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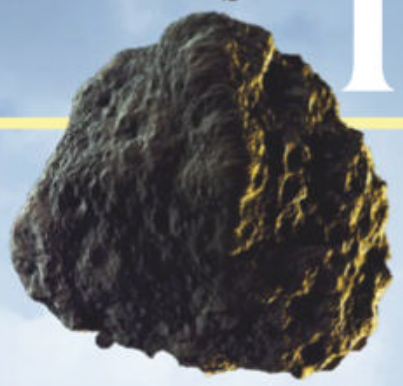
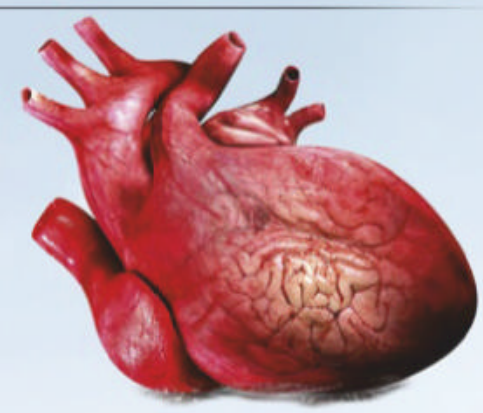


THE CHASE IN SPACE

Bold plans to intercept interstellar objects



HEARTS AND MINDS

Our brain isn't the only organ that influences thought

THE NEXT ICE AGE IS CANCELLED

Global warming **vs** the big freeze

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New efforts to bring back the hairy giant

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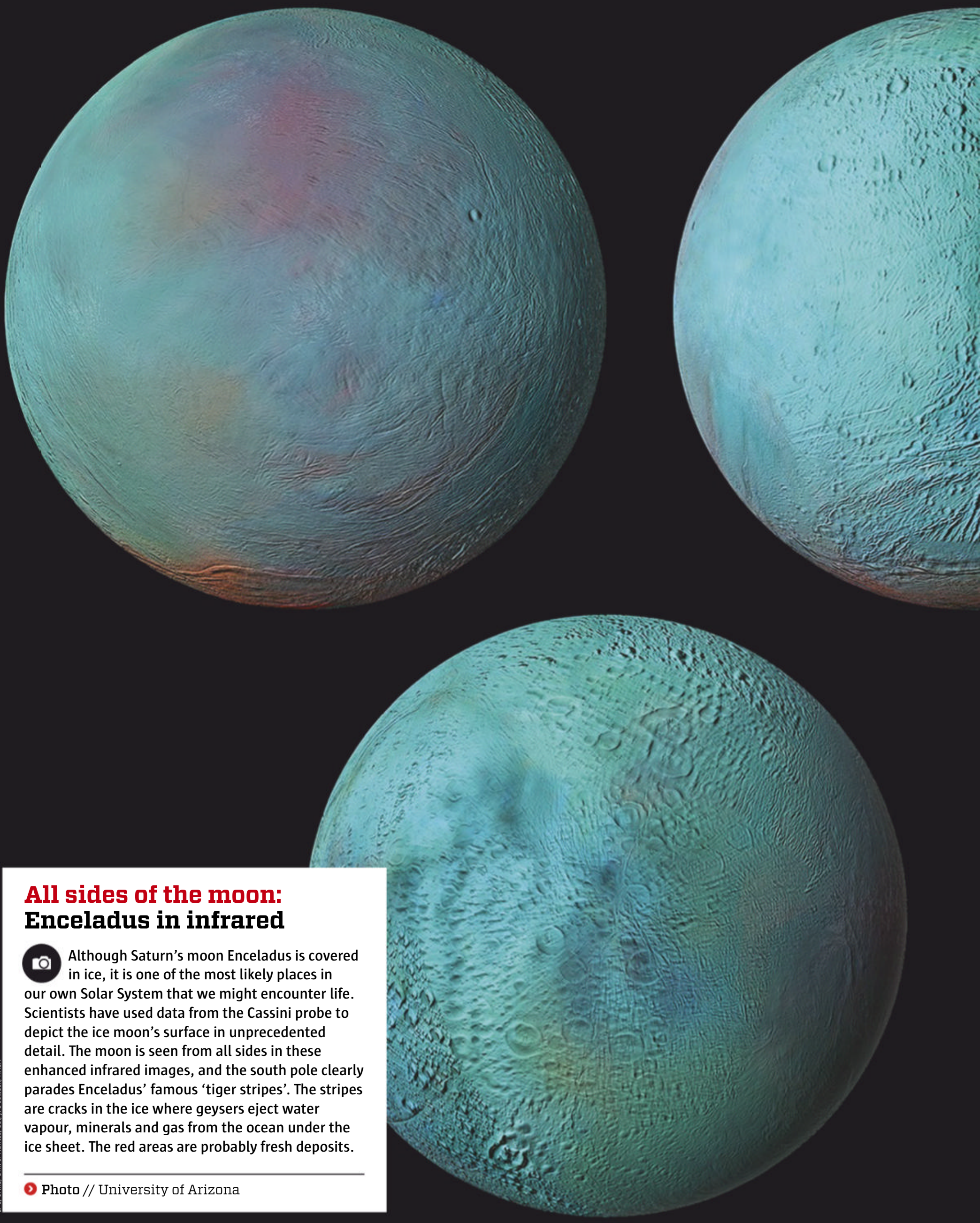
We share with our readers a fascination with science, technology, nature, culture and archaeology, and believe that through education about our past, present and future, we can make the world a better place.

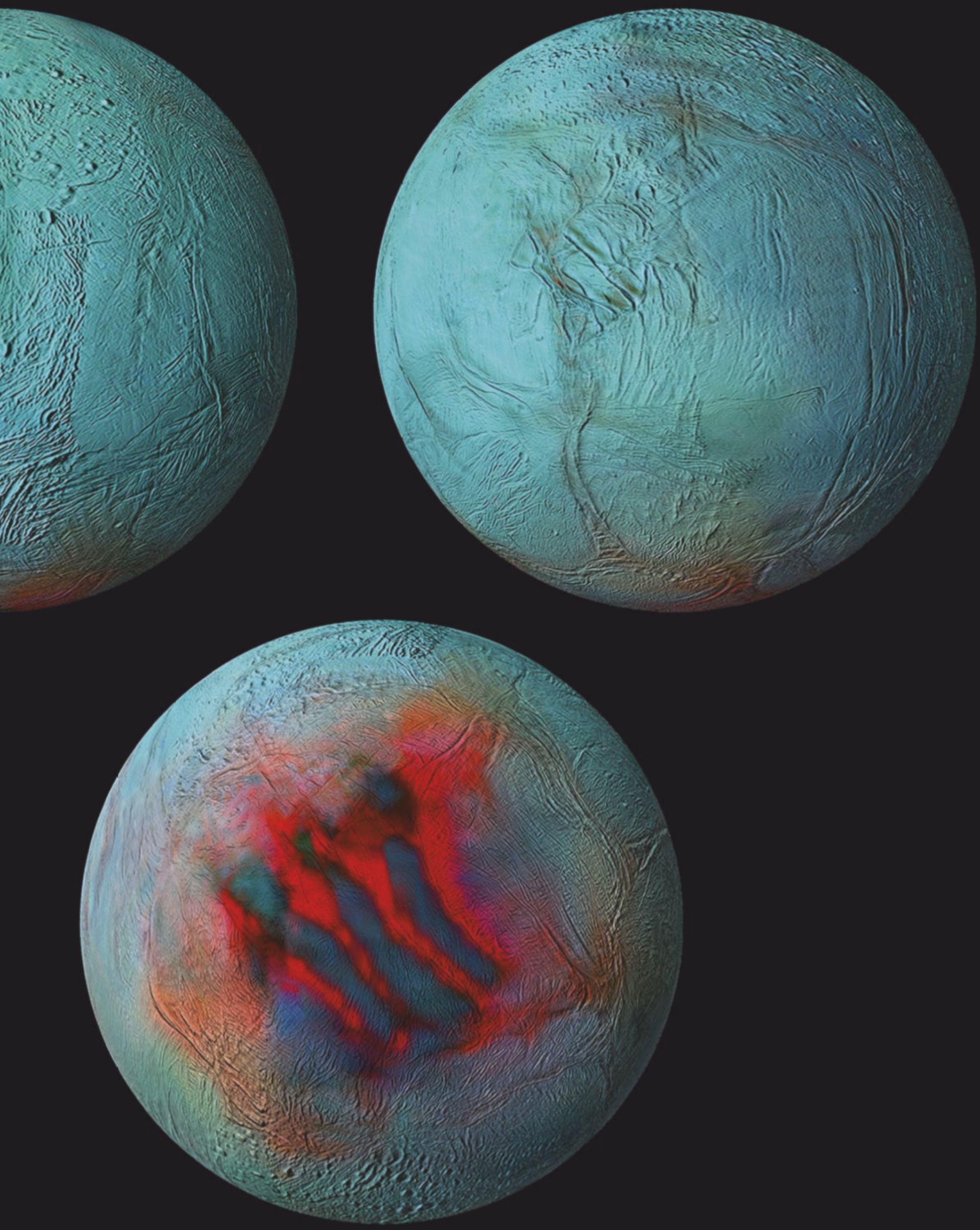


All sides of the moon: Enceladus in infrared

Although Saturn's moon Enceladus is covered in ice, it is one of the most likely places in our own Solar System that we might encounter life. Scientists have used data from the Cassini probe to depict the ice moon's surface in unprecedented detail. The moon is seen from all sides in these enhanced infrared images, and the south pole clearly parades Enceladus' famous 'tiger stripes'. The stripes are cracks in the ice where geysers eject water vapour, minerals and gas from the ocean under the ice sheet. The red areas are probably fresh deposits.

Photo // University of Arizona

LPG/CNRS/Uni. of Nantes/SSI/JPL-Caltech/NASA



Etna average: lava flow quadrupled in recent times

Lava flows from Italy's Mount Etna, cutting through the volcanic landscape like a river of fire. The volcano in Sicily is one of the world's most active, continuously erupting for almost 30 years and with its lava flow increasing from an average 0.2m³/s for 1900-1970 up to 0.8m³/s for the years since 1971. Etna is a stratovolcano, its 3326-metre-high cone made of many layers of hardened lava and ash. Eruptions have claimed 77 lives in historical times, most recently in 1987. This image was a winner in the 2020 Wildlife Photographer of the Year contest.

Photo // Luciano Gaudenzio

WILDLIFE PHOTOGRAPHER OF THE YEAR 2020

Cosmic collision causes a new type of black hole

For the first time, physicists have witnessed two black holes merging to form a medium-sized black hole that weighs 100+ times more than the Sun.

ASTRONOMY Astrophysicists have recently witnessed the biggest collision ever between two black holes, and the result is a large hole of a kind that scientists have never seen before. The two black holes individually weighed 66 and 85 times the mass of the Sun, and physicists' calculations show that the merger resulted in a black hole of 142 solar masses.

This indicates that the collision discharged energy corresponding to nine solar masses. Most of it flowed through space in the shape of gravitational waves, which the LIGO and Virgo detectors on Earth can measure.

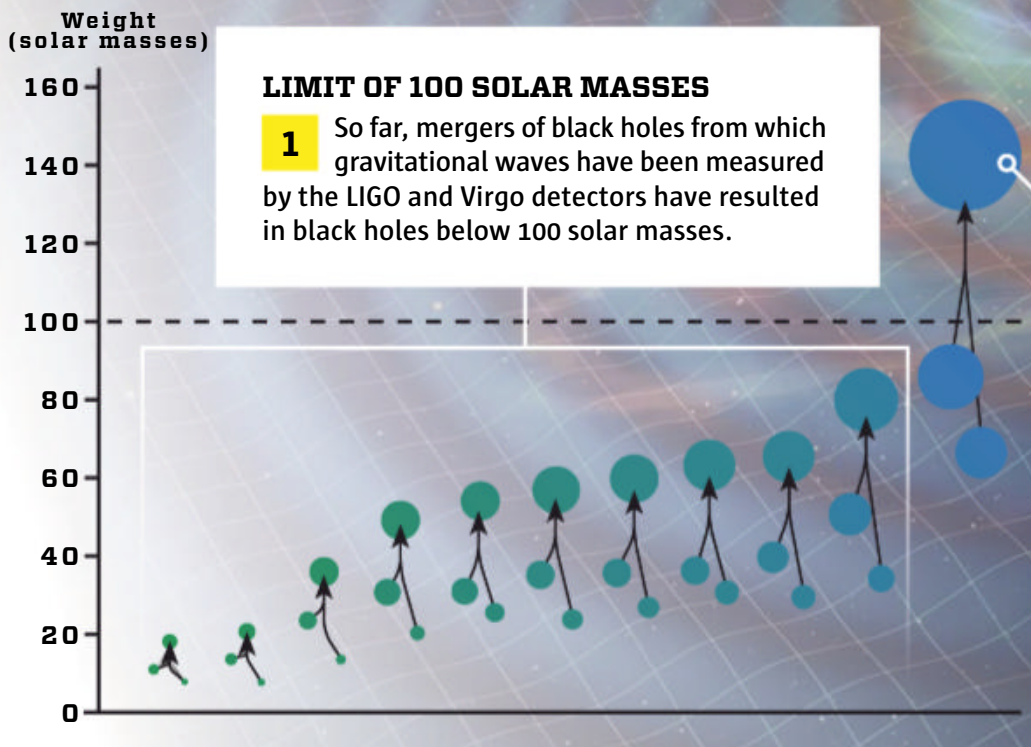
The merger of the two black holes is not only the biggest but also the most remote from which scientists have ever captured gravitational waves. It happened in a region that is now 17 billion light years away from us, although the collision did not happen 17 billion years ago, rather only seven billion years ago, when the universe was about half its present age. The region is now much further away because of the universe's expansion since then.

The black hole of 142 solar masses is particularly important because it is the first discovery of a medium-sized black hole which, according to theory, originates when two or more black holes merge. Smaller holes are formed by collapsing stars that weigh less than 60 solar masses. If a star is heavier than this, it should blow itself to pieces instead of becoming a black hole. So scientists suspect that the two black holes of 66 and 85 solar masses might therefore have themselves formed in earlier mergers between smaller black holes.

Astronomers now lack evidence only for the smallest category of black hole. According to theory, these would have formed shortly after the Big Bang, and weigh only as much as a large mountain. We have no evidence of these – yet.

Gravitational waves show the size of black holes

When black holes merge, large quantities of energy are discharged in the form of gravitational waves that flow through space. The strength of the waves demonstrates the weight of the holes.



LIMIT OF 100 SOLAR MASSES

1 So far, mergers of black holes from which gravitational waves have been measured by the LIGO and Virgo detectors have resulted in black holes below 100 solar masses.

NEW COLLISION SETS RECORD

2 Analyses of the merger of two black holes demonstrate that they were 66 and 85 solar masses respectively. The result was a black hole of 142 solar masses.

FOUR CATEGORIES OF BLACK HOLES

NOT FOUND

- **Original black hole:** According to astronomers' theories, very small black holes formed in the young universe were the size of atoms with the weight of a large mountain.

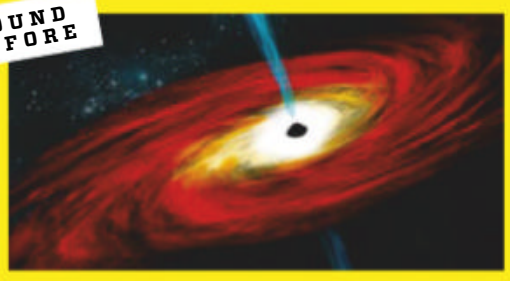
FOUND BEFORE

- **Star-mass black hole:** Formed when a star of 5-60 solar masses burns out and collapses. If the star is heavier, it is blown to pieces instead of ending up as a black hole.

FOUND NOW

- **Medium-sized black hole:** Weighs 100-100,000 solar masses, formed when two or more star-mass black holes merge to form a heavier black hole.

FOUND BEFORE



- **Supermassive black hole:** Weighs more than one million solar masses and probably exists at the centre of almost all galaxies, forming at the same time as the galaxy around them.

GETTY IMAGES/SHUTTERSTOCK/LIGO/CALTECH/MIT/R. HURT (IPAC)

OCEANBIRDWALLENIUS.COM

‘Oceanbird’, the world’s biggest sailing ship, to use plane-like wings

Big diesel-powered freighters could be challenged by an environmentally-friendly alternative. Shipbuilders will launch a 200-metre-long wind-powered ship in 2024.

TECHNOLOGY After 100 years with coal and diesel as the dominant fuels for the world’s ocean freighters, Swedish engineers are planning the return of the sailing ship. indeed they are developing the world’s biggest sailing ship, with a new concept in which the sails are shaped like five huge aircraft wings. Named ‘Oceanbird’, the ship is to be launched in 2024, and its first job will be to carry cars across the Atlantic.

Currently that task is undertaken by around 450 ships that together consume some 40,000 tonnes of diesel a day. Oceanbird’s 12-day Atlantic crossing is slower than these diesel-powered ships, but the climate is spared 90% of the greenhouse gases emitted by a corresponding diesel-powered vessel.

The wind-powered ship will weigh 32,000 tonnes and measure 200 metres in length and 40 metres wide. Its special sails can be moved up and down, towering 80 metres above deck and 105 metres above the ocean surface at their highest, while at their lowest position the ship is 45 metres high, reducing the wind pressure in poor weather, and allowing the ship to pass under bridges.

The companies behind the project are Wallenius Marine, SSPA, and the KTH Royal Institute of Technology in Stockholm. According to Wallenius Marine, the biggest challenge is to get the ship’s hull and sails to function as one aerodynamic unit that travels as fast as possible. The sails will be made of steel and composite materials, and must be able to rotate 360 degrees to make optimum use of the wind. The top speed will be 10 knots or about 19km/h. A spare engine, perhaps battery-powered, will be used when in narrow waters or manoeuvering in and out of harbours.

Test yourself

Answers to p82. No peeking!

1: 17. The numbers at the first table add up to 10, the numbers at the second table to 30. If the progression continues so that the third table adds up to 50, the missing number is 17.

2: G. In each translation the shape inside the triangle becomes the outer shape, while the outer shape becomes the inner shape.

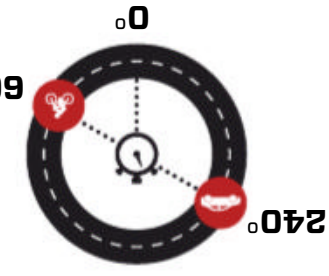
4: D. See page 22.

5: D. See page 45.

6: B. See page 13.

7: C. See page 66.

3: 10 minutes. At 36km/h the bike covers one lap in an hour, or 6 degrees per minute. The car is four times faster, at 24 degrees per minute. After 10 minutes the bike has covered 60 degrees and the car 240 degrees, so they are opposite each other with the timekeeper aligned in the middle.



SHUTTERSTOCK / OLIVER E. DEMUTH

Megalodon has been extinct for three million years; today we have only its teeth, which measure up to 18cm – more than three times longer than those of a modern white shark.

Scientists measure monster shark

New calculations indicate the probable appearance of this huge prehistoric megalodon shark. The hunter-scavenger seems equally suited to sudden attacks or long-distance cruising.

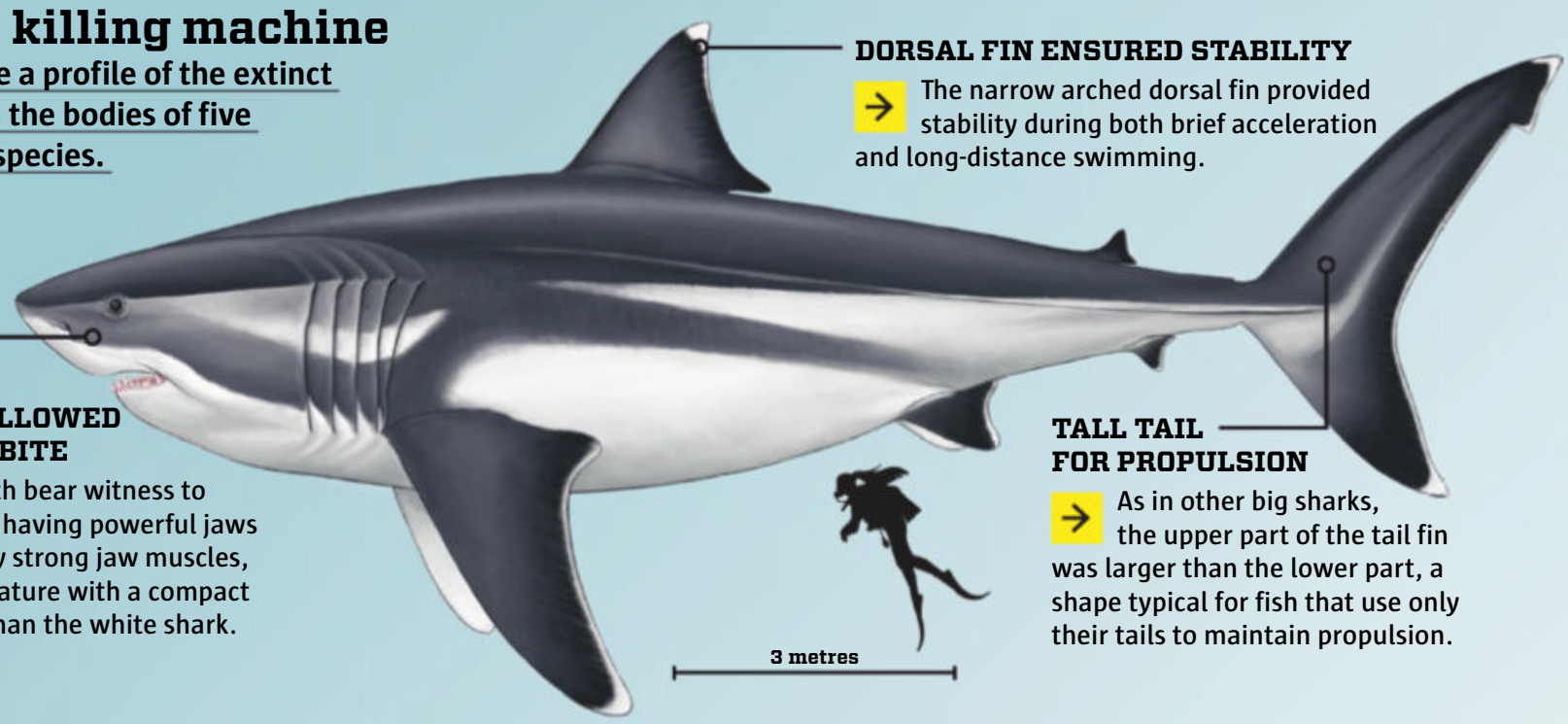
PALAEONTOLOGY For the first time, scientists have calculated the proportions of the largest shark that ever lived. Teeth from megalodon have been found throughout the world as the shark ruled the oceans for 20 million years before becoming extinct three million years ago. But its appearance has remained uncertain because shark skeletons consist of cartilage that quickly deteriorates, leaving scientists only the teeth. Comparisons with teeth from the biggest modern shark, the white shark, indicate that the prehistoric shark would have been 12 to 20 metres long, and it has previously been portrayed as a big version of the white shark. But scientists from the UK's University of Bristol now have a more detailed picture.

They measured the different body parts of five modern shark species, based on which they calculated the probable anatomy of a 16-metre megalodon (twice the length of a big white shark). The results indicate a prehistoric shark with a head 4.65 metres long, a dorsal fin standing 1.62 metres tall, and a tail 3.85 metres long. The shark's height from the top of the dorsal fin to the belly was 4.53 metres.

The scientists assumed a narrow, arched dorsal fin, like that on other big sharks. On the other hand, the head was wide to allow space for powerful jaw muscles. According to the scientists, the shark's body made it well suited for surprise attacks requiring rapid acceleration, but also for long-distance swimming at a modest pace. This would have allowed it to sweep large areas and supplement its diet with carcasses found on the ocean floor.

16-metre killing machine

Scientists made a profile of the extinct shark based on the bodies of five modern shark species.



DORSAL FIN ENSURED STABILITY

The narrow arched dorsal fin provided stability during both brief acceleration and long-distance swimming.

WIDE HEAD ALLOWED A POWERFUL BITE

The big teeth bear witness to megalodon having powerful jaws and consequently strong jaw muscles, providing the creature with a compact but wider head than the white shark.

TALL TAIL FOR PROPULSION

As in other big sharks, the upper part of the tail fin was larger than the lower part, a shape typical for fish that use only their tails to maintain propulsion.

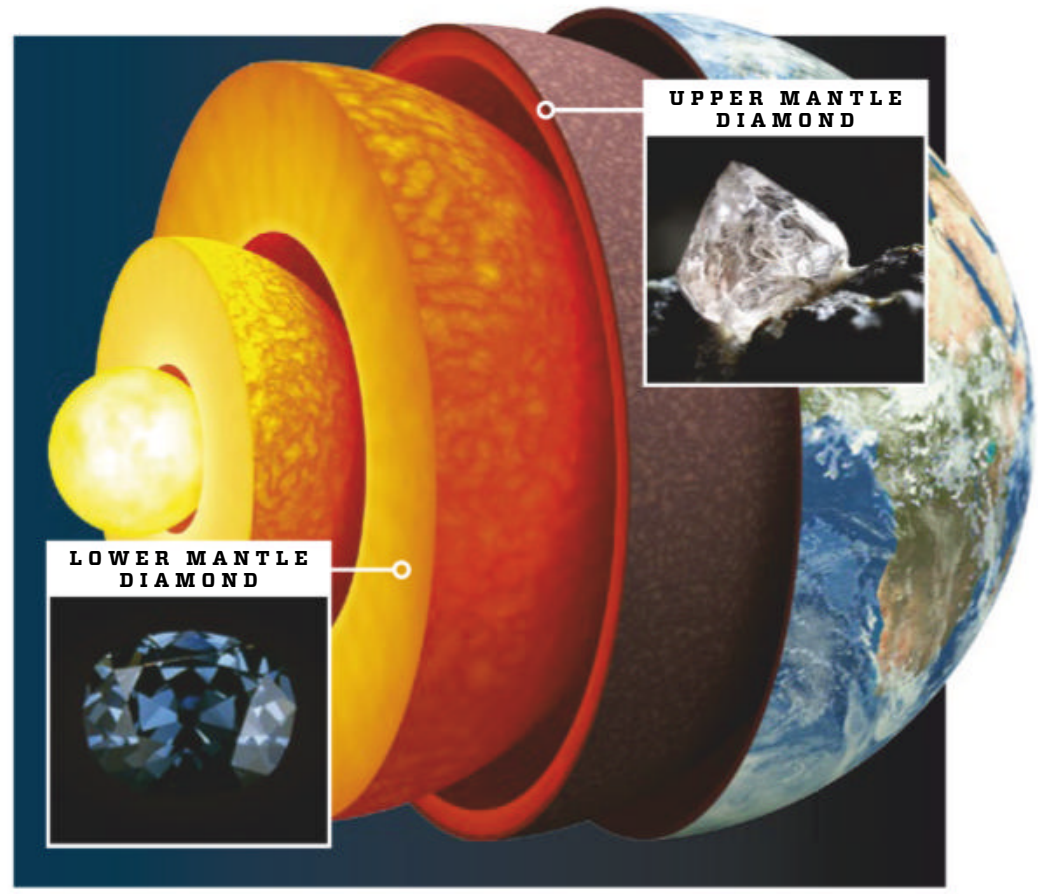
Superdeep diamonds reveal the limits of carbon-based life

The carbon cycle of life on Earth reaches no more than 660km into Earth's interior.

GEOLOGY For the first time, analyses of diamonds have demonstrated how deeply life leaves its mark inside the Earth.

All life on Earth is part of the carbon cycle. Plants and animals are made of carbon: they die and are broken down into carbon which returns to the ground or the ocean floor. The carbon is pulled into Earth's interior when tectonic plates push under one another, later returning to the surface via volcanic eruptions.

But how deep the carbon is pulled has been unknown until recently. The answer was found by scientists from the University of Alberta in Canada. They analysed different variants of carbon, oxygen and nitrogen in diamonds. Most diamonds form in Earth's upper mantle, down to depths of 250km. Diamonds from deeper layers are much rarer: the rarest and most expensive are superdeep diamonds, some formed in the lower mantle 660+km below the surface. The analyses showed that the elements in these diamonds were not in touch with Earth's surface, so the carbon cycle of life reaches its limits before that depth. The discovery will help geologists better understand carbon quantities in Earth's interior and the cycle's influence on climate change.



Analysis of superdeep diamonds from Earth's lower mantle (orange) shows that they formed from carbon that is outside the main carbon cycle of life on Earth.

MARK GARLICK/SPL, SHUTTERSTOCK & THE GRANGER COLL./RITZAU SCANPIX

SHUTTERSTOCK

Honey-bee venom becomes new weapon against cancer

Melittin in bee venom kills cancer cells in less than an hour. This could lead to aggressive new breast cancer treatments.

MEDICINE A bee sting can kill people that are allergic to bee venom, but the venom can also save lives, according to experiments made by scientists from the Harry Perkins Institute of Medical Research in Western Australia. The scientists researched whether honey-bee venom can be used against a particularly aggressive type of breast cancer known as triple negative. This is characterised by sick cells lacking characteristic proteins on their surfaces that other cancer cells have, proteins which are targeted by most types of cancer drugs. Hence this cancer type is difficult to treat.

The scientists injected the bee venom into lab-grown breast cancer tumours. The toxin killed all the cancer cells in less than an hour. The scientists subsequently repeated the experiment successfully on cancer tumours inserted into mice, and importantly established the dose for which healthy cells around the tumour were not harmed.

The active component of the bee venom is known as melittin, and it attacks cancer cells in several ways. Firstly it pokes holes in the cells' surfaces, killing many of them in the process. Then once the drug is inside the cells, it disturbs chemical signalling pathways, so the cancer cells can no longer divide.

Melittin's ability to poke holes in cancer cells inspired the scientists to test the ingredient in combination with chemo drugs that cannot enter cells, and the effect was improved considerably.

So it seems that bee venom may work both as a cancer drug in itself and to improve the effects of other treatments.

Honey bees use their venom when they sting, but it also works inside the bee's body as a protection against bacteria and viruses.

Approximately half of the bee venom consists of melittin, which experiments in Western Australia have proven can kill aggressive breast cancer cells.

How the Neanderthals lost their Y chromosome

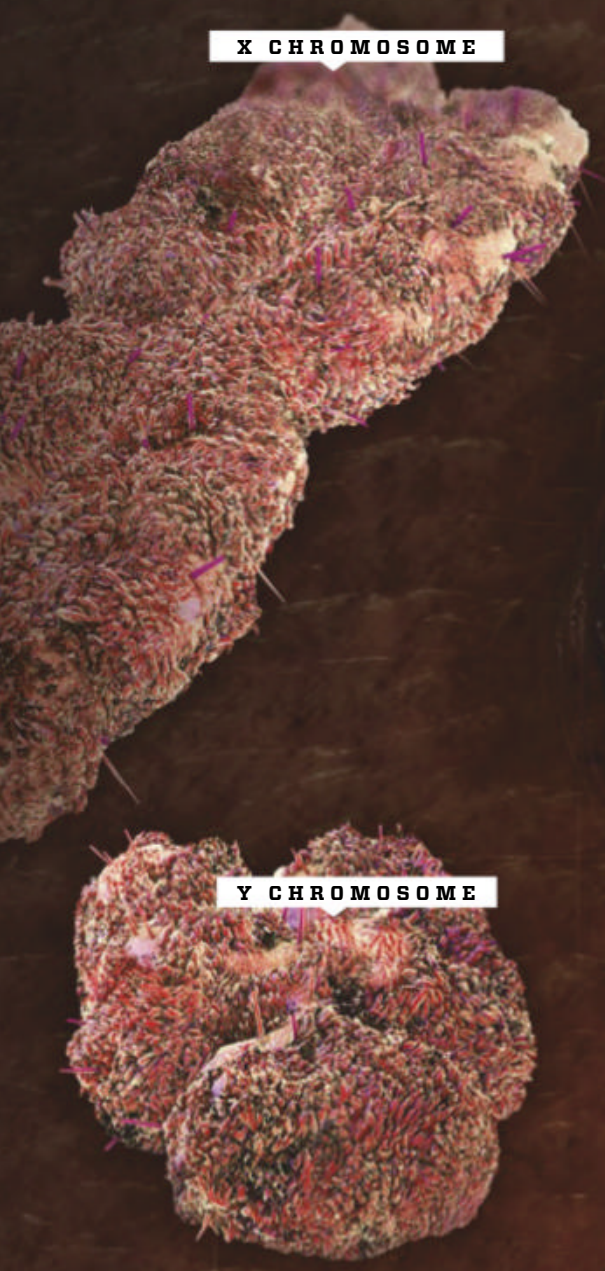
New genetic studies show that the Neanderthals replaced their male sex chromosome more than 100,000 years ago. They got their new chromosome from an early version of our own species.

EVOLUTION When our ancestors left Africa some 60,000 years ago, they met other human species on their way. And the meetings became intimate. Genetic studies have shown that modern humans mixed genes with both Neanderthals in Europe and Denisovans in Asia. But new evidence indicates that this cross-fertilisation had begun much earlier.

Scientists from the Max Planck Institute in Germany isolated the Y chromosome from three Neanderthals that lived 38,000-53,000 years ago, then compared it with the Y chromosome of two Denisovans. Surprisingly, the Neanderthals' Y chromosome was more like that of modern humans than those of Denisovans. It should be the other way around, because the Neanderthals and Denisovans development lines only separated hundreds of thousands of years after their common ancestors parted from ours.

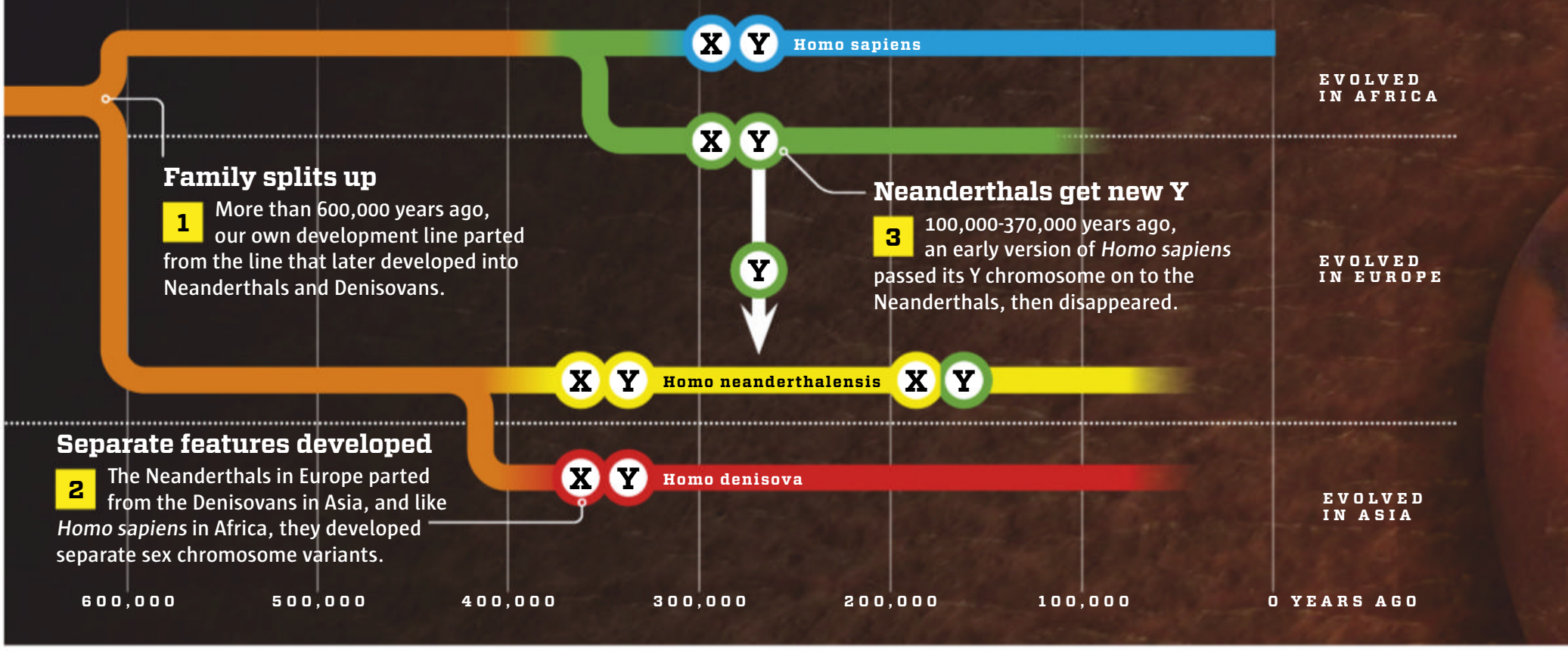
The most likely explanation is that a group of early *Homo sapiens* left Africa long before the migration wave from which we descend. According to the scientists, these early migrants passed their Y chromosome on to the Neanderthals 100,000-370,000 years ago.

The discovery supports the theory that *Homo sapiens* left Africa in many waves. In recent years, several discoveries have been made that point in this direction. In 2018, a 180,000-year-old *Homo sapiens* jaw was found in Israel. And in Greece, scientists found a 210,000-year-old skull in 2019 that is also reminiscent of *Homo sapiens*. Our species' history outside Africa seems to have been much longer than we used to think.



Early migrant mixed with Neanderthals

An early version of *Homo sapiens* passed its Y chromosome on to the Neanderthals in Europe long before our own ancestors left Africa.



New finds including this jaw from Israel indicate that early *Homo sapiens* left Africa as long as 200,000 years ago.

KATARINA HARVATI/UNIVERSITY OF TÜBINGEN & ISRAEL HERSHKOVITZ ET AL./AAAS/SHUTTERSTOCK / FLAVIO MASSARI/ALAMY/IMAGESELECT

ANDREW J. READ/NOAA PERMIT 16185

Cuvier's beaked whales exist in all oceans, but biologists know very little about them. The whale is particularly difficult to study because it stays under water most of the time.

Diving record broken by beaked whale

In an amazing dive, a beaked whale has remained under the water for one hour longer than the old record. According to biologists, this should not be possible.

ZOOLOGY Biologists from Duke University have recorded by far the longest dive ever observed by a mammal. The new record of 3 hours and 42 minutes was set by a Cuvier's beaked whale.

Over a period of five years, scientists have been placing satellite transmitters on beaked whales, observing a total of 3680 dives by 23 individuals. The dives lasted 59 minutes on average, so the record dive of 3+ hours was exceptional.

The record has surprised biologists for several reasons. Firstly it is almost one hour longer than the old record (also held by a beaked whale). Secondly, it should not be possible for a relatively small whale to remain immersed for such a long time. The beaked whale measures less than 7 metres and weighs only 2.5 tonnes, limiting the quantity of oxygen it can store in its body. In comparison, sperm whales, also known for long deep dives, weigh up to 50 tonnes, but their longest dive record is only 83 minutes.

The beaked whale has muscles with a high content of myoglobin that can store oxygen. But according to scientists' calculations, this should run dry after 77 minutes. Subsequently, the muscles convert sugar without the use of oxygen in anaerobic metabolism, producing lactic acid that accumulates in the muscles. According to the scientists, the beaked whale must have unknown physiological mechanisms that prevent it from accumulating lactic acid.

The whale might also have other techniques to make its oxygen reserves last longer than scientists expect, such as by lowering its cardiac rhythm and metabolism, or by shutting off the blood supply to non-essential organs, leaving only the brain, heart and muscles consuming oxygen.

2992

metres is the maximum depth reached by a beaked whale during its long dives, beyond most competing squid catchers.

AIRBUS/ KEN IKEDA MADSEN/SHUTTERSTOCK

The V formation ensures that all planes except the front one save energy. They get a free lift by the air vortices produced by the wings of the plane in front of them.

Airliners to fly in formation

Inspired by migrating birds, aircraft maker Airbus aims to develop a system in which airliners fly in a V formation to save tonnes of fuel per flight.

TECHNOLOGY Imagine looking out of your plane window and seeing a group of other airlines all around you. That could happen in years to come (when flights have resumed, post-COVID) if experiments by aircraft maker Airbus come to fruition.

