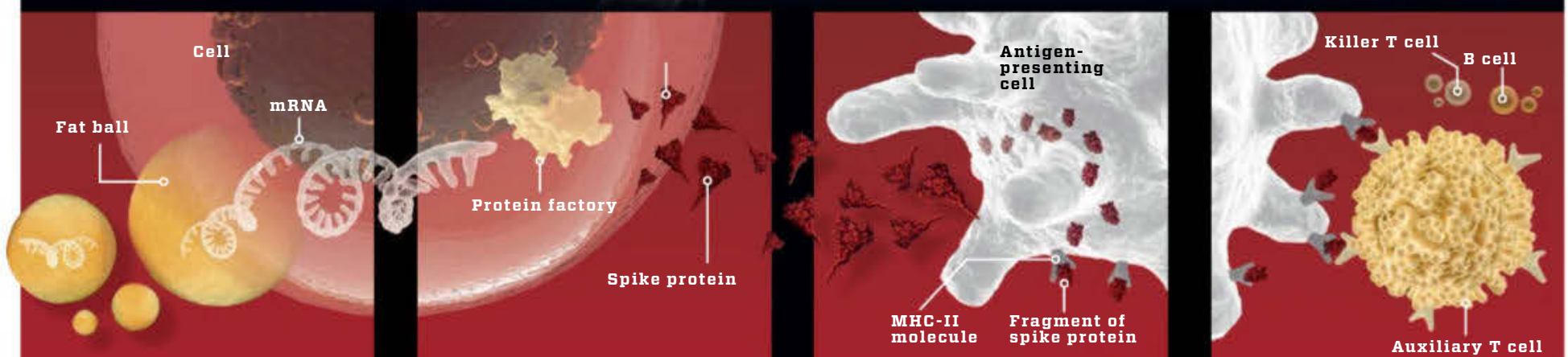
The brains behind the Pfizer vaccine, Ugur Sahin and his team from BioNTech, are optimistic. According to Sahin, the pandemic can be effectively contained before the end of 2021 if a major part of the population is vaccinated before the third quarter of the year. Once that has happened, Sahin will aim his new mRNA weapon at other contagious diseases. Hence the race against the pandemic may eventually help cure HIV, malaria, or influenza. SI

RNA prepares the immune system to fight

A vaccine protects you against a virus by teaching the immune system to recognise and then attack the virus. Several of the new COVID-19 vaccines achieve the goal using DNA-like RNA, which makes your own cells produce the virus proteins.

mRNA is much like DNA, but has only one strand of bases rather than two.

SHUTTERSTOCK



Fat balls deliver mRNA to cells

1 Scientists make mRNA (white) with genetic instructions to construct the coronavirus' spike protein. The RNA is wrapped in fat balls (yellow) and injected into the body. The fat balls subsequently deliver the RNA to cell interiors.

Cells construct virus protein

2 Your cells normally use mRNA – formed based on the genes in your own DNA – to construct proteins. The vaccine uses this machinery (yellow) to construct spike proteins (red triangles). The new proteins are secreted into the blood.

Immune cells cut up protein

3 The spike proteins are absorbed by cells from the immune system known as antigen-presenting cells (white). They break down the protein into small fragments, which settle on HC-II molecules (grey) on the surface of immune cells.

The immune system prepares for attack

4 The immune system's auxiliary T cells (pale yellow) bind to the fragments, subsequently activating other immune cells (yellow and green) – such as B cells – that produce antibodies against the virus, and killer T cells, which kill infected cells.

SHUTTERSTOCK OG MALENE VINTHER

It's the forgotten fourth state of matter...

PLASMA: CAN WE HARNESS THE FUEL OF STARS?

Solid, liquid, and gas. We know these three states, yet the fourth one makes up 99% of the visible universe. Plasma is the fuel of stars, and the red-hot state could fuel aircraft engines and perhaps even bring us infinite energy.

→ THE FORGOTTEN STATE

Plasma is the fourth fundamental state of matter, in which extremely high temperatures split atoms.

→ THE NEW ENGINE

Electrically-charged particles of plasma can be tamed, and might provide climate-friendly fuel for planes.

→ INFINITE ENERGY

Scientists aim to capture plasma in powerful magnetic fields to allow fusion power – an infinite energy source.

By **Rolf Haugaard Nielsen**

In a plasma ball, electricity converts gas into plasma. Scientists aim to harvest energy from this soup of hot particles.

KEN IKEDA MADSEN & SHUTTERSTOCK

Huge brooding grey-black banks of cloud fill the sky. Inside them, electrically-charged water drops and ice crystals are travelling up and down the cloud. Negative charges gradually collect at the bottom of the cloud, while Earth's surface grows ever more positively charged. Then suddenly the tension is equalised by a spectacular energy discharge: lightning.

Every time we see lightning, we are seeing plasma, the fourth fundamental state of matter – as compared with the three more familiar ones: solid, liquid, and gas. It is the intensive energy discharge of lightning that converts the air into plasma, in which atomic nuclei and electrons have been separated. In a split second, 10,000 amperes of current is discharged, travelling between the Earth's surface and the cloud at supersonic speed and heating the surrounding air to 25,000°C. The intense heat peels electrons off nitrogen and oxygen atoms in the air, converting them from gas into plasma.

99%

of the visible universe consists of plasma.

In principle, all substances can be converted into plasma. All that is needed to remove electrons from the atomic nuclei is a sufficiently high temperature. Scientists and engineers have already used plasma's unique qualities in fluorescent tubes and plasma TVs, but we have only just begun to understand and tame the immense energy of plasma. Plasma could replace jet fuel in airliners, and plasma engines are intended to play a central role in our colonisation of the Solar System. If physicists can manipulate this turbulent state with sufficient control, plasma could even become a practically inexhaustible source of energy.

99% of the universe is plasma

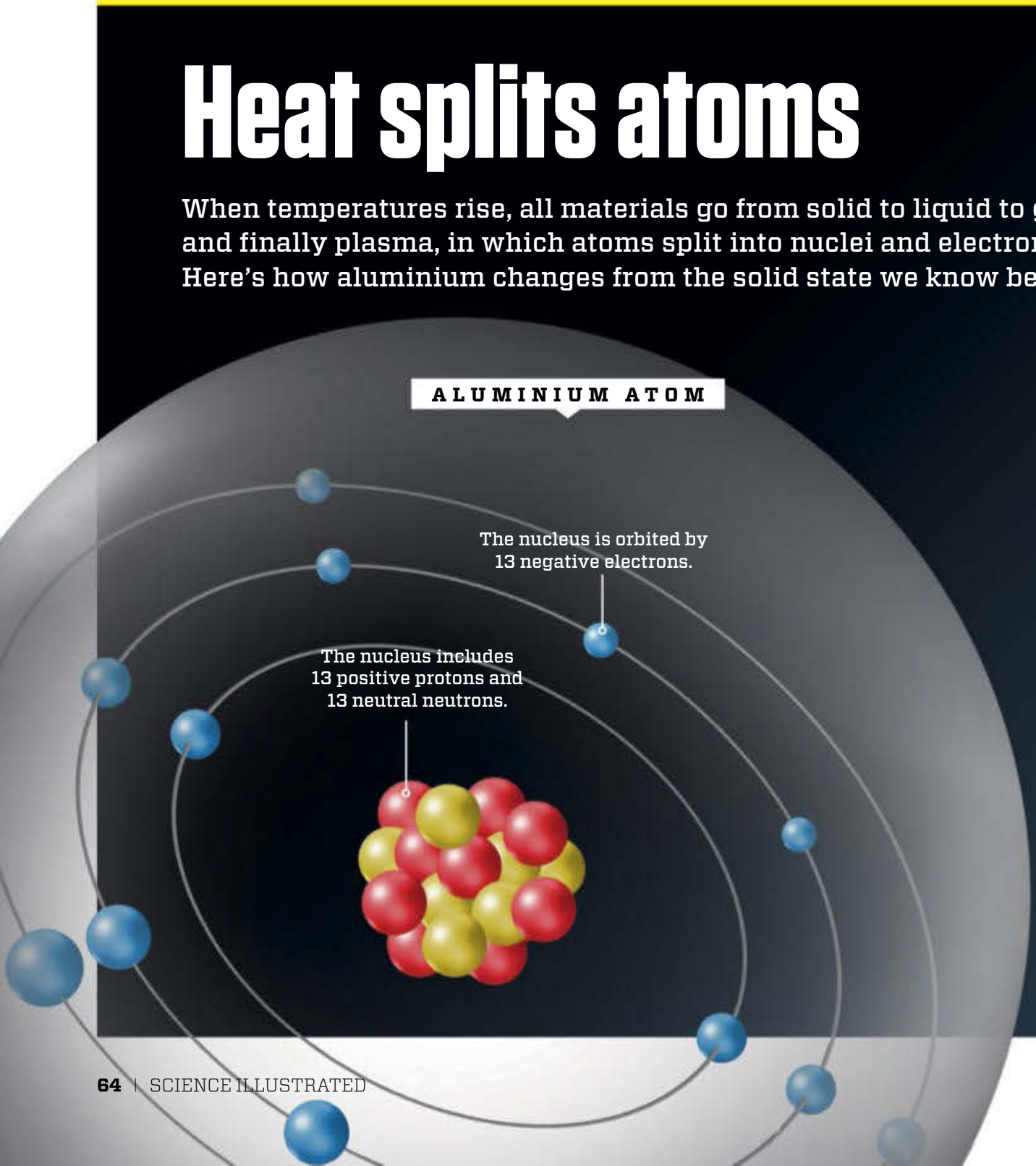
All substances change state as temperatures rise. We know this best from water. When the temperature is below zero, water is solid ice, with the atoms locked in a grid. As the temperature rises above freezing point, water becomes liquid – the grid disintegrates, and the molecules move about each other. When the water is heated to the boiling point of 100°C, it then becomes gaseous, in the form of water vapour: the molecules are moving freely in three dimensions.

Those are the three states of matter we encounter in our everyday lives. But if we continue the heating to above 1000°C, the water molecules will split into oxygen and hydrogen atoms. At a temperature of 10,000-12,000°C, the transformation into the fourth

→ THE FORGOTTEN STATE

Heat splits atoms

When temperatures rise, all materials go from solid to liquid to gas and finally plasma, in which atoms split into nuclei and electrons. Here's how aluminium changes from the solid state we know best.



