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WHAT IS THE CLIMATE 'TIPPING POINT'?

HOW HUMANS EVOLVED

SOLAR MAXIMUM

SUNSPOTS, SOLAR FLARES AND A TOPSY-TURVY MAGNETIC FIELD: HOW THE SUN'S UPCOMING PEAK WILL AFFECT EARTH

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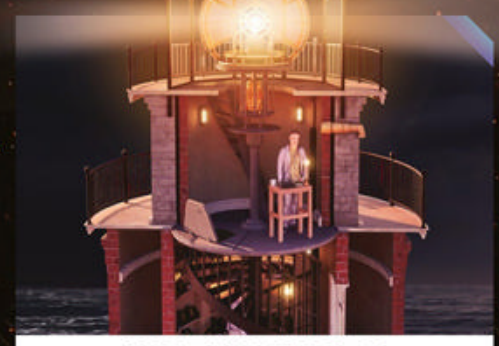

WHAT'S INSIDE A LIGHTHOUSE?

FUTURE
ISSUE 181

WELCOME

Issue 181

"The peak of the cycle, called solar maximum, can occasionally have dramatic effects here on Earth"

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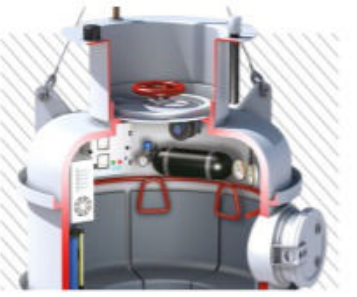
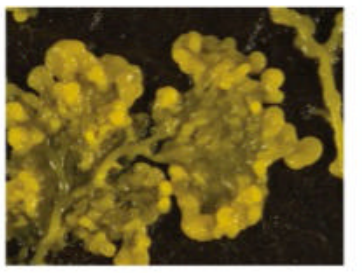
Solar maximum
PAGE 26

Most of us consider the Sun a mere part of the weather, warming our skin on a summer day or hiding behind a cloud. But this yellow dwarf star that sits 93 million miles from Earth has a cycle all of its own – similar to the seasons on Earth. The peak of this cycle, known as 'solar maximum', can affect Earth in very different and drastic ways to our usual winters or summers. An unusually long period of 'solar minimum' can plunge our planet into a little ice age, while solar storms and large solar flares during solar maximum can cause communications and power blackouts, and nudge the aurora borealis and aurora australis closer to the equator. On page 26, we explain what you can expect and even look forward to from the upcoming solar maximum. Enjoy!

Ben Biggs
EDITOR

HIGHLIGHTS





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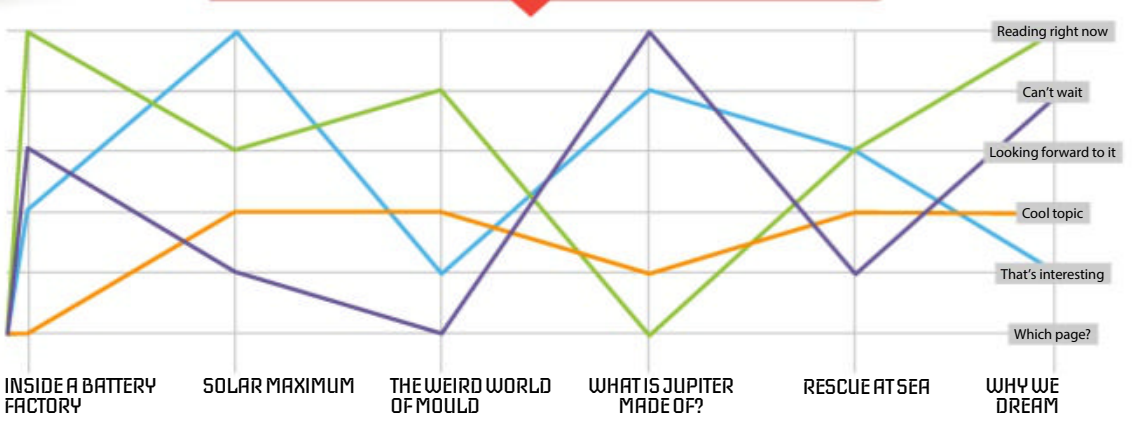

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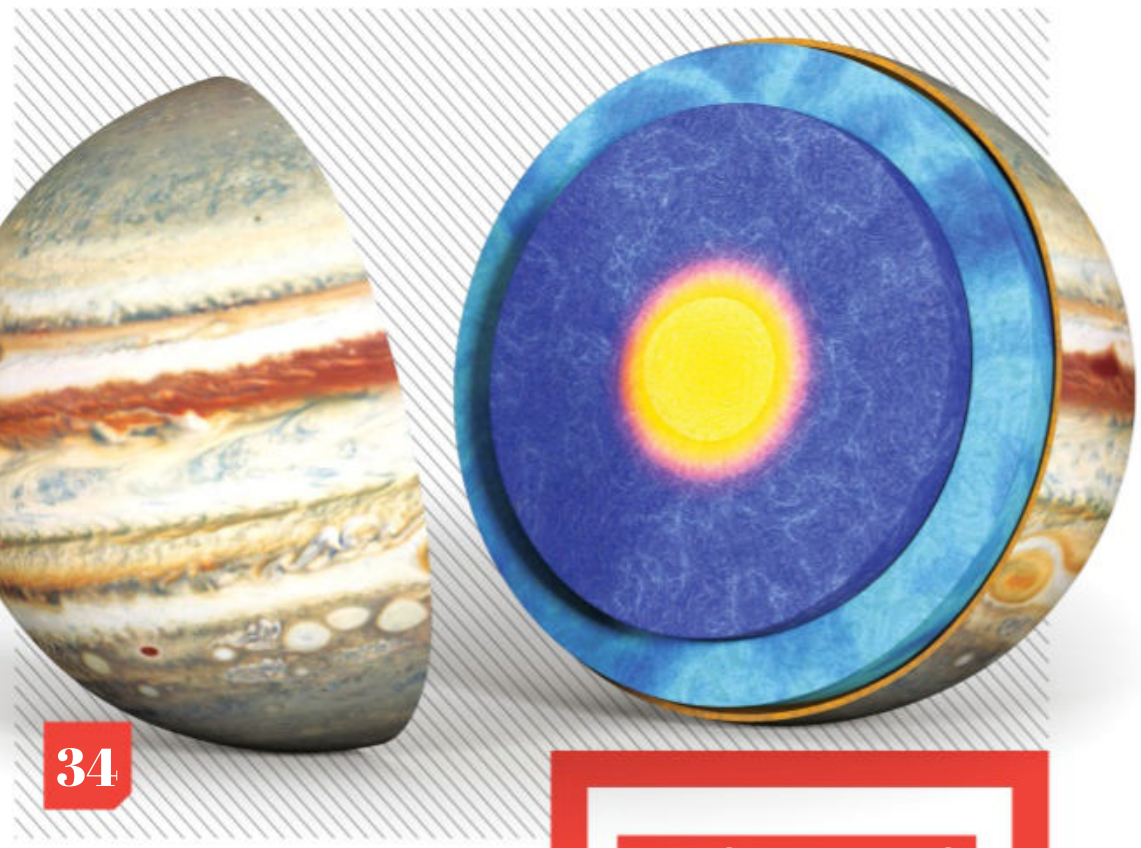

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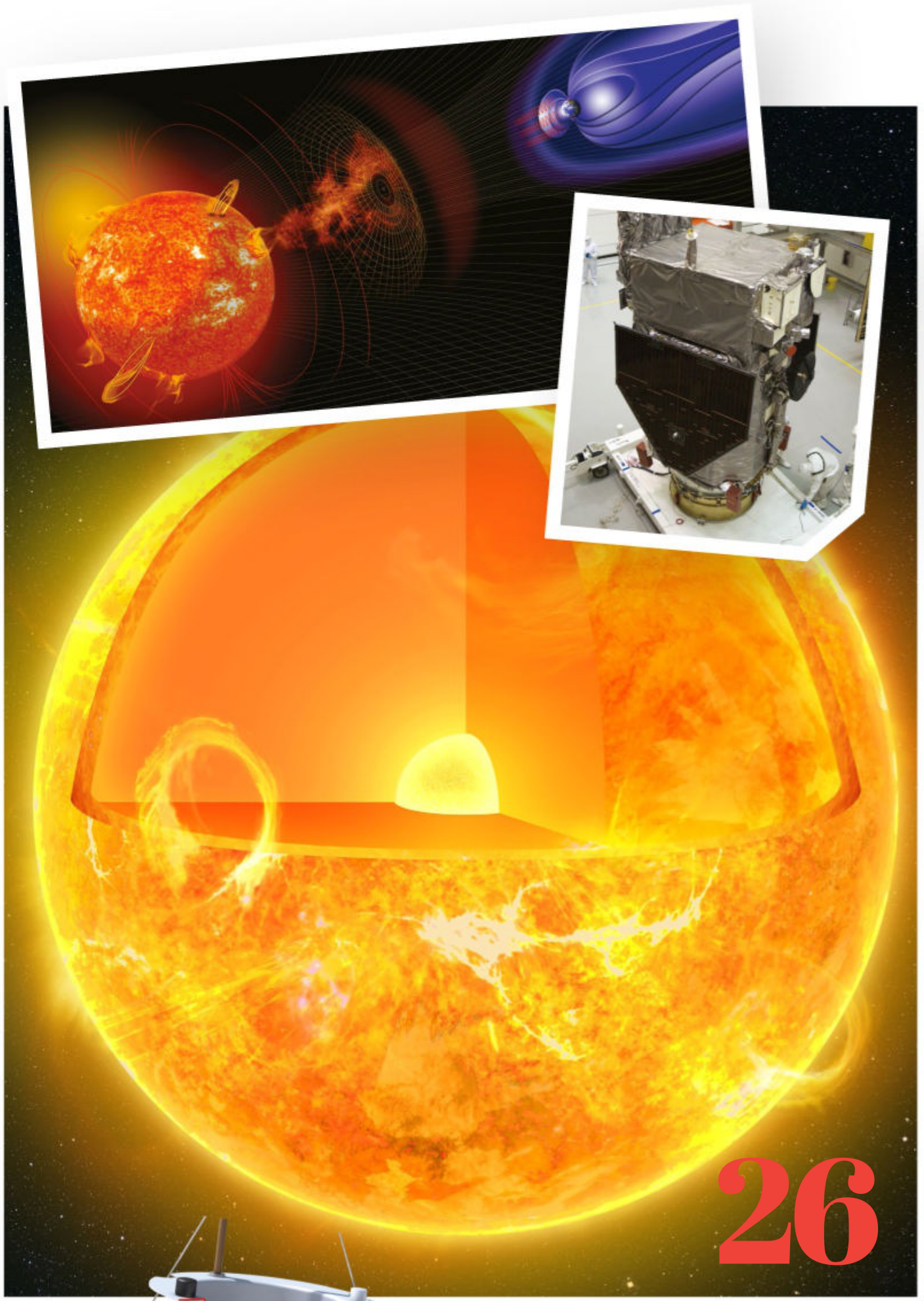
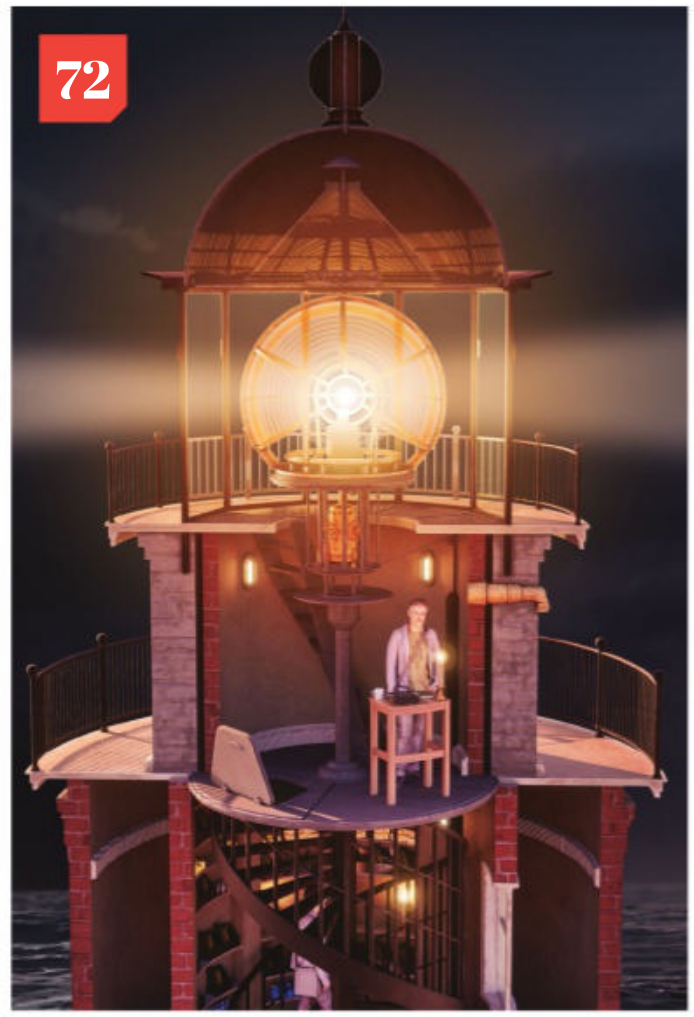




Moth hatchling

The hatchlings of the spectacle moth (*Abrostola tripartita*) can be seen breaking their way through their eggs in this image. After a few weeks developing in their eggs, the green caterpillar larvae of the spectacle moth tear tiny holes in the shells using their mandibles and break their way through. Spectacle moth eggs can be found on the leaves of common nettles across Europe.

Earth's closest nursery

Taken through the lens of the James Webb Space Telescope, this stunning image depicts a star-forming region of space called the Rho Ophiuchi cloud complex. The cosmic cavern at the centre of the red gaseous curtains has been carved by stellar winds from a star called S1, which is about the same mass as our Sun. The Rho Ophiuchi cloud complex is only 390 light years away from us.

Into the Great Blue Hole

This aerial photo, taken off the coast of Belize in Central America, shows a natural wonder of the world called the Great Blue Hole. Five reef islands, known collectively as Lighthouse Reef, form an atoll around a sinkhole that has dark and ominous waters. The watery sinkhole has a navy-blue colour because it is 125-metres deep, which is much deeper than the surrounding waters.

A shuttle for the shuttle

The NASA 905 was the first Shuttle Carrier Aircraft to ferry Space Shuttle orbiters from their landing sites to Florida's Kennedy Space Center during testing. The NASA 905 sported a wingspan of around 60 metres, which along with four powerful turbine engines could support the weight of a 2,000-tonne vehicle. The 905 carried its last shuttle, Endeavour, to Los Angeles in 2012.

Genes are switched ‘on’ when molecules called RNA make copies of DNA and send them to protein construction factories in the cell

HEALTH

‘Remote-controlled’ human cells implanted in mice

WORDS **DR ALAKANANDA DASGUPTA**

The gene activity of ‘designer’ human cells can be remotely toggled on and off with electric currents. In a new study, direct current (DC) from off-the-shelf consumer batteries triggered the release of insulin from genetically engineered human cells that scientists had implanted under the skin of diabetic mice. The insulin successfully restored the rodents’ normal blood sugar levels. The researchers hope this electrical fine-tuning of gene expression, broadly known as ‘electrogenetic’ technology, will eventually be integrated into wearable devices that can be used to tune the activity of designer cells implanted in the human body.

Wearable devices are already in vogue and can monitor pulse, blood pressure, blood sugar levels and more. But currently, no such technology can be used to control gene expression. To move this idea from science fiction into the real world, scientists at ETH Zürich and the University of Basel designed an interface called DC-actuated regulation technology (DART). It’s powered by DC from standard 1.5-volt AA or AAA batteries. As a proof of concept, they tested DART in a mouse model of type 1 diabetes. They implanted engineered human cells in the rodents’ backs and stimulated the cells through two acupuncture needles placed near the implantation site. The needles were attached to the batteries via a wire, whose end was plugged into a simple power switch.

The electrical current flowed through the needles and triggered minor oxidative stress in the designer cells, meaning it caused a slight buildup of reactive molecules called reactive oxygen species (ROS). These molecules were detected by a molecular sensor built into the cells. The sensor, which was engineered to work as a protein that latches onto DNA to turn a gene ‘on’ or ‘off’, then bound to a designated spot on the cell’s DNA, and in turn activated the gene of interest, the insulin gene. The human cells were genetically engineered to express, or activate, the gene of interest only if the ROS levels produced by the electrical current were high enough, and as the ROS dissipates, the gene switches ‘off’.

Stimulating the designer cells for just ten seconds once a day was enough to induce gene expression and trigger sufficient insulin release to restore normal blood glucose levels in the mice. “It’s a tremendous application of electrogenetics,” a technique that uses “electronic means to turn on specific gene expression,” said William Bentley, a synthetic biologist and professor at the University of Maryland. Bentley, who pioneered this technology and coined the term ‘electrogenetics’, added that the work still only “represents the tip of the iceberg in terms of electronic communication with and control of biology.”