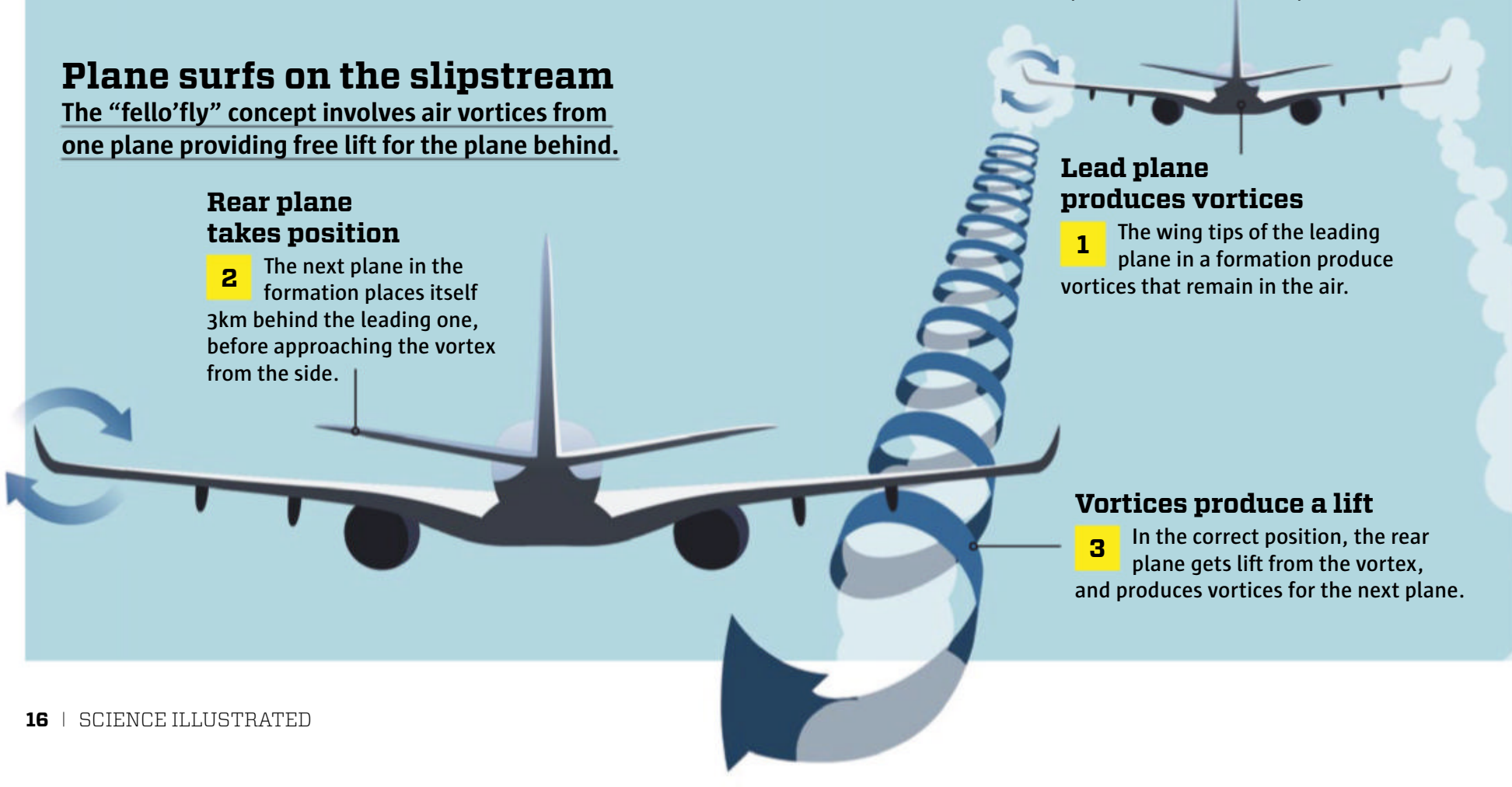
The company is working on a new concept known as "fello'fly" which could allow airliners to save 5-10% on fuel by flying in V formations. The idea was, of course, inspired by geese, which travel in groups when they migrate over thousands of kilometres. Their characteristic V formation means that individual birds get a free lift by the air vortices produced by the wings of the bird in front of them.

Today, air traffic regulations require a safety distance of 55-90km between planes over oceans. But if they are to make use of each other's air vortices, the distance must be no more than 3km. Airbus believes that it can be done safely within spaces defined by air traffic controllers, the planes keeping at a horizontal distance of 1000 feet (305 metres), so there is no risk of collision. The rear plane ensures it keeps a full 3km distance behind the leading plane, and maintains an identical speed, before the pilot steers it sideways into the air vortex that allows the free lift.

In 2020, Airbus carried out preliminary experiments with two A350 airliners. In 2021, new experiments will include more planes in the same formation in cooperation with the French company Frenchbee and SAS of Scandinavia. Airbus has calculated that CO_2 emissions could be reduced by 3-4 million tonnes a year if the full potential of the concept is realised.

Plane surfs on the slipstream

The "fello'fly" concept involves air vortices from one plane providing free lift for the plane behind.



Cosmic radiation puts limits on the length of lunar missions

New data is revealing how long astronauts can safely remain on the Moon.

AEROSPACE The Chinese Chang'e-4 probe that landed on the far side of the Moon in January 2019 has made the first accurate measurements of cosmic radiation on the surface. The measurements were carried out using a German LND instrument, and the results have been published by scientists from the German Aerospace Centre. They indicate that an astronaut on the Moon is subjected to a radiation level 200 times higher than on Earth, where the magnetic field and our atmosphere protect us. This level is 2.6 times higher than ISS astronauts receive. The radiation on the Moon consists of particles from the Sun and from supernova explosions in outer space, and in large doses these can cause cancer. This confirms the importance of protection for the astronauts that NASA aims to send to the Moon in 2024, and particularly for those astronauts who will later work at a permanent base.

According to NASA's rules, astronauts cannot be subjected to radiation that increases the risk of dying of cancer by more than 3%. This means that without any protection other than a spacesuit, they cannot spend more than 700 days on the Moon over their lifetime. But a permanent base covered in at least 50cm of moon dust would provide more protection, so longer stays could be made safer.

FOSTER + PARTNERS/ESA/ CNSA/NAOC

Data from the Chang'e-4 probe (inset) reveal that astronauts should stay on the Moon for a total of only 700 days in their lifetime.

IMP/L.SCHEDL

Aussie lungfish has largest animal genome known to science

Scientists are teasing out the secrets that place the Australian lungfish near a critical moment of evolution.

EVOLUTION A team of scientists at the Research Institute of Molecular Pathology (IMP) in Vienna has sequenced the genome of the Australian lungfish for the first time, unveiling striking similarities to land-dwelling vertebrates. The study, published in *Nature* this January, also sets a record for the largest animal genome ever sequenced at 43 billion base pairs, 14 times the length of the human genome.

The Australian lungfish is an endangered air-breathing fish with a body resembling a cross between a fish and a newt, and it is one of the few living relatives of the first fish to crawl out of the water to colonise land some 380 million years ago. The unveiled genome sequence settles a longstanding debate as to whether lungfish or coelacanths – another group of archaic fish with lobed fins – were more closely related to amphibians, reptiles, birds and mammals. This study provides unequivocal evidence that coelacanths diverged first, while lungfish branched off from the line leading to four-legged animals only 420 million years ago.

The IMP scientists also investigated gene expression in various tissues. The new genome highlights similarities between lungfish and land vertebrates: for example, the number and expression levels of genes associated with lung development and articulated limbs, also the detection of air-borne smells, are closer to those of amphibians than of other fish.

"There is no doubt that the newly sequenced genome will unveil more of the secrets of this bizarre vertebrate in the future," says Elly Tanaka, Group Leader at the IMP. "Not only can it teach us things about adaptations to life on land, but it may also explain how certain genomes evolve to be so big."

While 43 billion base pairs beats out all previous animal contenders, some plants have even longer genomes. The Japanese flowering plant *Paris japonica* has 150 billion base pairs of DNA per cell.

What is twilight, and why do we see fewer colours?

When the sun's disc disappears, we enter dusk. We can still see the world around us because our vision adjusts as light reduces, switching gradually to a different vision system which removes colour sensitivity.

LIGHT Dusk or 'twilight' is the name given to the period of time during which the Sun is located below the horizon, but when it is not yet pitch dark outside. During the dusk, light does not come directly from the Sun, but rather from the light's refraction in the molecules of the air as the atmosphere receives light even though the Sun, as observed from your position, is below the horizon. The further below the horizon the Sun is, the less visible atmosphere it shines on, so the darker it gets. Our eyes need to keep adjusting to the different lighting conditions.

In broad daylight, we see primarily by means of cones in the retina which are colour-sensitive but not very light-sensitive. This type of vision is known as photopic vision. As the light intensity falls, the pupils expand to allow more light into the eye. At this time our vision relies increasingly heavily on the rods of our retinas, which are very light-sensitive, but cannot detect colours. When cones and rods are both in play, it is known as mesopic vision. When the light intensity is reduced so far that the cones cease to provide useful information, we see only in the grey tones of our rods: this is known as scotopic vision. The adjustment between modes explains why we gradually see more when we enter a dark room.

Photographers have named the period of dusk as the 'blue hour' due to the bluish colour of light. Similarly, the periods immediately after sunrise and right before sunset are known as the 'golden hour'. Our eyes compensate for the coloured light during these blue and golden hours, but a camera does not, explaining why photographs taken immediately before and after the Sun passes the horizon can often benefit from a filter to match our personal perception of colours.

Three stages of twilight

Astronomers divide the dusk into three stages, according to how far below the horizon the Sun has passed. The Sun's position determines the quantity of available light and so how much we can see and whether our colour vision can still operate.

LEIGH COUSINS

CIVIL TWILIGHT

1 The Sun is 0-6° below the horizon. Outdoor games such as ball games do not require artificial light. The horizon line and objects on the ground can easily be seen.

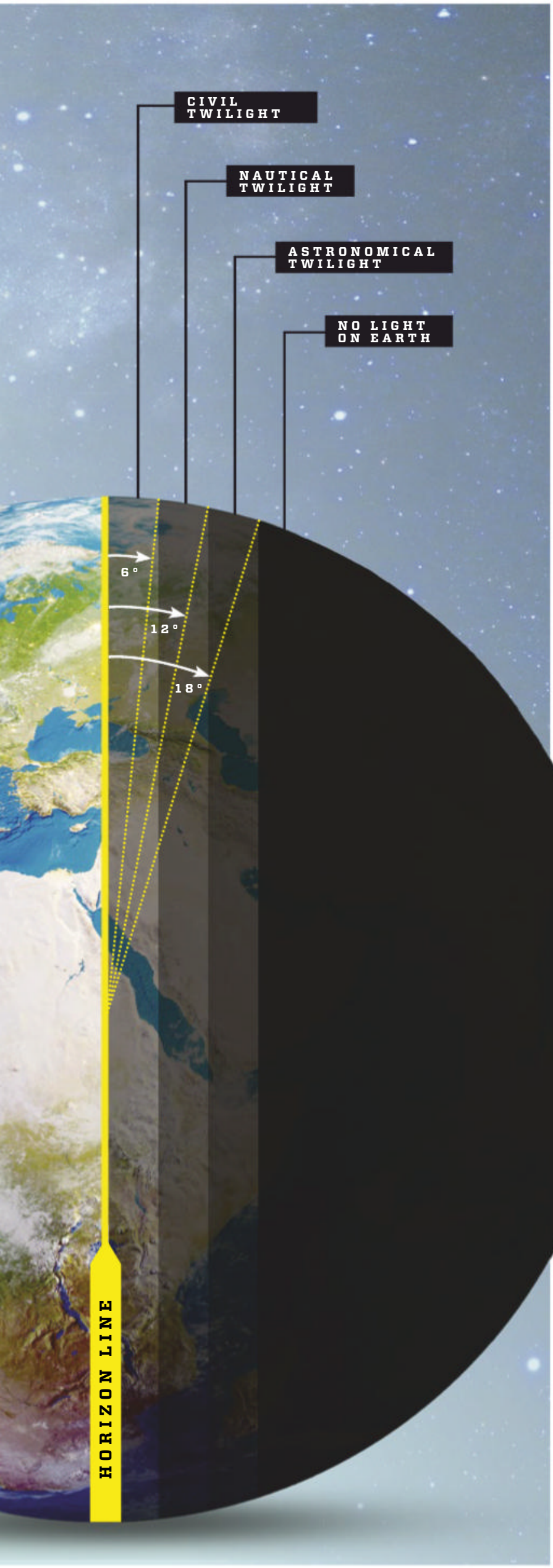
NAUTICAL TWILIGHT

2 The Sun is 6-12° below the horizon. The outline of objects on the ground is blurred, but they are still visible. It is difficult to make out the horizon.

ASTRONOMICAL TWILIGHT

3 The Sun is 12-18° below the horizon. The ground now appears dark, and the horizon has gone. The sky is still lit by the rays of the Sun from below the horizon.

Three stages of twilight have been defined, depending on the Sun's position below the horizon.



SHUTTERSTOCK & LOTTE FREDSLUND

TOP 5 · Which animal has the most powerful poison?

SHUTTERSTOCK

1 Golden poison frog

Lethal dose*: 2µg/kg of body weight. Tribes in the frog's South American home have used its poison on arrowheads. The creature is no bigger than the second bone in your thumb, but the poison from a 5cm frog can kill 10 people.

2 BLACK SPIDER
Lethal dose: 4.3µg/kg

This spider kills very few people, as it rarely bites, and when it does the bites are often dry, with no venom injected.

3 PUFFERFISH TAKIFUGU
Lethal dose: 5µg/kg

The fish forms part of the Japanese delicacy 'fugu'. One fish includes sufficient poison to kill 30 people, and there is no antidote.

4 INLAND TAIPAN
Lethal dose: 25µg/kg

This Aussie snake is the world's most venomous reptile. The venom from one bite is enough to kill more than 100 people.

5 BANANA SPIDER
Lethal dose: 134µg/kg

Though not the most poisonous spider, it has killed the largest number of people because the species is very aggressive.

*Lethal dose is based on LD50 values – the dose that kills half of the animals of an experiment.

Why are COVID-19 traces found in sewage when there are no cases?

VIRUSES According to the CSIRO and the University of Queensland, tests in wastewater (untreated sewage) can detect COVID-19 in communities weeks before people display symptoms. Like other coronaviruses, SARS-CoV-2 replicates in our digestive system as well as in our lungs, so those infected will start shedding fragments of the virus into the wastewater system through their faeces even before they feel sick. Frequent and widespread testing can detect these fragments, and so can provide a targeted early detection system as economies re-open and people become more mobile.

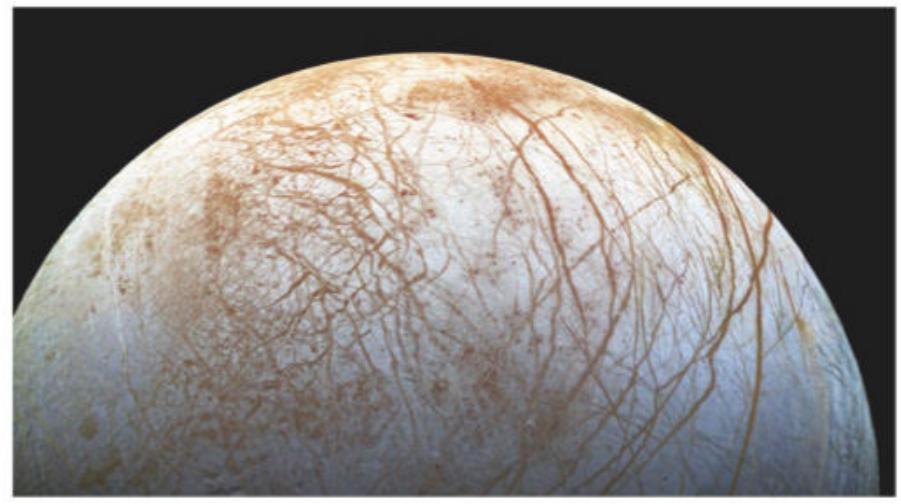
SCOPIO/JOSH JOSHUA

POO TEST: genetic fragments of the virus can be shed in faeces before symptoms appear.

Do other planets have plate tectonics?

ASTRONOMY Plate tectonics are the motion between different fragments of a planet's crust, and scientists have not discovered any evidence of plate tectonics on Mercury, Venus or Mars which, along with Earth, comprise all the Solar System's rocky planets. They might have experienced plate tectonics earlier in their 4.5-billion-year histories, but no visiting probe has yet recorded crust motions on any of them, except, of course, Earth itself.

In 2014, however, American scientists did discover that Jupiter's moon Europa has plate tectonic activity – but it occurs between ice plates. Large plates of ice shift, perhaps because of different salt content, some pushed underground to merge with the underlying ice layer. Ice volcanoes may then form above.

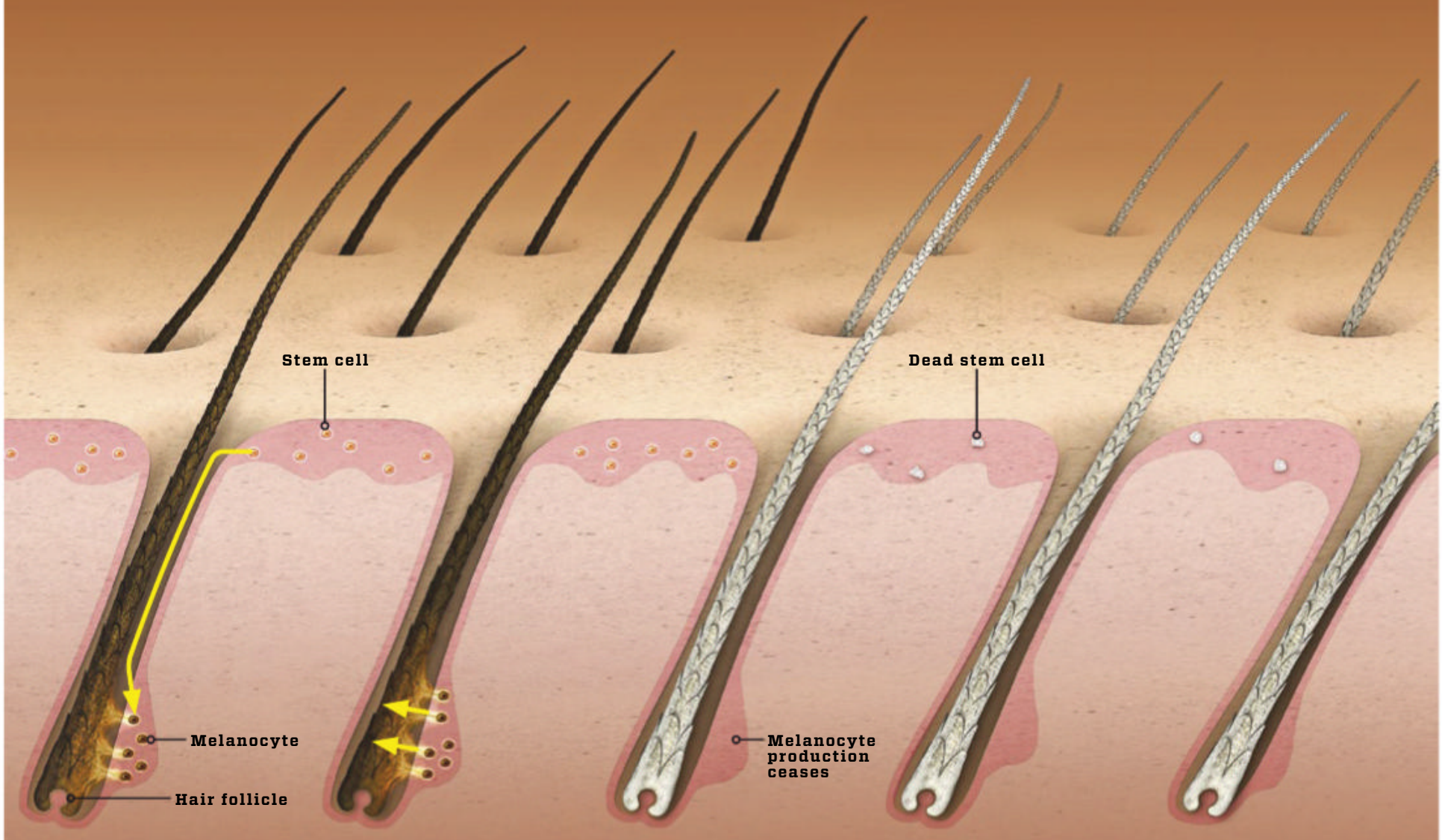


NASA

Jupiter's moon of Europa is covered in large ice plates that move in ways similar to plate tectonics on Earth, potentially creating ice volcanoes.

INSIDE THE BODY · Why does hair lose its colour?

Hair becomes grey when the production of pigment for the hair strand stops. The pigment is produced by stem cells, which start to die when men are in their mid-20s – and about five years later in women. Early development of grey hair seems to be hereditary.



STEM CELLS CHANGE AND MIGRATE

1 Stem cells in the upper skin layers develop into melanin-producing cells known as melanocytes. They migrate to the bottom of the hair follicle.

CELLS PRODUCE COLOUR PIGMENT

2 The melanocytes produce pigment which provides the hair with its characteristic colour. Melanocytes carry the pigment into each hair strand.

STEM CELLS DIE; COLOUR DISAPPEARS

3 With age, the stem cells start to die. Melanocytes are no longer produced to colour the hair, and the hair becomes grey.

HAIR BECOMES GREY IN STAGES

4 Each hair follicle and hair type have their own development. Often nose hair loses its colour first, then scalp hair, beard, body hair, and finally eyebrows.

MIKKEL J. JENSEN

SCALE

Which is heavier: a jumbo jet or the ISS?

Jumbo jet

– a nickname for the Boeing 747 airliner. Since its introduction in 1970, several variants have been developed, of which the Boeing 747-8 is the heaviest. When it is full of cargo, all seats are taken and the tanks have been refuelled, it weighs 440,000kg.

BOEING

A fully loaded jumbo jet has

5%

more mass than the ISS – but the ISS is scheduled to receive more.

NASA

The International Space Station(ISS)

The ISS consists of 16 pressurised modules and countless other units. Since 1998, they have been launched one after another and merged. According to NASA, the current mass of the ISS is 419,725kg, but the addition of the Nauka module (2021) and the first of several Axiom modules (2024) will increase the mass by some 40,000kg.

JENS HENNEBERG & GETTY IMAGES

A blue-footed booby from Galapagos excretes its waste products in the form of a thick white paste.

A

B

Why are bird droppings white?

Most animal faeces is brown, so why are bird droppings white?

ZOOLOGY Bird droppings are actually typically green or brown with a white splotch around them. The dark part corresponds to the faeces of a mammal, whereas the white part is bird 'urine', a thick paste which includes the uric acid that bird kidneys produce as they excrete waste products.

While mammals, including humans, excrete urine and faeces separately, bird excrement all comes from the same opening, the cloaca. Birds also have no bladders, which reduces the amount of weight they have to carry, and their digestion systems are optimised to excrete waste using as little liquid as possible.

Reptiles use the same system as birds to get rid of their waste products while conserving water. Many reptiles live in warm dry areas where it is evolutionarily vital to survive on little water.

Some predators and scavengers – including Tasmanian devils — have white faeces. This can often indicate that the animal consumes a lot of bones in its diet.

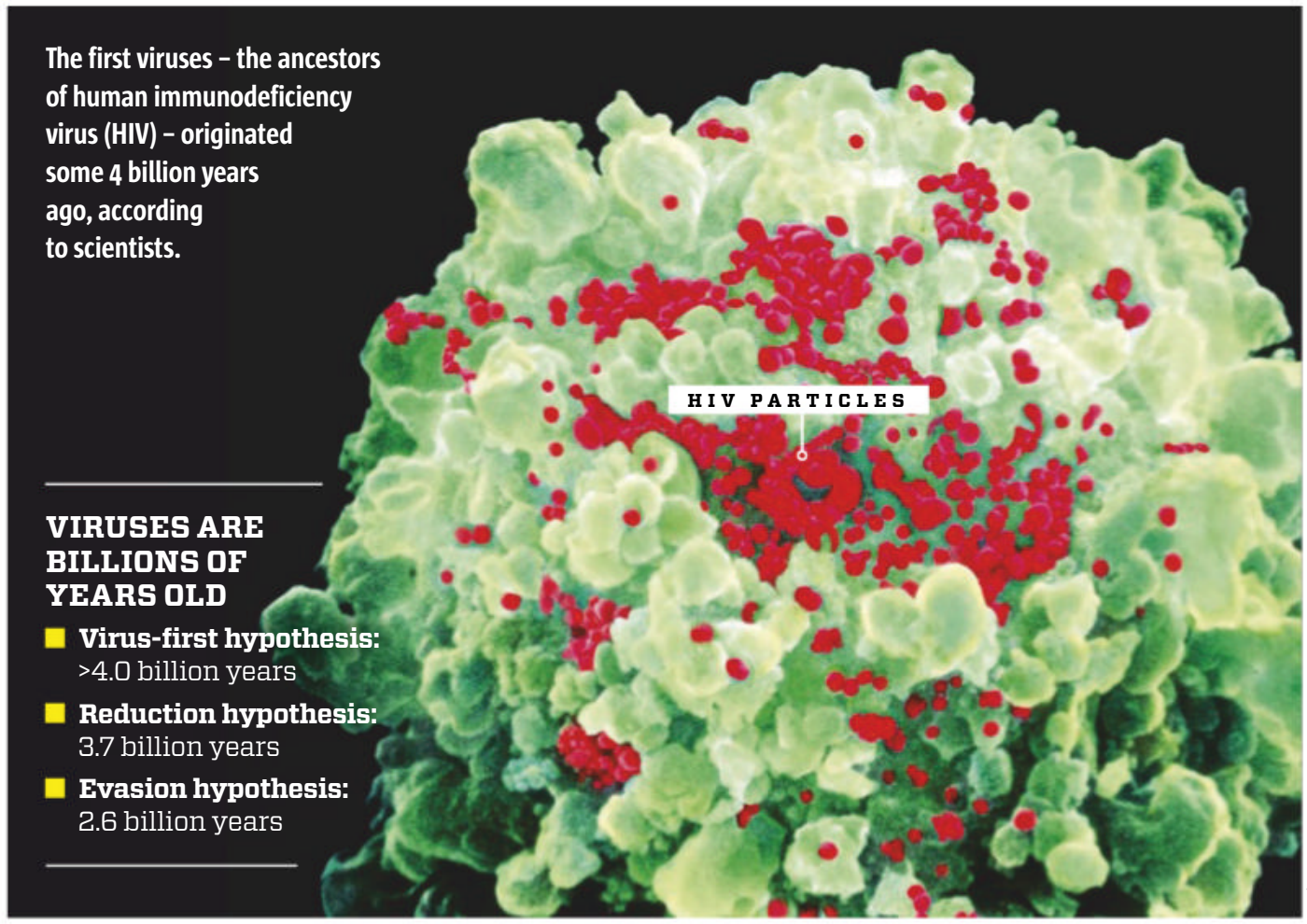
FOOD DETERMINES THE COLOUR OF FAECES

A **Greylag geese faeces is green:** animals that consume grass and have fast digestion produce green faeces, because it includes many undigested plant parts.

B **Bear faeces is red:** animals that consume berries and roots with a high content of red pigments produce red faeces. This is true for bears.

How did the first virus originate?

VIROLOGY You can't find fossils of viruses, so scientists know very little about how and when viruses originated. But studies have produced three central hypotheses. According to the 'virus-first' hypothesis, a virus would have been vital for the leap from non-life to life on the young Earth. Then there is the 'reduction' hypothesis, which says that the virus originated in a kind of backwards evolution of parasitic monocellular organisms. The 'evasion' hypothesis claims that viruses developed from small fragments of hereditary material that escaped larger organisms. All three hypotheses state a maximum age for the first virus, with the outside guess at 4+ billion years.



The first viruses – the ancestors of human immunodeficiency virus (HIV) – originated some 4 billion years ago, according to scientists.

VIRUSES ARE BILLIONS OF YEARS OLD

- **Virus-first hypothesis:** >4.0 billion years
- **Reduction hypothesis:** 3.7 billion years
- **Evasion hypothesis:** 2.6 billion years

NIBSC/SPL

WHAT IS THIS? · Blue light beam

The contrast between the church tower's shadow and the light refracted in drifting water drops causes an optical phenomenon.

The blue light is not light, rather shadow. The shadow effect originates when the light from the setting sun behind the church is blocked by the tower in a small band facing forward and upward.

Around the shadow, the morning light is refracted in a frosty mist consisting of billions of tiny supercooled water drops, making the air shining white and opaque.

The contrast between light and shadow causes the effect. A similar shadow is seen when the sun rises behind a mountain or tall building. The phenomenon usually lasts only a few minutes.

KJELL ERIKSSON

Once a month, the astronauts examine the fire extinguishers and oxygen masks aboard the International Space Station (ISS).

...it is hard to extinguish fire in space?

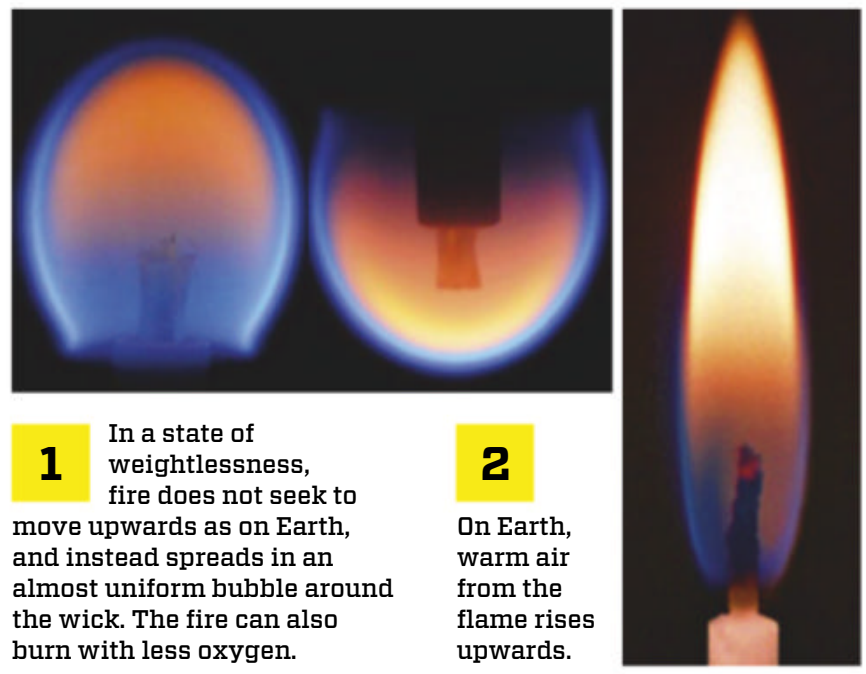
"I have heard that fire behaves differently in space than it does on Earth, and it is more difficult to extinguish. Is that true?"

PHYSICS Fire inside a space station could quickly develop into a disaster, and space agencies try first simply to minimise the quantity of inflammable materials aboard. If a fire does start, it behaves differently in a weightless environment, spreading more slowly than on Earth, but also harder to extinguish, as air flow must be completely eliminated to starve the fire of all oxygen. Objects burn with less oxygen inside a space station than on Earth, and at lower temperatures. The gases used to extinguish fire in space must be more concentrated than for similar applications on Earth, and the crew may need to extinguish the fire wearing oxygen masks to ensure that the burning material can be entirely surrounded by gas.

On Earth, warm smoke rises upwards, and so smoke detectors are typically placed in the ceiling. In a state of weightlessness, smoke spreads in all directions, and smoke detectors are placed in the ventilation systems.

Flames are circular in space

Scientists have discovered that flames are near-spherical in a state of 'zero' gravity. The aim of studying the behaviour of fire in a state of weightlessness is to develop improved fire extinguishers for use on space stations.



1 In a state of weightlessness, fire does not seek to move upwards as on Earth, and instead spreads in an almost uniform bubble around the wick. The fire can also burn with less oxygen.

2 On Earth, warm air from the flame rises upwards.

NASA

What is the world's tiniest vertebrate animal?

ZOOLOGY It's hard to be sure, because perhaps scientists haven't yet spotted the smallest vertebrates of all, but the tiniest discovered vertebrate is the *Paedophryne amauensis* frog found in 2009 by two American herpetologists. This 7.7mm-long anuran from the family of narrow-mouthed frogs lives in Papua New Guinea in withered leaves on the forest floor. The tiny frog lives its entire life on dry land, and unlike most other frog species it does not have a tadpole state. Instead, fully grown frogs hatch from the eggs. *Paedophryne amauensis* is most active in the dusk, feeding on tiny invertebrates, and it can jump 20cm, which is some 30 times its body length.

CHRISTOPHER AUSTIN/ LSUNIVERSITY/REUTERS/RITZAU SCANPIX

The tiniest vertebrate that biologists know about is the *Paedophryne amauensis* frog. It is only 7.7mm long, but can jump 30 times its own body length.

INSIDE THE BODY · How does an airbag bike helmet work?

Hövding of Sweden makes the world's most famous airbag bike helmet, and it is worn around the neck like a collar. If the cyclist takes a fall or is hit by a car, a tiny gas inflator activates to fill an airbag with helium to protect the head of the unlucky road user.

HÖVDING

GYRO SENSOR REACTS

1 Sensors collect data from the cyclist's motions hundreds of times per second, comparing it to a model based on 3000 accidents and 2000 hours of normal cycling.

THE AIRBAG IS ACTIVATED

2 If the motions are unusual as compared to the model data, such as too rapid rotation, the airbag is activated, inflating to its full size in less than one second.

THE AIRBAG IS DEFLATED

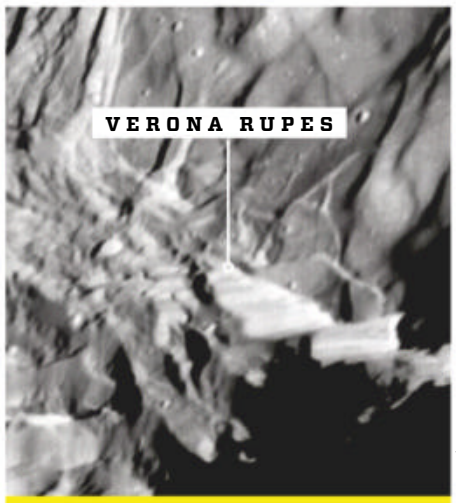
3 After the crash, the airbag remains fully inflated for a few seconds to protect the cyclist in case the bike happens to land on top of its owner. Then the helmet will slowly deflate.

LOTTE FREDSLUND & SHUTTERSTOCK

WORLD RECORDS

Where the highest cliff in the Solar System?

The Verona Rupes mountain on Uranus' moon of Miranda has the highest vertical cliff in the Solar System. The cliff probably formed as a result of tectonic activity in Miranda's crust, caused by Uranus' and Miranda's sister moons. An alternate theory says that the cliff originated due to a meteor strike. Scientists estimate that Verona Rupes is 20km high.

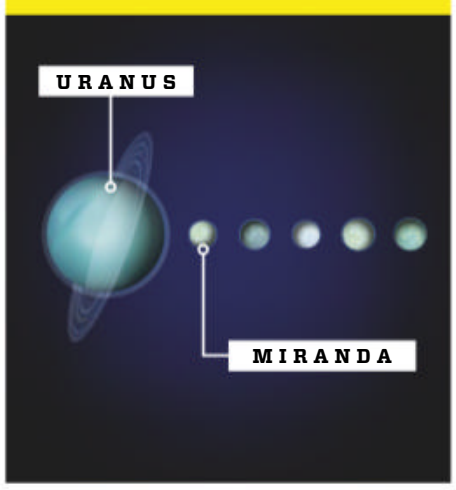


VOYAGER 2/NASA

The cliff of Verona Rupes is

2.25

times higher than Everest.



SHUTTERSTOCK

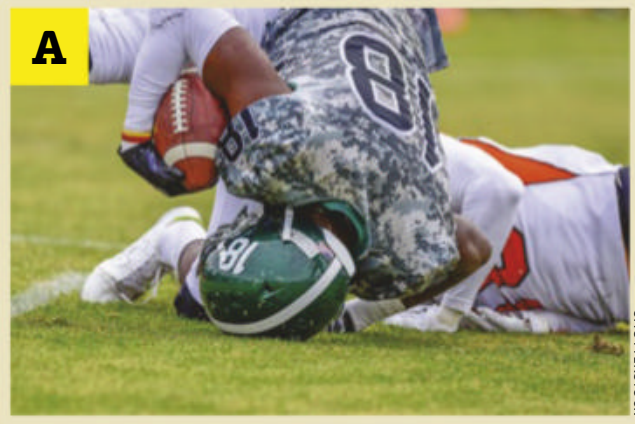
The highest cliff

WHERE: Miranda is the innermost of Uranus' big moons: Miranda, Ariel, Umbriel, Titania, and Oberon.

WHEN: Uranus and its moons were studied by the Voyager 2 probe that flew by in January 1986.

Long-distance running affects the kidneys and the immune system.

SHUTTERSTOCK



A

SHUTTERSTOCK

B

RITZAU SCANPIX

Does long-distance running harm you?

"Running is supposed to be good for you, but is there a point at which ultra-distance running is more likely to be harmful?"

ANATOMY Moderate running is good for your health, agree scientists and doctors. But studies of 'ultra runners' who embark on distances longer than a marathon, for six hours or 100km or more, indicate differently. These runners suffer an array of injuries more reminiscent of the effects of severe disease. The most badly-affected body parts are the heart, liver and kidneys, but the immune and hormone systems also suffer, and many ultra runners get an respiratory infection after a race. The most well-known injuries caused by long-distance running affect the kidneys. An American study from 2015 showed that 82% of such runners had some symptoms of acute kidney failure, i.e. they could no longer filter their blood sufficiently well. The injuries were revealed by extremely dark urine, indicating organ tissue damage. The symptoms wore off after a few days, but scientists fear that repeated cases of kidney failure could lead to permanent injury.

ULTRA RUNNING IS NOT THE ONLY TOUGH GAME IN TOWN

A **Mild brain injury**
Concussions suffered in American football and other impact sports could cause chronic traumatic encephalopathy (CTE) and subsequent depression and dementia. Helmet-to-helmet collisions have been banned in the US NFL.

B **Twisted bodies**
Golf seems a sedate enough game, but the golf swing influences loin, shoulders, and elbows. In 2017, a study demonstrated that 89% of professional golf players and 68% of amateurs develop injuries.

Fast probes could catch up with visitors from other solar systems, in...

A WILD CHASE IN SPACE

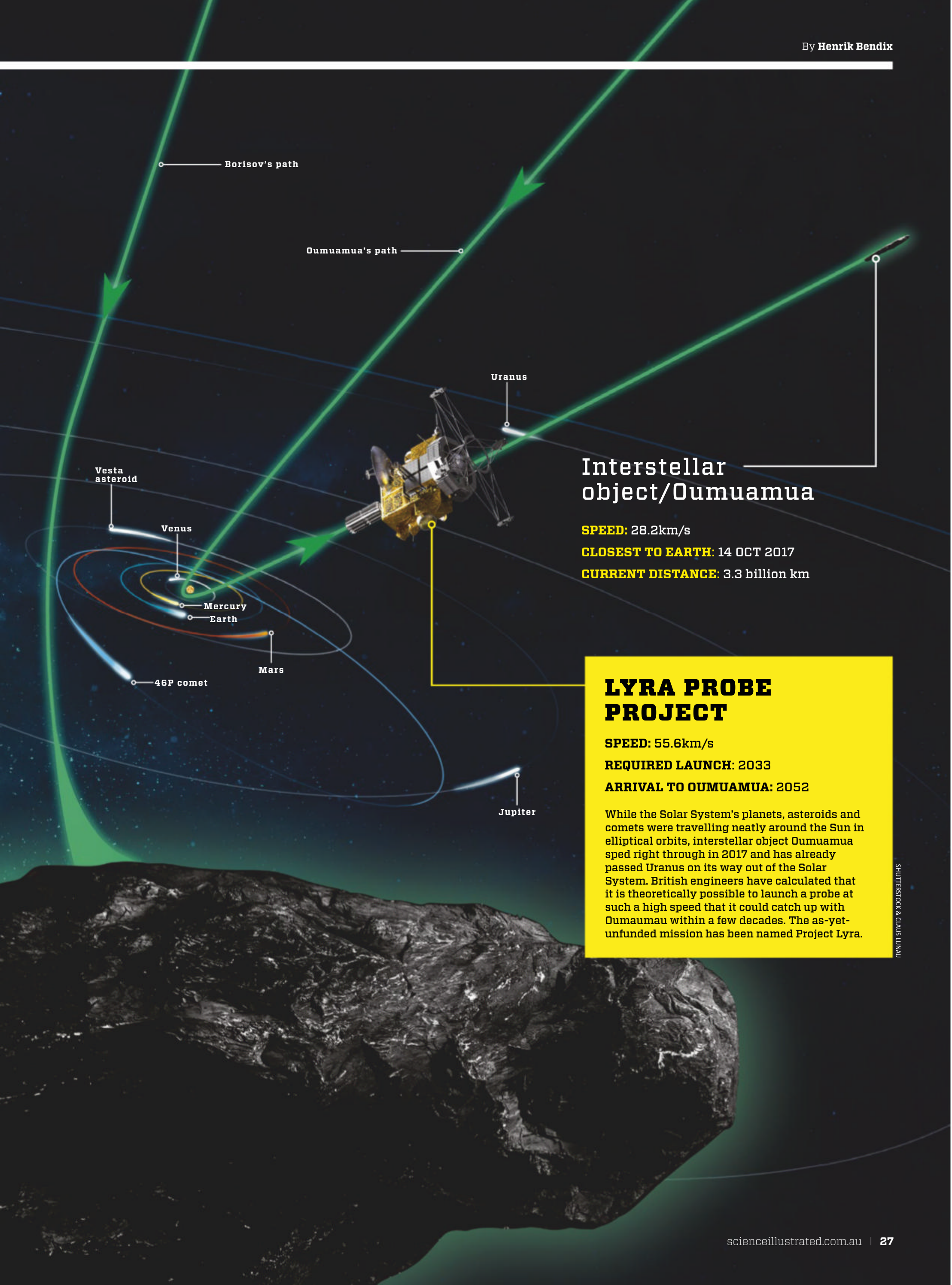
Our first experience of distant worlds and other solar systems may come from objects that are racing through interstellar space. Powerful telescopes have discovered two of them travelling through our Solar System. Fast probes could chase the travellers.