SOLID: Atoms are stuck in a grid

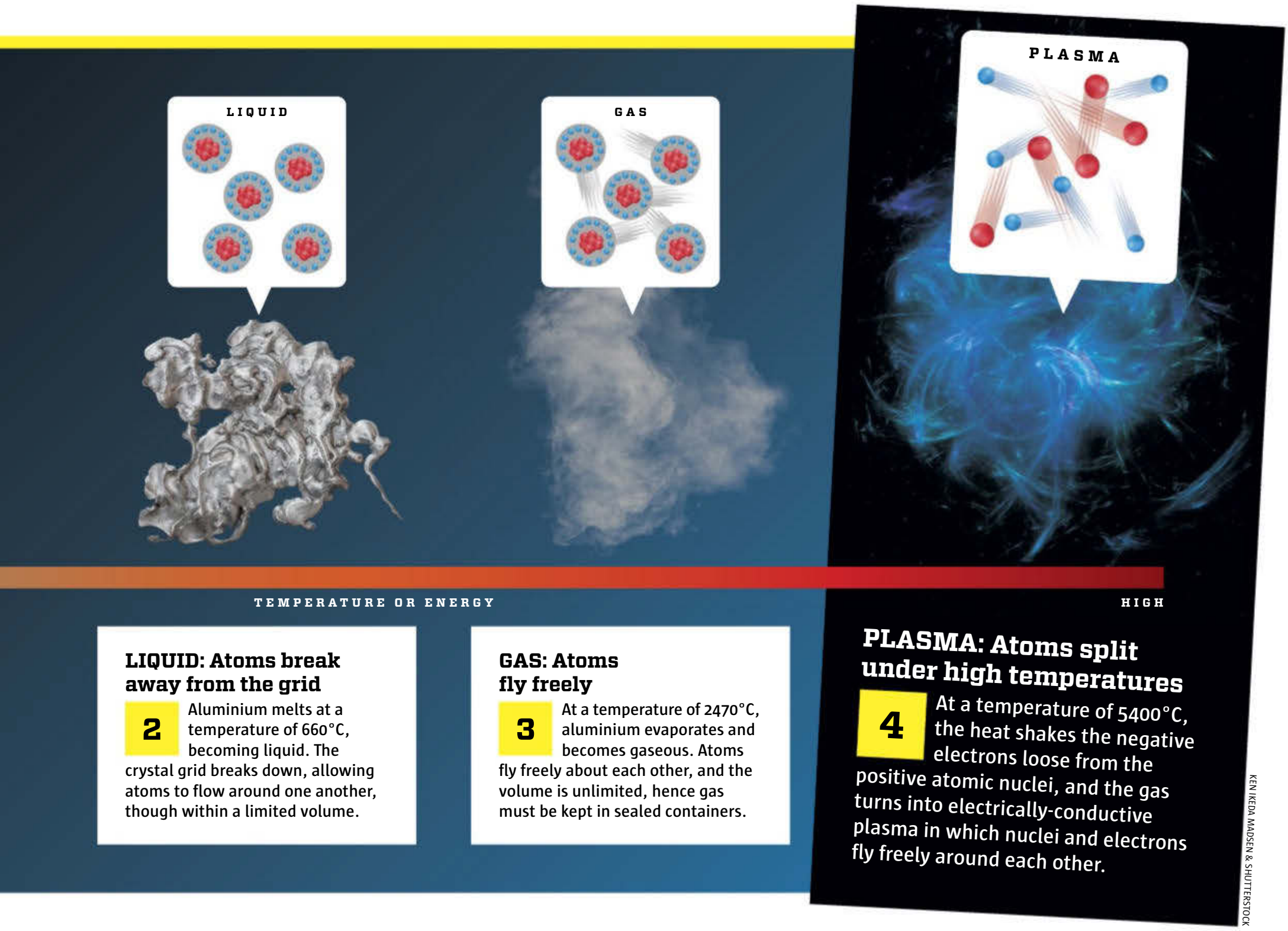
1 At ordinary temperatures, aluminium, which is used in everything from beer cans to planes, is a solid in which the atoms are locked in a crystal grid. The grid remains intact until melting point.

state takes place: the heat shakes electrons loose of the atomic nuclei, converting the gas into plasma, where negative electrons and positive ions – made up of protons and neutrons – are moving freely around each other. Their freedom of movement means that plasma is electrically conductive.

More than 99% of the visible universe – the bright stars and the hydrogen clouds in and between galaxies – consists of plasma. The hydrogen clouds are extremely thin, but plasma can also be highly compact, although it is then so hot that the atoms are ripped apart. This is the case at the centre of stars such as the Sun, which consist entirely of plasma. In the Sun's 15-million-degree-hot core, the pressure is 250 billion times the pressure at Earth's surface. The intense pressure compresses the hydrogen plasma so much that the hydrogen nuclei overcome their reciprocal electrical rejection, fusing into helium, which generates the energy that makes the Sun shine. Rocky planets such as Earth, orbiting their star in the inhabitable ▶

SHUTTERSTOCK

Lightning typically heats the air to some 25,000°C. The high temperature rips electrons away from the atomic nuclei or air molecules, changing their state into plasma.



LIQUID: Atoms break away from the grid

2 Aluminium melts at a temperature of 660°C, becoming liquid. The crystal grid breaks down, allowing atoms to flow around one another, though within a limited volume.

GAS: Atoms fly freely

3 At a temperature of 2470°C, aluminium evaporates and becomes gaseous. Atoms fly freely about each other, and the volume is unlimited, hence gas must be kept in sealed containers.

PLASMA: Atoms split under high temperatures

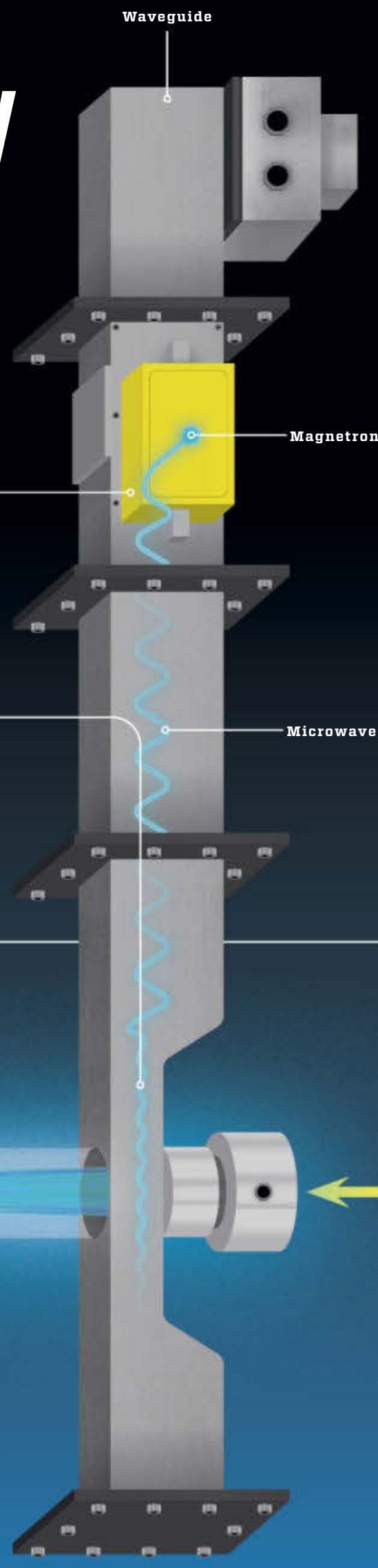
4 At a temperature of 5400°C, the heat shakes the negative electrons loose from the positive atomic nuclei, and the gas turns into electrically-conductive plasma in which nuclei and electrons fly freely around each other.

KEN IKEDA MADSEN & SHUTTERSTOCK

THE NEW ENGINE

Plasma engine is powered by electricity

Chinese scientists have tested an engine that uses air and electricity to produce plasma. The concept might one day replace jet engines, which emit 2.5% of the world's greenhouse gases.



Power turns into microwaves

1 Power from a battery is connected to a magnetron in which electron motions are converted into oscillations by means of a magnetic field, producing microwaves in a metal pipe that functions as a waveguide.

Microwaves are compressed

2 The metal pipe's height is halved, so the microwaves are compressed, improving the strength of the electric field produced by the waves, which can rip electrons from their atomic nuclei. The air turns into plasma.

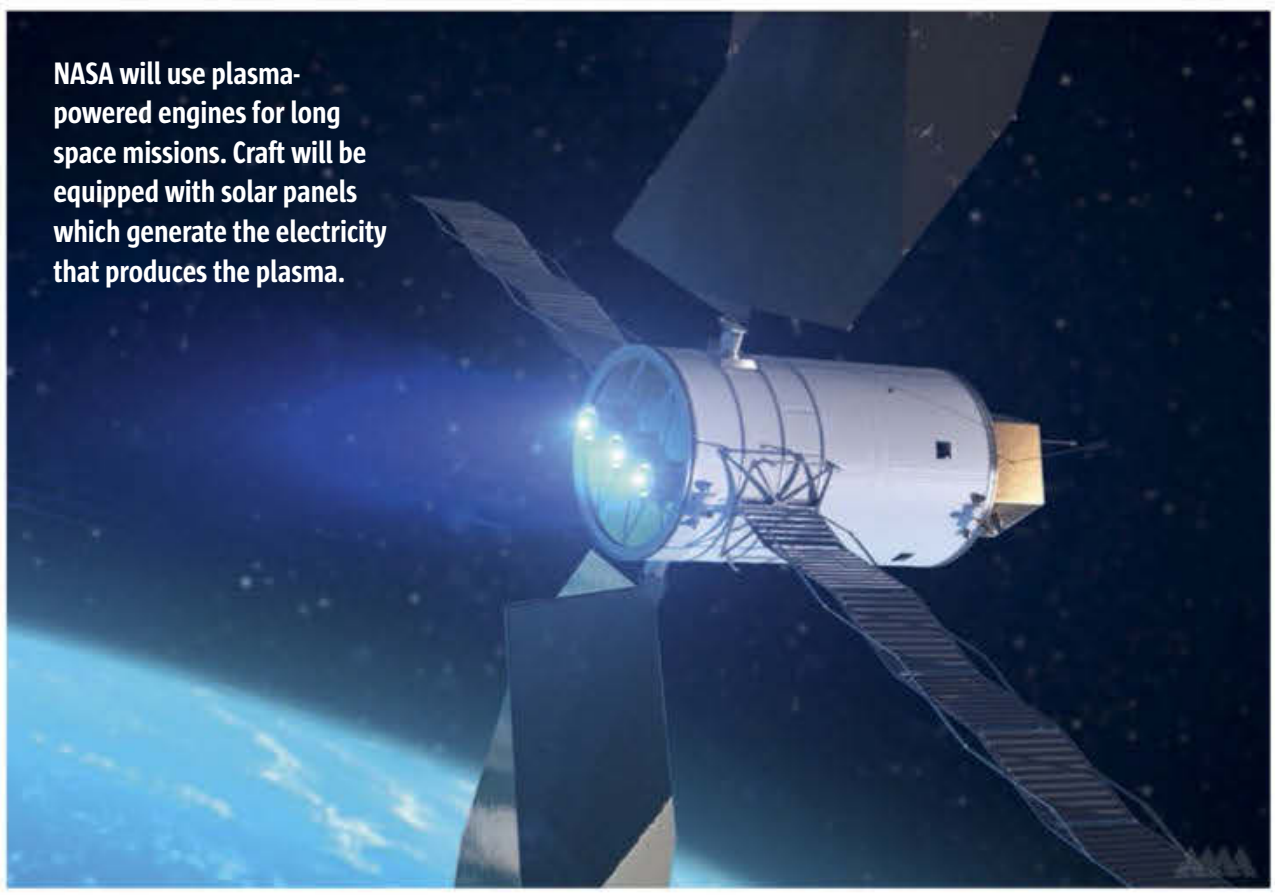
Compressed air is blown into the pipe

3 A compressor directs compressed air through the waveguide so that the air flow crosses the plasma. The plasma's charged particles are shaken and collide, the collisions increasing temperatures above 1000°C.

Plasma expands tremendously

4 The hot plasma expands and exits a pipe in the shape of a flame. In a test, the flame lifted a 1kg ball. According to the scientists, the engine could be scaled up to the forces delivered by a jet engine.

KEN IKEDA MADSEN



NASA will use plasma-powered engines for long space missions. Craft will be equipped with solar panels which generate the electricity that produces the plasma.

NASA

The Ad Astra company developed this plasma engine, VASIMR, which emits plasma at a speed of 50,000 metres/second.

AD ASTRA ROCKET COMPANY

zone where water flows on the surface, are rare exceptions in a universe dominated by plasma.