Artist's depiction of the metal-rich asteroid Psyche

SPACE

ASTEROID COLLISIONS OFFER CLUES ABOUT MAGNETIC METEORITES

WORDS **RAHUL RAO**

Rubble-pile asteroids form when asteroids collide and their shards reassemble into new asteroids. When they do, they might give the renewed asteroid a temporary magnetic field. This result might address a mystery that's baffled astronomers for years: some metallic meteorites hold traces of magnetism, as if they carry remnants of internal magnetic fields. Even if a meteorite does contain iron, it isn't expected to have a circulating dynamo like the one in Earth's inner core, which scientists think is needed to generate a magnetic field.

To investigate, Zhongtian Zhang and fellow Yale University planetary scientist David Bercovici turned to modelling asteroid collisions. When two iron-rich asteroids smashed into each other and scattered into shards, they discovered that some of those shards would coalesce into a chillier inner core that was coated by a warmer layer of molten rock. Then, if the shards were just the right size, the cold core would start stripping elements, such as sulphur, from the hot liquid. This model illustrated that the resulting heat transfer could create circulation sufficient to trigger a dynamo, and thus a magnetic field.

HISTORY

Ancient Roman emperor Nero's theatre discovered

WORDS **JENNIFER NALEWICKI**

Archaeologists in Rome think they may have found the ruins of Nero's theatre, a first-century imperial performance space that was widely described in ancient Roman texts but whose whereabouts had remained largely elusive. The theatre is named after Nero Claudius Caesar Augustus Germanicus, who served as Roman emperor from 54 CE to his death in 68 CE. Officials are calling the discovery of the theatre, located just east of Vatican City, "exceptional." It was likely where Nero rehearsed poetry and put on musical performances.

Almost a millennium after his death, Nero remains one of ancient Rome's most infamous rulers, accused of playing his fiddle while the city burned to the ground during an epic fire. While much has been written about the atrocities and poor governance that occurred under his leadership – he allegedly killed his own mother and two wives and lavishly and indulgently spent Rome's money – he's also remembered as a lover of music and the arts, leading him to offer public performances at his theatre, an act that the elite usually didn't partake in. He was particularly fond of playing the cithara, a portable harp-like instrument with seven strings. But when the powerful Praetorian Guard, the force in charge of protecting the emperor, withdrew their support of him, he reportedly took his own life, uttering: "What an artist dies in me!"

Did you know?

Nero was the fifth Roman emperor

Researchers unearthed a variety of artefacts scattered among the building's ruins. These included seven ornate medieval glass chalices, segments of bone used to carve out rosary beads, clay pots and urns, cooking vessels for baking bread, coins, combs constructed out of bone and numerous pieces of musical instruments. As for the remaining architectural elements of the theatre itself, archaeologists unearthed marble columns and plaster decorated in gold leaf. "It's a superb dig, one that every archaeologist dreams of," said Marzia Di Mento, the site's chief archaeologist. "Being able to dig in this built-up historically rich area is so rare."

The discovery came about as construction crews were working on reconfiguring Palazzo Della Rovere, a medieval palace, into a new luxury hotel, and was found buried beneath the structure's walled garden. Artefacts from the excavation will be put on display and added to a city-run public databank, contributing to the wealth of information gathered over the years on life in Rome throughout the centuries. Archaeologists plan to rebury the theatre once excavations wrap up.

Some remains found during the excavations of Nero's theatre

An illustration of *Streptococcus pyogenes*, which can cause necrotising fasciitis, a 'flesh-eating' infection

HEALTH

Man develops two different 'flesh-eating' bacterial infections

WORDS **KILEY PRICE**

A man was recently diagnosed with and treated for a 'flesh-eating' bacterial infection in his right leg, only to have it spread to his left leg four days later. The 58-year-old man arrived at Gregorio Marañón General University Hospital in Madrid with severe swelling in his right leg, chest pain and a fever – all potential signs of necrotising fasciitis, a rare and aggressive bacterial infection that sparks severe inflammation that can cause body tissue to die, or necrotise. To treat the man's infection, doctors administered a course of antibiotics into his veins, removed infected and damaged tissue from the leg and also performed a fasciotomy, which involves cutting connective tissue called fascia to relieve swelling and pressure on the underlying muscle.

Several types of bacteria can cause this 'flesh-eating' infection, and in this case the man caught two: *Streptococcus pyogenes* and *Staphylococcus aureus*. This isn't unheard of; past cases have also involved multiple species of flesh-eaters. But this is only the third documented case of metachronous necrotising fasciitis in which multiple sites of infection appeared at different times, rather than within the same day.

In the hours after his initial treatment, the man's swelling and pain levels subsided. However, four days after the intervention, doctors noticed severe redness and blistering in the patient's left leg and swiftly performed another fasciotomy. Cultures isolated from the tissues confirmed that the same bacteria had slowly spread to the man's opposite side, so his doctors quickly applied antibiotics and removed the dead tissue.

Did you know?

Group A strep can also cause strep throat

Each year since 2010 there have been roughly 700 to 1,150 cases of necrotising fasciitis caused by group A strep bacteria in the US, according to the Centers for Disease Control and Prevention (CDC), which also noted that this is likely an underestimate. "Even with treatment, up to one in five people with necrotising fasciitis [caused by group A strep] died from the infection." In this case, doctors administered early treatment with aggressive and repeated removal of damaged tissue. The patient was discharged from the hospital a month later, with no complications during the follow-up.

HISTORY

UNEARTHED 500-YEAR-OLD GOLD COINS WERE HASTILY HIDDEN DURING A DANGEROUS SITUATION

WORDS **JENNIFER NALEWICKI**

Archaeologists in Germany have uncovered a handful of 500-year-old gold coins buried among the ruins of a medieval monastery. Known as Himmelpforten, the Augustinian Hermit monastery housed monks from its founding in 1253 into the 16th century. The archaeologists think the four coins were hidden by one of the monks in 1525 during an uprising in which farmers stormed the monastery in Wernigerode, a town in central Germany. "The gold coins were of great value, and the small fortune was probably hidden by a monk in an acutely dangerous situation," said Felix Biermann, from the Saxony-Anhalt State Office for Monument Preservation and Archaeology. "It didn't end well, because the coins couldn't be recovered." Classified as guilders, currency used during the Holy Roman Empire, the coins include one that was minted in Frankfurt before 1493, during the reign of the Holy Roman Emperor Frederick III; another coin minted in Schwabach, outside Nuremberg, some time between 1486 and 1495, and two coins produced in Bonn by the Archdiocese of Cologne around 1480.

One of the four gold coins discovered at a monastery in Germany

SPACE

A mystery cosmic object is identified as dead star remains

WORDS **ROBERT LEA**

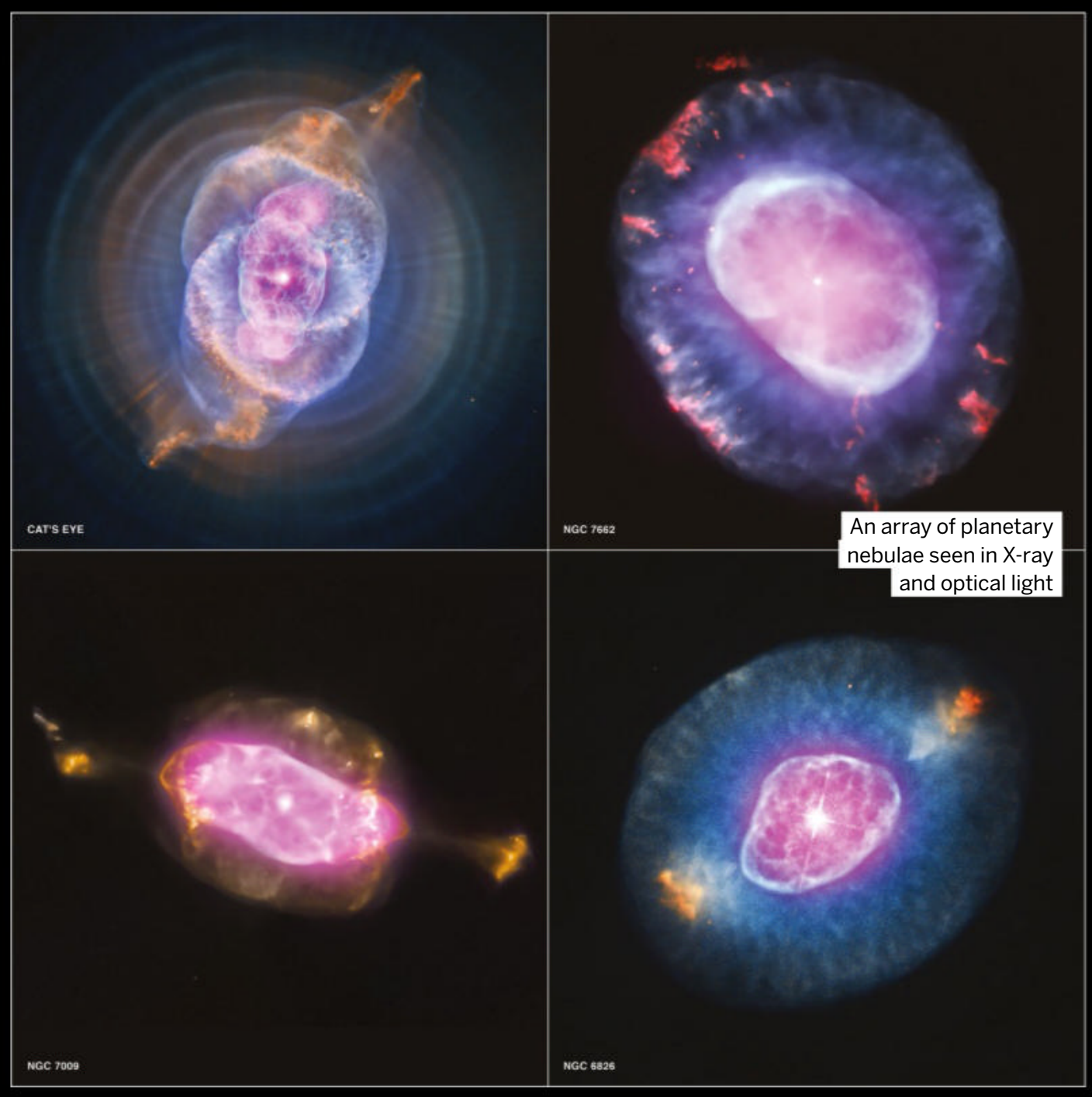
A strange cosmic object that has puzzled astronomers for two decades has been revealed to be the ancient remains of a long-dead star. More specifically, new research conducted with space and ground-based telescopes has shown the object, PM 1-322, is a variable planetary nebula. Originally discovered in 2005, PM 1-322 is located around 6,800 light years from Earth.

As the shells of long-dead stars, planetary nebulae such as PM 1-322 are key in understanding how elements forged by stars during their lives are spread throughout the cosmos after their deaths. Because such material becomes the building blocks for the next generation of stars and planets, planetary nebulae constitute a fossil record of our universe's evolution. But even among the most interesting planetary nebulae, with some resembling beautiful cosmic cat's eyes and butterflies, PM 1-322 stands out. That's because the new research, led by Masaryk University researcher Ernst Paunzen, indicates that PM 1-322's light output changes over long periods of time. Also, something within the object appears to be exhibiting eruption-like events.

Despite the name, planetary nebulae like PM 1-322 have nothing to do with planets. Instead they are expanding shells of gas and dust shed by stars when the stellar bodies have exhausted the hydrogen at their cores. Once that hydrogen is exhausted, the star's internal nuclear fusion process of turning the element into helium ends. This also ends the energy that supports the star from collapsing under its own gravity and triggers the rapid contraction of the core.

But as nuclear fusion still occurs in the star's outer layers, the shell of the star puffs out, turning it into what's known as a red giant. In about 5 billion years our Sun will undergo this transformation, with its outer layers swelling to the size of Mars' orbit. This expanded Sun will consume the inner planets of our Solar System, including Earth. After this transition happens, the outer layers of the star eventually disperse, leaving behind a cooling shell of gas and dust that's illuminated by a central stellar remnant.

Analysing archival data from the Zwicky Transient Facility (ZTF) and NASA's Wide-field Infrared Survey Explorer (WISE), the astronomers also spotted a bright object associated with PM 1-322, which they designated ZTFJ201451.59+120353.4. This could be what remains of the star that created the planetary nebula. The team found that the variability of this object could indicate it's being eclipsed by a companion star. The eclipse-like event was spotted in 2022 and seemed to last around half a year. "Our most likely interpretation is that our target object involves a hot central star surrounded by gaseous and dusty discs, an extended nebula and a possible companion star," the astronomers wrote in their study. "Further observations are required to shed more light on the true nature of this enigmatic object."



An array of planetary nebulae seen in X-ray and optical light

GLOBAL EYE

SPACE

EUROPE'S NEW ARIANE 6 ROCKET LAUNCH SLIPS TO 2024

WORDS **ANDREW JONES**

Europe will be without independent access to space satellites until at least 2024. The European Space Agency (ESA) and the CEO of France-based company Arianespace confirmed on 8 August that the inaugural launch of the new Ariane 6 heavy-lift rocket will slip into 2024. Ariane 6 was initially planned to begin flying in 2020 and ramp up its cadence to replace the older Ariane 5 rocket seamlessly. However, Ariane 6 has suffered a series of delays, caused by technical issues, COVID-19 and design changes, while the Ariane 5 flew its 117th and final mission in early July. Additionally, the failure of the Vega-C rocket in December last year leaves that rocket grounded, meaning Europe currently has no independent access to orbit. The European Commission earlier this year drafted a request for an 'ad-hoc security agreement' to allow some European payloads to fly on SpaceX rockets.

When exactly Ariane 6 will fly for the first time is still unclear. The Ariane 6 Launcher Task Force consists of the top management of the ESA, the French space agency CNES, the launcher system prime contractor ArianeGroup, and launch service provider Arianespace.

An artist's impression of the Ariane 6 rocket in space

Fungi samples were taken from the Dimbulagala dry zone forest reserve in central Sri Lanka

PLANET EARTH

Plastic-eating fungi may help tackle Earth's pollution crisis

WORDS **KILEY PRICE**

In the forest, certain fungi attach to trees and fallen logs to break down and digest the carbon within their wood before releasing it as carbon dioxide. But when their preferred meal isn't available, these wood-decaying fungi can chow down on plastic instead. White-rot fungi can break down lignin, an extremely strong organic polymer that helps give wood its rigidity, by using enzymes, which are proteins that accelerate the chemical reactions that take place within cells. "We were thinking, if these fungi can decay these decay-resistant hardwoods, and lignin particularly, they have some weapons with them to decay some other polymers as well," says Renuka Attanayake, a plant pathology professor at the University of Kelaniya in Sri Lanka.

For their study, the researchers isolated 50 fungal samples from decaying hardwoods found in the Dimbulagala dry zone forest reserve in central Sri Lanka. They then divided the samples into two main experimental conditions: a dish with low-density polyethylene, a type of plastic, and a dish with both the plastic and wood. After 45 days, it was clear that the fungi consistently preferred wood to plastic, but in both experimental set-ups, particularly the dish with just plastic, the fungi broke down the polyethylene. "We think that these organisms are metabolically flexible, I would say, and this may be an evolutionary advantage – [the fungi] had to survive in the environment utilising whatever was available."

Though the scientists don't yet know how the chemical pathways in the fungi change when they eat polyethylene, they do know that the white rot used some oxidising enzymes to break down both the wood and the plastic.

Did you know?

There are over 6 million fungi species in the world

To date, more than 430 species of fungi and bacteria have been found to break down plastic. Scientists believe that identifying and replicating the enzymes these microorganisms secrete to degrade plastic could eventually help remove some of the 400 million tonnes of plastic waste produced each year, which often sits in landfills or overflows into the ocean rather than being recycled.

This new study is a small step towards understanding how fungi could help tackle plastic pollution. First, though, scientists must see how wood-decaying fungi fare in different conditions, such as landfills, and whether they pose a threat to native trees. "Under restricted conditions we may be able to utilise this thing one day, but a lot more research has to be done before that," said Attanayake.

TECHNOLOGY

Google's 'mind-reading' AI knows music preferences based on brain signals

WORDS CARISSA WONG

Scientists used AI to translate people's brain activity into music

By examining a person's brain activity, artificial intelligence (AI) can produce a song that matches the genre, rhythm, mood and instrumentation of music the individual recently heard. Scientists have previously 'reconstructed' other sounds from brain activity, such as human speech, bird song and horse whinnies. However, few studies have attempted to recreate music from brain signals. Now, researchers have built an AI-based pipeline called Brain2Music that harnesses brain imaging data to generate music that resembles short snippets of songs a person was listening to when their brain was scanned.

The scientists used brain scans that had previously been collected via a technique called functional magnetic resonance imaging (fMRI), which tracks the flow of oxygen-rich blood to the brain to see which regions are most active. The scans were collected from five participants as they listened to 15-second music clips spanning a range of genres, including blues, classical, country, disco, hip-hop, jazz and pop.

Using a portion of the brain imaging data and song clips, the researchers first trained an AI program to find links between features of the music, including the instruments used and its genre, rhythm and mood, and participants' brain signals. The music's mood was defined by researchers using labels such as happy, sad, tender, exciting, angry or scary. The AI was customised for each person, drawing links between their unique brain activity patterns and various musical elements.