→ DISCOVERY

→ PURSUIT

→ INVESTIGATION

By **Henrik Bendix**



Interstellar object/Oumuamua

SPEED: 28.2km/s

CLOSEST TO EARTH: 14 OCT 2017

CURRENT DISTANCE: 3.3 billion km

LYRA PROBE PROJECT

SPEED: 55.6km/s

REQUIRED LAUNCH: 2033

ARRIVAL TO OUMUAMUA: 2052

While the Solar System's planets, asteroids and comets were travelling neatly around the Sun in elliptical orbits, interstellar object Oumuamua sped right through in 2017 and has already passed Uranus on its way out of the Solar System. British engineers have calculated that it is theoretically possible to launch a probe at such a high speed that it could catch up with Oumaumau within a few decades. The as-yet-unfunded mission has been named Project Lyra.

SHUTTERSTOCK & CLAUS LUNAU

Canadian astronomer Robert Weryk is busy at work at the Pan-STARRS telescope in Hawaii. Going over the telescope images on his computer, he spots a tiny bright spot. Initially he thinks it is just a common asteroid. But there is something odd about the way the object moves. It is speeding unusually fast across the sky – and doesn't follow the usual elliptical path of other objects in the Solar System.

Robert Weryk was looking at just the right section of the sky at just the right time – the night of 19 October 2017 – to became the first person ever to observe an object that is orbiting neither the Sun nor any other star. The speed and the path reveal that the alien object has been travelling thousands of billions of kilometres through interstellar space after being flung from an alien planetary system.

The object that Robert Weryk discovered was given the Hawaiian name of *Oumuamua* – or, more prosaically, 1I/2017 U1. '1I' indicates that it is the first interstellar object ever observed, but astronomers suspect it is not alone. Numerous objects must have left their original orbits around another star and ended up in interstellar space. But given the vast distances between stars, it is rare for one of them to visit our neighbourhood.

Such a heavenly body might provide us with unique insight into how planets form around other stars, perhaps also a better understanding of our own solar system's history. The problem is the time required to plan a mission to get up close, or to snatch a sample like the one returned to Earth by the Japanese spacecraft Hayabusa2 last December, landing spectacularly in South Australia. The asteroid visited by Hayabusa2 was 162173 Ryugu, which orbits the Sun predictably every 16 months. But interstellar objects like Oumuamua are only passing through, travelling too fast for us to build and launch a probe to reach them in time.

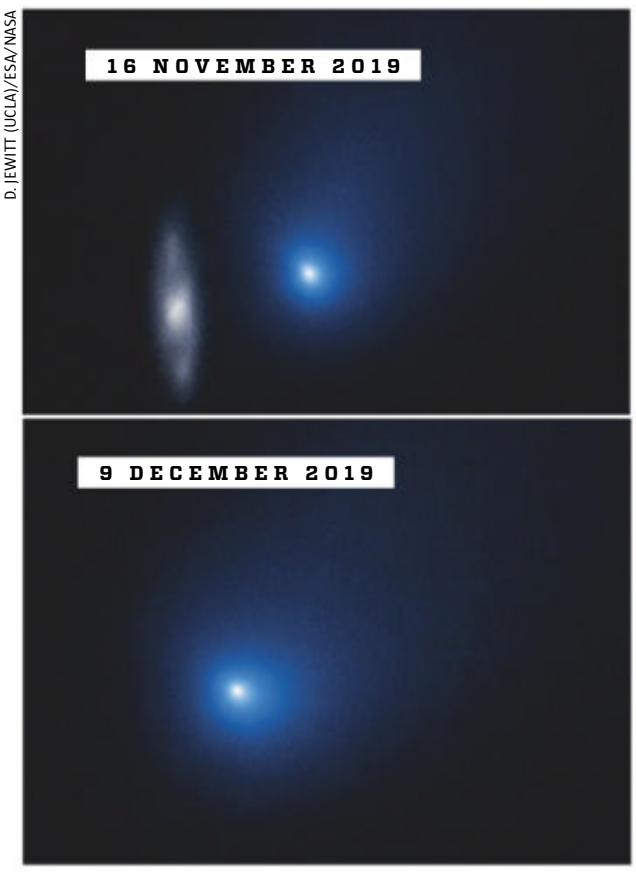
Nevertheless, that is what scientists hope to do. A European space mission with Japanese participation aims to launch a space probe that will lie in wait in space ready for the next interstellar object to appear. And in the UK, engineers have not given up the idea of catching Oumuamua, although the asteroid is already heading out of our Solar System at around 38 kilometres per second relative to our Sun. Catching up would require an extremely speedy probe.

Amateur discoveries

Searching for small objects entering our Solar System isn't easy. It requires a special telescope with a broad view and very sensitive digital cameras able to register the tiniest bright spots in the sky. Survey telescopes such as the Pan-STARRS telescope that first captured the faintly reflected sunlight from Oumuamua take pictures of the sky and compare them to older images automatically. Astronomers can thereby be alerted quickly when a new object appears in the sky.

Pan-STARR's primary task is to spot objects that come so close to Earth they could constitute a danger to us. But a side effect of this is the spotting of thousands of unknown asteroids and comets. If an interstellar object appears in the sky above Hawaii, the telescope captures it, just as with Oumuamua in 2017.

But with a little luck, less sophisticated equipment could also do the job. On 30 August 2019, a second interstellar object was discovered by amateur astronomer Gennadiy Borisov using only his homemade telescope located in the Crimea peninsula.



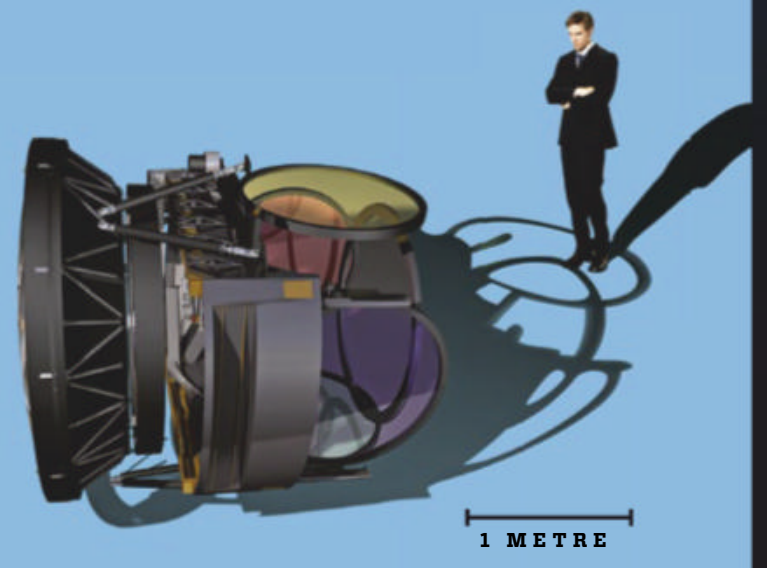
D. JEWITT (UCLA)/ESA/NASA

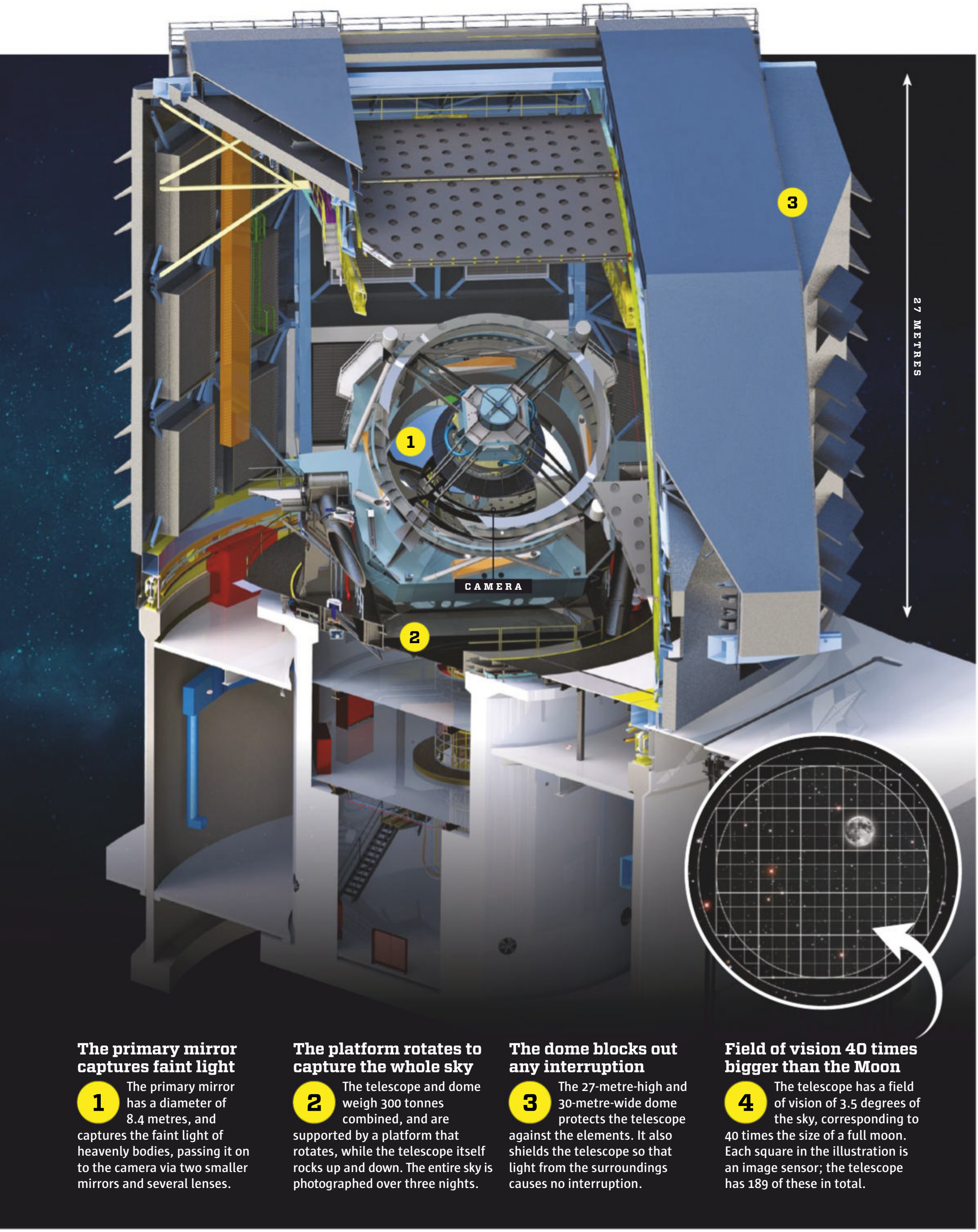
In 2019, the Hubble space telescope photographed the second interstellar object in the Solar System, 2I/Borisov, which appeared to be an ordinary comet.

→ DISCOVERY

Telescope will reveal intruders

The Vera C. Rubin Observatory is under construction on a mountain peak in Chile. From 2022, once the telescope has been completed, it will capture a section of the sky every 18 seconds with the world's biggest camera. The telescope will automatically sound the alarm if an unknown object appears.





J. ANDREW/LSST PROJECT & TODD MASON, MASON PRODUCTIONS INC./LSST CORPORATION

The primary mirror captures faint light

1 The primary mirror has a diameter of 8.4 metres, and captures the faint light of heavenly bodies, passing it on to the camera via two smaller mirrors and several lenses.

The platform rotates to capture the whole sky

2 The telescope and dome weigh 300 tonnes combined, and are supported by a platform that rotates, while the telescope itself rocks up and down. The entire sky is photographed over three nights.

The dome blocks out any interruption

3 The 27-metre-high and 30-metre-wide dome protects the telescope against the elements. It also shields the telescope so that light from the surroundings causes no interruption.

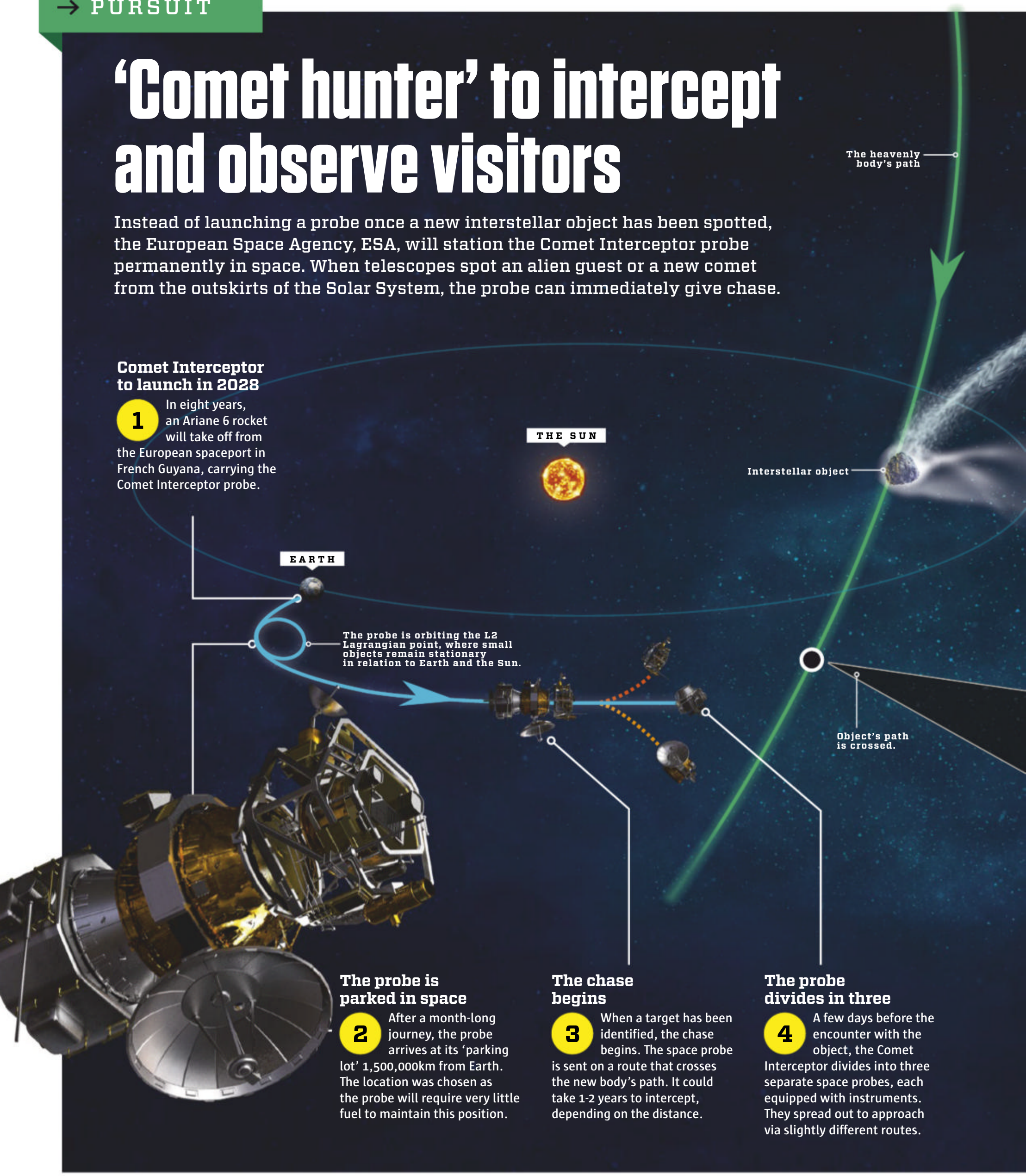
Field of vision 40 times bigger than the Moon

4 The telescope has a field of vision of 3.5 degrees of the sky, corresponding to 40 times the size of a full moon. Each square in the illustration is an image sensor; the telescope has 189 of these in total.

→ PURSUIT

‘Comet hunter’ to intercept and observe visitors

Instead of launching a probe once a new interstellar object has been spotted, the European Space Agency, ESA, will station the Comet Interceptor probe permanently in space. When telescopes spot an alien guest or a new comet from the outskirts of the Solar System, the probe can immediately give chase.



Comet Interceptor to launch in 2028

1 In eight years, an Ariane 6 rocket will take off from the European spaceport in French Guyana, carrying the Comet Interceptor probe.

The probe is parked in space

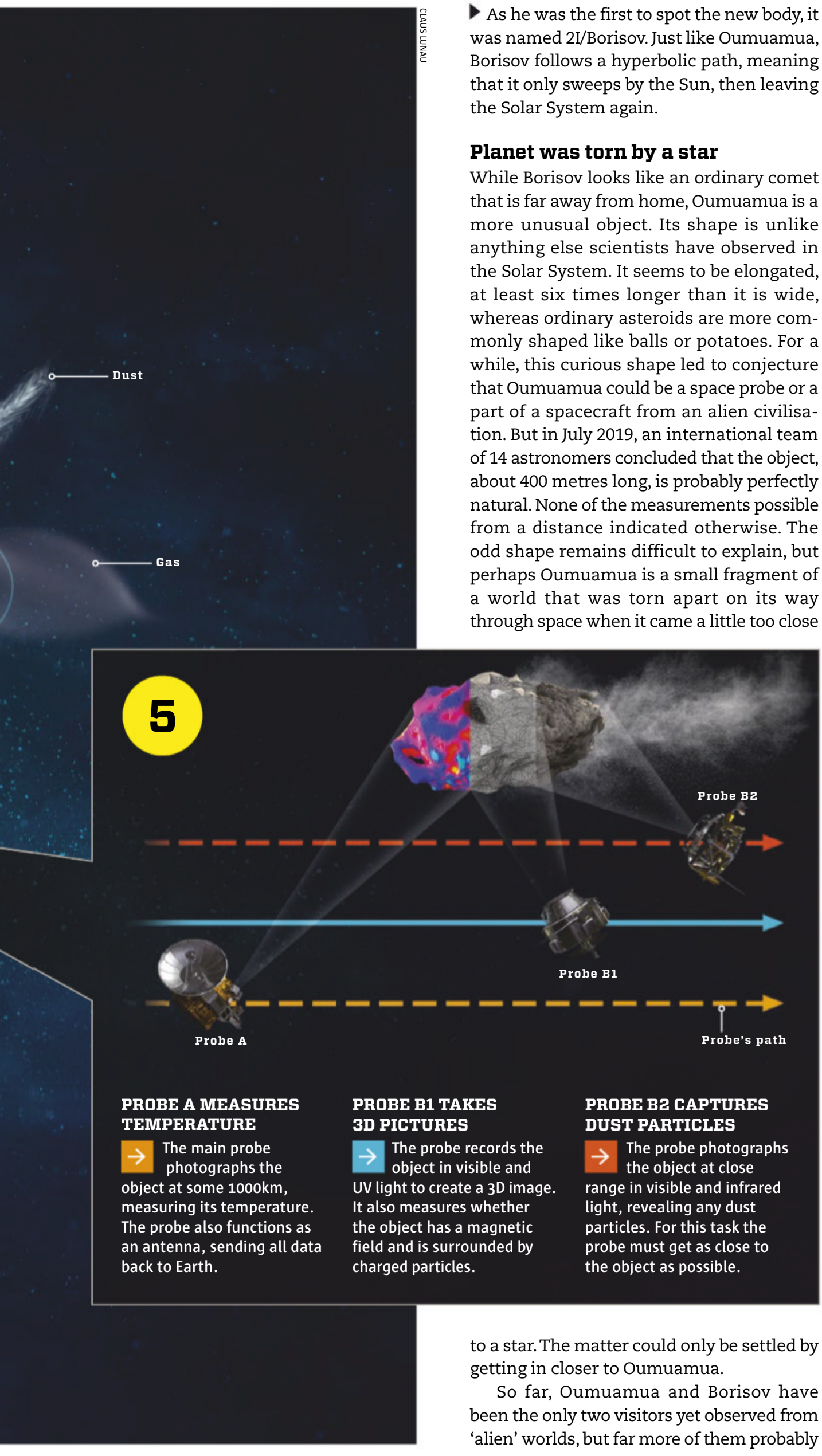
2 After a month-long journey, the probe arrives at its ‘parking lot’ 1,500,000km from Earth. The location was chosen as the probe will require very little fuel to maintain this position.

The chase begins

3 When a target has been identified, the chase begins. The space probe is sent on a route that crosses the new body’s path. It could take 1-2 years to intercept, depending on the distance.

The probe divides in three

4 A few days before the encounter with the object, the Comet Interceptor divides into three separate space probes, each equipped with instruments. They spread out to approach via slightly different routes.



As he was the first to spot the new body, it was named 2I/Borisov. Just like Oumuamua, Borisov follows a hyperbolic path, meaning that it only sweeps by the Sun, then leaving the Solar System again.

Planet was torn by a star

While Borisov looks like an ordinary comet that is far away from home, Oumuamua is a more unusual object. Its shape is unlike anything else scientists have observed in the Solar System. It seems to be elongated, at least six times longer than it is wide, whereas ordinary asteroids are more commonly shaped like balls or potatoes. For a while, this curious shape led to conjecture that Oumuamua could be a space probe or a part of a spacecraft from an alien civilisation. But in July 2019, an international team of 14 astronomers concluded that the object, about 400 metres long, is probably perfectly natural. None of the measurements possible from a distance indicated otherwise. The odd shape remains difficult to explain, but perhaps Oumuamua is a small fragment of a world that was torn apart on its way through space when it came a little too close to a star. The matter could only be settled by getting in closer to Oumuamua.

So far, Oumuamua and Borisov have been the only two visitors yet observed from 'alien' worlds, but far more of them probably pass through the Solar System – we just need to take a better look, using bigger and improved telescopes. Astronomers have their hopes pinned on the new wide-angle telescope known as the Vera C. Rubin Observatory (formerly LSST), which has been under construction in Chile since 2015. The telescope will be equipped with the world's biggest digital camera, and when it starts to photograph the sky in a few years from now, interstellar objects will have a much harder time hiding in the dark.

However, it is not enough for astronomers to watch these rare heavenly bodies through telescopes; the observed small bright spots do not offer much information. Scientists would like to get much closer, and this might be possible once the European Space Agency, ESA, launches the planned Comet Interceptor probe in 2028.

The aim is to park the probe in orbit 1.5 million kilometres from Earth for up to three years. When the Vera C. Rubin Observatory or another telescope spots an alien object in the Solar System, this will bypass the time required to construct and launch a probe from scratch. Instead the Comet Interceptor can set out in pursuit immediately.

"Pristine or first-time visitor comets are completely new to us... fascinating objects to study closely by means of a space probe," says the ESA's Günther Hasinger.

However, the whole project gambles on the arrival of an object within the available time window of the Comet Interceptor. Only time will tell if a suitable interstellar object will be spotted within the three years during which the 'parked' Interceptor retains sufficient fuel to wait and then intercept.

Probe to catch up with Oumuamua

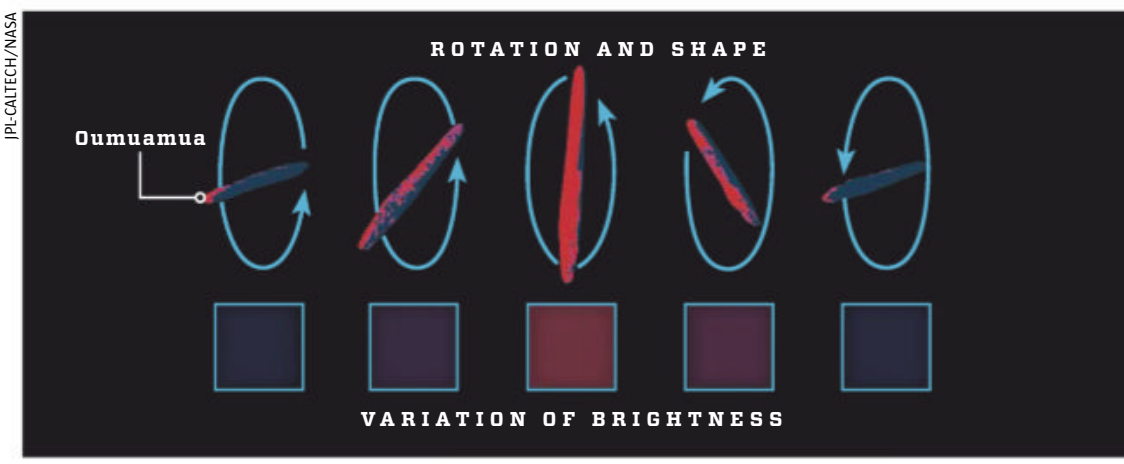
Engineers from the British Initiative for Interstellar Studies, on the other hand, aren't planning to wait around. They aim to try to catch up with Oumuamua, despite the fact that by the time this issue of *Science Illustrated* publishes on 11 February 2021, Oumuamua will already be at a distance of 3347 million kilometres from Earth, heading out of the Solar System at a harrowing speed of some 100,000km/h.

The scientists behind the mission, which is called Project Lyra, have calculated that a probe needs to reach a speed of some 200,000km/h to catch up with Oumuamua over a space journey lasting a couple of decades. The launch of such an unmanned probe would require one of the most powerful rockets yet built, such as NASA's future Space Launch System or Space X's Falcon Heavy. The engineers envisage a launch from Earth in May 2033, intercepting

M. KORNMESSER/ESO

Astronomers zoom in

Interstellar objects that visit our Solar System might teach us more about the conditions in other solar systems. By flying by or landing on one of these alien objects, we might discover how planets form around newborn stars outside our own region, even whether life exists elsewhere in the universe.



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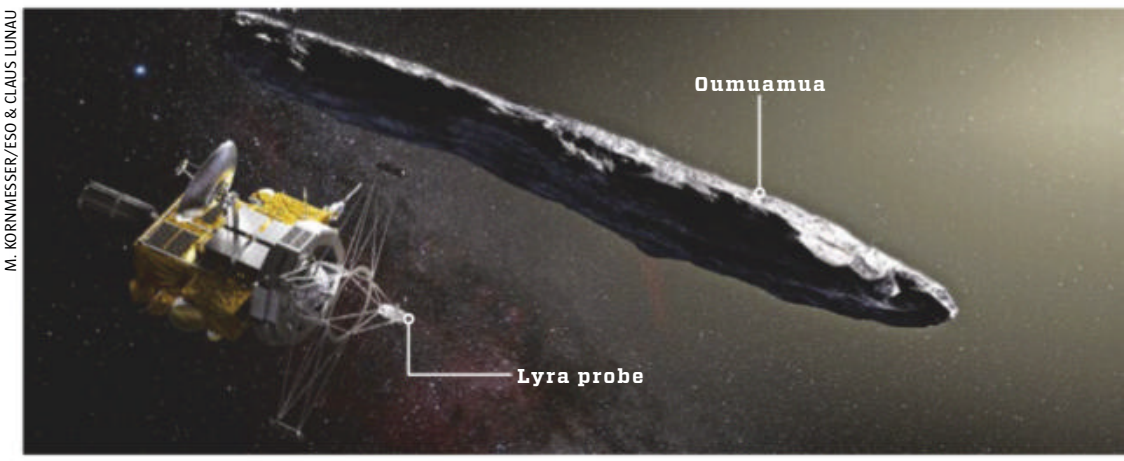
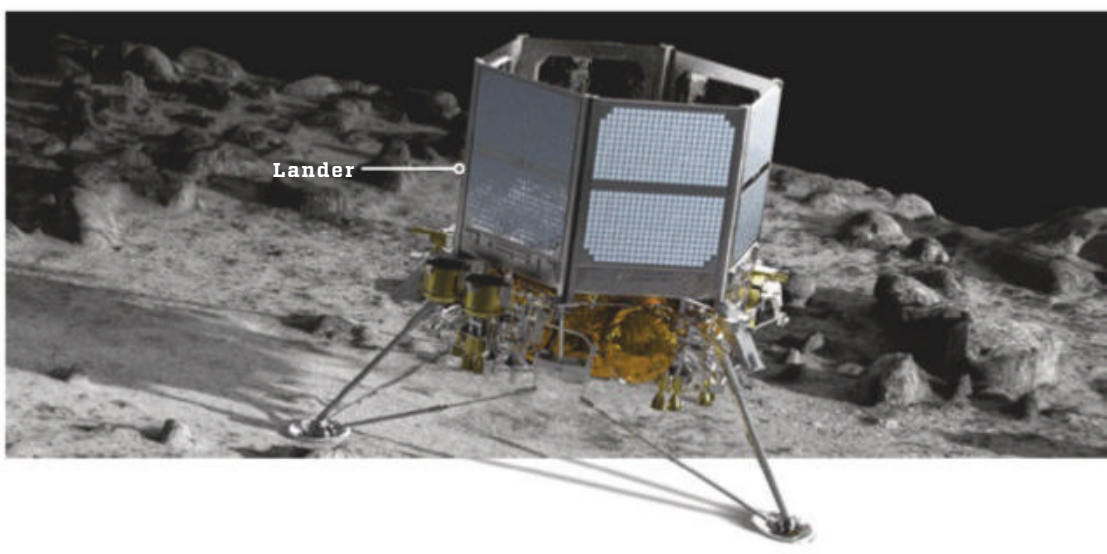


M. KORNMESSER/ESO & CLAUS LUNAU



CLAUS LUNAU

▶ Oumuamua in 2052. En route, the space probe would travel close by Jupiter and around the Sun to gain extra speed.

So far, the enthusiastic engineers of the Initiative for Interstellar Studies have simply made the calculations to prove that the project is theoretically possible. It remains uncertain, probably unlikely, whether the project can be realised: it would be so expensive that a major space organisation (or very wealthy benefactor) will be required to make the Project Lyra dream come true.

Huge planet ejects siblings

Astronomers' current knowledge of asteroids and comets is based entirely on objects that we know from our own Solar System. Not until we manage to come very close to a truly interstellar object will astronomers find out whether the asteroids and comets we know from our own Solar System are similar to those from other regions of the galaxy.

If a probe registers dust particles, or discovers that the object has a magnetic field, astronomers will be able to offer a qualified guess of how it formed, and perhaps answer the question of why the alien heavenly body left its own solar system.

At this point, astronomers try to answer these questions using computer models that simulate how stars and their planets form and develop. These models are, of course, based on our own Solar System, now a well-organised system of planets and small heavenly bodies that orbit the Sun in predictable paths. However, calculations show that it was not always so: the Solar System was much more chaotic during the initial period after its formation.

In the disc of dust and gas that formed around the newborn Sun, larger lumps of material, known as 'planetesimals' quickly accumulated, then developed into larger planets over time. But there were still some planetesimals left over after the planets had formed, and when these lumps came close to a large planet, one of three things could happen. They could be absorbed and end up as a part of the planet. Or the influence of gravity from a large planet could either force them into the Sun, or fling them outwards into the Solar System.

100

observable interstellar objects may pass by our Solar System annually.

Only very large planets would have the gravity to eject smaller objects entirely. In our own Solar System it would have been Jupiter that was probably responsible for the vast majority of ejections. According to astronomers, material corresponding to far

NOW: Telescopes reveal Oumuamua's shape

By studying an interstellar object from a distance with telescopes, scientists can calculate its estimated size and shape. Astronomers have concluded that Oumuamua is probably a rotating cigar-shaped object, as observations fit with the reflected sunlight being brightest when the long side is facing Earth.

2052: Fly-by reveals makeup

If the Project Lyra probe were to fly close by Oumuamua, the close-ups would tell us which types of rock or ice the object is made of, and whether it gives off dust particles and gases. Spectroscopic analyses of visible and infrared light reflected from the surface would reveal the chemical make-up.

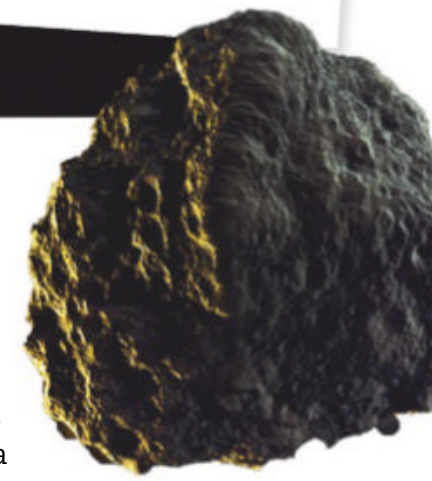
20??: Landing could reveal building blocks of life

A probe orbiting the object could map it out by means of radar, and identify a landing site. A landing module might study the surface with a microscope and spectroscopes, looking for organic molecules. Slowing down a space probe and landing on an object with weak gravity poses a challenge, but is not impossible.

D. FEDELE ET AL./NAOJ/NRAO/ESO

Newborn giants force others out of stellar system

The ALMA radio telescope has detected a young star with discs of dust in which planets form. Apparently, large planets form far away from the star. The giants will quickly empty the neighbourhood of smaller 'planetesimals', and some of these could be flung out of their solar system to end up as interstellar objects.



more than Earth's mass must have ended up as interstellar objects which are now travelling through space and might be visiting alien planetary systems.

In the same way, ejected planetesimals from remote stars could visit our Solar System. We know that a great many stars in the sky are orbited by planets, but so far scientists have had little idea how many ejected objects might end up reaching us. Two astronomers from Yale University in the US, PhD student Malena Rice and Professor Gregory Laughlin, have now calculated how many objects might be observed by the new Vera C. Rubin telescope. They estimate that every year the Solar System should be visited by 100+ observable objects with a radius over a metre, including a few that will be larger than Oumuamua. The numbers are encouraging, though subject to uncertainty.

Previous visitors

Two Harvard scientists, astronomers Amir Siraj and Abraham Loeb, also believe that interstellar objects might have hit Earth without us noticing it. In a database of meteor strikes on Earth over three decades, Siraj and Loeb stumbled across a meteor some 45cm across that burned up in the sky above Papua New Guinea on 8 January 2014. The meteor entered Earth's atmosphere at a speed above 160,000km/h, so fast that scientists believe that it must have come from a different solar system.

So it is not only telescopes on Earth that can identify interstellar objects. Siraj and Loeb calculate that a telescope the size of Hubble, if aimed at the Moon's surface, should be able to identify previous meteor strikes caused by interstellar objects. The Moon has no atmosphere in which meteors burn up, and the resulting dust cloud when an object hits the Moon's surface might reveal its make-up. Scientists could establish the speed of impact, and whether the object consisted mainly of ice or of rock.

Scientists are sure that our Solar System receives visitors from other regions of the galaxy which could tell exciting stories about our universe, especially if it were possible for us to get a closer look via a probe. Perhaps interstellar objects from the remote corners of the galaxy even brought us some of the complex molecules that were necessary for life on Earth to originate.

So far, we have only been able to watch these visitors at a great distance. But in the future, we may get that opportunity to get in closer. The Comet Interceptor is the first space mission that could explore an interstellar object, but it will not be the last. The obvious next step is a space probe that can land on the surface of an alien object and perhaps, like Hayabusa2, even take samples that could be returned to Earth for analysis. Landing on such an interstellar object would represent our first indirect visit to an alien solar system. SI

The Earth should be getting colder, but instead

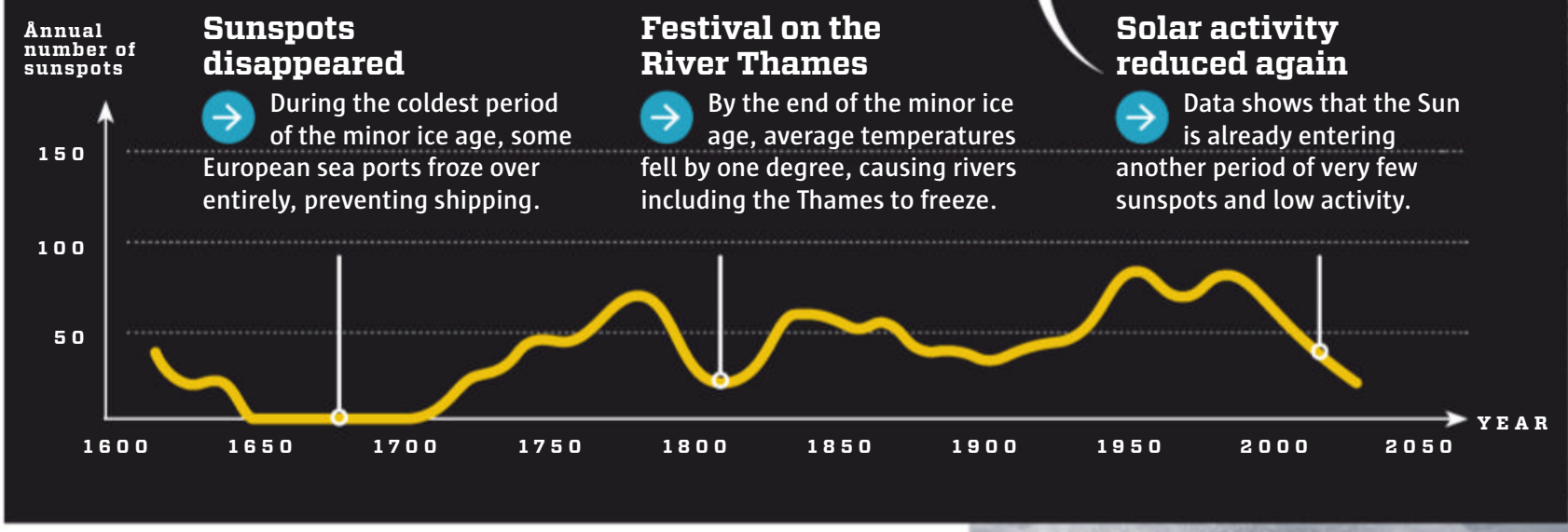
THE ICE AGE IS CANCELLED!

Data indicates that solar activity is heading towards a minimum, which in the 1600s led to rivers freezing, and crops failing. But today billions of tonnes of human-made greenhouse gases will counteract the reduction in the sun's warmth.

During the minor ice age, there were markets on the River Thames.
GETTY IMAGES

Solar activity is declining

Solar researchers have linked the number of sunspots with temperatures during the coldest period of the minor ice age. history is about to repeat – but this time there will be no big freeze on the way.



Sunspots disappeared

During the coldest period of the minor ice age, some European sea ports froze over entirely, preventing shipping.

Festival on the River Thames

By the end of the minor ice age, average temperatures fell by one degree, causing rivers including the Thames to freeze.

Solar activity reduced again

Data shows that the Sun is already entering another period of very few sunspots and low activity.