From Earth, we see the plasma of the Sun's more-than-one-million-degree-hot outer atmosphere, the corona. From this flows a constant stream of plasma in the form of protons and electrons, striking Earth's upper atmosphere, producing the auroras that can be viewed above the poles. The Sun also keeps plasma 'bombs' in its arsenal, with major solar eruptions known as coronal mass ejections, in which a huge bubble with billions of tonnes of hot plasma is shot from the corona, sometimes heading directly for Earth. At their worst, such a bubble could cut right through Earth's magnetic shield, releasing high quantities of electrically-charged particles deep into Earth's atmosphere, generating a geomagnetic storm that might disable technology, affecting electricity and telephone communication across entire continents.

So plasma involves extreme forces. And physicists aim to tame these forces to produce the fuel of the future.

Air plasma to power jet engines

In 1903 the Wright brothers paved the way for air travel when they achieved take-off with an engine-powered plane for the first time, flying (for all of 12 seconds) from a mound in North Carolina. Some 115 years later, aerospace engineer Steven Barrett and his colleagues from the Massachusetts Institute of Technology achieved a flight that might similarly go down in history. Their battery-powered model aircraft, with a wing span of 5 metres and a weight of 2.45kg, flew 55 metres. As with the Wright Flyer, this might not seem very impressive. But this plane was 'powered' by nothing but air.

Under the plane's wings were four arrays of thin wires, strung like horizontal fencing along and beneath the front end of the plane's wing. The wires act as positively charged electrodes, while similarly arranged thicker wires, running along the back end of the plane's wing, serve as negative electrodes. The front electrodes have a positive voltage of 20,000 volts, and their powerful electric field converts air molecules into plasma. The positive nitrogen and oxygen ions from the air are then attracted by the rear electrodes, which are at negative 20,000 volts. On the path between electrodes, each positive ion strikes millions of neutral air molecules, kicking them backwards, making the plane move forwards. According to Steven Barrett, the technology could be used to make silent drones, and airliners in which air-powered ion engines can supplement ordinary jet engines. Scientists are working on lower voltage propulsion, and on using more of the plane's surface.

100

million °C is the temperature required for fusion power plants.

The model aircraft from MIT travels forwards with a force of six newtons per kilowatt of electricity. (One newton corresponds to about the pressure you feel on your hand when you are holding an apple.)

Scientists at China's Wuhan University recently took another step forward, developing an engine that generates 28 newtons per kilowatt. The engine works using microwaves that convert the air into plasma hotter than 1000 degrees. Compressed air is directed through the plasma, which then expands and forces itself explosively out of a pipe. In an experiment using a small prototype, the plasma engine was able to lift a 1kg metal ball placed on top of the pipe. If they manage to upscale the technology, the Chinese scientists estimate that the plasma jet engine, which 'burns' only air, could become sufficiently powerful to achieve the forces generated by modern jet engines.

If plasma engines are to go mainstream in jet planes throughout the world, they will require batteries that can provide as much energy for their weight as delivered by the fossil fuels currently used. Today's lithium-ion batteries can manage approximately 250 watt hours per kilogram, which is still some 30 times less than jet fuel. But if equity could be achieved, and the batteries charged by electricity from solar panels or wind turbines, then plasma engines converting air during flight could make aviation entirely climate neutral in the future.

Plasma could power space trucks

It is not only down on Earth that plasma holds potential as a fuel. In space, the extremely hot state is even more efficient, as engines don't need to overcome air resistance and gravity as they do on Earth. And spacecraft have already flown by means of plasma produced in ion engines. When NASA's Dawn satellite entered orbit around the large asteroid of Vesta and the dwarf planet of Ceres, its engine was using a powerful electric field to convert gas into plasma, after which the positive ions in the plasma were sent backwards through a nozzle, pushing the satellite forwards.

On long space missions, this type of engine has one important disadvantage: the plasma makes the electrodes corrode, limiting the engine's life. To minimise the corrosion, only unreactive noble gases, such as xenon, can be used. We might overcome this challenge by developing plasma engines in which gas is converted into plasma using radio waves.

Another method which might pave the way for aerospace plasma engines involves trapping the plasma in a magnetic cage, so it does not touch the wall of the engine chamber. In that way, plasma engines can use a common gas such as hydrogen, which can be extracted in many places relatively close to Earth, such as the Moon or Mars. So plasma-powered engines could play a key role in humankind's colonisation of the Solar System, with spacecraft refuelled for a return or onward journey with hydrogen from bases built on different worlds.

The front-running plasma engine is the Variable Specific Impulse Magnetoplasma Rocket (VASIMR), which has been under development in the US for decades, first by NASA and now with the Ad Astra company. In the engine chamber, gas is first heated to thousands of degrees, by which it is converted into plasma. Subsequently a magnetic field directs the electrically-charged plasma into another chamber in which radio waves heat the plasma to one million degrees, causing it to expand tremendously. Finally, a magnetic field will direct the plasma into space through a nozzle – at speeds of 50,000+ m/s.

50,000

metres per second is the speed at which the VASIMR engine will shoot plasma into space.

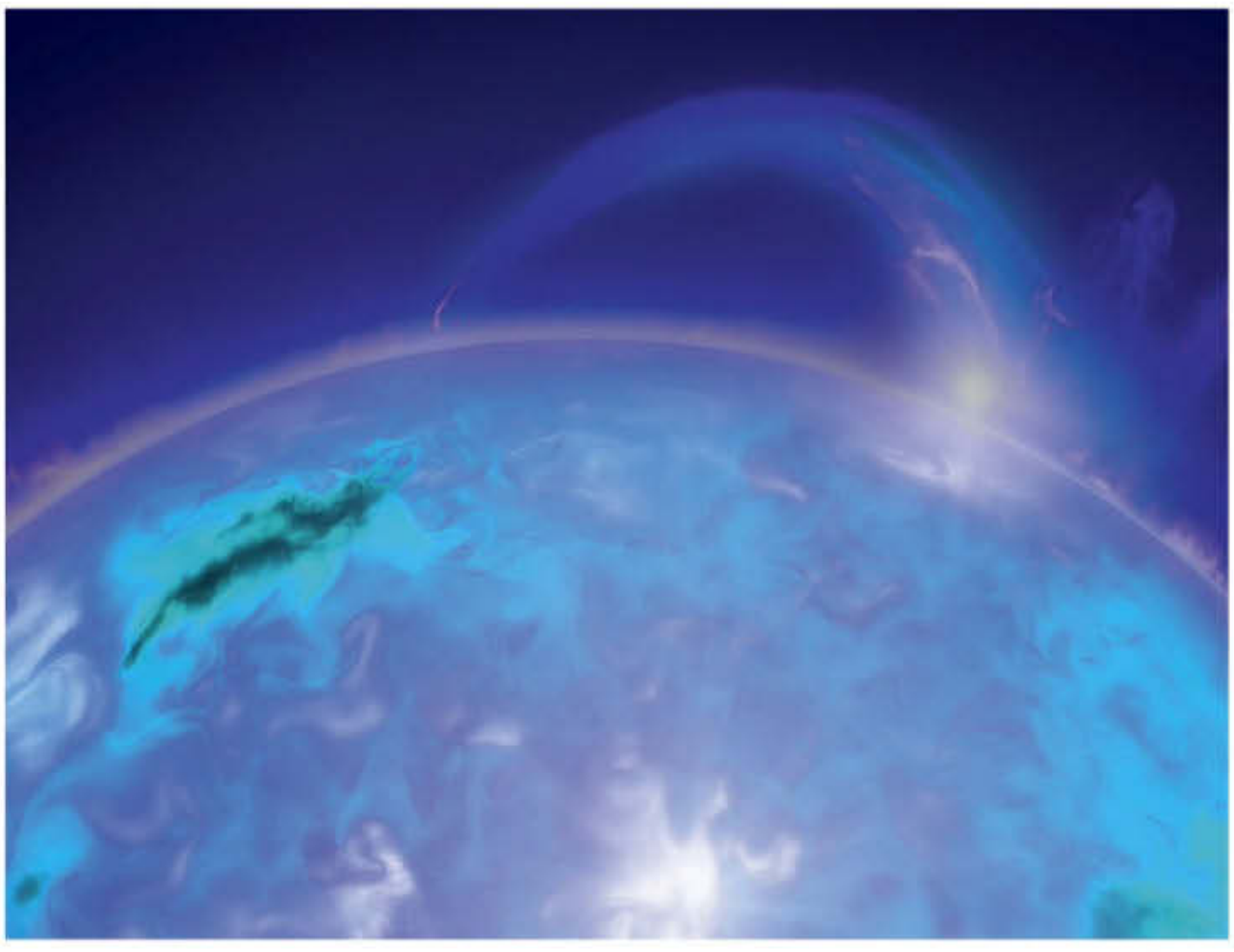
At 200kW, the current plasma engine can generate a force of just 5 newtons, which is not sufficient to lift a rocket up through the atmosphere. But it is enough to send a craft deeper into space from an orbit around Earth. Ad Astra is now carrying out crucial tests of the plasma engine on the ground, where it must complete a continuous 100 hours of operation before it can be tested in space. The technology may be particularly suitable for 'space trucks' – craft designed to haul cargo to and from the Moon. It might also suit long space missions. In the inner Solar System, solar panels might generate sufficient energy, so that a small nuclear reactor would be required only for missions to the outer planets.

Ocean water as fuel source

The most ambitious plan for the use of plasma as fuel is fusion power generation in a power plant that imitates the Sun. Inside the Sun, hydrogen exists as plasma in which atomic nuclei and electrons have split, and the atomic nuclei continuously fuse into helium, a process in which immense quantities of energy are discharged. Physicists and engineers in several countries are constructing reactors in which temperatures of 100-200 million °C will produce hydrogen plasma, so the atomic nuclei can undergo fusion just as they do inside the Sun. The most important fuel for fusion power plants is heavy hydrogen, which can be extracted from ocean water, plus superheavy hydrogen, which is produced in the reactor by radiating lithium with neutrons emitted when hydrogen becomes helium. The known reserves of lithium are sufficient for 1000 years (Australia is the world's leading producer), while ocean water is a practically infinite source of heavy hydrogen. Heavy hydrogen from 40 litres of ocean water and superheavy hydrogen from 5g of lithium (the content of a mobile phone battery) can supply as much energy as 40 tonnes of coal.

