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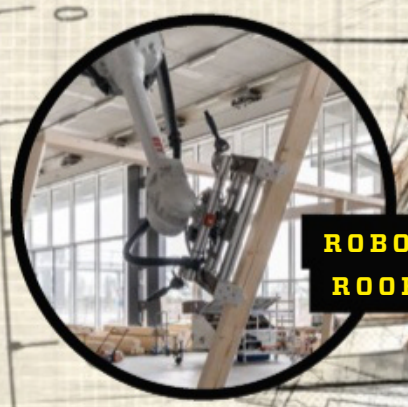

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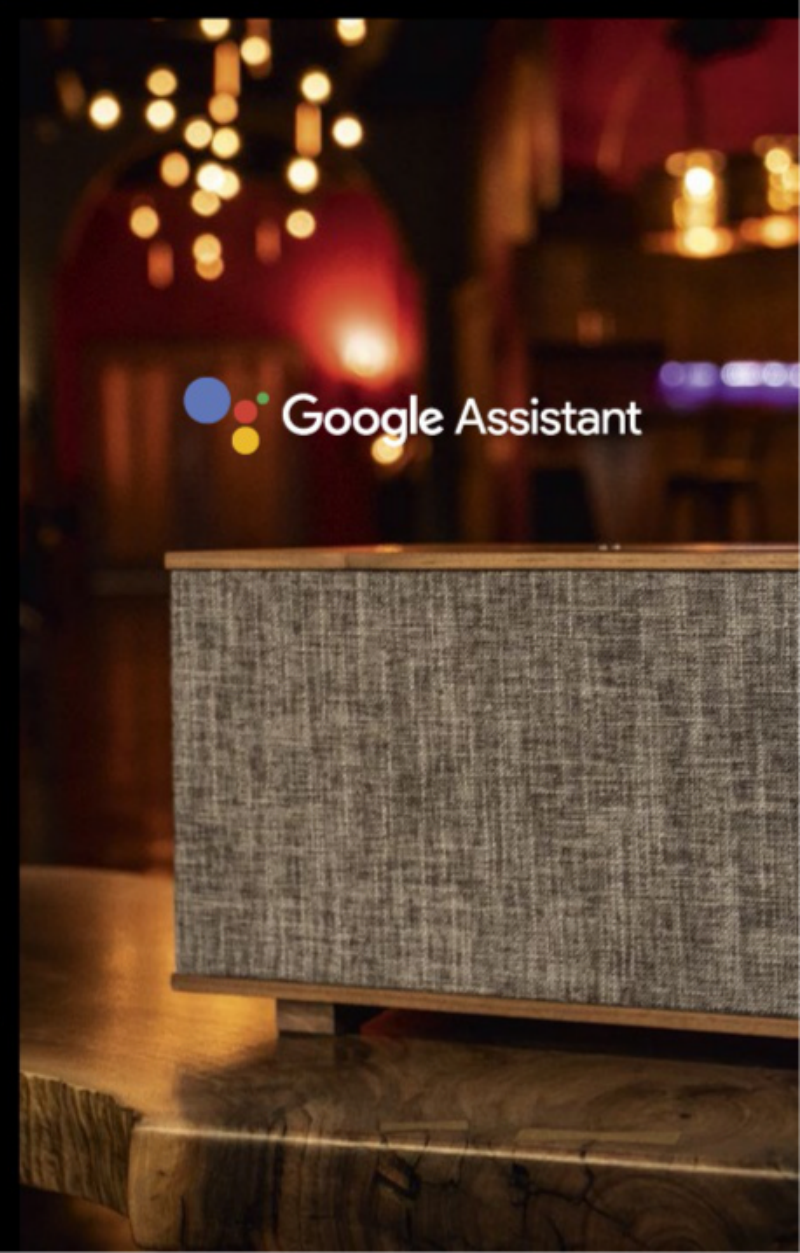

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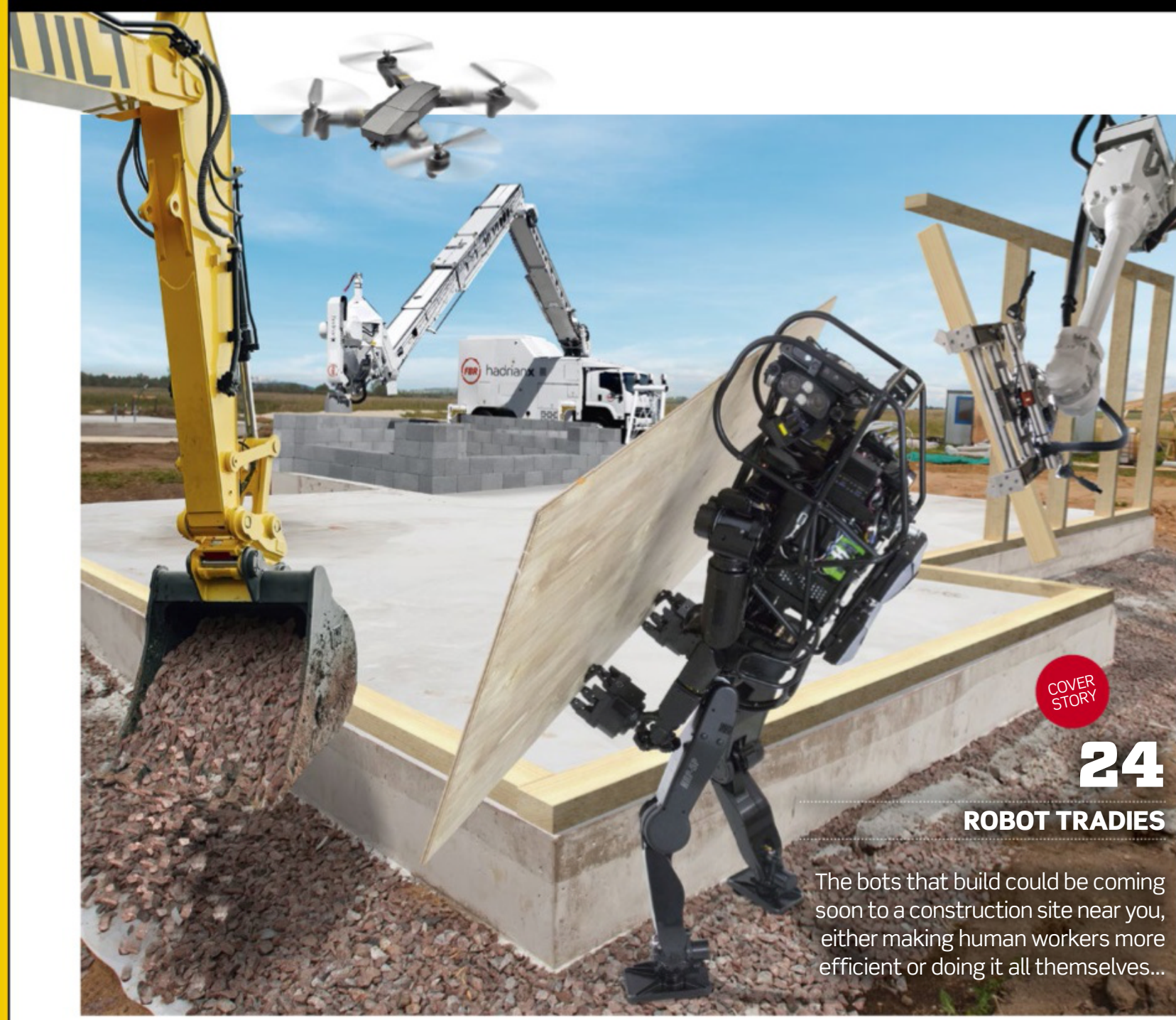
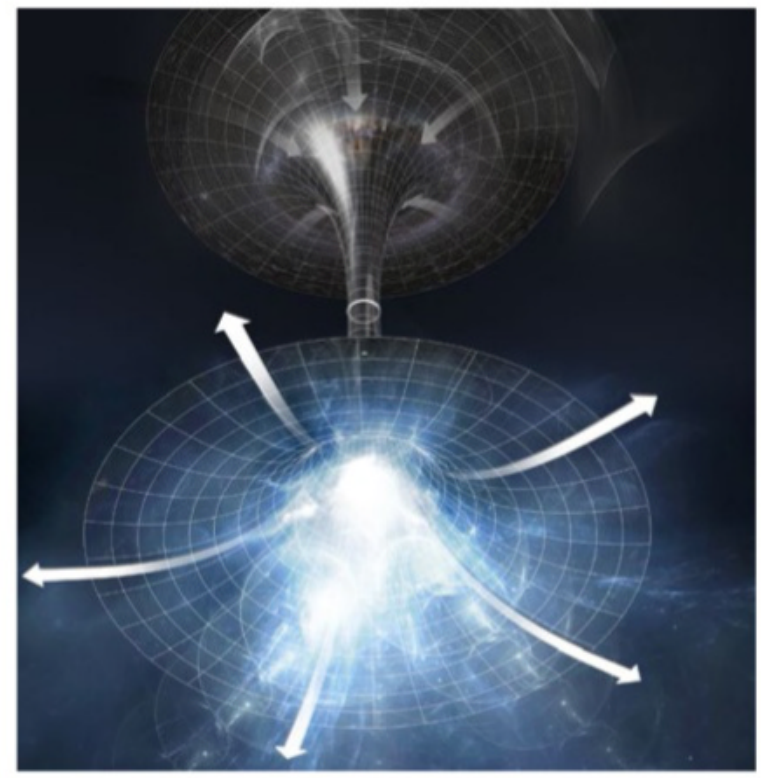


COVER STORY



REGULARS AND OTHER FEATURES

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THE SCIENCE ILLUSTRATED CREDO
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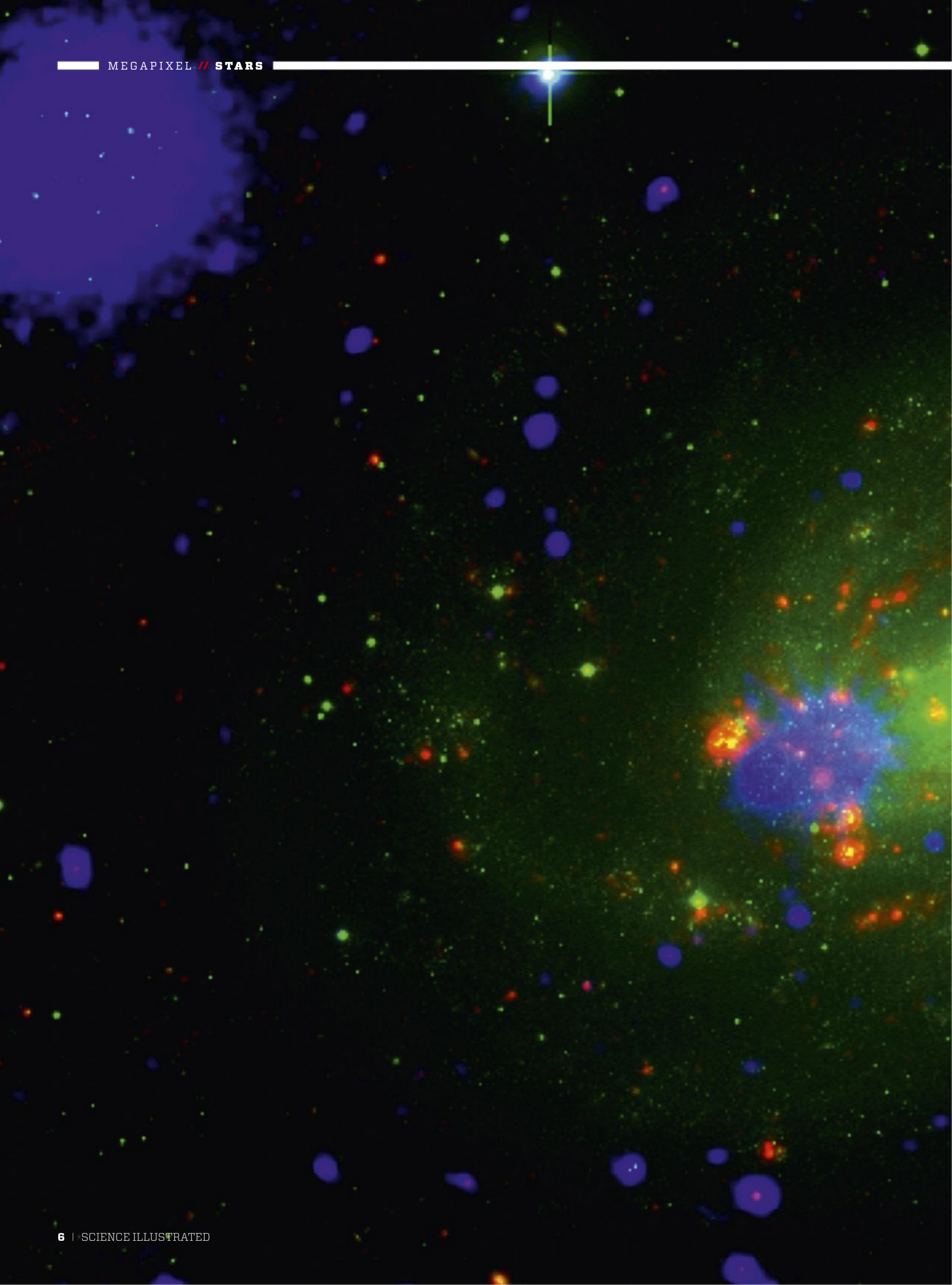

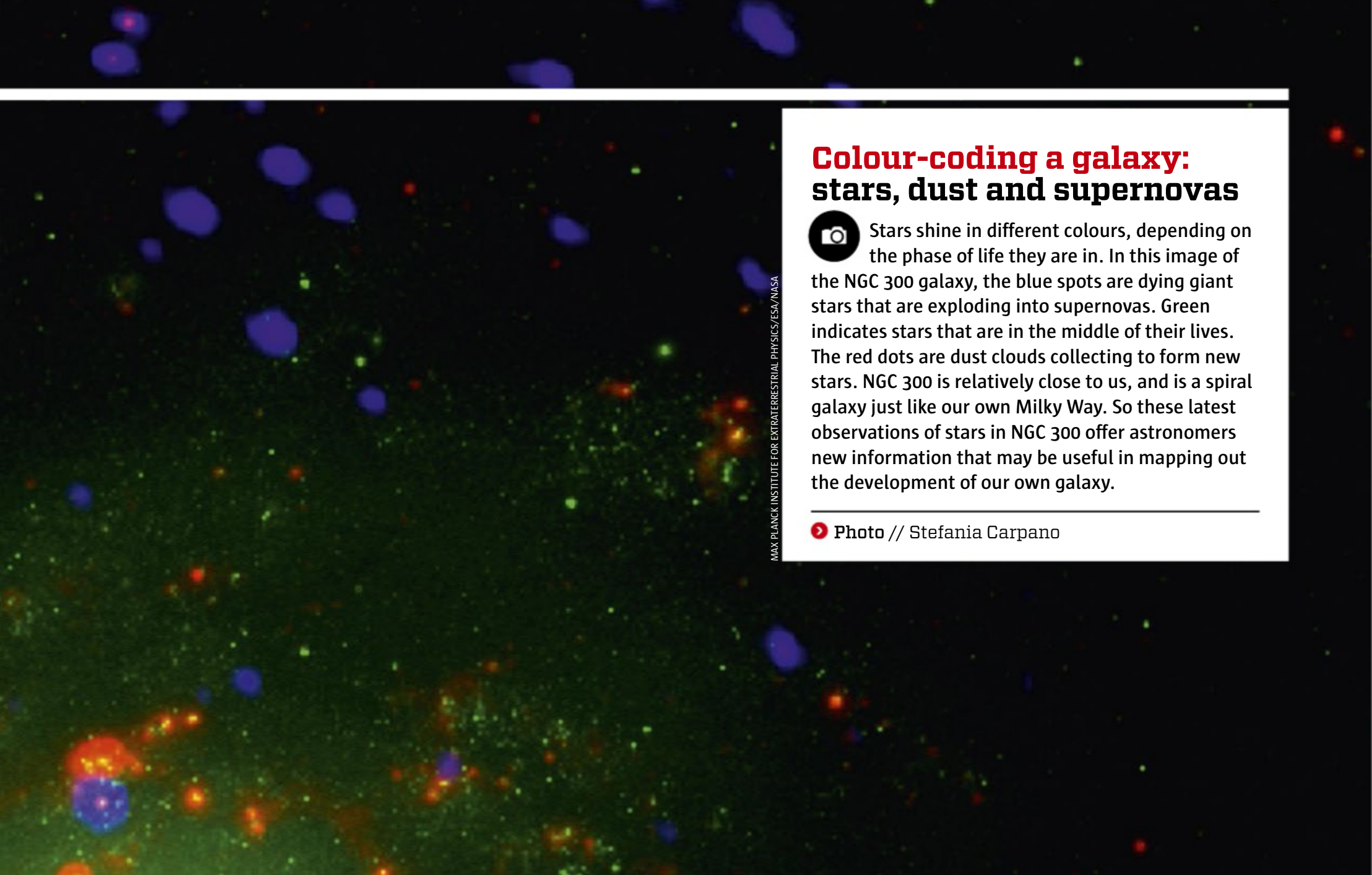

MAX PLANCK INSTITUTE FOR EXTRATERRESTRIAL PHYSICS/ESA/NASA

Colour-coding a galaxy: stars, dust and supernovas

Stars shine in different colours, depending on the phase of life they are in. In this image of the NGC 300 galaxy, the blue spots are dying giant stars that are exploding into supernovas. Green indicates stars that are in the middle of their lives. The red dots are dust clouds collecting to form new stars. NGC 300 is relatively close to us, and is a spiral galaxy just like our own Milky Way. So these latest observations of stars in NGC 300 offer astronomers new information that may be useful in mapping out the development of our own galaxy.

Photo // Stefania Carpano

Mutual benefits: tarantula and frog live in harmony

This little-studied *Pamphobeteus tarantula*, also known as a chicken spider, lives in the forests of Peru. Frogs are among the spider's prey, but one specific frog, *Chiasmocleis royi*, is excluded from the hunt and is instead allowed to live with the eight-legged predator. According to scientists, the frog helps the spider by consuming ants and fly larvae which might otherwise harm the spider or its offspring. In return, the tarantula protects the little frog from other spiders and small snakes.

Photo // Emanuele Biggi

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VISUAL INTELLIGENCE

PROBLEM 1: **C** and **G**.

PROBLEM 2:
J has been compressed to make the pattern fit.

LOGIC

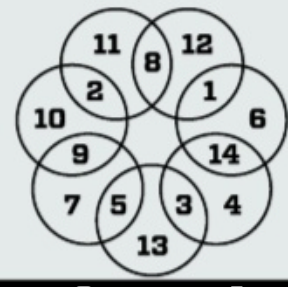
PROBLEM 5:
D. Circles and colours are distributed so there is only one of each kind in all horizontal and vertical rows.

PROBLEM 6:
420g. If half the ball's weight is H, we have the equation 2×H = 210 + H or H = 210.

NUMERACY

PROBLEM 3:
11. Start with the top number, move clockwise, and add the numbers in pairs: 5 + 6 = 11, 6 + 11 = 17, 11 + 17 = 28.

PROBLEM 4:



SCIENTIST IN FOCUS

7: **C) A Geiger counter.** He invented it when working for a company that manufactured communications equipment.

8: **D) UC Berkeley,** where he discovered berkelium, californium, etc.

9: **D) The heavy elements,** which are used in nuclear energy.

10: **C) The Manhattan Project,** the US nuclear weapon production project.

Test yourself Answers to p82. No peeking!

Hole in atmosphere drains Mars of water

Warm summers and dust storms are responsible for the Red Planet losing its rivers and oceans.

ASTRONOMY Until 3.8 billion years ago, Mars was almost as wet as the Earth, with lakes, rivers and a large ocean that covered around a third of the planet. It has long been a mystery to scientists where all the water went, but German and Russian astronomers have now found an explanation. The Red Planet has been drained of its water by dust storms and warm summers.

Mars has seasons just like Earth, but on the Red Planet they are much more extreme. The Sun is not perfectly at the centre of Mars' orbit, so the planet is much closer to the Sun during its southern hemisphere's summer than during the rest of the year. The atmosphere of the southern hemisphere is heated, causing a hole to appear, through which the planet's water vapour can escape. Normally, vapour is trapped in the atmosphere by a cold air layer located at an altitude of 60-90km. But this layer 'bursts' during the southern hemisphere's summer heat.

Scientists have tested their theory by means of computer simulations. These indicate that water will evaporate from the planet's surface, escape through this hole in the atmosphere's cold layer, and pass into a higher layer. From there the vapour moves towards the planet's poles, where it passes back down through the atmosphere to fall as snow.

But not all the water returns. In the upper atmospheric layers, water molecules are subjected to ultraviolet solar radiation that splits them into hydrogen and oxygen. The hydrogen dissipates into space, leaving the oxygen in the atmosphere. So Mars gradually loses water, and what remains collects as ice near the poles.

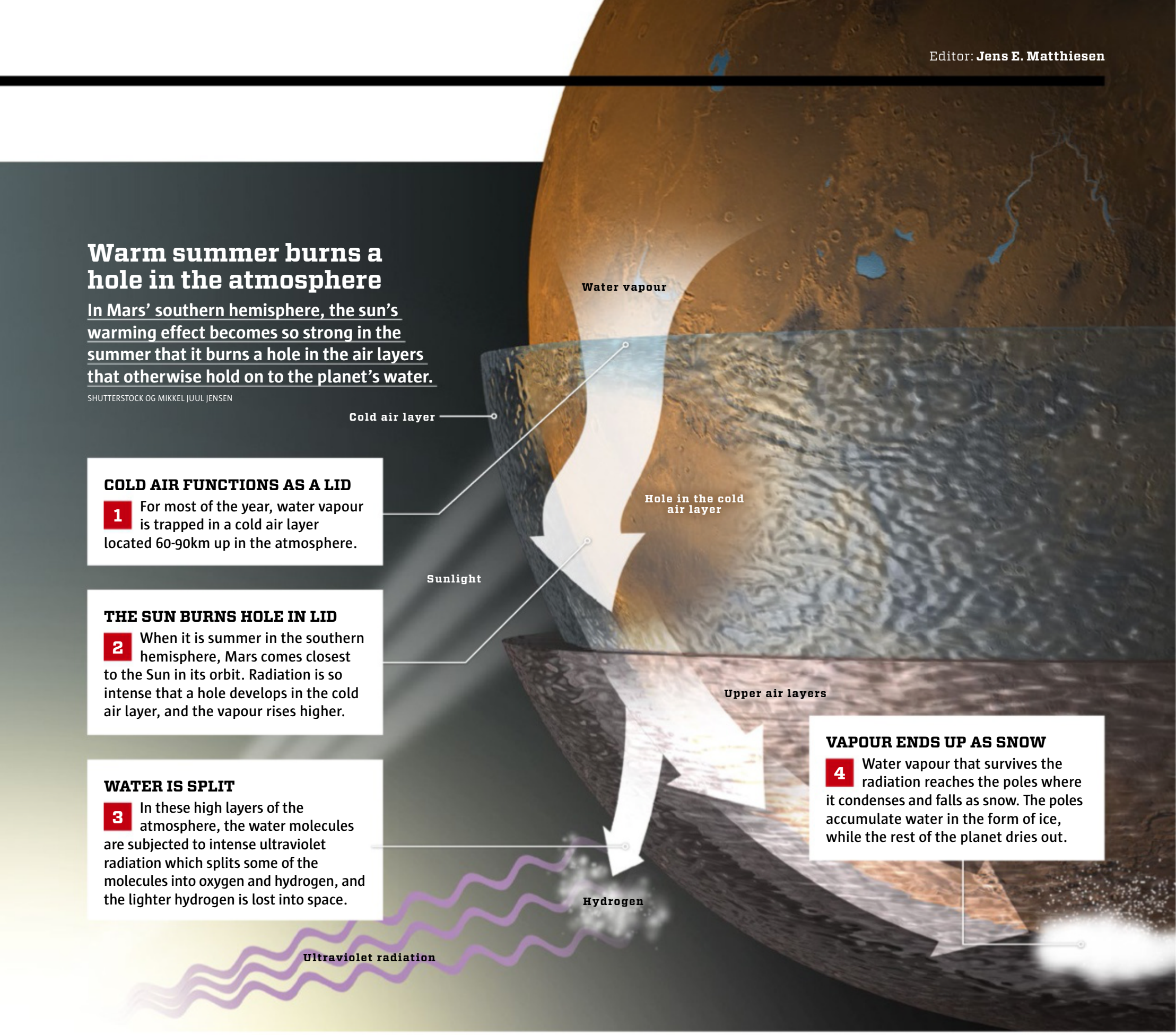
The computer model also shows that the process is intensified by dust storms that bring tiny dust particles carrying water molecules high into the atmosphere; it is even easier for these particles to reach the upper layers than for the water molecules on their own. This reinforces the effect: the less water on the surface, the more dust is stirred up by the storms, and the more water the planet loses.

Mars used to be a blue planet just like Earth, but 3.8 billion years ago it began to lose its water. Now, the remains exist as ice by the poles.

Warm summer burns a hole in the atmosphere

In Mars' southern hemisphere, the sun's warming effect becomes so strong in the summer that it burns a hole in the air layers that otherwise hold on to the planet's water.

SHUTTERSTOCK OG MIKKEL JUUL JENSEN



COLD AIR FUNCTIONS AS A LID

1 For most of the year, water vapour is trapped in a cold air layer located 60-90km up in the atmosphere.

THE SUN BURNS HOLE IN LID

2 When it is summer in the southern hemisphere, Mars comes closest to the Sun in its orbit. Radiation is so intense that a hole develops in the cold air layer, and the vapour rises higher.

WATER IS SPLIT

3 In these high layers of the atmosphere, the water molecules are subjected to intense ultraviolet radiation which splits some of the molecules into oxygen and hydrogen, and the lighter hydrogen is lost into space.

VAPOUR ENDS UP AS SNOW

4 Water vapour that survives the radiation reaches the poles where it condenses and falls as snow. The poles accumulate water in the form of ice, while the rest of the planet dries out.

Driverless cars to learn the meaning of fear

TECHNOLOGY Computers with artificial intelligence are taking on ever more tasks for us, and the prospect of autonomous driving, with a computer in control of our car, is fast becoming a reality. Self-learning systems could make computers safer, better motorists than humans if they can adequately sense the car's surroundings and observe traffic regulations and speed limits. But according to Microsoft researchers, the computers still lack a crucial quality: they do not feel fear.

SELF-LEARNING SYSTEMS are often used in connection with artificial intelligence, where computers learn from experience.

The researchers aim to change that. In an experiment they had a computer monitor a series of test subjects in a car simulator. The subjects wore pulse meters, using the pulse as a simple indication of the mental state of alarm. By allowing the artificial intelligence to link individual events such as near-crashes with the subjects' fear, the computer was later able to repeat the same journey and was then more careful and drove very cautiously in the places where alarm had been registered in the test subjects.

The scientists compared the computer with a similar computer which had not been taught by human fear, only by its own driving errors. The results revealed that the computer with a human fear input was much quicker at becoming a safe autonomous motorist, reaching the same level as the other computer with 25% fewer accidents.

The computer of a driverless car acts more carefully when it has identified traffic situations that cause a higher pulse rate in human drivers.

BY THE WAY

NEANDERTHALS HELD THEIR HEADS HIGH

The Neanderthal is often portrayed as a stooping caveman, but that is a myth. Based on a well-preserved skeleton, Swiss scientists have made accurate reconstructions of a Neanderthal's spine and pelvis, demonstrating that the vertebrae formed an S-shape which would deliver the same sway of the back as for *Homo sapiens*. This indicates that Neanderthals shared our balance and body posture.

MARTIN HÄUSLER/UZH

AND TALKING OF NEANDERTHALS ...

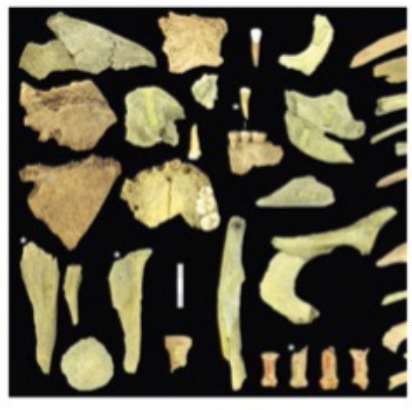
NEANDERTHAL SPEARS KILLED FROM A DISTANCE

Neanderthals killed large prey such as mammoths, and scientists used to think that hunters got close to prey, using their spears as stabbing weapons. But javelin throwers have now tested copies of 300,000-year-old spears, finding that they could also be used effectively from distances up to 20 metres.

ANNEMIEKE MILKS

CLIMATE CRISIS ENDED IN CANNIBALISM

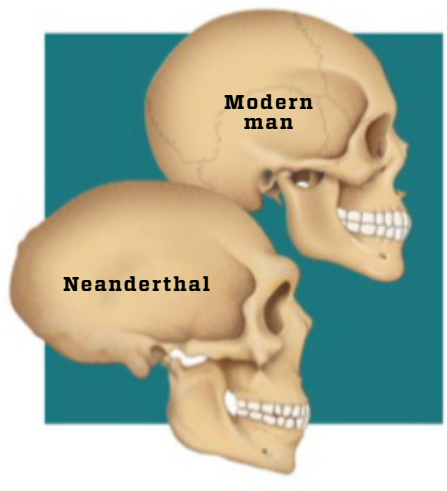
Bones from at least six Neanderthals who had been killed and eaten were found in France 20 years ago. Scientists have now taken a closer look at the location, discovering that the cannibalism was probably due to hunger when the climate warmed and their prey disappeared around 128,000 years ago.



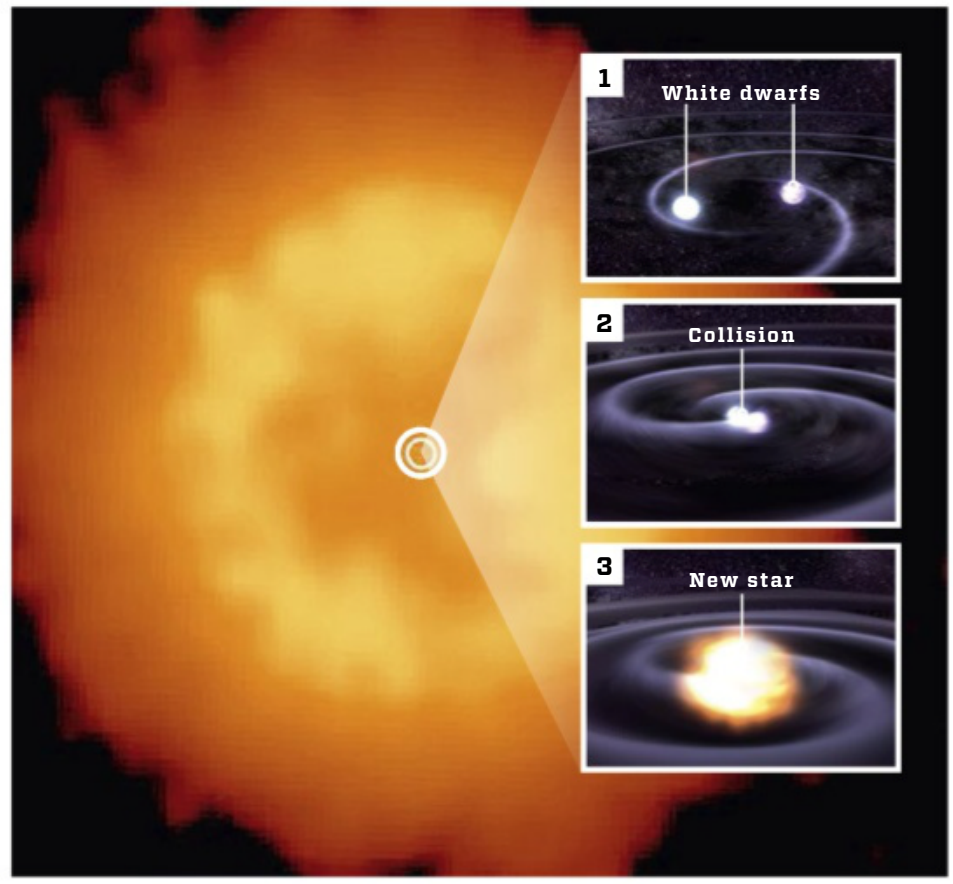
H. ROUGIER ET AL./UPV/EHU

NEANDERTHAL GENES GIVE US OBLONG SKULLS

People of European descent include a little Neanderthal DNA, because our ancestors mated with them. German scientists have managed to identify two specific genes that, in the Neanderthal variant, make our skulls slightly more oblong than in humans without the variant.



SHUTTERSTOCK



NASA

At the centre of this nebula there is a rare star which formed in a collision between two dead stars also known as white dwarfs.

Mysterious star reemerged from the dead

ASTRONOMY German astronomers have discovered a very unusual star in the Cassiopeia constellation. It shines 40,000 times more brightly than the Sun from the centre of a star nebula, but there is no indication that the radiation is produced by the fusion of hydrogen and helium, as in other stars. It also ejects charged particles in the form of a solar wind so intense that it should derive from two stars, not one.

According to astronomers from the University of Bonn, the reason may be that this star was indeed once two stars – not living, bright stars like our own Sun, but burnt-out dead stars: white dwarfs.

If the astronomers are correct, the strange star is the result of a very rare phenomenon in which two white dwarfs orbit each other ever more closely, finally meeting and fusing. In such cases, the combined mass is sufficient to revive nuclear processes in the star, not with hydrogen and helium as fuel, but using heavier elements such as oxygen and neon. This causes intense radiation that is emitted not in the visible spectrum, but as infrared light.

This theory can also explain the intense solar wind that is spun away at a speed of 58 million km/h. This would not be possible from a normal white dwarf.

Astronomers consider it quite the stroke of luck to find proof that stars can be reignited in this unusual way, since they estimate that there are only a handful of stars in the Milky Way that have gone through this process, and furthermore they do not live very long. Over a few thousand years such a revived star will exhaust its fuel reserves and then end its new life in a supernova explosion.

58 million km/h

– is the speed of the solar wind from this newly discovered star. The Sun's solar wind travels at a speed of 3 million km/h.

Shrimp builds diving bell of aluminium

ZOOLOGY The deep sea is one of the most hostile habitats on Earth, and you must be inventive to survive there. For crustaceans such as the shrimp, the limit is normally a depth of 4500 metres. Beyond that the pressure becomes too high and the water too acid. The acid corrodes the creatures' external calcium skeletons, so the pressure can easily destroy it.

So Japanese scientists were amazed when they recently found a shrimp-like creature living at a depth of 10,000 metres in the Challenger Deep seabed depression off the Philippines.

Close examination showed that the animal, *Hirondellea gigas*, can reinforce its calcium shell with a layer of aluminium. But that was a new mystery, as ocean water is poor in aluminium. Where did the metal come from?

The scientists examined deposits from the floor of the Challenger Deep, subjecting them to the chemical conditions of the creature's intestines.