After being trained on a selection of data, the AI could convert the remaining, previously unseen brain imaging data into a form that represented musical elements of the original song clips. The researchers then fed this information into another AI model previously developed by Google, called MusicLM. MusicLM used the information to generate musical clips that can be listened to online and fairly accurately resembled the original song snippets, although the AI captured some features of the original tunes much better than others.

"The agreement, in terms of the mood of the reconstructed music and the original music, was around 60 per cent," said Timo Denk, a software engineer at Google in Switzerland. The genre and instrumentation in the reconstructed and original music matched significantly more often than would be expected by chance. Out of all the genres, the AI could most accurately distinguish classical music. "The method is pretty robust across the five subjects we evaluated," Denk said. "If you take a new person and train a model for them, it's likely that it will also work well."

Ultimately, the aim of this work is to shed light on how the brain processes music. As expected, the team found that listening to music activated brain regions in the primary auditory cortex, where signals from the ears are interpreted as sounds. Another region of the brain, the lateral prefrontal cortex, seems to be important for processing the meaning of songs, but this needs to be confirmed by further research. This region of the brain is also known to be involved in planning and problem-solving. Future studies could explore how the brain processes music of different genres or moods. The team also hopes to explore whether AI could reconstruct music that people are only imagining in their heads, rather than actually listening to.

A great white shark in the waters outside Guadalupe Island, Mexico

ANIMALS

Cape Cod is a huge hotspot for great white sharks

WORDS **KILEY PRICE**

Cape Cod in Massachusetts is home to one of the world's biggest hotspots of great white sharks. Between 2015 and 2018, an estimated 800 great white sharks visited the area. This is the first estimate of abundance for great white sharks (*Carcharodon carcharias*) in the western North Atlantic Ocean. The finding "suggests that Cape Cod is among the larger aggregation sites worldwide," the authors of a new shark study wrote. But why are these apex predators gathering off Cape Cod's coasts? Because that's where their favourite meal resides. "Over the course of the past ten years, great white sharks have come back to Cape Cod to feed on the recovering seal population," said Megan Winton, a marine researcher and member of the Atlantic White Shark Conservancy.

Humans hunted both grey and harbour seals to the brink of extinction in the 1960s, but their populations have dramatically increased since 1972, when the US Marine Mammal Protection Act was passed, which makes it illegal to catch or kill marine mammals without a permit. Now there are roughly 30,000 to 50,000 grey and harbour seals in southeastern Massachusetts, according to a 2016 estimate. As a result, the number of great white sharks in this area has also been steadily rising. To track their numbers, the researchers identified individual sharks by analysing tagging data and recording their unique coloration patterns using underwater GoPro cameras. After more than 130 research trips over three years, they identified 393 individual great white sharks from 2015 to 2018. However, the researchers also wanted to account for the sharks' migratory behaviour, so they developed a model to calculate how many sharks were moving in and out of the area. After the research, they estimated that roughly 800 sharks aggregated in this region over the three-year period.

In the 1980s, great white shark populations in the Atlantic Ocean were just 27 per cent of what they were in 1961. But they have made a widespread comeback along the western North Atlantic coast in recent years, and this new study confirms that trend in Cape Cod.

Did you know?

The largest great white shark on record was over six metres long

"What I find most amazing is the speed at which the population recovered," Chris Lowe, director of the Shark Lab at California State University, Long Beach, said. Most of the great white sharks visited Cape Cod during late summer and early autumn, when ocean temperatures there are at their highest, before migrating out of the area in early winter.

"Their movements are very dynamic – they trickle in and out," said Greg Skomal, a recreational fisheries program manager at the Massachusetts Division of Marine Fisheries. "Some great white sharks simply stop by on their way north, while others spend more time along the Cape, likely because they have success feeding on seals."

Though Cape Cod is a hotspot for great white sharks, there has not been a reported attack on humans since 2018, and the risk posed to recreational swimmers remains low. "They are very cautious predators," said Winton, "But the increased presence and number of great white sharks off the Cape really drives home the need for ongoing research."

Yellowstone's Steamboat Geyser is the tallest active geyser in the world

PLANET EARTH

Yellowstone's geysers are at risk of extinction from climate change

WORDS **SASCHA PARE**

Yellowstone's geysers could fall victim to climate change and stop erupting as drought takes hold over the region. As temperatures soar and rainfall declines, the groundwater reserves beneath the national park could become insufficient to feed geysers. "Groundwater is fuel for geysers," says Michael Poland, a research geophysicist at the Yellowstone Volcano Observatory. "Without water, there's nothing for the geysers to erupt."

Unlike Yellowstone's Old Faithful, which currently blasts 20 times a day, Steamboat Geyser doesn't erupt on a predictable schedule, experiencing dry spells that can last between three days and 50 years. To determine what causes these dry spells, researchers searched for clues in the trees that grow around the geyser vent. When Steamboat erupts frequently, its spray coats the surrounding greenery in a thin layer of silica, a mineral found in the volcanic rocks that form geysers. The silica showers choke trees that grow within 30 metres of the vent, providing a reliable record of Steamboat's past activity. "Water erupting from the geyser is silica-rich, and when silica precipitates it clogs pathways that allow the trees to respire, photosynthesise and grow," said Shaul Hurwitz, a research hydrologist with the US Geological Survey.

The spray kills nearby trees and creates a protective barrier against bacteria and fungi that would otherwise decompose the wood. Trees at Yellowstone don't tend to survive beyond 300 years, Hurwitz added, but the geyser's blasts can preserve their wooden structures for centuries. The dead wooden structures that grew near the vent therefore embody time intervals when Steamboat did not erupt. When eruptions resumed, the silica-rich spray smothered and killed the trees. The researchers radiocarbon-dated tree skeletons that were within 14 metres of the vent and detected three periods of growth – in the late-15th century, mid-17th century and late-18th century. They then matched these periods with regional climate records and found that Steamboat's dry spells coincided with periods of drought.

"Even small changes in precipitation could affect the interval between eruptions," Hurwitz said. "More water means more frequent eruptions, while less water means less frequent eruptions." Changing weather patterns and temperature extremes linked to climate change could exacerbate these effects, Hurwitz said. "We might expect to see the geysers go to totally different behaviour in terms of the interval between their eruptions, erupting less frequently, and some of them might even go extinct," he said. But like Old Faithful, geysers that switch off when times are tough can spring back to life, Poland said. "Geysers are incredibly dynamic systems and change all the time, so there's always a chance that a geyser will die off or a new geyser will form as the hydrothermal plumbing system in the shallow subsurface evolves."

SPACE

CHINA TESTS THE WORLD'S LARGEST SOLAR TELESCOPE ARRAY

WORDS **ANDREW JONES**

The world's largest array of Sun-monitoring radio telescopes has begun trial operations in southwest China. The Daocheng Solar Radio Telescope (DSRT) consists of 313 dishes, each with a diameter of six metres, forming a circle with a circumference of 1.95 miles. A 100-metre calibration tower stands in the centre of the ring. The array has undergone half a year of debugging and testing, demonstrating the capability to consistently and reliably monitor solar activity with high precision. Trial operations officially started on 14 July.

Scientists simulate the effect of a much larger telescope and gain much higher resolution and sensitivity by collecting electromagnetic radiation from the Sun with the multitude of dishes. The signals are combined, then sophisticated mathematical algorithms are used to reconstruct images. DSRT's main task is continuous monitoring of the Sun and observing solar flares and coronal mass ejections (CMEs). It will also aid research into monitoring and early warning methods for pulsars, fast radio bursts and asteroids.

An aerial view of the construction site of the Solar Radio Telescope in Daocheng County, Sichuan Province, China

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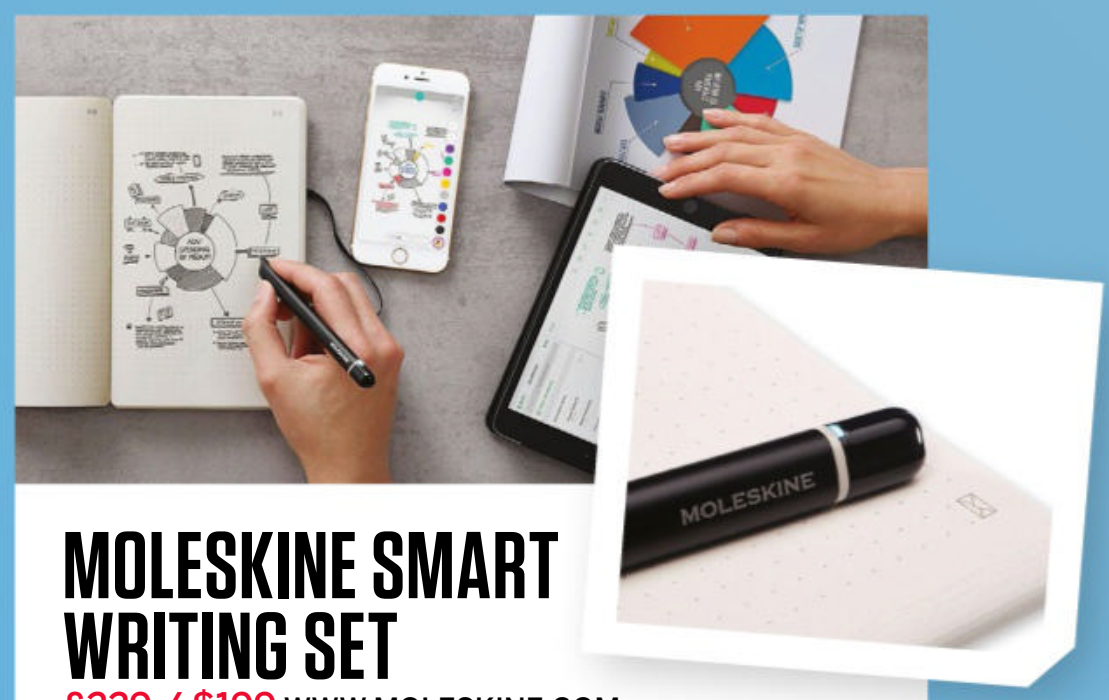

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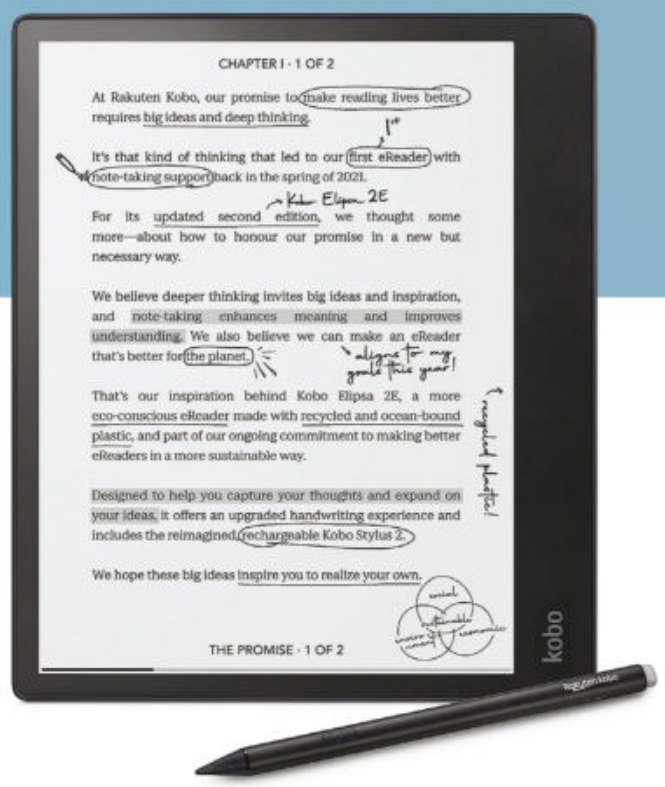

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SPECIAL

SOLAR MAXIMUM

WORDS ANDREW MAY

DID YOU KNOW? Although they look small against the Sun's surface, most sunspots are around the size of Earth

The Sun's 11-year cycle and its upcoming peak have been making headlines recently. Here's how it could affect us on Earth

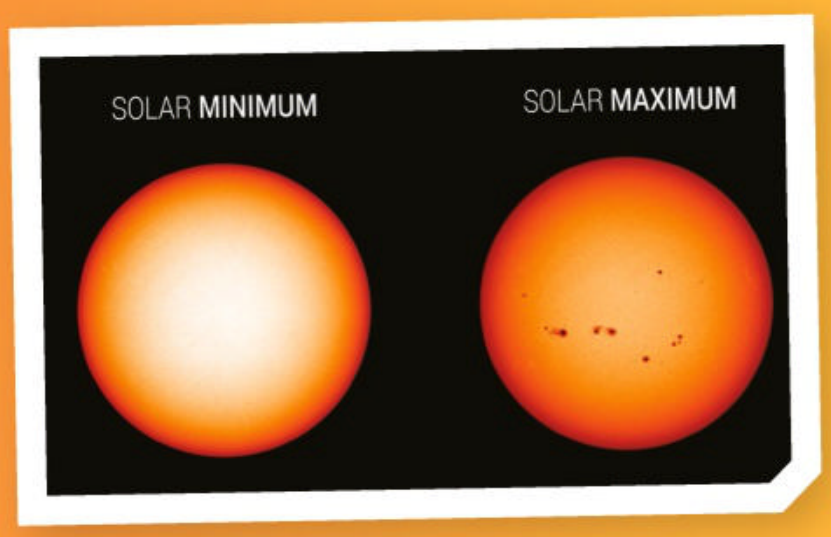
SUN

We couldn't live without the Sun. It's our main source of heat and light, and luckily for us, it produces both of these at a virtually constant rate, day after day, year after year. The small fluctuations in the Sun's brightness, for as long as people have been measuring them, have never been more than one part in a thousand. In less obvious ways, however, the Sun's behaviour is anything but constant, swinging between two extremes on a roughly 11-year cycle. For the most part this variability can only be observed with telescopes and other scientific instruments, but occasionally it can have more dramatic consequences. It was one such consequence that tabloid newspapers were referring to when they blazed headlines about a potential 'internet apocalypse' in June 2023.

The first hint that there might be more to the Sun than a constant source of heat and light came with the discovery of sunspots – black spots on the surface of the Sun. No one knows for sure who first observed these, but their existence seems to have been known long before the invention of the telescope. Sunspots can't have been easy to observe in those days, due both to a lack of magnification and the fact that it's extremely dangerous to look directly at the Sun. It's likely that ancient astronomers only did this when the Sun was very low on the horizon, or covered by haze. But even under these conditions, don't try it yourself, as it's not worth the risk to your eyes. A small telescope will give a much clearer view of our star, as long as it's used with a proper solar filter or by projecting the Sun's image onto a white card to protect your eyes.

The advent of telescopes early in the 17th century gave astronomers their first chance to study sunspots in detail, and it soon became clear that some years see far more of

A drawing of sunspots made by Galileo in 1613, using an early telescope



MINIMUM VERSUS MAXIMUM

By convention, a solar cycle starts at solar minimum, when the number of sunspots is at its lowest, and ends at the next solar minimum, around 11 years later, when the Sun once again looks relatively spot-free. Despite appearances, however, the Sun isn't exactly the same as it was, because its north and south magnetic poles swap places in the course of a cycle. It will actually be two complete cycles – or around 22 years – before everything is back exactly as it was. The most interesting period for professional and amateur astronomers alike occurs around halfway between two solar minima, when the sunspot count reaches its peak value. This is solar maximum.

them than others. The basic 11-year cycle was fully established by the middle of the 19th century. Around the same time, as people learned more about the physics of the Sun, they began to realise that sunspots were simply the most visible consequence of the solar cycle, and that a lot more was going on beneath the surface. The situation was clarified further still after the true nature of sunspots was worked out by American astronomer George Ellery Hale in the early years of the 20th century.

Ultimately, it all comes down to the Sun's magnetic field. Hale discovered that sunspots are the imprints on the photosphere – the Sun's visible surface – of huge magnetic tubes looping in and out of the Sun's interior. Sunspots actually occur in pairs – one being a north magnetic pole, while its neighbour is a south pole. The solar cycle is essentially an oscillation in the strength and orientation of the Sun's magnetic field, and as it progresses, so the number of sunspots first grows and then declines.