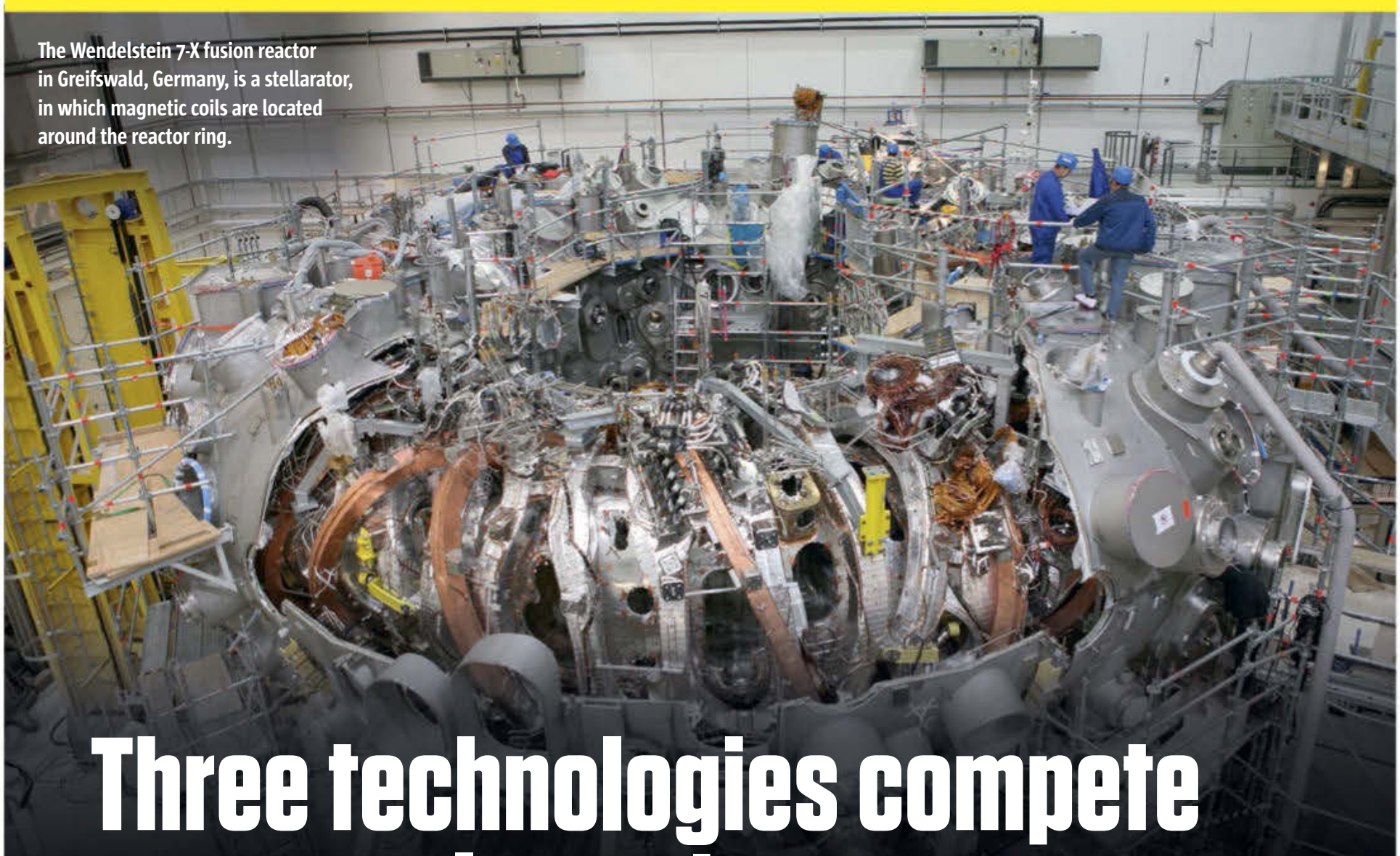
Fusion power plants seem to be safer than fission nuclear power because hydrogen fusion halts quickly if the supply of fuel to the reactor chamber is shut off, like a car running out of petrol. Fusion energy also leaves behind none of the highly radioactive fuel waste produced by fission energy in modern nuclear power plants, because the only waste product is helium.

If fusion can be successfully delivered, energy systems of the future might combine fusion energy with solar and wind farms to deliver the green energy revolution that so many scientists are working to create. And plasma, hitherto the forgotten state, could be the solution that takes us from coal and oil to a new world of inexhaustible and climate-friendly energy. SI



SHUTTERSTOCK

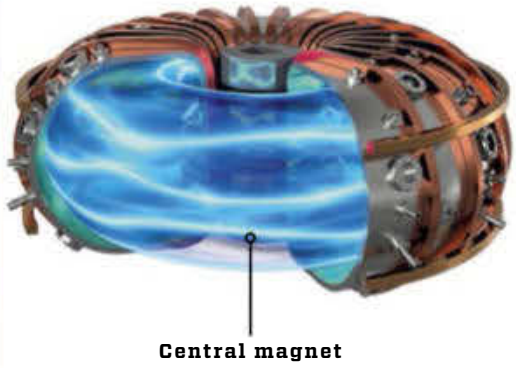
The Sun consists solely of plasma. In its core, the extreme heat of the plasma drives hydrogen atom nuclei to fuse into helium, discharging huge quantities of energy.



The Wendelstein 7-X fusion reactor in Greifswald, Germany, is a stellarator, in which magnetic coils are located around the reactor ring.

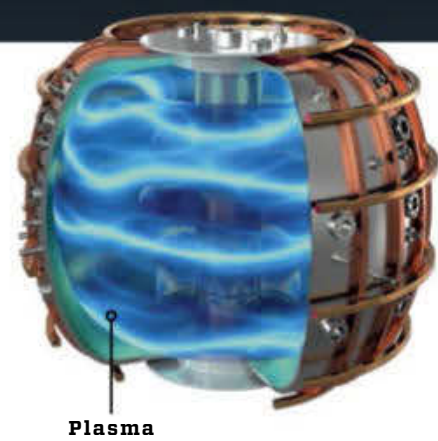
Three technologies compete to tame plasma's energy

Fusion power plants need to keep plasma at 100-200 million degrees C trapped in a magnetic cage, so its atoms can fuse and generate energy without the plasma cooling when it touches the reactor walls. There are three competing methods to achieve this.



Tokamak is the most thoroughly tested

1 This reactor is shaped like a car tyre, and the hydrogen plasma is trapped by a central magnet in the hole of the ring and magnetic coils around the ring. Hydrogen plasma can be trapped for an hour at a time. The world's biggest tokamak, ITER, is being built in France. It will be inaugurated in 2025.



Spherical tokamak could be a dark horse

2 In a spherical tokamak, the central magnet is located closer to the plasma, and so could trap the plasma for a longer time. The UK is spending more than A$300 million on a big spherical tokamak, STEP, which is to pave the way for the construction of power plants in the early 2040s.

Stellarator to operate continuously

3 The Wendelstein 7-X is Germany's project. Twisted magnetic coils around the reactor ring could theoretically capture plasma in the cage for months, which would be ideal in a commercial fusion power plant. On the other hand, stellarators are extremely difficult and expensive to construct.

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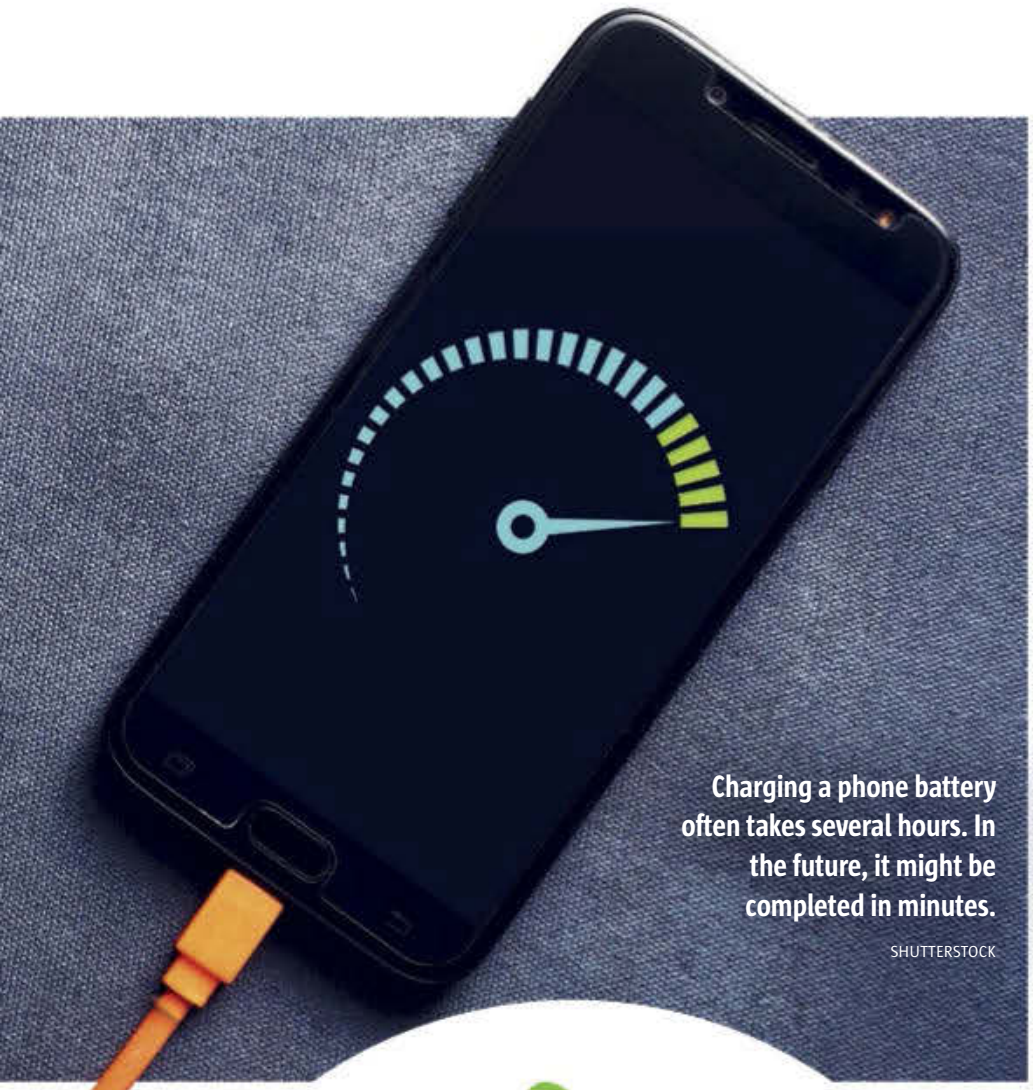
MA/SCI82

By **Søren Høgh Ipland**



Charging a phone battery often takes several hours. In the future, it might be completed in minutes.

SHUTTERSTOCK

The path to green power

New battery technologies aim to smooth the transition to a greener economy.

4

INNOVATIVE BATTERIES

New battery to charge phones, computers & cars *ULTRA-FAST*

New lithium-ion batteries use developments in nanotechnology to quintuple the voltage compared with ordinary batteries – and can considerably reduce the charging time for computers, smartphones, and electric cars.

1

American scientists from the Texas A&M University have invented a new technology that could lead to an upgrading of the lithium-ion batteries in our phones, laptops and electric cars. In short, the technology uses a scaffold of carbon nanotubes in the battery's one electrode, enabling it to handle far higher voltages, also becoming much safer as a consequence.

An ordinary lithium-ion battery has an electrode at each end, between which lithium ions travel as the battery is charged and discharged. When the battery is charged, the ions settle on the negative electrode – the anode. When it is discharged, they settle on the positive electrode – the cathode. Currently anodes are made mostly of a mixture of graphite and copper, but an anode made of pure lithium would dramatically increase the energy density of the anode, and hence of the whole battery. **It would increase battery capacity tenfold, and make charging much faster.**

The problem with lithium anodes is that they often wear out too quickly. When lithium ions collect in the anode, they tend to lump together and produce dendrites – small crystalline structures that look like trees. Over time, these dendrites grow, and eventually the battery can leak, potentially causing a short circuit and at worst an explosion.

However, the Texan scientists have a solution that makes it possible to build a battery with a more stable lithium anode. By adding a porous 3D scaffold made of tiny nanotubes, the formation of dendrites can be reduced. The nanoscaffold is made of carbon that is partly lined with molecules and able to bind to lithium ions. The scaffold is located in a continuation of the anode, holding on to the lithium ions so they will not lump together on the surface of the anode. This ensures that no dendrites form, even though the scientists use energy-dense lithium for the anode. Overcoming the dendrite issue could improve battery capacity and charging speed without compromising the safety or durability of the battery.

The Texan scientists say that their best anode can hold on to a voltage five times higher than is possible with ordinary lithium-ion batteries. With such capacity, charging time could end up being only a fraction of the present level, which would be an especially crucial benefit for electric cars.

SHUTTERSTOCK

The radioactive battery is encapsulated in a diamond layer to prevent radiation hazard.

Battery with *NUCLEAR WASTE* good for 1000+ years

A US company will introduce a battery made of recycled radioactive waste. It will be self-charging and can allegedly be used for thousands of years.

2

American company NDB (Nano Diamond Battery) is developing a prototype battery technology that could revolutionise global energy systems. The battery uses radioactive waste to generate power, so it does not need charging.