Sure enough, the combination of intestinal acid and digested vegetable food produced an environment that could liberate aluminium ions from the deposits. The crustacean eats ocean floor deposits to get the metal, which moves from the intestines into the calcium skeleton. When it meets sea water, the resulting aluminium hydroxide acts as a shield on the creature's surface, a kind of diving bell which can resist the pressure deep into the abyss.

DAIJU AZUMA

A shrimp reinforces its shell with aluminium to resist pressure even at a depth of 10,000 metres.

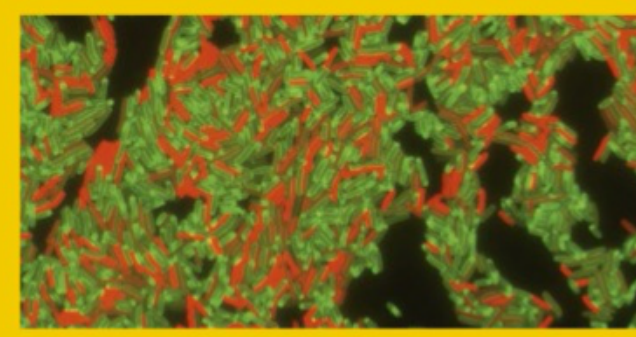
Revealed! The secret defence of bacteria

New experiments reveal bacteria's first defence against antibiotics. The discovery could lead to improved weapons against the microbes.

MEDICINE When bacteria are under attack from antibiotics, they activate a previously unknown defence mechanism that buys them enough time to become resistant, according to experiments made by scientists from the University of Lyon in France.

The scientists studied the behaviour of a mixture of resistant and non-resistant E. coli bacteria when subjected to the antibiotic tetracycline. As expected, the resistant bacteria could survive because they had a special protein that pumps the antibiotic out through the cell wall. The non-resistant bacteria lacked that special protein, but instead they activated another protein that works as a type of generic defence. Because it is not aimed at tetracycline specifically, it was not as efficient, but it could still pump out some of the antibiotic. The protein, known as AcrAB-TolC, was effective enough to keep the bacteria alive for sufficient time to receive genes from the resistant bacteria, which passed the gene producing the special protein against tetracycline on to the non-resistant bacteria.

If scientists can develop remedies against this AcrAB-TolC 'multi tool', they might prevent bacteria from sharing resistance in this way.



Resistant E. coli bacteria (red) help other bacteria (green) to survive antibiotics.

Emergency pump buys bacteria important time

A non-resistant bacterium can survive the first attack from an antibiotic just long enough to get resistant genes from another bacterium.

BACTERIA ARE ATTACKED

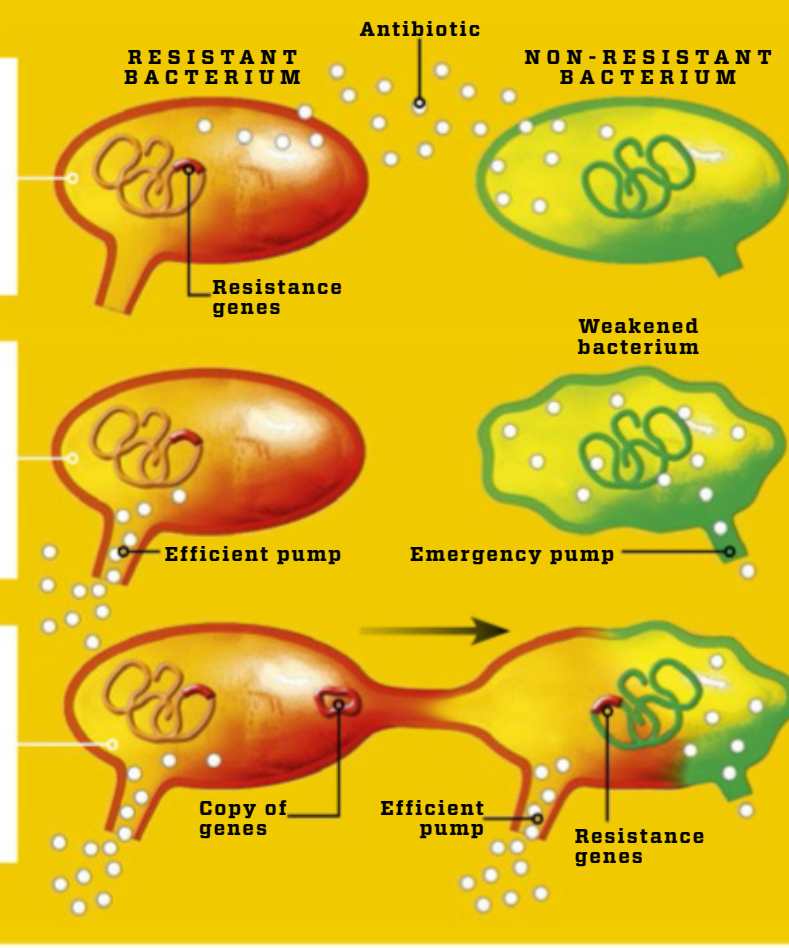
1 A resistant and a non-resistant bacterium are attacked by an antibiotic that enters both of them to destroy them.

DEFENCE ACTIVATED

2 The resistant bacterium can pump out all the antibiotic. The non-resistant one activates its less efficient emergency pump.

HELP ARRIVES

3 The resistant bacterium passes on the genes for the efficient pump, so the non-resistant bacterium becomes resistant.



CHRISTIAN LESTERLIN/INSERM & MIKKEL JUUL JENSEN

Earache? Check your smartphone

PHONE AND A CONE: a smartphone app and a paper cone can reveal liquid behind a child's eardrum.

A new app and a paper cone quickly and easily reveal middle-ear inflammation.

MEDICINE Earache is the most frequent reason for children to see a doctor – partly because there is not much parents can do at home to examine or ameliorate the condition.

Scientists from the University of Washington aim to change that. They have developed a phone app that can reveal fluid accumulation in the middle ear. Middle-ear inflammation is often caused by an infection that makes liquid collect behind the eardrum; the liquid pressure on the inside of the drum causes the pain.

The app uses the phone's speakers and microphone, with the only other thing required being a tiny funnel made of paper in the form of a cone. The pointed end of the funnel is placed in the child's external ear, and the phone's microphone is placed at the wide end of the funnel. The app emits a series of brief sounds sounding like bird chatter. The sounds are reflected by the eardrum back to the phone's microphone, and the interference patterns between the speaker and the reflected sounds are analysed by the app to reveal whether there is liquid behind the eardrum or not.

In experiments with 53 young children who had been taken to the doctor with earache, the app correctly revealed the liquid in 85% of cases, which is just as high a hit rate as can be achieved by an otologist. The experiments also showed that the app functioned equally well on a number of different mobile phones (where microphone and speakers can vary).

Acoustic image reveals ear inflammation

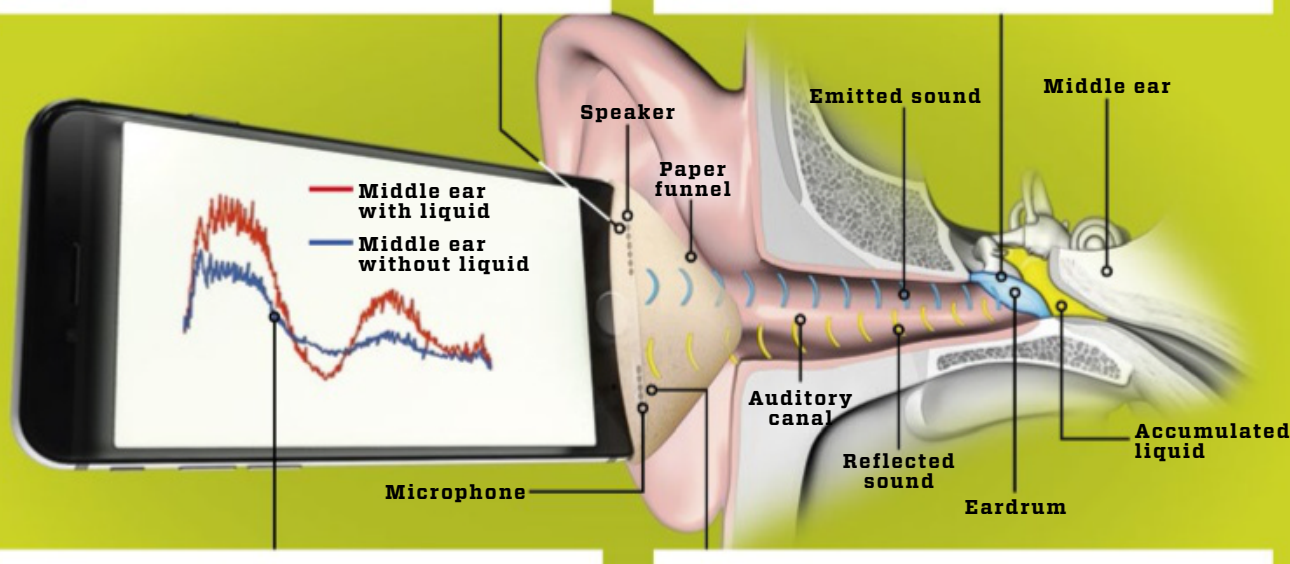
Inflammation of the middle ear is caused by infection that makes liquid accumulate behind the eardrum. A new app can reveal the liquid, if any.

SPEAKER EMITS SOUND

1 Sound from the phone's speaker travels through the funnel into the auditory canal.

EARDRUM REVERSES THE SOUND

2 The sounds reach the middle ear, from which they are reflected by the eardrum.



PATTERN MAKES A DIAGNOSIS

4 The variation in sound waves reveals any fluid accumulation in the middle ear.

MICROPHONE RECORDS SOUNDS

3 The emitted and reflected sounds merge to be recorded by the mike.

MIKKEL MEISTER/DENNIS WISE/UNIVERSITY OF WASHINGTON & MIKKEL JUUL JENSEN

Squishy robot survives drop of 180 metres

TECHNOLOGY A robot shaped like a transparent football could become a vital tool for rescuers in disaster zones. It tolerates being parachuted from helicopters or drones at altitudes up to 180 metres, able to roll over and record footage after landing to provide vital information for human rescuers that follow.

The robot was developed by scientists from the University of California in cooperation with the Squishy Robotics company. It has a core in which all electronic components are protected, around which there are six rods that all include shock absorbers, their ends linked by steel wires. With the robot's core surrounded by this large shock absorber, it is adequately protected no matter how it hits the ground.

To roll across the surface, small motors in the core tighten and relax the wires to change the robot's exterior shape, thereby shifting its centre of gravity.

The robot comes in several sizes, depending on its mission. As well as cameras and radio transmitters, it can be equipped with other sensor to measure for toxic or explosive gases in the disaster zone.

The robot was developed with support from NASA, with the long-term aim of launching it towards the surface of Saturn's moon Titan from a satellite, although much development remains for it to survive a fall from that altitude.

SQUISHY ROBOTICS

DROP & ROLL: Six shock absorbers protect the core of a new robot so it can survive falls from a great height.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Why do leaves change colour before they fall?

Most leaves include different quantities of yellow, orange and red colours all year round, but we see them only when the dominant green hues disappear in the autumn.

NATURE Australia has very few native deciduous tree varieties, and perhaps only one – deciduous beech or Fagus (*Nothofagus gunnii*) – which can match the magnificent autumnal colours displayed by the more common deciduous varieties elsewhere in the world. But what makes such leaves change from green to yellow, orange, red or brown?

It is, of course, chlorophyll in the leaves of trees that makes them appear green. Chlorophyll is important for plants' energy production, which takes place via photosynthesis, where the plant produces sugars based on light, water, and CO_2. The plant also produces oxygen as a waste product for the plant, though a vital resource for most of life on Earth, including humans.

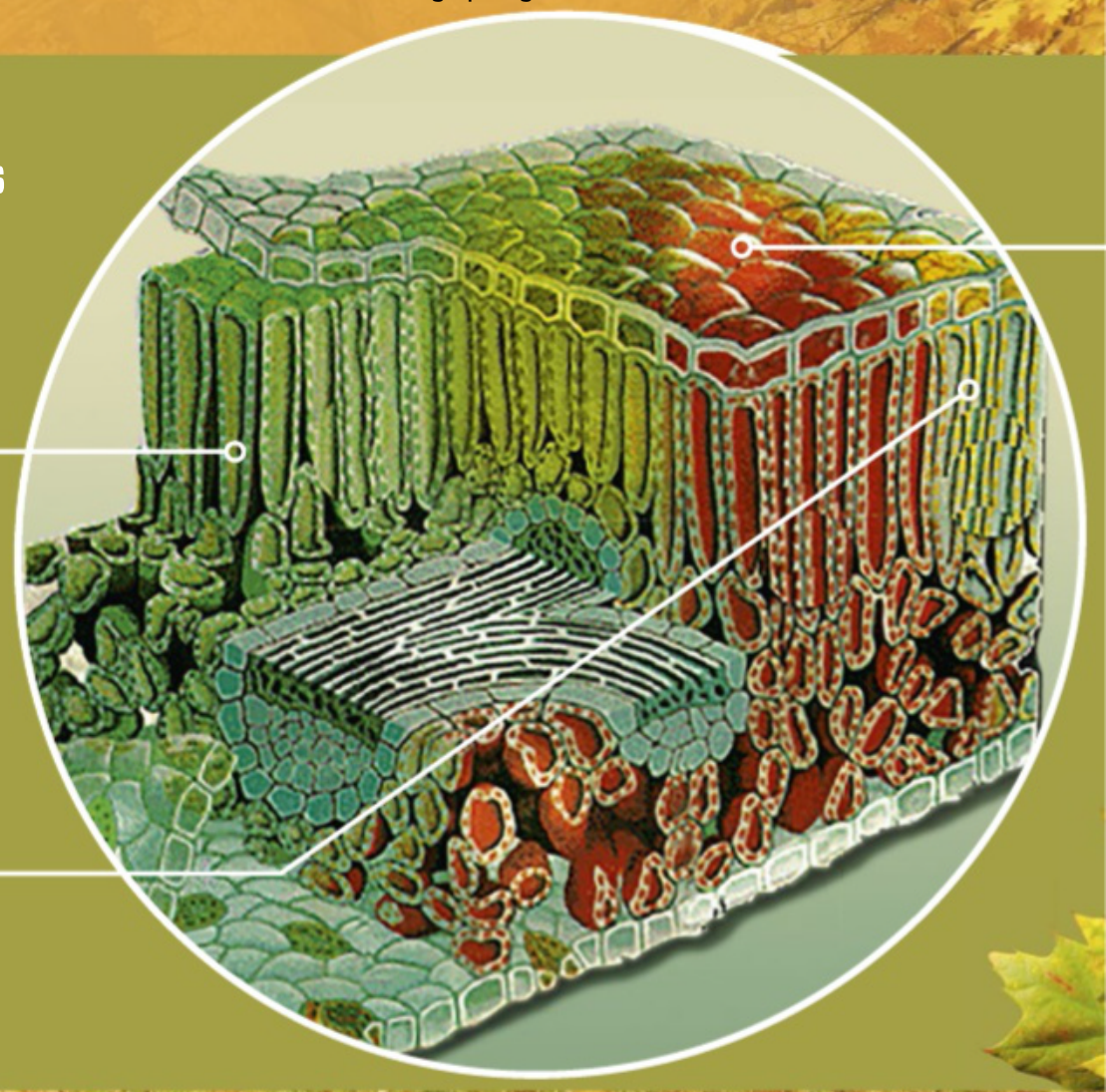
Other pigments are present alongside the chlorophyll, and although some of these are also included in photosynthesis, they are overwhelmed by the greens during the spring and summer. Chlorophyll is continuously destroyed by sunlight, but as long as the leaves grow, the tree constantly produces more.

When autumn comes, the production of the green pigment stops as the days become shorter and temperatures fall. As the remaining chlorophyll is broken down, the other pigments become more visible – yellow and orange carotenes, and reddish or purple anthocyanins. These reflect wavelengths of light other than green, and so provide such leaves with the beautiful autumn colours we see.

Norwegian scientists have shown that autumn colours are linked with the quantity of natural insect toxin that plants produce, finding that the clearer the autumn colours displayed by individuals of the downy birch species, the fewer insect attacks the trees suffered the following spring.

Green dominates hidden autumn colours

Leaves may be yellow, orange, red and purple, but the green colour of chlorophyll outcompetes the others.

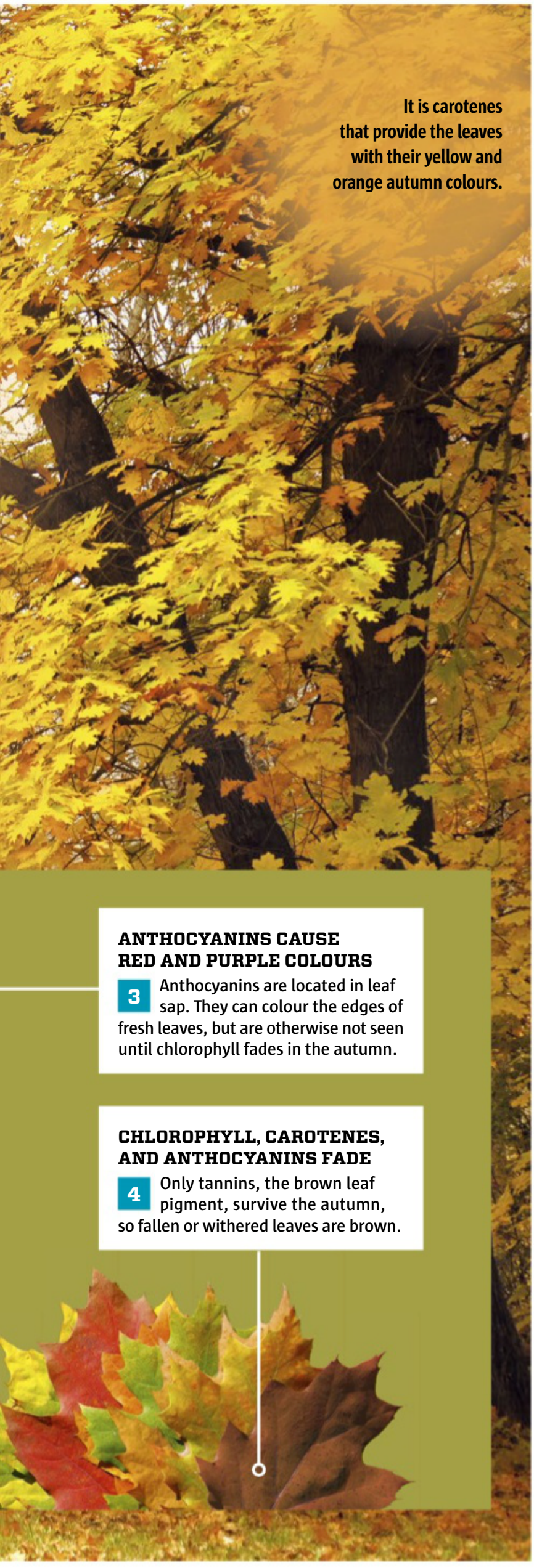


GREEN COLOURS ARE DUE TO CHLOROPHYLL

1 In the spring and summer, green chlorophyll dominates leaf colours. Chlorophyll exists in organelles in leaf cells known as chromoplasts.

CAROTENES COLOUR LEAVES ORANGE AND YELLOW

2 Carotene is what makes carrots orange. Like chlorophyll, it exists in chromoplasts and can be observed when the chlorophyll fades.



It is carotenes that provide the leaves with their yellow and orange autumn colours.

ANTHOCYANINS CAUSE RED AND PURPLE COLOURS

3 Anthocyanins are located in leaf sap. They can colour the edges of fresh leaves, but are otherwise not seen until chlorophyll fades in the autumn.

CHLOROPHYLL, CAROTENES, AND ANTHOCYANINS FADE

4 Only tannins, the brown leaf pigment, survive the autumn, so fallen or withered leaves are brown.

U.S. FOREST SERVICE OG SHUTTERSTOCK

WORST 5 · Which oil spill was the worst ever?

MARIO TAMA/GETTY

1 Persian Gulf War, Kuwait, 1991

11,000,000 barrels of oil. Iraqi troops trying to prevent the US army from landing in occupied Kuwait poured oil out along the coast, where they expected an attack. When they subsequently fled, they set all Kuwait's oil wells on fire.

2 LAKEVIEW GUSHER, CALIFORNIA, USA, 1910-11. **9,000,000 BARRELS.**

An oil well under high pressure got out of control, spilling oil for a year.

3 DEEPWATER HORIZON, GULF OF MEXICO, 2010. **4,900,000 BARRELS.**

An oil rig explosion caused an oil spill at a depth of almost 2 km.

4 IXTOC, BAY OF CAMPECHE, MEXICO, 1979. **3,300,000 BARRELS.**

A defective pump caused such pressure that it triggered an explosion.

5 ATLANTIC EMPRESS, VIRGIN ISLANDS, 1979. **2,100.000 BARRELS.**

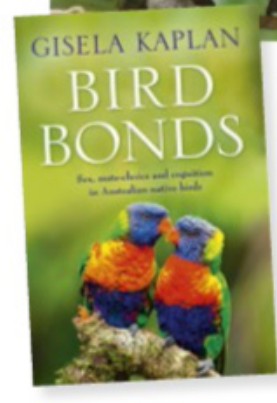
The Atlantic Empress tanker leaked all its oil following a collision.

How do bird feathers look so colourful?

BIOLOGY In birds, colours of longer wavelengths (red, yellow, orange) are produced using pigment, but the shorter-wave colours (blue, purple) are often created by the structure of the feathers. The combination of structures with carotenoids or psittacofulvins creates colours rich in middle wavelengths (greens).

Melanin is the most common endogenous pigment and accounts for 75% of all measured plumage patches in Australian birds. There are two forms of melanin: phaeomelanin in most birds, and eumelanin in parrots. Phaeomelanin produces rusty red and tawny yellow colours and is present in black plumage. But some of Australia's birds that seem boringly black in fact have structural colour and ultra-violet reflectance that we humans can't see.

PROFESSOR GISELA KAPLAN



This answer came from Professor Gisela Kaplan's new book 'Bird Bonds', which we found to be a riveting read. It's available from Macmillan Australia, RRP $34.99.

Is a black hole really a hole?

ASTRONOMY The term 'black hole' is used in many languages to describe the phenomenon in which a huge quantity of matter is united at one point, causing immense gravity. However, a black hole is not a hole in the ordinary sense, although the word can be considered usefully illustrative in describing conditions as a black hole is approached.

Just as 'up' and 'down' for a normal hole in the ground are defined with relation to gravity, a similar 'up' and 'down' also exist close to a black hole, at least while the approaching object remains at a distance. The closer to the 'hole' the object comes, the more directions lead 'down' and the fewer 'up'. If it passes the event horizon (the distance from the centre at which gravity is so strong that not even light can escape) all directions will be 'down'. In that regard, black holes are the biggest and most efficient holes in the universe.

SHUTTERSTOCK

Black holes involve such strong gravity that light cannot escape once it comes closer to the centre than the event horizon.

INSIDE THE BODY · Why do bruises change colour?

A blow to the skin can make blood vessels burst, so blood flows out into the surrounding tissue. The haemoglobin of the blood first colours the mark red, but once broken down, the colour begins to change.

DAY 1

The blood and its red pigment, haemoglobin, flows from damaged blood vessels to the epidermis, causing red marks.

DAY 2

The blood forces itself deeper into the skin. As observed through the thicker skin layer, the haemoglobin gains a bluish colour.

DAY 6

The immune system breaks down the haemoglobin into biliverdin, providing the bruise with a greenish hue.

DAY 8

Biliverdin is now broken down into bilirubin, which colours the bruise yellow.

DAY 10

Bilirubin is finally broken down into haemosiderin, leaving a brownish splotch.

DAY 14

Macrophages remove the last pigments of the bruise, making it disappear.

Bruises are coloured by blood. As the blood is broken down, the bruise changes colour.

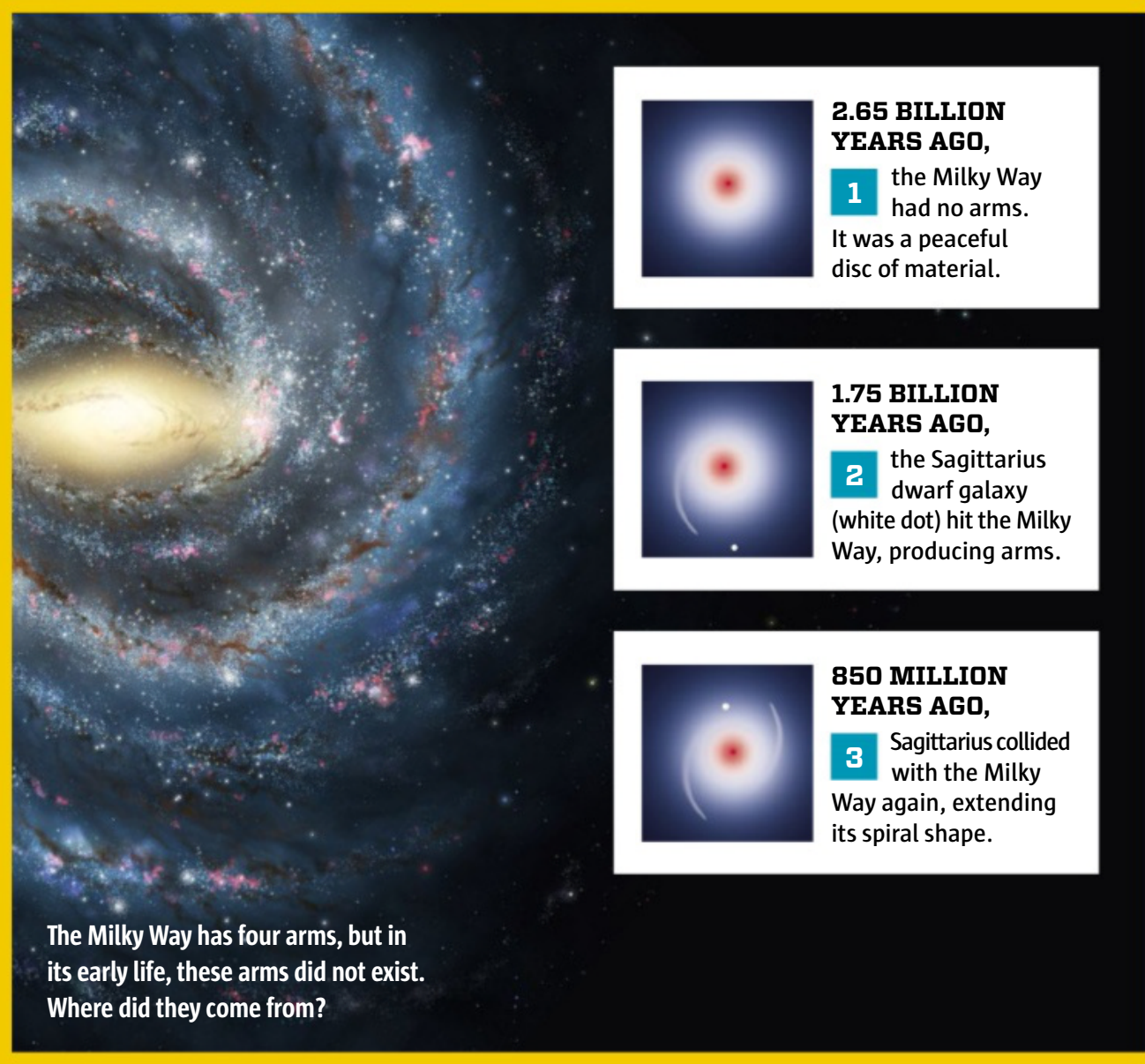
DEAN BERTONCELJ/THINKSTOCK

WHY DOES WATER TASTE COLDER AFTER A MINT?

When you chew on something that tastes of mint and subsequently drink a glass of water, the water feels colder. This is because menthol, which exists naturally in peppermint, stimulates the same sensory cells in the mouth that register cold. So mints cause a cold sensation even if the water itself is not cold.

SHUTTERSTOCK

Mints do not lower water temperature, but can stimulate our sensitivity to cold.



The Milky Way has four arms, but in its early life, these arms did not exist. Where did they come from?

How did the Milky Way get its spiral arms?

Last issue (p40-47) we described why scientists now believe that the 'bump' at the centre of our galaxy came first, not later as they had previously believed. But where did the spiral arms come from?

ASTRONOMY There are a series of theories concerning how galaxies such as the Milky Way got their arms. One thing is for sure: the size and the appearance of galaxies are governed by the results of galactic collisions in their past.

There is every indication that the Milky Way's spiral arms might also be due to such a collision. American scientists have concluded that the Milky Way's spiral structure is due to the Sagittarius elliptic dwarf galaxy colliding with our galaxy not once but twice, 1.75 billion and 850 million years ago. A computer model has demonstrated that dark matter brought by the dwarf galaxy disturbed the Milky Way's disc of stars, setting up 'ripples' which can still be observed. And it's not over yet. Scientists have calculated that the Sagittarius galaxy, which was violently elongated in these meetings, will hit our galaxy again in about 10 million years.

THE MILKY WAY GOT ITS ARMS AFTER COLLISION

- US scientists have calculated that the Milky Way's arms originated when our galaxy collided with the Sagittarius dwarf galaxy.
- Our Solar System is located in one of the Milky Way's four Orion arms. We are some 25,000 light years from the centre of the Milky Way.

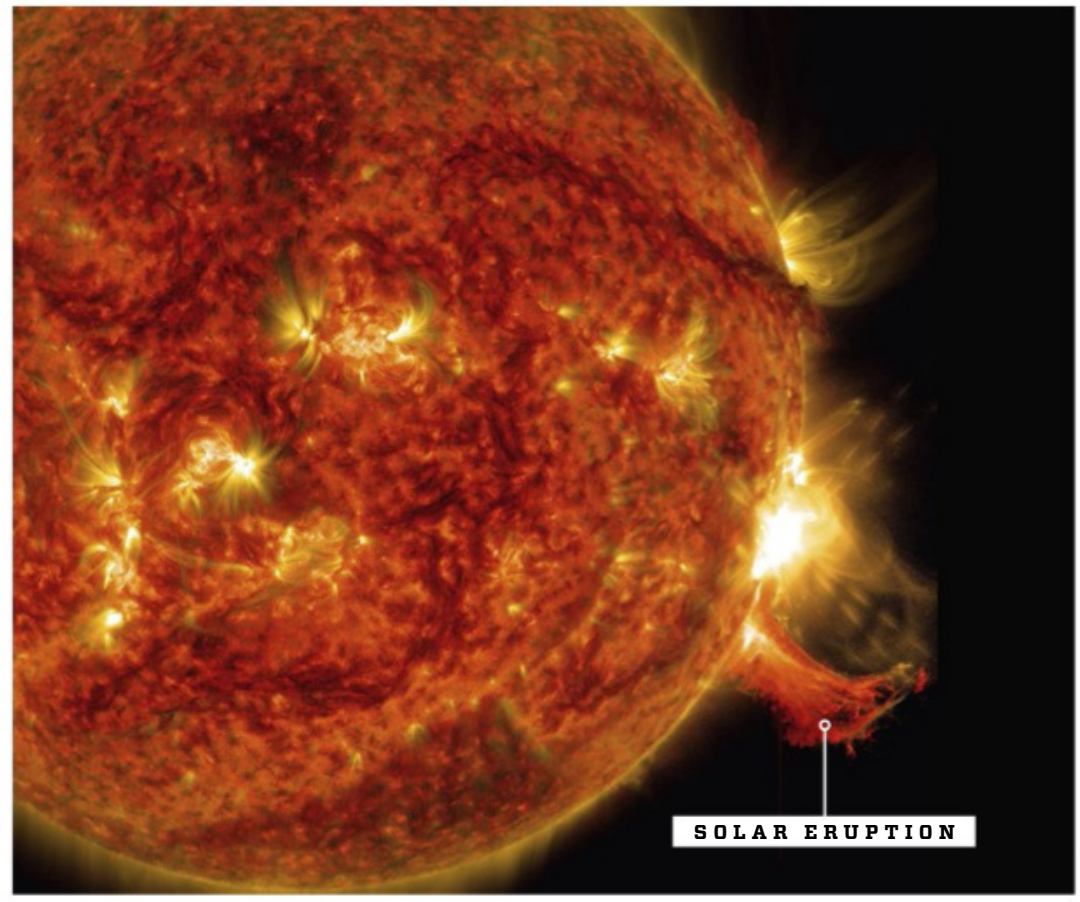
SPL/SCANPIX

Are all electronics equally exposed in solar eruptions?

TECHNOLOGY Solar eruptions send clouds of charged particles into space where they can interrupt signals from satellites, even influence Earth's magnetic field, causing fluctuations in high-voltage cables and elsewhere. Solar eruptions can also ionise electrical circuits, potentially destroying electronics in combination with the changing voltage. However, not all devices are equally sensitive. Well-protected electronics (such as refrigerators) are less exposed, whereas more complex circuits (in phones, driverless cars, etc.) are more vulnerable. Most exposed are electronics in internet, radio and satellite applications.

YOUR FRIDGE RESISTS SOLAR PARTICLES

- **No effect:** Simple or well-protected electronics such as old computers, domestic appliances and clock radios.
- **Exposed:** Technology based on internet or satellites, such as smartphones and GPS devices.



SDO/NASA

The Sun sends huge quantities of charged particles into space in solar eruptions. The particles can disturb Earth's magnetic field.

WHAT IS THIS? · Bluebottles are not one creature, but many

Australian bluebottles (main image) are smaller and less deadly than the Portuguese man-of-war (inset).

Beware the stingers! From 10,000 to 30,000 stings a year are reported from bluebottles in Australia, but there have been no recorded fatalities here.

› The bluebottle, or Indo-Pacific man-of-war, is a cnidaria-like jellyfish. But where a jellyfish is one organism, a man-of-war consists of an entire colony of small, specialised organisms. The 'float' (pneumatophore) is one individual, supporting the dactylozooid polyps of the tentacles, while the digestion and reproduction are carried out by other zooids.

› The Portuguese man-of-war (*Physalia physalis*, inset) is similar but larger and more deadly, common in warm regions of the Atlantic, the Pacific and the Indian Ocean. The tentacles contain cnidoblasts with toxins that have caused fatalities.

› Bluebottle (*Physalia utriculus*) tentacles can grow to 10 metres, but the Portuguese man-of-war can extend to 50 metres, making it a contender for world's longest animal.

HENNING SØGAARD OG / ISTOCKPHOTO

In the film *Inferno* (2016), a virus threatens to infect 95% of Earth's population.

Can a pandemic spread globally in one week?

In the film *Inferno*, a lethal virus threatens to spread from a cistern in Istanbul to 95% of Earth's population in only one week. Could a pandemic really spread so fast?

BIOLOGY A virus infection cannot spread any faster than the circulation of the atmosphere allows. Furthermore it often takes at least a day after a virus has settled in a host for it to take over the cells' production apparatus and make new copies of itself that can infect the next victim. A virus would take at least a month to conquer the hemisphere in which it breaks out, and a minimum of six months to infect the whole world.