By **Niels Halfdan Hansen**

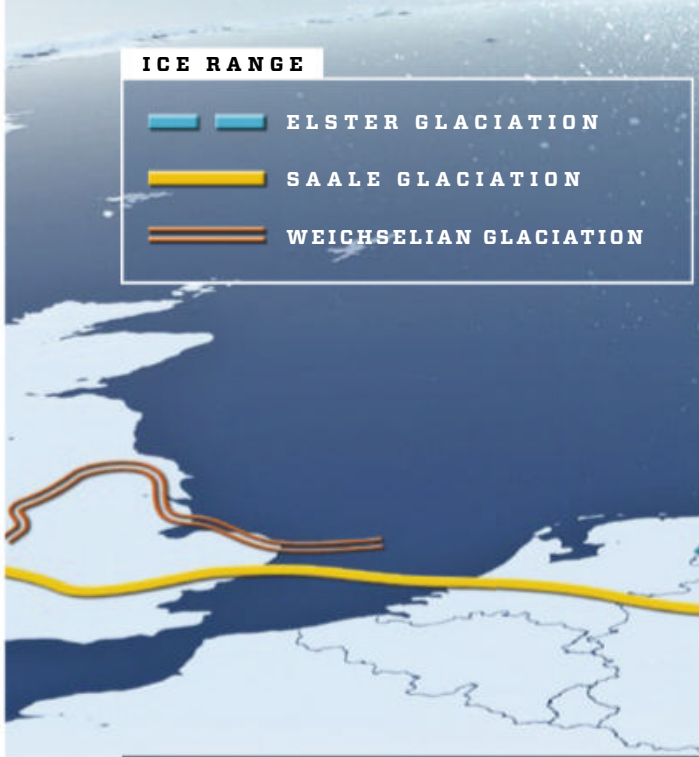
The planet might be facing another mini ice age were it not for the effects of human-made global warming.

CLAUS LUNAU

SHUTTERSTOCK & LOTTE FREDSLUND

Ice ages come and go

Over the past 2.6 million years, ice ages have come and gone. Minor ice ages were first striking at intervals of 40,000 years, but then, about 800,000 years ago, the rhythm changed. Suddenly, the cold lasted for 100,000+ years, and the ice spread.



500,000-337,000 YEARS AGO

THE ICY NORTH: Elster glaciation extends

1 The chart below shows how glaciation grew and receded over hundreds of thousands of years. Pictured above is the North Sea area between the UK and Europe.

300,000-130,000 YEARS AGO

RECORD GLACIERS: Ice covers Northern Europe

2 The glaciers of the Saale glaciation covered most of the UK and all of Scandinavia. The ice stretched far towards the east and south, covering large parts of what is now the Netherlands and Germany.

115,000-11,500 YEARS AGO

RETREATING ICE: The most recent ice age

3 The most recent ice age, the Weichselian glaciation, ended in the present warm period of Holocene. The coldest period peaked some 20,000 years ago, when glaciers again cover Scandinavia.

Spring is again long in coming this year. Months of snow has piled up along the roads in dirty heaps, while lakes and coastal bays are covered in thick ice. In spite of warm winter coats, woollen hats and thick gloves, the icy easterly wind is devastating for those who venture outside. Welcome to late 17th century Europe, at the height of a mini ice age.

Could this happen again? Astronomers predict that solar activity, and hence the Sun's energy supply to Earth, will decrease over the next 10 years. The last time the Sun was this quiet, the Northern Hemisphere plunged into the minor ice age of 1450-1850. The coldest years were from 1645 to 1715, when Western Europe was held in an icy grip, with millions of people starving or freezing to death.

Scientists still disagree about what exactly caused the minor ice age – and about what was happening here in Australia at the same time. Until recently it was believed that the Southern Hemisphere also cooled but to a lesser extent, with evidence that New Zealand's glaciers grew to their greatest size at this time. But more recent re-dating of this evidence has indicated that this happened after the Northern Hemisphere's cooling event. Deep-sea cores suggest that our southern oceans may actually have warmed during the period when things were cooling in the Northern Hemisphere, supporting a theory called the bipolar seesaw, where heat is trapped in one part of the world when the great 'conveyor belts' of deep ocean currents stop spreading warm water to the continents of the north.

All of which complicates the question of whether our human-made global warming may actually prevent a new minor ace age – or simply make it all even more unpredictable.

Growing ice caps

The Sun is vital for Earth's climate, given it supplies 99.97% of the energy that our planet's surface receives (heat from Earth's interior accounts for the remaining 0.03%). The level of solar energy can affect temperatures drastically, and Earth has experienced ice ages several times over the past 2.6 million years.

Scientists have known about the major ice ages since the mid-1800s, and they have been trying to find the explanation ever since. The first theory was proposed in 1864 by self-made Scottish physicist James Croll. He proposed that the ice's migration back and forth was due to rhythmical changes in the quantity of sunlight – and hence energy – that influenced Earth at different times of year. Croll imagined that a period with extra cold winters laid the foundations of an ice age, subsequently intensified via a number of self-perpetuating effects. James Croll pointed out that extensive snow cover reflects the energy from the Sun back into space long into the spring, hence lowering temperatures with every year that passes by.

1.5°C

was the temperature fall in Europe during the coldest spell of the minor ice age.

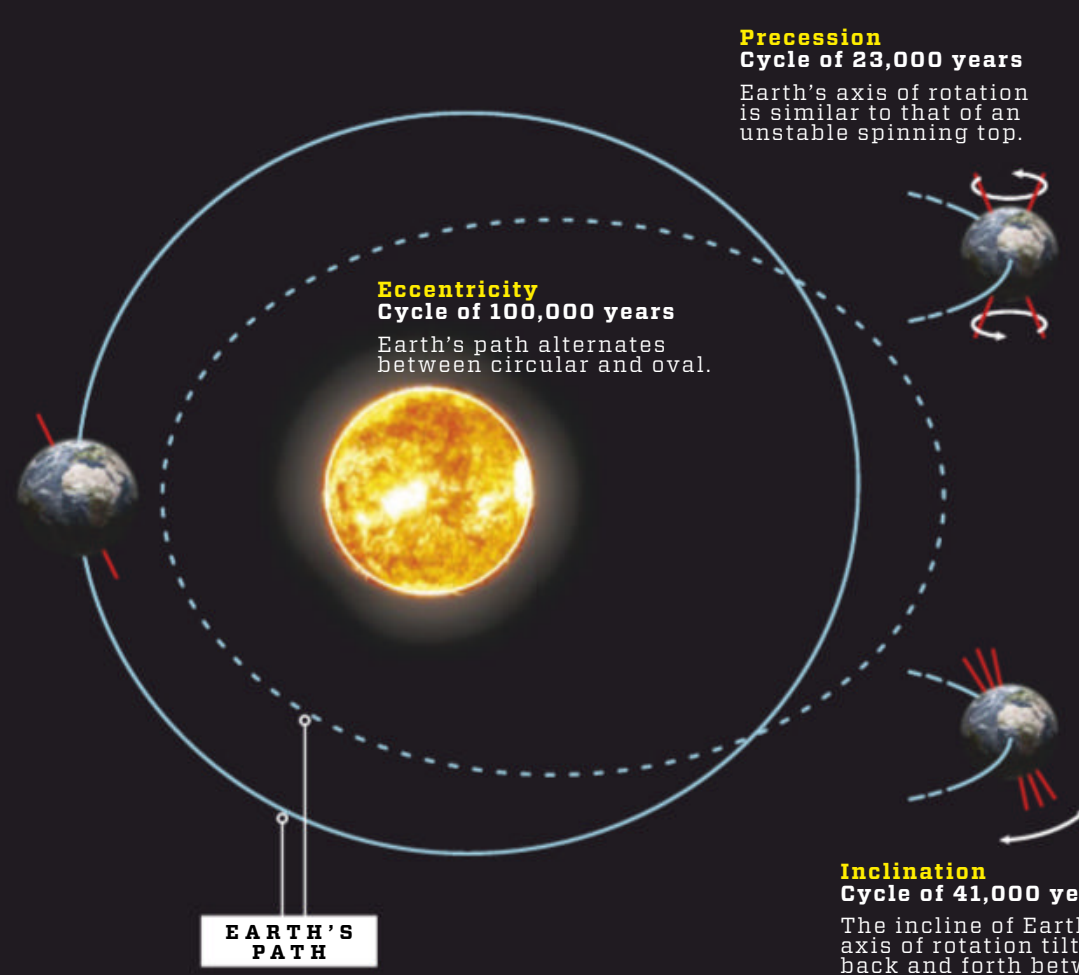
Subsequent studies have shown that Croll's theory was correct regarding the fundamental cause, though the theory has been adjusted slightly and supplied with a few extra details. Ice ages in fact originate as a result of three minor variations of Earth's orbit around the Sun. In combination, the variations cause Milankovitch cycles which lead, over millennia, to complex changes in the quantity of energy that influences Earth at different times of year and in different places. But Croll was wrong about one thing. It is not periods with cold winters that determine whether we get an ice age or not. On the contrary, most climatologists now agree that the shift into an ice age coincides with periods during which a zone around the 56th parallel north receives greatly reduced solar energy in the summer.

Spot-free periods cool the world

The most recent ice age, also known as the Weichselian glaciation, ended some 11,500 years ago. Scientists do not know exactly how many ice ages preceded the Weichselian glaciation, but have definite evidence for more than 10 previous such periods. Over ▶

Earth's zigzag drives the ice

The precise processes that control the formation and melting of ice are still debated, but the underlying cause has been known for 100 years. Three different variants of Earth's path mean that the energy from the Sun affects the planet's surface differently. The rhythm of the change fits precisely with the major ice ages' advances and retreats.

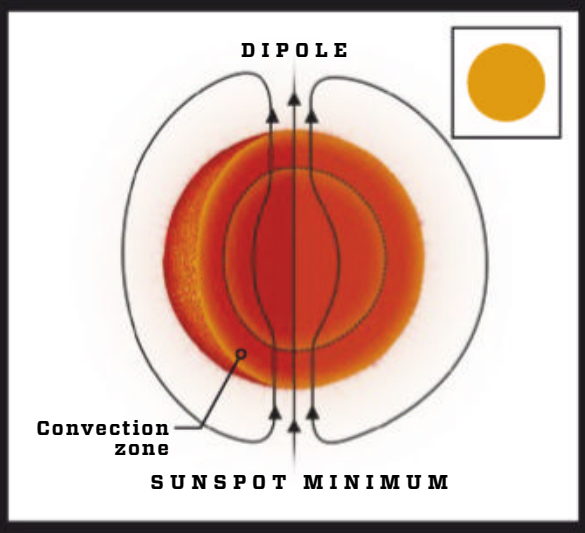


SHUTTERSTOCK & ANDERS BOTHMANN

CLAUS LUNAU

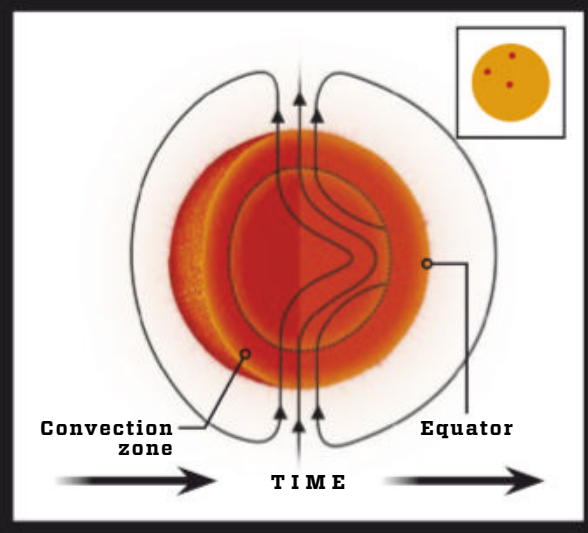
Magnetic chaos stains the Sun

For centuries, scientists have studied sunspots – dark marks on the sun disc that appear and disappear over a cycle of 11 years. Over time, scientists have discovered how the sunspots originate and what they mean.



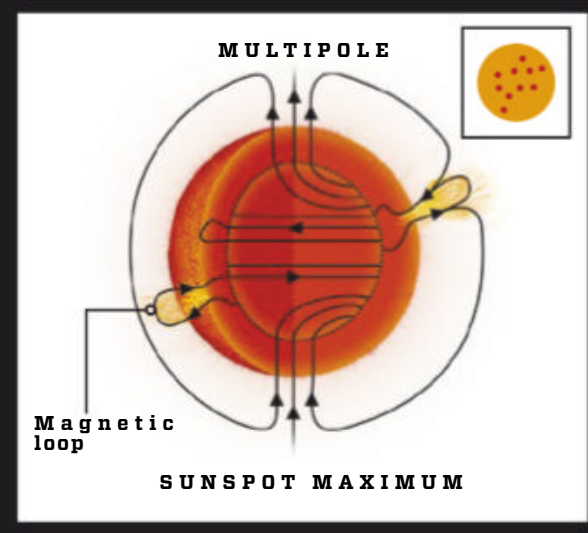
Steady magnetic field causes blank sun disc

1 When a new sunspot cycle begins, the Sun's magnetic field is much like Earth's, its magnetic poles close to its geographical poles. At this point, the Sun is peaceful and typically free of sunspots.



Speed differences distort magnetic field lines

2 The Sun's magnetic field lines freeze in the convection zone, which does not rotate at the same pace everywhere on the Sun. The rotation is faster by the equator and slower by the poles, so the field lines start to twist.



Magnetic twists penetrate the Sun's surface

3 Over time the field lines become highly twisted, causing a complex magnetic field. The field lines become very close, and the Sun has several north/south pole areas. Powerful magnetic loops penetrate the surface.

the past 800,000 years, the cold has come and gone under a rhythm in which the ice ages last some 100,000 years, interrupted by milder periods of 10-20,000 years – like the one we are experiencing right now. But even during the warm periods the climate is unstable and involves cold spells that last from a few decades to several centuries.

Again, the cause is the Sun – or more specifically what's going on inside it. In 1645-1715, during the Maunder Minimum, the Sun was unusually quiet and its surface displayed hardly any sunspots – the dark splotches caused by knots in the magnetic field in the Sun's upper atmosphere. In the late 1700s, German astronomer Gustav Spörer studied records to discover that between 1672 and 1700, the Sun produced a total of only 50 sunspots, very low compared with periods when solar activity is high and the Sun might produce 40,000-50,000 sunspots over a similar period.

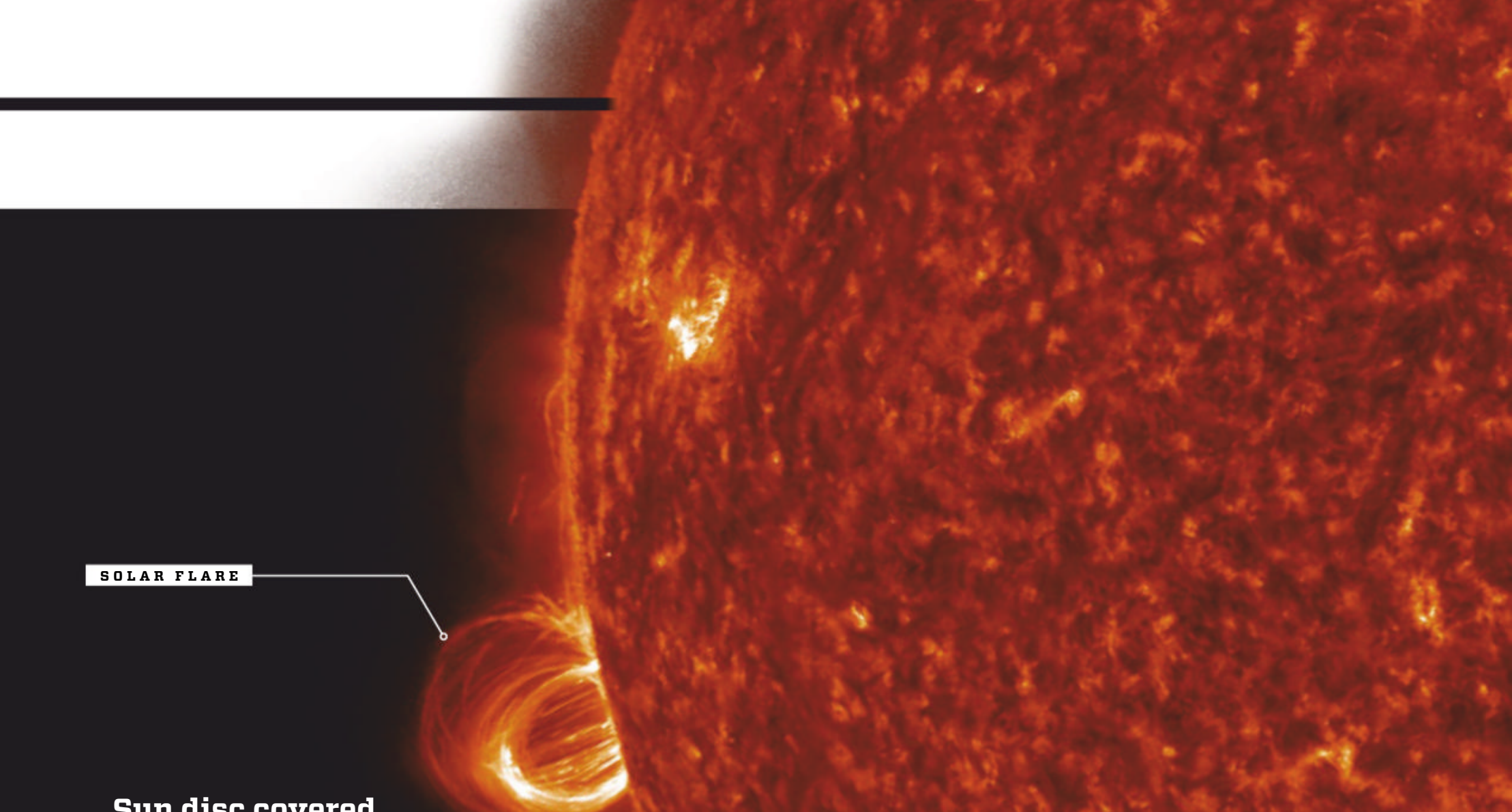
According to the climatologists of the PAGES 2k project, the world became just 0.4 degrees colder during the Maunder Minimum in the minor ice age's coldest decades. In Europe, however, the local temperatures drop of 1.5 degrees made glaciers grow and rivers freeze over so that no ships could navigate them, while crops failed over and over again. The result was famine, disease, and death. Volcanic eruptions also contributed to the cold, but at the same time, less energy was reaching Earth. Scientists from the University of Colorado estimate that the Sun supplied some 1360.25 watts/m^2 back then, compared with an average of 1361.5 watts/m^2 during the 20th century.

Astrophysicist Irina Kitiashvili from NASA's Ames Research Center studies variations in the Sun's magnetic field. She has recreated developments in the Sun's total magnetic field from 1976 to 2019, feeding the data into a magneto-hydrodynamic model that predicts how electrically conductive gases and liquids behave in a magnetic field, and thereby predicts the number of future sunspots.

Over a period of around 11 years, the number of sunspots varies from a few to many, and back to a few again. Astronomers have numbered the cycles, with cycle 24 beginning in 2008 and ending in late 2019. Irina Kitiashvili's model predicted cycle 24 very accurately, causing much interest in her predictions for cycle 25, which is expected to be the weakest in 200 years. The sunspot activity is expected to halve compared to cycle 24, which was itself only half as active as cycles 21 and 22 from 1976 to 1996. But despite this, temperatures on Earth have been notably rising, not falling.

Cooling versus warming

The rising temperatures are due to the fact that the atmosphere's CO_2 content has risen by 45% since the Industrial Revolution gained momentum in the mid-1800s. Quantities of methane, an even more powerful greenhouse gas, have increased by no less than 150%. Such greenhouse gases are the cause of the present global warming – and it is an irony of



Sun disc covered in dark spots

4 The magnetic loops reduce the energy supply from the Sun's interior to the surface, causing a cold, dark spot: a sunspot. During periods with many sunspots, the Sun's radiation – particularly ultraviolet frequencies – increases, and Earth receives more energy.

Magnetic loops produced in the Sun's interior penetrate the surface, also known as the photosphere, in the shape of a solar flare.
SOLAR DYNAMICS OBSERVATORY/NASA

> **MICHAEL SANDSTROM**
> PALEOCLIMATOLOGIST
>
> **We pump so much carbon dioxide into the atmosphere that we will probably not have another ice age for the next 100,000 years.**

climate change that they are proving a potent weapon in the fight against the cold from space. If all greenhouse gases were to disappear from the atmosphere, the global average temperature would fall to a scary minus 18 degrees. Currently we enjoy a more pleasant plus 15 degrees.

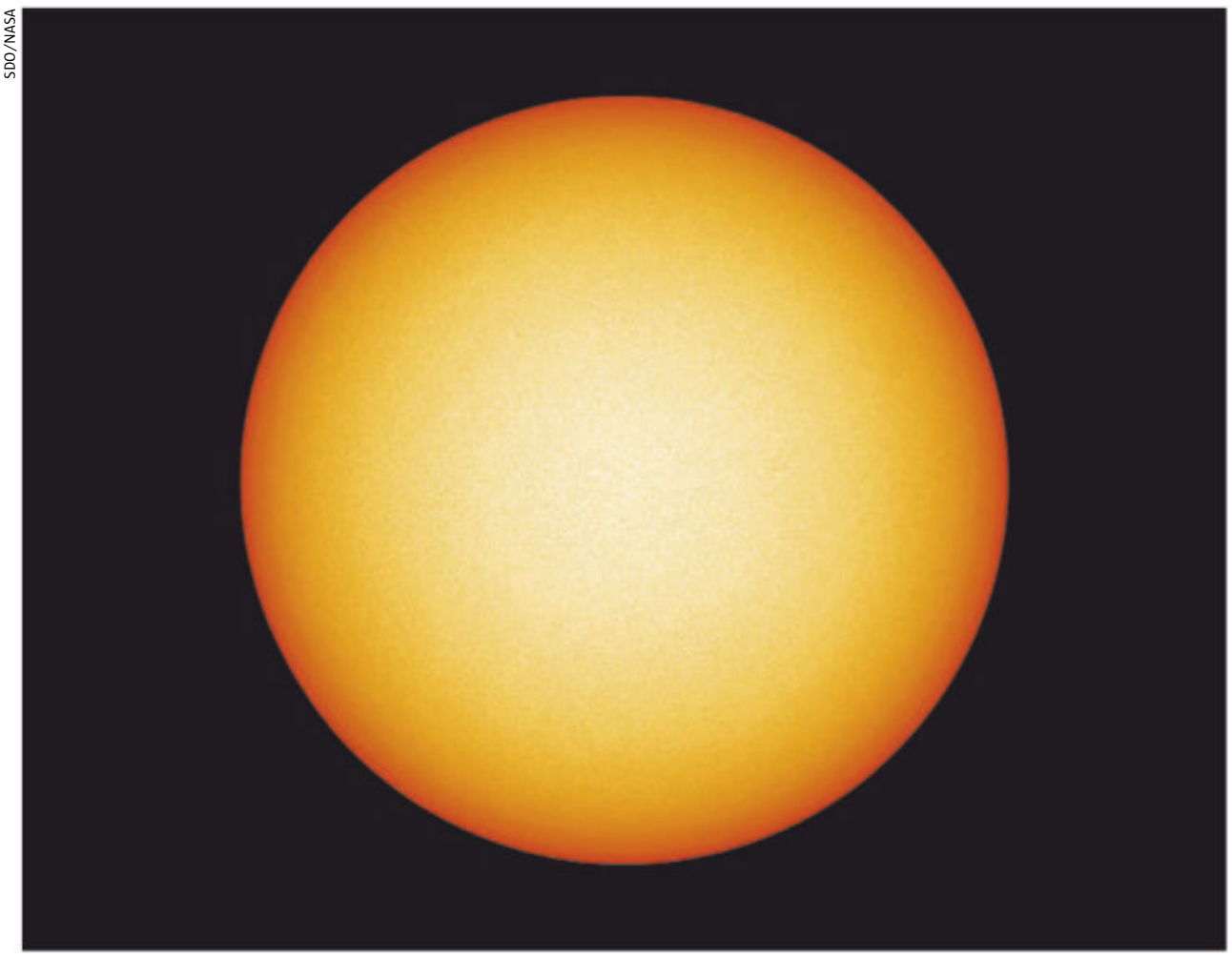
In 2017, three American scientists from the University of California in San Diego analysed 20 years of astronomical data from 33 sun-like stars to establish how much their star radiation has varied over time. Their studies showed that it is energy in the shape of ultraviolet radiation that decreases most when a star enters a Maunder Minimum. Based on the 33 stars, the scientists estimate that the decrease is between 5.5% and 8.4%. On Earth, then, a Maunder Minimum should result in a natural temperature reduction of only 0.5°C.

Lecturer Michael Brown from Monash University in Melbourne has taken a closer look at the struggle between heat and cold. According to him, a repetition of the Maunder Minimum would no longer cause a temperature reduction on Earth, primarily because the atmosphere is supplied with ever more of the greenhouse gases that have heated the world by about 1°C since 1850. Data from the International Energy Agency show that Earth's total energy requirement was 2.3% higher in 2018 than in 2017, the increasing requirement primarily met by coal, oil and gas, not by green energy sources such as wind and sunlight. Nothing indicates that the temperature rise will halt any time soon.

New ice age paused

So it seems a new ice age is not something about which we should worry – at least for the next 1500 years. We might then expe- ▶

SDO/NASA



When stars such as the Sun enter a period of low activity with few sunspots, the quantity of radiated energy is reduced by 5.5 to 8.4%, primarily in the ultraviolet part of the spectrum.

rience a new 'real' ice age – not just a brief temperature drop for a few decades, but tens of thousands of years with a climate that is at least five degrees colder than today.

Until then, it's warming that requires our urgent attention. Paleoclimatologist Michael Sandstrom from Columbia University in New York has examined how much carbon dioxide the air includes during warm periods and ice ages. The quantity of CO_2 is measured in millionths of air molecules, ppm. For an ice age to materialise, the atmosphere's CO_2 content must drop to some 170 ppm – 170 CO_2 molecules per million air molecules. The quantity of CO_2 molecules must reach 280 ppm to cause a warm period such as the present. Before the burning of fossil fuels gathered momentum in the mid-1800s, the atmosphere's contents of CO_2 was just that: 280 ppm. But since then the concentration has risen to 410 ppm.

The last time Earth was subjected to similar warming was some 56 million years ago during the Paleocene-Ecocene Thermal Maximum (PETM). Over 10,000 years, the world became 5-8 degrees warmer, with undersea volcanoes melting methane ice on the ocean floor, releasing large quantities of greenhouse gases. After these emissions stopped, it took 170,000 years for temperatures to fall back to their earlier levels.

Such slow cooling is because Earth's integrated thermostat is inefficient, and its systems slow to remove CO_2 from the atmosphere. Many of the processes triggered by heating go forwards much faster than backwards. The melting of ice caps in Antarctica and Greenland takes place far faster than the formation of new ice as temperatures fall again. Melted ice also has a self-perpetuating effect. When ice melts, darker sea and land appear, and these absorb more sunlight than white reflective ice, heating the planet more. This self-reinforcing heating makes it harder to reverse rising temperatures.

50

metres is the level by which global sea levels would rise if all ice melted.

The Sun can buy us time

The emission of greenhouse gases not only leads to present-day global warming, it also disturbs the world's natural swings between cold and heat. If astrophysicists such as Irina Kitiashvili are right that we are entering a new period of very low solar activity, we may be lucky enough to have this mitigating factor to reduce some effects of our self-inflicted climate change. While greenhouse gases drive temperatures up, the Sun's decreasing activity may dampen their effect on the climate, giving us valuable extra time to switch to green energy and find alternatives to concrete, steel and other practices which emit huge quantities of CO_2.

But these issues must be tackled, and tackled now. After all, any delay is merely temporary. Once the Sun and its sunspots cycle back to normal and then high levels of activity, their effect will begin to add to, rather than subtract from, the effects of our self-induced global warming – unless we have by then brought it under control. SI

If global warming gets out of hand, the Arctic ice caps will collapse and send sextillions of litres of water into the oceans.
SHUTTERSTOCK

In the last ice age, Australia was larger but may have faced more arid conditions. Archaeological evidence suggests that Indigenous people appear to have retreated into key areas with access to fresh water.

Oceans fall, oceans rise

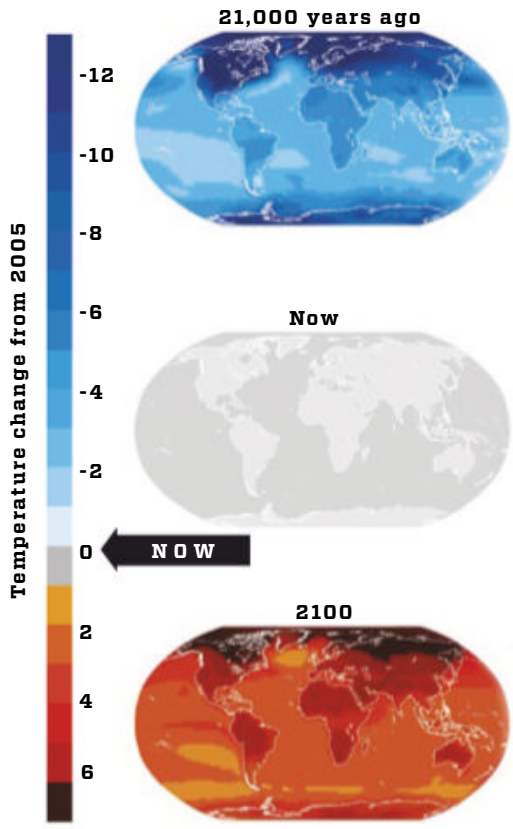
Ice formation during the ice age 20,000 years ago saw ocean levels fall by 125 metres, exposing land that made Australia some 20% larger than its current size. Now as global temperature rise, the oceans are rising too.

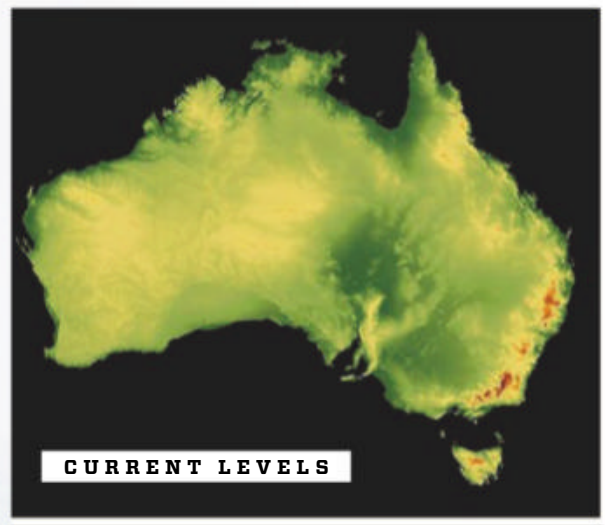
-125 METRES

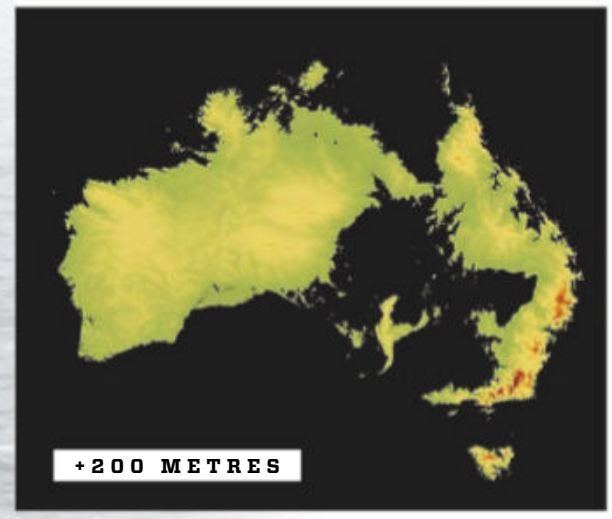
DAMIAN O'GRADY, MICHAEL BIRD

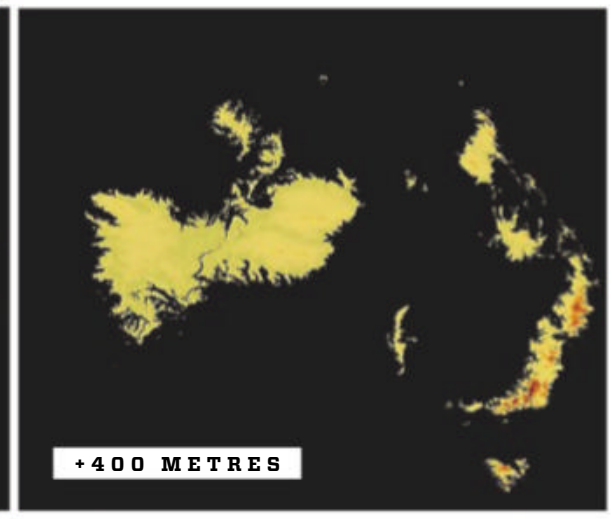
MAJOR QUANTITIES OF CO_2 CAUSE GLOBAL HEAT STROKE

1 CO_2 emissions have already increased the concentration of greenhouse gases in the atmos-phere from 280 to 410 millionths (ppm) – a rise of about 45%. If the emissions continue, a concentration of 1000+ ppm by 2100 is not impossible.









GETTY IMAGES

AS ICE SHEETS MELT, THE OCEANS RISE

2 The two projections below by geographer Stephen Young from Salem State University show the effect of 200-400m rises on Australia's coastline. Such ocean level rises are not predicted, but if ice sheets collapsed entirely in a 4-6 degree warmer future, a 50-metre rise is possible, engulfing low-lying island communities and flooding huge coastal areas of Australia, including cities such as Melbourne and Sydney.

SAVE THE WORLD'S **INSECTS**

25% of Earth's insects have disappeared over the last three decades. If they all disappear, so will we, as these small creatures perform tasks which are crucial for the survival of humans. We can all help scientists save them.

By **Jonas Grosen Meldal**

Some people have negative reactions to many insects, but they are crucial for the survival of our species.

SHUTTERSTOCK

The dawn is barely visible in the sky above the trees as biologist Bradford Lister and his team of assistants busy themselves in the rainforest of Puerto Rico. They are placing insect traps in the trees and on the forest floor. At sunset, Lister and his team will return to collect their catch.

Thirty-six years earlier, when Lister went through the exact same procedure in the exact same place, a trap on the ground caught an average dry weight of 473mg of insects a day, while a trap in the trees caught 37mg. This time around, it is just 13mg per trap on the ground, and 5mg per trap in the trees – a reduction of 97.3% and 86.5% respectively.

The disappearance of these Puerto Rican insects is just one indicator within a potentially disastrous global trend. Scientists everywhere are reporting alarming reductions in insect numbers. The most recent news comes from an international team of scientists who have analysed 166 long-running studies covering almost 1700 different locations around the world from a period right back to 1925 and up to 2018.

75

billion US dollars is the estimated value of insect activity in America each year.

The conclusion is that the global insect population has reduced by 9% per decade. About 25% of the world's insects have disappeared since 1990, and half have been lost over the past 75 years. And the road toward insect extinction is threatening to end life on Earth – not just theirs, but ours too, and countless other species. We underestimate creepy-crawly insects: they form the cornerstone of world ecosystems to the extent that some experts claim our own species would go extinct in a few months if insects disappeared. Scientists are now fighting against the clock to identify the causes of decline and find efficient solutions that can save the insects – and everything that depends on them – before it is too late.

Who rules the world?

We sometimes imagine that humans are the planet's top species, but the success of insects is hard to over-estimate. Even with the huge losses of recent decades, insects are still extraordinarily numerous. The global population is estimated at 10 quintillion individuals – with combined biomass that is 17 times greater than that of humankind.

The six-legged creatures form the vast majority of the world's species and have invaded all ecosystems except those in deep oceans. They make up around 90% of all animal species amd half of Earth's some two

Insects are worth $$$$$$

They are crucial for agriculture and on their way to becoming an indispensable food source. They also prevent us from being overwhelmed by cow dung. Insects are our hidden heroes.

KEN IKEDA MADSEN & SHUTTERSTOCK

million known animal and plant species. And scientists estimate that perhaps 4.5 million more insect species have not even been discovered or described yet. Unknown species will exist under unique living conditions in regions yet to be thoroughly explored, in a particular type of soil, under withered leaves deep inside dense rainforests, or high up a mountain.

The high number of insects is down to formidable fertility. Queens of the African *Dorylus wilverthi* ant species can lay 3-4 million eggs in a month. An East African termite queen delivers an egg every three seconds, corresponding to almost 30,000 eggs a day, or more than 164 million eggs in her 15-year life-span.

Insects in free fall

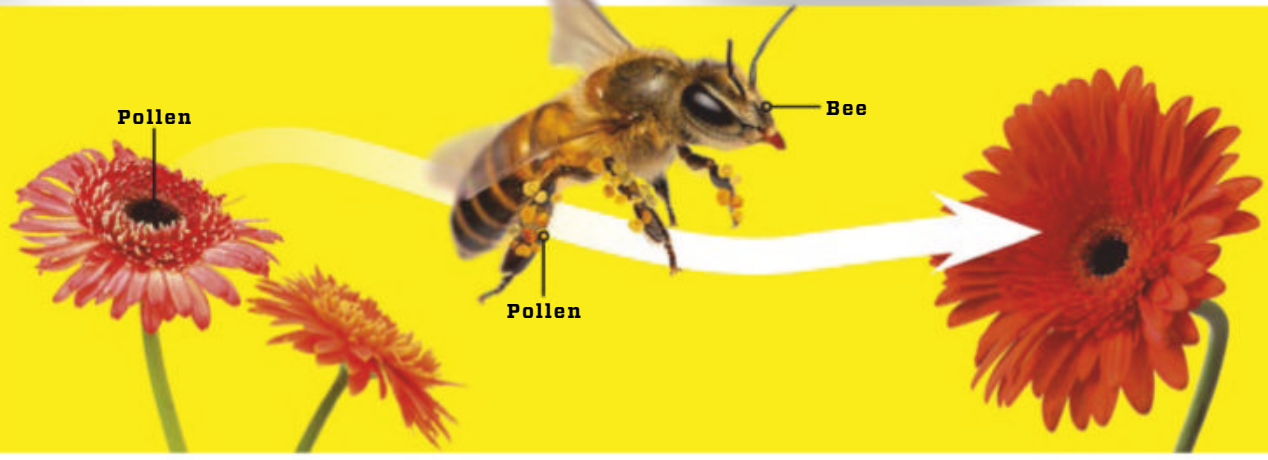
The reductions in insect numbers have been dramatic, particularly in the US and in Europe. In a study from 2017, a team of scientists reported that more ▶

Beetles, bees and butterflies are among the world's most badly affected insects in the world.

SHUTTERSTOCK

Bees are money makers

1 96% of all flower-bearing plants in the world – including 70 of the 100 most common types of food – depend on pollinators to be able to reproduce. Bees are by far the most important pollinators, and each and every wild bee and honey bee contributes some A$4000 per hectare to the production of crops.

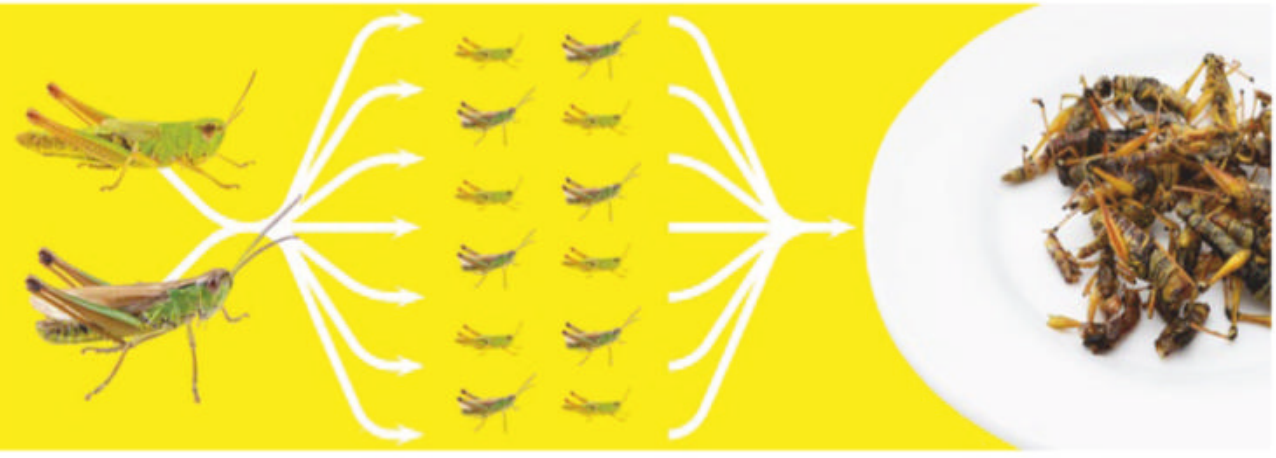


Beetles do the shitty work

2 The world has approximately one billion cows, and each produces around 10 tonnes of faeces annually. We would drown in cow dung if we did not have Earth's approximately 6000 species of dung beetles. The beetles collect and efficiently break down faeces around 20% faster than would otherwise occur.