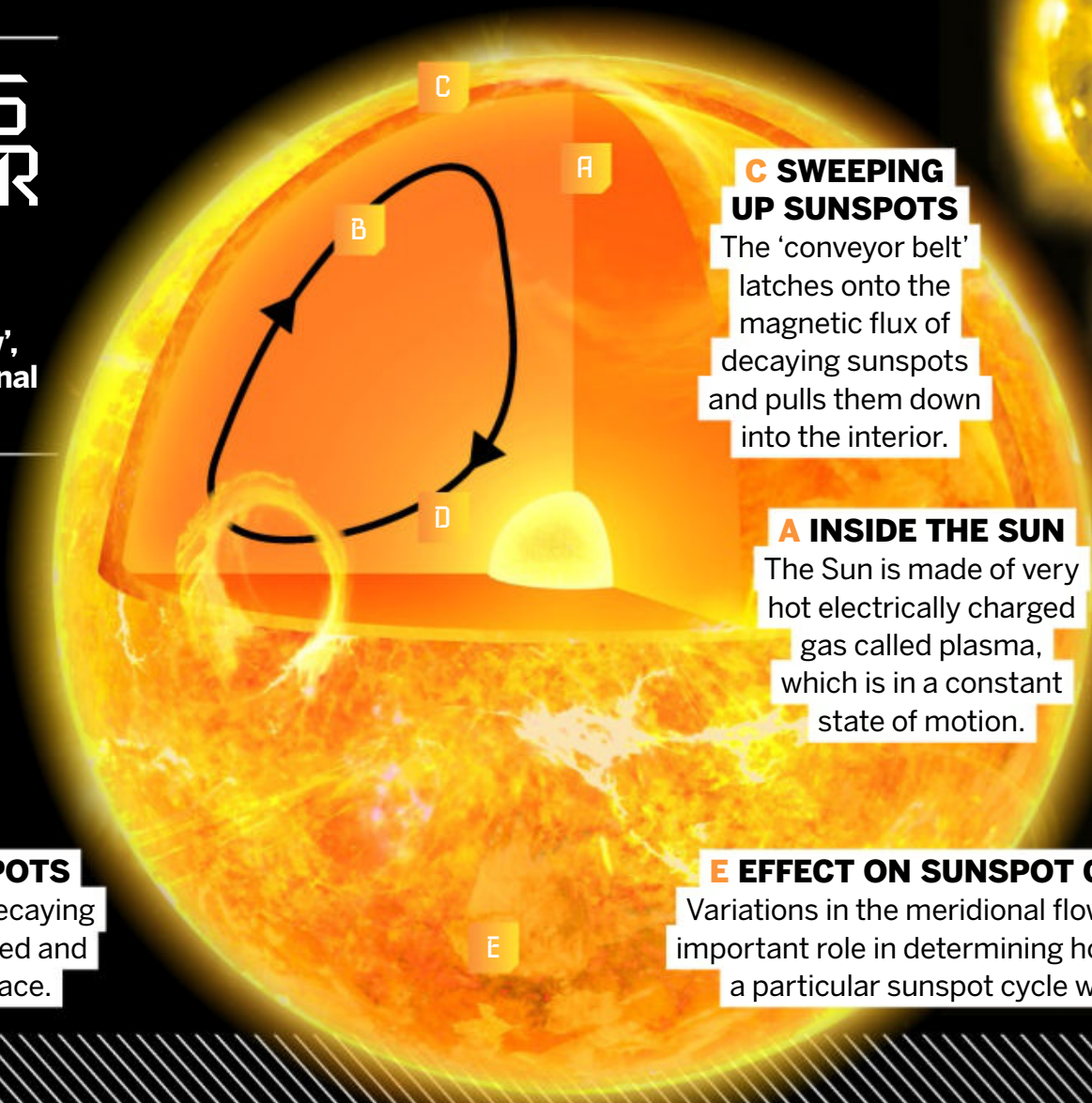
Did you know?

Solar cycle 24 was unusual in lasting exactly 11 years

Unlike many things in astronomy – eclipses, for example – the timing of the solar cycle is difficult to predict with any precision. That '11-year' figure is just a rough average, and solar cycles can actually be anything from 8 to 14 years in duration, as well as varying considerably in intensity. This latter fact is important to us because the peak of the cycle, called solar maximum, can occasionally have dramatic effects here on Earth. This happens

THE SUN'S CONVEYOR BELT

Technically called the 'meridional plasma flow', the Sun has a giant internal transport system



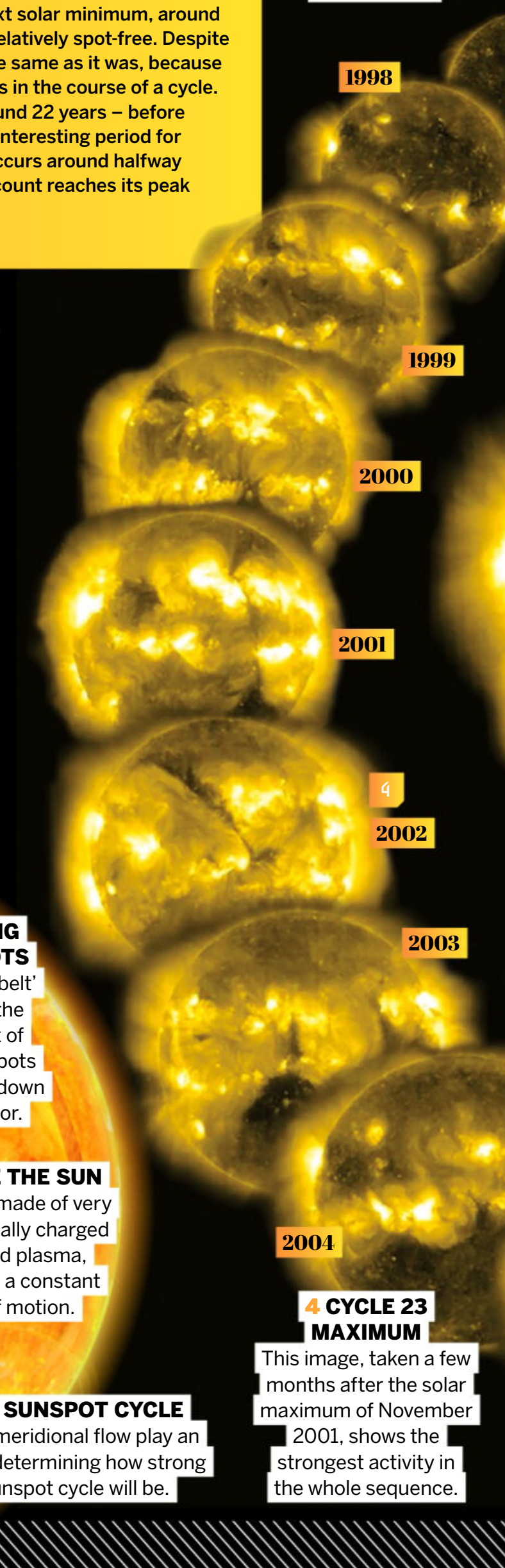
B THE 'GREAT CONVEYOR BELT'
The meridional plasma flow travels along the surface to the poles, then sinks and returns to the equator.

C SWEEPING UP SUNSPOTS
The 'conveyor belt' latches onto the magnetic flux of decaying sunspots and pulls them down into the interior.

A INSIDE THE SUN
The Sun is made of very hot electrically charged gas called plasma, which is in a constant state of motion.

D RECYCLING SUNSPOTS
Deep inside the Sun, the decaying sunspots can be reanimated and bob back up to the surface.

E EFFECT ON SUNSPOT CYCLE
Variations in the meridional flow play an important role in determining how strong a particular sunspot cycle will be.



3 CYCLE 23 START
This was taken a few months before the start of cycle 23 in August 1996.

4 CYCLE 23 MAXIMUM
This image, taken a few months after the solar maximum of November 2001, shows the strongest activity in the whole sequence.

DID YOU KNOW? The formula for total sunspots dates from 1848 and isn't as simple as just counting visible sunspots

THE LAST TWO SOLAR CYCLES

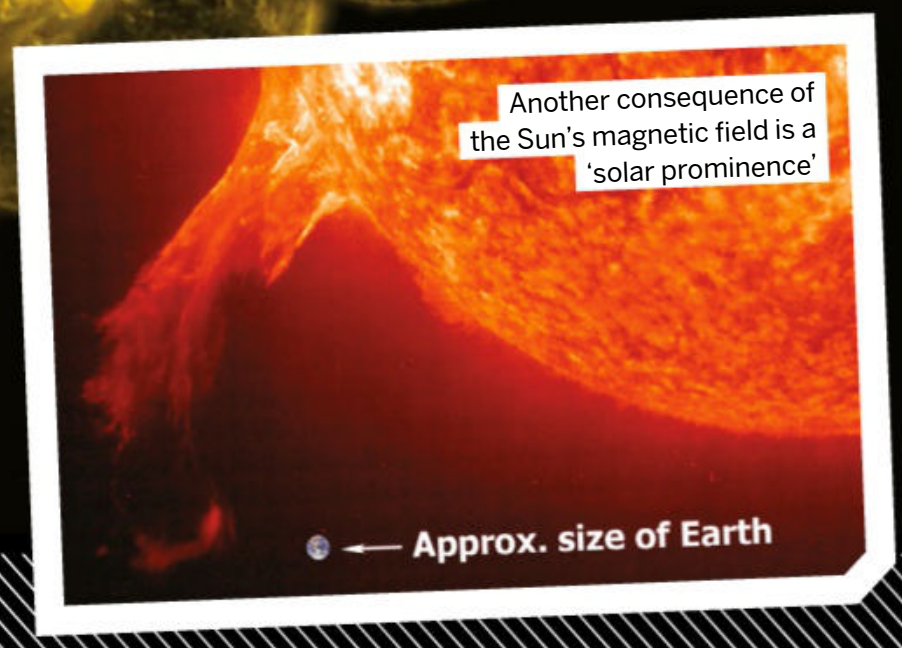
22 years of space-based observations cover solar cycles 23 and 24 in their entirety

6 CYCLE 24 MAXIMUM
Considered a disappointment by many astronomers, the 2014 solar maximum was noticeably weaker than its predecessor.

1 SOHO IMAGES
All of these images were obtained by the European Space Agency's Solar and Heliospheric Observatory (SOHO), launched in 1995.

2 UV DATA
Images taken by SOHO's extreme ultraviolet telescope show activity in the Sun's corona far more clearly than visible light.

5 CYCLE 24 START
This image, which once again shows minimal activity, comes soon after the start of a new cycle in December 2008.



SOLAR ACTIVITY AND EARTH

Intense activity on the Sun can create geomagnetic storms on Earth. Here's how it happens

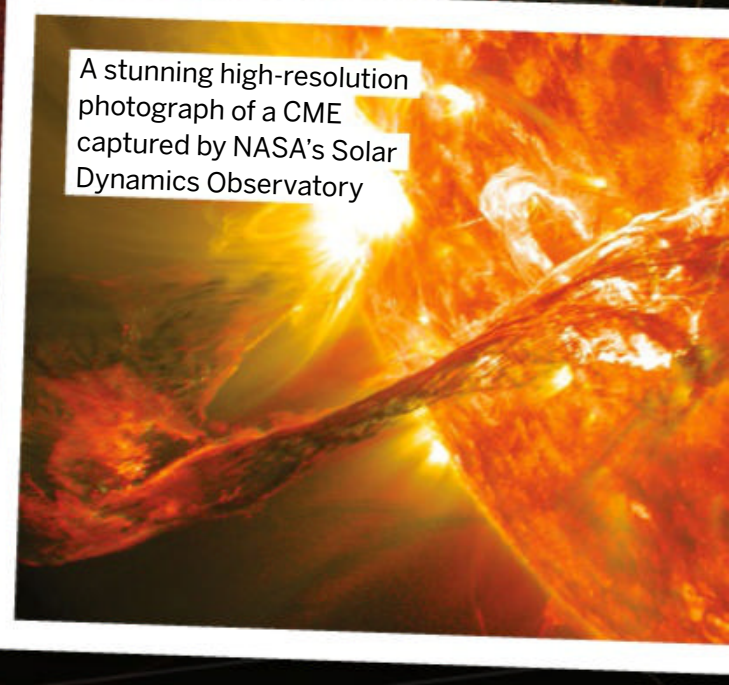
1 SUN'S MAGNETIC FIELD
Most solar activity is driven by changes in this field, which is strongest around solar maximum.

2 SUNSPOTS
These occur in pairs, where the magnetic flux loops up out of the Sun's surface.

3 PROMINENCE
This is a loop of plasma projecting out of the Sun's surface. Like a sunspot, it has a magnetic origin.

4 SOLAR FLARE
Shorter lived than sunspots or prominences, this burst of intense radiation is caused by the sudden release of magnetic energy.

5 CORONAL MASS EJECTION
CMEs are bubbles of magnetised plasma that are blasted out into space from the Sun's outer layer, or corona.



A stunning high-resolution photograph of a CME captured by NASA's Solar Dynamics Observatory

because extremes of magnetic activity on the Sun can blast out high-energy material from its outermost layer, called the corona. If one of these coronal mass ejections (CMEs) then manages to reach our planet, it can trigger a major geomagnetic storm capable of disrupting all kinds of electrical equipment.

In the time that humans have been using electrical technology, the most intense storm of this kind occurred in September 1859, a few months before a solar maximum. Known as the Carrington event, it's named after amateur astronomer Richard Carrington, who not only observed the massive solar flare that almost certainly produced the offending CME, but also made the connection between it and the technological chaos that followed. Telegraph systems, the precursors of today's telephone and data networks, failed all over the world, with some telegraph machines even starting fires or giving their operators electric shocks.

Did you know?

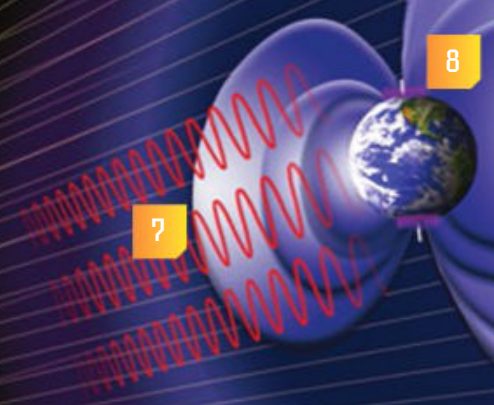
The Daniel K. Inouye Solar Telescope is the biggest of its kind

Today we are far more reliant on communication networks than people were in the 1850s, so the potential for serious disruption is proportionately greater. As a result, organisations like the UK Meteorological Office constantly monitor 'space weather' phenomena that have the potential to impact us on Earth, in the same way that they monitor ordinary weather. As well as CMEs, phenomena to watch out for include solar flares, which are powerful bursts of electromagnetic radiation, and solar radiation storms, involving streams of fast-moving, high-energy particles in the form of protons and electrons. All these phenomena tend to hit a peak around solar maximum, and they could all cause serious damage to our communications infrastructure if they were powerful enough.

DID YOU KNOW? A relatively minor geomagnetic storm destroyed 40 brand-new SpaceX satellites in February 2022

7 EARTH'S MAGNETIC FIELD
This creates a 'magnetosphere' around our planet which protects us from most of the particles emitted by the Sun.

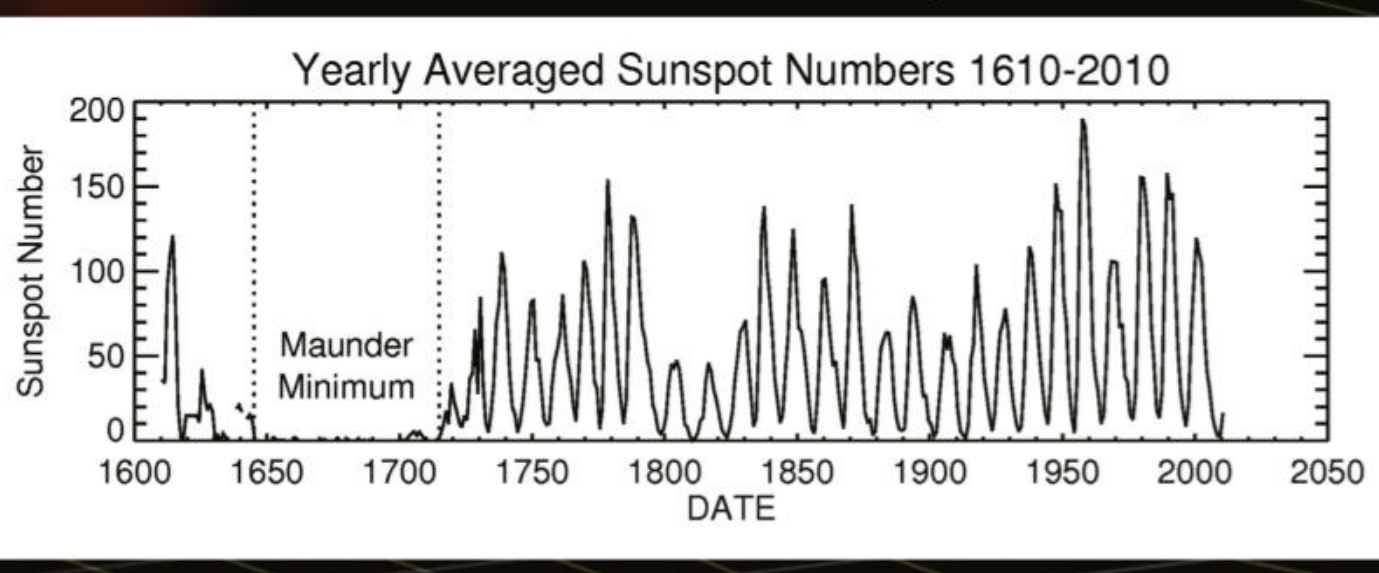
8 EFFECTS ON EARTH
When CMEs or high-speed particles arrive at Earth they can batter the magnetosphere, resulting in a geomagnetic storm.



6 SOLAR ENERGETIC PARTICLES
High-energy charged particles streaming out from the Sun into space. These are usually associated with CMEs and solar flares.