In order for a disease to spread rapidly, it must meet four requirements. Firstly the disease must spread via the air and be able to infect across long distances. Secondly the disease must be so aggressive that even a few virus particles or bacteria can infect a person. Finally, the disease must multiply quickly and then the host must spread the infection before developing symptoms which would lead to the host being isolated and so unable to have contact with others.

Influenza is the disease that comes closest to meeting these criteria. The 1918 flu – also known as the Spanish Flu – killed 50-100 million of Earth's 1.8 billion inhabitants at the time.

Killer flu spreads in six months

A simulation shows that an outbreak of mutated avian flu could kill more than 30 million globally in six months.

MONTH 1

Casualties:
28,582

1 A virus breaks out and infects 800 people in South East Asia. It spreads locally over land and between continents via air travel.

MONTH 3

Casualties:
10,120,312

2 For every person who is infected with the virus, it spreads to an average of between two and three more people, but no more than that.

MONTH 6

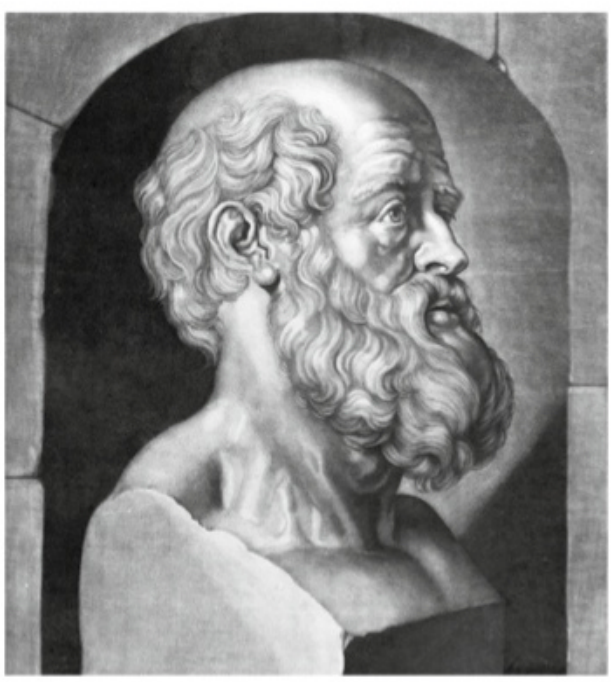
Casualties:
32,918,534

3 After six months, the virus has spread across the world. The number of casualties has tripled in the previous three months, and the spread continues.

IMAGESELECT

WHO WROTE THE FIRST BOOKS ABOUT SCIENCE?

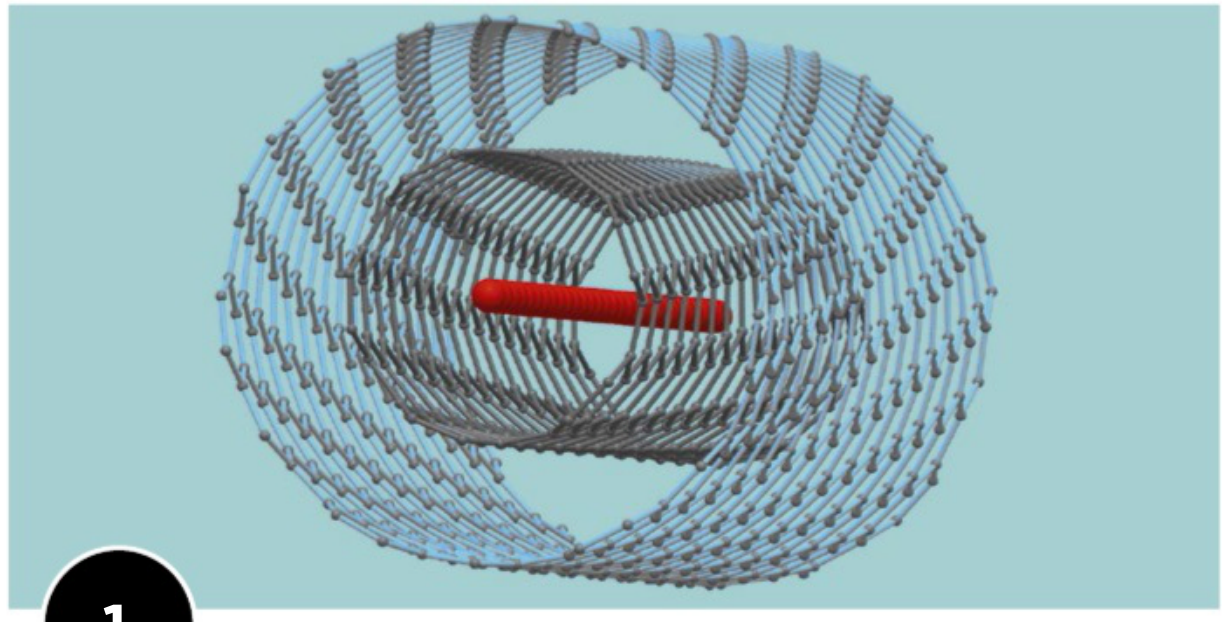
A definitive answer to this question is difficult to give, as many of the earliest known writings on knowledge are lost and may not even be correctly attributed – we know, for example, that Pythagorus did not come up with the theorem named after him. Among the earliest extant examples of what could be considered scientific books is the Hippocratic Corpus, a collection of disparate books on the subject of medicine, but again we don't really know if the 5th century BCE Greek physician Hippocrates of Kos wrote any of the 60 or so titles in this collection.



WELLCOME COLLECTION

A possible bust of probable early science writer Hippocrates of Kos. The answer above comes from a new illustrated book *Scientifica Historica* by Brian Clegg (Murdoch Books, $39.99), which follows how the world's great science books chart the history of knowledge.

TOP 5 · What material is strongest compared to its weight?



LEI SHI, FACULTY OF PHYSICS/UNIVERSITY OF VIENNA

1 Carbyne

Strength: 60-75MNm/kg*. Carbyne consists of carbon atoms linked by alternating single and triple bonds, or by double bonds. Chains of carbyne 6000 atoms long have been synthetically produced under laboratory conditions.

2 GRAPHENE
STRENGTH: 47-55MNm/kg

Carbon atoms arranged in a hexagonal pattern that is only one atom thick. Graphene is also extremely good at conducting electricity.

3 NANOTUBES
STRENGTH: 43-50MNm/kg

Tubes of carbon atoms in a hexagonal pattern, again only one atom thick. The tubes can have diameters of as small as 0.4 nanometres.

4 DIAMOND
STRENGTH: 25-65MNm/kg

Carbon atoms in which each atom is bound to four others in a 3D network. Diamond forms naturally at depths of 140-190km.

5 ZYLON
STRENGTH: 3.8MNm/kg

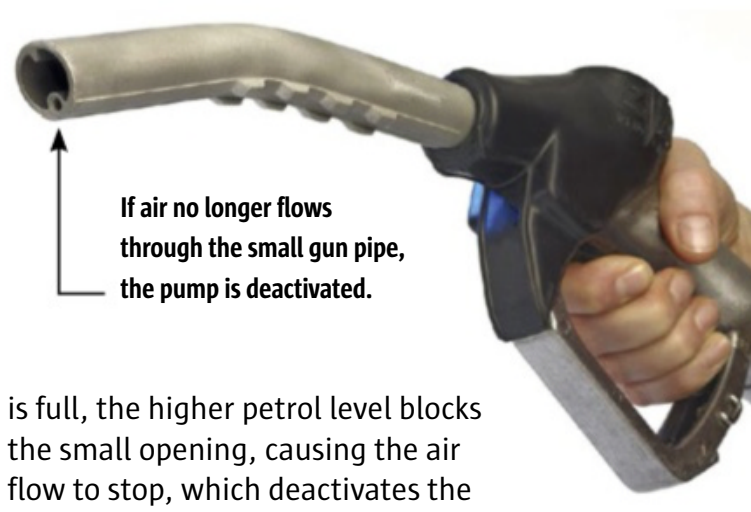
Synthetic organic fibres used, among other things, to make sure that Formula 1 race-car wheels don't come off and end up rolling into the crowd.

*Meganewton metres of force that a fibre can resist divided by its mass.

How does the petrol pump know when your tank is full?

TECHNOLOGY The filling station's pumping system is based on the venturi effect, which describes the pressure decrease in a liquid as it flows from a big pipe to a smaller one. The pressure reduction causes suction, which the petrol pump uses as a safety measure. By diverting the petrol through the narrow passage of the gun, a suction effect results, sucking in air through a smaller pipe that begins at the end of the petrol gun which is inserted into the car.

When you begin to refuel, air passes freely back through the small pipe, and the gun may even allow you to lock it off, so that petrol flows by itself. But once the tank is full, the higher petrol level blocks the small opening, causing the air flow to stop, which deactivates the pump. The system was invented in 1939 and is purely mechanical, with no electronics that could be hazardous in such close contact with petrol fumes.



IMAGESELECT

18+

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AVAXHOME-

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The latest construction workers are computerised:

ROBOT TRADIES' CONSTRUCTION REVOLUTION

A driverless excavator does the digging, a robotic arm lays 1000 bricks per hour. With new accurate sensors and smart algorithms, robots have built entire houses. In a few years, these robot tradies may be a common sight.

CLAUS LUNAU & BUILT ROBOTICS INC. & FBR LTD & AIST & ROMAN KELLER/NCCR DIGITAL FABRICATION

Computers draw accurate 3D models of houses using algorithms that have been fed data about many previous construction projects. They have 'learnt' the rules of architecture.

TRUCK DRIVER

A driverless excavator excavates the foundations. It manoeuvres by a combination of GPS and sensors that measure the vehicle's inclination and acceleration.

By **Mikkel Meister**

BUILDING MANAGER

A drone monitors construction. It takes photos and analyses them via algorithms 'trained' by analysis of previous data to recognise materials and patterns.

BRICKLAYER

A robotic arm builds walls at a speed of 1000 bricks/hour. The arm grabs bricks, adds adhesive, rotates the bricks and lays them, all in one motion.

ROOFER

Robotic arms assemble a timber frame for the roof. Controlled by algorithms, the arms saw and connect posts into a structure that can carry a roof.

CARPENTER

A robot installs plasterboard. It navigates by emitting laser beams and measuring distances based on reflections from the surroundings.

It's another noisy construction site, with excavators, cement mixers, and power tools pounding out their noise. A roof is mounted on one house while foundations are excavated on an adjacent site. In a third house plasterboard is being installed onto timber framing. But there are no human beings here. All the tasks – from the casting of foundations to the installation of the last roof tiles – are being carried out by robots, while drones are flying about to check the progress.

This is how a construction site might soon be able to operate. Small computers, artificial intelligence and new sensors are enabling robots to build an entire house, from erecting the walls to installing the roof, within a single day.

Robots have already proved that they can build houses almost without human assistance, as in Switzerland, where the robot-constructed DFAB House opened in February 2019. Robots have also been selected, appropriately, to build a new robot museum in Seoul which opens in 2022. But beyond special cases, these developments will make houses easier to build, and that is becoming vital. According to the UN, by 2030 new homes will be required for some three billion people – 40% of the world's population.

Not only can the new robotic building crews handle physical construction tasks, they are also on their way to taking over the roles of architects and building managers by designing, planning and supervising the entire construction process.

Automatic arms paint cars

Robots have been used in factories for decades, of course. In the car industry, robotic arms have welded and painted car bodies since the 1970s. Unlike people, robotic arms can repeat the same motions and tasks around the clock, maintaining accuracy without getting tired or injured. Robots can carry out monotonous jobs that include many repetitive tasks, and can do so more efficiently than humans.

30

minutes is the time in which drones can quickly map a 20,000m² work site.

But a factory is a predictable place. There is a standard process, from individual parts entering the system until the completed product appears at the other end. In such a setting it is relatively simple to design a robot to pick things up from a belt conveyor and put them in a box over and over again.

A construction site is a far more complex environment: machines and building materials can end

TRUCK DRIVER

Driverless excavator excavates the foundations

The worker in the cabin has been replaced by a box of computers and sensors. Based on a 3D model of the building, the robot independently excavates the foundations highly accurately.

ARM FOLLOWS INSTRUCTIONS

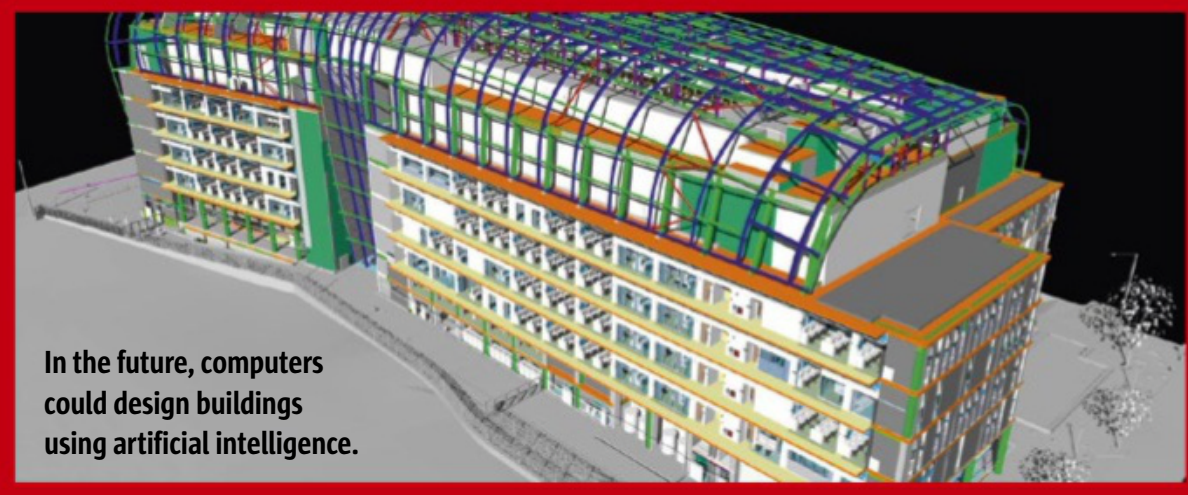
A computer calculates how the arm should move by means of meters that measure the excavator's inclination and acceleration. The data is registered in the computer and converted from data code into mechanical energy, so the arm's motions can be fine-tuned constantly.

BUILT ROBOTICS INC.

up in unexpected places; construction schedules can change; delays or weather conditions can require that workers switch to jobs other than those planned. Flexibility in cooperation and the value of traditional skills are among the reasons that the construction business is still dominated by human workers.

Lasers for 'eyes'

In recent years, new technologies have made robots much more flexible and increasingly autonomous. One crucial technology is the increasing power of small embedded computers, those which are integrated in a machine and customised to carry out specific jobs, unlike an ordinary computer which functions independently, not embedded. Embedded computers are used widely, examples being those in traffic lights and the navigation equipment of planes. Today, these computers are powerful enough to solve calculation-intense tasks such as ongoing image analysis that ▶

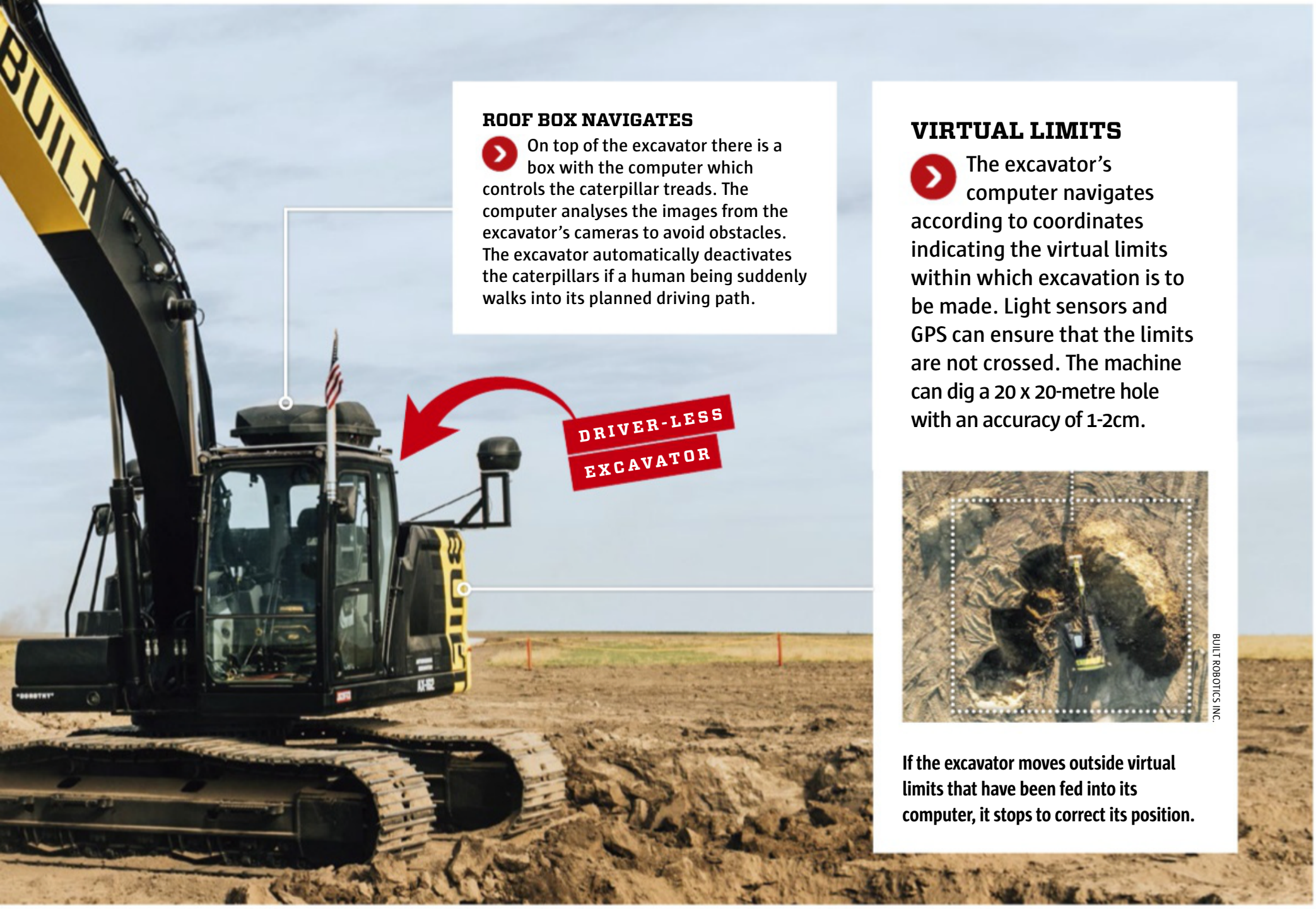


DAQRI

In the future, computers could design buildings using artificial intelligence.

Algorithm architects

Before long, a computer could take over the role of the architect. Given the general idea of a building, the computer could decide what to do by having learned from data covering thousands of other construction projects. Its algorithms are fine-tuned according to all this 'experience' to calculate the ideal materials for a specific type of building, the location of water pipes and cables, and the thickness of the roof for optimum insulation. The robo-architect then sends a 3D model via Wi-Fi to the robots which stand ready to construct the building.



ROOF BOX NAVIGATES

On top of the excavator there is a box with the computer which controls the caterpillar treads. The computer analyses the images from the excavator's cameras to avoid obstacles. The excavator automatically deactivates the caterpillars if a human being suddenly walks into its planned driving path.

VIRTUAL LIMITS

The excavator's computer navigates according to coordinates indicating the virtual limits within which excavation is to be made. Light sensors and GPS can ensure that the limits are not crossed. The machine can dig a 20 x 20-metre hole with an accuracy of 1-2cm.

BUILT ROBOTICS INC.

If the excavator moves outside virtual limits that have been fed into its computer, it stops to correct its position.

CARPENTER

Robotic carpenter works according to colour codes

The HRP-5P robot can take a plasterboard sheet, place it up against a wall with one arm and install it with the other. HRP-5P navigates by laser light emitted in all directions, with sensors measuring how quickly the light is reflected back from different angles and objects. A colour-coded 3D map is developed and is then used by the robot to calculate its path for moving around a room safely and efficiently.

HRP-5P is 182cm tall and weighs 101kg. A camera in its head can differentiate between power tools.

AIST

robots can use to distinguish between the many different tools and materials used on a construction site.

At the same time as the development of embedded computers, sensors have become more accurate. They are used in conjunction with LiDAR technology, using lasers to allow robots to create a detailed 3D map of their surroundings. Laser light is emitted, and the sensors measure distances and shapes based on reflections and the speed of reflectiion from the surroundings. LiDAR is already used in driver-less cars, and it will make robots better at navigating the changing environment of a building site.

Drones provide the plan

New technological breakthroughs mean that robots could go further, taking over the entire construction process.

The Komatsu company in Japan has automated the process of measuring, excavation and levelling the site for a house. According to the company, it previously took up to three days for human land surveyors to make an altitude map of an area covering 20,000m², but drones and real-time kinematic positioning (RTK) can draw up an accurate 3D map of the area in about 30 minutes. RTK improves the accuracy of an ordinary GPS signal by comparing GPS coordinates with a signal from an antenna on the construction site. This can correct any small deviations from GPS satellites which are located thousands of kilometres away and so improve GPS accuracy from a few metres down to a few centimetres. A drone equipped with a 20-megapixel camera takes one photo per second, combining them with GPS coordinates so that a computer can subsequently make a 3D map which is transmitted to Komatsu's autonomous machines, including data on where and how much soil is to be removed. Armed with this information a bulldozer and excavator begin to remove soil completely independently.

The HRP-5P carpenter robot can turn through

300

degrees. Humans can rotate only around 80 degrees.

3D printer builds a house in a day

Once the soil has been levelled, there's still the challenge of building walls. For this job, engineers throughout the world are turning to a method normally used for rather smaller things: 3D printing.

These 3D printers for houses use an additive process by which layers are printed on top of other layers to form the walls of the house. An American company, Contour Crafting, has developed a printer

with a print-head that moves in all directions – length, width, and height – via a rail system. Quick-drying concrete flows from the nozzle on the head. In time even exterior treatments and electrical installations could be be printed using the same process. According to Contour Crafting, a house of some 180m² which might take six months to construct conventionally can be printed in 24 hours.

Robot is a quick bricklayer

3D printers spray material from nozzles, but there are also robots that imitate a bricklayer's job, placing bricks on top of each other in an accurate pattern.

The SAM100 robot consists of an arm that takes bricks from a belt conveyor, adds mortar, and lays the bricks on the wall. A column on either side of the field of activity emits laser light that functions as the bricklayer's string line when the robot places the bricks. The robotic arm motions are controlled by algorithms that match the arm's speed and angle in proportion to the line. According to Construction Robotics, which is responsible for SAM100, the robot can remove 80% of the physical lifting work for a human bricklayer while making them three to five times more efficient, because they need only install the robot, feed it bricks and mortar, and adjust the joints. SAM100 can lay up to 3000 bricks a day compared with 500 for a human bricklayer.

Map renewed every three seconds

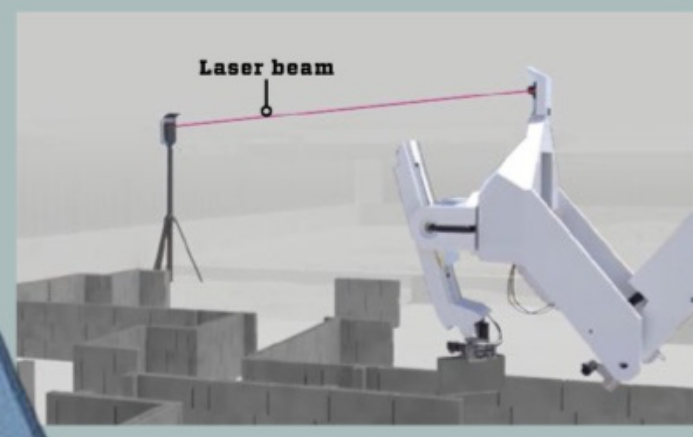
Other robots are ready to carry out carpentry work inside the house. Japanese scientists have programmed the HRP-5P humanoid robot to collect plasterboard sheets and install them using electric power tools.

The robot is equipped with motors and flexible joints allowing its body to rotate in wider angles and to carry more weight than people. The robot moves about the construction site by means of LiDAR technology. ▶

BRICKLAYER

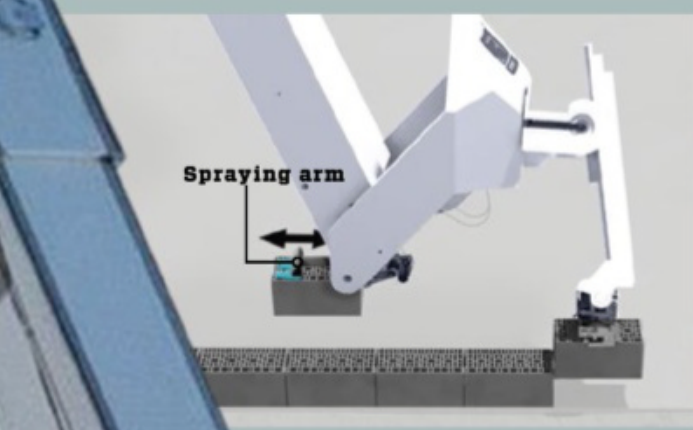
Robotic arm lays 1000 bricks per hour

The Australian robot Hadrian X builds walls at record speed. The robotic arm uses laser light for positioning and lays bricks made of lightweight concrete which are 12 times bigger than ordinary bricks and harden in 45 minutes.



LASER CONTROLS ARM

1 The robotic arm's position is calculated and continuously adjusted by sending laser light from the arm to a permanent station that measures the angle of approach and distance, keeping movements accurate.

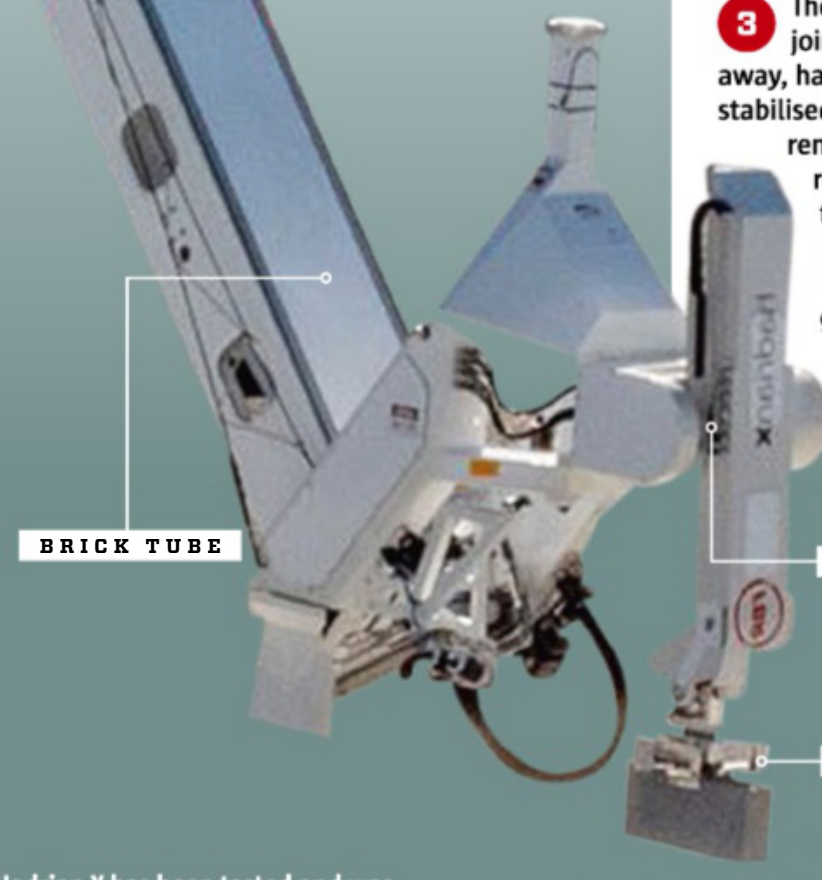


ADHESIVE IS ADDED

2 Bricks keep coming via the hollow arm. When a brick arrives, a spraying arm moves back and forth to add adhesive, the brick is rotated and then passed on to the most external of the gripping mechanisms.

BRICKS ARE LAID

3 The arm's most exterior joint is up to 30 metres away, hanging freely and stabilised by motors so it remains vertical regardless of jerks in the rest of the arm due to wind gusts or other issues. The gripping mechanism rotates bricks and lays them.



Hadrian X has been tested and was found able to lay the bricks for an entire house in three days.

CLAUS LUNAU & FBR LTD

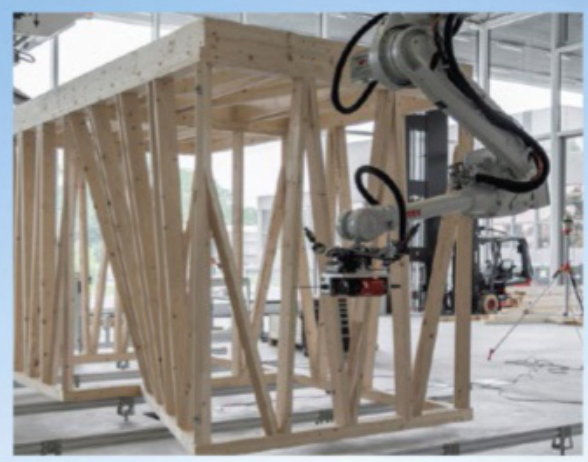
ROOFER

Robotic arms calculate and assemble the roof structure

Robotic arms saw up timbers of the right sizes, place them accurately, drill holes in them, and fix the posts into a frame that will carry the roof of a house.

ROMAN KELLER/NCCR DIGITAL FABRICATION

ROMAN KELLER/NCCR DIGITAL FABRICATION



GRAMAZIO KOHLER RESEARCH/ETH ZÜRICH

Robotic arm saws up posts

1 A robotic arm uses a circular saw bench. The arm's position is adjusted in 3D based on light sensors that measure distances and angles to the surroundings. Another robotic arm drills holes in the posts.

Algorithm avoids collisions

2 The computer which sends commands to the two robotic arms uses an algorithm to continuously correct the arms' mutual motions as the wooden posts are placed in their proper positions.

Arms position the timbers

3 The robots place the posts in a geometrical pattern designed to carry a roof without the need for any supporting fittings and plates, saving both time and materials.

Every three seconds the robot emits a shower of laser light which hits objects in the room, updating a detailed 3D map consisting of the points from which the light is reflected. Then when HRP-5P lifts a plasterboard sheet in front of its head, blocking the head's camera and sensors, it can still navigate correctly because it holds the latest 3D model of its surroundings in its memory, and continues to update it.

Before the installation of a plasterboard sheet, the robot must choose the right gear, and for this purpose it uses algorithms with artificial intelligence – neural networks inspired by the human brain – to recognise and differentiate between electric screwdriver, drilling machine and hammer.

Robot-built house has opened

The new generation of computer-controlled workers has already proved that they can take over almost the entire construction process. The DFAB House in Switzerland opened in early 2019. Its load-carrying walls were made by a computer taking metal threads and welding them together into a wall-shaped grid, which was then filled with concrete. The second floor rests on a large concrete plate that was 'printed' by a 3D printer. The roof-carrying woodwork that sits on the concrete plate was sawn, drilled in and assembled by robotic arms.

24

is the number of hours required by the most recent 3D printers to print an entire house.

The next step for the robots may be to take over the task of installing electricity and water pipes, and indeed contractors have already begun to use robots in these fields. Building Information Modelling (BIM) technology allows robots to handle these sensitive installations. BIM provides computer-generated 3D models of houses, from the walls and roof to the location of pipes and cables. These models are constantly amended during the course of the construction so they can be used to fine-tune the motions of the robots.

Mars base to be built by robots

If the future of automated building seems assured, such robots can do more than just solve the problem of housing shortages by more quickly building houses. This could be key to the colonisation of the Solar System, especially in adverse environments such as Mars, where the thin atmosphere subjects astronauts to harmful space radiation. They will need a protective base, but for every kilogram of payload in a space rocket, nine times as much fuel is required. With existing

IN SWITZERLAND, ROBOTS HAVE BUILT AN ENTIRE HOUSE.

The roof is complete

4 When the posts have been positioned, the entire structure can be placed on top of a house. In this photo, the posts carry the roof of the Swiss DFAB House, in which all parts were built by robots.

ROMAN KELLER/NCCR DIGITAL FABRICATION

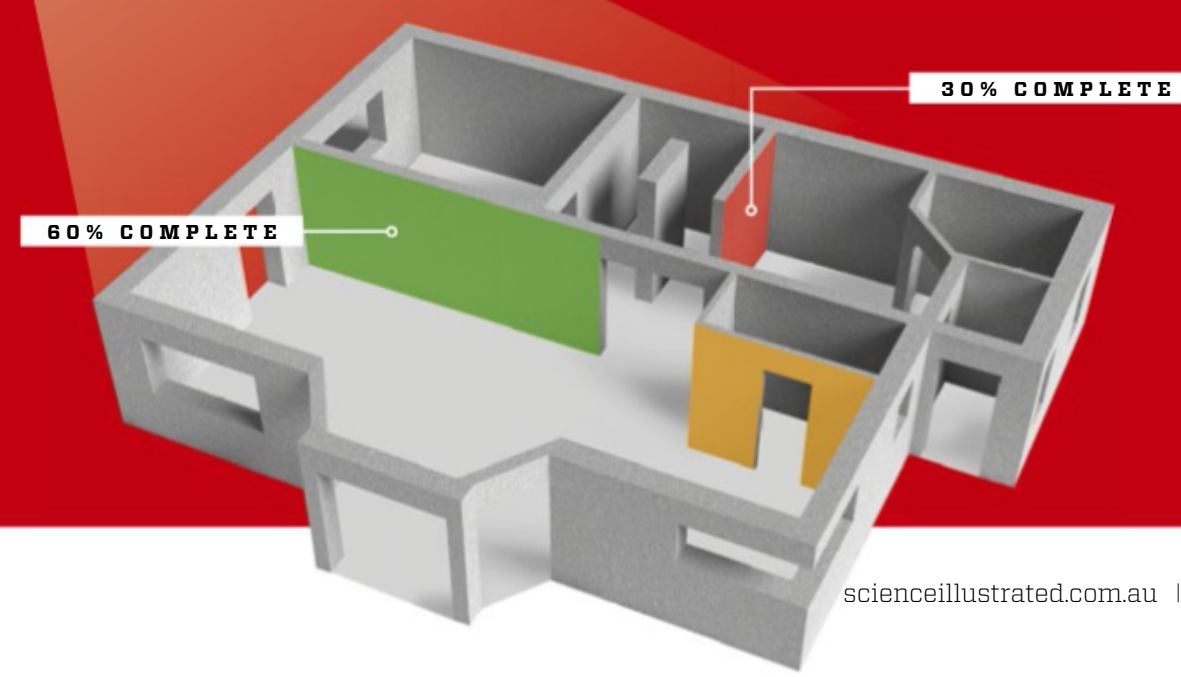
technology it simply isn't possible to send astronauts to Mars with all required machinery and building materials. But it may be possible to send robots which could build a base for astronauts to use later.

NASA is cooperating with AI SpaceFactory in the development of 3D printers which could build a base on Mars. The base is to be printed with a material made of basalt, which exists on Mars, mixed with bioplastic that could be extracted from plants grown on the planet. The resulting material would protect against cosmic radiation and insulate against the extreme temperatures on Mars.