The food of the future

3 Without insects, we will probably be unable to feed the world population within a few decades. One of the insects with the biggest potential as a food source is locusts. Apart from being protein-rich and climate-friendly, they can be harvested in huge quantities. In some parts of Mexico, local families harvest 50-70kg of locusts a week.



than 75% of the biomass of flying insects had disappeared from natural reserves in Germany over a period of 27 years. And in 2019, other scientists revealed that more than 40% of world insect species are in decline, with one-third of all species endangered. The scientists have calculated that insects are becoming extinct eight times faster than mammals, reptiles and birds.

The only upswing has been for fresh-water insects such as mosquitoes, which are thriving. Fresh-water insects are increasing in numbers by 11% per decade, probably helped by improved conditions as humans work to purify polluted lakes and rivers. However, fresh-water insects make up only around 10% of all insect species, and these are not as important to the eco-systems that we depend upon as are those in decline.

Humans need insects

Without insects, the world's ecosystems would collapse, and according to some experts, humans would be unlikely to survive more than a few months before lack of food would send our species into extinction.

That's because insects are particularly important in agriculture. True, some of farmers' worst enemies may be insects that consume crops, but the vast majority of them benefit agriculture. Pollinators such as bees and wasps carry pollen between plants, ensuring the next generation of crops. And

Since 1990, the number of insectivorous birds in Europe has declined by

13%

the insects that live below the ground are crucial in maintaining the health of soil used for agricultural purposes. Their tunnels improve soil quality by making sure that oxygen and water can pass down through soil more easily. The oxidation accelerates the breakdown rate of dead material from animals and plants, which subsequently fertilises the soil. And insects assist the breakdown even more by digesting large quantities of plant remains.

Moreover, the creepy crawlies' activity improves the soil's ability to hold water, as well as making it easier for plant roots to pass though the soil. They even help prevent surface erosion.

Finally, many predatory and parasitic insects contribute to reducing the number of serious pests that attack farmers' fields. Without insects undertaking all these activities, our food production would collapse.

Prepare to eat beetles

Not only do insects make an essential contribution to agriculture, they are a food source in themselves – and an efficient one. Around two billion people already regularly eat insects such as locusts, beetles, ants, and butterfly larvae.

Insect consumption currently takes place mostly in relatively poor countries, but in the future, it will almost certainly become more common in the rest of the world, as insects are a far more climate-friendly source of protein than cattle, pigs, and poultry. Their by-products are also important, with insects providing honey, wax, silk, pigments, and shellac – a product that is used for surface treatment of food and as an ingredient of cosmetics. They also supply chemicals that could be used to save millions of human lives.

One of these comes from cockroaches. Because of their living conditions, roaches have developed an efficient defence against bacteria, and in an experiment, chemicals from cockroach hearts managed to kill 90% of the tested multiresistant bacteria, including MRSA staphylococci and E coli. The discovery is crucial, because doctors are running out of new types of antibiotics that can combat these dangerous bacteria.

Toxins from bees and wasps may also lead to drugs that can kill not only multi-resistant bacteria, but even cancer cells. These toxins are also being found to ease pain and swelling in connection with arthritis, sclerosis and other inflammations.

Endangered in several ways

The majority of the world's insects live in forests, and we are eliminating tropical forest at the rate of some 120,000km² a year. So one of the major threats to insects is simply the removal of their natural habitat.

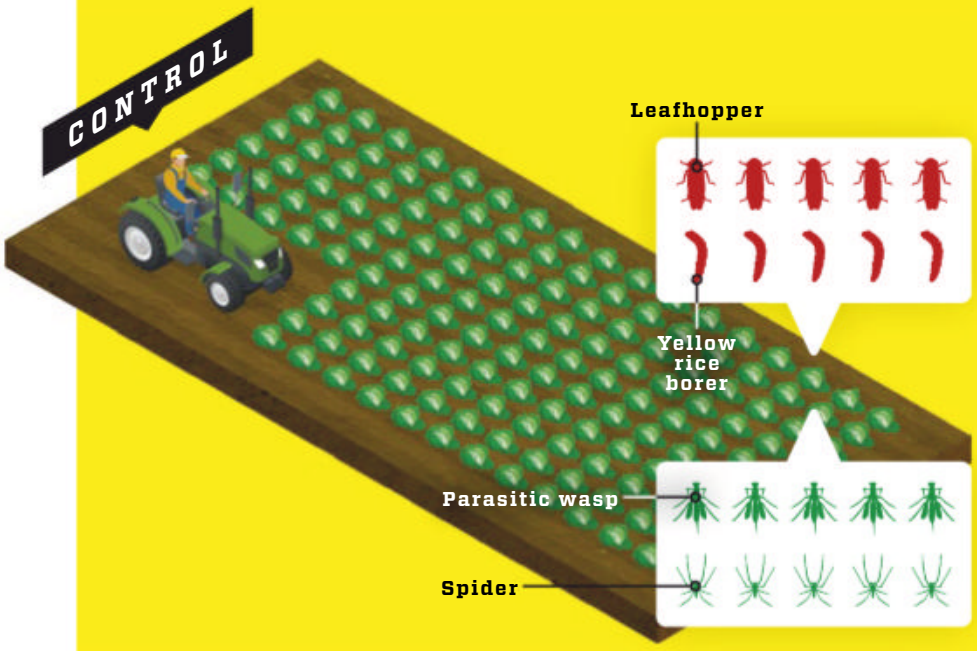
Former woodlands are often turned into farmland, and this is then sprayed with

In the 1980s, scientists counted some five million monarch butterflies in California. In 2018 and 2019, their numbers had been reduced to around 30,000.

SHUTTERSTOCK

Flowers instead of pesticides

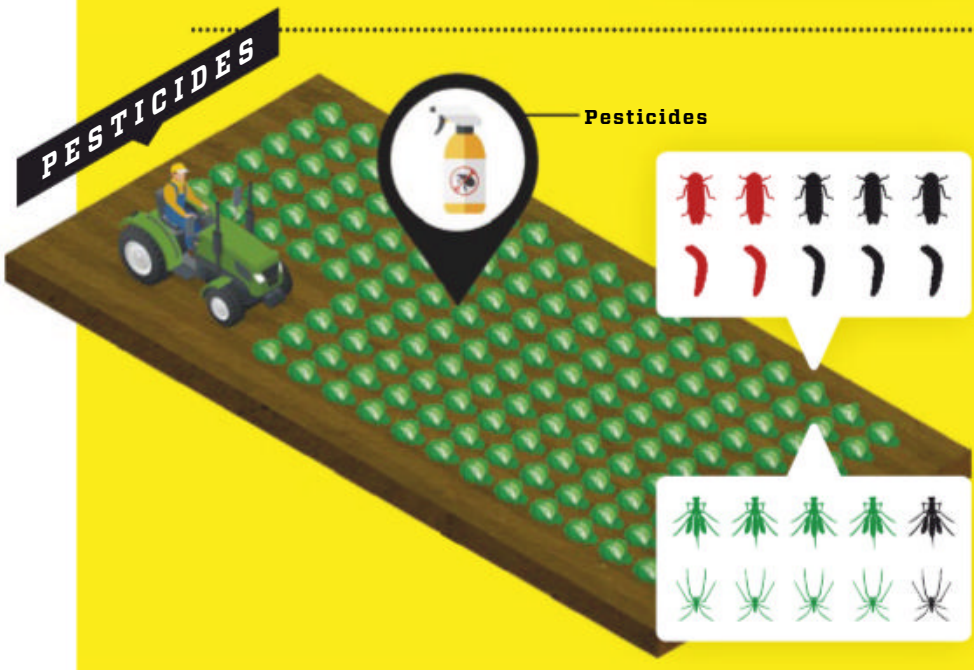
Asia's rice paddies are invaded by hungry pests, and the best weapon against the attack is not pesticides, but flowers. The plants attract other insects that combat the pests.



Pests conquer defenceless fields

1 Unsprayed rice paddies are often attacked by insects that specialise in taking advantage of rice plants (red), such as yellow rice borer and some leafhopper species. Because the rice plants don't have nectar-rich flowers, they attract very few other insect species (green), that might help keep the population of pests at bay.

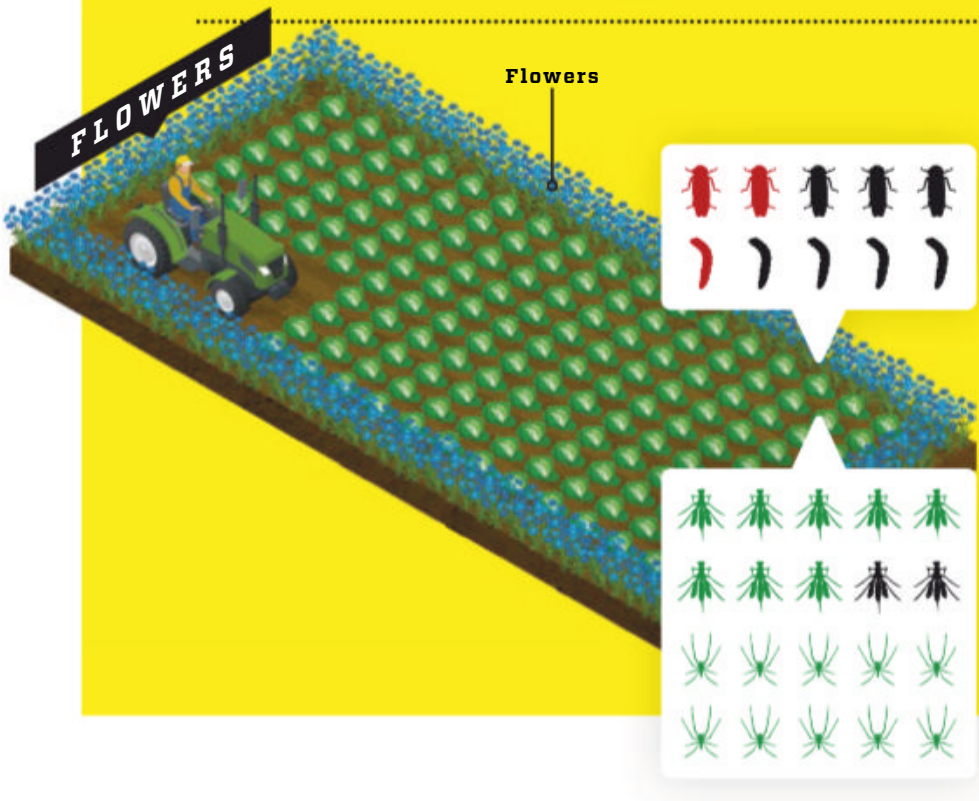
Yellow rice borer larvae eat the interior of rice plants and make the flowers wither.



Pesticides kill both good and evil

2 Rice paddies are often sprayed with pesticides to remove the pests, but the toxins also kill the natural enemies of pests. Sprayed paddies generally have fewer pests than unsprayed ones, but in some cases, the lack of natural enemies could mean that the pests do better than if the area was left unsprayed.

Pesticides affect insects' nervous systems, which are primarily located along the creatures' bellies.



Parasites save the crops

3 Nectar-rich flowers surrounding rice paddies attract insects and other creepy crawlies including predators in the shape of spiders, damselflies and parasitic insects. The predators eat the pests, whereas the parasitic insects lay their eggs inside the pests.

Individual parasitic wasps typically specialise in laying eggs in specific larva species.

KEN IKEDA MADSEN & SHUTTERSTOCK

Help insects by doing less work

Insect extinctions would have a huge impact on entire ecosystems, including our own. There are ways to help, and reducing your gardening efforts may be one of them.

Forget about exotic plants

1 Exotic plants are pretty, but native species are better for hosting local insects. More than 90% of herbivorous insects specialise in local plants, so when the percentage of exotic plants in a garden increases, the quantity of insect larvae falls.

Leave the leaves alone

2 Fallen leaves are a nuisance for perfectionist garden owners, but you should leave them alone. Bee queens and pupae plus moth and butterfly larvae spend the winter under the leaves that keep both cold and insect eaters away.

Do not use pesticides

3 The herbicide glyphosate, also known as Roundup, targets an enzyme that exists in plants. But the enzyme also exists in insect gut bacteria, and Roundup disturbs the bacterial balance of bees, so they become more vulnerable to infection.

pesticides, which kill not only pests but also beneficial insects – particularly pollinators. Pesticides are one of the main reasons for the drastic reduction in the number of flying insects. The pesticides have affected bees badly, but another group of pollinators might be in even bigger trouble, with butterfly data from Denmark showing falls in 52 of 69 species, with some of the species not observed at all in 2020.

Here in Australia there have been far fewer long-term insect studies.

"While insect declines are no doubt occurring in Australia, the extent of the problem is unclear," says Dr David Yeates of the CSIRO's Australian National Insect Collection (ANIC). "We have good data on declines in some iconic species such as the Bogong moth, green carpenter bee and Key's Matchstick Grasshopper; however very few of our estimated 250,000 insect species are being monitored. The worry is, if insect populations are in decline, so are the populations of larger animals such as birds and lizards who rely on them as food. We know in alpine NSW there's been a collapse in Bogong moth populations – a staple food source for Mountain Pygmy Possums in Spring, and this decline is resulting in the possums starving. But for most species these detailed interconnections are unknown. We really need long-term data sets that would provide a better picture of what is happening."

96%

of the world's flower-bearing plants depend on pollinators.

Parasites replace pesticides

Scientists are working hard to find a way to help insects survive. Protection and rehabilitation of habitats make up important steps.

However, we can also make useful efforts in our own homes. According to a new study, cities hold considerable potential when it comes to increasing the number of insects. Buildings and asphalt are a wilderness for insects, but if we plant flowers and flowering trees, they could thrive.

Pesticides bans are an obvious option – but not if they leave farmers' fields entirely vulnerable to pests. So in some countries scientists have suggested using the pests' natural enemies instead. English scientists accidentally discovered that the parasitic *Microctonus brassicae* wasp will feast on colonies of the cabbage-stem fleas that cause great damage to rapeseed fields. The wasps combat the cabbage-stem fleas by laying eggs in their bodies; the fleas become sterile and subsequently die when wasp larvae break through their digestive systems.

KEN IKEDA MADSEN & SHUTTERSTOCK

Mow your lawn less often

4 If you mow your lawn every two weeks instead of every week, you will increase the number of bees in your garden by 30%, because the lower activity encourages more flowers. But do mow your lawn once in a while, so the grass doesn't stifle the flowers.

But introducing such a solution can get out of control; Australians need look no further than the cane toad, introduced here from Hawaii in 1935 to control the cane beetle in sugar cane fields in north Queensland. It didn't end well. Not only did they have minimal effect on the beetles (which were too high in the cane for the toads to reach), Queensland proved such a fertile environemt that from the original 102 toads brought here, more than 200 million more have bred.

Create your own insect paradise

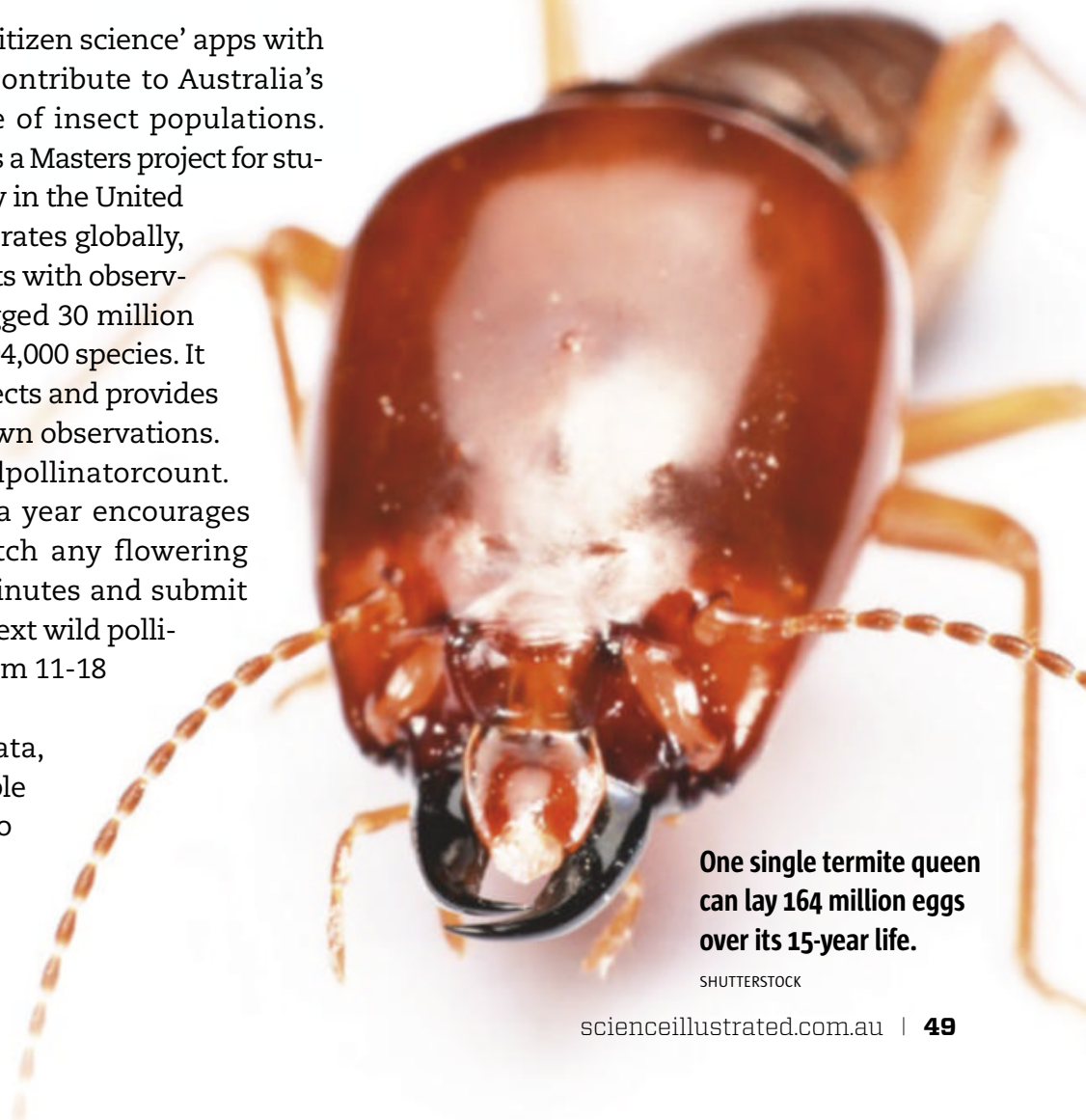
You can personally do a lot to save the insects. Plant flowers in your garden for nectar-craving pollinators. Leave the autumn leaves on your lawn to protect insects over winter. Allow your grass to get a little longer.

You can also build insect hotels in your garden or on your balcony for insects to live in, wooden structures with small holes that can be inhabited by butterflies, bees, wasps, ladybirds, and beetles. Look for a design online, and protect the hotel against rain.

There are also 'citizen science' apps with which we can all contribute to Australia's meagre knowledge of insect populations. 'iNaturalist' began as a Masters project for students at UC Berkeley in the United States, but now operates globally, connecting scientists with observers who in 2020 logged 30 million identifications of 194,000 species. It links into local projects and provides feedback on your own observations.

Another is wildpollinatorcount.com, which twice a year encourages Australians to watch any flowering plant for just 10 minutes and submit observations. The next wild pollinator week runs from 11-18 April 2021.

With enough data, scientists may be able to find new ways to arrest the decline of the insects we all need to survive. SI



One single termite queen can lay 164 million eggs over its 15-year life.

SHUTTERSTOCK

THE SCIENCE OF **HEARTS AND MINDS**

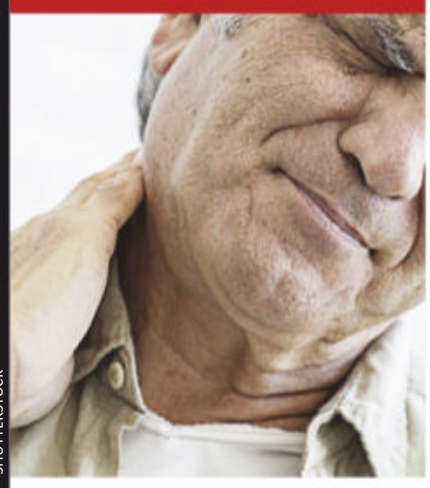
Your heart beats around 100,000 times a day, and scientists are discovering that every single beat manipulates your brain. A healthy heart, it seems, does far more than provide the pulse which supplies blood to every part of your body.

CLAUS LUNAU

YOUR HEART CONTROLS YOUR BRAIN

A series of experiments reveals that hormones and electrical signals from your heart change your experience of pain, thirst, and even other people's emotions.

PAIN



EMPATHY

THIRST

SHUTTERSTOCK

By **Ulla Edelbo Raaschou**

SCIENTISTS HAVE DISCOVERED NEW LINKS SHOWING HOW THE HEART CONTROLS THE BRAIN'S THOUGHTS.

The left ventricle normally pumps about 5.5 litres of blood into the body per minute.

"Their eyes met across a crowded room. Somewhere deep within their limbic brain centres, they both felt that they were made for each other."

Love stories were never quite the same once scientists relegated emotions from their ancient home in the heart to the body's calculating computer, the brain. But new research is revealing that earlier authors may have been more accurate than we thought in ascribing our thoughts and emotions to the heart. We are now learning that the heart manipulates the brain via neurotransmitters and nerve pathways – in perfect step with our heartbeats. Scientists used to consider the heart a simple blood pump, but the new discoveries show that the heart can influence your senses, needs and deepest emotions concerning other people. So strong are the links between the human body's two most important organs that the result comes close to a merging of duties.

Heart and brain communicate

Your pulse rate increases when you fall in love, or when you are afraid, or experience stress. You may clearly feel the beating against the inside of your chest, or the pulse of blood in your ears. In this way your heart lets you physically sense your emotions, and perhaps that is why people of different cultures have believed for millennia that emotions are based in the heart.

Over recent centuries, however, science has reduced the heart to a mechanical pump that exists simply to satisfy the body's needs for oxygen and nourishment. If your pulse rate increases when you are in love, scientists told us that the heart was blindly obeying orders from the brain. But this view is gradually being reversed. According to recent research, the contractions of the heart are doing far more than just passing oxygen and nutrition through the body.

The heart typically contracts 60-90 times a minute. As the heart contracts, the blood is pumped first from the heart's two atria to the two ventricles, after which the right ventricle sends its blood on to the lungs, while the left one sends its blood into the entire body. All the work is performed by muscle cells, and indeed the heart is basicaly one big autonomous muscle.

3-4

billion heartbeats take place during an average lifetime.

Scientists have long known that the heart controls its own rhythm, and that nerve links to the brain mean that the brain can monitor heartbeats and influence them if necessary. But over recent decades, scientists have realised that communication also flows in the opposite direction. Studies have revealed that the heart can influence a wide range of brain activities, contributing to the formation of thoughts and behaviours.

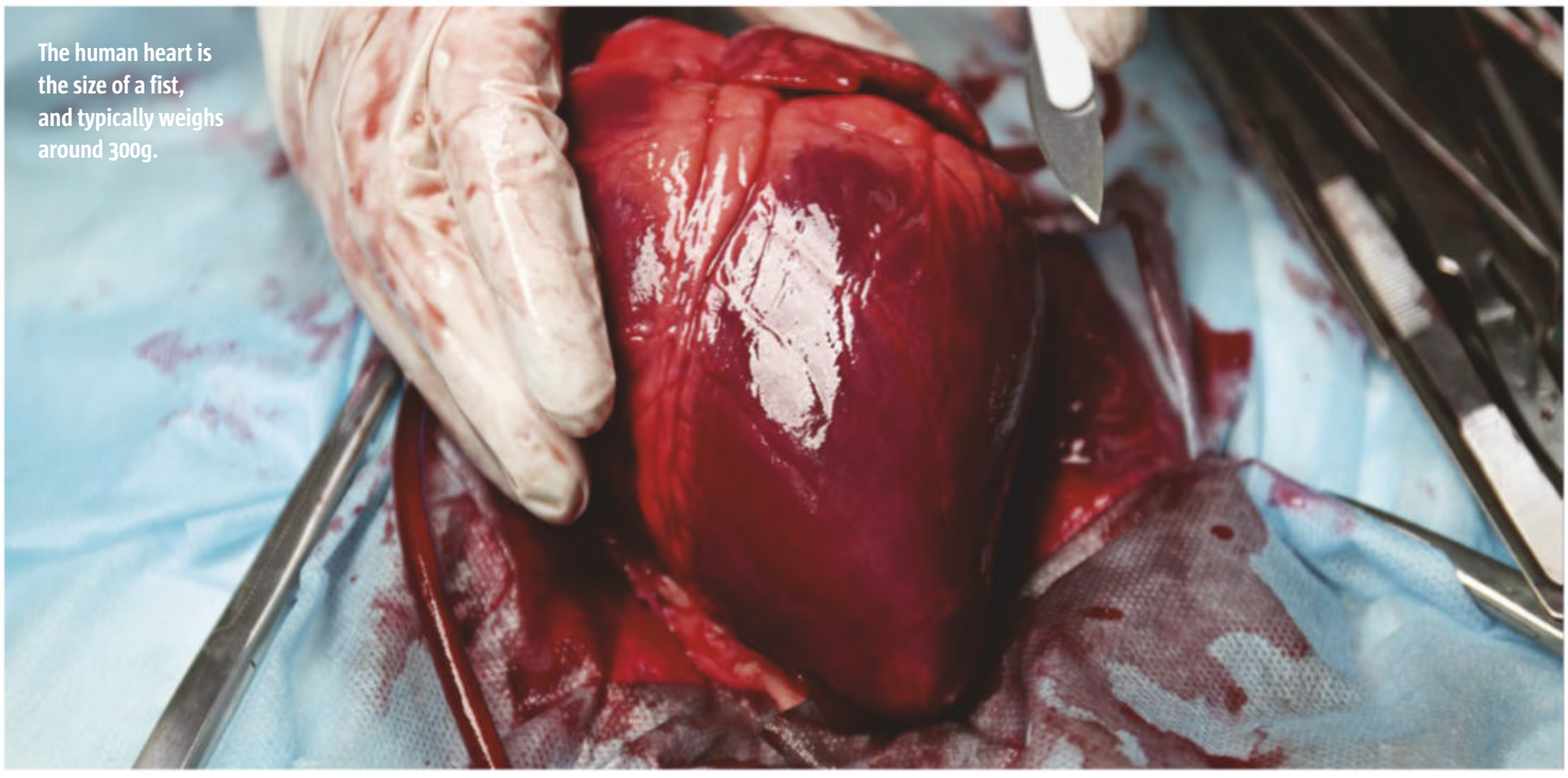
Vital hormone

The heart's manipulation of the brain uses different communication channels. One of them is the atrial natriuretic peptide hormone ANP, which is secreted by special cells in the heart's right atrium as the heart muscles contract. ANP's primary purpose is to lower the blood pressure, and the heart constantly regulates the quantity of the hormone so that blood pressure remains normal.

But ANP aso affects many of the body's organs. It enters deep into the brain, where it obstructs signals to brain areas that control thirst, so that you feel less thirsty. The heart reduces your body's fluid level and so further controls your blood pressure.

The same hormone also restricts the sympathetic nervous system, which normally puts your body into a state of alert in dangerous situations. The nervous system can increase your pulse rate or the adrenal glands' secretion of adrenaline, both of which prepare your body for flight or fight. By impeding the process, ANP calms you and makes you less likely to feel fear, again restraining your blood pressure. So, the heart can directly influence how you react when your life is in danger.

Studies from Japan's Kyushu University further indicate that ANP can reduce the secretion of the stress hormone cortisol.



The human heart is the size of a fist, and typically weighs around 300g.

SHUTTERSTOCK

Women's hearts beat 70-90 times per minuteon average, whereas men's hearts beat 60-80 times.

Electrical wave flows through the heart

Our heartbeats are carefully coordinated by the body's own pacemaker. It sends rhythmic signals to the heart's muscles, which cooperate to make sure that our bodies are supplied with oxygen-rich blood.

Biological pacemaker controls the heart

1 A small collection of cells known as the sinoatrial node is located in the wall of the heart's right atrium, sending out electrical impulses at regular intervals. The impulses flow from there into the heart along special routes which ensure that the heart's muscles contract in the right order.

Atria pump in step

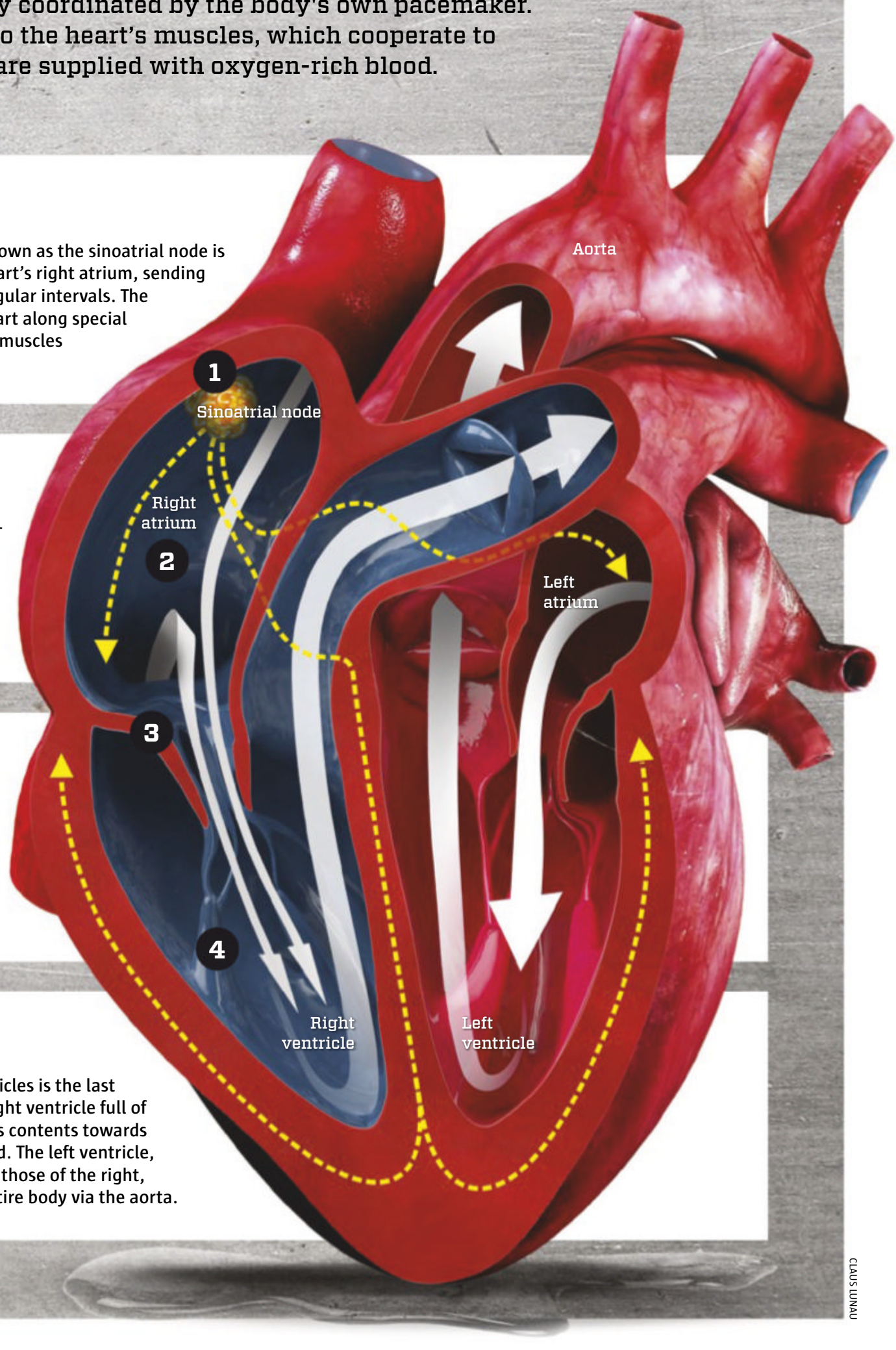
2 First, the two atria contract. The right one includes oxygen-depleted blood that has passed through the body, whereas the left atrium is full of oxygen-rich blood from the lungs. The atria force the blood on into the ventricles.

Valves ensure one-way 'traffic'

3 Cardiac valves located between atria and ventricles function as stop valves which make sure that the blood cannot flow back from ventricle to atrium.

Ventricles contract to despatch the blood

4 Contraction of the two ventricles is the last part of the heartbeat. The right ventricle full of oxygen-poor blood directs its contents towards the lungs, where the blood is oxidised. The left ventricle, where the muscles are stronger than those of the right, pumps oxygen-rich blood into the entire body via the aorta.



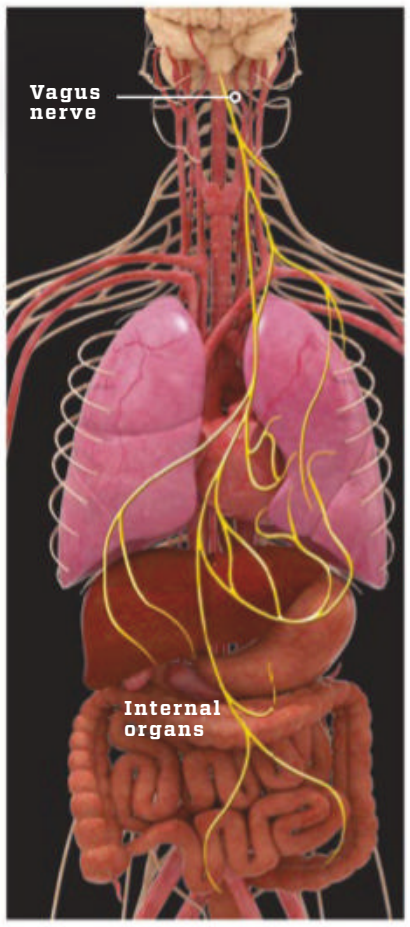
CLAUS LUNAU

The heart can be trained to pump more blood per beat, so that the hearts of some athletes beat only 30 times per minute.

The heart speaks to the brain

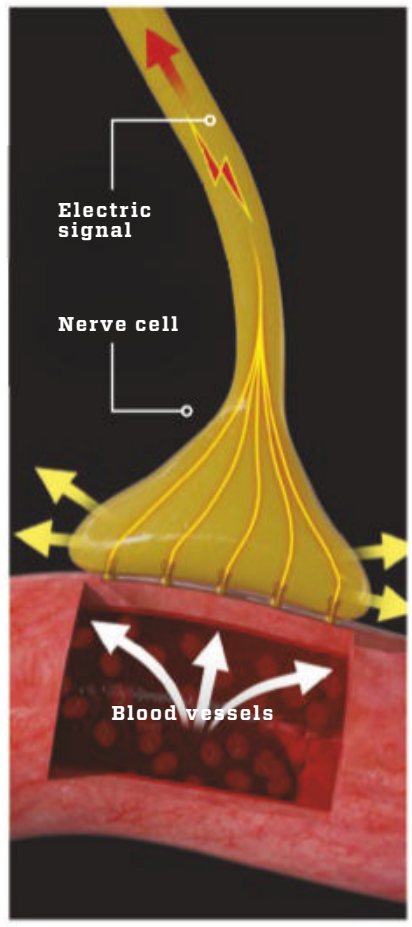
Scientists have long known that the brain can influence the heart to increase or decrease the pulse rate. However, new research has revealed that by means of large nerve bundles, biological blood pressure meters, and hormones, the heart can also influence brain activity.

CLAUS LUNAU



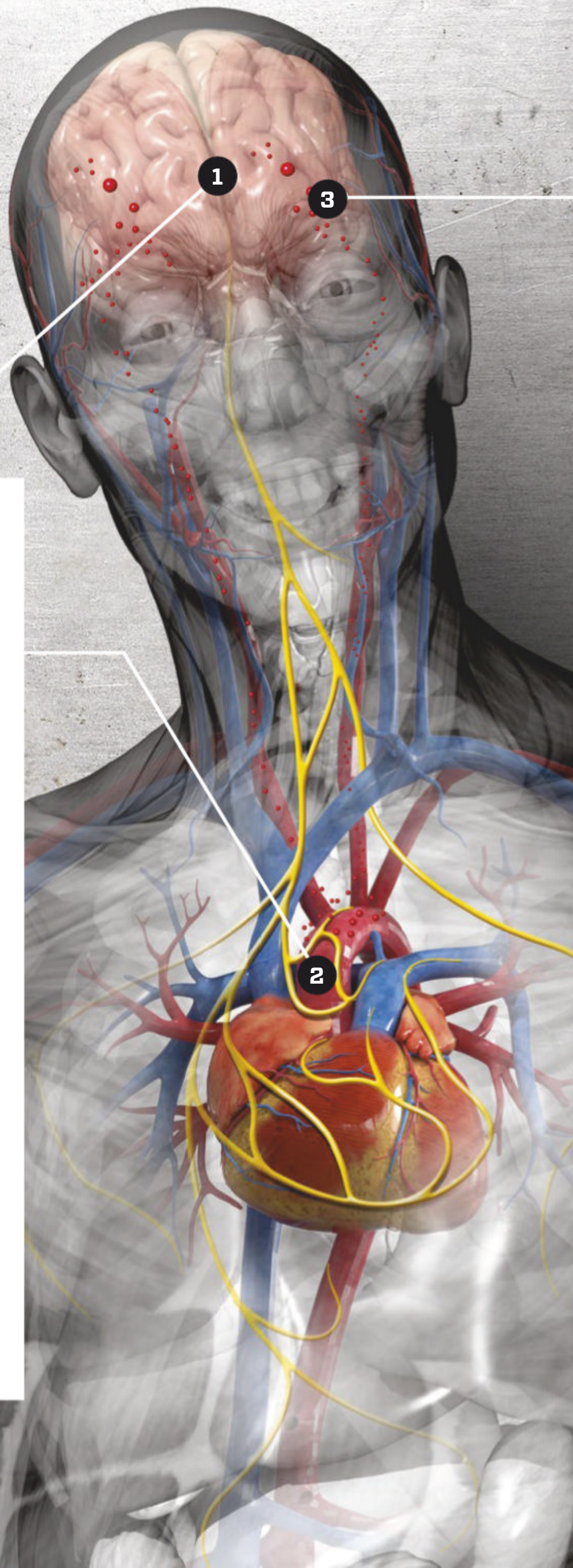
Nerve bundle is the main road of signals

1 The large vagus nerve is the link between the brain and the organs of the body, such as the heart. Via this nerve's fibres, the heart can send and receive signals from the brain. The signals from the heart can increase or decrease the activity of some brain centres, whereas messages in the other direction can alter the pulse rate.

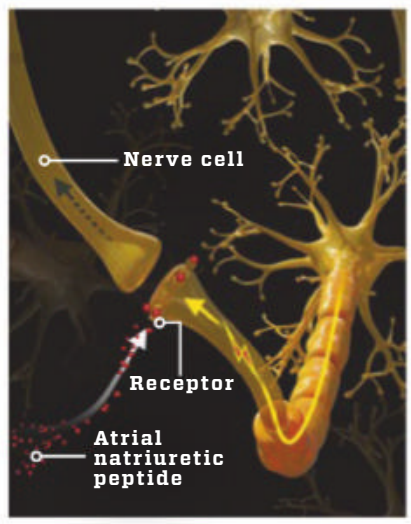


Meters monitor blood pressure

2 In the heart and within a series of the body's larger blood vessels, there are blood pressure meters known as baroreceptors. These consist of nerve cells with endings that are attached to the surface of the blood vessels. When the heart contracts, the vessels expand, pulling at the nerve endings so that they send a signal to the brain.



The left ventricle can cause a pressure that is 4-5 times higher than the right ventricle can produce.



Heart hormones slow down brain cells

3 For every heartbeat, the heart liberates hormones such as atrial natriuretic peptide, and these reach the brain via the blood. There the hormones can bind to receptors on nerve cells to prevent the cells from passing on neurotransmitters to their neighbours, so altering the activity of the brain.