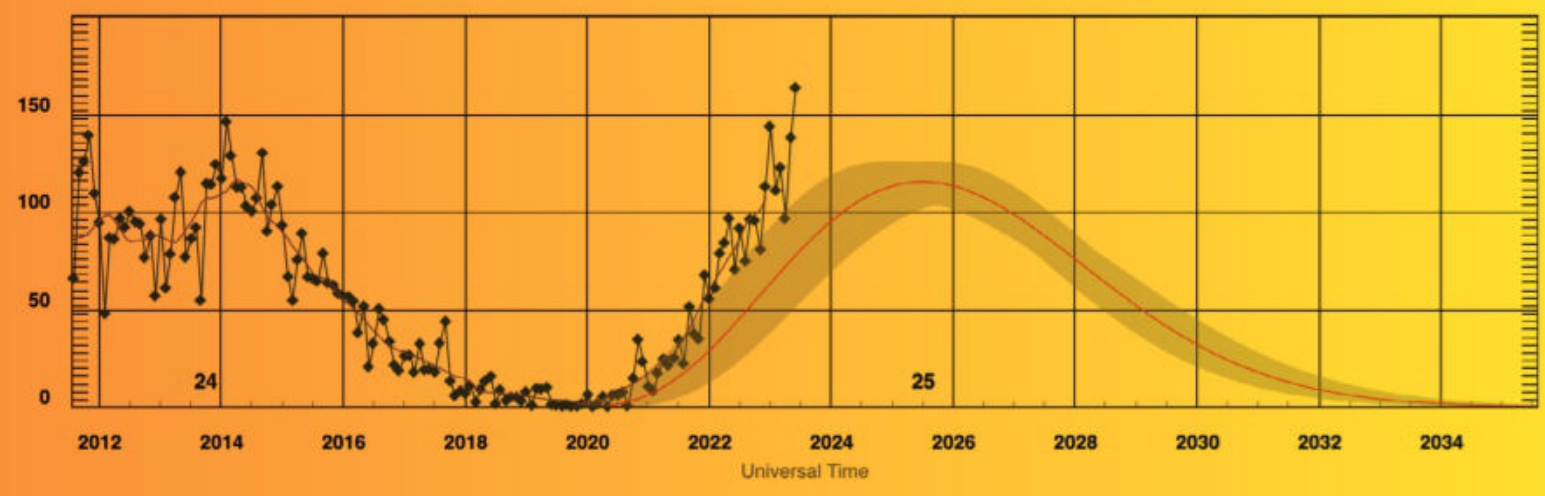
6

The Maunder minimum saw a dramatic reduction in the number of sunspots



WHEN IS THE NEXT SOLAR MAXIMUM?

If the current solar cycle played out exactly like the previous one, we would expect the next solar maximum to occur around April 2025, with a peak sunspot number of around 116. But it's been clear for some time that the Sun is a lot more active this time around, with the sunspot number increasing faster than expected ever since the last solar minimum at the end of 2019. It now looks as though the next maximum may occur as early as May 2024, with a peak sunspot number of around 195. It's not just sunspots that are on the increase, either – geomagnetic storms are too. 2022 saw 55 of them, compared to just 32 at the same point in the previous cycle.



5 FACTS EXTREME SOLAR STORM EFFECTS

1 RADIO BLACKOUT
Solar flares produce bursts of high-energy electromagnetic radiation that can disrupt Earth's upper atmosphere and interfere with radio communications – including those used by emergency services.

2 HIGH-ALTITUDE RADIATION
A different kind of solar radiation, in the form of fast-moving charged particles, can be hazardous for astronauts in Earth orbit, and sometimes even for people in high-flying aircraft.

3 POWER OUTAGES
When a CME hits the magnetosphere, it can batter it so much that rogue currents are induced in ground-level electrical systems, resulting, for example, in disruption of the power grid.

4 LOSS OF GPS
Intense solar activity can give rise to an upper-atmospheric phenomenon called scintillation, which has the potential to disrupt the high-precision satellite signals used by GPS navigation systems.

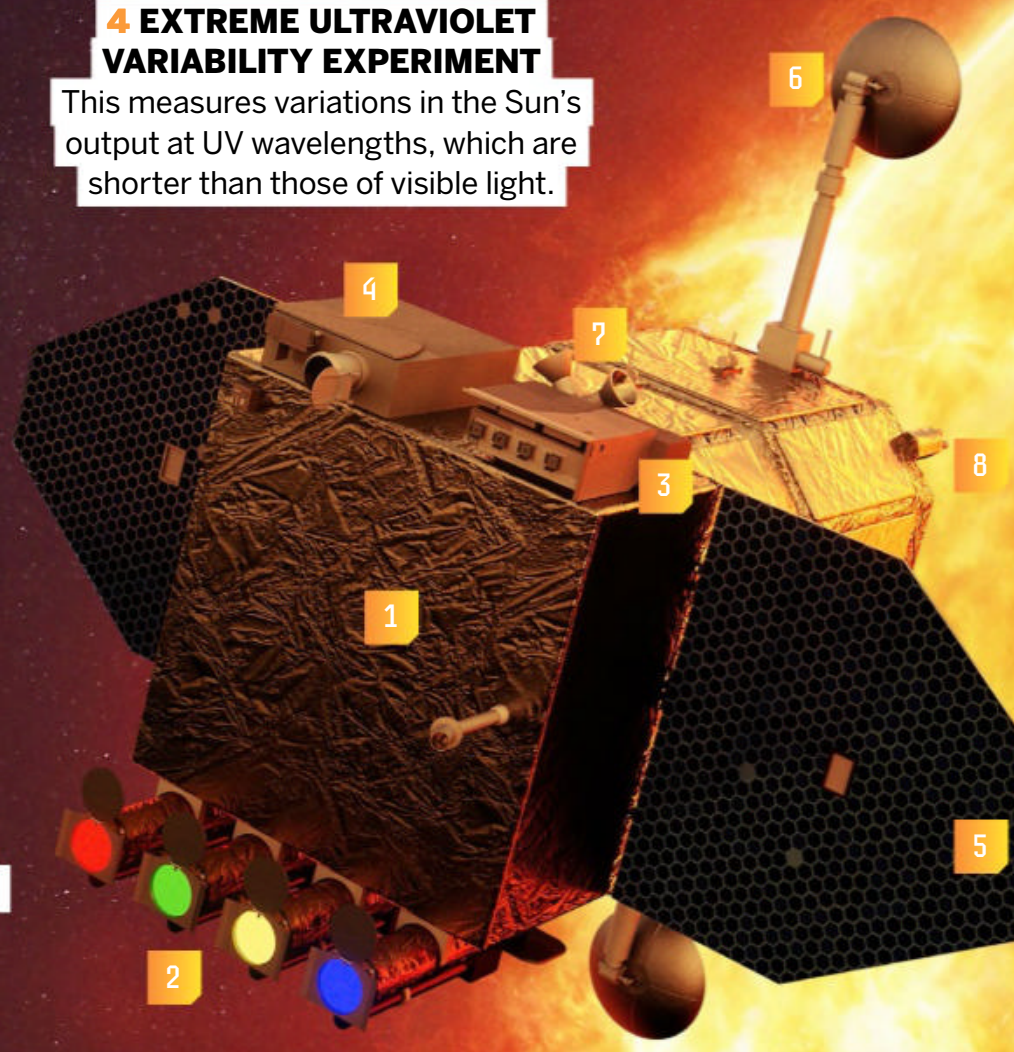
5 SATELLITE DAMAGE
High-energy electrons emitted by the Sun can cause physical damage to a spacecraft's sensors and electronic systems, as well as its solar panels, thus degrading its effectiveness.

SPECIAL

NASA's Solar Dynamics Observatory seen prior to launch in 2010

SOLAR DYNAMICS OBSERVATORY

Launched in 2010, NASA's SDO captures high-resolution images of the Sun's ever-changing appearance



1 THE SPACECRAFT
4.5 metres in length and 1,560 kilograms, SDO is situated in a geosynchronous orbit around Earth.

2 ATMOSPHERIC IMAGING ASSEMBLY
This records high-definition pictures of the Sun in ten different wavelengths every ten seconds.

3 HELIOSEISMIC AND MAGNETIC IMAGER
This instrument is designed to track electric currents and magnetic activity in the corona.

4 EXTREME ULTRAVIOLET VARIABILITY EXPERIMENT
This measures variations in the Sun's output at UV wavelengths, which are shorter than those of visible light.

5 SOLAR ARRAYS
Specially shaped to avoid blocking the antennae, these produce 1,450 watts of electrical power.

6 HIGH-GAIN ANTENNAE
This pair of radio antennae can transmit 18 megabytes of data back to Earth every second.

7 STAR TRACKERS
By identifying star patterns, these ensure the satellite is always pointing in exactly the right direction.

8 THRUSTERS
These make small adjustments to the spacecraft's orbit to ensure it can keep working year after year.

OBSERVING THE SUN

Any telescope can be used to view the Sun, as long as it's fitted with a suitable filter. Today professional astronomers almost always use purpose-built solar telescopes. One of the first of these was the Einstein Tower in Potsdam, Germany – pictured below – so called because it was originally built around a century ago to test some of Einstein's theories. As with most astronomical instruments, the best place for a solar telescope is in space, above Earth's atmosphere. We've already mentioned one of the most important Sun-observing spacecraft, the European Space Agency's SOHO, which was launched in 1995 and is still operational today. But even more powerful in terms of the quality of its images and the rate at which it can take them is NASA's Solar Dynamics Observatory.

This brings us back to those warnings of an 'internet apocalypse'. To some extent these can be traced back to a 2021 study that looked at the possibility of a solar storm powerful enough to cause widespread disruption occurring in the next decade. The study concluded that the likelihood of this happening was somewhere between 1.6 and 12 per cent. Such an event could cause trillions of pounds worth of damage and leave many people without an internet connection – or possibly even without electrical power – for a long time. Even so, the risk of it happening is really quite low, and there's no obvious reason why those tabloid headlines suddenly appeared in the middle of 2023. Contrary to some reports, they weren't triggered by any specific 'NASA warning' at the time.

That being said, it's true that we are rapidly approaching the next solar maximum, so we may well see an increase in dramatic solar phenomena and 'space weather' events over the coming months. We're currently in solar cycle 25 – that number signifying the 25th cycle since methodical records began in 1755 – and its peak wasn't originally expected until 2025.

However, the sunspot count has been going up so rapidly that it now seems likely the maximum will occur around a year earlier, some time in 2024. The original expectation was that, similar to its predecessor during cycle 24, this solar maximum wouldn't be a spectacular one, peaking at around 125 sunspots per month. But that number had easily been surpassed by June 2023, which saw over 160 sunspots – the highest figure since shortly after the peak of solar cycle 23 in 2002. This suggests that we could be seeing almost 200 sunspots per month by the time we reach solar maximum.

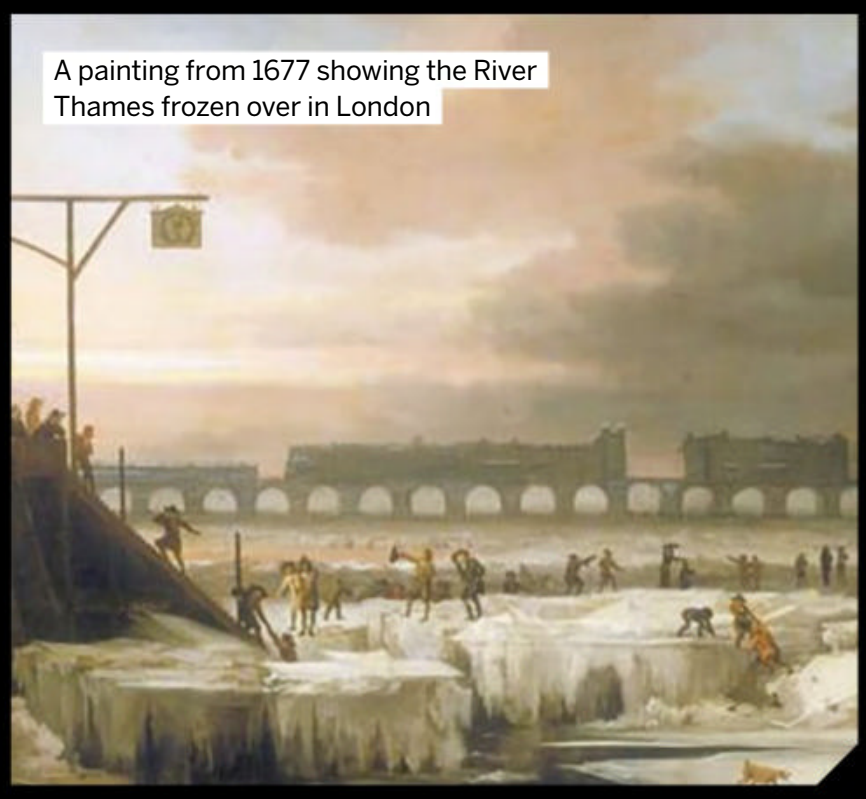
Did you know?

NASA has 26 operational Sun-observing spacecraft

DID YOU KNOW? Coronal rain occurs when plasma in the solar corona cools, condenses and falls back to the Sun's surface

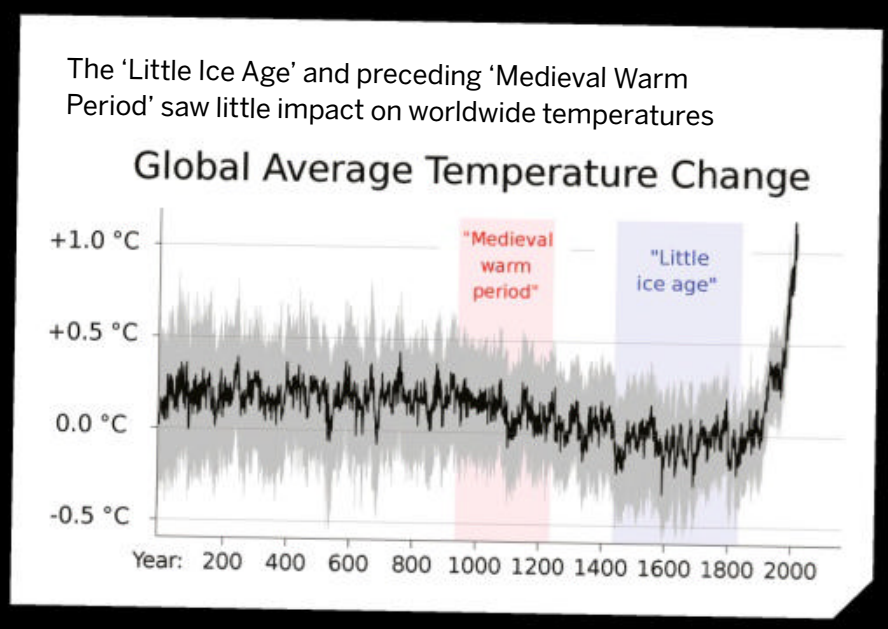
THE LITTLE ICE AGE

A few centuries ago, it wasn't uncommon for the River Thames to freeze over in central London, while similarly cold weather was experienced in other parts of Europe. This period has been dubbed 'the Little Ice Age', although that's something of an exaggeration, as the last real ice age saw global temperatures drop by around six degrees Celsius, compared to a cooling of less than one degree during the Little Ice Age. That's a much smaller change than the one we're seeing now, in the opposite direction, due to greenhouse gas emissions. Even so, it's interesting to ask why the Little Ice Age occurred at all. Some scientists think the solar cycle may have had something to do with it. The peak of the Little Ice Age, from around 1650 to 1715, coincided with an extended period of unusually low solar activity. Lasting through several 11-year solar cycles, this period is referred to as the Maunder minimum after astronomers Edward and Annie Maunder, who retrospectively studied it in the 1890s. More recently, climate modelling by NASA has indicated that this reduction in solar activity may have been a contributory factor in creating the Little Ice Age.