A grand vision of the future might see robots handling construction work on moons, planets and asteroids throughout the Solar System, so that humans can arrive to populate fully constructed bases in which to live, work, and carry out research. SCI

Drones monitor the site

Canadian scientists have developed drones that can fly around a construction site, taking photos and analysing them using image recognition. The drones can recognise different materials and patterns to chart the progress of walls, insulation and more. The images are compared with the 3D building design already encoded and colour-coded for the drones, which can then send new or updated instructions to other robots on the site.



SHUTTERSTOCK

Scientists made some key discoveries during the past decade, and they expect just as many from the 2020s.

SHUTTERSTOCK

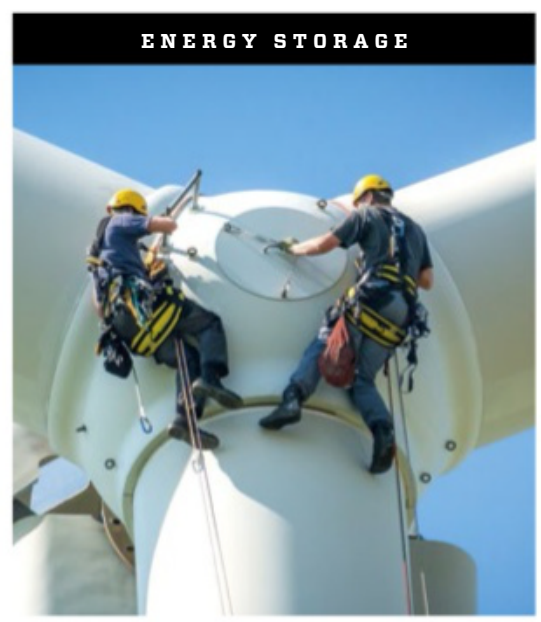
By **Rolf Haugaard Nielsen**

Dear Santa...

SCIENTISTS' GREATEST WISHES FOR THE 2020s

Solar fuel, the elimination of malaria, and a theory about everything – we asked scientists what they would most like to see develop during the next decade.

CERN



SHUTTERSTOCK

SHUTTERSTOCK & CLAUS LUNAU

THE 3 GREATEST WISHES

Dear Santa...

CERN physicists are rarely modest! They would like an accelerator with a 100km circumference worth A$35 billion. Such a giant could reveal the dark matter of the universe, and that could be the scientific breakthrough of the century.

SHUTTERSTOCK

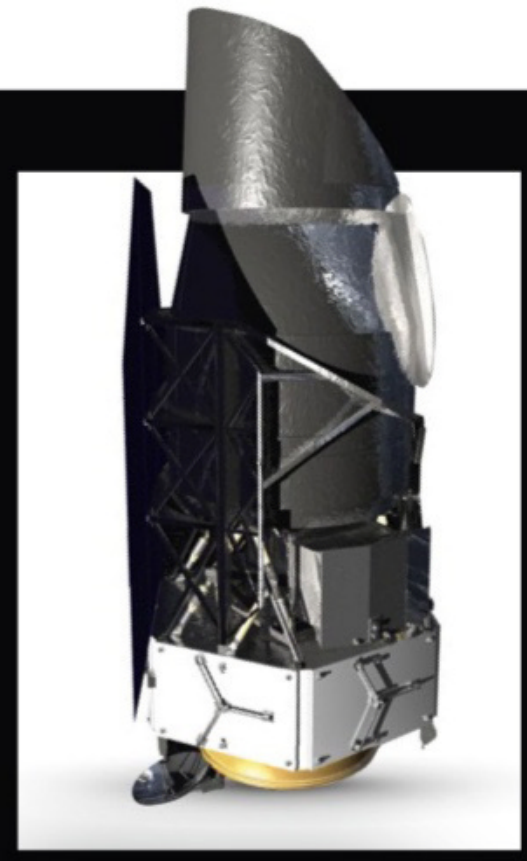
Earth-like rocky planets are the main targets for the James Webb telescope.

The James Webb telescope seeks life on Earth 2.0

The TESS satellite is searching for inhabitable rocky planets near close Sun-like stars, and from 2021 the James Webb space telescope is to search for life on the most promising of those planets. The space telescope can find evidence of life by recording spectrums of the rocky planets' atmospheres. When the reflection from the star and the heat radiation from the planet pass through the atmosphere, different molecules absorb the wavelengths of the light differently, revealing their existence. If the atmosphere contains lots of oxygen, it might indicate that the planet includes photosynthetic plants. Another sign of life is methane, which is produced by bacteria and ruminants.

Dark energy mystery solved?

In 1998, astronomers discovered that remote supernovas shone unexpectedly weakly when compared to close ones. The reason was that the remote supernovas are further away than expected, because the expansion of the universe has accelerated over the past five billion years. The acceleration could be due to dark repulsive energy, which the WFIRST space telescope will be used to investigate. The WFIRST's 2.4m-wide primary mirror has a field of vision 100 times bigger than Hubble's, so WFIRST could observe more supernovas from the time when the expansion of the universe began to accelerate.



NASA

The WFIRST's 2.4m-wide mirror is connected to a near-infrared camera.

SHUTTERSTOCK

Universe history

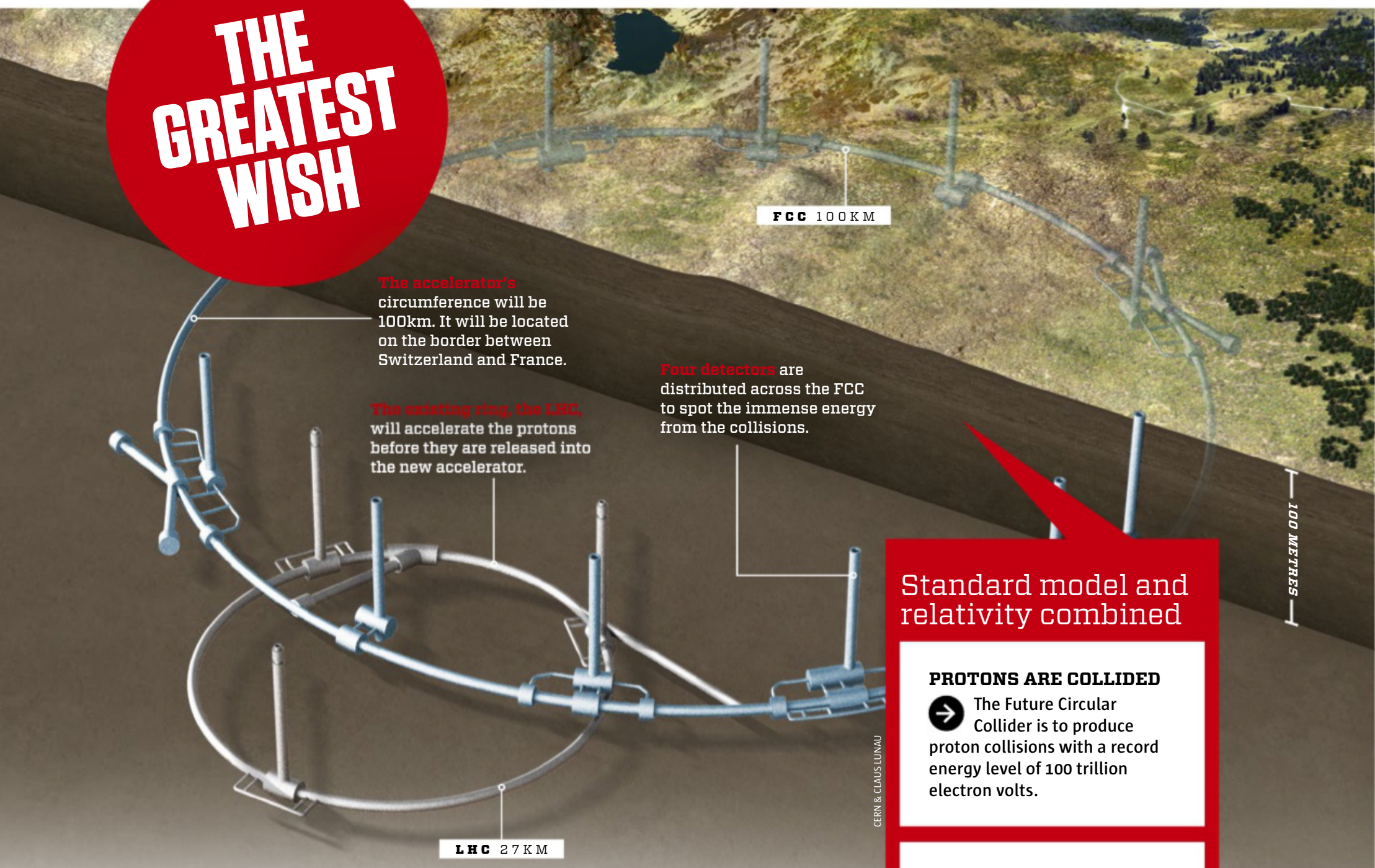
3. ACCELERATION
Five billion years ago, dark energy accelerates the universe's expansion.

2. INFLATION
All energy and matter are flung apart as the universe expands faster than the speed of light.

1. BIG BANG.
The universe expands tremendously 13.7 billion years ago.

ROEN KELLY/DISCOVER MAGAZINE

THE GREATEST WISH



CERN & CLAUS LUNAU

Standard model and relativity combined

PROTONS ARE COLLIDED

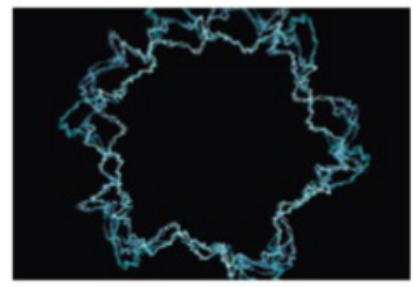
The Future Circular Collider is to produce proton collisions with a record energy level of 100 trillion electron volts.

TWIN PARTICLES ARE REVEALED

The collisions aim to produce twin particles, scientists' best theory to explain the composition of dark matter.

EVERYTHING CONSISTS OF SUPERSTRINGS

If the twins are identified, it will support the super-string theory, which combines the world of atoms and gravity.



SHUTTERSTOCK

Huge accelerator aims to confirm ultimate theory

Physicists would like a huge new accelerator which can produce twin particles. If they succeed, their 'theory of everything' will be complete.

All the galaxies of the universe rotate so rapidly that the outermost stars would be flung in all directions were they not maintained in their orbits by a major, invisible mass known as dark matter. Twin particles are physicists' best theory of dark matter, and they hope to be able to produce them in a new, huge accelerator.

According to its plan, the Future Circular Collider (FCC) will have a circumference of 100km and is be built in an underground tunnel near CERN in Geneva. There it will collide protons at an energy level seven times more intense than in the existing Large Hadron Collider. The aim is either to find twin particles or to exclude their existence. The twins are predicted by physicists' superstring theory, which combines the two pillars of modern physics and astronomy: the standard model that describes the world of atoms, and relativity theory that describes gravity, time, and space. If the FCC identifies twin particles, it would support physicists' theory of everything.

THE GREATEST WISH

SHUTTERSTOCK & CLAUS LUNAU

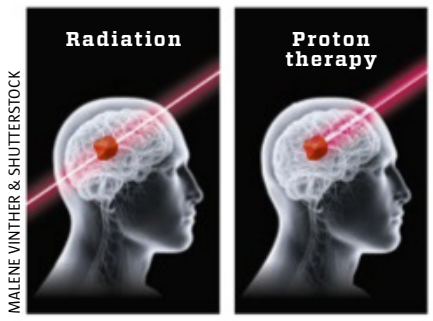
3 approaches to curing cancer

IMMUNE THERAPY IMPROVES BODY DEFENCE

1 Medical immune therapy, by which drugs stimulate the body's immune system to attack cancer tumours, could have its major breakthrough in the 2020s.

PROTON THERAPY ONLY AFFECTS CANCER CELLS

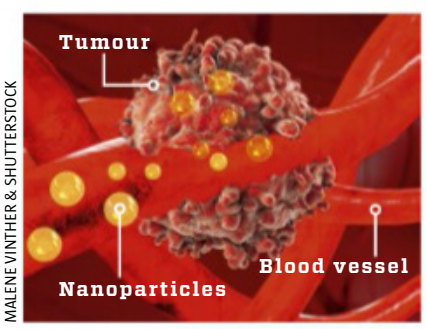
2 Proton therapy influences only the tumour, unlike radiation, which passes through the entire brain, injuring healthy cells as well as the cancer.



MALENE VINTHER & SHUTTERSTOCK

NANODRUGS SNEAK TOXIN INTO THE TUMOUR

3 The next generation of chemotherapy has no side effects, as small nanoballs will enter directly into cancer tumours via the blood stream.



MALENE VINTHER & SHUTTERSTOCK

Our genes to provide a cure for cancer?

Doctors aim to equip the body's killer cells with cancer-identifying genes. The method could cure even terminally-ill cancer patients.

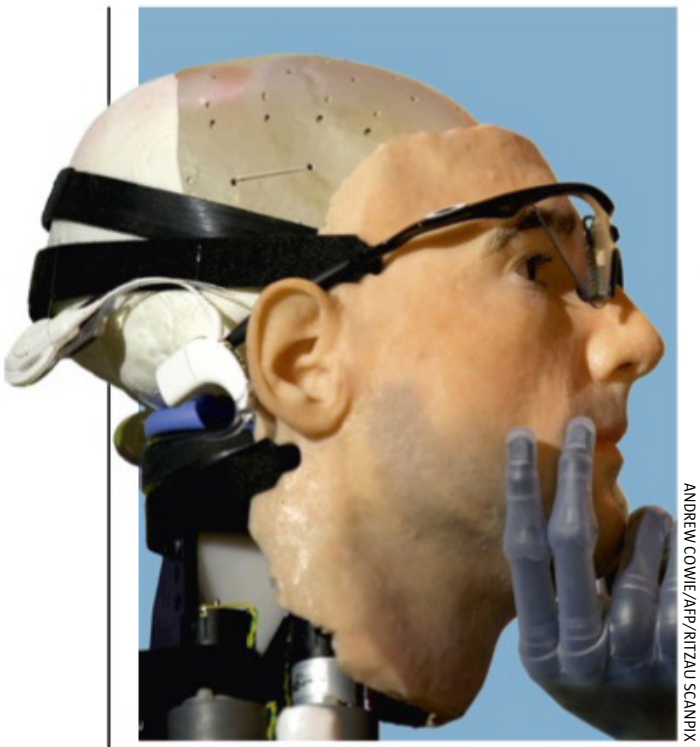
A new type of immune therapy might revolutionise cancer treatment. The therapy upgrades the patient's own immune cells that have turned blind to the cancer tumours.

First, doctors extract immune system killer cells from the patient, and in the lab, CRISPR gene editing is used to insert a gene into them that makes the tumours visible to the immune system. The GM cells are subsequently injected back into the patient's blood, where they find and eliminate all tumours. So far the method has only been tested on a few patients, but several of them have been almost miraculously cured.

The next step for scientists is to test safety, as the method involves a risk of the upgraded immune cells attacking the body's healthy cells, which could kill the patient. So the therapy is currently only tested on terminal patients that accept the risk. Later, the treatment will be tested on large groups of cancer patients before the treatment finds its way into hospital cancer wards.

Dear Santa...

Doctors would like to find the ultimate cure against cancer, which might remove tumours without injuring the rest of the body. They have a series of new treatments in the pipeline, so perhaps Santa will fulfill their wishes in the 2020s.



ANDREW COWIE/AFP/RITZAU SCANPIX

Robotics engineers have created a body of prostheses and artificial organs.

Artificial body parts save lives

If you are injured and lose a body part, you can already have an artificial ear or nose 3D-printed using your own cells. Spare parts will become better and more numerous in the 2020s.

If your arm is amputated, you can have an artificial prosthesis that is controlled by the power of thought via an electronic link to the nervous system. Hand prostheses mimic a sense of touch that delivers a natural sensation of whatever the user holds, making a prosthesis less clumsy.

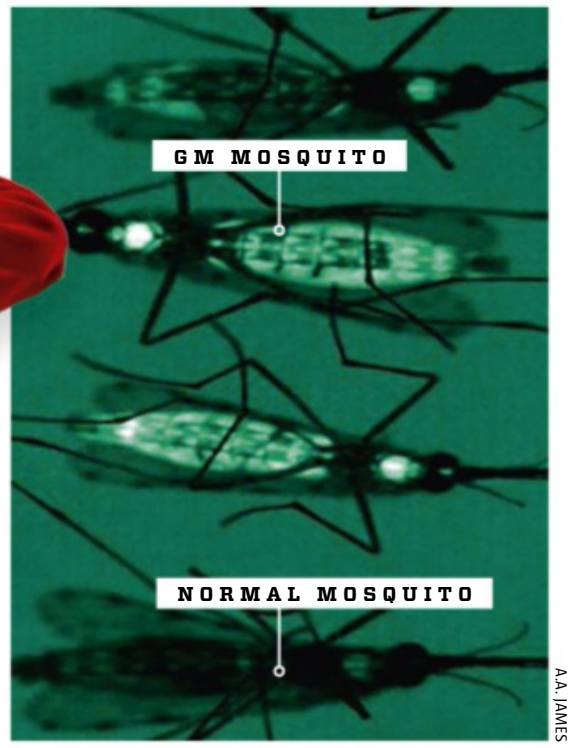
Chinese and US scientists have even printed tiny copies of human kidneys and livers. The kidneys were kept alive in a nutrient fluid for four months, during which time they proved that they could purify blood. Over the next 10 years doctors will also be able to print detailed networks of blood vessels and cells, so full-sized kidneys and livers could be printed and transplanted to patients.

DECODE GENETICS

The deCODE company has sequenced the genomes of 2636 Icelanders.

Everyone gets genome-sequenced

In several areas of the world, scientists are sequencing large numbers of individual genomes, such as in Iceland, where 2636 people have had their genomes sequenced. The projects aim to spot the genetic causes of common diseases such as cancer, dementia and cardiovascular diseases. During the 2020s, newborn babies may have their genomes sequenced at birth, revealing the diseases that the baby risks developing in his/her lifetime. In adults, a personal genome can reveal how quickly specific medication is converted, so that drug types and doses can be customised for individual patients.



A.A. JAMES

The bright mosquitoes include a gene that is resistant to the malaria parasite.

GM mosquitoes eliminate malaria?

More than one million people throughout the world die of malaria annually, but now scientists have genetically manipulated mosquitoes to be immune to the malaria parasite and so unable to spread the dreaded disease to humans. The characteristic is dominant, so if the GM malaria mosquitoes are released into the wild and mate with other mosquitoes, the offspring will be immune to the malaria parasite. Theoretically, the GM mosquitoes could spread immunity against the parasite to all wild malaria mosquitoes in a few months, eliminating the tropical disease.

The method has only been tested in the lab, and the strategy does involve risk. If something were to go wrong and the gene to act in an unexpected way, biologists would be unable to limit the spread once the GM mosquitoes had been released into the wild.

THE 2010s came bearing gifts of science

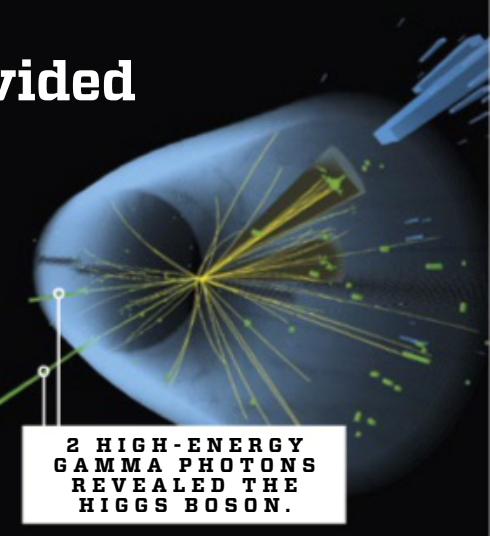
Observations of the universe's most dramatic events, a new particle produced in huge collisions, and the ability to design the perfect human being – in the past decade, scientists gave us great gifts that are changing life on Earth for the better.

SHUTTERSTOCK

The Higgs boson provided atoms with mass

In 2012, CERN physicists finally recorded the Higgs boson that provides all atomic building blocks with mass. With that discovery, physicists' standard theory was proven accurate: all matter in the universe is made of six types of quarks, three types of electrons, and three different neutrinos, interacting via the exchange of force-carrying particles.

T. MCCAULEY/CERN



2 HIGH-ENERGY GAMMA PHOTONS REVEALED THE HIGGS BOSON.

PHYSICISTS

CLAUS LUNAU

CLAUS LUNAU

STAR DANCE MADE SPACE OSCILLATE

1 **Two neutron stars** begin to orbit each other, emitting gravitational waves as their orbits become ever smaller.

2 **The stars' speeds** increase, and right before the collision the gravitational waves are so powerful that detectors on Earth spot them.

Scientists have deliberately given five monkeys hereditary diseases by editing their genes.

CHINA NEWS SERVICE/GETTY IMAGES

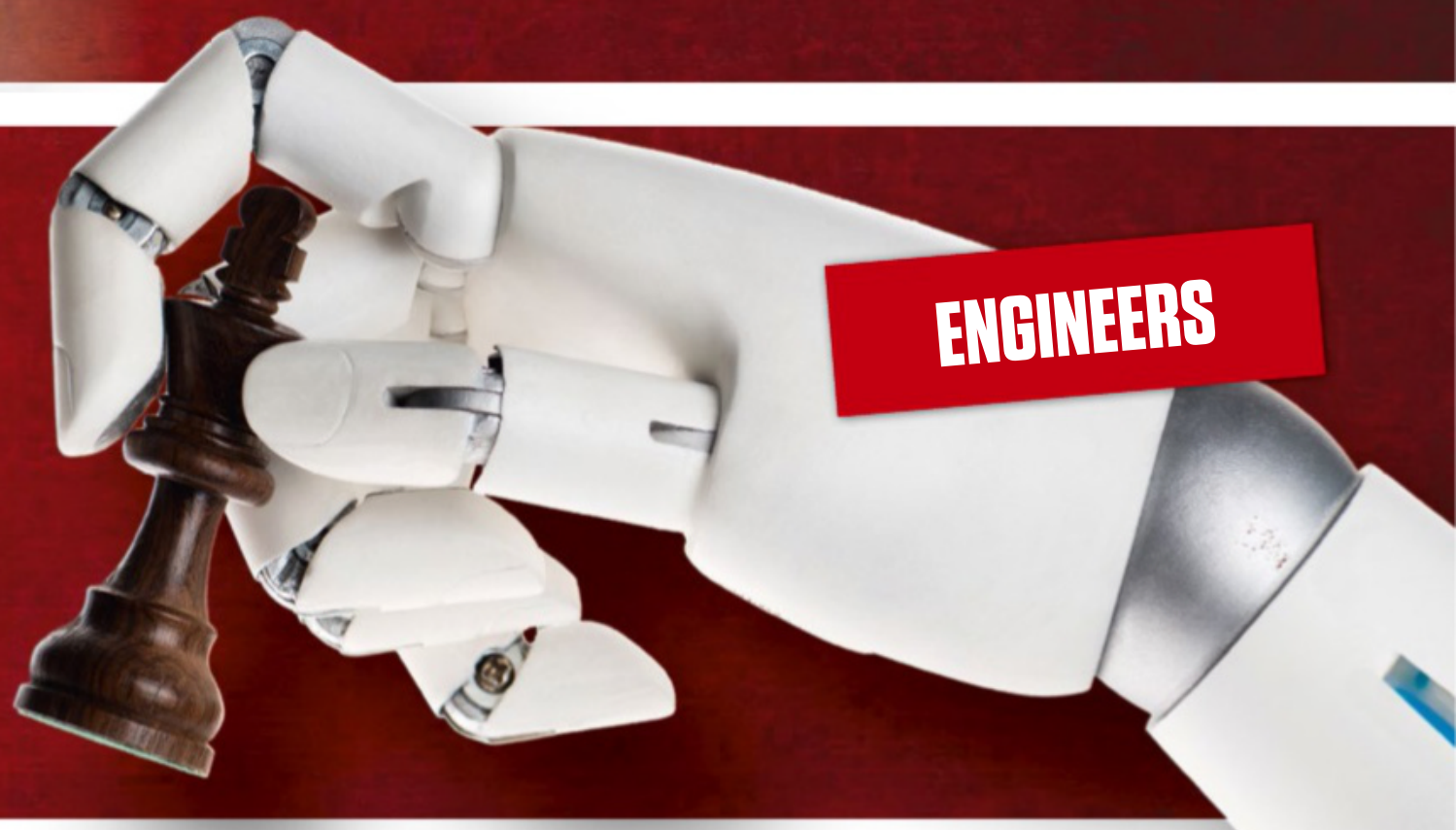
DOCTORS

Gene editor allowed us power over life

Geneticists' great Christmas present of the 2010s was the CRISPR gene editor. Diseases such as muscular atrophy and blindness could soon be cured.

The CRISPR gene editor was used for the first time in 2015. It allows scientists to edit genes very accurately, and the method is so efficient that it might eventually eliminate all gene diseases.

CRISPR functions by a genetic 'tracker dog' identifying the gene that is to be manipulated. An enzyme then cuts both DNA strands of the coil, after which the unwanted gene, such as a disease gene, is removed and the strands are linked again. As well as removing sick genes, geneticists can insert another gene into the hole, which could add new qualities to the organism. In farming, the method could create healthier food by preventing allergy-causing substances finding their way into our crops. However, the major possibilities are in medicine. Successful clinical testing offers a hope of curing cancer, while animal-based experiments hold the promise that we might one day cure muscular atrophy, cystic fibrosis and blindness. Another possibility is to eliminate hereditary diseases via gene editing of fertilised eggs, by which the manipulated genes are passed on to all future generations. However, scientists fear that CRISPR will be abused to create babies with desired qualities such as blue eyes, maths talent, empathy, or strong muscles.



ENGINEERS

Artificial intelligence boom

In 2018, computers finally beat humans in mind power. The AlphaZero chess program competed with the world's best chess program Stockfish, which no human being can beat. AlphaZero was fed only the rules of the game, then played millions of games with itself over a few hours, learning enough to beat Stockfish.

SHUTTERSTOCK

CLAUS LUNAU

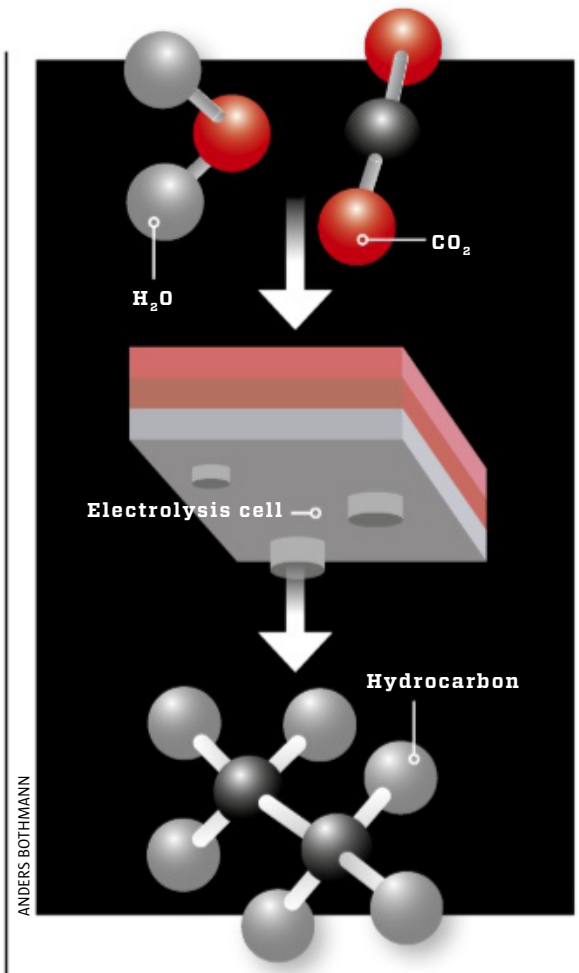
3 **In the collision** the neutron stars merge into a black hole. A few per cent of their mass is flung into space, causing a kilonova.

Gravitational waves revealed cosmic booms

When major masses are accelerated rapidly or collide, gravitational waves are created that roll through space to make spacetime oscillate. In 2015 the US LIGO detectors captured gravitational waves for the first time, from a collision between two black holes. Two years later, scientists observed a collision between two neutron stars that merged into one large black hole. A wealth of telescopes observed the subsequent light emission and proved that brief gamma-ray bursts originated from collisions between neutron stars. The observations also contributed to proving Einstein's relativity theory, which predicted the existence of such waves more than 100 years ago.

Dear Santa...

Sunlight and wind already supply the world with climate-neutral energy. But what can we do with surplus power when the Sun shines brightly and the wind is strong? Storing it might help reduce global warming... so that Santa won't lose his home in the snow.

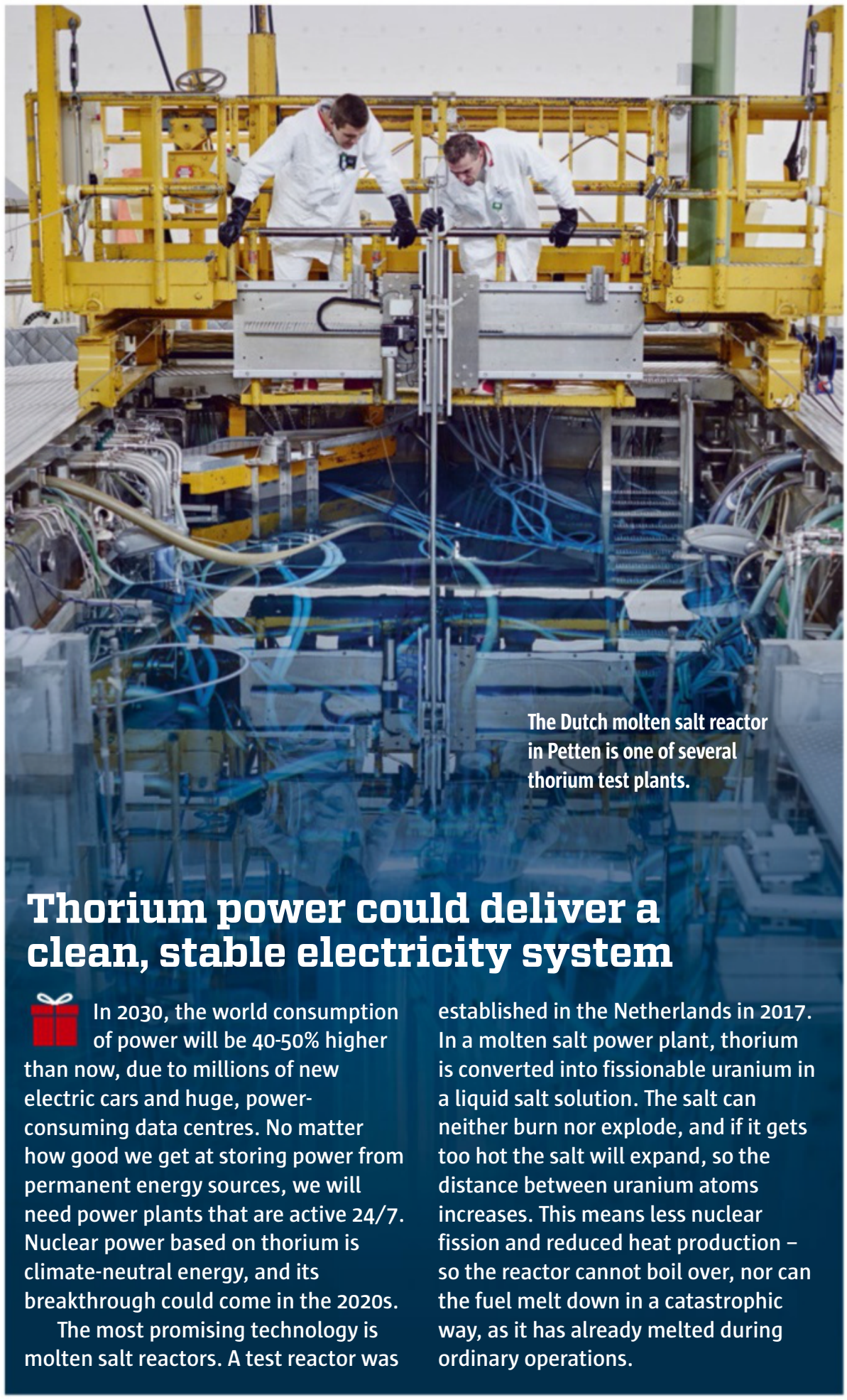


ANDERS BOTHMANN

The electrolysis cell converts water and carbon dioxide into hydrocarbons.

Converting gas into solar fuel

CO_2 can be sucked out of the atmosphere or extracted from power-plant smoke and converted into climate-neutral fuel. The technology is still only in the research phase, but the industrial breakthrough could come in the 2020s. Once the CO_2 has been extracted, it is sent into a new type of electrolysis cell together with water. A current is sent through the cell so that the CO_2 reacts with the water to produce liquid fuel such as petrol. If the current for the electrolysis comes from sunlight, wind or hydropower, the resulting fuel will be climate-neutral, as the carbon dioxide the car emits came from the atmosphere. Solar fuel could be used in existing cars until electric or hydrogen-powered cars take over.