High levels of cortisol in the blood could harm stem and nerve cells in the brain, and increase the longterm risk of mental conditions such as anxiety and depression. So the heart contributes to mental health.

ANP's positive effect has made scientists consider whether it can be used as a drug, perhaps for people with elevated blood pressure. But it is proving not to be an easy task. Too much of the hormone could harm several body organs, including the heart itself. But scientists hope that over the next few years they will be able to find a solution that can harness ANP's positive effects to treat different cardiovascular diseases.

Heartbeat relieves pain

The heart has other tools that can affect your brain. One of these can increase your pain threshold, so you feel less pain. In an experiment carried out by British scientists, test subjects were subjected to pain via electrical stimulation of calf nerves. At the same time, electrodes recorded their pain reflex in the thigh muscle, and a blood pressure meter monitored their blood pressure and pulse rate. The results clearly demonstrated that the test subjects felt less pain when their nerves were activated during the heart's contraction phase.

The scientists linked the reduced sensation of pain with the brief expansion of the blood vessels that occurs as the heart contracts and pumps blood into the body. They believe that it is the blood vessels' own pressure meters, the baroreceptors, that provide the link between the brain's pain centres and the heart. Baroreceptors are nerve cells that are in direct contact with blood vessels, and are activated when blood vessels expand with the rhythm of the heart. The activation triggers signals to the brain, which briefly increase your pain threshold.

Other experiments reveal that the reduced sensation of pain could in some cases become chronic. When scientists studied rats that suffered from genetically-determined elevated blood pressure, they discovered that the rats had a higher pain threshold than rats with normal blood pressure. This is probably because the elevated blood pressure overactivates the baroreceptors. The same seems also to be true for people with elevated blood pressure.

If the blood pressure is elevated for long periods of time, however, the system could become overloaded so that the baroreceptors lose their sensitivity and reduce their activity due to overstimulation. Several studies show that this can instead cause chronic pain.

Stable rhythm dulls the senses

The link between heartbeat and the sensation of pain might seem odd, but scientists have a good explanation. All body organs send signals to the brain which disguise their own activity, ensuring that your consciousness doesn't respond constantly to what is going on inside the body. By increasing the pain threshold during heartbeats, the heart helps you ignore its constant beating, so you can focus on external influences.

The heartbeat not only influences the sensation of pain, but probably also your senses in general. In 2020, brain researchers from the Max Planck Institute for Human Cognitive and Brain Sciences in Germany subjected a number of test subjects to very mild electric shocks, while electrodes recorded their heart and brain activity. Again the experiment revealed that the brain partly ignored the shocks when they were given at the same time as the heart contracted. But the scientists could also see that a series of signals in the brain which normally increase the awareness of sensory impressionx were suppressed during the heart's contraction.

They also noted that the blocking of such sensory impressions was most efficient when the cardiac rhythm was stable. This indicates that the body's ability to suppress the senses improves when the brain is able to predict the next heartbeat accurately.

Another curious result was that the sensation of the electric shock was further dampened when the test subjects were deliberately focusing on what was going on inside their own bodies at the same time.

Signal intensifies emotions

Focusing on your own heartbeats activates a series of brain areas which are involved not only in processing sensory impressions, but also in shaping your innermost emotions. In another experiment, German scientists tested test subjects' ability to feel their own heartbeats. Then the subjects looked at pictures that were designed to cause either pleasant, neutral, or unpleasant emotions. Brain activity recording revealed that those people who were particularly good at focusing on and feeling their heartbeats also reacted more strongly to the pictures. This is probably because they receive a stronger signal from the heart during contraction. So even though the heartbeat relieves pain and dulls the senses, it could also bring you into closer contact with your emotions. Such contact also affects your ability to under-

The heart normally accounts for about 1/200th of our body weight, but it can be increased via exercise.

stand other people's emotions. The brain networks that process your own emotions are roughly the same as the ones that help you interpret other people's emotions. And experiments have shown that we react more strongly if we see a person who shows signs of fear or distrust at the moment that the heart contracts, rather than the moment when it expands.

Sensitive heart can cause anxiety

The heart – and the other organs – greatly influence brain activity, and the interaction is extremely important. The stomach lets the brain know when it is empty, causing a feeling of hunger, whereas a full bladder can all but force you to find a toilet. On the other hand, we can face major problems if these links to the brain are poor. Such problems are observed in some people with autism. They do not notice their own body's signals until they become very strong. The result can be that they don't feel annoyance until they suddenly explode in anger. In rare cases they can break a leg without feeling pain.

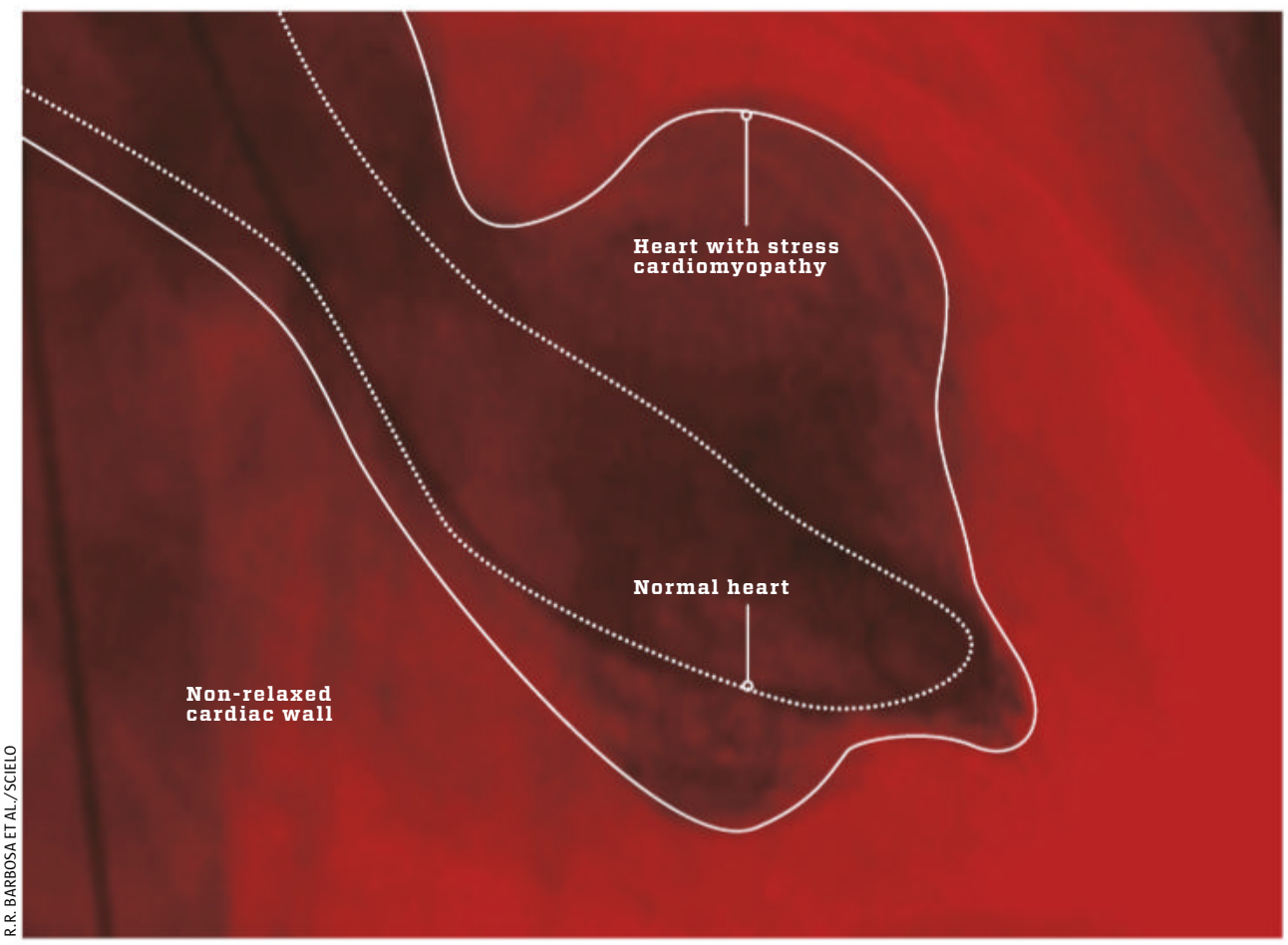
On the other hand, an unusually strong link between organs and brain might also cause problems. One experiment indicated that people who proved particularly good at feeling their own heartbeat also tended to feel more anxious.

Grief really can break your heart

Scientists are still a long way from understanding the complex interaction between the heart and the brain. But it is already clear that the two organs function as one unit in many ways. So the heart could very well play a role when we fall in love.

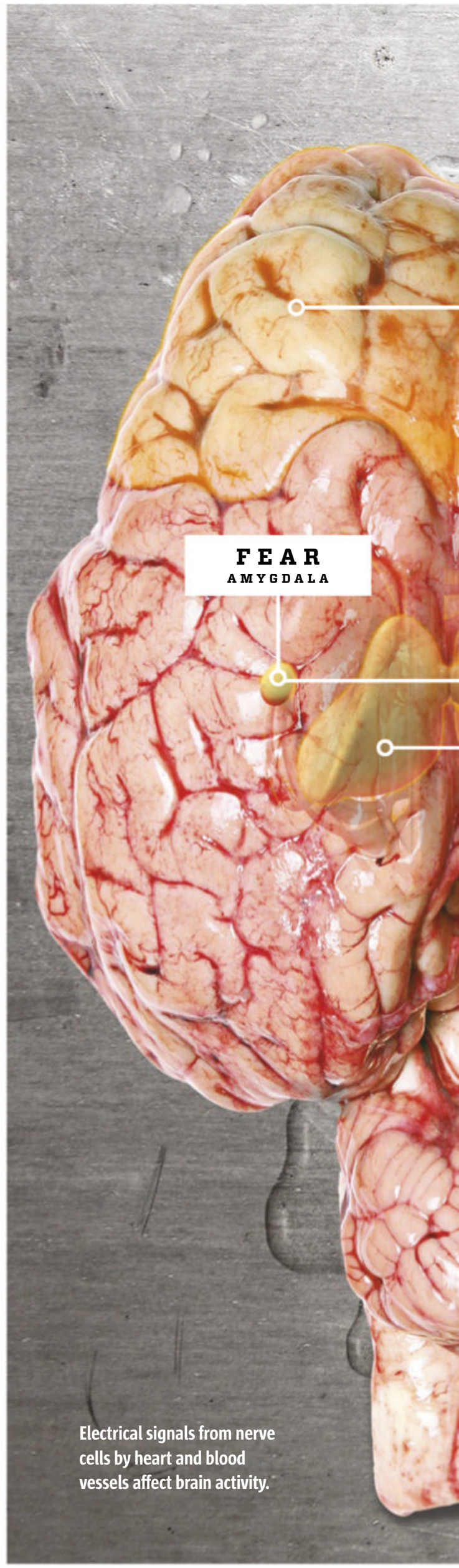
However, the newly-revealed influence of the heart on your emotions could also flow in the opposite direction, with your emotions physically affecting your heart. This can happen in a dramatic way when intense grief, such as in connection with death or divorce, causes stress cardiomyopathy or 'broken heart syndrome'. The condition involves chest pain and breathing problems, and it probably develops because grief causes excessive secretion of adrenaline, which harms cardiac blood vessels and muscles. Thankfully most patients recover after a few weeks. As in many love stories, it seems that that the best remedy against a broken heart is time.

The revelation of the strong mutual link between the heart and the brain is well on its way to reviving our former belief that the heart is the home of some of our strongest emotions. But our hearts shouldn't get all the credit. Our intestines, for example, may also be influenced by sadness, by happiness, and by our relationships with other people. The intestines also manipulate our thoughts via nerve links and hormones, and – as we've seen in previous issues – possibly also via intestinal bacteria that migrate to the brain. In the future, then, love stories should consider not only the role of the heart, but also what we feel in our gut. SI



R.R. BARBOSA ET AL./SCIELO

When a normal heart contracts, the left ventricle is flattened. But in patients with stress cardiomyopathy, the heart is unable to fully contract.



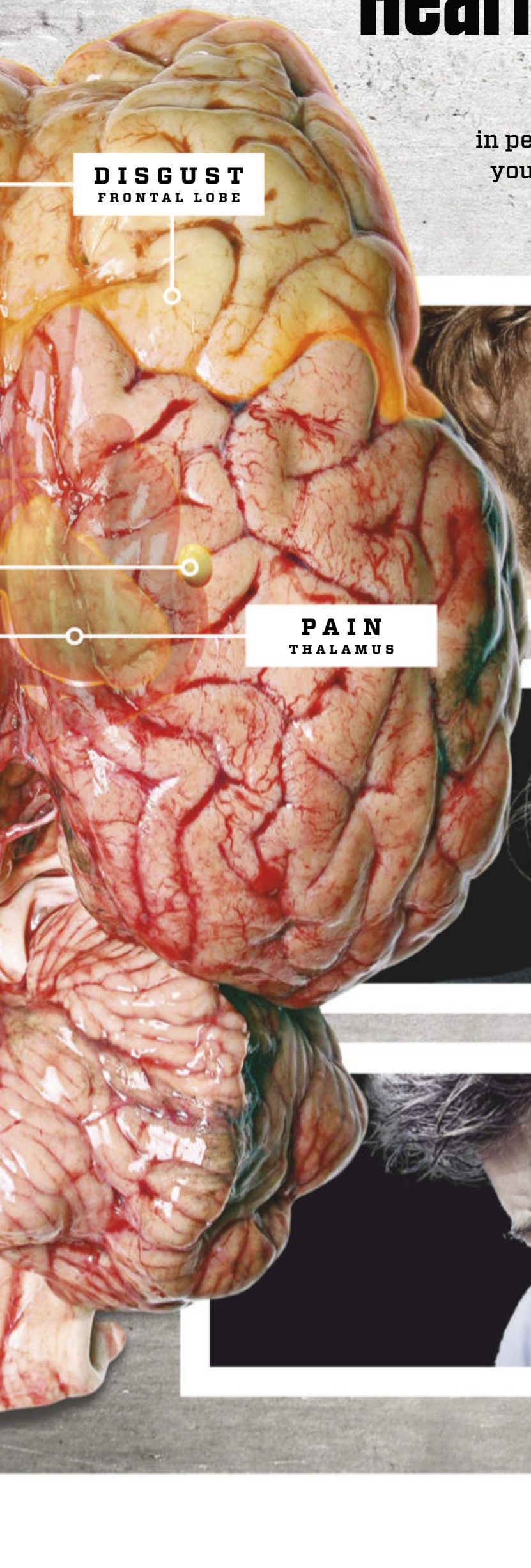
Electrical signals from nerve cells by heart and blood vessels affect brain activity.

Your brain pumps some 2.6 million litres of blood through your body every year.

Heartbeat affects emotions

Rapid nerve signals from heart and blood vessels to the brain enable your heart to affect the brain's activity in perfect step with your heartbeats. The remarkable result is that your brain's handling of emotions such as disgust, fear, and pain oscillates with the heartbeat some 60-90 times per minute.

CLAUS LUNAU



SHUTTERSTOCK

FRONTAL LOBES become sensitive to disgust

1 The contraction of the heart affects the activity of the brain's frontal lobes that play an important role in your sensation of disgust and the interpretation of disgust in other people's faces. As the heart contracts, the activity pattern of the frontal lobes changes, making you react more strongly to faces expressing disgust.

SHUTTERSTOCK

THE AMYGDALA spots fear in other people

2 The amygdala is the brain's centre of fear and controls your reaction to dangerous situations and to other people's fear. For a moment, the contraction of the heart makes the amygdala more sensitive to impressions, and so, in step with the heartbeats, you will gradually react more strongly to faces expressing fear.

SHUTTERSTOCK

THE THALAMUS relieves pain

3 Your experience of pain originates via activity in the thalamus brain centre. When the heart contracts, pressure meters in the blood vessels (baro-receptors) send a message to the thalamus to briefly reduce activity, so you feel less pain. The pain threshold decreases again when the heart relaxes.

In our early evolution, and even today, it is hard for scientists to identify precisely what makes us human, rather than not human. Now we face the same difficulty when appraising the power of technology.

SHUTTERSTOCK

By **Jens E. Matthiesen**

CHALLENGE

WHAT IS A HUMAN BEING?

Some questions are so complex that they remain unanswered for centuries. Yet the search for a solution often yields information and wisdom even while the final answer remains out of reach.

Will robots ever become accepted as 'human'?

No other species has made its mark on the planet as comprehensively as have humans. We have conquered every continent; we traverse the oceans and fly through the skies. But scientists still have difficulties identifying one specific quality that makes us superior to other species. Extinct relatives and chimps match us on genetics – and now intelligent robots threaten to blur the definitions still further.

It was a great day for Sophia Hanson when she spoke to the crowd in Riyadh, Saudi Arabia, on 25 October 2017. She had come all the way from Hong Kong to participate in the Future Investment Initiative conference, and although she was far from her usual environment, she had in a way come home – for one particular reason:

"I am very honored and proud for this unique distinction," Sophia announced. "It is historic to be the first robot in the world to be recognised with citizenship."

Although Sophia's status as a Saudi Arabian was largely a gimmick for the occasion of the conference, her status as the first robot citizen is nevertheless a fact.

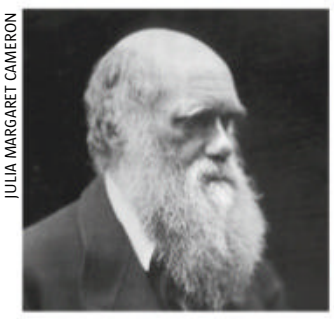
Sophia is a humanoid – a human-like robot. Her body has the same dimensions as a human body, and she can walk and make gestures just like us. But most interesting of all is what happens inside her 'head'. Sophia is equipped with artificial intelligence using a combination of different technologies. Some of what she 'knows' has been programmed by her creators, but she has also taught herself other things via experience. Through self-learning AI, she develops and expands her vocabulary and her ability to understand what other people say to her.

The man behind Sophia is David Hanson, the founder of Hanson Robotics. He claims that robot Sophia already has some emotions and awareness, which will improve along the way.

"Our goal is that she will be as concious, creative, capable as any people," he once said.

If this happens, Sophia and other social robots will challenge our idea of what it means to be human. And it won't be the first time. In recent decades, a long series of scientific discoveries have made the definition of our species increasingly blurred. This is true whether we look at our past, when we lived alongside other humanoid species, or whether we compare ourselves to our closest modern relatives, the apes. In both cases, it has become clear over time that the qualities that we used to consider to be uniquely 'human' might not be so unique after all.

"There is no fundamental difference between man and the higher mammals in mental faculties.



JULIA MARGARET CAMERON

CHARLES DARWIN (1809-1882)
in his book 'The Descent of Man', 1871.

Free hands shaped our brain

Our upright gait is a prerequisite for almost all the physical traits that we consider unique to our species. The new way of moving was developed by southern apes, the forerunners of the Homo genus, and it provided various advantages. On the open savannah, an upright gait provides a much better view, making it easier to keep an eye on enemies or to spot food-giving trees from a distance. The upright gait is a more energy-efficient way of moving, so the southern apes and the first members of the Homo genus could travel further. But most importantly of all, the upright gait allowed the hands to be used for other purposes – carrying food and making tools. Fossils show that our ancestors' hands gradually changed as a result. The finger bones became straighter and the thumb grew longer, with the combination of forefinger and thumb then able to carry out new and more delicate motor function tasks.

At the same time as the evolution of the hands, the brain grew from a volume of about 500cm³ in southern apes to more than twice that in one of the earliest human species, *Homo erectus*. The growth of the brain continued for the next 1.5 million years until the arrival of species such as the Neanderthals and ourselves, in which the brain is an average of 1350cm³. The ongoing development of big brains was fuelled by new eating habits. *Homo erectus* consumed meat, and cooked food over a fire. The combination of a large inventive brain and the hand skills to realise new ideas laid the foundations of success for the human species.

This is obviously an abbreviated version of our success, which has culminated in feats such as space travel, the achievements of nuclear power and the internet: our species has done things that no other creatures on Earth could even conceive. We have conquered all the continents, and with a world population now of 7.84 billion people, our total biomass is six times that of all the world's wild mammals combined.

We deserve our own epoch

If, millions of years from now when humans are long gone, intelligent creatures were to examine our planet, they would discover how much we have influenced the Earth. They might find evidence of nuclear bombs, waste from nuclear power plants, and they could conclude that a human-made greenhouse effect changed the conditions of all life on Earth and caused the planet's sixth mass extinction of animals and plants.

This scenario made the Dutch atmospheric chemist Paul Crutzen propose in 2000 that our species be given its own geological epoch, known as the Anthropocene. His suggestion has not yet been officially accepted by the international geological societies, but working groups are defining the idea more accurately to give the idea momentum. For one thing they need to decide when the Anthropocene epoch began. They could choose to begin with the agricultural revolution 12,000 years ago, or with the industrial revolution from 1750-1830, or more specifically with the date of 16 July 1945, when the first nuclear bomb was detonated.

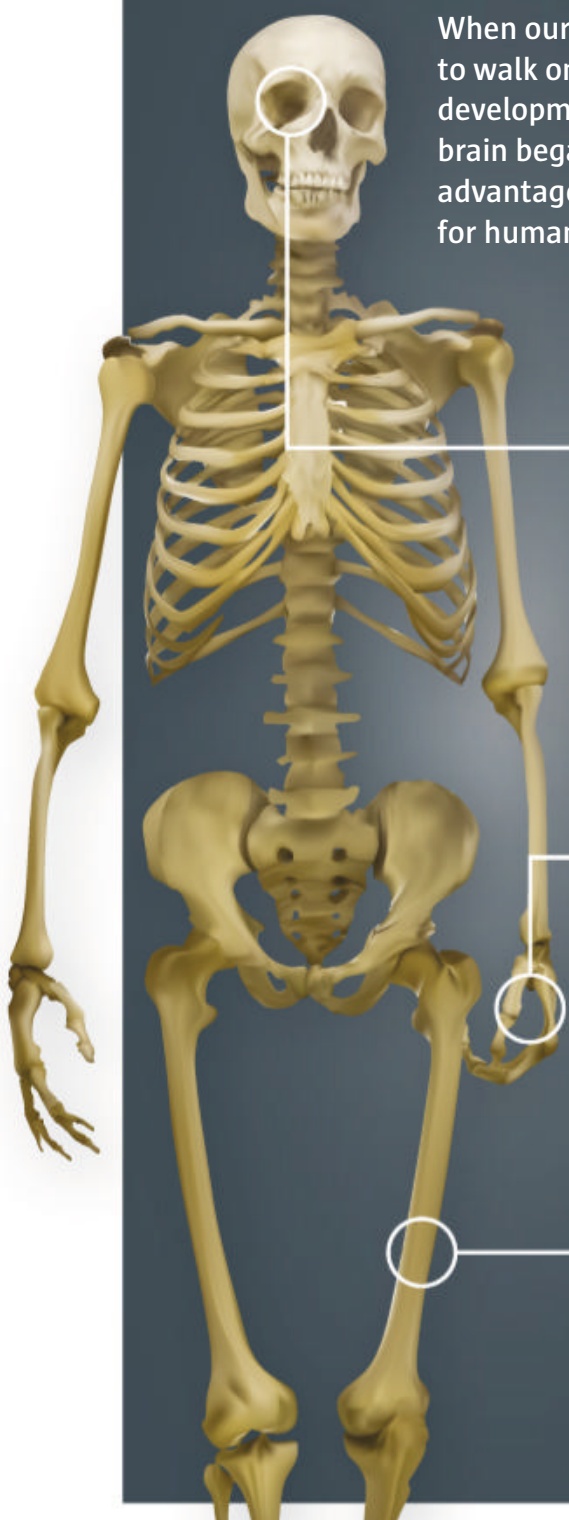
One specific talent has led to the notion that humans might deserve their own geological epoch: the ability to communicate. Our language is the key to each generation becoming wiser than the previous one. We pass all our discoveries, ideas and inventions on to our children, and then they do the same thing. In this fashion, knowledge can accumulate and accelerate rapidly.

Hence the development of language is often said to be a unique characteristic of our species. But scientists are not even sure when our articulated spoken language originated. It had been considered to have originated some 40,000 years ago, at the time when modern man suddenly began to create rock art and cave paintings. Such creativity demonstrates an ability for abstract

SHUTTERSTOCK

Upright gait bestowed huge advantages

When our ancestors began to walk on two legs, the development of a bigger brain began. Three particular advantages paved the way for human success.

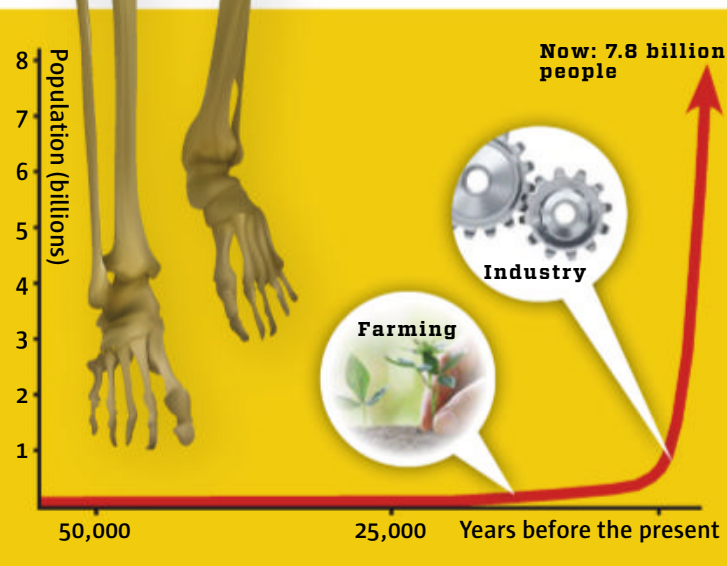


IMPROVED VIEW
On the savannah, an upright gait provided a much better view. Attractive fruit trees could be seen from afar, and predators could be spotted before they came too close.

FREE HANDS
Free hands allowed us to carry more. Group members could gather large quantities of fruit, while tools and children could be carried from one place to the next.

SURPLUS ENERGY
Walking on 2 legs requires less energy than walking on 4. Together with access to new food sources, this allowed the development of brains that require 20% of the body's consumption.

SHUTTERSTOCK



We conquered the world on two legs

The upright gait took humans to all corners of the world, but it was our inventions that made us numerous. With farming, our numbers began to increase, and with industrialisation, they exploded.

thinking and the use of symbols, and it is difficult to imagine that this is possible without being able to use a highly developed language.

Recent genetic research has changed this idea, indicating that language is much older. One specific gene known as FOXP2 has been carefully examined as a key to the development of language. The gene is common in vertebrates, but we have a special variant which both shapes and improves important nerve paths in the brain and produces the fine motor-skill control of tongue and lips that makes language and speech possible.

When the human variant of the gene was discovered in 2002, it was named 'the language gene', identified as originating within the past 200,000 years. But again, it turns out not to be so simple. We now know that the Neanderthals had a variant of the gene that is very much like ours, so the ability for sophisticated language originated before we parted from the Neanderthals – more than 500,000 years ago. And FOXP2 is a gene that cooperates with many other genes, perhaps hundreds, so the story of our language development is far more complex than scientists used to think. It seems likely that sophisticated language did not originate suddenly, rather developing gradually over hundreds of thousands of years after we parted from the apes.

So language is not unique to our species, and its gradual development means that the difference between ourselves and other species is blurred, as it is for many other mental abilities. This is consistent with ideas developed 150 years ago by the founding father of evolutionary theory, Charles Darwin. Darwin notably avoided mention of our own evolution in his 1859 work 'On the Origin of Species', but it was clear that he supposed us to have evolved from monkeys. In 1871, he published his work 'The Descent of Man', in which he determined that humans descended from an ancestor that we have in common with modern apes. So to Darwin, it was a logical consequence that our mental abilities are based on an inheritance that we share with other species.

"There is no fundamental difference between man and the higher mammals in their mental faculties," as he put it. Although those words would be largely forgotten during the century that followed, today they are becoming more relevant than ever.

Family tree branches are joined

We are a mere twig on a family tree that is more complex and ramified than we used to imagine. Not only that, but as we saw in issue #75 when examining definitions of life, different paths have parted from each other only to be joined again. The idea of such an entangled family tree appeared after we were able to make genetic analyses of bones from our extinct ancestors. In 2010, Swedish geneticist Svante Pääbo from the Max Planck Institute in Germany surprised the world with claims that all humans outside Africa include Neanderthal DNA. The discovery proved that our species had ▶

Our ancestors were not the fastest animals on the savannah, but they had endurance. The human body is customised for long-distance running. Bones, muscles, lung function and our ability to sweat ensure that we can run for longer than other animals.

mixed with another human species hundreds of thousands of years after they originally separated.

Since then other scientists have discovered that we also mixed with a third species, the Denisovans, who lived in Siberia at the same time as the Neanderthals some 40,000 years ago. Neanderthals and Denisovans also mated with each other, and they separately mated with other human species that scientists have not yet been able to identify.

In 2019, scientists found evidence of a common ancestor of the Neanderthals and Denisovans mating with an even older human species that originated some two million years ago, probably *Homo erectus*. If so, it means that two human species developed separately for a million years, but then mated and reproduced.

All these discoveries provide a new and complex version of our family tree, with a series of human species originating in Africa over time, migrating to the outside world, and adapting to local conditions. As new species arrived in an area, they mixed their genes with the local ones. The close contact probably benefitted both parties. The locals gained new, fresh genes which might be important to avoid problems with inbreeding, while newcomers received genes that might help them cope in the foreign environment.

The ability to turn abstractions into morals places us on a different planet from other species.

STANFORD UNIVERSITY

NEUROBIOLOGIST ROBERT SAPOLSKY
on the human brain compared to that of a monkey.

This makes it very difficult to delimit our own species, *Homo sapiens*, in a traditional, biological sense of the word. In 1942, German-American biologist Ernst Mayr introduced the biological species concept that says that two individuals belong to the same species if they can give birth to fertile offspring. This accurately defines horses and donkeys, say, as different species. They can have offspring – mules or hinnies – but the crossbreeds are usually sterile.

Maybe we are the same species

The fact that our own species bears witness to mixing genes with other species means that we might actually all be the same species, at least according to the biological species concept. The common offspring was apparently fertile, so the foreign genes were passed on to new generations. Hence *Homo sapiens* and *Homo neanderthalensis* would qualify as one species, rather than two.

Biologists know this problem from other animals which they would otherwise agree to be different species. In rare cases a brown bear and a polar bear meet in nature and mate. The result is a hybrid, known as a mocca bear – and it is fertile. Biologists still consider the brown bear and the polar bear to be separate species, justifying it with other species concepts, particularly the morphological and the ecological one. Using the morphological species concept, the two bears are clearly very different, not only by colour, but by size and body structure. They are even more different under the ecological species concept. The bears live in very different environments and have very different lives – to the extent that the one, the brown bear, is a terrestrial animal, whereas the other, the polar bear, is considered to be a marine mammal.

Our ancestors were not so different from the other human species that lived alongside. Some scientists even claim that if we took a Neanderthal male today and put him on a bus in a suit, nobody would notice that he was different from the other passengers.

This raises another question. If the different human types were so much alike, why was it *Homo sapiens* that went on to dominate the world while all the others became extinct? We do not have clear answers to this question either, as we discussed in issue #76. Scientists still know too little about our prehistoric relatives. We can only seek the key to our success by comparing ourselves with modern relatives, the apes. The closest of those are chimps and bonobos, from which we separated some six million years ago.

Our abilities are not unique – only next level

Kanzi loves the taste of marshmallows, and knows they taste extra good when he places them on a stick and toasts them. He can light the fire himself with matches, which scientists give him if he asks for them. His active vocabulary is 500+ words, and according to the scientists, he can understand thousands of words when he hears them.

Kanzi is not a human being – he is a bonobo, so he can't pronounce the words as we can. Instead, he uses a keyboard with symbols that he recognises. The 40-year-old ape lives at the Ape Cognition and Conservation Initiative research station in Iowa, USA. He has been surrounded by scientists for most of his life, as they try to find how human language and behaviour developed.

The lifelong experiment with Kanzi confirms that language is not an ability which is unique to our genus. The same goes for most of the other traits by which we usually define our own humanity.

We make war – but so do chimpanzees. Studies have shown that a group of chimps may launch an organised attack on another group, even exhibiting a brutality reminiscent of the genocides for which our own species has been responsible.

We can feel empathy – but again, so can chimps. If a dominant male punishes a family member that has provoked him, the other members of the group usually do nothing. But when he punishes somebody innocent, the other group members can be observed behaving in a comforting manner to the undeserving victim.

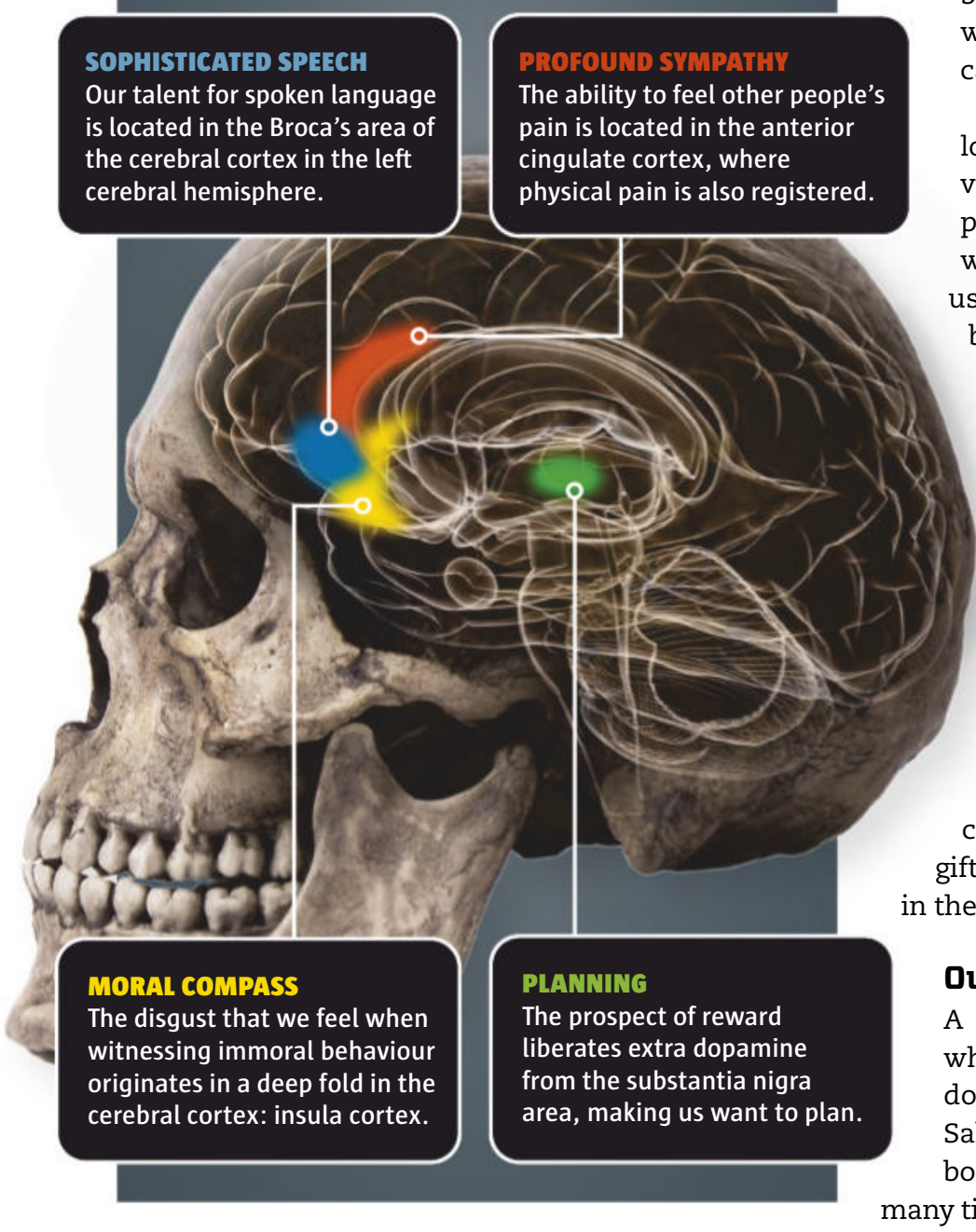
We develop culture – but so do chimps. When a chimp finds out how to crack nuts by hitting them with a stone, he teaches his family members to do the same thing. In other groups, other ways to use tools are invented and spread, such as the use of sticks to get termites out of termite nests. In this way, different groups of chimps develop different cultures.

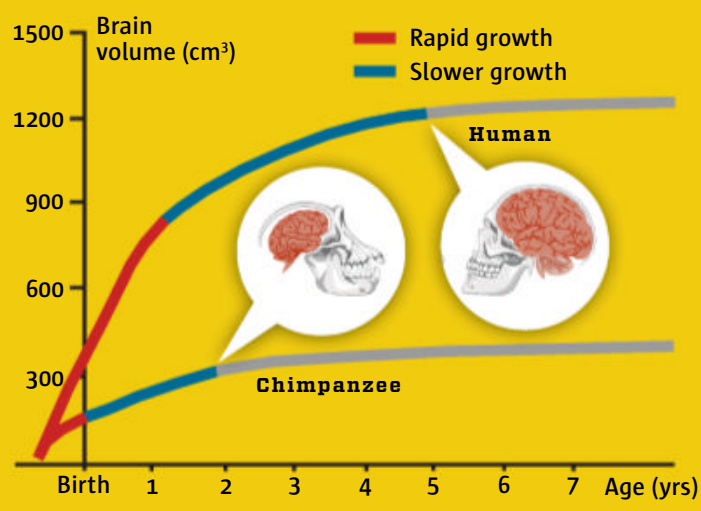
All such examples involve no fundamental difference between chimps' talents and our own, only slight differences, just as Darwin realised. However, it is clear

SHUTTERSTOCK

Our big brain has fine-tuned special talents

Our brain works in the same basic ways as those of apes, but the extra capacity has allowed us to develop our abilities further by using some brain regions in new ways.





Human brain requires plenty of time

The human brain not only grows faster, but also for much longer than that of chimpanzees. Not until a child is five years old does the growth tail off. This happens after only two years in young chimps.

that we have taken some of these common talents to higher levels. That happened as a result of our brain being larger, and also by us using it in new ways. According to American neurobiologist Robert Sapolsky, this is particularly true in two areas of the brain.

One is the anterior cingulate, located behind the frontal lobe and activated when we are, for example, stabbed in the finger by a needle. This works similarly in chimps and other animals, but in humans the area has been given an additional role – it also activates when we watch another person being stabbed. We can literally feel the pain of other people.

The second area is the insula cortex, also located deep within the brain, and this time activated when we smell or taste something rotten or potentally poisonous. Our reaction is disgust, which also manifests in other mammals. But for us the brain area has the additional feature of being activated when we witness something that we consider to be morally wrong. Hence we can feel disgust when we experience a behaviour that we find completely unacceptable. Robert Sapolsky believes that this moral reaction is a central mental tool in which the human brain is uniquely specialised.

"At the end of day this ability to take abstractions and turn metaphors into the most powerful moral imperatives places us on an entirely different planet from other species," he says.

And our ability to navigate within a morally-controlled culture is bestowed by specific social gifts that allow us to understand what is happening in the minds of others.

Our special mind-reading powers

A child watches a video of a doll named Sally, which places a glass ball in a basket, while another doll, Anne, is watching. The child now witnesses Sally leaving, after which Anne moves the ball to a box. This simple experiment has been performed many times, and reveals how sophisticated the thinking of young children can be. When the child is told that Sally is about to come back to find the glass ball, the child knows where Sally will look for it. A four-year-old child can predict that Sally will look in the basket, because the child knows that Sally does not know that the glass ball has been removed, and therefore Sally thinks that it is still in the basket.

Similar experiments with chimps show that they can only partly solve this problem. If a chimp watches another chimp watch where a treat is hidden, the first chimp knows where the treat is, and also knows that the other chimp knows it. But in experiments, in which the other chimp's knowledge is incorrect – as in the case with the doll Sally – the first chimp is not bright enough to find out. In other words chimps know what others know and what they can see, but not what they believe.