A painting from 1677 showing the River Thames frozen over in London

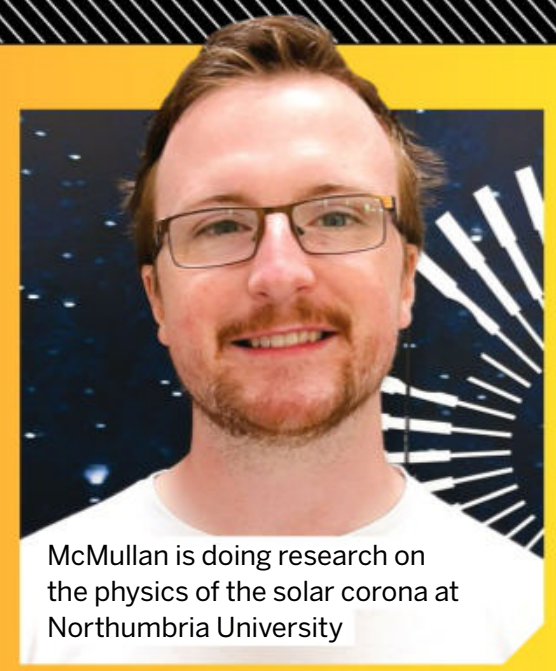
"We may well see an increase in dramatic solar phenomena"



The 'Little Ice Age' and preceding 'Medieval Warm Period' saw little impact on worldwide temperatures

USING AI TO EXPLORE SOLAR PHYSICS

Astronomer Luke McMullan explains how deepfake images can help understand a phenomenon called 'coronal rain'

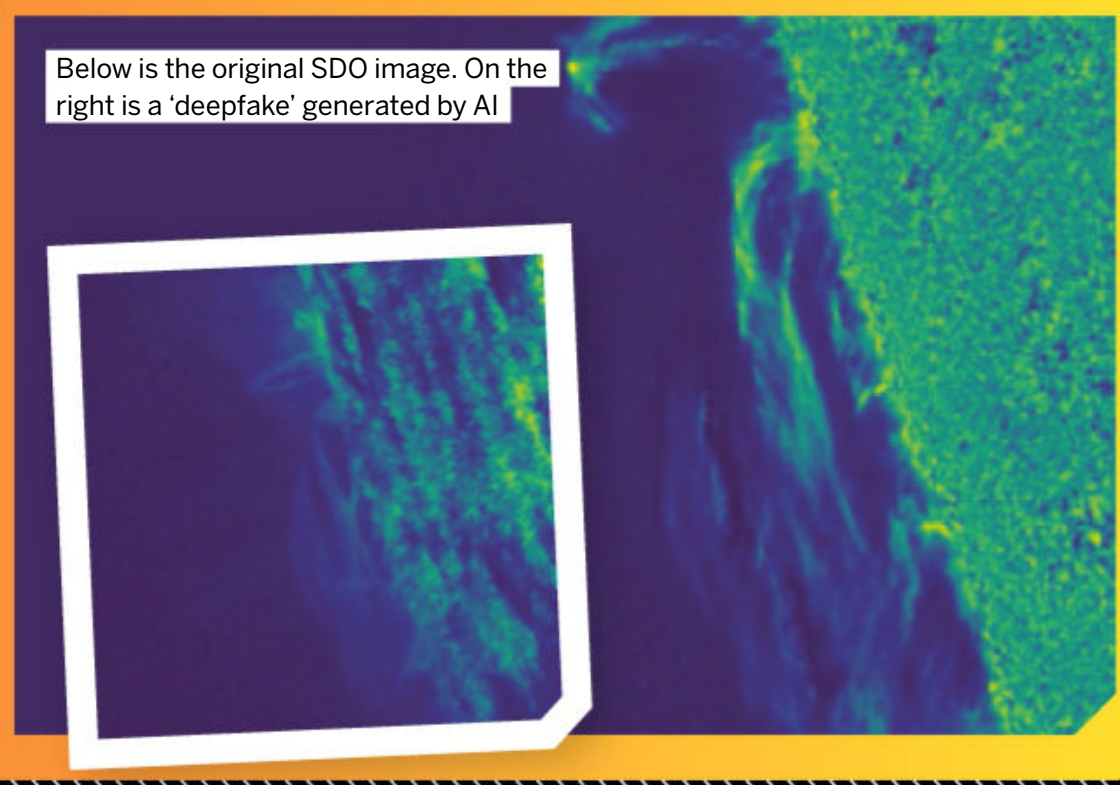


McMullan is doing research on the physics of the solar corona at Northumbria University

Can you tell us about the work you've been doing with SDO data?
SDO is a fantastic instrument which allows incredible images of some of the most important structures of the solar corona, specifically for my research on coronal rain. However, the rain observed is obscured by hotter components in the corona. My current research uses machine learning to overcome this by training an algorithm to resolve the rain we see by showing it resolved rain images by other instruments, and essentially make 'deepfaked' images that have the resolving ability of the other instruments with the rain-capturing ability of SDO.

Deepfake images are often presented as a bad thing. Are you saying they have positive uses too?
Exactly. The ability to make a realistic fake image given a large enough example dataset is an incredibly powerful tool. Like all tools it's up to the wielder to determine their intentions with it, but we as scientists are finding more and more incredibly useful and beneficial uses of this tool.

What has your work with AI taught us about the Sun, and what are you hoping it might achieve in future?
So far my work has mostly been setting the groundwork for answering my overall science question: what mechanism is responsible for the heating of the corona? For this I need to quantify the amount of coronal rain that's produced in the solar atmosphere. This is necessary as this rain can only be produced under specific heating conditions. In order to quantify the amount of rain, we need a complete image of the Sun with all the rain well resolved. Using AI, I have successfully produced images that capture most of the coronal rain and can resolve them enough that individual clumps can be seen. With these 'faked' images, my plan is to then design a second AI algorithm to learn what coronal rain looks like and be able to quantify the amount seen on the Sun at any time.

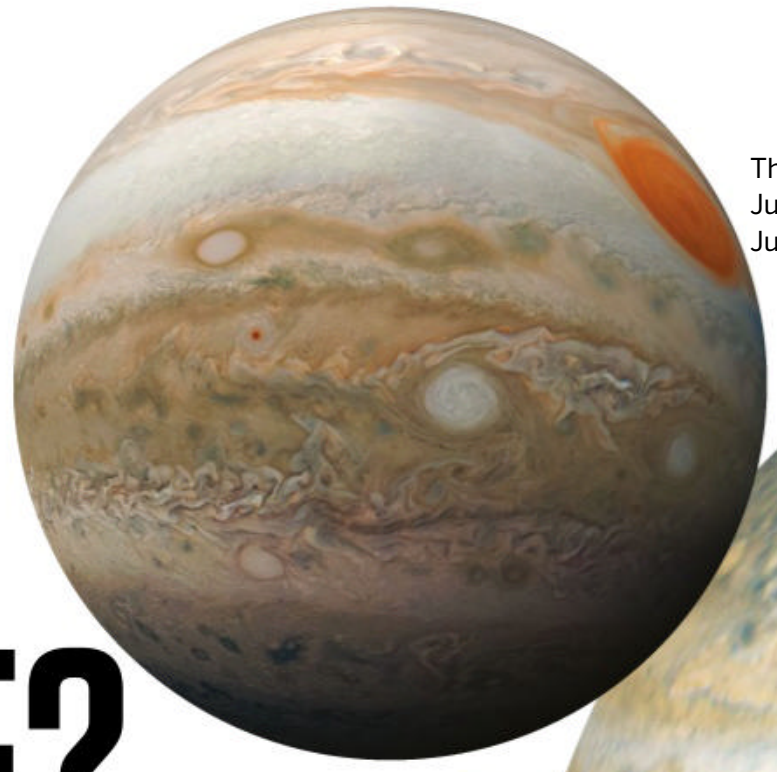


Below is the original SDO image. On the right is a 'deepfake' generated by AI

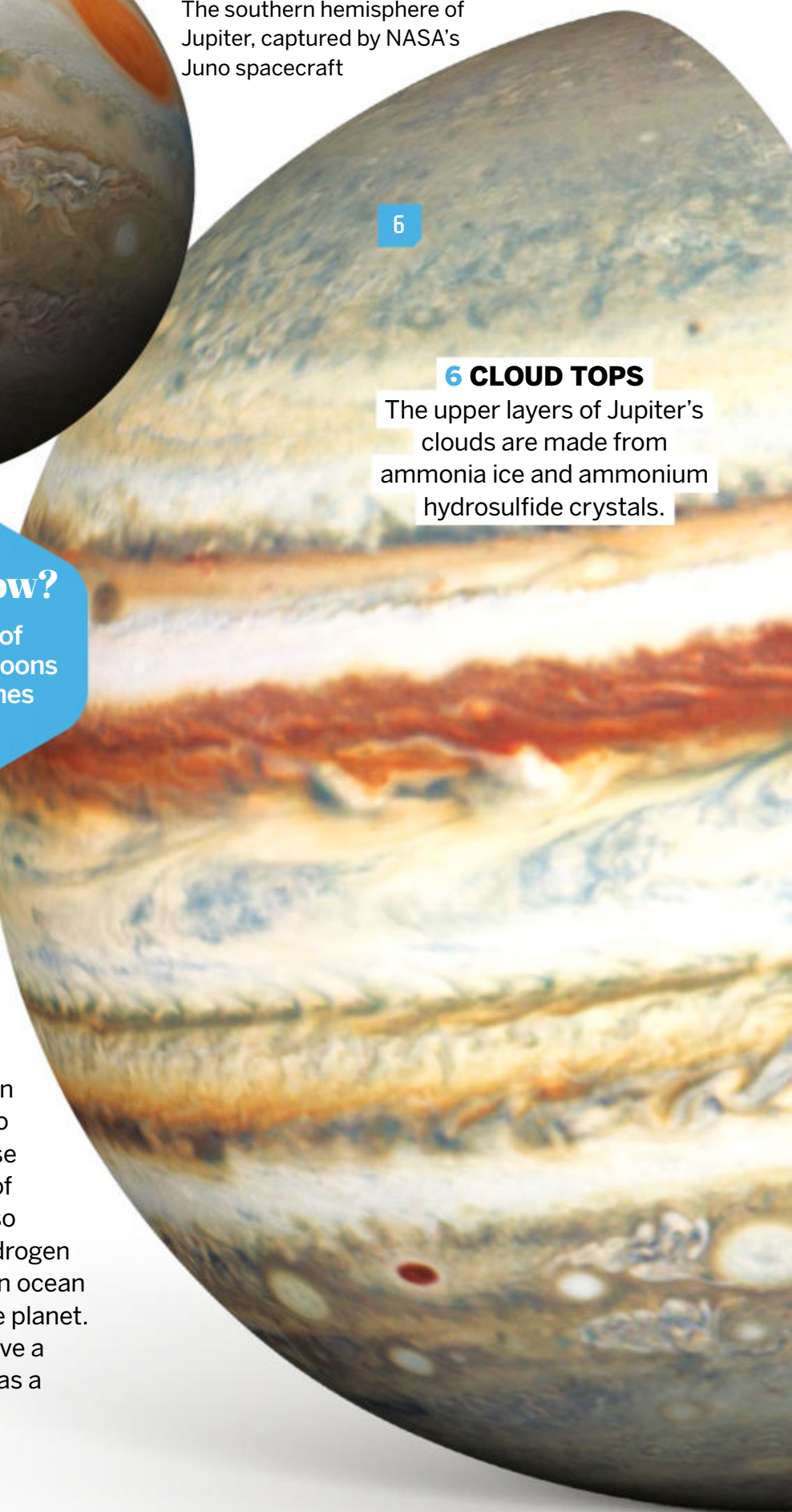
WHAT IS JUPITER MADE OF?

Plunge beneath the surface of the Solar System's largest planet

WORDS **SCOTT DUTFIELD**



The southern hemisphere of Jupiter, captured by NASA's Juno spacecraft



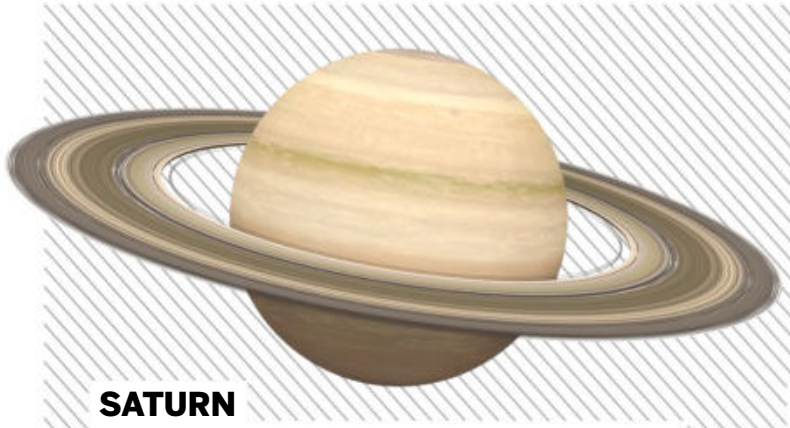
6 CLOUD TOPS
The upper layers of Jupiter's clouds are made from ammonia ice and ammonium hydrosulfide crystals.

Did you know?
Only 57 of Jupiter's moons have names

Between 365 and 601 million miles from Earth is a swirling, giant ball of gas that the Romans named Jupiter. Along with the rest of the planets in the Solar System, Jupiter was formed 4.5 billion years ago. Much like the Sun, Jupiter is mostly made up of hydrogen and helium – the two most abundant elements in the universe. Scientists think that Jupiter got all of its hydrogen and helium from the leftover gas and dust after the Sun had formed. But unlike the Sun, Jupiter doesn't have enough mass to fuse hydrogen and helium and ignite into a fiery ball of energy. Jupiter's mass would need to increase by at least 83 times to be in with a chance of becoming a star by triggering nuclear fusion.

Without a rocky surface or icy exterior, Jupiter is categorised as a gas giant. It's divided into distinct layers that begin with 44-mile-thick bands of sulphur and phosphorus clouds. Beneath these clouds lies a 13,000-mile-thick atmosphere of hydrogen and helium. On Earth, hydrogen and oxygen teamed up to form the water in the world's oceans, whereas the majority of the hydrogen on Jupiter has no such elemental friends to make water. Instead, under the immense pressure and scorching temperatures of Jupiter's atmosphere, the hydrogen is so compressed that the once-gaseous hydrogen atoms are squeezed together to form an ocean of liquid hydrogen that covers the entire planet. This also means that Jupiter doesn't have a true surface, existing in the Sun's orbit as a swirling ball of gas and liquid.

A GASSY FAMILY



SATURN
Saturn is the second-largest planet in the Solar System and is mostly made from hydrogen and helium. A dense iron and nickel core sits at the planet's heart, surrounded by a metallic ocean of liquid hydrogen.

NEPTUNE
As well as being one of the four gas giants in the Solar System, Neptune, along with Uranus, is also known as an ice giant. This is due to the abundance of ice crystals that form in its frigid atmosphere.

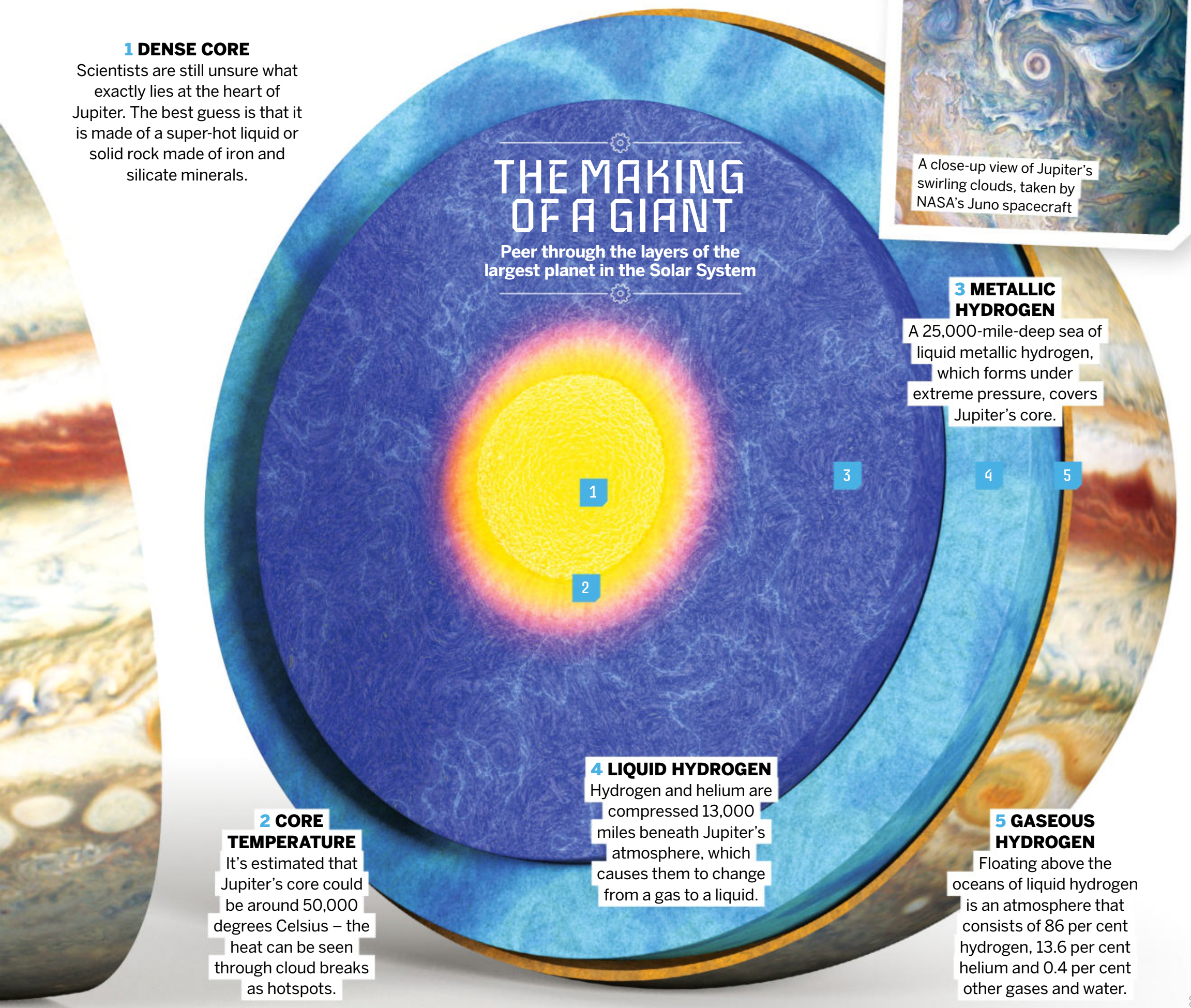
URANUS
Like all the gas giants, Uranus has no solid surface and consists mainly of gas, liquid and an icy atmosphere. The force of gravity on gas giants like Uranus is greatly reduced because of their significantly lower density.