HEIN VAN DEN HEUVEL/NGR

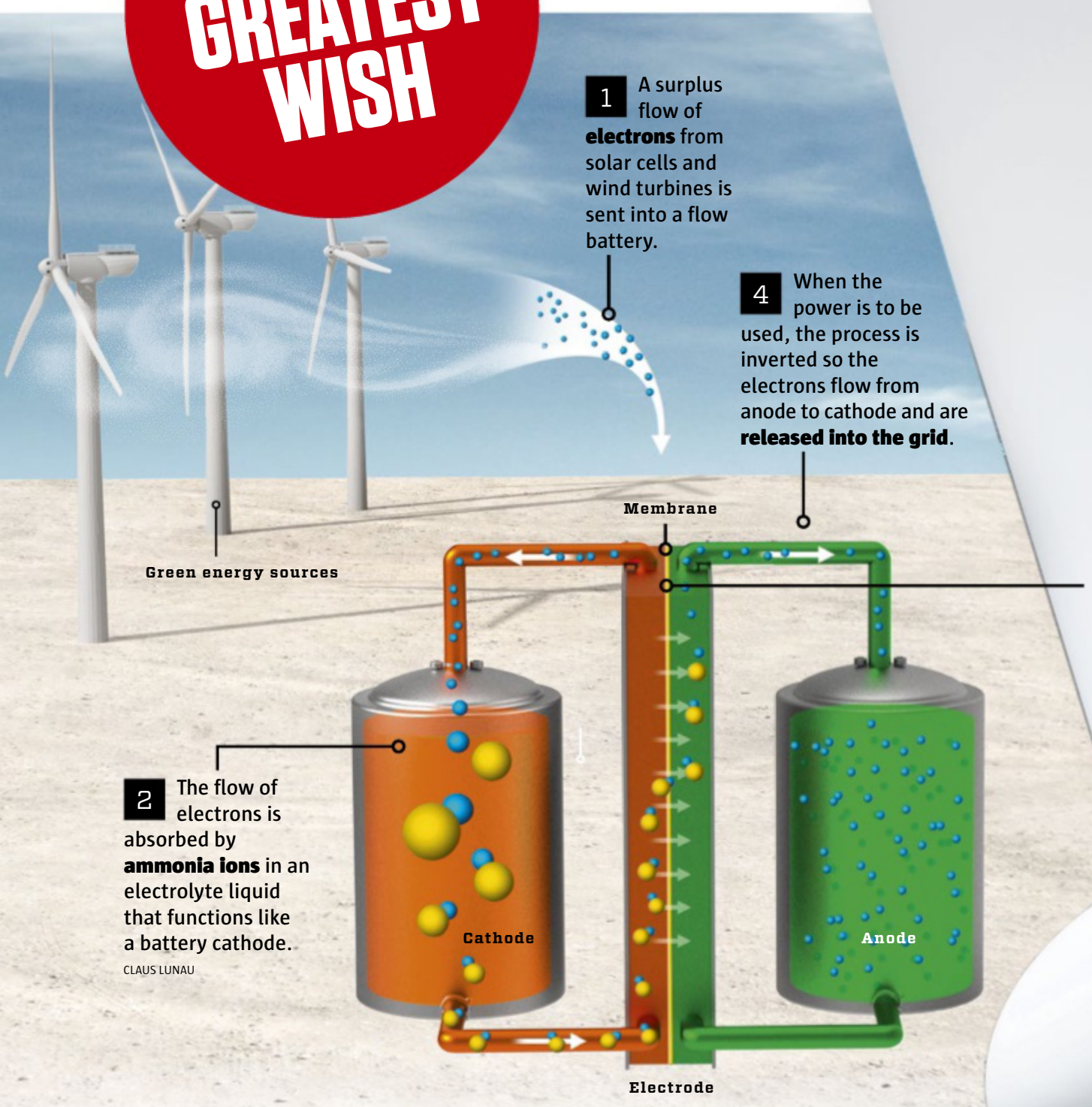
The Dutch molten salt reactor in Petten is one of several thorium test plants.

Thorium power could deliver a clean, stable electricity system

In 2030, the world consumption of power will be 40-50% higher than now, due to millions of new electric cars and huge, power-consuming data centres. No matter how good we get at storing power from permanent energy sources, we will need power plants that are active 24/7. Nuclear power based on thorium is climate-neutral energy, and its breakthrough could come in the 2020s.

The most promising technology is molten salt reactors. A test reactor was established in the Netherlands in 2017. In a molten salt power plant, thorium is converted into fissionable uranium in a liquid salt solution. The salt can neither burn nor explode, and if it gets too hot the salt will expand, so the distance between uranium atoms increases. This means less nuclear fission and reduced heat production – so the reactor cannot boil over, nor can the fuel melt down in a catastrophic way, as it has already melted during ordinary operations.

THE GREATEST WISH



CLAUS LUNAU

Surplus power is stored efficiently

In the 2020s, solar and wind power will be cheaper than coal-generated power, but production will vary over days and years. So power requires large-scale storage.

Electricity is the cleanest energy carrier of all. The climate problem only arises because we generate the power by means of coal, oil and gas. In the 2020s, solar and wind power will become cheaper than coal-generated power, and this, together with climate consciousness, will see the use of clean energy sources explode, providing engineers with a new challenge. Solar cells are more efficient on sunny days and in the summer, while wind turbines depend on wind. It will be necessary to store electricity, and in this regard flow batteries seem the best solution when big cities are to be supplied with power. In the battery, energy is stored as chemical energy by means of ammonia ions until the electricity is required. The world's biggest flow battery with a capacity of 800MWh will be put into service in China in 2020.

Flow batteries aim to make sure that wind energy can be used to its maximum efficiency.

SHUTTERSTOCK

SHUTTERSTOCK & LOTTE FREDSLUND

Rising mountains force a reversal of evolution

First they laid eggs, then they gave birth to live offspring, and now they lay eggs again. South American lizards surprise scientists.

50 million years ago
Remote ancestors laid eggs

1 Like most other lizards, the ancestors of South American Liolaemus lizards laid eggs. At this point in time, the Andes Mountains had not yet formed.

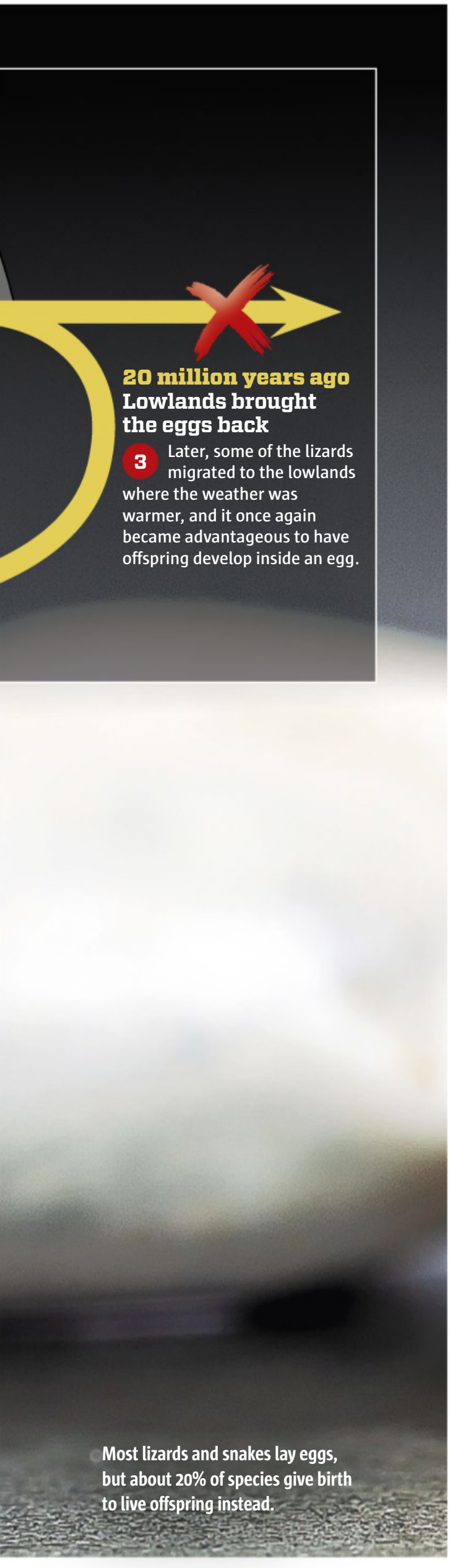
30 million years ago
Mountains triggered births

2 The Andes mountains rose up, and the new altitudes were colder, so that offspring did better developing inside the mother's warm belly and being born alive.

By **Jonas Grosen Meldal**

When evolution shifts into reverse

Animals can evolve back towards their ancestors. Scientists used to think this was impossible, but new algorithms and gene analyses demonstrate that this has happened to lizards, frogs, and even humans.



Most lizards and snakes lay eggs, but about 20% of species give birth to live offspring instead.

High up in the Andes, a heavily pregnant lizard is crawling around the rocks. Suddenly, she stops and spreads her hind legs. Shortly afterwards a small head protrudes, wrapped in a thin, transparent membrane, which the mother immediately tears to pieces. Fifteen minutes later, three babies are moving about.

This is how the small lizard and its peers have had offspring since their ancestors took a dramatic evolutionary step 30 million years ago and began to give birth to living offspring instead of laying eggs. The change in the lizards' biology was so significant that scientists used to consider it impossible that they might go back to laying eggs again. However, a new study carried out in 2018 by scientists from Chile and Australia has revealed that it has already happened to some lizard species.

This discovery and other new studies are demonstrating that animals can regain features that their ancestors lost 100 million years ago or more. Evolution may jump back and forth much more than we used to imagine, and the phenomenon can even be observed in our own bodies.

Gone for good, says Dollo's Law

Major evolutionary changes such as the South American lizard's shift from eggs to live offspring are quite normal in nature. Snakes lost their legs, humans said goodbye to their tail, and penguins can no longer fly. New conditions can make features redundant or inconvenient, so that animals sometimes evolve to get rid of them.

And according to Dollo's Law, once they are gone, they are gone for good. The law, introduced by the Belgian palaeontologist Louis Dollo in 1890, stated that evolution cannot be reversed.

Since then, the idea has dominated the theory of evolution – and with good reason. The recreation of a lost feature would seem to require a very unlikely process in which a series of altered genes must change back into their former versions. In the case of the lizards, the genetic changes would be considerable. The change from laying eggs to giving birth to live offspring requires birth canal restructuring, a much thinner egg shell, development of a placenta, and immune system changes so that the mother does not reject the baby as a foreign body.

Dollo's Law has held sway for more than 100 years, and not only because it seems sensible in principle. So far, scientists have simply not had the tools to disprove it. But sophisticated algorithms and new DNA reading methods are making it possible to get a more detailed picture of millions of years of evolution – and so reveal some of evolution's biggest secrets.

Algorithms turn back time

Family trees are the key to understanding the pasts of animals, as of ourselves. A family tree can tell us that our closest and most remote mammal ancestors are furred. So we must descend from furred animals.

Similarly, Australian and Chilean scientists revealed for the first time in 2018 that several groups of egg-laying lizards from South America descend from ancestors that gave birth to live offspring. So in the course of their evolution the South American lizards have gone from eggs to live offspring and back to eggs again. The surprising ▶

» conclusion is based on their family tree, where the egg-laying lizards are surrounded by lizards that give birth to live offspring.

The method seems simple, but until recently such a study would not have been possible. In order to draw up a family tree, scientists first need to form a general view of all the ways in which the species of the family tree can be related. Four species add up to 15 possible versions of the family tree, and then the scientists need to calculate which one is the most likely based on the animals' genes and other factors. If there are 10 species, they can be related in 34 million different ways, and it becomes much more difficult to find the most likely family tree. The study of the South American lizard includes the genes of 258 species.

This 'mapping out' of DNA from so many species would have been almost impossible only a few years ago, but today it is possible thanks to new and relatively cheap DNA sequencing methods. Even then the analysis of the species' kinship requires so much computing power that scientists have only recently been able to churn all the data. The scientists' algorithms sorted through a total of 500 possible family trees – a process that might take weeks – to reach the most likely family tree.

Apart from the genes from the lizards, the scientists also fed their algorithms data about extinct lizard fossils and the environments of individual species. From this the scientists could reveal that the first change from egg to live offspring probably took place when the Andes mountains rose up 30 million years ago. The new mountains lifted the lizards so high that the air around them became colder. Cold is lethal for embryos that develop in eggs outside the mother's body, so the lizards began to keep their embryos in their stomachs until the embryonic stage had been completed. The egg shell was replaced by a thin membrane, and the offspring was viable at birth. Later, some lizards moved into the warmer lowlands at the base of the mountains, making it warm enough to lay eggs again.

258

species were included in the construction of the lizards' family tree.

The lizards are just the most recent example of animals that violate Dollo's Law. Improved technology has allowed scientists to find others. A study from 2011 showed that just one of the world's 6000+ frog species had developed teeth in its lower jaw – a feature that the ancestor of frogs lost at least 225 million years ago.

Humans also seem to have violated the law. Two muscles at the top of our backs merged into one for our remote mouse-like ancestors 89 million years ago. But a few million years ago, evolution did a back flip, and the muscle again divided in two.

Most genes survive the loss

All these violations of Dollo's Law have forced scientists to reconsider the function of evolution. Instead of imagining that the genes of a specific characteristic are lost when it disappears, scientists now think that in many cases the genes remain intact but simply inactive. And as long as the genes are intact, the lost feature can be recreated.

Scientists have found an example of this phenomenon in poultry. The birds lost their teeth more than 60 million years ago, but most of the genes that can produce teeth are still fully functional. By changing only one single gene, scientists can activate all these genes and make poultry develop teeth again. The birds' tooth genes probably survived ▶

ALLISON WHITING/BYU/NSF & SHUTTERSTOCK

They had wings, then they lost wings; now 40% of stick insects develop their wings again.

Walking sticks fly again

Stick insects were wingless for 50+ million years, but suddenly became able to take flight again.

About 95 million years ago, stick insects lost their wings. That's the conclusion of a group of American and German scientists that mapped out the plant-like insect's family tree. However, 40% of modern stick insects have a set of wings. The family tree reveals that the high number of winged species come from no fewer than four groups of stick insects which got their wings back independently of each other. The first such incident took place some 40 million years ago.

The wings of stick insects are similar to those of other insects, and scientists have no doubt that stick insects use the same genes to form their wings. The genes were preserved intact despite the creatures doing without wings for 50+ million years, remaining probably because the genes also play an active role in the formation of the insects' legs.

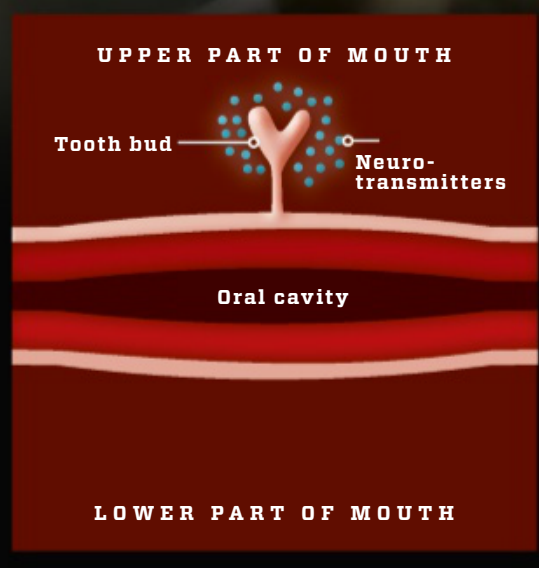
Frog finds its lost teeth after 225 million years

Frogs lost their lower teeth 330-230 million years ago. Five million years ago, one species got them back again.

NO LOWER TEETH

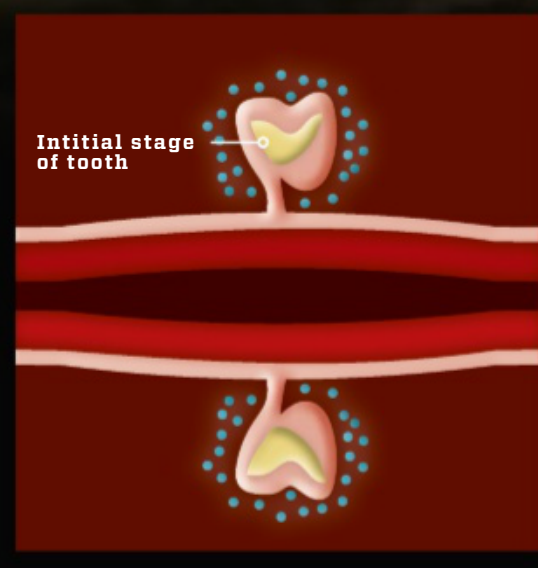
SHUTTERSTOCK & COURTESY OF DR. MARK WILKINSON. © TRUSTEES OF THE NATURAL HISTORY MUSEUM, LONDON & LOTTE FREDSLUND

FROG COPIED UPPER TEETH



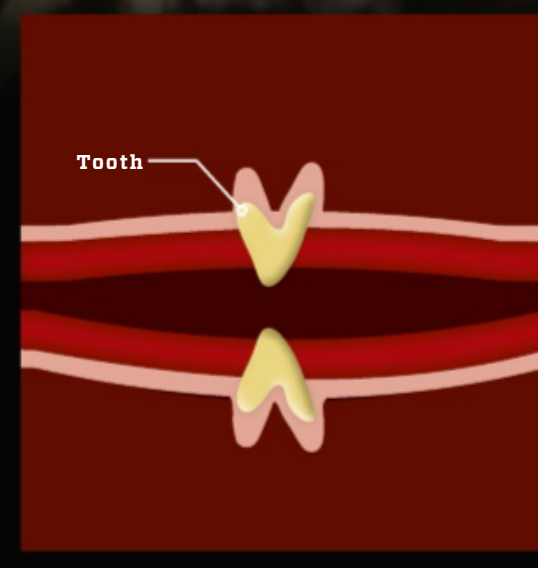
Neurotransmitters trigger the formation of teeth

1 During a frog's embryonic development, a series of mouth genes are activated resulting in different neurotransmitters causing a layer of cells to produce a tooth bud. In the vast majority of frog species, the genes of the lower part of the mouth are not activated.



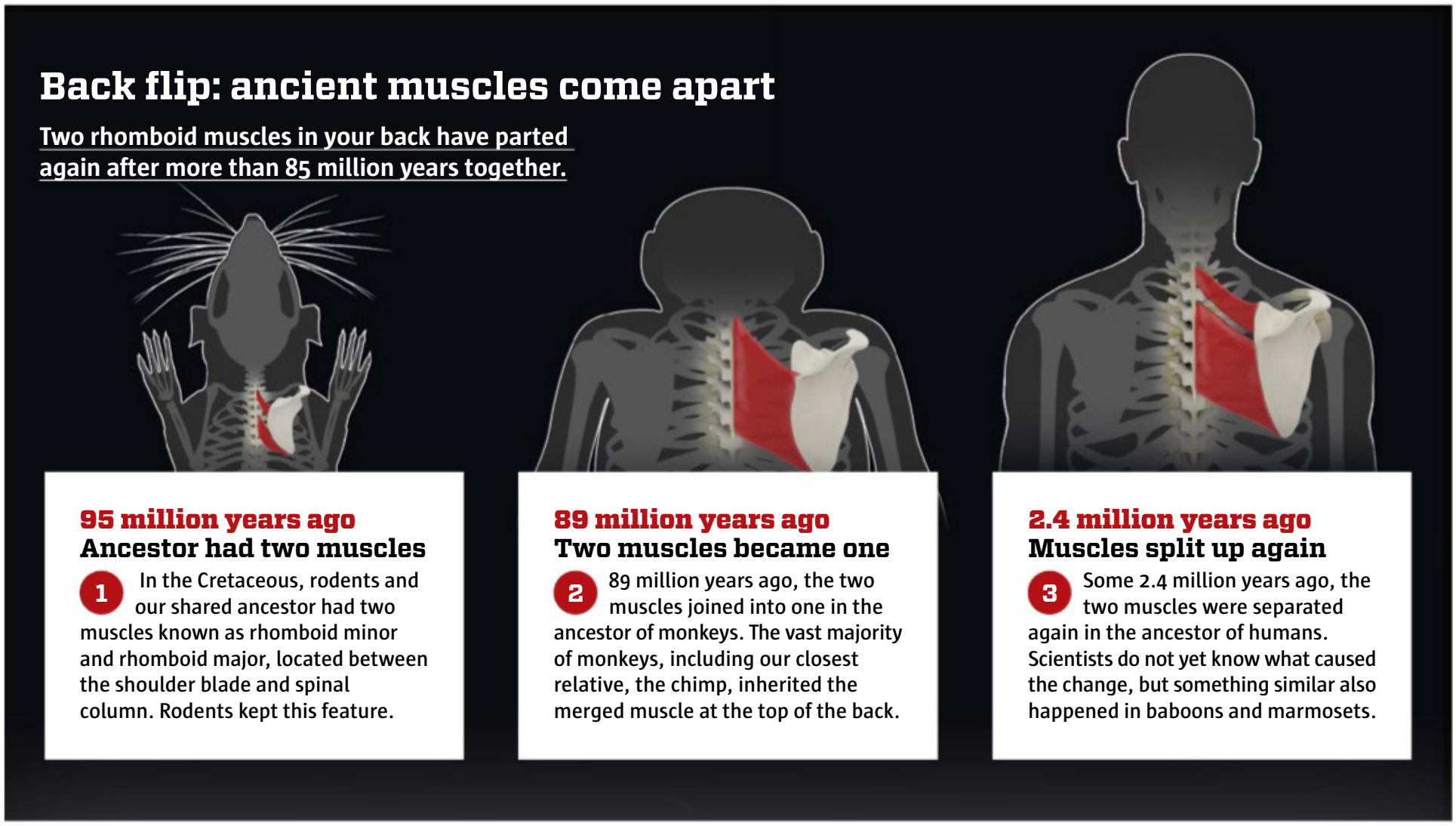
Genes are active all over the mouth

2 In one single frog species, the South American *Gastrotheca guentheri*, the tooth genes are apparently activated in both the lower and the upper parts of the mouth, and neurotransmitters make sure that tooth formation is triggered in both places.



Frog ends up with ancient set of teeth

3 The *Gastrotheca guentheri* frog grows a fully developed set of teeth in both the lower and the upper parts of its mouth. The formation of the lower teeth probably happens in the same way as it once did in a remote frog ancestor at least 230 million years ago.



CLAUS LUNAU

in spite of the loss of teeth because the genes also have other useful functions in the animals' bodies. The vast majority of genes are involved in more than one process, and they can play roles in several types of tissue. The birds' tooth genes may continue to play an important role, in feathers and elsewhere, even though they are no longer active in the mouth.

Easy change to birth

Changes of gene activity rather than changes to the genes themselves also seem to be key to the lizards' journey from egg-laying to live births and back again.

An international team of scientists in 2019 studied two closely-related Chinese lizard species, one that lay eggs and one that gives birth to live offspring. The scientists identified the genes that were responsible in each case and studied them. Much to their surprise, the results indicated that a change from egg-laying to live offspring is not very complicated in genetic terms.Again the difference between the two species were primarily differences in gene activity. The genes responsible for the egg shell also exist in lizards which give birth to live offspring, but they find much less expression. And since the genes are still present, the steps back to egg-laying are not as extreme as previously believed. That conclusion is supported further by the same reverse from live birth to egg-laying being observed in some snakes. Most boas have abandoned egg-laying and now give birth to living offspring, but the *Eryx jayakari* desert snake's nutrient-deficient surroundings have led the animal back to laying eggs, according to a major study by the American Yale University, in which scientists mapped out a family tree including 41 boa species.

40+

modern people have been born with tails.

An Australian reptile species provides us with an even more direct impression of the transition between egg-laying and live births. The *Saiphos equalis* lizard makes use of either strategy, depending on its habitat. Near the coast, the lizard lays eggs, but in the mountains it gives birth to live offspring. The fact that one single species can exhibit such different behaviours supports the theory that evolution can take huge steps without dramatic gene change.

Ancient traits appear in embryos

Animals and humans keep the genetic tools for long-forgotten jobs or developing long-lost body parts, and this is particularly clear during their embryonic development. Whales and dolphins both descend from a four-legged terrestrial animal, and they still develop small hind legs when the embryo is in a very early stage. In the vast majority of cases the limbs disappear completely before birth, but exceptions exist.

In humans, a tail can be observed in the sixth week of embryonic development. It usually disappears, but again, exceptions exist. There are several dozen examples of children that have been born with tails, and scientists still discuss exactly how and why the tails are formed. An even more ancient trait can be observed in human embryos: gills, in spite of our ancestors giving up gills 350+ million years ago. The retention of such ancient traits allows animals to hold on to possibilities for 'reverse' evolution.

Unlike other dolphins, this individual has four limbs.

TAIJI WHALE MUSEUM/ AP/RITZAU SCANPIX & SHUTTERSTOCK

Return of the dinosaurs

In recent years, scientists have tried to find out exactly what is required to rewind animal evolution. Some scientists would like to be able to recreate long extinct species such as mammoths or dinosaurs, and several of the changes might prove so simple that they can happen naturally without our help – as in the case of the egg-laying lizards and the frog with teeth in its lower jaw.

Birds evolved from their dinosaur ancestors, and they changed a lot in the process. For one thing they lost their teeth, yet one small adjustment of the activity of two genes could give them back their teeth. Scientists know a natural mutation that can make this adjustment take place, but the mutation is lethal, so the embryos never hatch. In the future, a more harmless mutation might result in an adult bird with teeth. In the lab, scientists have also discovered small adjustments that could give birds leg-bones and skulls reminiscent of the ones on related dinosaurs such as the Velociraptor of the Cretaceous – so the birds have several opportunities to take a step or two back towards their remote ancestors.

The South American hoatzin bird probably already took such a step. Most birds have no claws or only small claws on their wings, but in the hoatzin's offspring the claws look like those on the bird's ancestors. Scientists now think that earlier in its evolution the hoatzin lost the use of its claws, only to regain them later because the offspring found them useful for climbing trees. SCI

Mutations activate tails and teeth

Humans with tails, poultry with teeth, and dolphins with hind legs – ancient features once lost are revived in a few individuals after having been missing for millions of years. Known as atavism, the phenomenon is only possible because the genes responsible never quite disappeared.

SWNS/RITZAU SCANPIX & JOHN F. FALLON AND MATTHEW P. HARRIS

People are born with tails

Human embryos produce a tail in the fourth week of the embryonic stage, but it is broken down again between the sixth and eighth weeks. However, there are exceptions, and at least 40 modern people have been born with real tails. The tails are normally removed at birth, but in India, a boy kept his tail for 18 years, and it grew to a length of 18cm.

Poultry grows crocodile teeth

For decades, scientists have known a mutation by the name of talpid2 in poultry. The mutation kills embryos before they hatch, but it also makes them start to produce teeth in their jaws. The small teeth are conical and reminiscent of the teeth of the closest relative of modern birds, the crocodile.

Dolphin grows an extra set of fins

Dolphins normally only have one set of fins, which developed from their four-legged ancestors' front legs. The ability to form hind limbs is long gone, but an unusual dolphin caught off the coast of Japan in 2006 had an extra set of fins. That is probably because the dolphin regained its ancient ancestors' ability to form hind limbs.

9 STROKES OF LUCK PRODUCED OASIS EARTH

Our hospitable world should not exist. If Earth had not collided with another planet, it would have been barren today – and that is only one of many ifs. As scientists zero in on alien worlds, they are realising that Earth may be the luckiest planet in the entire universe.

→ EARTH FORMS

1. Supernova provided heat
2. Saturn stopped the potential devastation caused by Jupiter
3. Earth ended up in a narrow 'Goldilocks' zone

→ LIFE BECOMES POSSIBLE

4. Collision provided Earth with the perfect size
5. The Moon stabilises our seasons
6. Active geology is Earth's thermostat

→ LIFE IS PROTECTED

7. Free oxygen paved the way for sophisticated life
8. Jupiter prevents meteor strikes
9. The magnetic field was saved at the last minute

SHUTTERSTOCK

By **Niels Halfdan Hansen**

0.0000 00000 00781 25%*

was the likelihood of Earth developing conditions that could support life. Statistically speaking, that makes us one planet in 25 quadrillion. Our Earth is the result of nine great strokes of luck.

*__Method:__ The number was reached by multiplying the likelihood of the nine strokes of luck in the following article, each based on a qualified guess.

LIKELIHOOD:
5%
Very few exoplanet systems have two gas giants that hold each other at bay, leaving space for rocky planets.

5000 MILLION YEARS AOG:

Supernova provided heat

1 The Sun, the Earth and the other planets formed from a cloud of material. If a nearby star had not accidentally exploded into a supernova at the same time, Earth would have ended up as a lump of ice, according to new research. The supernova provided many radioactive substances such as aluminium ^{26}Al which formed part of the new planet. The energy from the radioactive decay made surplus water evaporate and is still keeping Earth's interior warm.

LIKELIHOOD:
10%
Without a supernova, planets get a composition that will probably make them uninhabitable.

SHUTTERSTOCK & CLAUS LUNAU

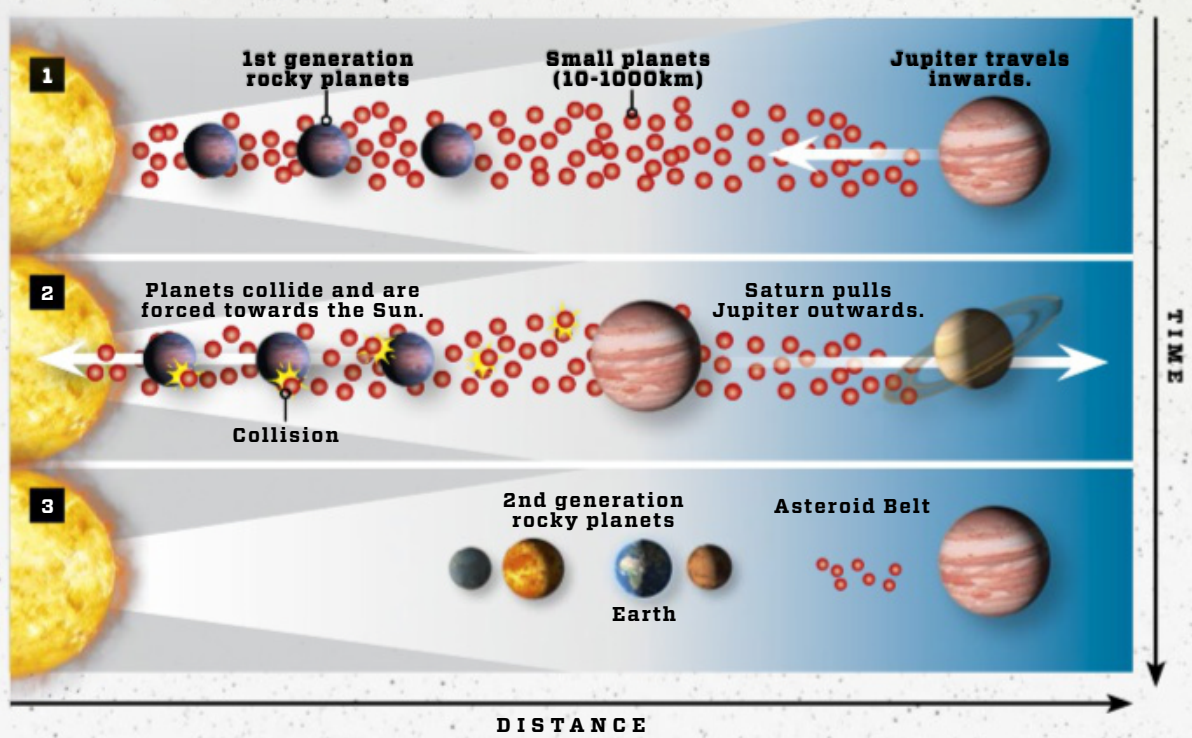
4600 MILLION YEARS AGO:

Saturn stopped Jupiter's devastation

If Saturn had not halted Jupiter's voyage towards the Sun, Earth and the other rocky planets would never have formed.

2 Astronomers have discovered many Jupiter-like exoplanets, but they are very often located in a rather close orbit around their stars. Just like Jupiter, they probably formed far from their stars, only to travel inwards towards it. En route, they removed all rocky planets.

Solar systems with hot Jupiters close to their star consequently lack any Earth-like planets at the required distance to the star. Scientists have calculated that it took an extra gas giant such as Saturn to force Jupiter back out, leaving space for Mercury, Venus, Earth and Mars.



Jupiter travels inwards

1 Jupiter travels inwards in the young Solar System, in which large rocky planets orbit close to the Sun. This is what many exoplanet systems still look like.

Planets collide

2 Jupiter makes the other planets collide, forcing them towards the Sun, until Saturn's gravity halts Jupiter's inward voyage.

Jupiter makes room

3 After Jupiter moved outwards again, it was possible for the Earth and other planets to form from smaller planets. Only a few other planetary systems are like this.

SHUTTERSTOCK

High above the planet's dark side, a probe silently passes with its sensors aimed at the dark landscape 1000km below. It is collecting data about the atmosphere's composition, looking for any light sources on the surface, and listening for radio noise, trying to find out whether there is life on the planet.

The answer is clearly yes, as the planet that the probe is flying above (back on 8 December 1990) is our own world, the Earth. The probe looking for life on our planet is called Galileo, and this part of its mission is not as crazy as it might sound. Based on Galileo's observations, astronomer Carl Sagan and his colleagues are able to conclude that an inhabitable planet will emit certain evidence that technological equipment can detect from far away.

Five years later, in 1995, astronomers discover the first exoplanet orbiting a star that is reminiscent of the Sun. Suddenly, Galileo's peculiar mission becomes highly relevant. The planet, 51 Pegasi b, is a red-hot Jupiter-like giant which orbits its star very closely, so it is almost certainly both lifeless and uninhabitable. But the discovery triggers a new space race – the search for inhabitable worlds in other solar systems and hence the answer to one of the biggest questions in science: did life find other oases in the universe, or is life on Earth just a highly unlikely stroke of luck?

Searching for another Earth

By 2019, the number of confirmed planets outside our Solar System had reached 4071 (and rising), distributed across 3043 star systems, of which 659 have more than one planet. But although scientists now have thousands of planets to choose from, the vast majority of them can be immediately disqualified as Earth-like worlds.

Scientists quickly discount gas giants, but most rocky planets do not qualify either, because their orbits are either too close to or too far from their star, or the planets differ too much in size from our world, or have the wrong type of star. As new exoplanets are discovered and astronomers learn more about some of the ones they already know, the list of the most probable candidates is updated. The one currently considered to come closest to matching Earth is the exoplanet of K04878.01. It has an ESI (Earth Similarity Index) value of 0.98, where Earth is defined as 1. The planet K04878.01 is almost the same size as Earth and is located in an orbit which means that it receives only 3% more radiation than Earth from its star, which is also very similar to the Sun.

However, other studies involving factors that are not included in the ESI value indicate that K04878.01 has an atmosphere with 10 times higher pressure than Earth, making it unlikely that life as we know it can thrive. Another candidate, the TRAPPIST-1e planet, has almost no atmosphere. Though these two planets are reminiscent of Earth in many ways, they have apparently developed differently from our own.