The battery's cells are made of graphite recycled from nuclear power plants. Graphite is used for temperature regulation in reactors, and over years of use it absorbs so much radiation that the material becomes radioactive itself. Graphite includes high levels of the radioactive isotope carbon-14. When the carbon-14 decays, it is converted into harmless nitrogen, giving off antineutrinos and high-energy electrons. The latter generate the electric current which can be harvested.

Before the scientists can harvest the electricity from the radioactive graphite, they must convert it into small carbon-14 diamonds, made in a mould under extreme pressure and high temperatures. The resulting diamond structure functions as a semiconductor in which the free electrons can travel until they strike a supercapacitor that can store the electricity.

While the energy benefits are potentially high, clearly a key question will be how to protect users from the potential ill-effects of exposure to radioactivity. To achieve this protection, the company aims to encapsulate each radioactive carbon-14 diamond in an impenetrable layer of lab-made carbon-12 diamonds that are not radioactive. As diamond is one of the world's hardest materials, such a shell would prevent the radiation escaping, no matter how roughly the battery is treated. **The result is a battery that can constantly recharge itself until the radioactive material becomes inactive. And carbon-14 has a half-life period of 5730 years.**

The technology behind the diamond battery is not a new one. The principle has been propounded since the 1970s, and in 2016 a team of scientists from the University of Bristol managed to demonstrate the idea in practice. Now, the US company NDB aims to mass-produce the technology. The company suggests that the concept could be used in anything from smartphones to car batteries, delivering a power source which can both recharge itself and have a longer life than the product it powers.

Scientists *CONVERT YOUR HOME* into one huge battery

Bricks could hold on to electrical charge if they were filled with special nanofibres, converting our homes into storage facilities for solar energy.

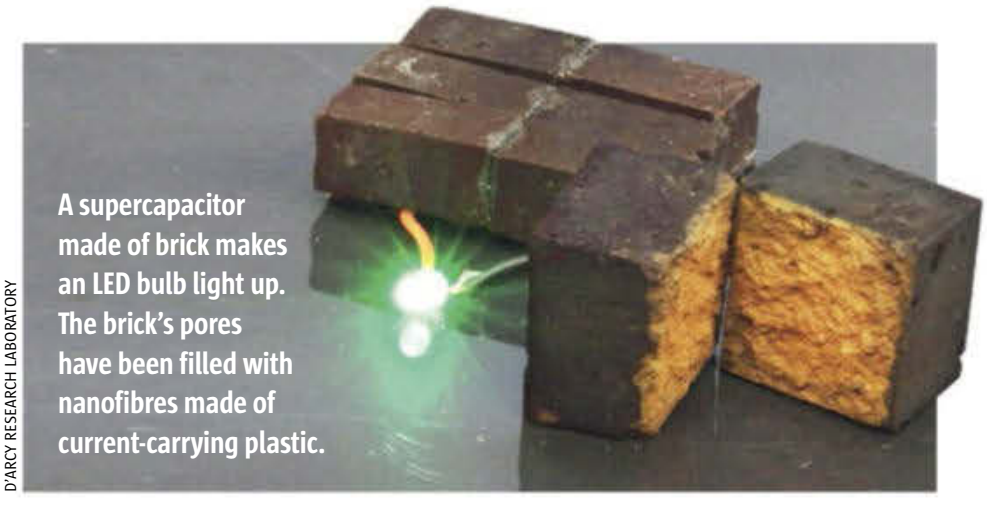
3

American scientists from Washington University in St. Louis have developed a brick that looks like a traditional red house brick, but which functions as a battery. The trick is to fill the brick's pores with nanofibres made of a special plastic polymer that can maintain an electrical voltage. If our buildings could be converted into large batteries in this way, we could solve one of the biggest challenges of the switch to green energy, which is energy storage. **Solar panels on your roof could generate electricity, with the bricks of your house storing the energy until you need it.**

Technically speaking the new brick is not a battery, it is a super-capacitor. A capacitor consists of two current-carrying plates separated by a layer of some different material through which the voltage cannot travel. When you charge a capacitor, it is like rubbing a balloon against a sweater, generating negative and positive charges respectively, which attract each other. In a capacitor a negative charge is created on one of the plates and a positive charge on the other, producing an electrical field that polarises the layer between. The voltage difference remains in the layer until the energy is discharged as electricity to an external circuit.

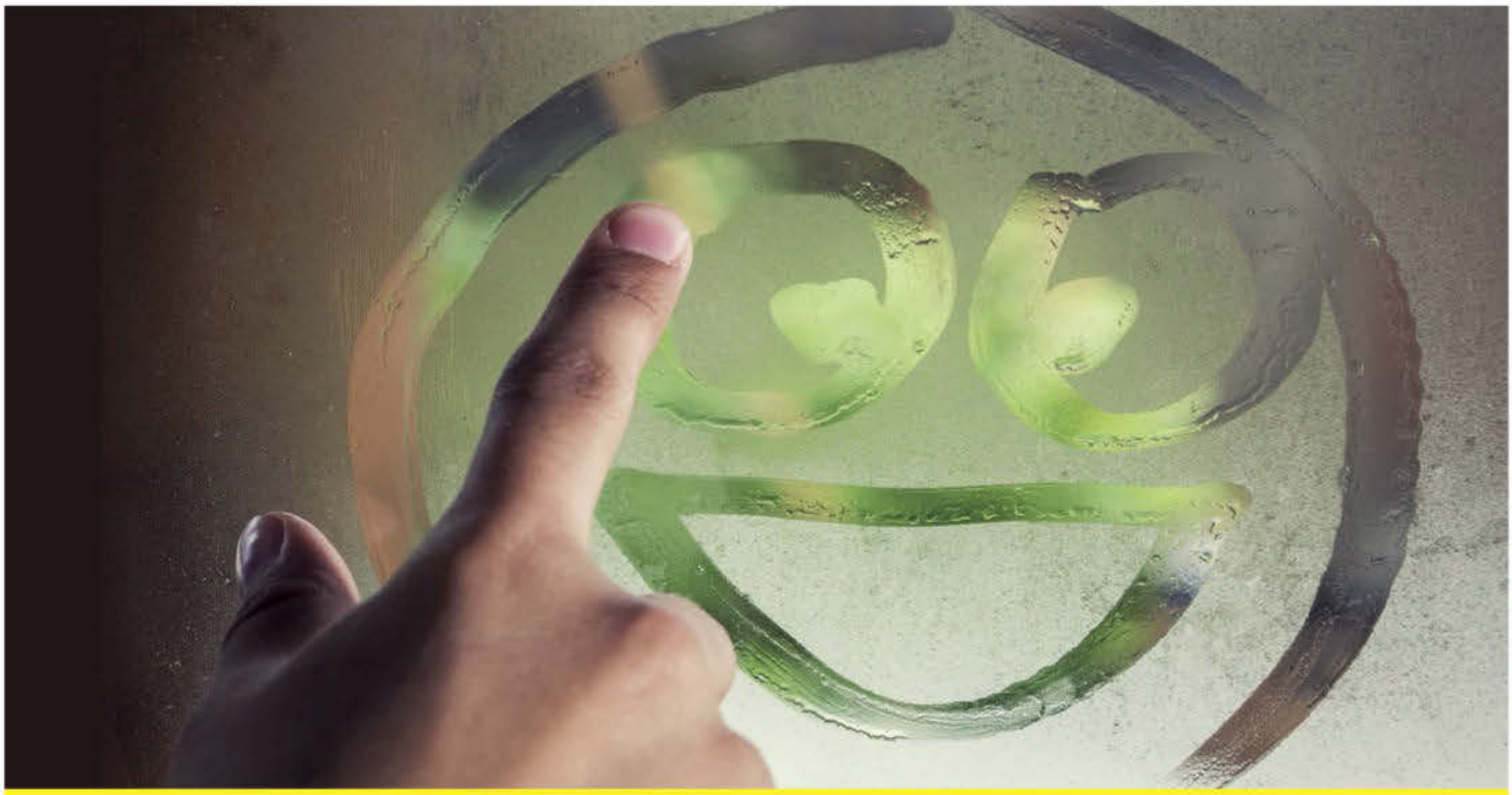
A capacitor's capacity increases when the surface of the plates is made larger, or when the distance between them is reduced. So a super-capacitor's plates are lined with porous nanomaterials that provide them with a much larger surface area, while the plates are separated not by a thick layer, but via immersion in an electrolyte solution and separation by a thin plastic film. Both criteria are thereby satisfied – the same structure as that of an ordinary capacitor is obtained, but with a far larger surface area and lower distance between the plates.

The new Washington University electric brick functions like the plates of a supercapacitor. Scientists first deposit the current-carrying plastic polymer PEDOT, which is covered in nanofibres, in the brick, after which they divide it in two and immerse the pieces into electrolyte gel. When the two brick halves are reunited, the scientists have a supercapacitor. The next stage will see the scientsts try to improve the capacitor's energy density.



D'ARCY RESEARCH LABORATORY

A supercapacitor made of brick makes an LED bulb light up. The brick's pores have been filled with nanofibres made of current-carrying plastic.



SHUTTERSTOCK

Battery sucks electricity OUT OF HUMID AIR

Scientists from Tel Aviv University have developed a battery that can self-charge using air with high humidity. It could become an important source of renewable energy particularly in tropical countries. Most of Australia's coastal areas are humid enough to benefit.