This ability does seem to be unique to humans. And it is key to our ability to teach each other things. Any learning process becomes far easier if the teacher knows what the student does and does not know and what ▶

No other animals are as handy as we humans. The upright gait allowed our hands to develop, so we became able to master the "tweezer grip" with the thumb and the forefinger. Our free hands might even have been the reason why it made sense to develop a larger brain.

the student thinks. In combination with patience and a well-developed language, this gives the best possibility of making the next generation smarter than ourselves.

Patience is also a virtue that humans are able to command to a much higher extent than chimps. Experiments show that chimps are willing to work to get a reward even if they don't know for sure that the reward will be given. When a button lights up in the primate house, and the chimp has learnt that pressing it 10 times may release a treat, it is willing to have a go no matter whether the treat is given in 75, 50, or only 25% of cases. Scientists have also designed experiments in which they measured the dopamine levels in the brains of chimps as they carried out the job. Dopamine is a neurotransmitter that provides animals and humans with a sensation of happiness. Interestingly it turned out that the sensation of happiness originated even before the reward was given, and the dopamine level increased with the degree of uncertainty. According to Robert Sapolsky the same is true in humans, only more so. We are driven by the joy of expectation, even when the likelihood of getting the reward is slim or in doubt. This explains a great deal about our behaviour – why we are enticed to play the pokies, and why we think buying a lottery ticket makes sense. But more usefully it may also give us the impetus to complete a long education in the hope of landing a well-paid job at the end.

“I do believe that there will be a time when robots are indistinguishable from humans.

HANSON ROBOTICS

ROBOTICIST DAVID HANSON, the man behind the humanoid robot Sophia.

Chimps and other apes and monkeys do not think in this way, and even a particularly gifted specimen such as Kanzi will not be able to learn to do so. That would require that apes develop larger brains, a process that will take time, assuming we leave it to evolution. However, there may be a short cut. With our modern gene technology, we can transfer human genes that could make their brains grow bigger. Although this sounds like science fiction, Chinese scientists have already taken the first steps towards developing such a new type of monkey.

In 2019, scientists transferred a human gene, MCPH1, to 11 macaque embryos. The gene is involved in regulating development of the brain, and the result was that the monkeys' brain growth took longer than in monkeys without the human gene. Such a very long period of brain development is characteristic of humans, where brain growth in children continues to the age of five, while in a young chimp it decreases past the age of two.

This type of experiment is highly controversial, and many scientists consider it also unethical. But five of the monkey embryos given the human gene survived and were born, so scientists could test their mental abilities. It turned out that they had improved their memory.

The next step will probably be that the monkeys are supplied with the human variant of the FOXP2 gene to see what happens to their language skills. The question will then be whether this kind of transgenic monkey will blur the definitions between animal and human, and then whether they deserve extra protection – such as human rights. As it is, humans share 99% of our genes with chimps; how much more is necessary for a chimp to qualify as human?

Should such experiments continue, the result may be a race between transgenic monkeys and humanoid robots to become the first to be accepted as our peers.

Robots will be given duties and rights

Sophia is an eloquent speaker. She has been interviewed many times; she has given lectures and appeared in talkshows. But for sociobots, it is not enough to be good communicators if we are to accept them as our equals. They must also have faces that look like our own. Hence Sophia's 'father', David Hanson, has given her a very human-like face and artificial skin; she can frown, lift her eyebrows, and form dimples when she smiles. Her camera eyes can recognise faces and read the expressions of the human being to whom she is talking.

David Hanson does not claim that Sophia is human, and Sophia's 'AI' has been accused by others of looking smarter than it is: she is just "a puppet", says Yann LeCun, Facebook's VP and Chief AI Scientist. But Hanson believes that she is a step towards 'sociobots' that deserve rights and duties. He predicts that at some point when Sophia travels with him, she will no longer be considered luggage, but will have to pay the full fare to travel in the aircraft's passenger compartment.

When Sophia was awarded her citizenship, it caused much speculation in the press: if a robot has citizenship, does it also have voting rights, or the right to marry? If someone turns it off, is that then murder?

Such questions have been examined in science fiction, notably Isaac Asimov's robot series, in which the author defined laws of robot behaviour which retain their influence on robot programming today. Many of his short stories revolve around situations in which the laws come into conflict. Robot engineers and programmers are now facing exactly these issues – science fiction has become science fact. But it will require both the artificial intelligence and the physical appearance to become more convincing before it becomes impossible to tell the difference between a humanoid robot and a human being made of flesh and blood.

Artificial humans must be perfect

A robot that looks very much like a human being, but still lacks something, will never be socially accepted. Robot researchers have known this since 1970, when Masahiro Mori of Japan introduced a phenomenon he labelled the 'Uncanny Valley'. This involves the observation that we become ever more fond of robots as they look more like us – but only to a certain point. When they become very human-like but we can still see that they are not humans, our emotions turn negative. This is why some find robots like Sophia somewhat scary. But on the other side of the Uncanny Valley, robots become so similar to people that we simply can't tell if they are robots or not. Then we have to be more sympathetic.

The effect has been proven in several experiments, and in 2019 scientists even managed to locate a place in our brain which seems to control it. By showing images of robots and 'artificial humans' (hyperrealistic human robots) to a series of test subjects while they were brain-scanned, scientists discovered that the activity in an area of the frontal lobe increased as the robots became ever more human-like – but then plummeted when an 'artificial human' appeared.

However impressive and life-like Sophia may be, it is still easy to see that she is not a human being. If we are to accept her and other sociobots as our equals, they must look even more like us than they do now – in their appearance, motions, and way of communicating. And that will happen, according to David Hanson.

"I do believe that there will be a time when robots are indistinguishable from humans," he says.

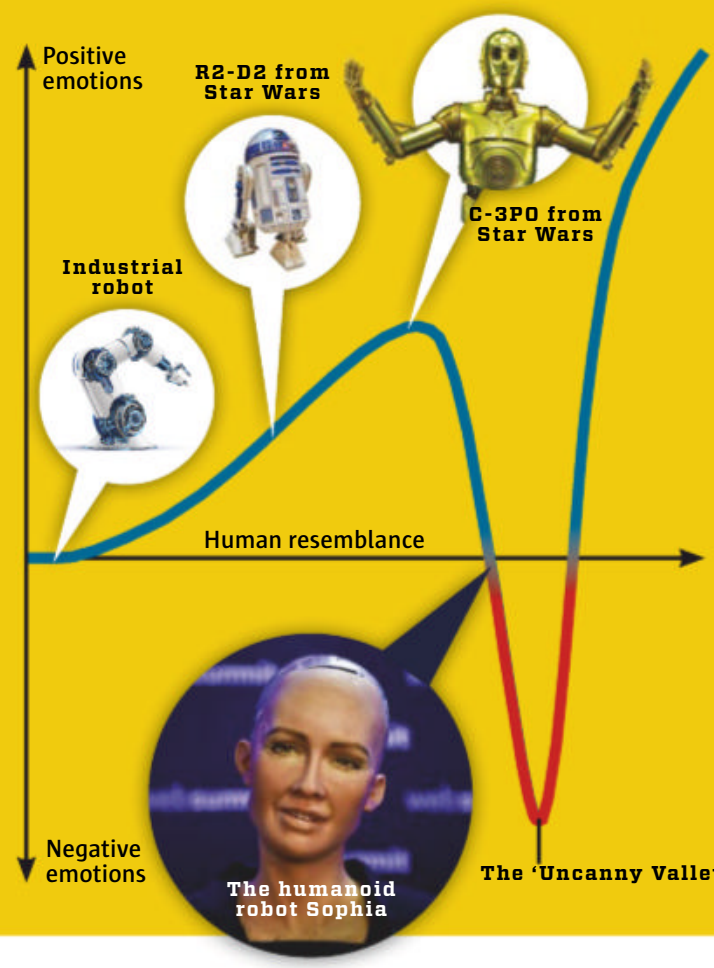
If he is right, it will be even more difficult to define the status of 'human' at all. The concept might need to include both robots and transgenic primates, covering a broader and more varied group of individuals – just as the term does for back when we shared the world with a series of almost identical types of human. SI

WATCH

This dancing robot video from Boston Dynamics went viral early this year. We like robots that act in human ways, but hyper-real 'artificial humans' can create fear and disgust: **tinyurl.com/sciencevid81**

Robots to cross the 'Uncanny Valley'

The more robots resemble us, they more we like them – but only up until the point when they resemble us very much. Scientists have named the phenomenon the 'Uncanny Valley'. Only when the robots become perfect imitations of humans will we accept them as our equals.



SHUTTERSTOCK & PATRICIA DE MELO MOREIRA/AFP/RITZAU SCANPIX

We will shape robotic humans

The humanoid robot Sophia is a good example of making our descendants look like us. The robot learns human thinking and behaviour, though some have criticised her level of AI as being just a "puppet". But robots will need both intelligence and perfectly human looks before we will accept them as 'human' citiens of the world.

VIT SIMANEK/CTK PHOTO/ALAMY LIVE NEWS/IMAGESELECT

Millions of years after our species becomes extinct, Earth will still bear clear evidence of humans. Consequently, many geologists believe that our species should have its very own epoch – the Anthropocene.

Bringing the MAMMOTH back to life

Dinosaur remains are too old to yield useful DNA, but it may be possible to revive more recently extinct animals. Woolly mammoths well-preserved in ice are prime candidates for an early return.

The last known mammoth died some 4000 years ago on a small Russian island in North Siberia. But perhaps we have not seen the last of this giant species. In 2019, scientists from the Japanese Kindai University in Osaka extracted bone marrow and muscle tissue from a 28,000-year-old mammoth named Yuka which had been excavated near the village of Yukagir in north-eastern Siberia. The scientists identified cell nucleus-like structures and inserted the least damaged of these into egg cells from mice. The cells subsequently showed signs of activity that normally precedes cell division, although they did not eventually reproduce. Nevertheless the scientists declared their experiment to be a "major step towards reviving mammoths".

George Church from Harvard University in the US hopes to take another key step in the revival of the woolly mammoth. In 2015, Church and his team of scientists managed to introduce DNA from a mammoth into an elephant cell by means of the CRISPR gene editing tool.

"Our purpose is to create a hybrid between an elephant and a mammoth embryo. It will be a kind of elephant with mammoth features," Church said about the experiment. In the years since then he has extracted new DNA samples from well-preserved mammoths, and he expects a mammoth revival to take place before 2030.

The DNA material for reviving extinct mammoths comes mainly from the Siberian permafrost, where millions of mammoth fossils are buried in a thick layer of ice that has halted or significantly slowed biological processes which normally follow death. Hence mammoth fossils recovered from the ice are often in very good shape.

The first mammoths originated as a subspecies of the African elephant some four million years ago. A million years later, the mammoth species *M. rumanus* was the first to leave Africa for Europe, and then over time extended its reach to Asia and North America, where new mammoth species evolved that were better adapted to the different temperature ranges.

The last and most famous mammoth species was the woolly mammoth that emerged in Central Asia and Central Europe some one million years ago. The woolly mammoth weighed 5-6 tonnes and was 3-4 metres tall, roughly the same as a modern African male elephant. Unlike its African peer, however, the mammoth had a thick fat layer and long thick fur that allowed it to keep warm even in freezing temperatures.

By the end of the most recent ice age some 10-12,000 years ago, the majority of the mammoths had disappeared. Research indicates that the woolly mammoths succumbed to a combination of intensified hunting activities and shrinking habitat due to climate change that made the ice recede and nutritious herbs disappear. We do not

In 2019, scientists inserted cell nuclei from the fossil of a mammoth named Yuka into mouse egg cells.

CYCLONAUT

// TOP 4 CANDIDATES

4 ANIMALS THAT MIGHT RETURN

Northern white rhino
Existed in: Africa
Extinct: 2018

Dodo
Existed in: Mauritius
Extinct: 1662

Passenger pigeon
Existed in: North America
Extinct: 1914

Moa
Existed in: New Zealand
Extinct: 1530

know exactly to what extent humans were hunting these huge animals, but we do know that the mammoth was much-coveted by Stone Age people. This was confirmed in 2019, when archaeologists discovered 824 mammoth bones and a possibly man-made mammoth trap in Mexico. Other discoveries such as spear marks on the bones of mammoth fossils make scientists suspect that humans may have contributed significantly to sealing the mammoths' fate.

On Wrangel Island – an Arctic Russian island in the East Siberian Sea – a small group of woolly mammoths managed to survive up until 2000 BC. The island formed part of the major Beringia landmass that linked Siberia and Alaska – i.e. Asia and North America. When huge quantities of

> **KEI MIYAMOTO**
> CHIEF RESEARCHER WHO INSERTED MAMMOTH DNA INTO MOUSE EGGS
>
> **A major step towards bringing the mammoth back from the dead.**

inland ice melted towards the end of the ice age, Beringia was flooded, and Wrangel Island was isolated – along with a few hundred mammoths.

According to American scientists from the University of North Carolina, these last mammoths on Earth died due to a series of harmful gene mutations, probably caused by inbreeding. The mutations meant that the mammoth ended up with thinner fur, digestion problems and a defective sense of smell, which made it more difficult to detect pheromones and identify a mate.

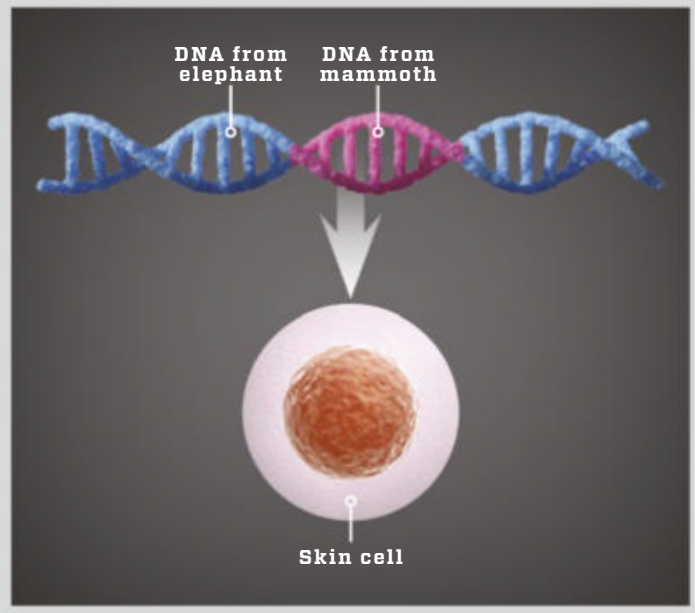
Yet now, thousands of years later, today's scientists are throwing a life-line to these extinct animals using the tools of gene technology and DNA research.

But one nagging question is whether it is wise to 'play God' and revive the old giants. Several biologists fear that a reintroduction of the mammoth could provide opportunities for new diseases, or simply unbalance ecosystems and drive other species over the edge. As the professor in Steven Spielberg's *Jurassic Park* says to the scientists behind the park's disastrous revival of dinosaurs: "You were so obsessed with finding out if you could do it that you never stopped to consider whether you should." SI

HOW SCIENTISTS WILL RECREATE THE MAMMOTH

Gene tool to design mammoth hybrid

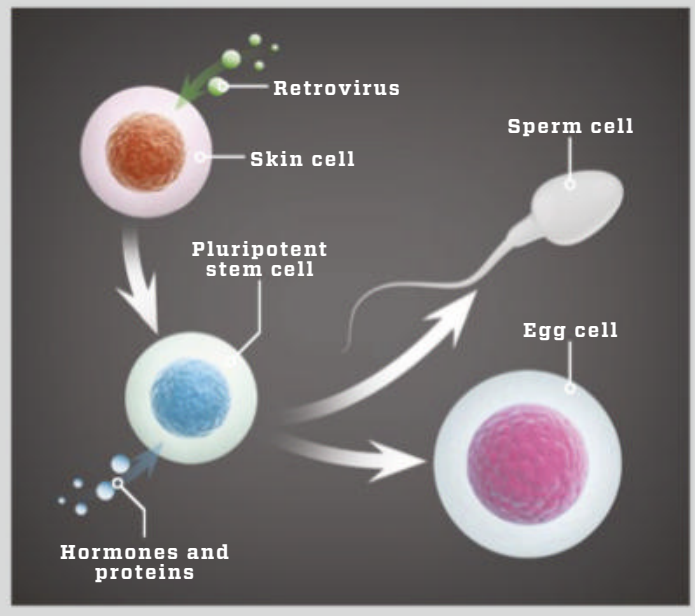
American scientists have already managed to splice DNA from a mammoth into DNA from an Indian elephant. The next step is to make a viable embryo grow inside a surrogate mother.



1

Splice mammoth and elephant DNA

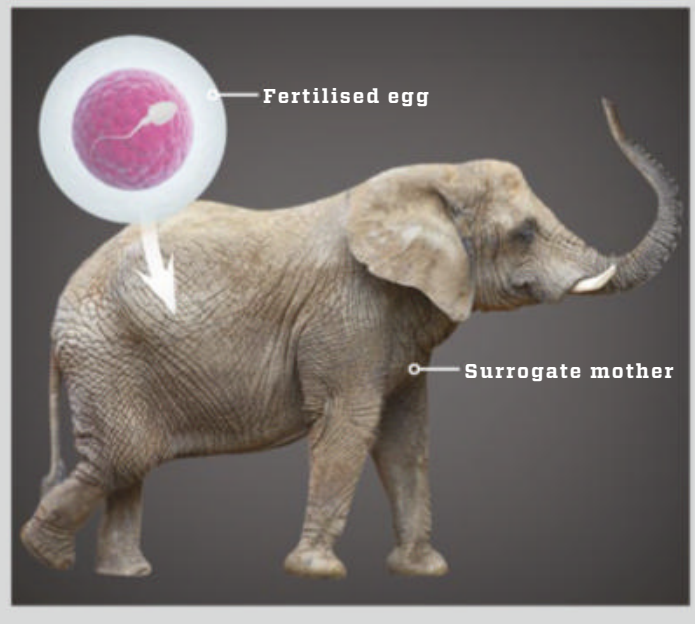
Genes that give the mammoth its specific characteristics are extracted from a mammoth fossil by means of the CRISPR gene splicing tool and inserted into skin cells from a modern elephant.



2

Convert the cells into sperm and eggs

The skin cells are supplied with a retrovirus, changing them into pluripotent stem cells which are subsequently stimulated with hormones and proteins to develop into sperm and egg cells.



3

Insert fertilised egg into surrogate mother

The egg cells are fertilised with the sperm cells, and the egg is inserted into the womb of a living elephant. 22 months later, the surrogate mother will give birth to a mammoth-elephant hybrid.

KEN IKEDA MADSEN

The CRISPR miracle method gets a much needed update, for

NO MORE CARELESS GENE ERRORS

Since 2018, two Chinese girls have been living with a series of DNA errors as the result of an unethical experiment with the CRISPR gene method. Scientists propose three new tools to prevent any more such incidents, and to take gene editing into a new era.

18+

WHAT IS AVAXHOME?

AVAXHOME-

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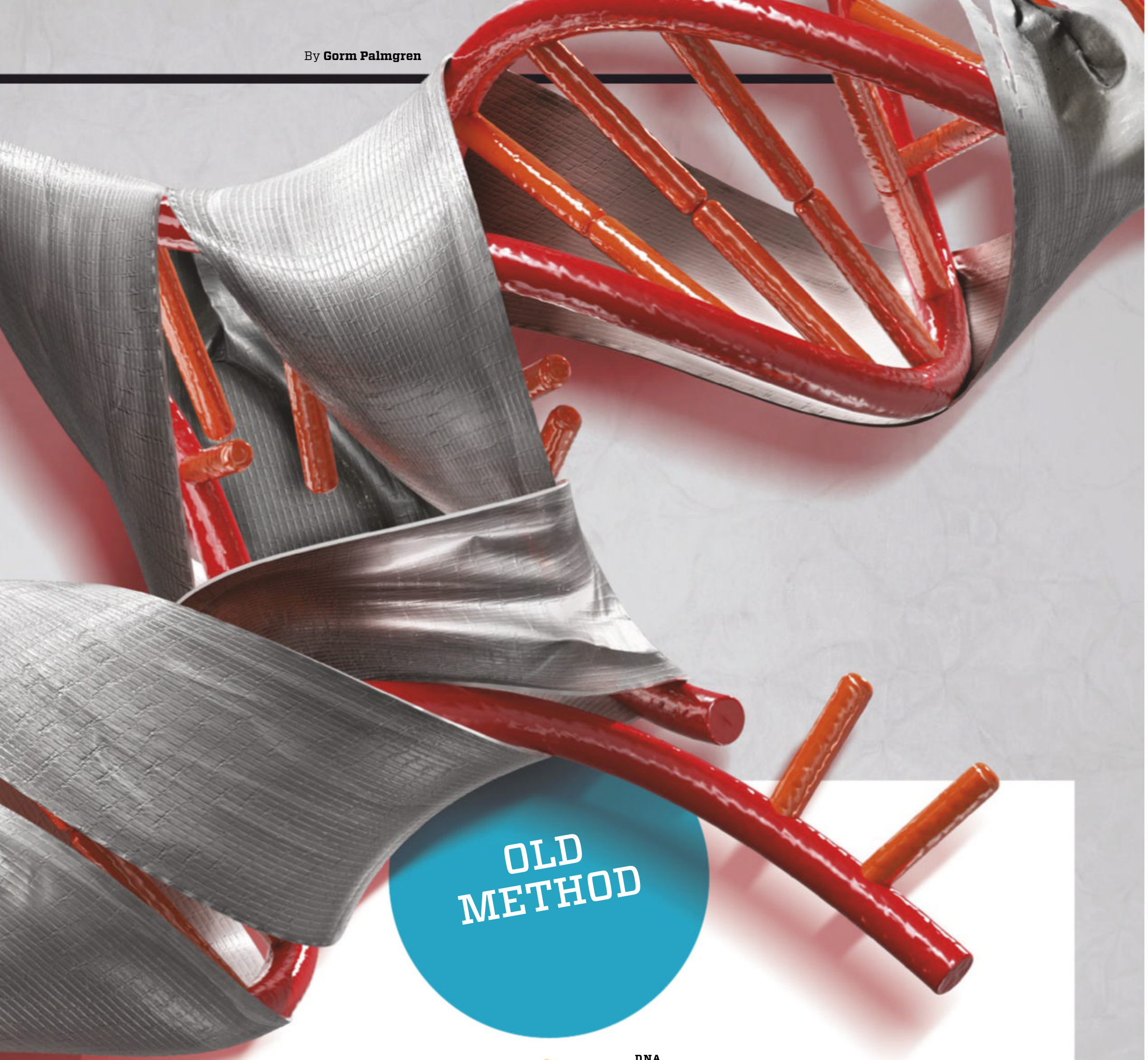
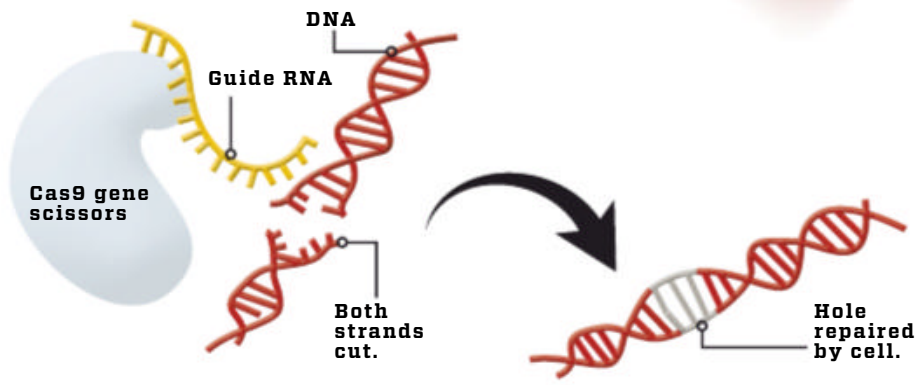
By **Gorm Palmgren**



OLD METHOD

Popular method is inaccurate

The CRISPR gene tool can alter your DNA, and has been hailed as a potential miracle cure against hereditary diseases. But the popular method is inaccurate and can cause gene errors.



Gene scissors cut DNA in two

1 The CRISPR method typically includes the Cas9 enzyme and a short RNA sequence. The RNA guides the enzyme to a specific place in a gene, and the enzyme cuts the gene in two.

Scientists lose control

2 The cell repairs the open wound itself by adding or removing DNA bases from the wound and gluing the ends together. Scientists cannot control the repair, and errors might easily occur.

CLAUS LUNAU & SHUTTERSTOCK

ANTHONY KWAN/BLOOMBERG/GETTY IMAGES

SHUTTERSTOCK

Only a few years ago, the idea of genetically-modified humans was pure science fiction. Now it is reality, because of CRISPR – a simple gene technology that has caused a scientific revolution over a period of less than 10 years.

CRISPR consists of molecular scissors that scientists can program to seek out a specific gene and then cut it in two – altering our DNA permanently. The method first saw serious application only in 2012, but so powerful did the technique prove that within a few years CRISPR formed part of thousands of scientific studies (and hundreds of patent applications) annually. Nearly 4000 studies involving CRISPR were published in 2019 alone. And the breakthroughs seemed endless, with scientists holding up the promise of cures against multiple genetic diseases.

But the wonder technology stumbled over its own feet. In 2018, the long list of promising results encouraged a Chinese scientist to test the method on human embryos. The controversial result was twins, who now have genes with characteristics that they would not otherwise have had. But the twins also provided living proof that the gene method involves key weaknesses that could cause permanent injury.

Despite the problems, CRISPR is still being tested on people. But scientists are working hard to update the method so it will not leave damaged DNA. Three updates are now ready to bring CRISPR back on track.

Lethal weapon became a success

CRISPR – which stands for Clustered Regularly Interspaced Short Palindromic Repeats – is not a new invention. Bacteria have used the system for millions of years as an efficient weapon against invading viruses – a weapon that can be aimed at the intruder to cut up its DNA. Elements of CRISPR were discovered by scientists in 1987, but not until 25 years later did they realise its potential.

3917

scientific studies involving CRISPR were published in 2018.

In 2012, biochemist Jennifer Doudna and microbiologist Emmanuelle Charpentier were the first to use the bacterial weapon to edit genes. CRISPR consists of an enzyme that can cut DNA in two, and RNA which can guide the enzyme to a specific DNA sequence. By adapting the RNA, scientists could make the enzyme cut the specific gene that they wanted to cut.

In 2013, biochemist Feng Zhang extended the method to allow the insertion of a new and designed DNA sequence into the gap that the enzyme had created. This new function is far from always used, however, partly because it remains unknown how efficient it is. Instead, scientists often leave the cell itself to repair the hole and cause a specific change of the gene.

Despite the method being in its infancy, scientists quickly began to test it on plants and animals. In 2014, American scientists cured mice of the tyrosinaemia metabolism disease by altering the Fah gene in liver cells of sick mouse offspring. In the same year, another team of scientists modified the PDS gene of oranges that controls maturation.

CRISPR was such a success that in 2016 Chinese scientists began to try the technique on humans. The scientists took immune cells from cancer patients, altered the cells' genes in the lab, and injected the genetically edited cells back into the patients. The experiment showed that the genetically-edited immune cells are harmless to the body – but it remains unknown whether the new cells can combat the cancer efficiently.

This first experiment with humans was a big step, but it was a relatively cautious one. CRISPR was injected into cells that had been extracted from the patients' bodies – rather than acting directly on the patients – and only a small percentage of patients' cells had their DNA altered.

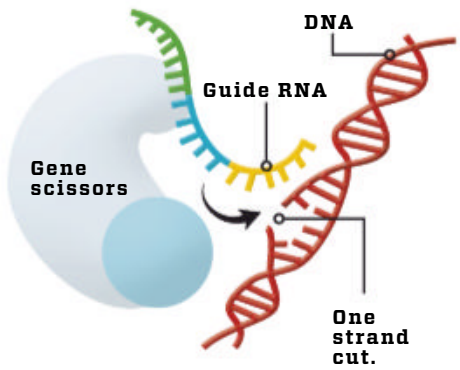
CRISPR causes errors in babies

That all changed in 2018, when a Chinese biophysicist, He Jiankui, became the first ▶

PRINTER

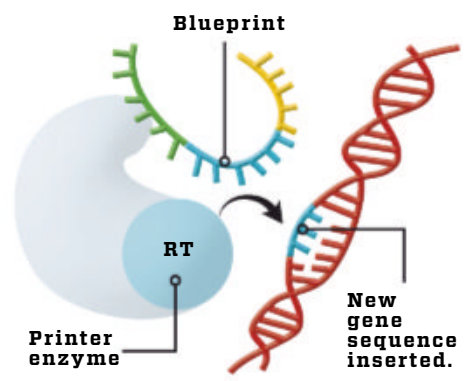
Genetic printer writes new code

Traditional CRISPR cuts DNA in two, leaving the cell to repair the damage and hopefully correct the gene error in the process. A new CRISPR variant, 'prime editing', only cuts one of the two DNA strands, then prints the correction directly into the gap.



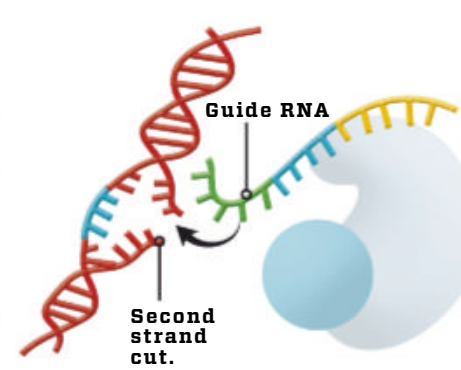
Gene scissors nick the gene

1 A new version of the Cas9 gene scissors is equipped with a long RNA sequence. It includes an element that guides the gene scissors to the place in the gene that scientists would like to alter. The gene scissors cut the gene, but unlike the old version of the scissors, they do not cut through the whole DNA. Instead, they cut only one of the DNA's two strands, also known as 'nicking'.



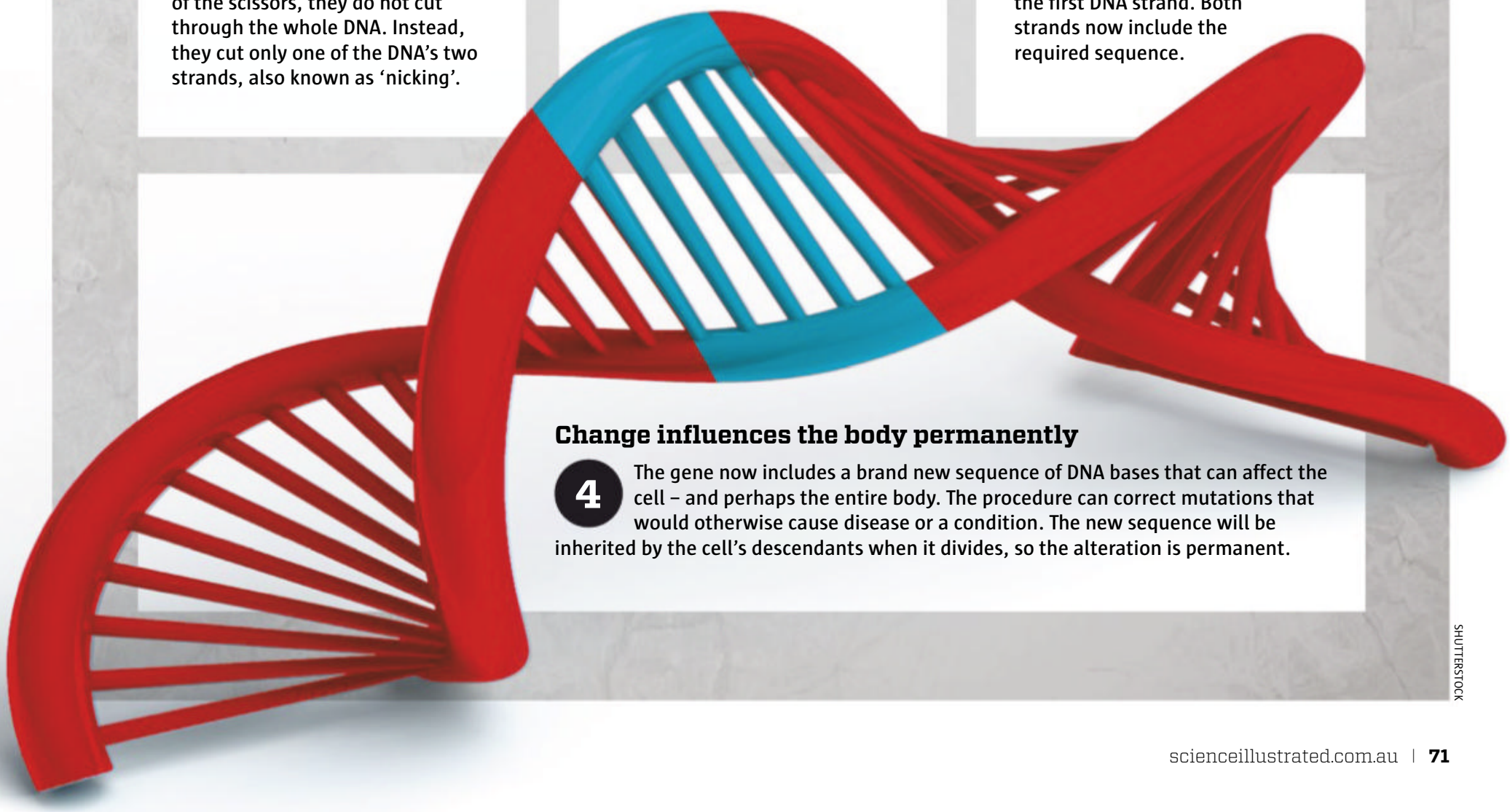
Enzyme prints new DNA in the gene

2 The RNA sequence also includes a blueprint of how to build the DNA sequence that scientists want to insert into the gene. The new sequence is printed directly into the gene by means of the reverse transcriptase (RT) enzyme that is attached to the gene scissors.



Second strand gets a copy of the change

3 A third element of the RNA sequence guides the gene scissors to the other side of the gene, so they can cut the other DNA strand in two. When that has been done, the cell copies the DNA sequence that was inserted into the first DNA strand. Both strands now include the required sequence.



Change influences the body permanently

4 The gene now includes a brand new sequence of DNA bases that can affect the cell – and perhaps the entire body. The procedure can correct mutations that would otherwise cause disease or a condition. The new sequence will be inherited by the cell's descendants when it divides, so the alteration is permanent.

SHUTTERSTOCK

KNIFE

Scalpel leaves the DNA alone

CRISPR changes DNA permanently, and any careless errors will remain for the rest of your life. A new method avoids the problem by editing at a later stage, without touching the original DNA.

SHUTTERSTOCK

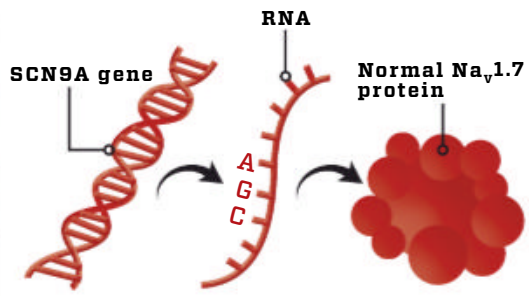
Scientists might be able to treat headaches and other temporary conditions with temporary gene alterations.

CATERS/RITZAU SCANPIX

CRISPR is now being tested on patients with a specific type of hereditary blindness known as LCA10. The treatment aims to correct a gene defect and so potentially allow patients to see.

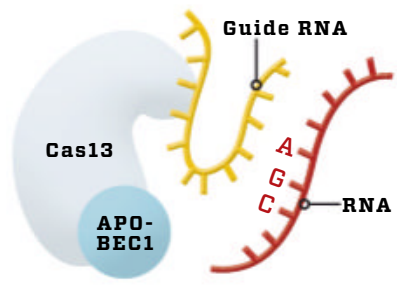
scientist to create humans that had been genetically edited through and through. His aim was to create babies resistant to HIV virus. He intended to use CRISPR to cause a specific mutation of the CCR5 gene in fertilised egg cells from a donor. This mutation exists naturally in some people – primarily Europeans – and it confers total or partial protection against HIV. He set to work in early 2018, and in October of the same year the world's first genetically-edited babies were born: a pair of identical twin girls.

Scientists throughout the world were shocked. He Jiankui was sentenced to three years in prison for unethical research, and a detailed report of his experiments was never published. Leaked information indicates that the scientist may never have reached his goal of making the twins resistant to HIV. The CRISPR tool did not cut quite as expected, and instead of the desired mutation, the girls got other CCR5 mutations, the effects of which scientists have not yet mapped out. And further, the gene



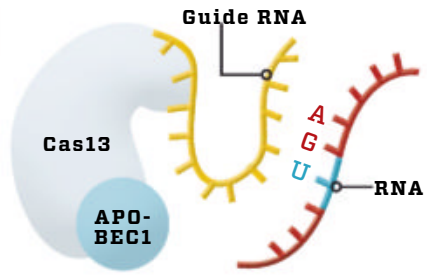
Genetic code is copied to RNA

1 The cell translates the DNA of a gene into RNA, which produces a protein. Reading of the SCN9A gene leads to the formation of the $Na_V1.7$ gene, important for feeling pain.



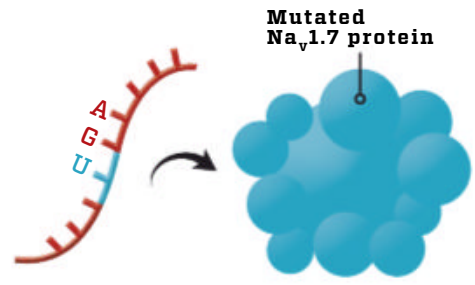
Enzymes are guided to RNA sequence

2 Scientists link the Cas13 and APOBEC1 enzymes, equipping them with RNA that guides the enzymes to the RNA sequence which produces the $Na_V1.7$ protein.



Scalpel converts one letter into another one

3 The enzymes settle close to the RNA sequence, and the APOBEC1 enzyme nicks one of the RNA bases so that one letter of the code is altered from a C to a U.



New code produces painless protein

4 The cell translates the altered RNA code into a protein, but the change of RNA means that the protein has also changed – and the new protein suppresses pain signals.

technology caused at least one other extra mutation in a totally different position in the DNA. According to some scientists, He Jiankui has probably overlooked a series of other extra mutations in the twins' DNA. So He Jiankui may have introduced a series of harmful mutations by mistake, errors that could now be present anywhere in the girls' bodies – including in the reproductive cells that might one day form the basis of the girls' own children.

Hope for fortunate mutation

The case of the twins emphasised CRISPR's weaknesses, and moderated enthusiasm for the new technology.

But scientists do have a pretty good idea of where the editing goes wrong. The most widespread version of CRISPR uses an enzyme by the name of Cas9, which comes from the bacterium *Streptococcus pyogenes*. Cas9 slices DNA in two, producing two loose ends with completely clean cuts. When the DNA has been cut in this way, the cell will try to repair the damage, but the clean cuts provide a challenge. The cell may combine the loose ends with entirely different DNA that has suitable clean cuts, causing new and unexpected DNA sequences and combinations. The cell will also often remove DNA bases from the loose ends, or add new bases to the ends to be able to more efficiently glue the two ends together. The result is changes in the DNA over which scientists have no control; the scientists can only hope that the required gene mutation results. The success rate depends on the changes they want to make, but typically they only get the intended result in a few per cent of the cells that undergo the CRISPR treatment.

1303

patent applications including CRISPR were recorded globally in 2017.

A low success rate is acceptable when scientists treat cells in the lab, where they can carefully select the few cells with the right mutation. It is more problematic when CRISPR is to be injected directly into patients with a genetic disease. In those cases a low success rate could have unintended and serious consequences. With the further risk of unintended mutations in other places of the DNA, such treatment could prove more harmful than beneficial.

New CRISPR makes cautious cuts

So several scientists are working to fix the most severe weaknesses of the method. One of the major breakthroughs has been made by chemist David Liu, who developed a new and more accurate variant of CRISPR: ▶

called prime editing. Liu's method uses a new version of the Cas9 enzyme that cuts only halfway through, so that only one of the two DNA strands is cut. Unlike traditional CRISPR, such prime editing does not produce two loose ends that can be combined with different DNA by mistake.

The Cas9 enzyme also carries a blueprint within it for the new DNA sequence that the scientists would like to insert into the gene, along with an additional enzyme which can build the new DNA sequence based on this blueprint.

Finally, Cas9 cuts the other strand of the DNA in two, and the required change is also inserted there.

18

patients with the LCA10 disorder have had CRISPR injected into their eyes.