For life to have time to originate and evolve, it's crucial that both the planet's orbit and the star's radiation have remained fairly constant over billions of years. Furthermore a planet's habitability is not only measured by external conditions, but also in the planet's interior. An active underground is vital for life on Earth, and that is probably also the case on other worlds. Plate tectonics stabilise conditions on the planet's surface by adjusting the atmosphere's content of greenhouse gases. The carbon ▶

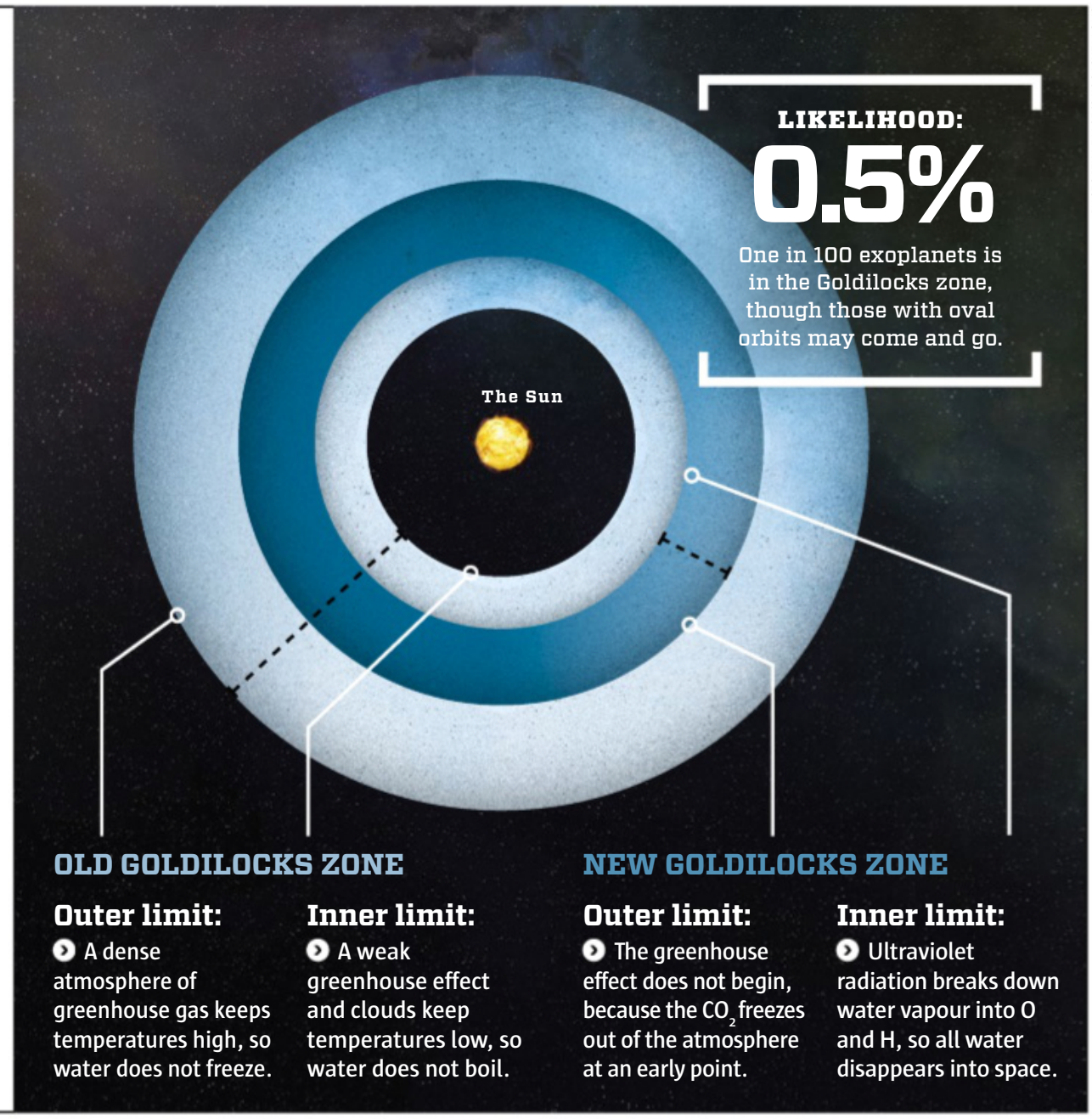
4540 MILLION YEARS AGO:

Earth ended up in Goldilocks zone

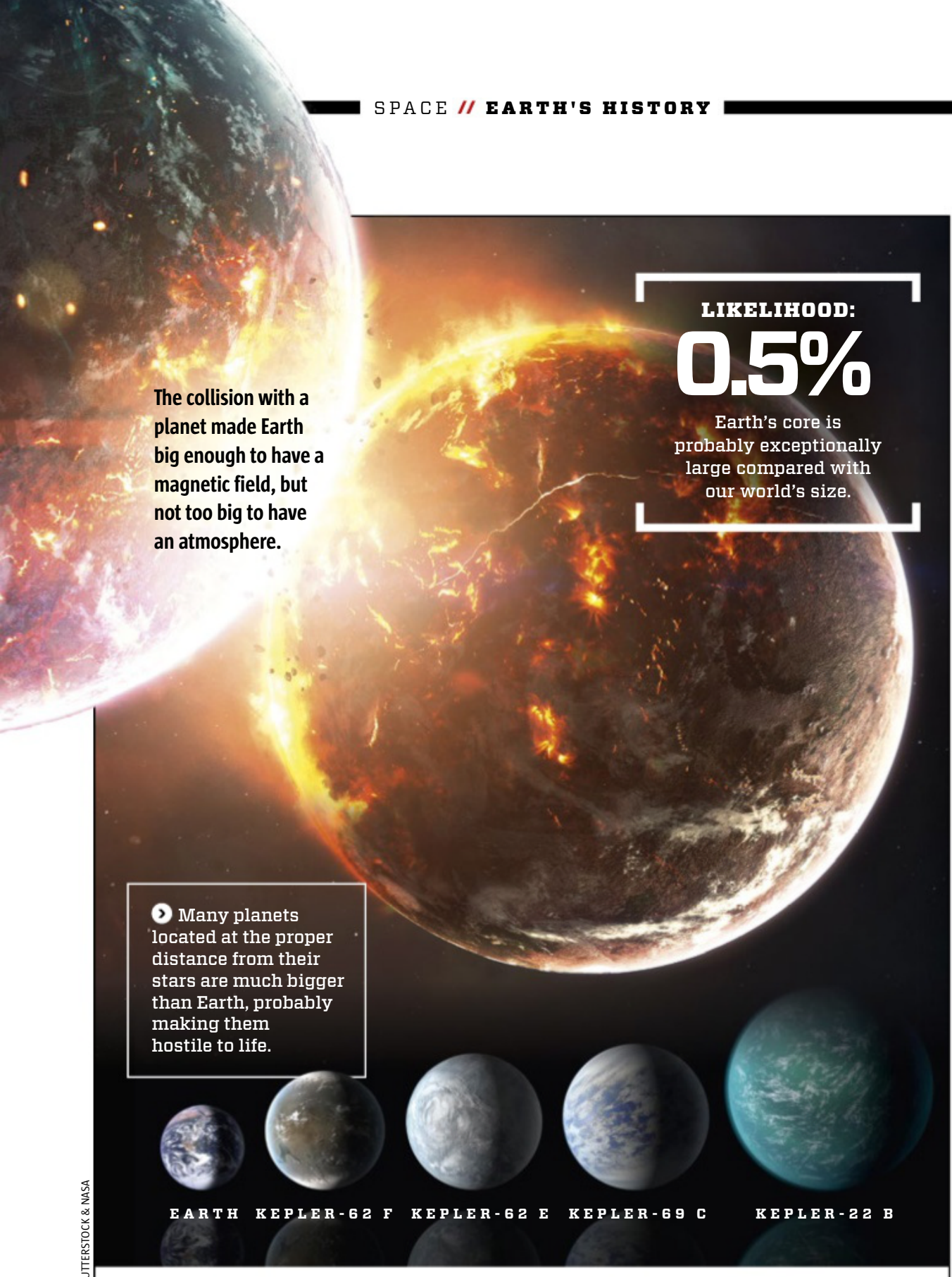
Liquid water can only exist at a specific distance from the Sun.

3 Liquid water is central for life on Earth – and perhaps for life in general. This makes heavy demands on the distance between a planet and its star. If the distance is too short, water becomes vapour. If it is too far away, it will freeze. But Earth was located 'just right', in the narrow region astronomers have named the Goldilocks zone. Solar radiation has increased since its formation, but Earth has been perfectly located for all of its 4.6 billion years.

Several studies, the most recent one from 2019, indicate that the Goldilocks zone is even narrower than previously believed. According to the new calculations, if a planet's atmosphere is to support higher life then it must be located in a band that only includes 25% of the zone that scientists previously considered habitable.



SHUTTERSTOCK & LOTTE FREDSLUND



SHUTTERSTOCK & NASA

4520 MILLION YEARS AGO:

Collision provided Earth with the perfect size

The collision with another planet was a stroke of luck for Earth, providing it with a large iron core and a magnetic field but without the world being too big to include life.

4 Earth was originally smaller than it is now, but a few million years after its formation it collided with a planet, Theia, that was the size of Mars. In the collision, Theia's iron core sank to the bottom of the Earth, while the lighter material was flung into space, producing the Moon. So Earth has an unusually large core compared with its size, and that contributes to giving the planet a magnetic field which protects life from radiation.

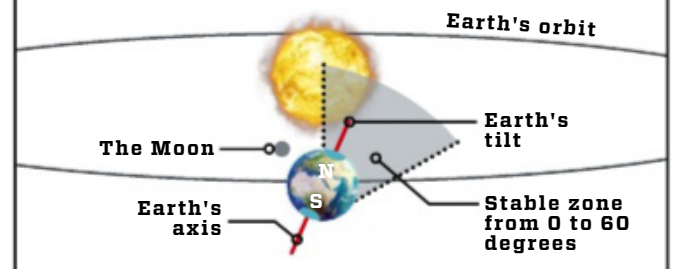
Planets with such large cores are normally much bigger than Earth, and probably uninhabitable because of processes that are likely to change a rocky planet twice as big as the Earth into a gas planet. The planet will either become veiled in a dense atmosphere of hydrogen and helium with a pressure up to thousands of times that of Earth, or, if it is positioned closer to its star, the atmosphere will evaporate, leaving a red-hot uninhabitable world.

SHUTTERSTOCK

4510 MILLION YEARS AGO:

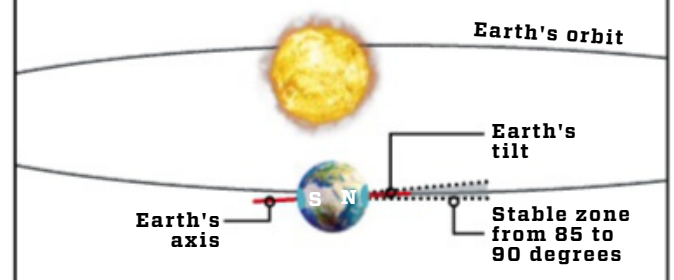
The Moon stabilises our seasons

5 The Moon determines Earth's rotation, and is consequently vital for the climate. New computer simulations show that the Moon makes the direction of Earth's axis more stable. The direction determines the seasons. A rocky planet the size of Earth that does not have a large moon will experience variations of its axis direction up to 10° over 10,000 years, causing unstable seasons and a highly variable climate.



WITH MOON: Wide, stable zone

As long as Earth has the Moon as a satellite, the planet can maintain a stable orientation in space and hence stable seasons while its axis of rotation tilts between 0°-60°.



WITHOUT MOON: Narrow, stable zone

If Earth lost the Moon, the stable zone would shrink. Earth would only be able to keep up a stable orientation if the tilt of the axis of rotation was 85-90°.

cycle adds CO_2 to the atmosphere in case of volcanic eruptions, while old crust plate carries carbon into the planet's interior again.

In 2015 Japanese scientists headed by geologist Takehiro Miyagoshi simulated the interiors of rocky planets that are bigger than Earth. It turned out that the crust becomes too thick and the pressure in the planet's interior too high for plate tectonics to work. Other analyses have shown that plate tectonics are difficult to trigger even on rocky planets that combine the right size with the right temperatures and composition. Scientists do not even know for certain how the process was initiated on Earth.

Super telescope to find oxygen

Today, astronomers can observe only exoplanets' diameters and the distance to their stars, but new telescopes will provide them with much more detailed information. One of those will be the Extremely Large Telescope (ELT), which will be the world's biggest when it is aimed at the universe for the first time in 2025. The telescope will be a part of Europe's southern observatory in the Atacama Desert of Chile, and will have a diameter of 39 metres. The diameter of the biggest Earth-based telescopes currently are around 10 metres, and the ELT will produce images that are 16 times sharper than those coming from the Hubble telescope.

One of the telescope's central tasks will be to find out how many Earth-like systems at different development stages exist in the galactic neighbourhood of our Solar

3200 MILLION YEARS AGO:

Active geology is Earth's thermostat

Most worlds become either too warm or too cold, but Earth's plate tectonics regulate the climate by means of CO_2.

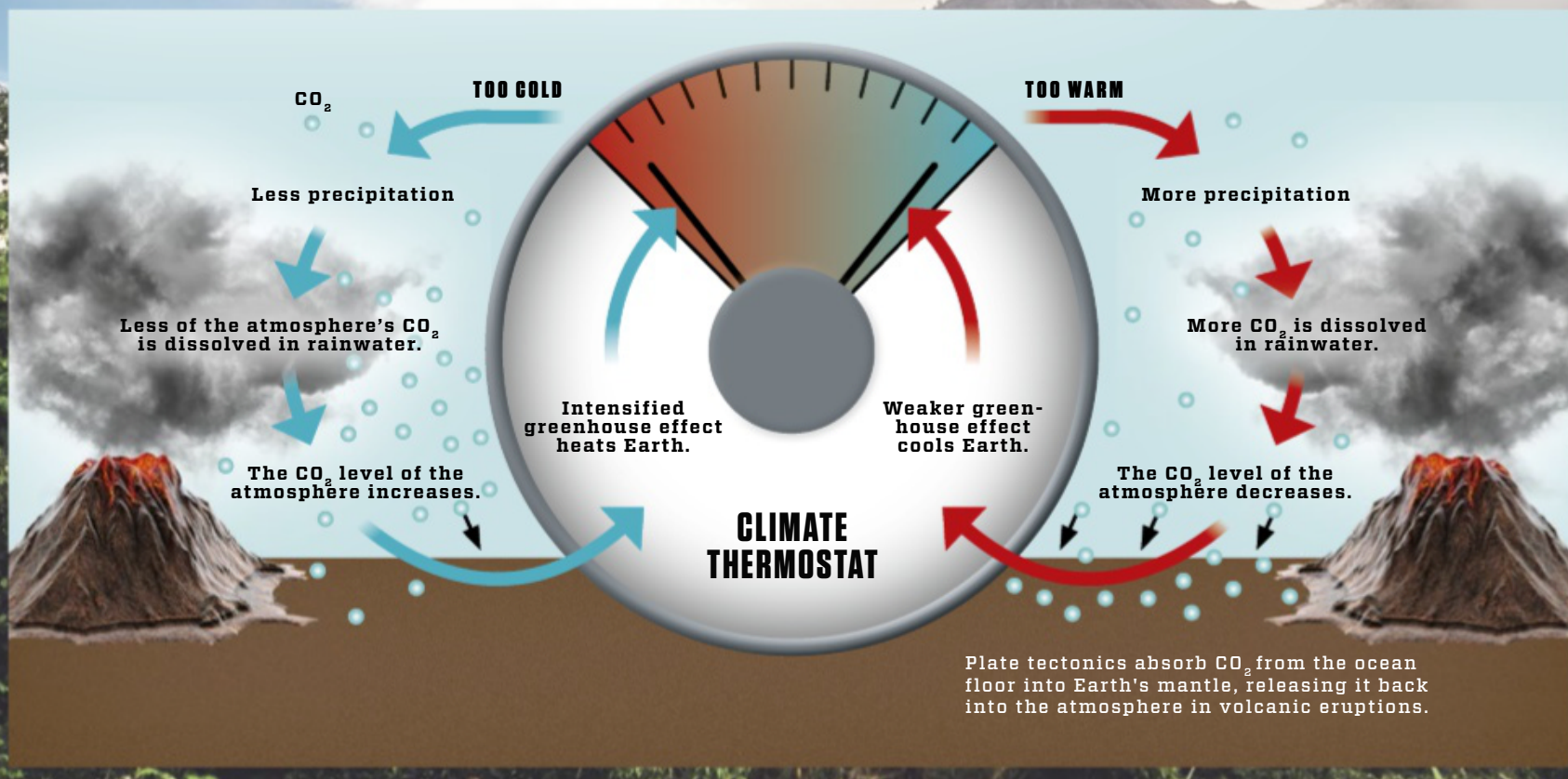
LIKELIHOOD:

1%

No other planets in the Solar System have plate tectonics – the precondition of a stable climate.

6

Earth's climate has fluctuated over its lifetime from greenhouse heat to ice ages when glaciers and sea ice covered major parts of our planet. But every time the temperature becomes extreme, Earth's thermostat adjusts the atmosphere's content of greenhouse gases. Plate tectonics, which absorb and re-emit the greenhouse gas of CO_2, seem to be vital for a planet's habitability. In 2019, scientists from the Carnegie Institution for Science in the US calculated what would have happened if Earth had not had such a thermostat. The likely result would have been out-of-control global warming, as on Venus, or almost no atmosphere, as on Mars.



SHUTTERSTOCK & LOTTE FREDSLUND

LIKELIHOOD:

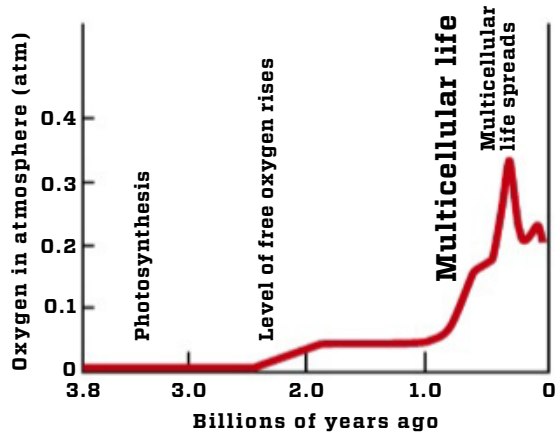
5%

Free oxygen requires that several conditions be met. We have found no exo-planets with free oxygen.

850 MILLION YEARS AGO:

Free oxygen paved the way for sophisticated life

7 Oxygen is necessary for all higher animals. In Earth's early life, all oxygen was bound in chemical compounds, but that changed when ancestors of modern blue-green algae invented photosynthesis. New research indicates that this began to happen 3400 million years ago. So while oxygen was secured and bound by iron, etc., for the first millions of years, 850 million years ago the oxygen level began to rise in the upper ocean and the atmosphere, paving the way for multicellular life.



WIM VAN EGMOND/SCIENCE PHOTO LIBRARY

Jupiter attracts asteroids and other objects, that might otherwise have struck Earth.

SHUTTERSTOCK

LIKELIHOOD:

50%

Many solar systems have a gas giant, but it is often too close to the star to protect other planets.

750 MILLION YEARS AGO:

Jupiter prevents meteor strikes

Rocks and ice lumps would rain down on Earth and pose a threat to life if Jupiter were not so fortuitously located that its gravity protects us from meteors.

8 Meteors were beneficial to the young Earth, helping to form the planet that we know. They increased Earth's mass and supplied much of its water. Perhaps they even brought some central building blocks for the origin of life. Today, meteors represent a severe problem for Earth. Ever since the origin of higher life some 750 million years ago, such creatures have been threatened by major strikes like the one that wiped out the dinosaurs 66 million years ago. Luckily, Earth has a cosmic protector in Jupiter. Simulations show that far more large objects would strike inner Solar System planets if the gas giant did not function as a vacuum cleaner whose gravity attracts rocks and ice lumps.

System. That will involve analysing proto-planetary discs around newborn stars, with astronomers particularly interested in the distribution of elements, molecules and mass. This information can fill in holes in the history of Earth's birth as well, and reveal whether our Solar System's childhood was normal or special. The ELT should also provide data about the mass of exoplanets. Knowing the planets' diameters from the space telescopes, astronomers will also be able to calculate their density and consequently provide us with a qualified guess of their chemical make-up. With this knowledge, scientists might be able to find out if there is a chance that the planet has a protective magnetic field and active geology, including plate tectonics like Earth.

Astronomers also hope that the ELT will prove to be so powerful that the telescope can analyse the atmospheres of many of the known Earth-like planets – not least the top candidates of K04878.01 and TRAPPIST-1e. The scientists would particularly like to find free oxygen. The gas reacts very easily with other compounds, so it would only remain in the atmosphere of a rocky planet if oxygen is continuously produced. And that probably only happens where there are complex biochemical processes like Earth's photosynthesis to provide a basis for higher forms of life. Over the next 10 years, the ELT and other new instruments will bring us closer to an answer for whether life has developed in other places, or if Earth is just the luckiest planet in the universe. SCI

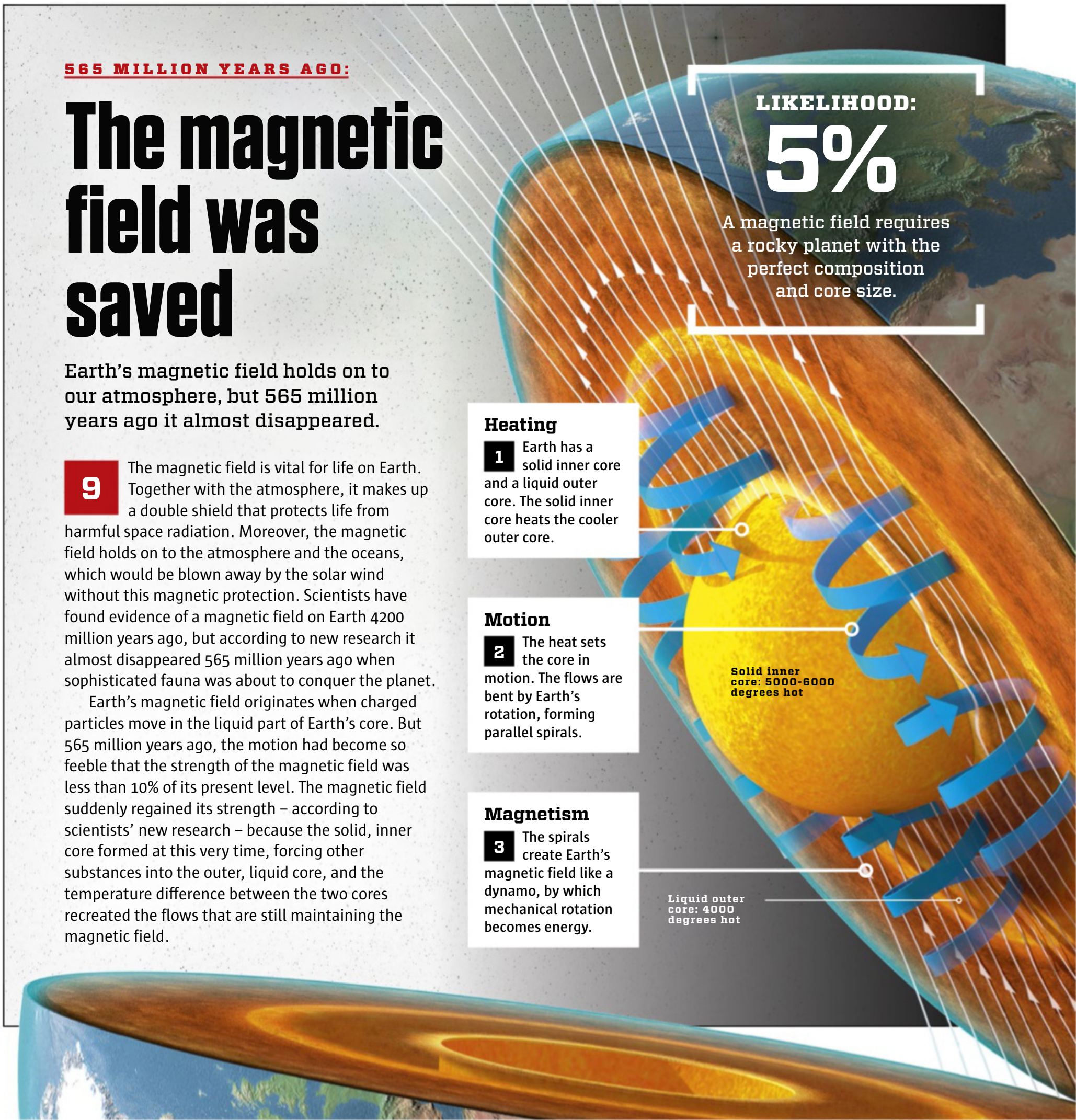
565 MILLION YEARS AGO:

The magnetic field was saved

Earth's magnetic field holds on to our atmosphere, but 565 million years ago it almost disappeared.

9 The magnetic field is vital for life on Earth. Together with the atmosphere, it makes up a double shield that protects life from harmful space radiation. Moreover, the magnetic field holds on to the atmosphere and the oceans, which would be blown away by the solar wind without this magnetic protection. Scientists have found evidence of a magnetic field on Earth 4200 million years ago, but according to new research it almost disappeared 565 million years ago when sophisticated fauna was about to conquer the planet.

Earth's magnetic field originates when charged particles move in the liquid part of Earth's core. But 565 million years ago, the motion had become so feeble that the strength of the magnetic field was less than 10% of its present level. The magnetic field suddenly regained its strength – according to scientists' new research – because the solid, inner core formed at this very time, forcing other substances into the outer, liquid core, and the temperature difference between the two cores recreated the flows that are still maintaining the magnetic field.



CLAUS LUNAU

SERIES

THE BATTLE OF THE BRAIN

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

If you hit your head hard on asphalt, it could trigger a chemical explosion in your brain, with lengthy consequences.

SHUTTERSTOCK

By **Gorm Palmgren**

COULD CANNABIS CURE CONCUSSION?

Take a pill and avoid concussion? Scientists are working on a ground-breaking drug which could finally curb the disabling symptoms that can develop following even mild concussions.

The cyclist speeds down the cobblestone road, and though the shopping in his handlebar basket bounces up and down, his brain is at rest, safe behind a thick skull and protected by fluid which absorbs all blows and motions. But all this changes dramatically as a door of a parked car suddenly opens. The cyclist hits the door and flies over the handlebars, his head hitting the tarmac road with the impact of all of his mass and momentum.

The severe blow is more than the fluid can protect against, so that the soft, fragile brain tissue is forced against the hard inside of the skull, recoiling back to hit the back of the braincase. The two collisions stretch and twist the brain cells. Their cell membranes leak, and neurotransmitters flow freely in and out. The result is chemical chaos that will initially paralyse the brain causing a moment of unconsciousness, and which could continue to drain the brain cells for weeks or months, so that the cyclist will have difficulties thinking and focusing.

Today, doctors can only help the victims by recommending peace and rest, but scientists from the University of Miami and elsewhere are on the track of a pill that would prevent the brain's chemical processes from going berserk following such a hard blow – and so has the potential of curbing the severe symptoms that might follow.

Men and children often affected

Some 0.5% of the world population is estimated to suffer concussion annually as a result of falls, accidents, sports injuries, or violence. The true number is probably much higher, since many people find it

BEFORE FIGHT

The brain floats inside a protective case

The brain is extremely fragile, unable to protect itself against blows. The body has built its own defence consisting of several different layers.

SPL

Case protects soft tissue

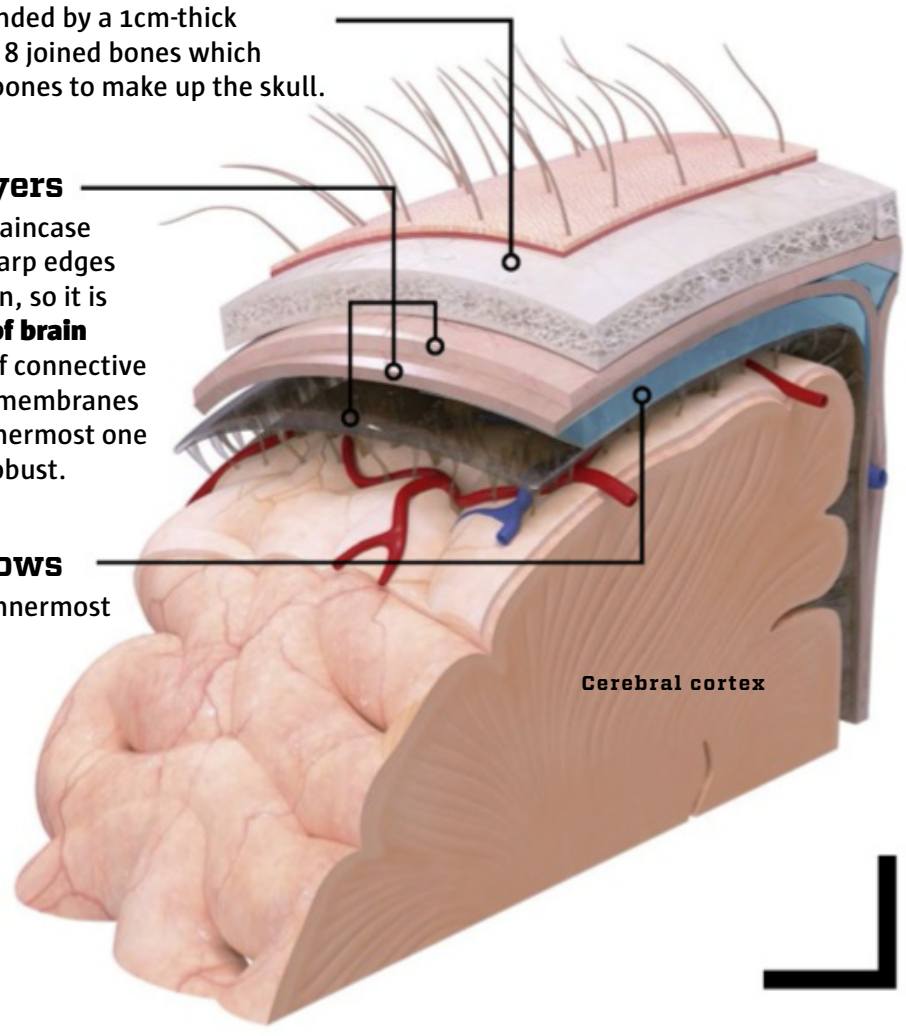
The brain is surrounded by a 1cm-thick **braincase** made of 8 joined bones which combine with the facial bones to make up the skull.

Membranes in layers

The inside of the braincase includes several sharp edges that could injure the brain, so it is covered in **three layers of brain membranes** consisting of connective tissue. The two external membranes are hard, whereas the innermost one is cobweb-like and less robust.

Fluid prevents blows

Between the two innermost brain membranes, about 150ml of **cerebro-spinal fluid** functions as a kind of shock-absorbing zone. The fluid means that the pressure caused by the brain's weight against the bottom of the skull is greatly reduced.



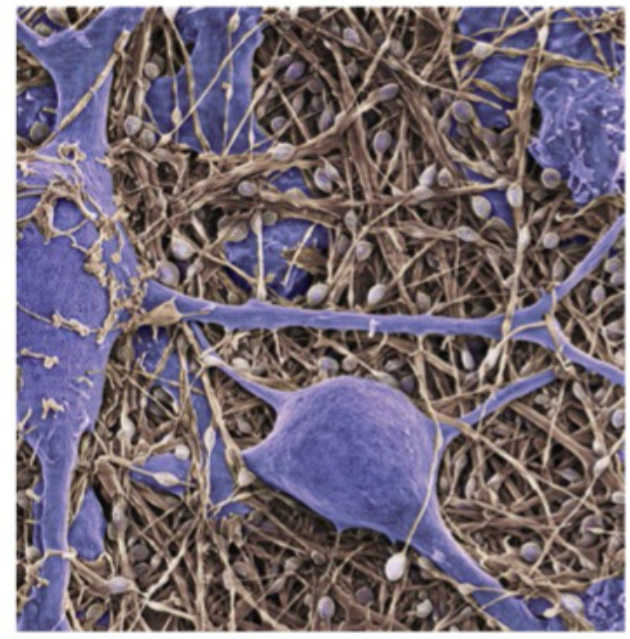
unnecessary to consult a doctor, even after everything goes black following an encounter with a cabinet door or a hard ball. However, research indicates that even a mild concussion could cause years of headaches, confusion, light sensitivity, motor-function difficulties, depression, and even reduced IQ.

According to statistics, it is children, young people and men that most commonly suffer concussions. A British study from 2014 showed that two-thirds of all patients with concussions were men with an average age of 30. The same trend emerged from a Swiss study conducted in 2018 where 61% of victims were boys and young men, while the average age of around 3000 patients under the age of 18 who suffered concussions over a period of two years was only 12.

However, it is children, young people and men who also stand the best chances of recovering quickly. Both the Swiss and British studies concluded that the older the patient, the longer they have symptoms after a concussion, while girls and women generally take longer to recover and have a greater risk of after-effects that remain for more than a year.

More forceful than a missile

While millions of people around the world struggle with long-term symptoms following concussion, the brain's own defence is so efficient that it often curbs the violent forces at play during a collision. In 2007 American scientist Kevin Guskiewicz from the University of North Carolina mounted accelerometers on the helmets of 76 football players



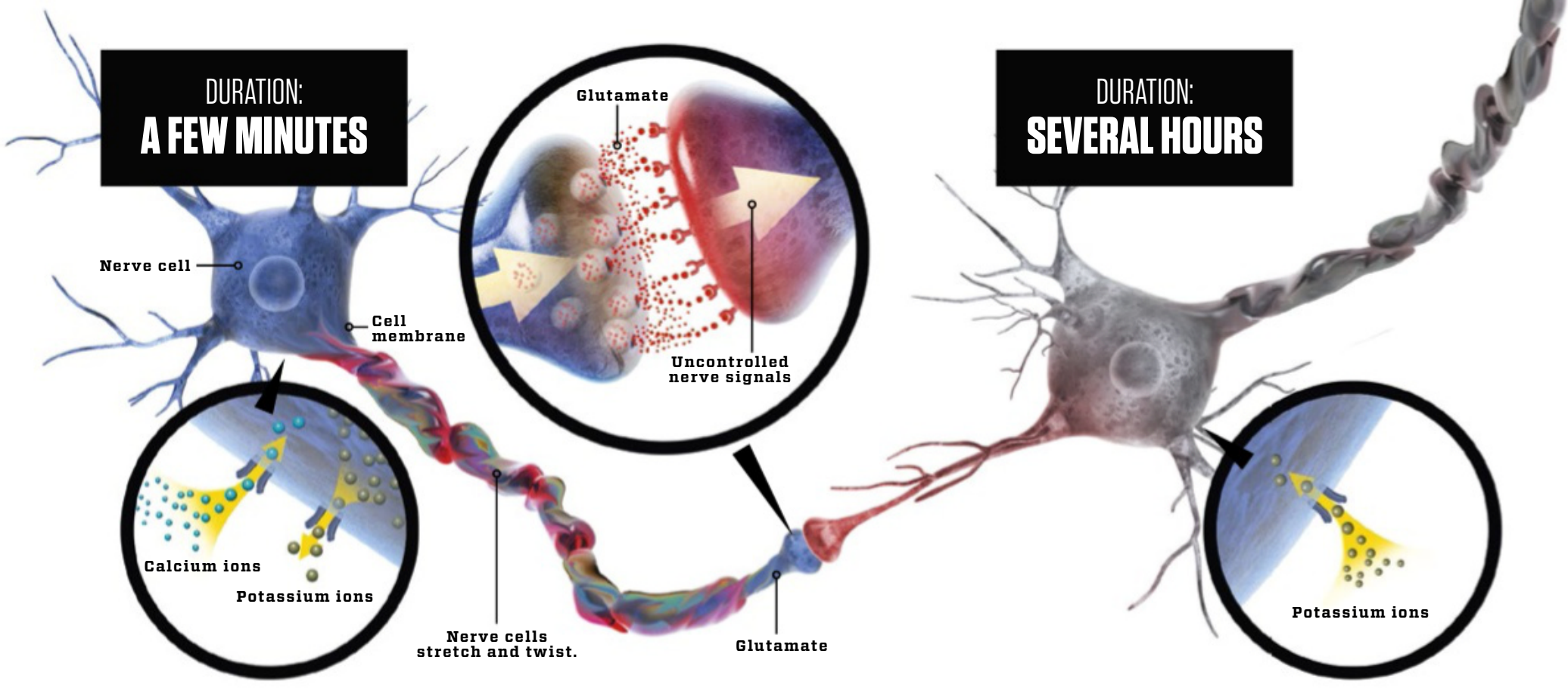
SPL

To be able to communicate effectively, nerve cells are deeply dependent on the ion balance between the inside and outside of the cell.