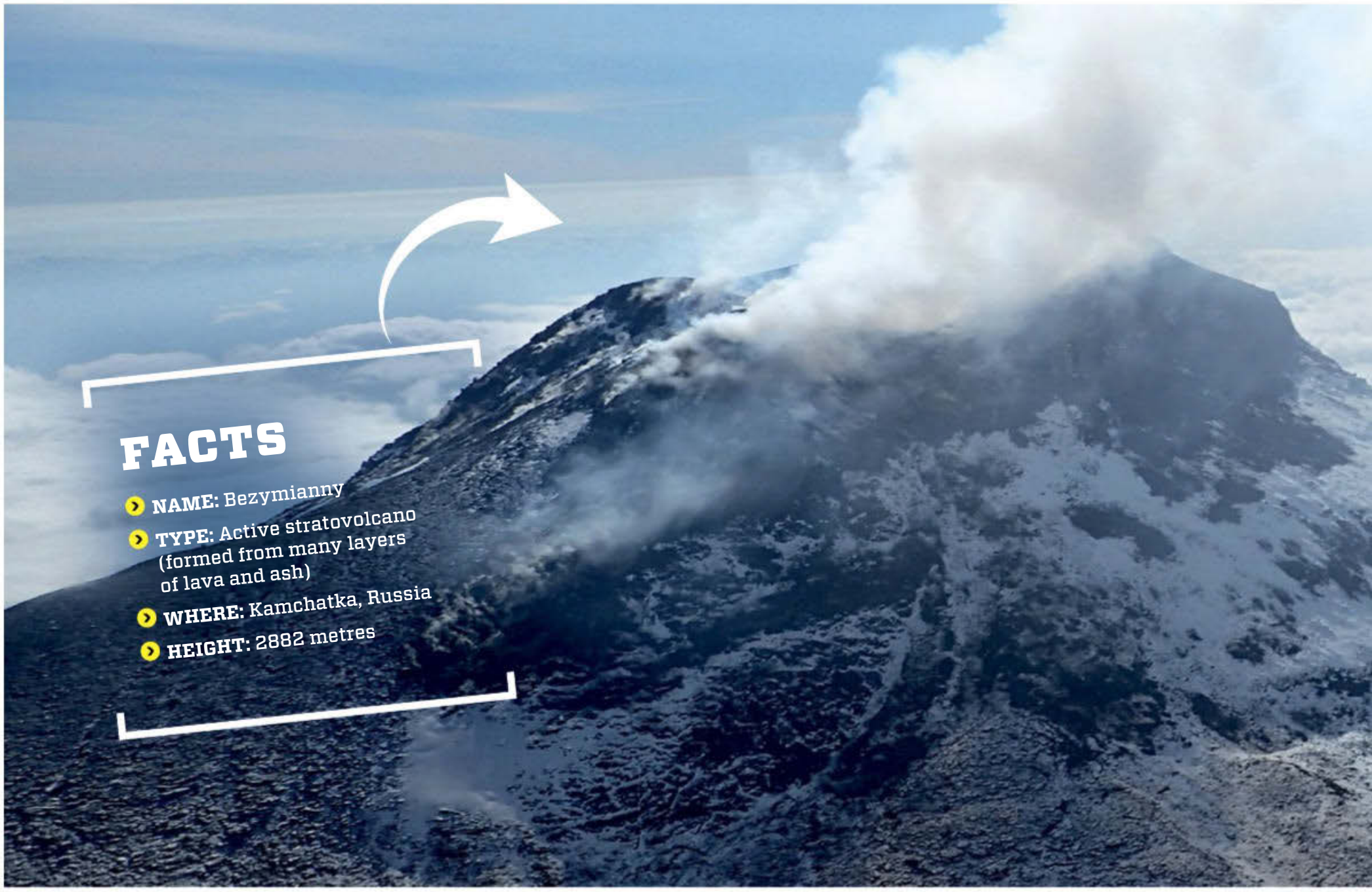
4

Hydropower – the generation of energy from water – is not new; we have long harvested mechanical energy from dams, and hydrogen fuel from electrolysis of water. But now a team of scientists aims to take hydropower to a whole new level. **The scientists have invented a battery that charges itself when exposed to air with a humidity higher than 60%.**

The inspiration dates far back to 1843, when famous physician Michael Faraday looked into an incident in London where a worker died of an electric shock from a steam boiler. The boiler's steam had somehow created an electric charge in the boiler, and after a series of experiments Faraday concluded that the electricity came from the friction between the water vapour and the boiler's metal surface.

Intrigued by this story, scientists from Tel Aviv in Israel created an experiment to test whether they were able to generate electric charge in different types of metal via contact with water vapour. They built a device in which moist air passed into a sealed Faraday cage that would keep external electricity out of the experiment. In the cage there was a brass cylinder with a ground connection, and inside the cylinder, they placed the metal test material. By measuring the voltage difference between test material and brass cylinder, the scientists could determine whether the water vapour created a voltage in the test material. And it did. While some metals were unaffected, others became charged. The results were particularly good with zinc, for which an air humidity level of 60% could make the device – effectively now a battery – charge itself to a voltage of 1V. That's close to the charge of an ordinary 1.5V AA battery as used in everything from remote controls to flashlights.

The scientists believe their invention offers huge potential, particularly in developing nations where many people still lack access to stable or cheap electricity, and especially for those in the tropics, where air humidity levels would charge the batteries at most times of the year. Australia's coastal regions could benefit, as the annual humidity averages above 70%, and higher in the mornings. Inland, however, humidity levels are lower, and the batteries would fail to charge more often than not.



FACTS

- **NAME:** Bezymianny
- **TYPE:** Active stratovolcano (formed from many layers of lava and ash)
- **WHERE:** Kamchatka, Russia
- **HEIGHT:** 2882 metres

Scientists discover patterns in growth, showing that

Volcanoes have a circle of life

Shortly after volcanoes collapse, they begin to regenerate again. Scientists have reconstructed the process by collecting volcanic data from more than six decades. The new knowledge could minimise casualties from future eruptions.

Darkness fell several hours ago, but the sand on the Indonesian beach of Tanjung Lsung is still warm. Music is coming from a stage right on the water's edge, where a pop-rock band called Seventeen is playing. There is no warning whatsoever as a high wall of water roars suddenly from the ocean, sweeping away everything on the beach and crashing into the palm tree beyond. When the sun rises the next morning, 22 December 2018, more than 420 people have been killed among the ruins of small tourist towns up and down the coast. Among the musicians from Seventeen, only the lead singer survives.

Tsunamis can be terrifying events. Only last month New Zealand sent out tsunami alerts after off-shore earthquakes, and many readers will remember the 2004 Boxing Day tsunami and the inconceivable devastation it left behind. But the cause of the wave that engulfed Tanjung Lsung was no earthquake. It was caused by a sudden massive slide of material pouring down the sides of the island volcano Anak Krakatau as it began to erupt, striking the ocean with massive force, raising a tsunami which then headed towards the closest shores.

Predicting such disasters is notoriously difficult. But a team of scientists is hoping that more than 60 years of data from previous volcanic collapses will help them better

By **Niels Halfdan Hansen**

IVAN KOULAKOV

understand both volcano collapses and the way they reconstruct themselves afterwards, so that natural disasters like the one on Tanjung Lsung beach can be predicted, and loss of life greatly reduced.

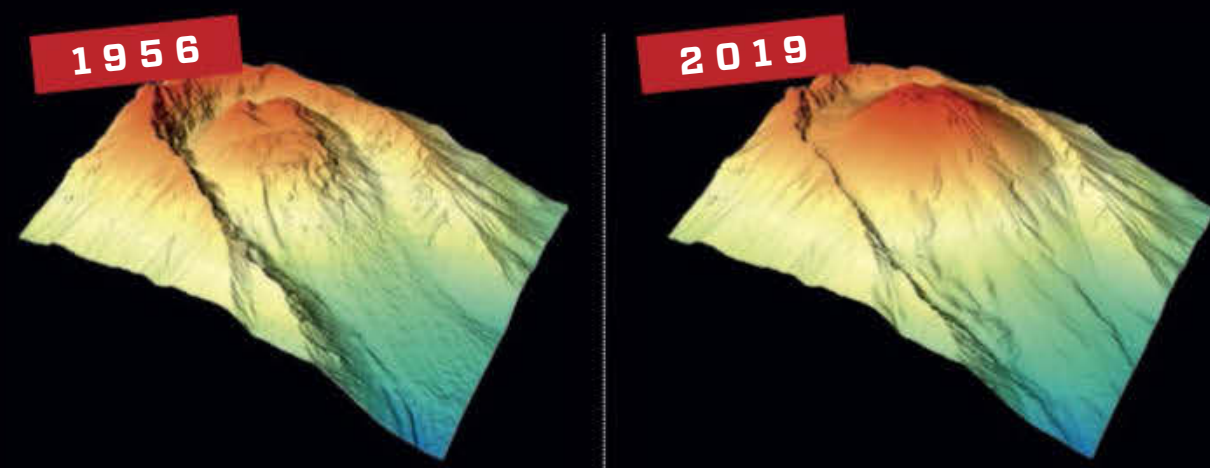
Volcano reveals its life cycle

The collapse of Anak Krakatau is just one of many ways in which volcanoes can present danger to their surroundings as pressure from magma increases. Scientists are constantly improving their ability to interpret small earthquakes, gas leaks and altitude changes of Earth's crust – characteristics that contribute to an overall impression of a mountain on the edge of a breakdown. Yet the exact moment of an eruption remains hard to predict, and often the devastation still takes local communities by surprise.

One area now being studied is the full cycle through which many volcanoes go. After an eruption that spews one side of the mountain into the ocean, or destroys the volcano cone completely, there is a period of reconstruction that may take hundreds or thousands of years before ▶

Hyperactive volcano rebuilds itself

Bezymianny is one of the world's most active volcanoes, making it particularly interesting to scientists. In some 60 years, Bezymianny has almost entirely reconstructed itself after its eastern flank was destroyed in a 1956 eruption.



GFZ

Two lava bubbles in the abyss

1 In March 1956, Bezymianny exploded, but by August of the same year Soviet geologists had identified two small lava domes that were already forming in the remains of the crater.

Volcano has reconstructed

2 By April 2019, the effects of the eruption 63 years previously were almost entirely rebuilt. The volcano grows by an average of more than 15,500m³ a day.

the volcano is once again ready to blow. Russian and German scientists – headed by geologist Alina Shevchenko from the Helmholtz Center in Postam, Germany – have now studied for the first time how a volcano reconstructs its cone from scratch.

Bezymianny, located on the Kamchatka Peninsula to the far east of the Asian continent, is around three kilometres high. Until the 1950s it had been considered extinct, but since a dramatic eruption in 1956 it has been one of the world's most active volcanoes. (Its immediate neighbour, Kluchevskaya Sopka, made international news in March with a large eruption forming a new cone on its north-western flank.) Bezymianny is one of 15 'lab volcanoes' around the world which are monitored particularly closely by scientists, along with some of its most famous peers – Etna, Vesuvius, Mount St. Helens, and Fujiyama.

Two lava domes emerged

When Bezymianny blew up in 1956, the entire eastern side of the volcano disappeared, removing some 700,000m³ of rock. But the mountain began to rebuild remarkably quickly. According to scientists, so much of the volcano has been recreated in the decades since the original explosion that the Bezymianny should regain the size and height it had in 1956 within another 10-15 years – probably then ready for another large eruption. So in just 80 years it will have completed a full life cycle – many times faster than the average volcano.

Alina Shevchenko and her colleagues have meticulously analysed all available data from Bezymianny. They had access to a large archive of photos and data from Soviet and pre-Soviet times, and by adding more recent satellite photos, the scientists were able to recreate a highly detailed life-cycle of this active volcano.

The scientists understood the process by which Bezymianny began to build a new cone so quickly. Two deep volcanic conduits some 400 metres apart supplied a flow of magma which produced two lava domes. Towards the mid-1970s, these domes grew larger as the pipes moved, reducing the distance between them to 200 metres. Eruptions were becoming ever more violent, with material being thrown over ever further distances.

36,000

people died in 1883, when the original Krakatau volcano erupted.

Shortly before 2000, the two pipes became connected, forming a central crater pipe surrounded by an almost symmetrical volcano cone, as had existed before 1956. The scientists' studies also reveal that alternating layers of ash and lava have stabilised Bezymianny's new cone.

NURUL HIDAYAT/BISNIS INDONESIA/EPA/RITZAU SCANPIX

In 2018, the Indonesian island volcano Anak Krakatau erupted, causing a fatal tsunami after its flanks collapsed into the strait between Java and Sumatra. The eruption reduced the volcano in size by two-thirds.

Together with data from the nearby Shiveluch volcano, which is unable to build a new cone, the results have provided the team with improved knowledge of when volcanoes are stable and when they are weak, and that will be useful in predicting a flank collapse like those of Bezymianny in 1956 and Anak Krakatau in 2018. Flank collapses, where an entire side slides, have historically been highly lethal, especially where the rock ends up in the ocean and triggers a tsunami. The very name 'Anak Krakatau' means 'child of Krakatou', indicating how the volcano had reconstructed itself since 1883, when the original volcano famously erupted in an explosion so loud it was heard in Perth, Western Australia. Some 36,000 people were killed in 1883, mainly from the resulting tsunami. Anak Krakatau rose above the waves as a new island after fresh activity at the end of 1928.

New knowledge used in Hawaii

There are other volcanoes with flanks that might collapse. Scientists are closely monitoring Kilauea on the south-east coast of Hawaii. It barely reaches above the water, but beneath the waves the volcano is massive, and unstable. The southern flank – known as Hilina Slump – is already sliding down at a slow speed of about 10cm a year. Scientists fear that pressure from gravity and new magma will suddenly accelerate the slide, causing the flanks to collapse.

A flank collapse from Kilauea would deliver a huge threat to Hawaii, though beyond those islands other land masses are so distant that the energy of a tsunami would be spread across a very large area. Calculations indicate that waves striking the main American coast could be as low as one metre high, or as high as five metres.