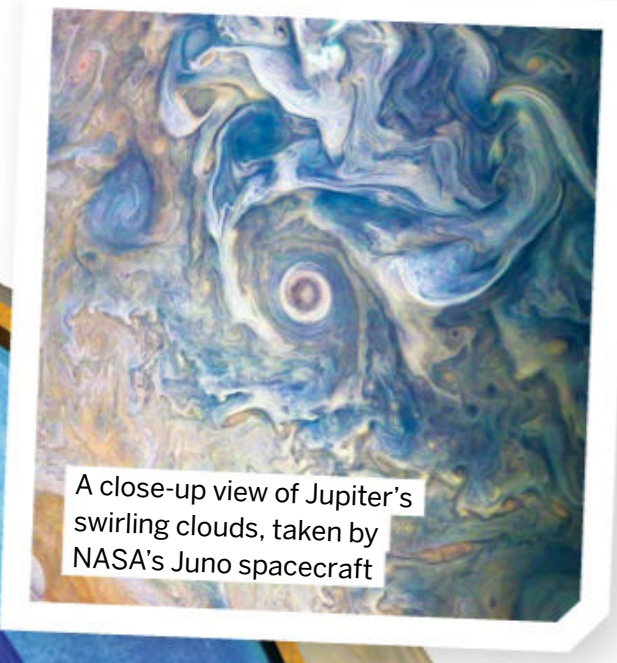
DID YOU KNOW? The winds on Jupiter can reach speeds of more than 400 miles per hour

THE MAKING OF A GIANT

Peer through the layers of the largest planet in the Solar System

1 DENSE CORE
Scientists are still unsure what exactly lies at the heart of Jupiter. The best guess is that it is made of a super-hot liquid or solid rock made of iron and silicate minerals.




A close-up view of Jupiter's swirling clouds, taken by NASA's Juno spacecraft

2 CORE TEMPERATURE
It's estimated that Jupiter's core could be around 50,000 degrees Celsius – the heat can be seen through cloud breaks as hotspots.

3 METALLIC HYDROGEN
A 25,000-mile-deep sea of liquid metallic hydrogen, which forms under extreme pressure, covers Jupiter's core.

4 LIQUID HYDROGEN
Hydrogen and helium are compressed 13,000 miles beneath Jupiter's atmosphere, which causes them to change from a gas to a liquid.

5 GASEOUS HYDROGEN
Floating above the oceans of liquid hydrogen is an atmosphere that consists of 86 per cent hydrogen, 13.6 per cent helium and 0.4 per cent other gases and water.

GAZING AT A GAS GIANT

In 2011 NASA launched a probe called Juno on a one-way trip to Jupiter. After five years of wandering through space, Juno embedded itself in a 53-day orbit around the gas giant. Juno's mission is to study Jupiter's composition and understand the planet's evolution. To achieve this, the spacecraft is equipped with a whole host of sensitive instruments, including light spectrometers, magnetometers and particle detectors. During the craft's first 35 orbits of Jupiter, the probe gathered more than three terabits of scientific data, revealing secrets about Jupiter's atmospheric composition and clues as to what lies in the centre of the planet. Now that Juno is done with its primary mission, it's on an extra mission around the planet's moons to learn more about how they formed. Juno will continue exploring Jupiter and its many natural satellites until 2025.


An illustration of the Juno spacecraft orbiting Jupiter

RESCUE AT SEA

From the hammering surf to the ocean's depths, these vehicles retrieve the missing and stranded

WORDS **AILSA HARVEY**

During the summer season, more than 10,000 incidents at sea are reported to lifeguards in the UK. Meanwhile, between 1,500 and 2,000 people go missing each year while travelling on sea vessels. The world's oceans can be violent and unpredictable, catching out many who enjoy and explore it. When this happens, there are specialised sea vehicles and technologies on hand to save lives. But there are many factors that contribute to their success. Firstly, where a person is stranded determines the time frame that rescuers are working with. Without food and water, a person floating in the ocean could survive for up to three days. However, when being churned by waves, lifeguards need to resurface swimmers within a matter of seconds.

Sea rescues also include those below the surface. Just as people enjoy the thrill of surfing the tide, the exploration of the ocean thousands of metres down has also risen in popularity. But this venture comes with increased safety complications. The further underwater a vessel travels, the lower the visibility for navigation is. More significantly, the water pressure increases with every metre descended, so humans can't survive beyond a certain depth without a pressure chamber. One of the highest profile deep-sea rescues to take place occurred on 18 June 2023, when a submersible called Titan went missing in the Atlantic Ocean while carrying tourists to the site of the Titanic shipwreck. Unfortunately, the submersible was found to have imploded shortly after its descent, with no survivors. However, during the documented three days of searching, the mission demonstrated how aircraft surveillance, remotely operated vehicles, ships and sonar technology can be used to track down people and technology lost at sea.

DID YOU KNOW? Tidal currents can travel at speeds of over nine miles per hour

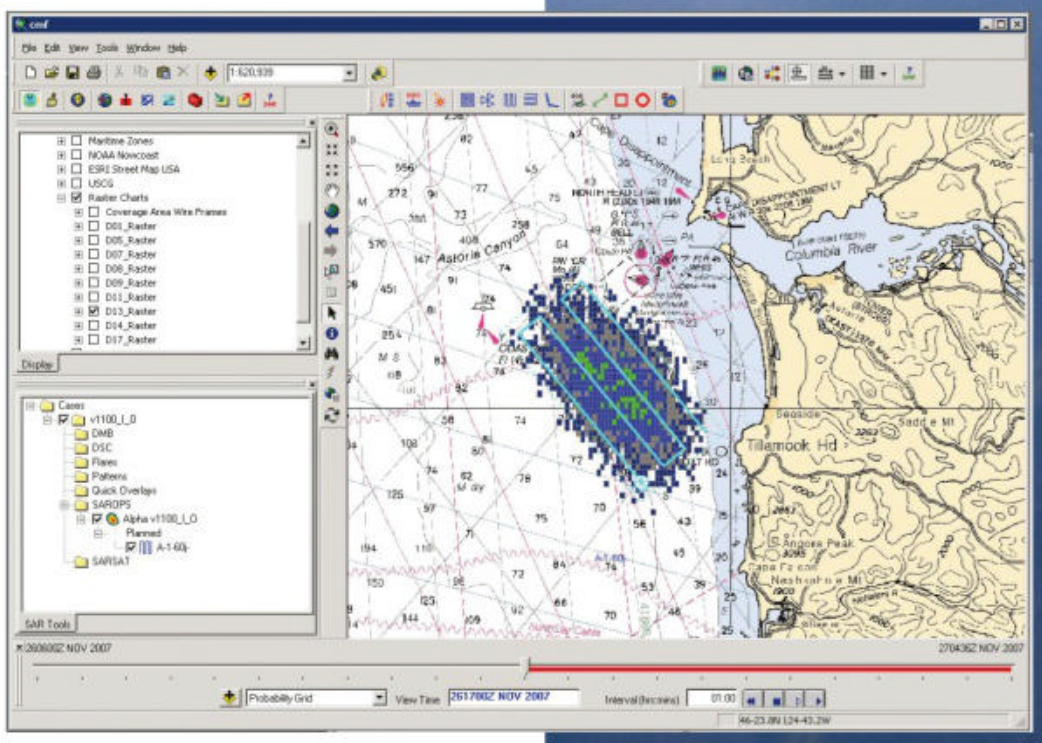
© Getty

COASTGUARD CALCULATIONS

When a person or watercraft goes missing, how do coastguards know precisely where they should look first? Using data of the area where the missing people were last seen, local weather events, ocean temperature and ocean movement patterns, rescuers can consult an artificial intelligence (AI) algorithm. This data-analysis tool informs them of the most likely locations the missing people could be found if they're floating with the tides.

When an individual has fallen overboard, crucial extra information, such as the person's height and weight, increases the accuracy of tracking their movements and their chance of recovery. Beyond narrowing down the search area, this will also inform coastguards of the estimated time frame they are working in. Based on a person's biological data and the ocean temperature, the algorithm will deduce how long the individual is likely to survive before hypothermia or exhaustion take hold.

When all of the data is inputted into a computer algorithm, a map displays the best area to search



Did you know?

Sonobuoys measure about 13 by 90 centimetres

SOUND WAVE SEARCHERS

After being dropped into the deep, sonobuoys emit sonar to locate the lost

1 RELEASE
Sonobuoys are released from planes to cover the likely area of a missing vessel.

2 STABILISATION
After the sonobuoy is shot from a plane, a parachute is deployed to stabilise the device.

3 WATER ACTIVATION
Sonobuoys have salt-water activated batteries. When the device enters the ocean, it starts listening almost immediately.

4 DIVISION
Upon impact with the water, the sonobuoy separates into two tethered pieces.

5 BUOYANT UNIT
The top half of the sonobuoy, containing a radio frequency transmitter, floats on the water.

6 HANGING UNIT
The lower portion of the device hangs at a designated depth by suspension cable.

DID YOU KNOW? The first navy submarine rescue took place in 1939, saving 33 people from the sinking USS Squalus

WHAT IS MARINE SALVAGE?

A vessel can face difficulties at any stage in its voyage, whether it's docked or out to sea. The process of salvaging a ship can involve towing a boat, extinguishing any fires, repairing a ship at sea, refloating a sunken or sinking vessel or rescuing any of the cargo on board. Professional coastguards and specially trained engineers are usually called to salvage missions, and some of the equipment they may deploy includes tugboats, cranes and floating docks to support sinking vessels.

However, there isn't always enough time for support to be called in. In some instances, other ships that happen to be passing by might take part in marine salvage. According to marine salvage law, someone who helps save another vessel should receive a reward, as they have put their safety at risk purely to help another. This law is the reason some captains decline any help offered to them, as they don't want to risk handing over their ship or its valuable contents.

Specially designed salvage vessels are equipped with cranes

Did you know?

There are around 3 million shipwrecks on the ocean floor

RETRIEVING SUBMARINERS

How submarine rescue bells collect survivors from trapped vessels

1 PRESSURE GAUGES
The internal pressure of the bell is monitored to make sure it remains close to atmospheric pressure.

2 MATING SKIRT
This skirting at the base of the bell seals onto a submarine's escape hatch, and the water between the two vessels is pumped out.

3 RESCUEES
About six people can enter the rescue vehicle through the submarine escape hatch and sit on the bench inside.

4 WINCH
The bell is attached to a vessel at the surface, which lowers it to the rescuees and hoists it back to the surface again.

5 HANDLES
To limit the chances of the occupants being injured, there are handles they can use for support during the ascent to the surface.

6 UMBILICAL CABLE
A thick support cable keeps the rescue bell from sinking. The chamber can descend to around 300 metres.

7 OXYGEN TANK
High-pressure oxygen is stored in this small tank. It's released into the chamber during the course of the rescue for breathing and adjusting the pressure inside.

8 SCRUBBER
Excess carbon dioxide exhaled by the bell's occupants is removed from the chamber through this device.

9 HATCH
There are hatches at the top and bottom of the bell. These close when the skirts aren't sealed onto another vessel to prevent the main chamber from flooding with water.

8 RELAYING SIGNALS
Sound wave signals are relayed through the cable to the floating device, which transmits the data to crew on other craft.

7 HYDROPHONE ARRAY
Each arm of the array has five evenly distributed hydrophones. These emit sound energy and receive data from returning sound waves that have bounced off submerged objects.

DEPLOY THE UNDERWATER DRONES

Sending an entire crew into unknown danger to search for missing swimmers, vehicles or boats puts rescue teams at risk. Sometimes it's a much quicker and safer option to search beneath the surface with a drone first. Drones are operated remotely and are ready to travel immediately, while a rescue diver will take time to mentally and physically prepare for descent. If an exact location is unknown, drones can cover extensive areas of water within a short space of time while relaying video. Ultimately, these machines can reduce the time taken to locate individuals when there are less people available to dive. Some drones are even equipped with robotic arms that can lift items to the surface. In less time-critical missions, drones can be deployed to scour smaller spaces and dangerous zones. The deep sea can be treacherous to navigate, with body-crushing pressures and narrow trenches. Btu small drones can investigate these with no risk to human life.

Small underwater drones are the most practical and safest way to record deep-sea footage

DEEP-SEA RESCUE

This deep search and rescue (DSAR) submarine scours the dark ocean depths at 500 metres

1 PORTHOLE
The crew use this viewing window to navigate through the murky water.

2 LAUNCH
Within 15 minutes of hearing of a missing vessel or vessel in distress, the DSAR submarine is lowered into the ocean.

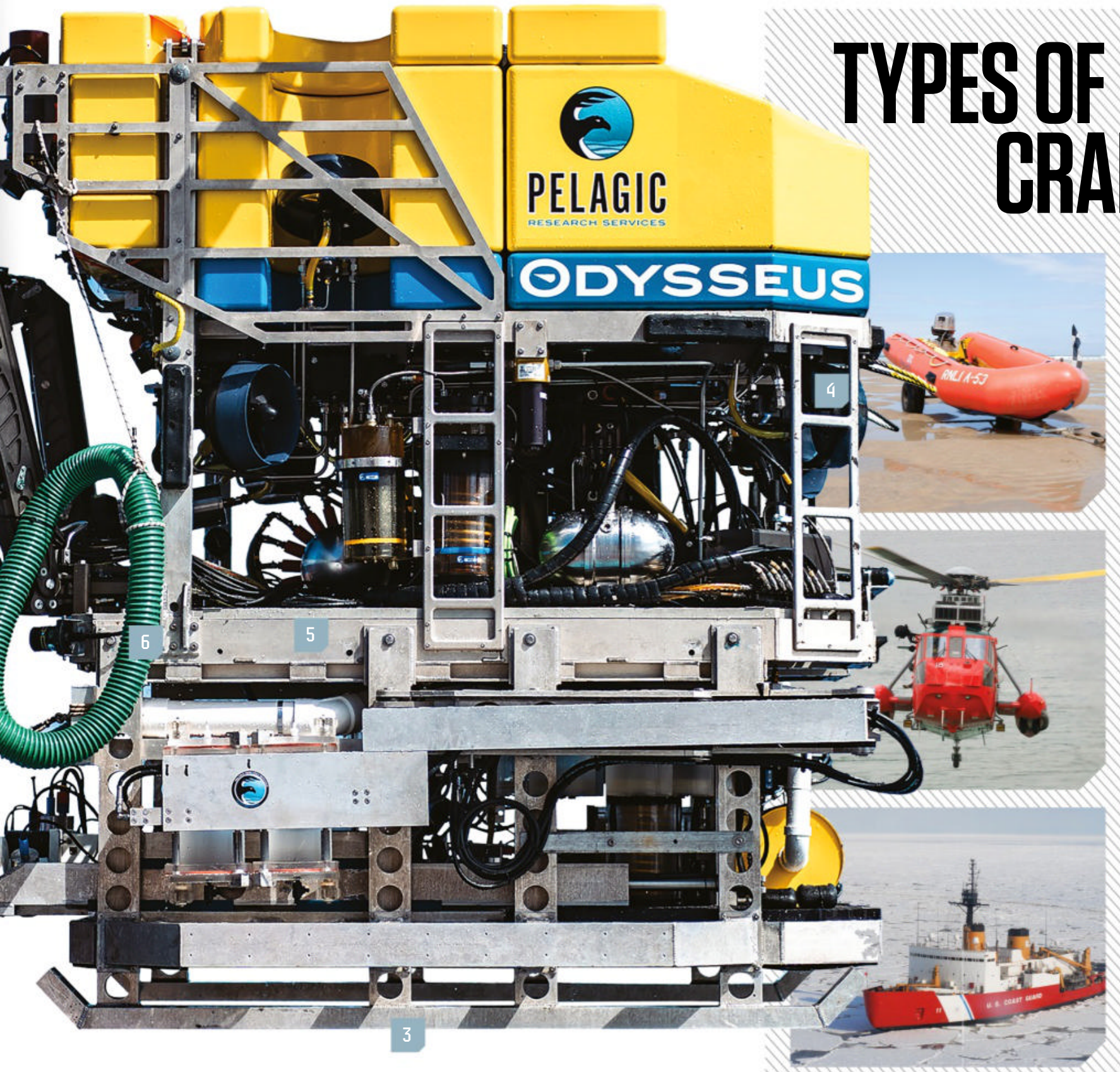
3 SIZEABLE RESCUE
The DSAR is designed to retrieve an entire crew in one descent. Around 27 people can be returned to the surface in this vessel.

4 CONNECTING HATCH
When a stranded submarine is located, the DSAR seals itself to the top of it via this hatch.

5 TREATMENT ON BOARD
After the rescued passengers are returned to the launching vessel, they will usually be medically assisted in a pressurised hyperbaric chamber to regulate oxygen levels in the body.

6 PROPELLERS
The maximum speed of the vessel is around 13 miles per hour.

DID YOU KNOW? Odysseus 6K is attached to a 7,500-metre umbilical cable



ODYSSEUS' OPERATION

How the remotely operated vehicle (ROV) Odysseus 6K discovered debris of the Titan submersible

1 4K CAMERAS
A panel of cameras and lights relayed imagery of the deep sea in real time to crew on board the ship at the surface.

2 ARTICULATED ARMS
Two robotic arms were controlled from the mothership to manipulate and explore any discovered objects.

3 MAXIMUM DEPTH
The ROV can navigate to depths up to 6,000 metres below the surface. The Titan submersible debris was retrieved at 3,810 metres.