Chemical chaos paralyses the brain

CLAUS LUNAU

A concussion triggers an explosion of ions which cascade in and out of the nerve cells, draining them of energy, so the brain does not function properly for several weeks.



Ions cascade in and out of nerve cells

1 The blow twists the nerve cells, destroying the cell membranes. The injured nerve cells leak, with large quantities of potassium ions cascading out of the cells, while calcium ions flow in from the surroundings. Moreover, the cell liberates large quantities of the glutamate neurotransmitter, causing an explosion of nerve signals in the adjacent cells.

Clean-up drains cells of energy

2 In order to restore the balance, the potassium ions must be pumped back into the nerve cells. This requires large quantities of energy, draining the cells of oxygen. The remaining high level of potassium ions also influences the cell's energy production, causing an energy crisis, so that the clean-up gets even slower.

and recorded no fewer than 100,000 head collisions over the course of five seasons. The accelerometers measured g-forces of 61-169, which is several times more forceful than the acceleration of a typical missile. Yet only 13 of the players got concussion.

When things do go wrong, it can be a result of not only the brain's acceleration when it hits the skull, but also of whether the forces make the brain rotate, so that the nerve cells get twisted and stretched. In these cases there is a higher risk of the cell membranes being destroyed and leaking. It can also be a disaster for nerve cells, which are dependent on maintaining a controlled balance between ions and neurotransmitters on the inside and outside of the cells.

Nerve cells send signals to each otherby alternately letting out sodium and potassium ions through the cell's surface, the membrane. This causes an electrical voltage difference that passes along the cell's nerve thread as a signal until it reaches the end of the nerve thread, the synapsis. There, special signal molecules are liberated, with neurotransmitters binding to receptors on the adjacent cell to pass on the signal.

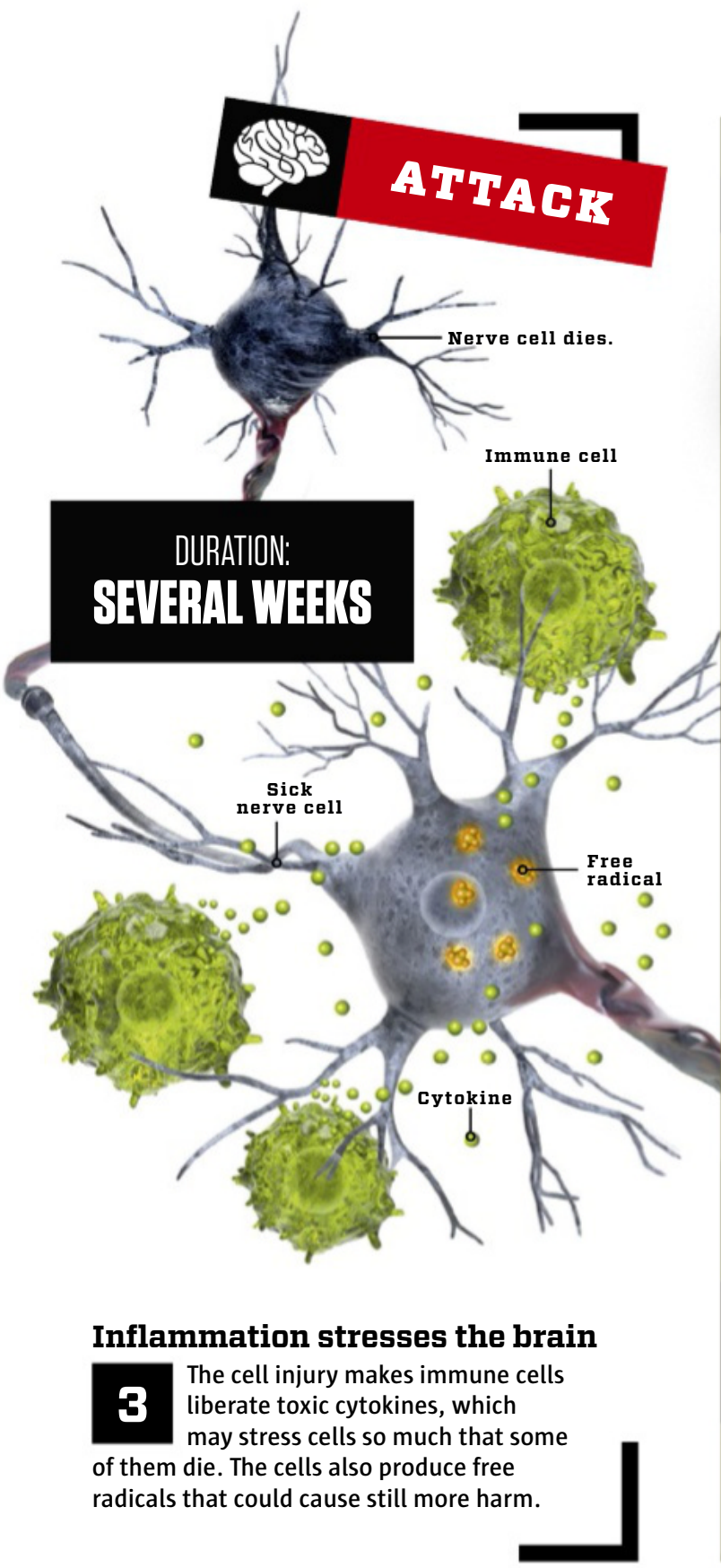
This becomes a difficult task during the chemical chaos that follows a collision, with ions and neurotransmitters flowing freely in and out of membranes and thereby triggering an explosion of random nerve signals. Moreover, the brain must subsequently carry out a huge clean-up to restore the ion balance between the cells' insides and outsides, and this process drains the nerve cells of energy while it's under way, making it even harder to send signals.

This chemical chaos is the cause of all the symptoms that follow in the wake of a concussion. So it is also the target of the new pill that is being developed by scientists from the University of Miami in cooperation with the Scythian Biosciences company of Canada. They are currently testing the pill's effect on rats.

Although only a few results have been published, the scientists explained in a release from 2018 that the rats generally get fewer concussion symptoms when they are treated with the pill's two active ingredients.

Concussion causes depression

One of the two ingredients with which scientists are working at the moment is cannabidiol, which exists in cannabis plants, though it does not have a euphoric effect. ▶



Inflammation stresses the brain

3 The cell injury makes immune cells liberate toxic cytokines, which may stress cells so much that some of them die. The cells also produce free radicals that could cause still more harm.

Concussion affects your IQ

Studies show that even mild concussions could reduce your IQ for decades. Women and children are the most badly affected.

20,000+

Australians are hospitalised with a traumatic brain injury or concussion every year, but many more concussions are thought to go unreported.

24 hours

is how long a person should be kept under observation on suspicion of concussion. The person should be checked once or more an hour to make sure that he or she remains conscious.

7 points

is how much the IQ is reduced on average in people who have been subjected to a concussion.

SHUTTERSTOCK

Scientists around the world are using the drug to treat anything from sclerosis to epilepsy, and they now believe that this ingredient might also save the injured brain by restoring the ion balance between the inside and the outside of nerve cells and functioning as an antioxidant, which prevents more injury, but also by influencing the immune system and curbing the out-of-control inflammation that the hard knocks can cause.

A series of animal experiments offer cause for optimism. A study by the State University of Maringá in Brazil from 2014 showed that cannabidiol reduces the negative effect on mice's ability to learn following a blood clot. And in two other experiments from the United States, mice that were treated with cannabidiol-like substances experienced fewer problems with both their fine motor skills and their memory after induced concussions. The individual effects of the ingredient are well documented by several experiments, but so far nobody has examined whether it can also eliminate the symptoms caused by hard blows to the head.

The other ingredient of the proposed pill is an NMDA antagonist that curbs the activity of the glutamate neurotransmitter, which could otherwise trigger an explosion of neurotransmitters in the brain. Such an explosion is the reason why many people are briefly unconscious after a hard blow, but it also has more wide-ranging consequences. The profusion of nerve signals burden the nerve cells, even causing some of them to die. Moreover, the brain tries to compensate for the major quantities of glutamate by making permanent changes, such as breaking down some of the glutamate receptors that are located on the surfaces of nerve cells.

100,000

head collisions were recorded over five seasons by accelerometers fitted to the headgear of only 76 American football players.

Because such changes can be long-term, they alter the way in which the brain works, and that could influence the ability to learn. The same changes are observed in the brains of people with depression, and indeed scientists also believe that around half of victims of concussion develop depression within a year of the accident. This is what the pill's NMDA antagonist aims to stop, and the effect is supported by studies by the University of California, which demonstrate that the ingredient can eliminate such changes in the brains of rats with concussion.

When the final results of the scientists' ongoing experiments have been delivered, they plan to continue with clinical testing on humans. The best-case scenario is that the pill might be available in pharmacies or hospitals within 5-10 years. If so, scientists will have discovered yet another severe brain condition for which cannabis might hold the key to a cure. SCI

Cannabidiol from cannabis plants has featured in preliminary clinical research studies of anxiety, cognition, movement disorders, and pain relief. It may also help relieve concussion symptoms.

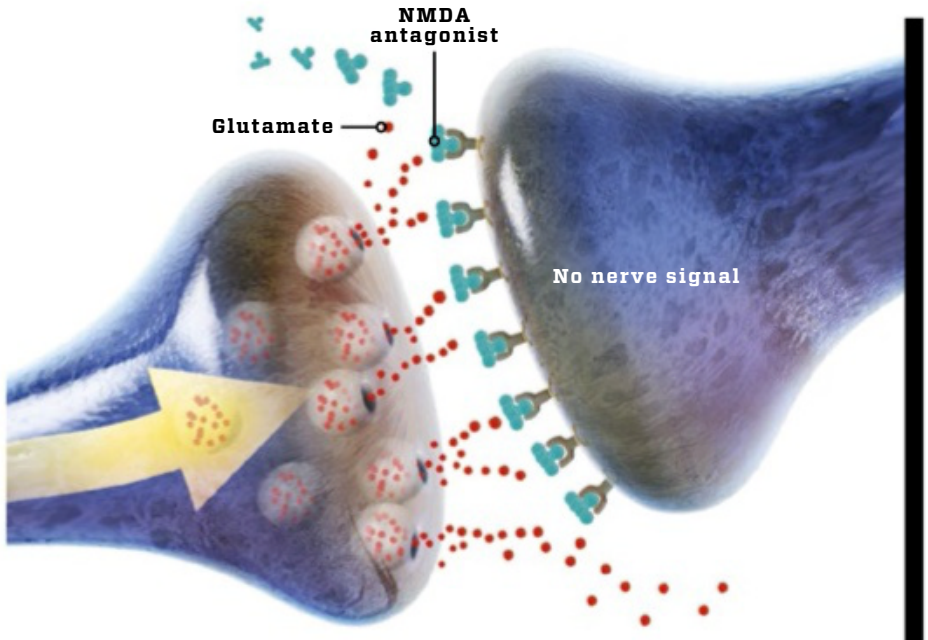
SPL

DEFENCE

Pill gets the brain chemistry in order

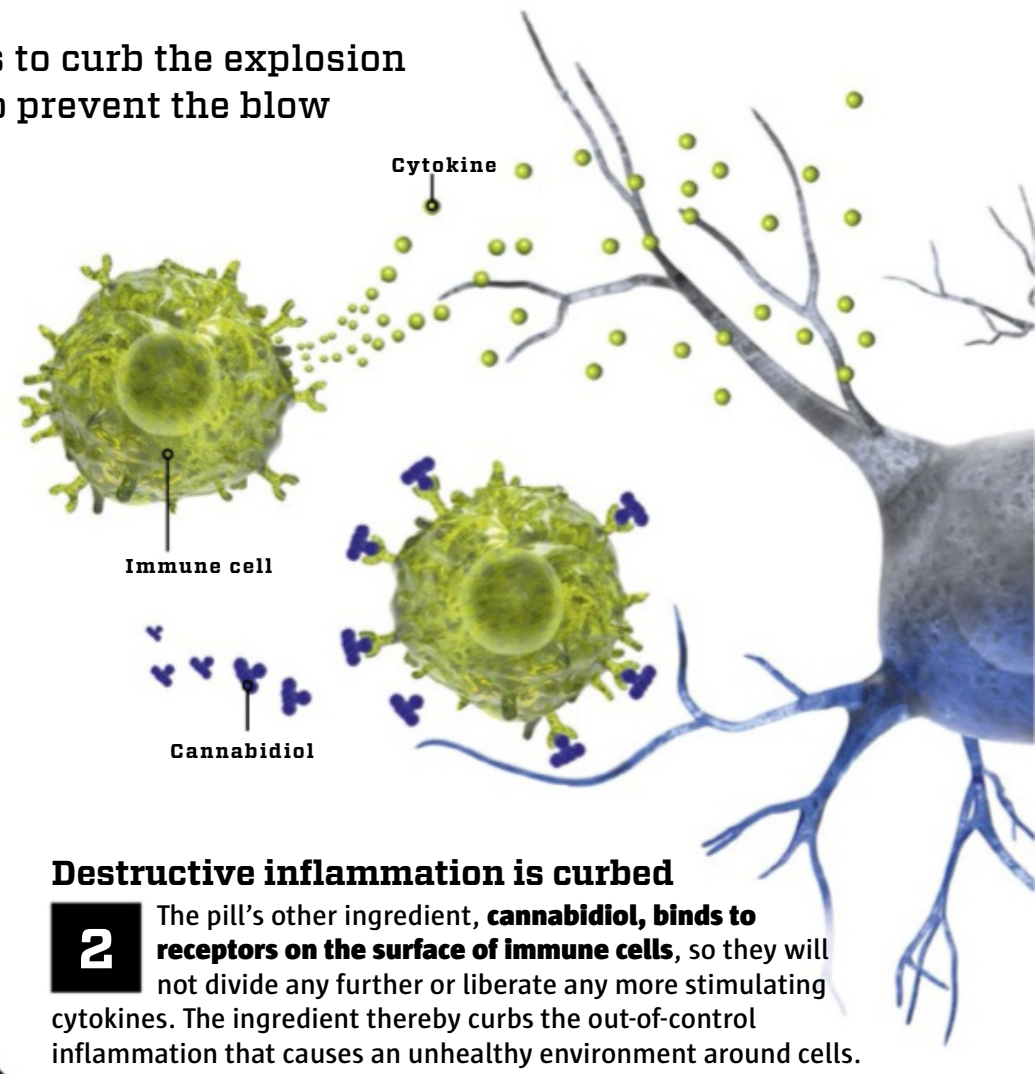
By means of two active ingredients, a new pill aims to curb the explosion of neurotransmitters following a concussion, and to prevent the blow from causing permanent harm to the nerve cells.

CLAUS LUNAU



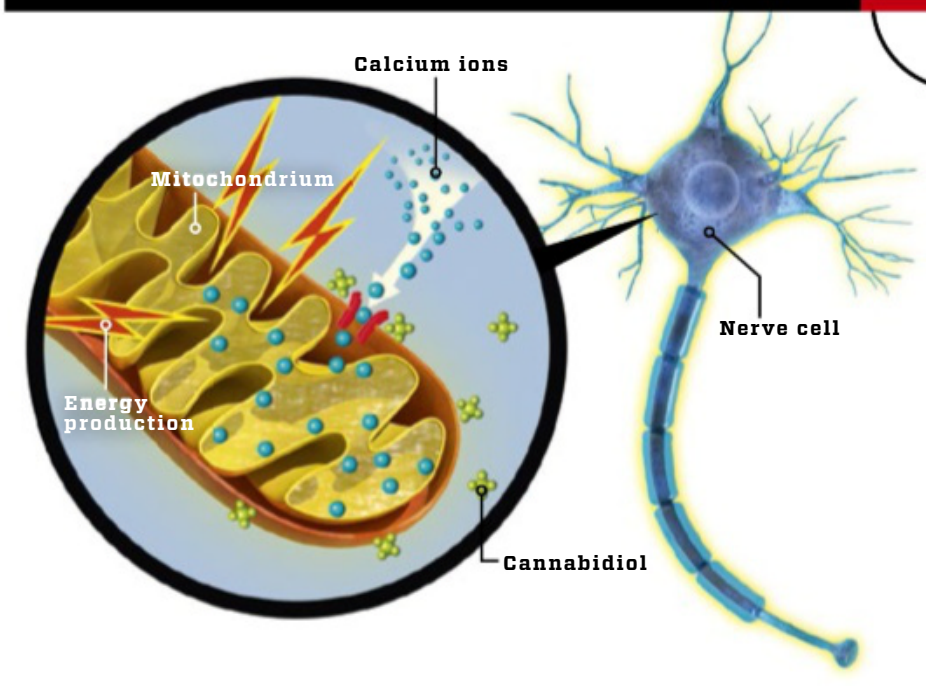
Prevents out-of-control nerve signals

1 The pill's first ingredient is an **NMDA antagonist, which binds to receptors on adjacent cells**. The NMDA antagonist prevents the glutamate neurotransmitter binding to the receptors and causing an out-of-contol explosion of nerve signals that partially or completely aralyses the brain.



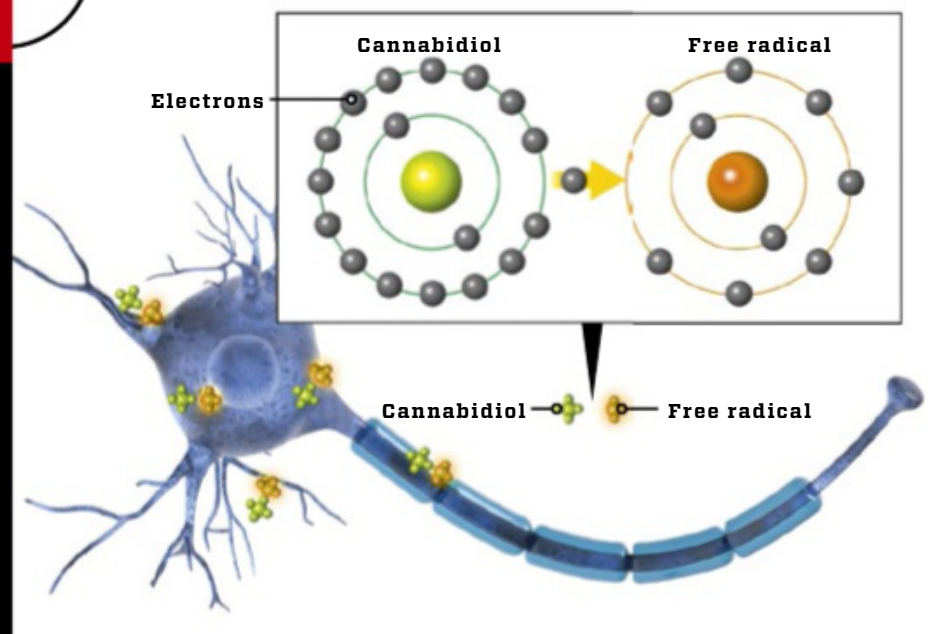
Destructive inflammation is curbed

2 The pill's other ingredient, **cannabidiol, binds to receptors on the surface of immune cells**, so they will not divide any further or liberate any more stimulating cytokines. The ingredient thereby curbs the out-of-control inflammation that causes an unhealthy environment around cells.



Stimulates cell power stations

3 **Cannabidiol also causes the power stations of the nerve cells, the mitochondria, to produce more energy** for the drained cells. At the same time, the ingredient binds to a receptor on the surface of the mitochondrium, making it absorb and remove the major quantity of calcium ions that otherwise disrupt the cell's work.



Disarms free radicals

4 The stressed nerve cells produce free radicals, chemically unstable molecules with one or more unpaired electrons in their outer shells. The molecules might destroy the cell in their search for electrons, but **cannabidiol reduces the effect by donating an electron to the molecule.**

CLIMATE CHANGE: EXAMINING THE PAST

The truth about the climate

CONTINUING SERIES:
1 degree warmer or 10?
We give you the
plain answers.

Earth's climate is changing – but in the course of its history, our planet has experienced numerous climate crises, and life has survived. The challenge today is the sheer pace of change, and whether humans and other life can adapt quickly enough. Scientists are now using the past as a guide to show us how the future could develop.

→ HIGH TEMPERATURES

252 million years ago, temperatures rose to 28°C, the highest level in recent history, causing a lack of oxygen in the oceans.

→ HIGH CO_2 LEVEL

375 million years ago, the quantity of CO_2 increased to ten times the present level, making plants go berserk.

→ HIGH OCEAN LEVEL

125,000 years ago the poles melted, making ocean levels rise by up to nine metres, transforming the planet.

By **Gorm Palmgren**

460 million years ago, the ocean level was 400 metres higher than today. But the climate changed so slowly that life had time to adapt.

CLAUS LUNAU

252 MILLION YEARS AGO

- **PERIOD:** Permian-Triassic
- **CO_2 LEVEL:** 4.5 times higher than now
- **TEMPERATURE:** 28 degrees – 13 degrees warmer than now
- **OCEAN LEVEL:** 25m lower than now

A suffocating temperature rise

Some 96% of all marine animal species were wiped out when Earth's temperature rose by 10+ degrees over a short period of time. The cause is unknown – perhaps volcanic eruptions or meteor strikes – and scientists have been unsure if it was the heat or its secondary effects that made the world uninhabitable. Now a new computer simulation shows that ocean warming may have led to massive oxygen depletion, causing mass suffocation of many species.

70% of all vertebrates died out, including the 2m-long lystrosaurus.
SHUTTERSTOCK

Heat = oxygen depletion

1 Warm water holds less oxygen than cold. Yet the heat intensified animal metabolism, so more oxygen was required.

The Equator made it

2 More species survived near the Equator where they had already adapted to an environment of warm oxygen-poor water.

It may come as a surprise to discover that although today's CO_2 emissions, temperatures and ocean levels are rising at an alarming speed, all three are at almost their lowest levels in 600 million years. Earth's climate could be considered as being close to 'zero'.

But we are nevertheless in a climate crisis, as never before have these three factors followed each other so closely to reach rock bottom at the same time. The central question now is what happens when things go the opposite way?

Most scientists agree that the ongoing climate change is due to a severe rise in the atmosphere's CO_2 content, which is causing temperatures to rise, making the poles melt and ocean levels rise. This will turn animals' and plants' living conditions – and so also our food sources – upside down, and will flood cities, making millions homeless.

Over the past millions of years, such CO_2, temperature and ocean level fluctuations have had repeatedly major effects on animals and plants, in some cases triggering mass destruction. Climate researchers are now focusing on periods of Earth's history which are much like the present to get an idea of what the future of the world might be – and how things might be prevented from going so wrong again.

Temperatures could rise by 7°C

For the last almost 10,000 years, Earth's average temperature has been very constant. But something started to happen in 1900. Over a period of only 100 years, temperatures rose by 1 degree as a result of industrial development. Over the next 100 years a rise of

Echinoderms such as these sea lilies dominated the oceans, together with mussel-like brachiopods and squid.

SHUTTERSTOCK

Death at the poles

3 More species became extinct near the poles, where animals had difficulties adapting to the warmer water.

NOW:

OCEAN TEMPERATURES COULD RISE BY 10°C

If our CO_2 emissions continue at the same rate, ocean temperatures might rise by 10 degrees before 2300, reaching the same level as in the Permian-Triassic extinction event. The geology is different than it was 252 million years ago, but according to the scientists behind the new computer simulation, the climate of 2300 will meet 35-50% of the requirements for being able to trigger same scale of global mass destruction.

Ocean warming causes oxygen depletion, which might at worst make much marine life suffocate.

IMAGESELECT

another 1-2 degrees is expected. Hopefully, more accelerated temperature rises can be prevented, but the worst case scenario might see still higher temperature rises. If another seven degrees were added by 2300, the average temperature would reach 22 degrees. The temperature itself is one thing, but it is the speed of change which is most alarming. Such a rapid rise temperature rise would be almost unprecedented in Earth's history.

Most other temperature fluctuations have happened gradually over millions of years. One exception to the rule occurred during the PETM period 56 million years ago. Temperatures rose by eight degrees over a period of 20,000 years, ending at a level of 25.5 degrees – 11 degrees warmer than now. The temperature rise was probably triggered by emissions of the methane greenhouse gas from the ocean floor, and the rising heat might have begun a self-sustaining process.

In 2019, California Institute of Technology climate researcher Tapio Schneider introduced a theory of how a temperature rise could dissolve cloud cover and so take the climate beyond a critical point. Without ▶

DID YOU KNOW...

that Earth's temperature has varied between warm periods averaging above 24°C and cold periods below 15°C four times in the past 542 million years?

375 MILLION YEARS AGO

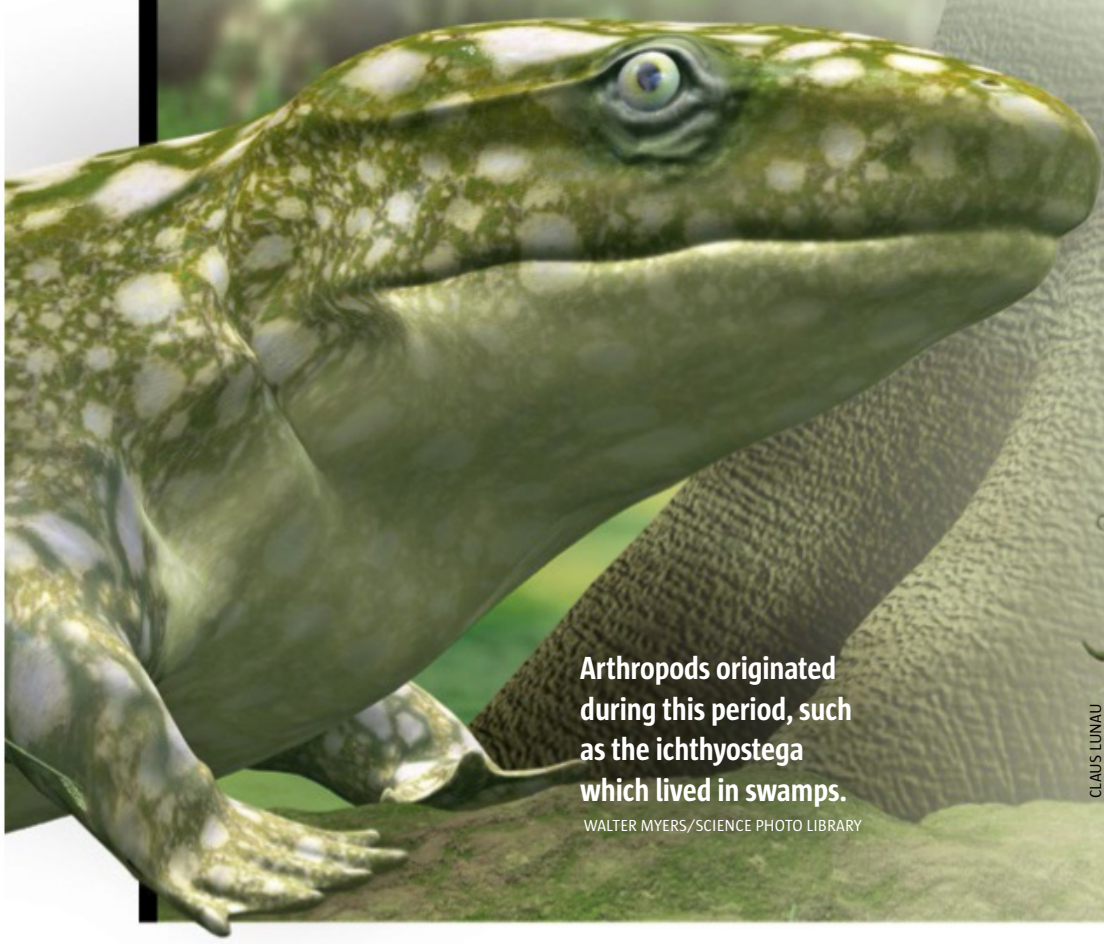
- **PERIOD:** Devonian
- **CO_2 LEVEL:** 10 times higher than now
- **TEMPERATURE:** 25 degrees – 10 degrees warmer than now
- **OCEAN LEVEL:** 250m higher than now

Lots of vegetation bad for animals

Plants use CO_2 during photosynthesis, and with CO_2 at 10 times the present level, growth conditions were exceptional in the Devonian. Yet the world was struck by mass extinctions in which 70% or more of all species disappeared. Volcanic eruptions and meteor strikes have been blamed, but an alternative theory says plants are responsible.

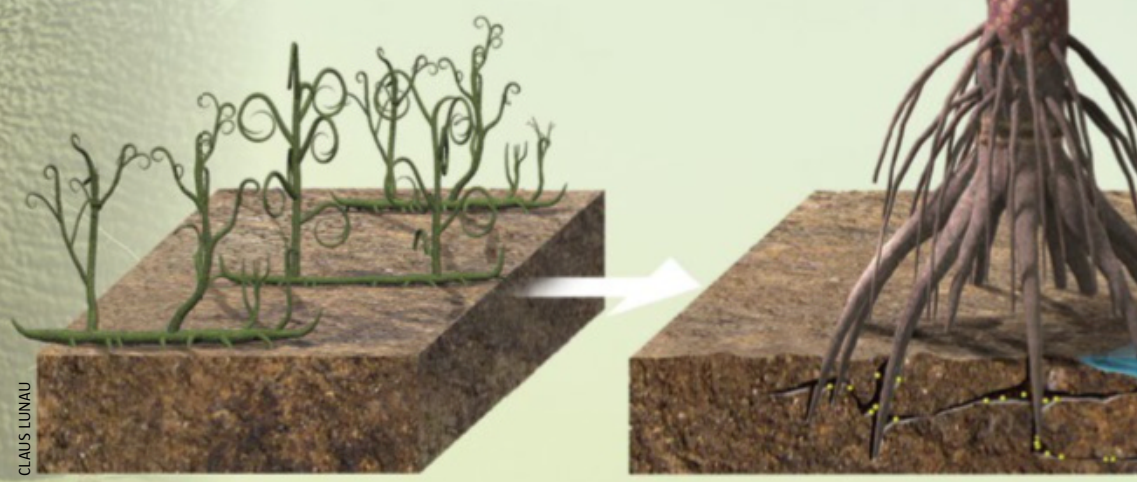
The first trees ruptured the rock

1 The air's high content of CO_2 helped plants establish a presence on dry land some 370 million years ago. Low bushes developed into the ancestor of trees, Archaeopteris. The trees grew deep into cracks and cavities in the ground, their hefty roots rupturing the rock.



Arthropods originated during this period, such as the ichthyostega which lived in swamps.

WALTER MYERS/SCIENCE PHOTO LIBRARY



CLAUS LUNAU

EARLY DEVONIAN

LATE DEVONIAN

clouds, less of the sun's energy is reflected back into the atmosphere. Instead, it will heat Earth's oceans and surface, contributing further to global warming. And once activated, such a negative spiral takes a long time to reverse. After the warming during the PETM 56 million years ago, 170,000 years passed before the climate stabilised.

Rapid change kills life

This marked change of temperature during the PETM may be extremely fast in geological terms, but it's still very slow compared with today's temperature rise. To find a period that is closer to the present climate scenario, scientists must take a look at a disaster that was triggered by an external event. At the end of the Cretaceous 66 million years ago, a mass destruction event wiped out not only the dinosaurs that had ruled Earth for 160 million years, but 75% of all animal species. The mass destruction was most probably due to a violent and sudden temperature drop caused by a meteor the size of Mount Everest striking Earth near the town of Chicxulub on the Yucatan Peninsula in Mexico. The energy release corresponds to one billion Hiroshima nuclear bombs, and the collision sent huge quantities of dust and soot into the atmosphere, blocking out the sunlight. Temperatures fell suddenly and drastically. According to research, the event affected the climate for up to 5000 years and limited biodiversity for 20,000 years after the strike.

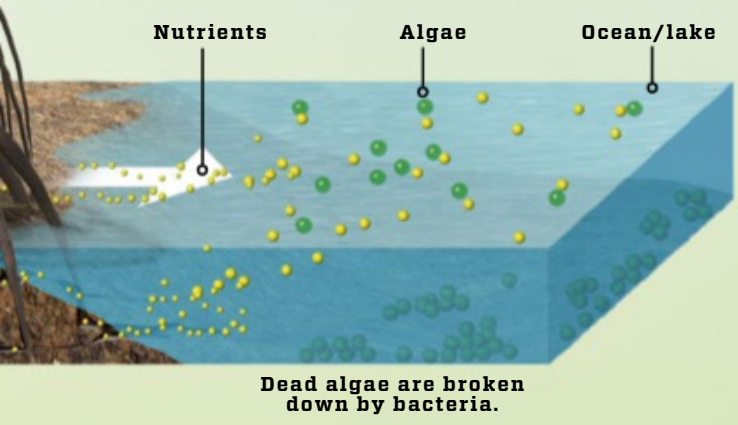
Things went very differently with the slower temperature rise during the PETM, because life had time to adapt. Animal species reacted by shrinking in order to

Nutrients in the water

2 CO_2 from the air was dissolved in water to produce carbon dioxide, which entered the cracks and weathered the rock, liberating nutrients that washed into oceans, lakes and streams.

Algae caused depletion

3 The nutrients made algae thrive. After their death, they sank to the bottom where they were broken down by oxygen-consuming bacteria, whose oxygen consumption caused oxygen depletion, making animals suffocate.



NOW:

PLANTS SUFFER 'GROWING PAINS'

Satellite surveillance shows that Earth's vegetation has become more dense since 1982, with 70% of the increase due to CO_2 levels. Globally, plants' photosynthesis has increased by 33% over the past 100 years due to the rise in CO_2 levels. Several studies suggest that the higher CO_2 level makes tiny algae, phytoplankton, spread in oceans and lakes, causing the risk of oxygen depletion. But the growth is partly counteracted by higher temperatures.

Higher CO_2 levels in the atmosphere have made plants spread. SHUTTERSTOCK

become better at regulating their heat, while biodiversity actually ended up increasing. Whether temperatures rise or fall, it is the speed of the climate change which is the key to how life is affected.

CO_2 explosion since 1800

When it comes to the CO_2 content of the atmosphere, we are again now experiencing an unusually rapid rise. For almost a million years up until the year 1800, the CO_2 level was fairly constant: 200-300 ppm (parts per million), corresponding to 0.02-0.03%. But within the past 200 years, it has risen to 400 ppm. Depending on what we do to prevent further increases, the CO_2 level by 2300 is expected to be 400-700 ppm or, worst case, 2000 ppm. And again the levels themselves aren't unprecedented – it has reached 7,000 ppm before. It's the rate of increase which makes this such a dramatic climate change.

Indeed if charted over hundreds of millions of years, the CO_2 content of the atmosphere has been on the decrease. Over the past 542 million years, the CO_2 content of the atmosphere has been reduced to ▶

DID YOU KNOW...

that the atmosphere's CO_2 level peaked at a rate 17 times higher than now 540 million years ago? It was good for plants, but not so much for animals.