But there are other volcanoes under threat of flank collapse, and some of these are located far closer to densely populated areas of our planet. One of these is Mount Teide, nestled in its crater atop the Canary Island of Tenerife, where a tsunami could devastate coastal areas of North-Western Africa and Europe.

The improved insight into the interior life-cycle of volcanoes is vital information for upwards of 500 million people who live in the shadow of these energetic mountains. In good times, local residents benefit from their volcanic neighbours, which contribute fertile farmland, warm water, and thermal energy. But the price is a constant threat of violently destructive eruption. Any new information which improves the ability of scientists to predict disasters in advance could be a real life-saver. SI

Volcanic triple threat

Toxic gases, red-hot lava, then a tsunami – an eruption followed by a flank collapse can devastate surrounding areas, making any improved prediction a vital life-saver.

Volcano belches out death and destruction

1 Vapour takes up about 1600 times more volume than the equivalent water. So intense pressure develops when red-hot magma encounters underground water. The result is likely to be a violent eruption.

Eruption destroys the flank

2 The intense pressure forces out lava and gases with sufficient force to make one of the volcano's sides collapse. The lava then rapidly spreads across the collapsed flank.

A tsunami strikes the shores

3 As the volcano's flank strikes the water with intense force, the mechanical energy produces intense pressure that sends a tsunami towards nearby shores.

CLAUS LUNAU

Good luck and bad have delivered

MAJOR TRIUMPHS IN SCIENCE HISTORY

A sloppy biologist, a cloudy day, and an unexpected pool of dog urine. Inspiration can come from the most unlikely events, helping scientists to lay the foundations for some of the world's major scientific breakthroughs.

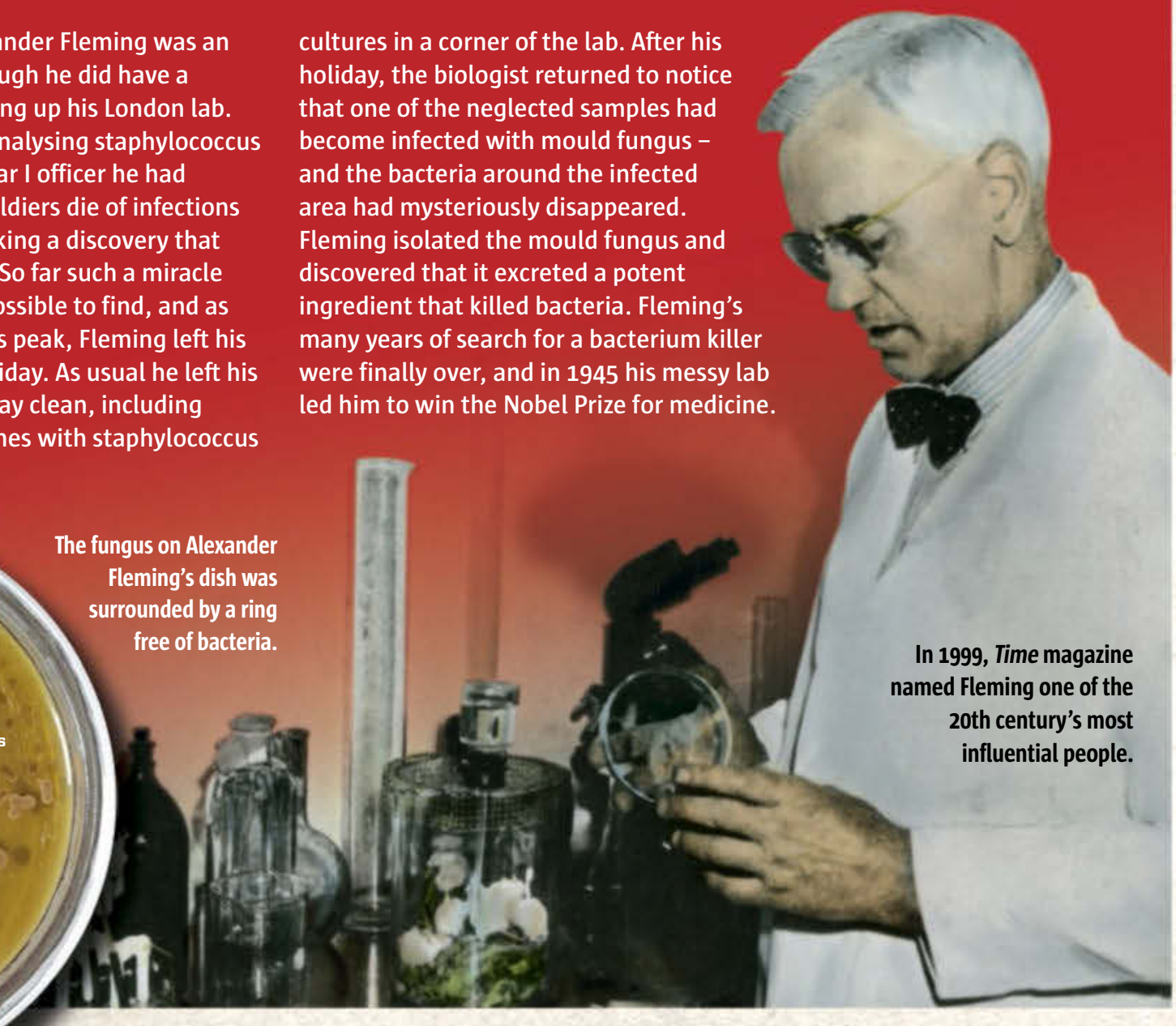
PENICILLIN

Messy laboratory saved millions of lives

A summer holiday and a reputation for a messy laboratory combined to bring penicillin to the attention of physician Alexander Fleming. The Nobel prize-winning discovery has probably saved millions from fatal bacterial infections.

Scottish biologist Alexander Fleming was an excellent scientist, though he did have a reputation for not tidying up his London lab. In 1928, Fleming was analysing staphylococcus bacteria. As a World War I officer he had witnessed countless soldiers die of infections and he dreamed of making a discovery that could kill the bacteria. So far such a miracle cure was seeming impossible to find, and as the summer reached its peak, Fleming left his studies for a family holiday. As usual he left his lab without a pre-holiday clean, including unsupervised glass dishes with staphylococcus cultures in a corner of the lab. After his holiday, the biologist returned to notice that one of the neglected samples had become infected with mould fungus – and the bacteria around the infected area had mysteriously disappeared. Fleming isolated the mould fungus and discovered that it excreted a potent ingredient that killed bacteria. Fleming's many years of search for a bacterium killer were finally over, and in 1945 his messy lab led him to win the Nobel Prize for medicine.

The fungus on Alexander Fleming's dish was surrounded by a ring free of bacteria.



In 1999, *Time* magazine named Fleming one of the 20th century's most influential people.

RITZAU SCANPIX/AKG-IMAGES

By **Jesper Rovsing Olsen**

HIEROGLYPHS

Tri-lingual stone broke the code

In 1799, Napoleon's French soldiers were expanding a fort in Rosetta, Egypt. Soldiers tore down the ancient city walls to use the stones for the new fortifications, and it was noted that one of the old stones from the wall was covered with three sets of characters. The mysterious stone was immediately sent to Cairo, where a team of scientists realised that the soldiers had made a unique discovery. The text on the stone proved to be the same words written in Ancient Greek, Demotic Egyptian, and hieroglyphic script. Both demotic and hieroglyphs had baffled Egyptologists for centuries, but by comparing the stone's Greek text with the others, the scientists were finally able to understand Demotic. Subsequently in 1822 Jean-Francois Champollion of France made the leap required to solve the mystery of hieroglyphs.

The Rosetta Stone enabled both Demotic Egyptian and hieroglyphic script to be translated, thanks to the Stone's inclusion of the same text in Ancient Greek characters.

DEA/G. DAGLI ORTI/DE AGOSTINI/GETTY IMAGES

HIEROGLYPHS

were last used in the 5th century AD – but their meaning was lost until freshly deciphered in 1822.

EGYPTIAN DEMOTIC

was the written language of Ancient Egypt and was deciphered in the early 1800s.

ANCIENT GREEK

was known to classicists thanks to the survival of of Greek texts, many thanks to Islamic scholars.

DNA

Others got credit for DNA discovery

The newly-graduated MD Friedrich Miescher was hearing-impaired, and so chose to work in research instead of being in contact with patients. He was particularly interested in tissue diseases, and eagerly examined bandages with bloody pus that his lab received from a medical clinic. From the pus he extracted white blood cells, and in 1869 he managed to extract a weak acid from the blood cells. Miescher named the material 'nuclein' and soon discovered that nuclein also existed in many other cells, not just those from blood. The discovery was so ground-breaking that Miescher's sceptical boss insisted he repeat all his experiments, and the results were not published until two years later. Friedrich Miescher had no idea that he had discovered DNA, the human hereditary material, and he died at the age of 51 before he was able to complete his research. Instead it was the German biochemist Albrecht Kossel who was awarded the Nobel Prize in 1910 for mapping out the complete chemical composition of Miescher's nucleic acid.

UNIVERSITY OF TÜBINGEN

Miescher had wanted to become a hands-on doctor, but turned to research only because he had a hearing problem.

PAP TEST

SHUTTERSTOCK

Easy test revealed cancer

Georgios Papanicolaou was studying cell changes during ovulation in female guinea pigs. In 1923 he began studying human vaginal liquids under his microscope to see if the phenomenon was also at play in women. One of the donors happened to have cervical cancer, and Papanicolaou realised he could clearly see the cancer cells. His discovery meant that women could easily be screened to find abdominal cancer. Today the test is known as the Papanicolaou or 'Pap' test.

MICROWAVE OVEN

EVAN-AMOS/BETTMANN/GETTYIMAGES

A melted Mr. Goodbar chocolate bar alerted Percy Spencer to the cooking potential of microwaves and the invention of the microwave oven in 1945.

Melted chocolate bar led to the microwave oven

In 1945, engineer Percy Spencer was visiting an electronics and arms factory, where he was introduced to a magnetron that was used for radars. As he observed the device, he discovered that a chocolate bar in his jacket pocket was melting. Spencer realised the magnetron's microwaves must have caused the melting, and he tried holding a bag of corn seeds in front of the device. The seeds soon popped. The experiment showed that microwaves were able to heat food – and the microwave oven was soon born.

The first commercial microwave was 1.5 metres high and weighed 350kg.

RADIOACTIVITY

SHUTTERSTOCK

A cloudy sky and a failed experiment revealed radioactivity

In 1896, physicist Henri Becquerel placed a little uranium on a photographic plate, wrapped it all in paper, and went outside. His theory was that sunlight would make the uranium emit radiation, and that would be revealed on the plate. Unfortunately, the sky was overcast, so Becquerel placed the uranium and photo plate in a drawer instead. After some time he developed the plate and saw that the uranium had left a mark even though it had not been exposed to sunlight. The uranium had emitted its own radiation: radioactivity.

SMALLPOX VACCINE

Jenner infected a little boy with smallpox to prove that he had found a vaccine against the disease.

CHRISTOPHEL FINE ART/UIG/GETTY IMAGES

Milkmaid eliminated dreaded disease

When he was a boy, Edward Jenner overheard a milkmaid saying that she would never develop smallpox because she had already had cowpox – a harmless version of the lethal disease. He never forgot it, and later proved it.