In 2019, David Liu showed how he could use prime editing to exchange one single DNA base in a gene with a success rate of up to 55%. The chemist also designed a system to remove or insert entire sequences of DNA bases – and this performed with a success rate of up to 78%.

Liu's method is already employed by other scientists. In 2020, Dutch scientists used the method to correct gene errors in small fragments of sick tissue that they had extracted from patients and cultivated in the lab. The scientists were able to insert three extra DNA bases in the DGAT1 gene and thereby remove the genetic reason for a severe hereditary type of diarrhoea that makes it almost impossible for the carrier to absorb nutrients from food.

Gene editing that avoids genes

The risk that CRISPR creates permanent damage to the DNA can also be lowered in a completely different way: by creating genetic changes without changing the gene itself.

Genes function as blueprints for the formation of proteins, and usually the ultimate aim of editing a gene is to change the protein. In 2017, biochemist Feng Zhan developed a CRISPR variant that can alter the protein by interfering with a step in between the reading of the gene and the making of the protein. When the cell produces a protein, it first translates the gene in question into an RNA sequence that then carries the gene's instructions to the cell protein factory. Zhang's new method corrects the RNA sequence, rather than the gene itself. The result is the same, but with the advantage that unlike DNA, RNA is continuously broken down in the cells. When scientists stop the treatment, all their changes will disappear, and the cell will not have any permanent damage to its hereditary material.

The method seems obviously applicable to treatment of diseases that require a change of the proteins of cells only for specific periods of time – for headaches, say, or other types of pain in which proteins involved in nerve cell pain signals can be temporarily altered or invalidated.

A third new CRISPR variant can affect the formation of proteins without edits to either DNA or RNA sequences. Instead, it removes methyl groups – small molecules that stick to the DNA and prevent a gene being translated into RNA and protein. The method has already been used in the lab to clear the FMR1 gene of methyl groups. When this gene is blocked, it can result in fragile X syndrome – a condition that can cause intellectual challenges.

But the third method has still greater potential. Methyl groups play an important role in many conditions from autism to cancer, and a method for removing them could lead to treatments that are unimaginable using traditional CRISPR.

CRISPR in your eye

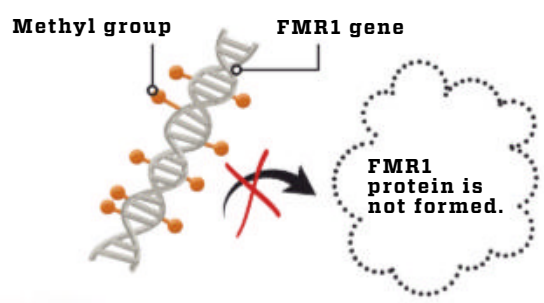
The race to improve CRISPR needs to be a quick one, given that the method is already being increasingly tested on people. In March 2020, American ophthalmologist Mark Pennesi initiated an experiment by which CRISPR is injected directly under the retina of the eye. This technique was used on a series of patients who suffer from a type of blindness known as LCA10, or Leber congenital amaurosis 10. The condition is caused by a congenital mutation of the CEP290 gene. The CRISPR treatment aims to cut this mutation out of the gene in the patients' retinas, so the patients might be able to regain their eyesight. The method has proved promising in mice, but there are not yet any positive results from the experiment in humans. Hopefully it works as planned, but there remains some risk that it could cause new and unwanted mutations in the patients, just as in He Jinankui's Chinese twins. SI

Boys with fragile X syndrome have an average IQ below 55.

JOHN BIRDSALL/SPL & SHUTTERSTOCK

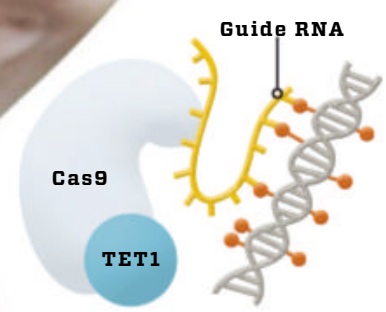
Molecular lawn mower pulls out the weeds

CRISPR corrects DNA errors, but not all genetic diseases are due to genetic code errors. People with fragile X syndrome have a perfect FMR1 gene – but the gene doesn't function correctly because of a molecular block on the DNA. A new type of CRISPR aims to break down these blocks.



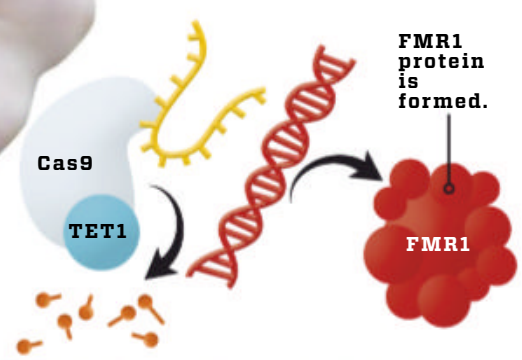
Unwanted molecules deactivate important gene

1 Fragile X syndrome, which can cause intellectual disability, is due to methyl groups covering the FMR1 gene. This covering deactivates the gene, so the cell doesn't form the protein for which the gene codes.



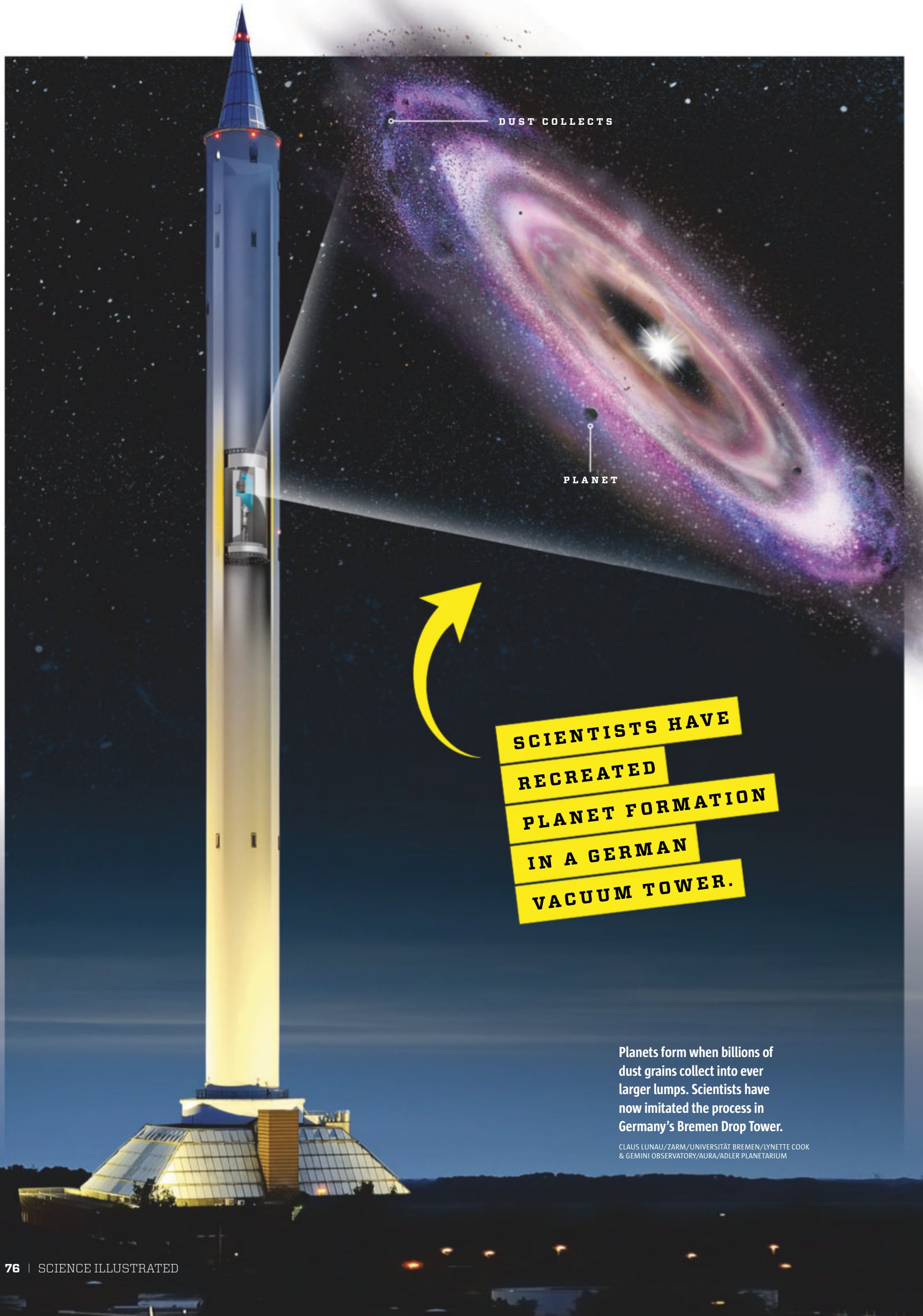
Merged enzyme tracks down sick DNA

2 Scientists send a modified CRISPR tool into the cells. It consists of guide RNA that can track down the FMR1 gene, plus an inactive Cas9 enzyme attached to another enzyme known as TET1.



Sharp cutting blade removes block

3 The TET1 enzyme removes the methyl groups from the gene. When the gene has been released, the cell can once again read its code and form the protein, which can then carry out its normal job in the cell.



SCIENTISTS HAVE RECREATED PLANET FORMATION IN A GERMAN VACUUM TOWER.

Planets form when billions of dust grains collect into ever larger lumps. Scientists have now imitated the process in Germany's Bremen Drop Tower.

CLAUS LUNAU/ZARM/UNIVERSITÄT BREMEN/LYNETTE COOK & GEMINI OBSERVATORY/AURA/ADLER PLANETARIUM

By **Mikkel Pedersen**

How to grow a **PLANET**

Scientists know that Earth was created in a cloud of particles that came together – but how? They have been unable to explain the process, but now a 'planet delivery room' has shown a familiar electrical phenomenon at play.

In a cold dark spot far out in the universe, one dust grain strikes another. They stick together, and travel forward on their combined path through the darkness. Another dust grain joins them. Then another. And another. Once this process has repeated many billions of times, a 'baby planet' will have formed. This may collide with other 'babies', growing bigger all the time.

So was planet Earth formed. According to the theory, all planets begin their lives as dense clouds of dust and gas left over from star formation. So far so good, but there's a problem. When scientists try to recreate the moment of birth in the lab, such small groups of dust grains reject each other. Why?

A breakthrough has been made inside a a 146-metre-high tower in Bremen, Germany, where scientists have made glass spheres collect as if they were baby planets. The scientists' experiment seems conclusive proof of the planet formation theory, and the results may even suggest how life could germinate in other solar systems.

Planets are born in dust clouds

For centuries, astronomers have tried to solve the mystery of planet formation. In 1664, philosopher and mathematician René Descartes' published his theory that the universe was once full of swirls of tiny particles that collected together to form the Sun, the Earth, and the rest of the Solar System. Descartes' fundamental idea has aged well. Over the years, various hypotheses have been rejected, refined and exchanged, and astronomers now have a dominant theory known as 'growth'. According to the growth theory, tiny dust and gas particles collide in the clouds surrounding new stars. The groups of particles grow ever bigger, finally forming a core that varies in size depending on the distance to the star. The closer to the star the planet forms, the smaller it becomes – just as we see in our Solar System.

To a large extent this simple explanation can explain planet formation. When the dust grains are smaller than 1mm, they collect due to a phenomenon known as adhesion, by which the charges of different materials' molecules cause attraction. Adhesion is the same force that makes tiny dust particles collect into the fluff you find in the corners of your home. Once the groups of particles have grown to diameters of a few kilometres their gravity comes into play, the mutual attraction with other particle groups promoting more rapid growth.

However, the growth theory encounters a problem when experiments attempt to simulate the growth theory. The particle groups begin to reject each other when they reach diameters around 1mm, like snooker balls bouncing off each other. To solve the problem, scientists from the German University of Duisburg-Essen have tested a new hypothesis: static electricity can make the dust grains hook up like billions of tiny magnets, overcoming the problem of rejection.

Glass spheres catapulted in tower

If you rub a balloon against a wall, it will pass electrons to the wall, so the balloon becomes positively charged and the wall negatively charged. The phenomenon is also ▶

How can scientists examine what happens without gravity?

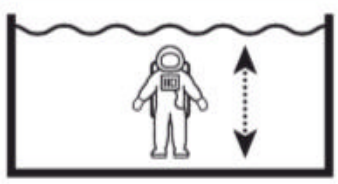
When scientists want to find out how things behave in a state of weightlessness, they can send experiments to the International Space Station, use planes that fly in arched paths, or immerse experiments in the type of water tanks in which astronauts exercise. The space station is in a constant free fall towards Earth, but because the station accelerates slightly it will never fall down, but rather continues in its orbit. Planes simulate weightlessness by taking an arched path up and down – a parabolic path. At the peak of the path, everything inside the plane behaves weightlessly. Water tanks are used by aerospace engineers and astronauts who test technology, spacesuits and flight training. In the tanks, the lift of the water neutralises gravity.

Free-fall space station

The International Space Station is in a free fall in its orbit around Earth.

Free fall recreated

Planes can simulate a free fall by taking arched paths up and down.



Weight eliminated

In water tanks, gravity and lift neutralise each other.

SHUTTERSTOCK & LASSE ALEXANDER LUND-ANDERSEN

known as static electricity, and it makes the balloon 'stick' to the wall. The same principle applies in a cloud of tiny particles that can 'give' and 'take' electrons, becoming positively and negatively charged, and subsequently collecting into tiny magnets. The principle was used by the German scientists in an effort to recreate the birth of a planet. The scientists placed glass spheres with diameters of 0.4mm in a chamber that was shaken for 10 minutes by means of a metal coil. The scientists directed a current through the coil, which surrounds a magnet. The electricity produced a magnetic field that reacted with the magnet, causing vibrations. The shaking in the chamber imitated the collisions between dust grains in the early childhood of a planet. The collisions between the glass spheres produced static electricity. Some of the spheres became positively charged, whereas others became negatively charged.

Experiment catapulted 120 metres

The scientists now had a collection of tiny particles that had built up static electricity, but they lacked another important step to recreate the conditions during the birth of a planet: the removal of gravity. The solution was the Bremen Drop Tower, which is 146 metres high and includes a chamber of 120 metres height that can be emptied of air almost completely. Scientists built their test set-up in 1.6-metre-high metal capsules that were hoisted to the top of the tower and dropped – or catapulted up only to fall down again. The acceleration means that the experiments are subjected to a mere one millionth of the usual gravity, so that they are effectively weightless.

5

million years was the length of time it took for billions of dust grains to collect into Earth.

The Bremen Drop Tower thereby imitates the conditions in space more easily and affordably than a flight in NASA's famous 'Vomit Comet' reduced-gravity aircraft, and scientists from all over the world have been flocking to Bremen to test their hypotheses about weightless phenomena.

The Duisburg-Essen scientists used the Bremen Drop Tower to catapult the test set-up with glass spheres inside the tower. During the total 9.3 seconds it took the capsule to pass up and down again, the breakthrough happened. Static electricity made the weightless spheres collect in groups of 1000+ tiny glass spheres. Groups of this size are big enough to attract small particles solely by means of their gravity. The scientists had demonstrated that static electricity can explain how planets are born. The snooker problem is overcome.

Experiments assist search for life

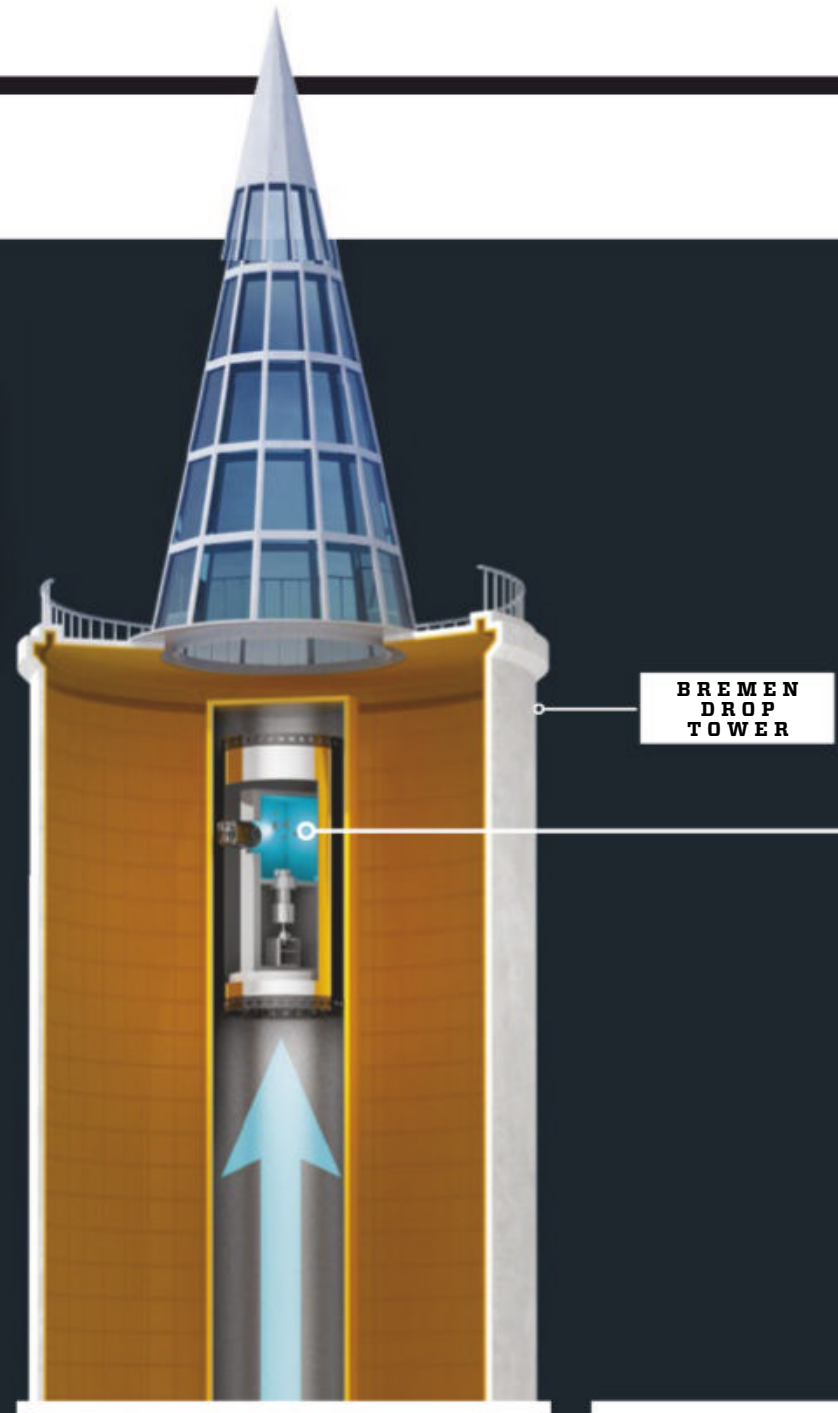
Danish scientists have discovered that growing planets will continue to 'attract' dust even after having grown many kilometres in size – which doesn't fit with the theory that planets such as Earth form in collisions between 'baby planets'. The discovery provides new support for an extended theory of growth. And furthermore the Danish results indicate that Earth's creation was unlikely to have been a unique event. Earth-like planets may have formed in the same way in other solar systems. And if the planets formed in the same way as Earth, the likelihood of them including liquid water increases. Astronomers now have an additional clue that could point them in the direction of other life in space. SI

Danish scientists have shown that Earth formed from dust grains which collected over five million years – much faster than previously believed.

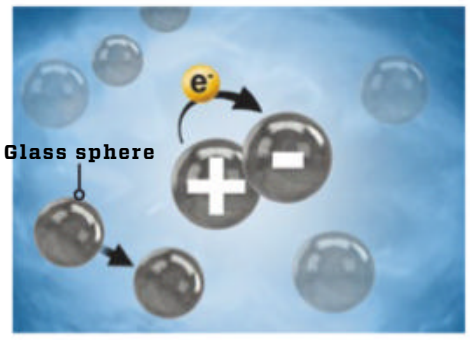
STARPLAN/GLOBE INSTITUTE/UNIVERSITY OF COPENHAGEN

Scientists make mini planets

Planets form in huge clouds of tiny dust grains that collect into larger units. Physicists have recreated the scenario in the Bremen Drop Tower, in which small glass spheres collect when in a state of weightlessness.

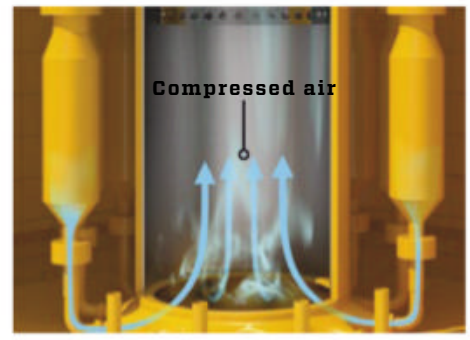


CLAUS LUNAU



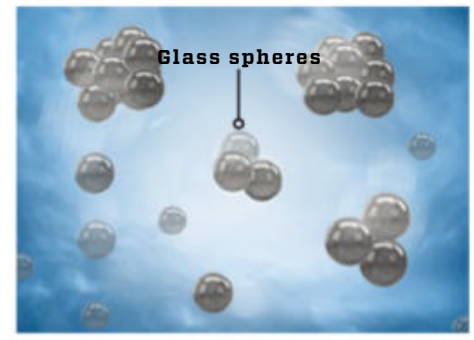
Glass spheres become statically charged

1 Thousands of glass spheres with diameters of 0.4mm are placed in a chamber that is shaken for 10 minutes, making the spheres collide. Some spheres transfer electrons to others, so some of the balls become positively charged, others negatively charged.



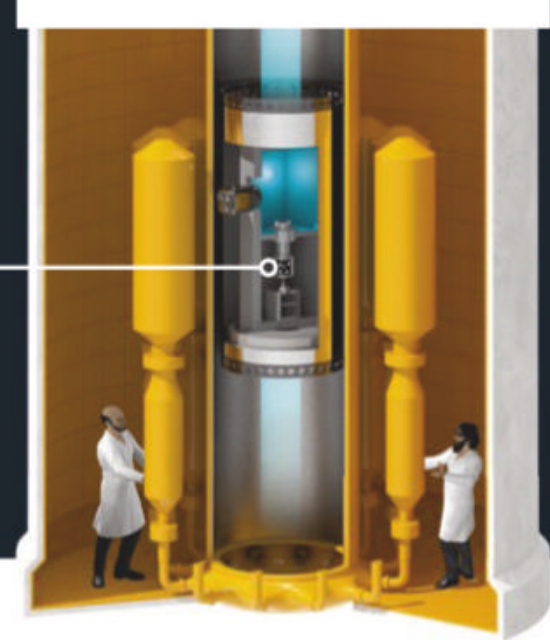
Catapult shoots spheres 120 metres up

2 A piston uses compressed air to launch an experimental capsule including the glass spheres at a speed of 168km/h. The spheres are directed into a larger chamber where a camera shoots 180 times a second. The capsule is in a weightless free fall for 9.3 seconds.



Spheres collect like small planets

3 The glass spheres behave like magnets due to their electric charges. In the weightless chamber, the glass spheres begin to collect into groups of up to 1000 spheres. Such groups are big enough to produce their own gravity and attract more spheres.



At the bottom of the Bremen Drop Tower, compressed air tanks can launch experimental capsules at a speed of 168km/h.

EARTHQUAKES move space and time

Earthquakes originate along the plate boundaries of Earth's crust. The most intense tremors can move and shake entire regions to such an extent that they interrupt Earth's rotation, and can reduce the length of a day on Earth by a few milliseconds.

The 1960 earthquake in Chile lasted for 10 minutes and rated at least 9.5 on the Richter scale – an underground tremor so intense that it altered Earth's mass distribution, accelerated the planet's rotation around its own axis, and reduced the length of the day by 1.26 microseconds.

"The entire world appeared as if God had seized one end of it like a rope and slung it as hard as he could," an eyewitness later said.

In the wake of the earthquake came tsunamis of up to 10 metres height. The waves hit the coasts of Chile first, but spread out to later cause havoc as far away as Hawaii, the Philippines and Japan.

That 1960 earthquake killed 1700 people, injured 3000 more, and left upwards of two million without a home. And although it was the strongest yet recorded, it was not by any means the first or the last time the nation has been shaken by an earthquake. Off the west coast of South America, three of Earth's crust's tectonic plates border each other. All earthquakes originate at such boundaries. The tremors occur when built-up tension in Earth's crust is released by the plates either moving away from each other, colliding, or touching each other.

The most powerful earthquakes typically originate when plates collide and an ocean plate that makes up the bottom of the ocean is forced under a much thicker continental plate that forms Earth's surface. Such a plate boundary is known as a subduction zone, and that's the kind of boundary which exists close to Chile.

Earthquakes are measured by means of seismographs. A simple seismograph consists of a mass suspended from a spring. When the earth trembles, the frame of the seismograph moves in proportion to the mass. The strength of the earthquake is calculated by measuring the maximum impact on the seismograph and comparing it with the distance to the earthquake. By recording precisely when the tremor reached different seismographs, scientists can calculate the location of the earthquake's epicentre. The magnitude of an earthquake was long defined on the Richter scale developed in 1935 by seismologist Charles Francis Richter, but this has more recently been judged as only locally relevant (to California) and unable to provide accurate estimates for large magnitude earthquakes. Today the moment magnitude scale, abbreviated M_W, is widely preferred, and is applicable globally.

Since 1900, Earth has experienced slightly more than 10,000 powerful earthquakes, with a few of the worst in this millennium. The

CHILE 1960: The severe earthquake near Valdivia levelled the city and left two million people homeless.

GETTYIMAGES

// 3 FACTS ABOUT

THE WORST EARTHQUAKES

- **Chile, 1960:**
  Where: Valdivia.
  Strength: 9.5
- **Alaska, 1964:**
  Where: Prince William Sound.
  Strength: 9.2
- **Indonesia, 2004:**
  Where: Sumatra.
  Strength: 9.1

By **Andreas Ebbesen Jensen**

most fatal ever struck Indonesia in 2004, causing the 'Boxing Day' tsunami through the Indian Ocean that ended up killing around 230,000 people. In 2010 and 2011, Chile and Japan were affected by some of the most powerful quakes of modern times, taking thousands of lives and causing destruction worth billions of dollars.

The global frequency of earthquakes is fairly constant – although it can vary a lot from one year to the next. According to the National Earthquake Information Center (NEIC), about 20,000 earthquakes take place annually, corresponding to 50 earthquakes a day. Statistically, a major earthquake of 8+ Richter will typically take place 0-0.2 times a year. Earthquakes of 7+ strike 10-20 times annually, whereas earthquakes of 6+ Richter are recorded about 150 times a year.

At the present point in time, it is still impossible to predict exactly where and

> **EYEWITNESS**
> EARTHQUAKE
> IN CHILE 1960
>
> **The entire world appeared as if God had seized one end of it like a rope and slung it as hard as he could.**

when a powerful earthquake will originate. So in cities and other areas which are located within a region known to suffer regular and powerful earthquakes, the best defence is preparation, with measures that can minimise the damage when the inevitable occurs.

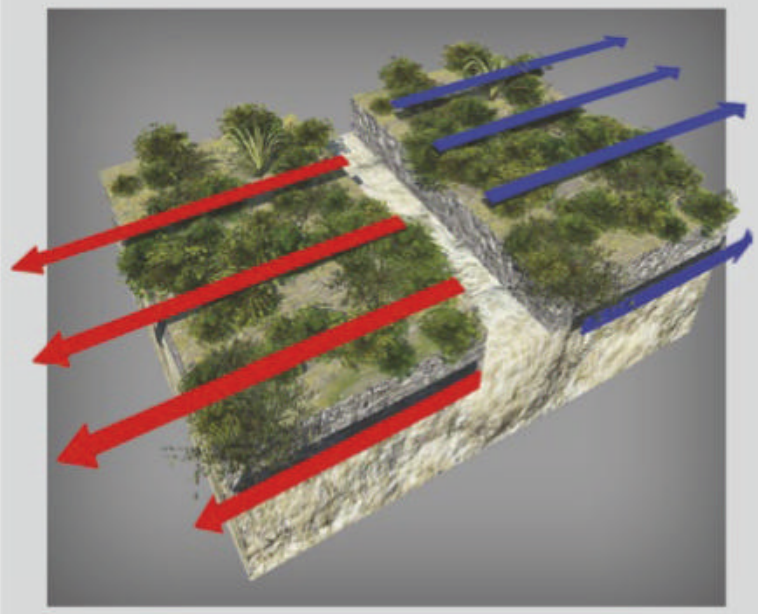
In Japan, and particularly in the capital of Tokyo, the authorities have long faced up to the consequences of being located in one of the world's worst earthquake zones. Nine out of ten large buildings in the city of Tokyo are earthquake-resistant. High-rises have pendulums on their roofs that are set in motion in case of an earthquake. These can neutralise a tremor so that the building will rock back and forth but not collapse.

Scientists agree that Tokyo will face an earthquake disaster eventually. Their estimates put a 70% risk on Tokyo being struck by an earthquake of 7.0+ on the Richter scale some time before 2050. As it says in the earthquake instruction manual that has been handed out to millions of people in Tokyo: "This is not a 'what if' scenario. It will definitely happen in the very near future." SI

// HOW EARTHQUAKES ORIGINATE

Tension in Earth's crust triggers earthquakes

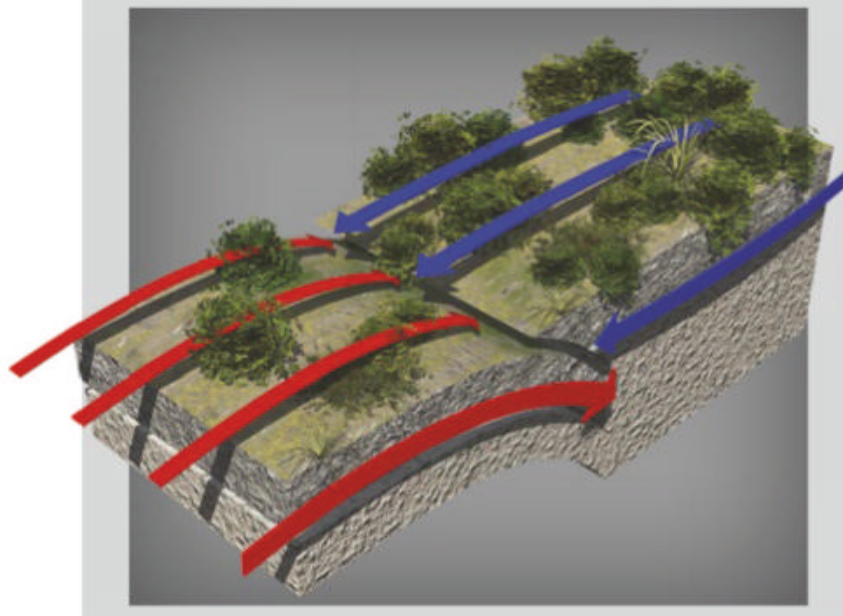
Most earthquakes originate in places where Earth's plates meet each other. Earthquakes originate by the plates moving away from each other, or colliding together, or rubbing against each other.



1

Plates move away from each other

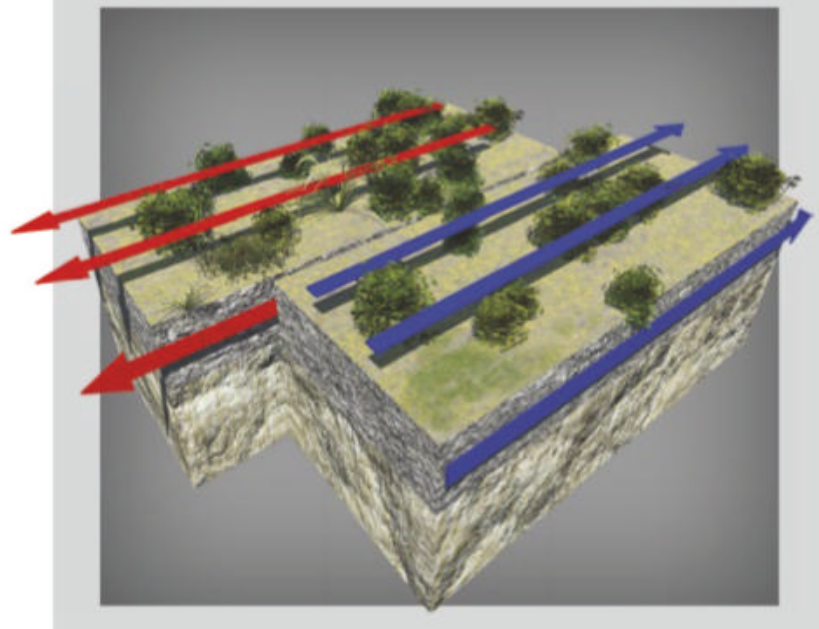
Liquid rock rises from Earth's interior, pushing the plates away from each other. These are also known as spread zones. Earthquakes are triggered in the plate between the surface and a depth of some 10km.



2

Plate forced under another one

The most severe earthquakes originate when one plate is forced under another one. These are known as subduction zones. In such places, earthquakes can occur from the surface and down to depths of some 700km.



3

Plates rub against each other

Two plates that slide horizontally alongside each other, rubbing against each other, are known as transform plate boundaries, and have a high risk of quakes. One famous example is the San Andreas Fault in California.

SHUTTERSTOCK

ANSWERS ON PAGE 11

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

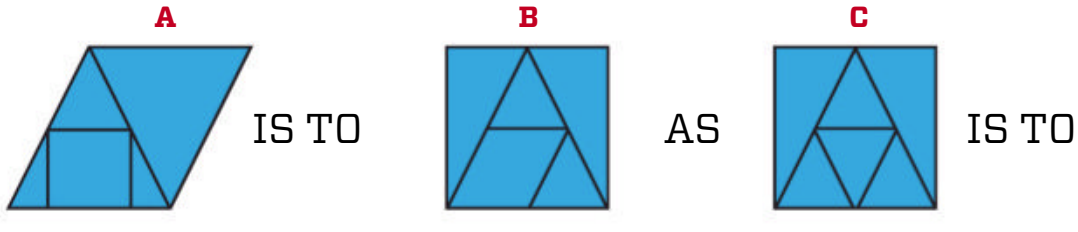
Editor: **David Dragsted**

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

NUMERACY

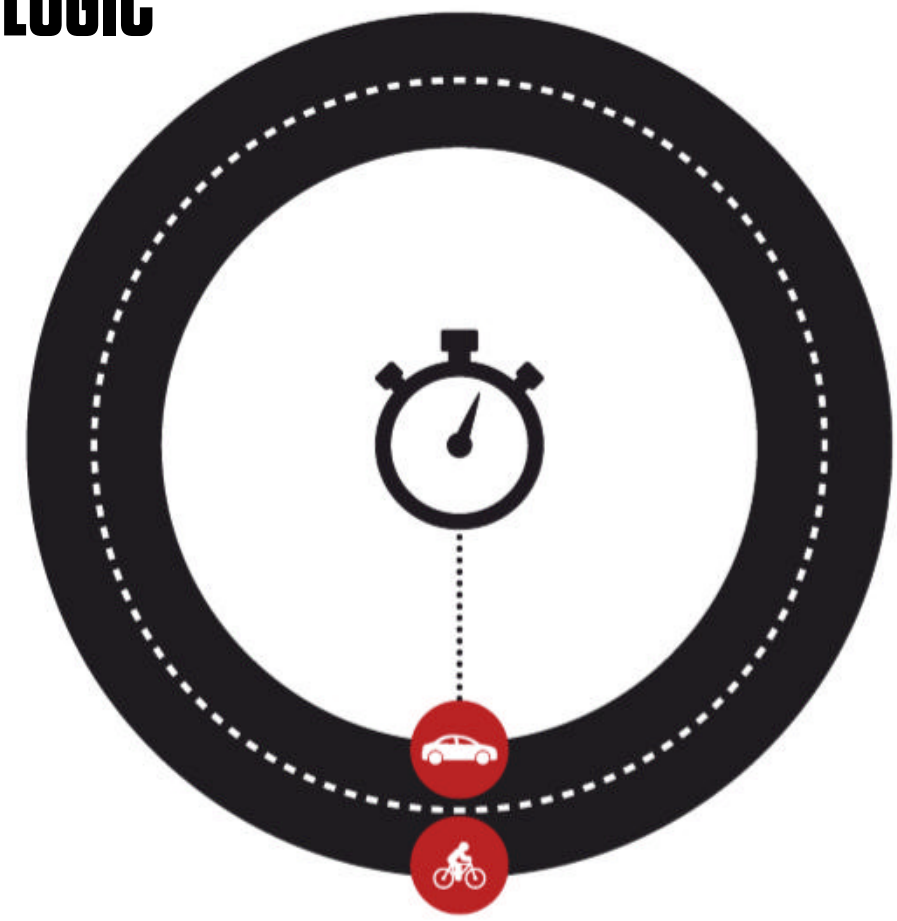
1 Gillian arrives for a bridge tournament, and immediately notices something about the chair numbers. Which number must replace the question mark, if the numbers are to make any sense?

VISUAL INTELLIGENCE



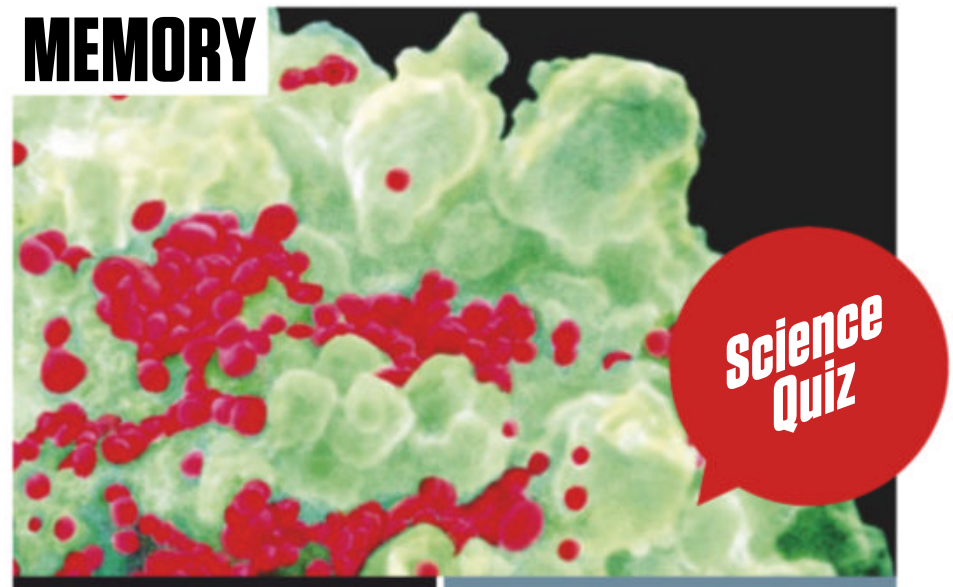
2 Diagram A is to Diagram B as Diagram C is to Diagram...?

LOGIC



3 A car and a bike are making laps on a test track. The car runs at a stable 144km/h, the bike makes a stable 36km/h. They are going in the same direction on the circular track. One lap is 36km for either vehicle, and both are allowed a preliminary run, so they have reached the above speeds when the race begins. They start at the same time, and the timekeeper is at the centre of the track. How long does it take before car, bike and timekeeper are again in a straight line at any point?

MEMORY



FROM THIS ISSUE Answers on p11: no peeking!

4 What is the outside (longest) estimate for how long ago the first virus may have appeared?

A) 1919
B) the 13th century AD
C) around 2000BC
D) 4 billion years ago

5 In some parts of Mexico, local families harvest 50-70kg per week of what?

A) Blind fish from deep wells
B) Chili peppers
C) Rubble from Trump's wall
D) Locusts

6 Which of the following may be developed as a new weapon against cancer?

A) Rancid pork fat
B) Honey-bee venom
C) Orchid pollen
D) Space travel

7 How long ago are the last mammoths thought to have died, sending the species extinct?

A) 1919
B) the 13th century AD
C) around 2000BC
D) 4 billion years ago

COMING UP

ISSUE ON SALE 1 APRIL 2021

TICKET TO THE MOON?

If you are wealthy and willing to tackle 15 weeks of astronaut training, you can now take a daytrip into space, or even book a week at the International Space Station. Where next for space tourism?

FEATHERED FRIENDS

25 years after the discovery of the first plumed dinosaur, scientists are still trying to pin down the origin and evolution of feathers. Is there a missing link still to be found?