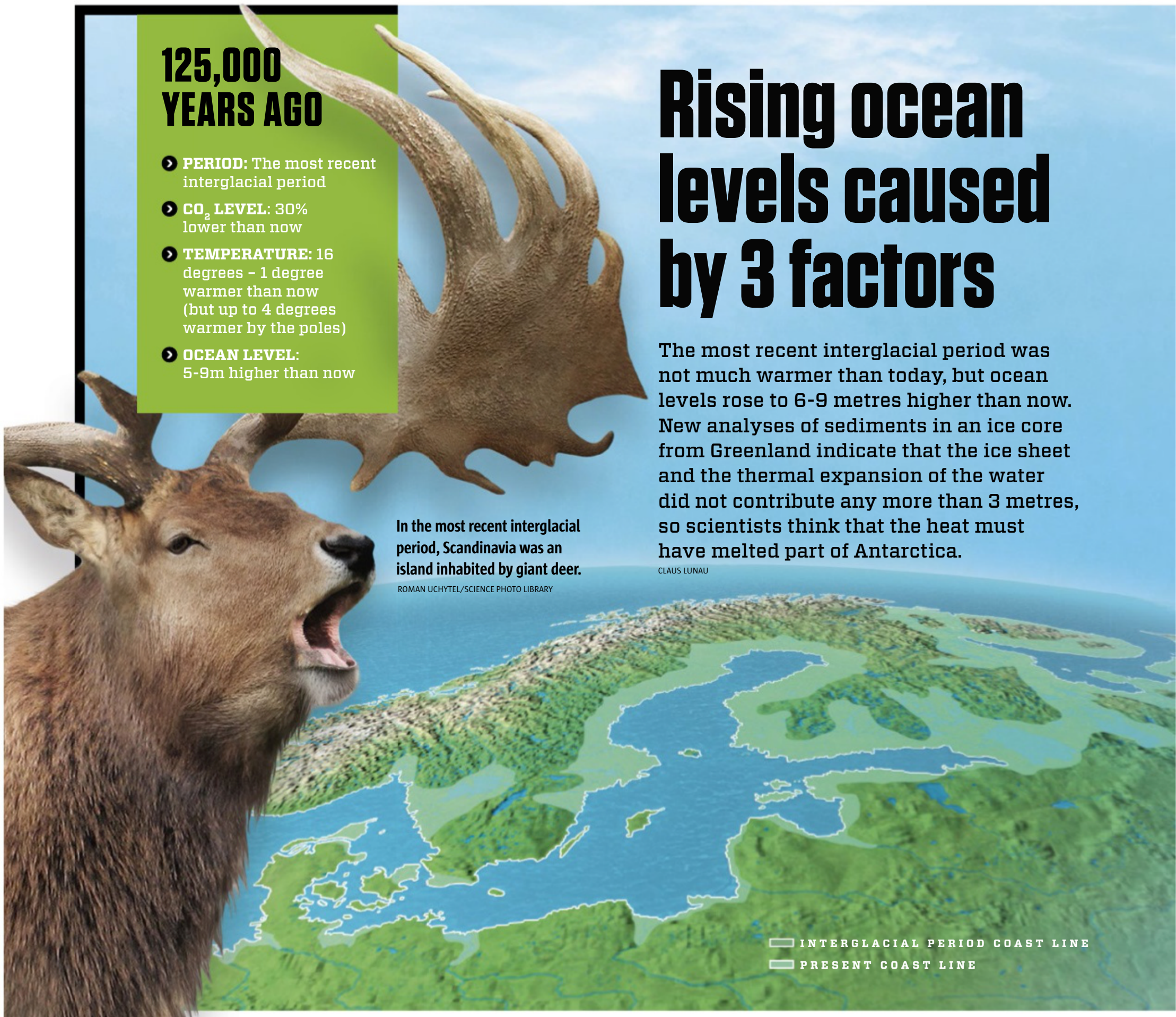
125,000 YEARS AGO

- **PERIOD:** The most recent interglacial period
- **CO_2 LEVEL:** 30% lower than now
- **TEMPERATURE:** 16 degrees – 1 degree warmer than now (but up to 4 degrees warmer by the poles)
- **OCEAN LEVEL:** 5-9m higher than now

Rising ocean levels caused by 3 factors

The most recent interglacial period was not much warmer than today, but ocean levels rose to 6-9 metres higher than now. New analyses of sediments in an ice core from Greenland indicate that the ice sheet and the thermal expansion of the water did not contribute any more than 3 metres, so scientists think that the heat must have melted part of Antarctica.

CLAUS LUNAU



In the most recent interglacial period, Scandinavia was an island inhabited by giant deer.

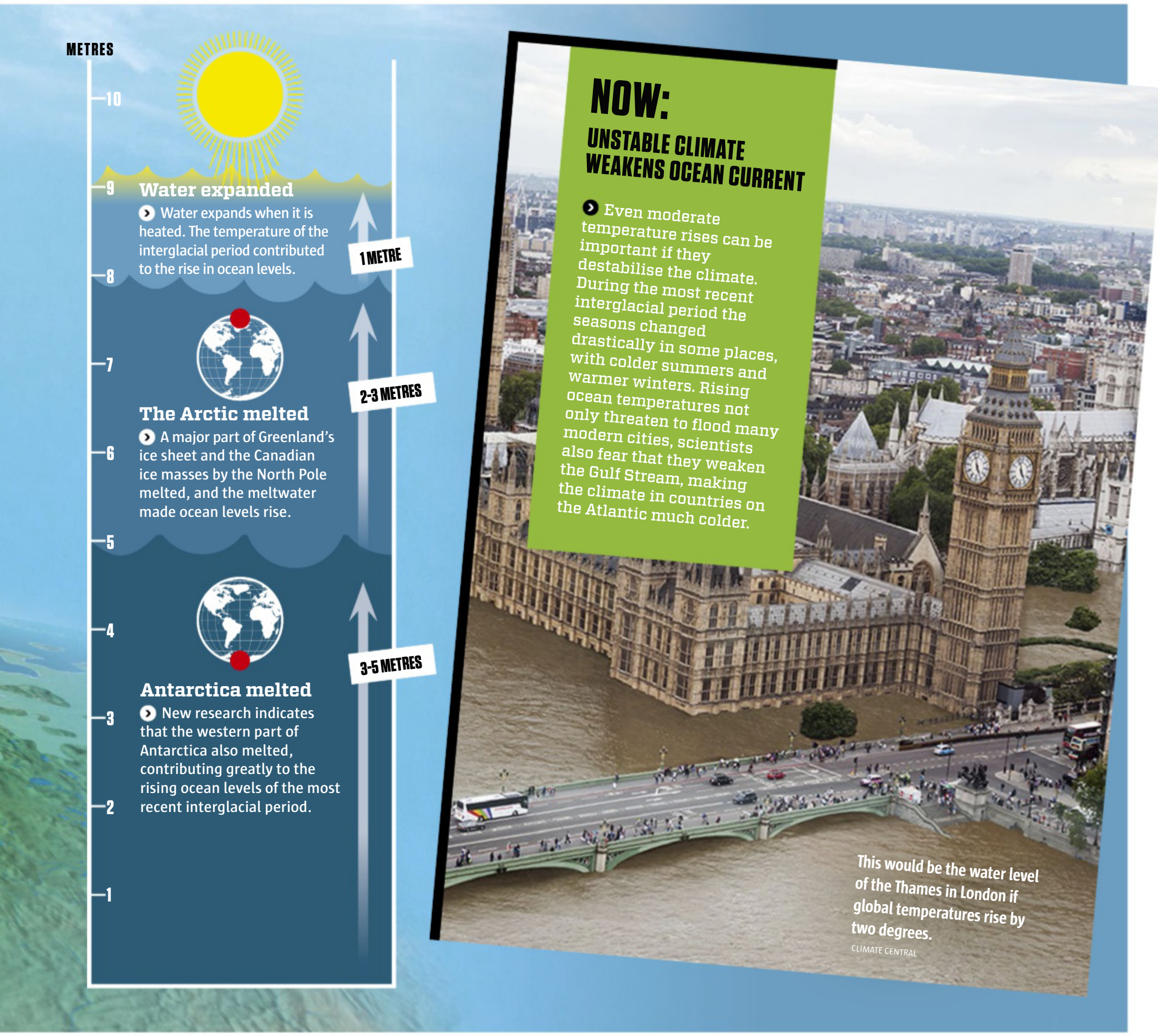
ROMAN UCHYTEL/SCIENCE PHOTO LIBRARY

▶ 1/20 by natural processes, as in the long run, CO_2 is absorbed by the ocean and the ground and hence removed from the atmosphere; plants absorb CO_2 via their photosynthesis and include it in organic material. Though the natural processes can also work in the opposite direction, as they do in connection with volcanic eruptions, the net effect without human burning of fossil fuels would be that the CO_2 content of the atmosphere would continue to fall in the long term. But human activity is overwhelming these natural processes. Over only 500 years, from 1800 to 2300, humans could cause the CO_2 level to increase tenfold if we continue to emit CO_2 in the way we used to. The consequences of such rapid change are totally unpredictable. The only thing we know for sure is that it will be dramatic. In the Devonian period 375 million years ago, the CO_2 level reached as high as 4000 ppm, and according to one theory the CO_2 level boosted algae growth in the oceans so much that many animal species died out due to lack of oxygen.

New species

Ocean levels have followed the same pattern as CO_2 levels, decreasing over the past 542 million years, though time-delayed by about 50-100 million years. Both are historically low right now, but rising considerably. The ocean level depends on more than just the quantity of CO_2, also on other factors including underground changes through the motions of continental plates.

During the Ordovician geological period some 460 million years ago, Earth had the highest water level ever, 400 metres higher



than today. It was by no means a disaster for life on Earth, indeed the high water levels led to the formation of many lakes, delivering a diversity of ecological niches where animals and plants could develop. Together with a benign climate it caused an explosion of species. Moss animals, sea urchins, and corals were among the new animal groups that originated, and plankton thrived in the water, providing food for other animals.

Life also thrived during the most recent severe ocean level rise, in the interglacial period 125,000 years ago. Although the ocean level rose by 6 to 9 metres, animals and the human hunter-gatherers of the era just followed the water inland. But if something similar were to happen over the next couple of centuries, it would be far more critical for today's more closely-packed humanity, with our cities and food production that cannot easily be moved.

Climate has changed throughout Earth's history; for life as a whole, even major climate change does not necessarily result in mass destruction. The planet can handle change. The question is: can we? SCI

DID YOU KNOW...

that the present ocean level is almost the lowest in Earth's history? It peaked 400 metres higher than now 460 million years ago, and yet life thrived.

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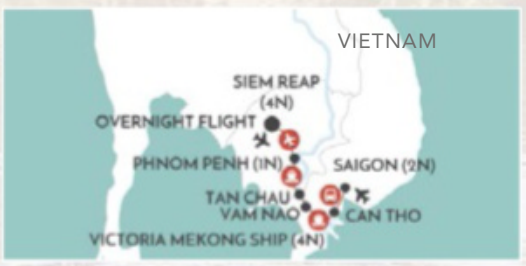

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WILD THEORY

The CHIME telescope measures flashes of radio waves from space. The flashes could come from white holes.

ANDRE RECNIK/CHIME COLLABORATION

By **Rolf Haugaard Nielsen**

Black holes invert into White holes

Black holes die in a violent transformation, sending all their matter back into space again and becoming white holes, according to a new theory that is to be tested, perhaps changing our idea of the universe for good.

Large swirling gas clouds and stars are sucked into the black hole, to a place where gravity is so intense that not even light can escape. But eventually the feasting stops: the black hole cannot swallow anything more because all that matter cannot be further compressed. The hole 'reverses' into a white hole that ejects all its matter into space with violent force. A white hole is the opposite of a black hole. Where a black hole swallows matter which cannot escape again, nothing can enter a white hole because of the enormous pressure on the matter that comes roaring back into space.

That is the sensational theory of white holes, an idea now to be tested by the new CHIME radio telescope in Canada, which began scientific operations in 2018. With CHIME, astronomers can analyse thousands of radio wave flashes that could come from white holes. And if the holes do exist, it will turn astronomy upside down.

Spacetime is made of rings

Black holes were introduced with Einstein's general relativity theory, which describes gravity as curved space: masses bend time and space around them, and thereby attract other masses. The bigger the masses, the bigger the bending. Black holes are so massive that they swallow everything around them, and they have been proven to exist via astronomical observations.

White holes have never been directly observed, but they exist in quantum ring theory. The theory tries to unite Einstein's general relativity theory with quantum mechanics, which describes the tiniest building blocks of atoms. According to quantum mechanics, space is the same everywhere, but according to relativity theory, space is variable, because large masses such as black holes change the curvature of space.

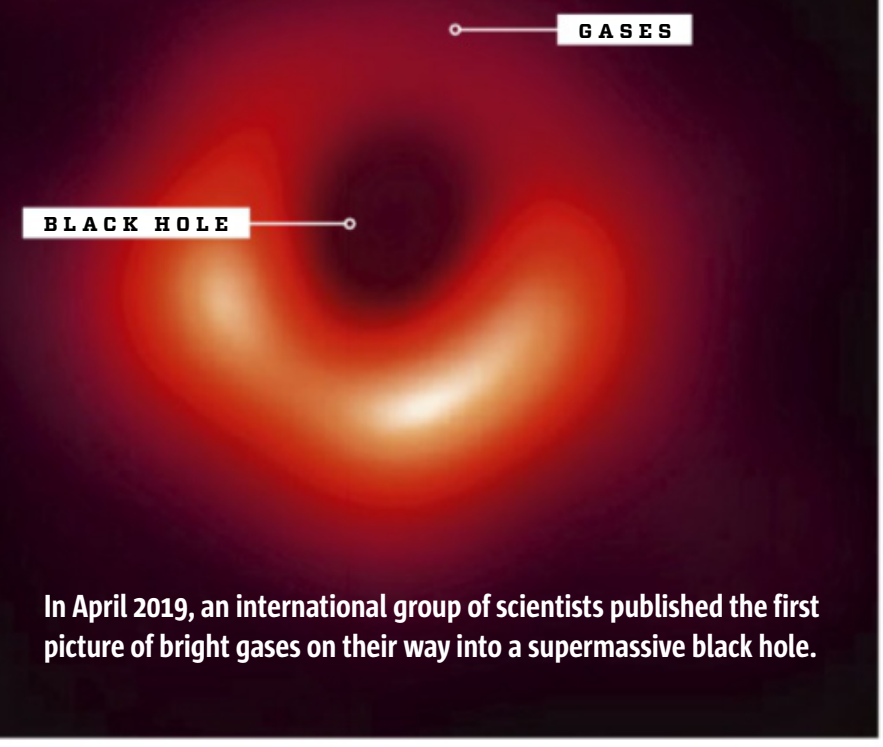
Quantum ring theory explains the conflict by describing how spacetime can be divided, just like the atoms of quantum mechanics, into its smallest possible components, which are rings. The rings are linked, a little like chain-mail armour, and they make up spacetime. If we had the ultimate super-microscope, we would be able to see the rings of the armour. According to the theory, nothing in the universe can ever be smaller than such a ring.

According to the classic theory of black holes, their ingested matter will become ever more concentrated towards an infinitely small point, but quantum ring ▶

Small black holes from the Big Bang become white holes

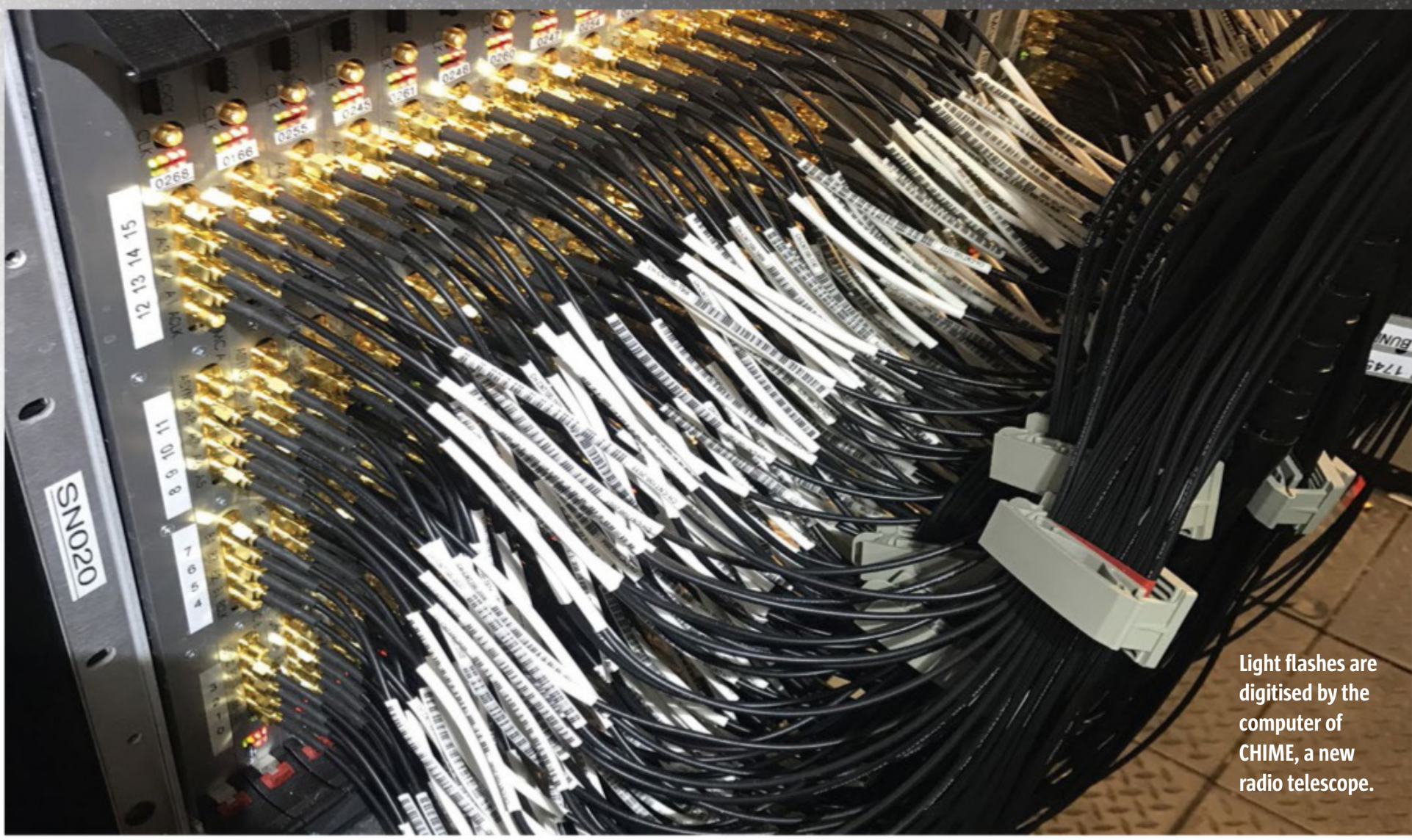
The most common black holes are the size of stars and form after stars collapse and explode into supernovas. The Milky Way includes 100 million of these holes. At the centre of the Milky Way and other major galaxies, there are supermassive black holes with masses corresponding to millions or billions of stars.

Both supermassive black holes and black holes the size of stars live long lives. So according to the theory of white holes, many years will pass before the black holes 'die', turn white, and send all the swallowed matter back into space. But smaller black holes do not last as long. According to scientists, many small black holes might have formed right after the Big Bang; these black holes could be converted into white holes as we watch the skies today. When the transformation happens, the holes emit flashes of radiation which astronomers are trying to detect with the CHIME radio telescope.



In April 2019, an international group of scientists published the first picture of bright gases on their way into a supermassive black hole.

EHT COLLABORATION



CHIME

Light flashes are digitised by the computer of CHIME, a new radio telescope.

▶ theory clearly implies that the limit on size will be that of a spacetime ring. When the volume reaches this limit, an intense outward pressure will switch the black hole to a white one, ejecting all its compressed matter back into space.

Violent conversions flash

During the past decade, astronomers have identified more than 60 mysterious radio wave flashes. The flashes come from sources that are relatively small – down to 10km in diameter – and yet they emit more energy in one micro-second than the Sun radiates over decades.

The life-span of a black hole is long, but the observed flashes might be evidence of white-hole conversions of small black holes that formed right after the Big Bang. These might be reaching their ring-size limit in the present and, according to the theory, when this happens, they emit radio flashes. So scientists believe that the 60+ radio flashes observed might come from the universe's oldest black holes becoming white holes.

The wavelengths of radio flashes could reveal if the flashes are from white holes or other known phenomena. A small black hole that formed shortly after the Big Bang will emit radiation with short wavelengths when it is converted into a white hole. But at the same time these small black holes will be very far away, because they have existed since the beginning of the universe, which is constantly expanding. The original short wavelengths would therefore be stretched considerably as they reach Earth.

CARLO ROVELLI
QUANTUM PHYSICIST

A white hole is a black hole in reverse: inside it, matter can only travel outwards."

Larger black holes from the Big Bang live longer than the smallest ones, and when they become white, they will emit radio waves with longer wavelengths than the small black holes. But the wavelengths will not be stretched so much on the way to Earth, because the black holes are closer to us when they make the switch to white holes. Carlo Rovelli, one of the founding fathers of the quantum ring theory, believes that wavelengths from remote and close white holes will be almost identical, something unknown from other radio sources in space, where wavelength always increases with distance.

Did a white hole give birth to our universe?

The Canadian CHIME radio telescope began scientific operations in September 2018. CHIME detects radio waves by means of four 100m-long pipe-shaped antennas cut in half. The antennas cover 200 square degrees of the sky – a thousand times larger in area than a full moon and a wider view than any other radio telescope, enabling astronomers to capture thousands of radio flashes and compare their wavelengths and distances. With this data scientists can test the theory of radio flashes being triggered as a black hole turns white.

If scientists find white holes, we must reconsider how everything began. According to classic cosmology, the universe originated in an explosion – the Big Bang. But according to some scientists, the universe is born and dies over and over again. According to that theory, a newborn universe expands for billions of years, after which gravity takes over, compressing everything into a supermassive black hole. If quantum ring theory holds true, the black hole becomes a white hole, ejecting all the matter again and giving birth to a new universe. The discovery of white holes might therefore not only turn our knowledge about black holes upside down, but could also support the theory of a cyclical universe. SCI

White holes eject matter

Incredible quantities of matter are compressed in a black hole, but according to quantum ring theory, the matter can never become compressed into a space smaller than a quantum ring. When the volume is this far reduced, the pressure becomes too intense, and a reversal spews all the matter into space. The hole turns white.

BLACK HOLE SWALLOWS EVERYTHING

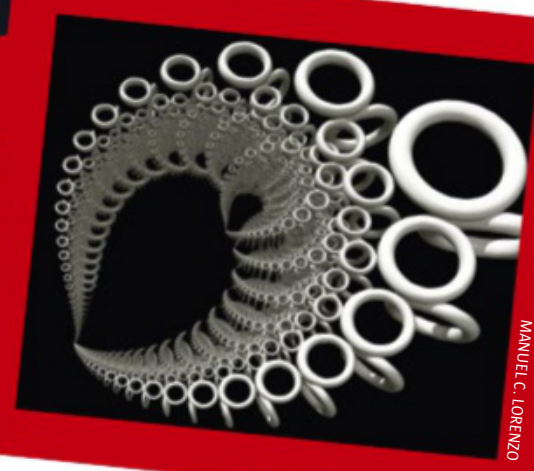
1 A black hole swallows all dust and gas around it. According to relativity theory, all the matter will be ever more compressed into a point infinitely small with infinite density. But according to quantum ring theory, there is a limit beyond which the matter cannot be compressed.

BLACK HOLE

QUANTUM RING

MATTER COMPRESSED TO QUANTUM RING

2 According to quantum ring theory, space-time consists of small linked rings. When the matter of a black hole is compressed so much that it reaches the size of one of these rings, violent outward pressure results – as when a spring reaches its maximum compression. The black hole must then stop swallowing matter.



MANUEL C. LORENZO

According to quantum ring theory, small rings are the tiniest components of the universe.

WHITE HOLE SPEWS IT

3 The black hole gives in to the pressure and collapses: it is now converted into a white hole. All compressed matter in the hole is released into space. In a black hole, no matter can escape, but when it becomes white and ejects matter into space, nothing can enter.

WHITE HOLE

CLAUS LUNAU

In 1905, the last Chinese Père David's deer was shot. Luckily the English Earl of Bedford had previously imported a small group, so that in 1985, 18 individuals could be brought back to China, where they have bred into 700 wild animals.

Endangered species stage a comeback

As few as seven individuals remained, but conservation and an unfailing will to survive brought critically endangered species back from the edge of extinction.

STAFFAN WIDSTRAND

DEER RETURNS TO CHINA | A detour to England saved the Père David's deer.

By **Staffan Widstrand**

In spite of the crested ibis being Japan's national bird, the last wild individual died in 2003. But a group of seven birds were found in China, and now artificial hatching centres are making sure that 100 ibises are returned to nature each year.

STAFFAN WIDSTRAND

JAPAN ERADICATED ITS NATIONAL BIRD | But seven individuals were found in China.

MIREILLE DE LA LEZ/WILD WONDERS OF EUROPE

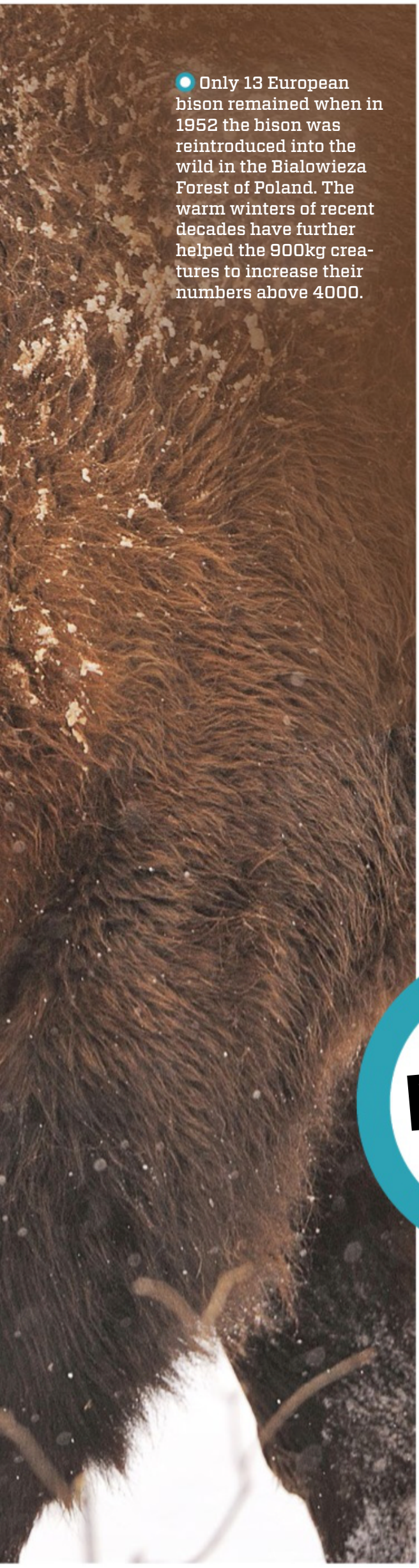
The arctic fox is deeply dependent on its primary food, lemmings. Acid rain, due to sulphur from coal-fired power plants, reduced the lemming population and threatened to wipe out the arctic fox. But since then a reduction in the number of coal-fired power plants is helping the fox to grow in numbers.

CARBON FREEZE SAVES ARCTIC FOX | Only four litters were born in 1999.

BISON THRIVES IN POLAND | For the first time in 250 years, wild bison are roaming Europe.

PhotoDoc

ENDANGERED SPECIES STAGE A COMEBACK.



Only 13 European bison remained when in 1952 the bison was reintroduced into the wild in the Bialowieza Forest of Poland. The warm winters of recent decades have further helped the 900kg creatures to increase their numbers above 4000.

STEFANO UNTERTHINER/WILD WONDERS OF EUROPE

The Hawaiian goose became the rarest goose in the world after the introduction of pigs, cats, dogs, and rats to Hawaii reduced the population to 30 individuals in 1952. They were captured and bred in captivity, and the islands now host 2500 of the geese.

STAFFAN WIDSTRAND

GEESE OVERCAME INVASION | Pigs and rats took over Hawaii.

Muskoxen once existed throughout the Arctic, but after extensive hunting they ended up only in Northern Greenland and a few Canadian islands. Attempts to reintroduce muskox to Scandinavia have establised small numbers there, but as it has not lived in the wild for there hundreds of years, it is now considered an invasive species in Sweden.

VINCENT MUNIER/WILD WONDERS OF EUROPE

THE MUSKOX RETURNS TO SWEDEN | But even its small numbers aren't entirely welcome.

STAFFAN WIDSTRAND

In the 1980s, 80% of all eastern imperial eagle offspring were killed by high-voltage power lines. Then when the population of rabbits, the bird's primary prey, was subsequently reduced, it came close to extinction. Now rearranged power lines and other solutions are helping the population to increase by 7% annually.

HIGH VOLTAGE KILLED YOUNG EAGLES | Now their numbers are back on the rise.

Przewalski's horse was reduced to just six individuals, but now, together with red deer and ancient cattle, the horse is part of reestablishing 'Europe's Serengeti' – huge steppe regions with thousands of wild species.

MILAN RADISICS/WILD WONDERS OF EUROPE

WILD HORSE RETURNS TO GRAZE | Przwalski's horse reestablished in 'Europe's Serengeti'.

STAFFAN WIDSTRAND

PhotoDoc

ENDANGERED SPECIES STAGE A COMEBACK.

The Arabian oryx 'went extinct' in the wild in the 1970s, primarily due to hunting. Thanks to a successful breeding programme, the oryx was the first species to be re-classified back to 'endangered' from the status of 'exterminated in the wild'.

LONG-HORNED ANIMAL WAS HUNTED DOWN | But the oryx is now ex-exterminated.

Test Yourself

SEE THE ANSWERS ON PAGE 10

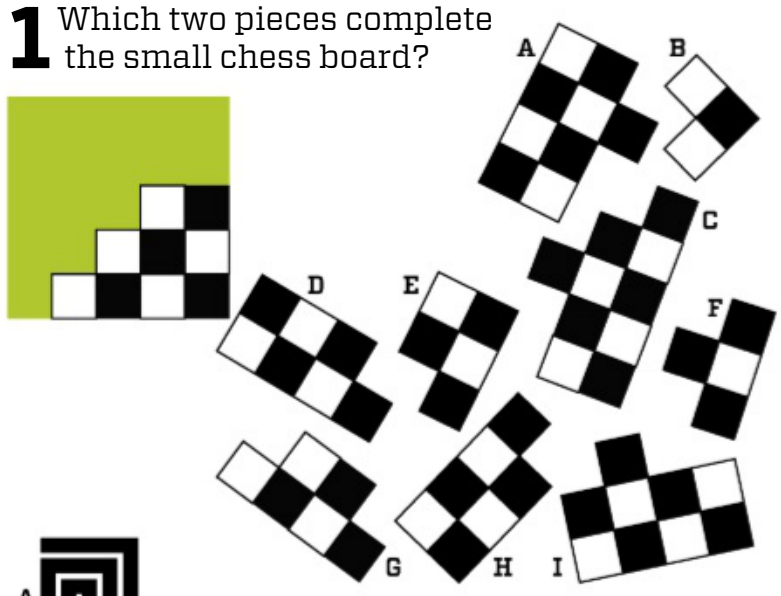
MIND-BOMBS!

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

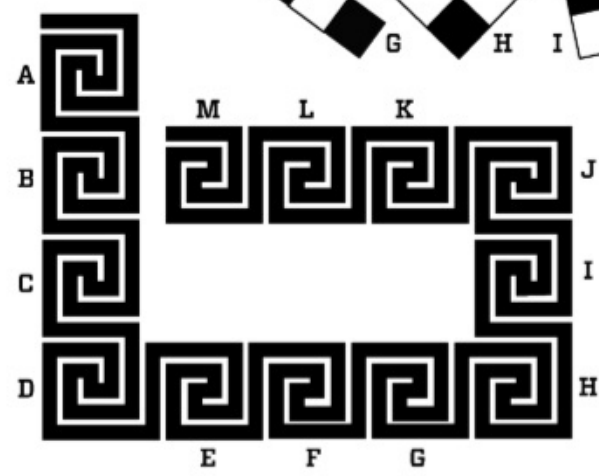
Editor: **Nanna Vium** //
Text & Art: **Anker Tiedemann**

VISUAL INTELLIGENCE

1 Which two pieces complete the small chess board?

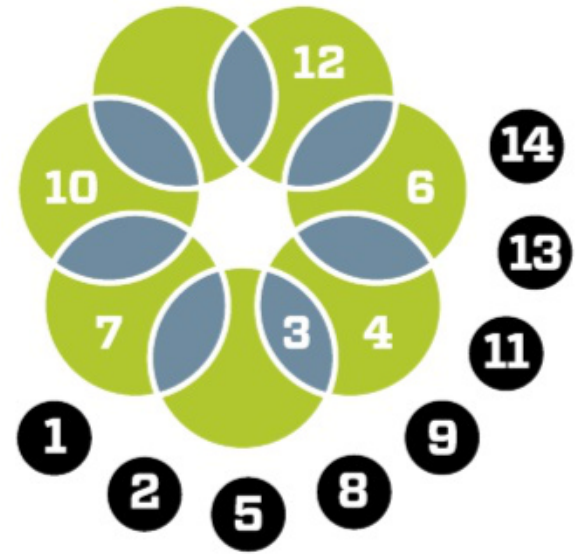


2 Where is the minor imperfection in this Greek ribbon?



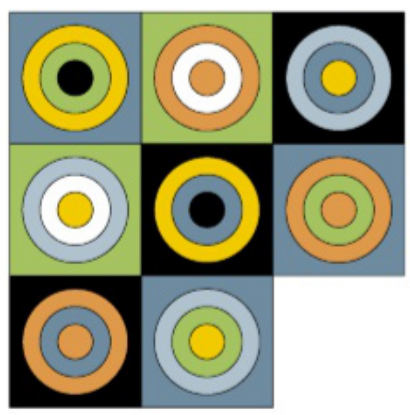
NUMERACY

3 Which number replaces the question mark?



4 Place the numbers 1 to 14 so that the three numbers in each circle total 21.

LOGIC



5 Which figure fits into the empty space?

6 If a soccer ball for adults weighs 210g plus half its own weight, how much does it weigh in total?

Scientist in Focus

CREATIVE COMMONS

Name: Albert Ghiorso
Life span: 1915-2010

American identified 12 elements

As a teenager, Albert Ghiorso built radio circuity that was better than the military's. Later, he became a nuclear scientist, beating the record for identifying the most elements – in 30 years, he discovered 12. He also developed methods for expanding the periodic table.

7 He allegedly invented the first commercial version of which instrument?

- **A) The atomic clock**
- **B) The thermometer**
- **C) The Geiger counter**
- **D) The Stylophone**

8 Ghiorso spent the majority of his career at which famous Californian university?

- **A) Oxford**
- **B) Manchester**
- **C) Harvard**
- **D) UC Berkeley**

9 Ghiorso was particularly interested in which specific type of elements?

- **A) The Pleiades**
- **B) The Actinides**
- **C) The Sylphs**
- **D) The heavy elements**

10 During World War II, Ghiorso worked on a specific project. Which one?

- **A) The Brooklyn Project**
- **B) The Bronx Project**
- **C) The Manhattan Project**
- **D) The Alan Parsons Project**

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