When Jenner became a doctor, he began to study the statistical connection between the two diseases. He concluded that a person who was infected with the mild cowpox version of the disease developed immunity to the deadly smallpox. To test his theory, Jenner in 1796 infected an 8-year-old boy with cowpox. After a mild fever, the boy recovered, and then a few months later, Jenner deliberately injected smallpox into the boy. Thankfully, the research held, the milkmaid's remark proved true, and the boy survived. To convince colleagues, Jenner had to repeat the experiment on several other children – including his own 11-month-old son. In honour of the milkmaid, Jenner named the discovery 'vaccine', derived from the Latin for 'cow': *vacca*.

BACKGROUND RADIATION

It's not pigeon poo, it's the Big Bang...

Two physicists thought that pigeon droppings were causing an annoying noise in their antenna – but they were actually hearing the sound of the universe's birth.

Two American physicists, Arno Penzias and Robert Wilson, were fine-tuning one of the world's biggest radio telescopes in 1964. Much to their annoyance, the equipment, designed to detect radio waves from space, was making an irritating sound that they could not trace. The physicists were initially convinced that bird droppings were causing the noise, so they carefully cleaned the antenna out – and shot all pigeons in the vicinity. It made no difference. They tried covering all the sharp edges with tape – still no effect.

A chance conversation with a colleague alerted Penzias and Wilson to a Princeton University research project related to the 'Big Bang' – the theory that the universe originated in a huge explosion. The scientists behind the project were predicting that the cosmic background radiation from the explosion should still be detectable – perhaps with a large radio telescope. The colleague explained to Penzias and Wilson that their pigeon noise might just be the weak radiation remaining from the formation of the universe. Meetings with the Princeton scientists confirmed the suspicion: Penzias and Wilson had accidentally detected the afterglow of the Big Bang. It earned them a Nobel Prize in 1978.

NATIONAL PARK SERVICE

Physicists Penzias and Wilson were awarded a long series of prizes for their discovery of background radiation, though they had originally blamed it on pigeons.

INSULIN

Swarming flies solved the mystery of diabetes

In 1889 two German doctors noticed an unusual concentration of flies gathered around a small pool of urine left by a laboratory dog. It was unusual enough for Joseph von Mering and Oscar Minkowsky to discuss why the flies were so interested in the dog urine. They analysed the liquid and discovered that it included lots of sugar. So the dog was excreting excess sugar – a sign that it had diabetes. Yet the dog had been perfectly healthy a few days earlier when it had arrived at the clinic. The two doctors had since removed its pancreasin an effort to establish that organ's role in digestion. But if the dog had developed diabetes after its pancreas was removed, that meant that the gland must produce a material that regulates the blood sugar level of the body. Minkowski and Mering did further research but never found out that insulin was the decisive substance – but it was their work, in cooperation with their peeing dog, that solved the mystery of diabetes and pointed later scientists in the direction of insulin.

SHUTTERSTOCK

// TEST YOURSELF

ANSWERS ON PAGE 11

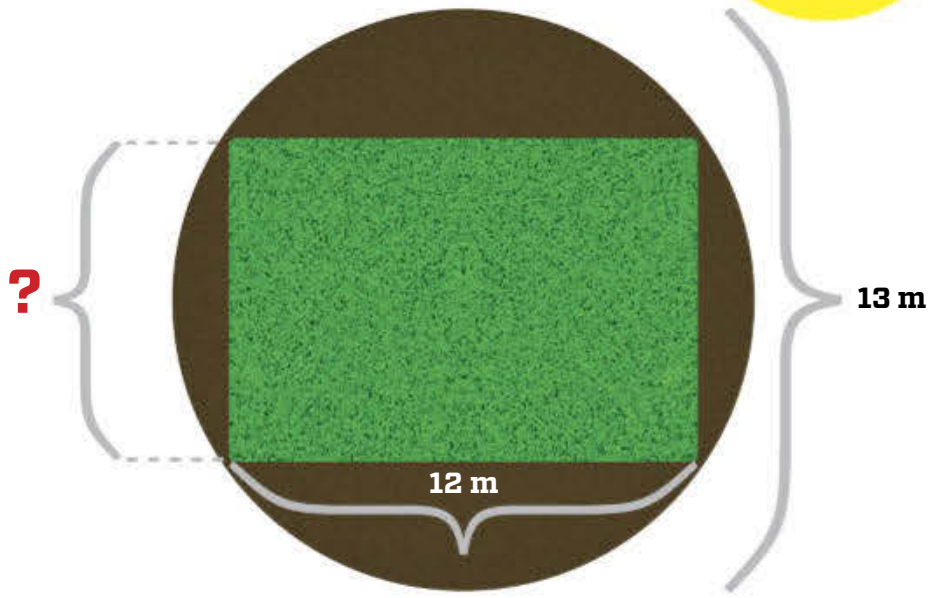
Solve problems designed for different types of intelligence, and find out in which you excel!

Editor: **David Dragsted**

Text & Art: **Anker Tiedemann & Erik Wied**

LOGIC

1 Helen has bought a circular plot of land, diameter 13 metres. She aims to establish a rectangular playing field of grass and would like the field to include as much space as possible. If this field is 12 metres long, how wide will it be?

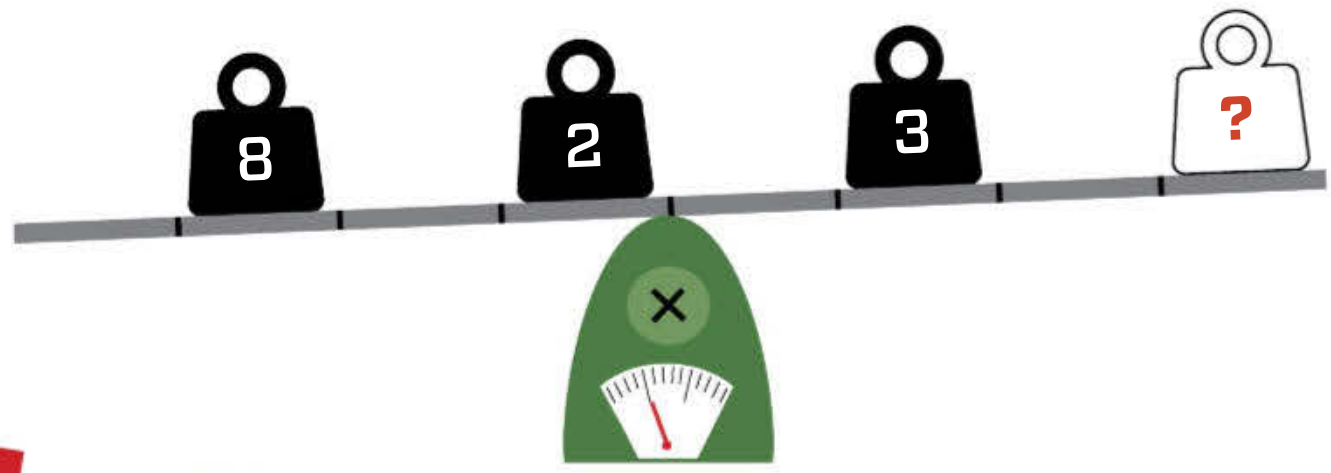


NUMERACY

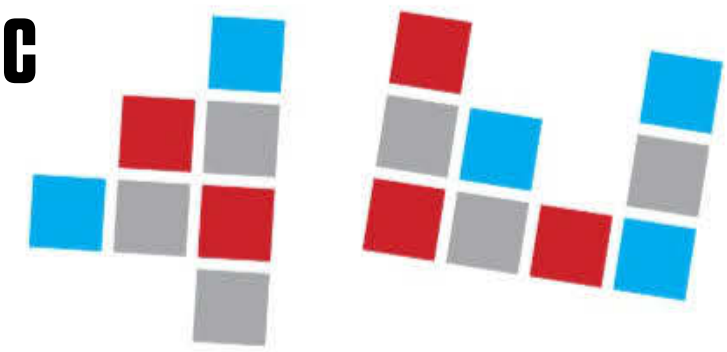
4 In a local election, a total of 12,345 votes were cast. All votes were distributed between four people, and Nos. 2, 3 and 4 on the list got 512, 2513, and 4814 fewer votes than the winner. How many votes did the winner get?

VISUAL INTELLIGENCE

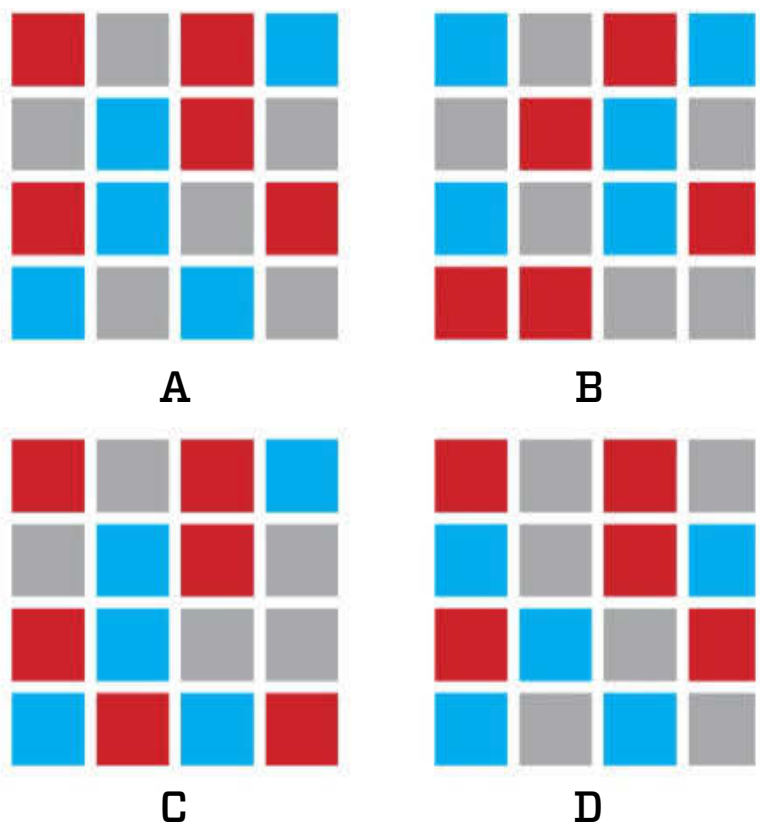
2 What value weight replaces the question mark to balance the scales?



LOGIC



3 Which box below is made up of the two elements above?



MEMORY

FROM THIS ISSUE Answers on p11: no peeking!

5 Scientists have identified what as the source of an unexplained Fast Radio Burst?

A) 100,000 planets
B) A black hole
C) A magnetar neutron star
D) Alien intelligence

6 What altitude must you achieve to officially enter the realm of space?

A) 100km
B) 1000km
C) 10,000km
D) 100,000km

7 During which of the following events might you witness the creation of plasma?

A) The Bathurst 1000
B) A deep-sea dive
C) Charging an electric car
D) A lightning storm

8 What might scientists use to convert your whole home into an energy storage battery?

A) Underfloor heating
B) Lithium-doped roof tiles
C) Super-capacitive bricks
D) Nuclear waste in concrete

// DON'T MISS THE NEXT ISSUE

COMING UP

ISSUE ON SALE 13 MAY 2021

PLUTO'S REVENGE!

In 2006, Pluto had its status downgraded from 'planet' to mere 'dwarf planet'. Astronomers have never thought much of Pluto... a frozen and lifeless rock. But images from the New Horizons probe have changed everything: life might be thriving under that freezing cold crust.

PLUS: THE SCIENCE OF PAIN

Our genes reveal the importance of pain – and how we may have inherited our pain threshold from Neanderthals.

Effortless Lawn Care

Packed with premium features, the award-winning battery-driven SILENO Robotic Lawnmower mows the lawn without human intervention, reliably, evenly and quietly. It knows where to mow and when to return to its charging station.

Rain or shine. Simple or tricky. Steep or narrow. A GARDENA Robotic Lawnmower can handle complex lawns with ease.

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