4 THRUSTERS
Odysseus 6K has four forward thrusters and three vertical thrusters.

5 VEHICLE WEIGHT
The ROV weighs 1,700 kilograms, so it needs to be lifted off the mothership by a large crane and be placed in the water.

6 SUCTION SAMPLER
This tube sucked up small samples from the ocean that were analysed at the surface.

TYPES OF RESCUE CRAFT

LIFEBOATS

For inshore sea rescues, lifeguards board an inflatable lifeboat. One lifeguard will focus on steering the boat through crashing waves to the casualty, while a second has their hands free to reach and rescue those in need.

HELICOPTERS

When someone needs to be retrieved from the sea during rough sea conditions – or a severely injured person from on board a boat – coastguards may perform an air-sea rescue. This involves lowering down one of the coastguards with a harness or stretcher.

SHIPS

While smaller ships owned by coastguards can be deployed in specific emergencies, larger ships sail the ocean for longer periods and patrol the seas. Coastguards will also conduct some training on these vessels.

HOVERCRAFT

Hovercraft trap a layer of air underneath them as they move, preventing them from getting stuck in mud and shallow water. They can whizz over water and difficult terrain to reach those who have become caught in estuaries and mudflats.

JET SKIS

Jet skis speed across the sea at up to 70 miles per hour and are often used to help surfers. Platforms with handles are attached to the back of jet skis so that surfers who have lost their boards can hold on and be pulled out of danger in a matter of seconds.

THE PRESIDENTIAL MOTORCADE EXPLAINED

How this fleet of vehicular chaperones gets the United States President safely around

WORDS **SCOTT DUTFIELD**


A presidential motorcade travelling in London during Obama's state visit to the UK

Did you know?

Four US presidents have been assassinated

As the leader of one of the world's most powerful nations, the president of the United States doesn't travel without a swarm of security personnel, known as the Secret Service. When the Secret Service was founded in 1865, its job was to tackle a growing concern over currency counterfeiting. However, in 1901 the focus of the Secret Service shifted towards protecting the welfare of the president following the assassination of the 25th President of the United States, William McKinley, during a public appearance in Buffalo, New York.

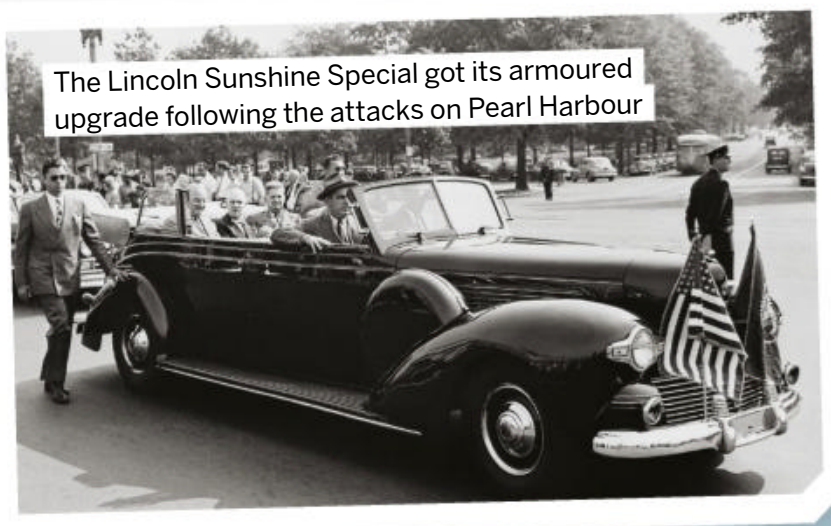
Now the Secret Service protects the president, along with other members of the US administration such as the vice president, when travelling around America and during international visits. That protection comes in the form of a military-style operation known as the presidential motorcade. Weapons experts, surveillance sensors, doctors and even a satellite connected to the Pentagon are just some of the security details that form the armoured fleet.

At the heart of this impressive procession is the presidential limousine, known as 'the Beast'. This limousine is over five metres long and is packed with gadgets and state-of-the-art weaponry: smoke screens, electrifying door handles and oil slicks are some of the many gizmos said to be packed into the Beast to ward off any attack. The car's exterior is also bullet-proof and hermetically sealed to protect the president inside from both biological and chemical attacks.

In the event that those security measures fail, the Beast has its own oxygen supply and a built-in refrigerator to store bags of blood that match the president's blood type. The car's tyres are also reinforced with kevlar to protect against punctures and the fuel tanks are encased in a special foam, preventing the tank from exploding on impact.

THE FIRST PROTECTED PRESIDENT

In 1941, Franklin D. Roosevelt became the first president to ride in an armoured vehicle – a Cadillac that once belonged to the gangster Al Capone. The car was originally seized from Capone following the gangland boss' arrest for income tax evasion and was held by the Treasury Department from 1932. The only armoured components of the car were the bulletproof glass windows – the rest of the car remained vulnerable to attack. In 1942 Roosevelt got an armoured upgrade, a 1939 Lincoln 'Sunshine Special', nicknamed so because Roosevelt enjoyed riding with the roof down. This more robust vehicle was not only equipped with bullet-proof windows, but armoured body plating and a bullet-resistant fuel tank and tyres.


The Lincoln Sunshine Special got its armoured upgrade following the attacks on Pearl Harbour

9 HAZARDOUS MATERIALS MITIGATION UNIT

Within this large truck are sensors to detect the threat of any nearby chemical, biological or even nuclear weapons.


The presidential "Beast" pulling up the Royal Palace during the 2022 NATO Summit in Spain

10 PRESS VANS

These vans transport journalists from major media outlets, as well as the White House media teams.

DID YOU KNOW? In 1899 William McKinley became the first President of the United States to ride in an automobile

BIDEN'S MOTORCADE

The formation of this fortified fleet keeps the 46th president safe on the go

3 PRESIDENTIAL LIMOUSINE OR DECOY?
At the centre of the motorcade is the presidential limousine, codenamed Stagecoach, and an identical 'spare' limousine.

2 SWEEPERS AND LEAD CARS
A procession of police motorbikes and patrol cars ride in front of the presidential limousine to clear the way for its journey and ensure the motorcade keeps moving.

1 PILOT CAR
At the head of the motorcade are the route and pilot cars. They scout out the journey ahead and send security information back down the entire motorcade.

5 WATCHTOWER
This electronic countermeasure vehicle, codenamed Watchtower, is equipped with technology to jam communications such as remote detonations and detect potential threats from missiles or unmanned aircraft.

4 HALFBACK
The president's Secret Service protection vehicle, codenamed Halfback, acts as the first line of defence for Stagecoach. A row of armed Secret Service agents sit facing outwards from the rear window.

8 THE ID CAR
As the intelligence centre of the motorcade, the ID car surveys the surroundings and identifies potential threats before they have the chance to become a problem.

7 HAWKEYE RENEGADE
The Secret Service's Counter Assault Team is packed into vehicles collectively nicknamed 'the Hawkeye Renegade'. Within each vehicle are elite Secret Service agents waiting with state-of-the-art weaponry.

6 SUPPORT VEHICLES
Military personnel, along with cabinet members and security, file into the rear support vehicle.

11 ROADRUNNER
The Mobile Command and Control Vehicle, codenamed Roadrunner, keeps the president securely connected with the Pentagon.

12 AMBULANCE
In the event of an emergency, an ambulance follows along at the rear of the motorcade to offer medical attention.

13 REAR GUARD
A parade of police vehicles at the rear of the motorcade offer further defensive and surveillance support.

14 OVERWATCH HELICOPTER
When required, the Secret Service can call upon a helicopter for aerial surveillance and support.

15 GROUND FORCE ONE
Sometimes the president's 13-metre-long armoured bus, known as Ground Force One, tails behind the motorcade.

FRACKING UNCOVERED

With fossil fuels in ever-scarcer supply, fracking may soon be coming to a location near you. But what does that mean for you and your home?

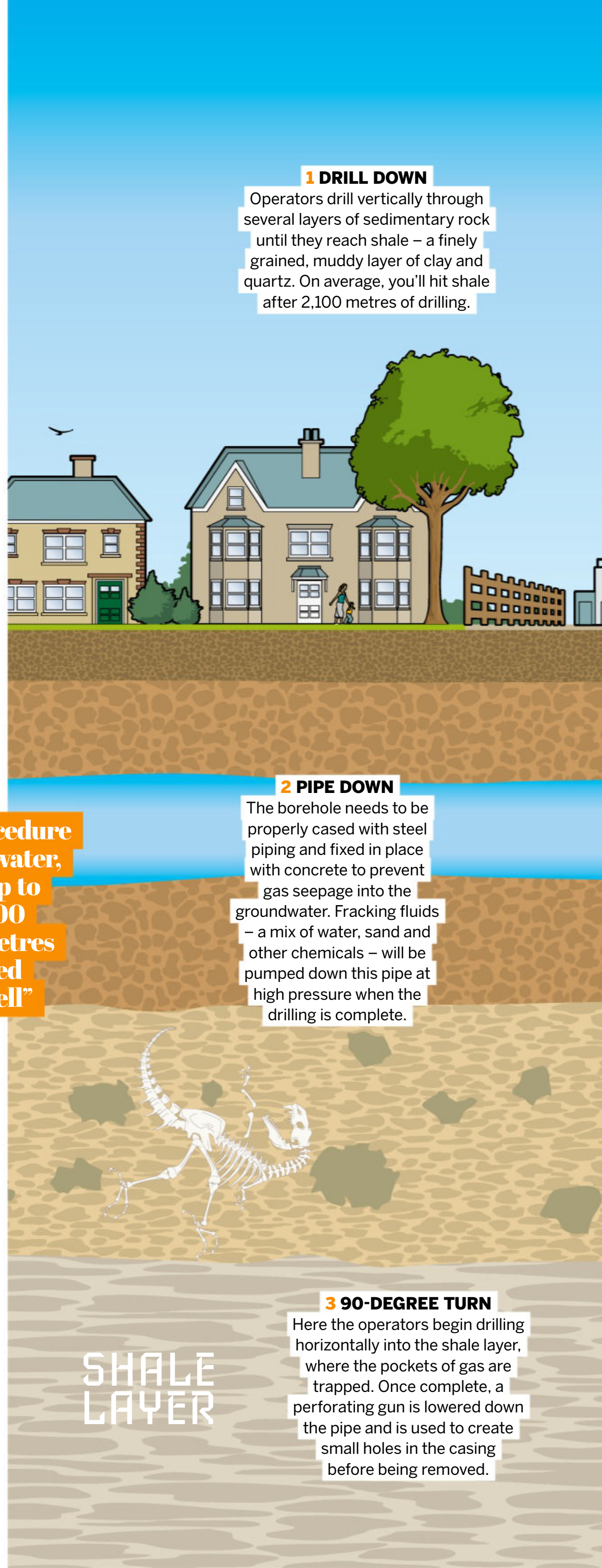
WORDS **NIC FLEMING**

A man holding a lighter next to his kitchen sink leaps back as a giant flame engulfs the screen. This scene is from the 2010 documentary *GasLand*, which tells the story of the town of Dimock, Pennsylvania, an area that has become synonymous with the consequences of fracking. It's a scene that captures the public's fears in a single flare. But it's also indicative of how the debate can generate more heat than light, with scientific evidence often left to simmer on the sidelines. Fracking – the common name for hydraulic fracturing – involves injecting water, sand and additive chemicals into rock layers, mostly shale, at high pressure. This creates tiny new rock fractures, releasing pockets of natural gas trapped underground.

While fracking has been about since the 1940s, the relatively recently developed technology to frack horizontally into the shale layer has opened up huge new reserves that couldn't be accessed with just a vertical drill. Large-scale use of the technique has already pushed down gas prices in the US, and large deposits exist in the UK, which the government is keen to tap. Yet there are concerns over fracking's environmental impact. The procedure guzzles water, with up to 30,000 cubic metres needed per well. Around half of the water pumped underground stays there, leading to fears toxic fracking fluids can contaminate groundwater and drinking water supplies. But a report released in October 2013 by Public Health England, an agency of the Department of Health, claimed the risks of fracking were low and that problems publicised in other countries are typically down to operational failure. Improperly cased piping and spillages of stored fracking fluid on the surface are among the prime culprits. The report suggested that the process of fracking itself can be performed safely with good practice.

Widespread public concern spurred the US Environmental Protection Agency to conduct a major study on the impact of fracking on drinking water, using chemical tracers to find out where injected fracking fluids end up. Its findings were published in a 2016 report, stating that fracking "can impact drinking water resources under some circumstances," especially when wastewater is improperly stored or inadequately treated before it's discharged.

"The procedure guzzles water, with up to 30,000 cubic metres needed per well"



DID YOU KNOW? Over 20 per cent of US gas comes from shale

FRACKING IN FIVE SIMPLE STEPS

All you need is a suitable location, several thousand cubic metres of water, a very long pipe and somewhere to put all that gas...

1

5

2

3

4

5 WASTE DISPOSAL
Fracking wastewater needs to be disposed of carefully, as it picks up contaminants from deep within Earth. These can include heavy metals, brine, organic compounds and even radium.

GROUNDWATER

4 FRACTURE THE ROCK
Now it's time to pump the fluids down the pipe. The high pressure causes rock fractures, and the sand works as a doorstop of sorts, enabling gas trapped in pores to escape. The gas flows back up the pipe, where it's collected and stored.

High air pressure during winter leads to the formation of fog, frost and snow showers

WHAT IS ATMOSPHERIC PRESSURE?

This invisible force drives the world's weather

WORDS **SCOTT DUTFIELD**

Earth's atmosphere is 60 miles thick and is packed from surface to outer space with gaseous molecules, the majority of which are made of nitrogen and oxygen. Individually, the force exerted by each of these atmospheric molecules isn't strong enough to feel, but together they create an enormous amount of pressure. At sea level, air pressure is recorded at around 1,013 hectopascals. As you move upwards in altitude and through Earth's atmospheric layers, the air pressure decreases. For example, at the peak of Mount Everest – almost 5.5 miles altitude – the air pressure drops to around 300 hectopascals. At sea level, air molecules are more densely packed together and collide with each other. These collisions exert a force that's known as atmospheric pressure. The density of air molecules decreases as you move from the surface, therefore there are fewer collisions and less pressure is generated.

Other than altitude, several factors can affect or change the pressure of the atmosphere, such as temperature. Under hot conditions, air molecules become excited and increase their physical distance from one another, reducing air density. This also leads to fewer molecular collisions and reduces the amount of pressure exerted. Conversely, when the temperature is cold, air molecules become more densely packed and increase in pressure. Warm low-pressure air rises and is quickly displaced by cooler, higher pressure air. Fluctuation in high and low pressures by ascending and descending air dictates the world's weather. For example, low-pressure warm air rises, cools and condenses into clouds and precipitation.

Did you know?

One cubic metre of air contains 10 trillion trillion molecules

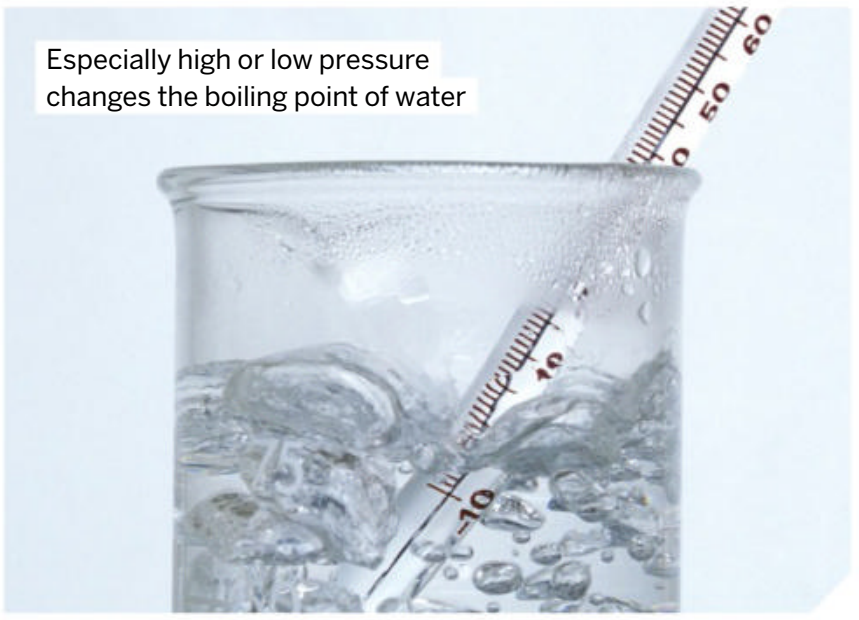
HOUSEHOLD MEASUREMENTS

Changes in air pressure are recorded using an instrument called a barometer, of which there are two types. The aneroid barometer uses a small box or diaphragm made from beryllium and copper. As air pressure changes, the diaphragm contracts under higher pressure, or expands under lower pressure. The diaphragm is hooked up to a needle, which acts as a gauge to indicate the amount of air pressure being applied to it.

Using a similar expansion and contraction principle as the aneroid barometer, a mercury barometer measures changes in the level of mercury-filled tubes. Invented in 1643, the mercury barometer was first created by Italian physicist Evangelista Torricelli, who originally used water in his ten-metre-tall barometer. However, he soon discovered that much denser mercury could do the same job on a much smaller scale.

The face of the commonly used aneroid barometer

DID YOU KNOW? The invention of the mercury barometer was also the first time anyone had produced a vacuum in a laboratory

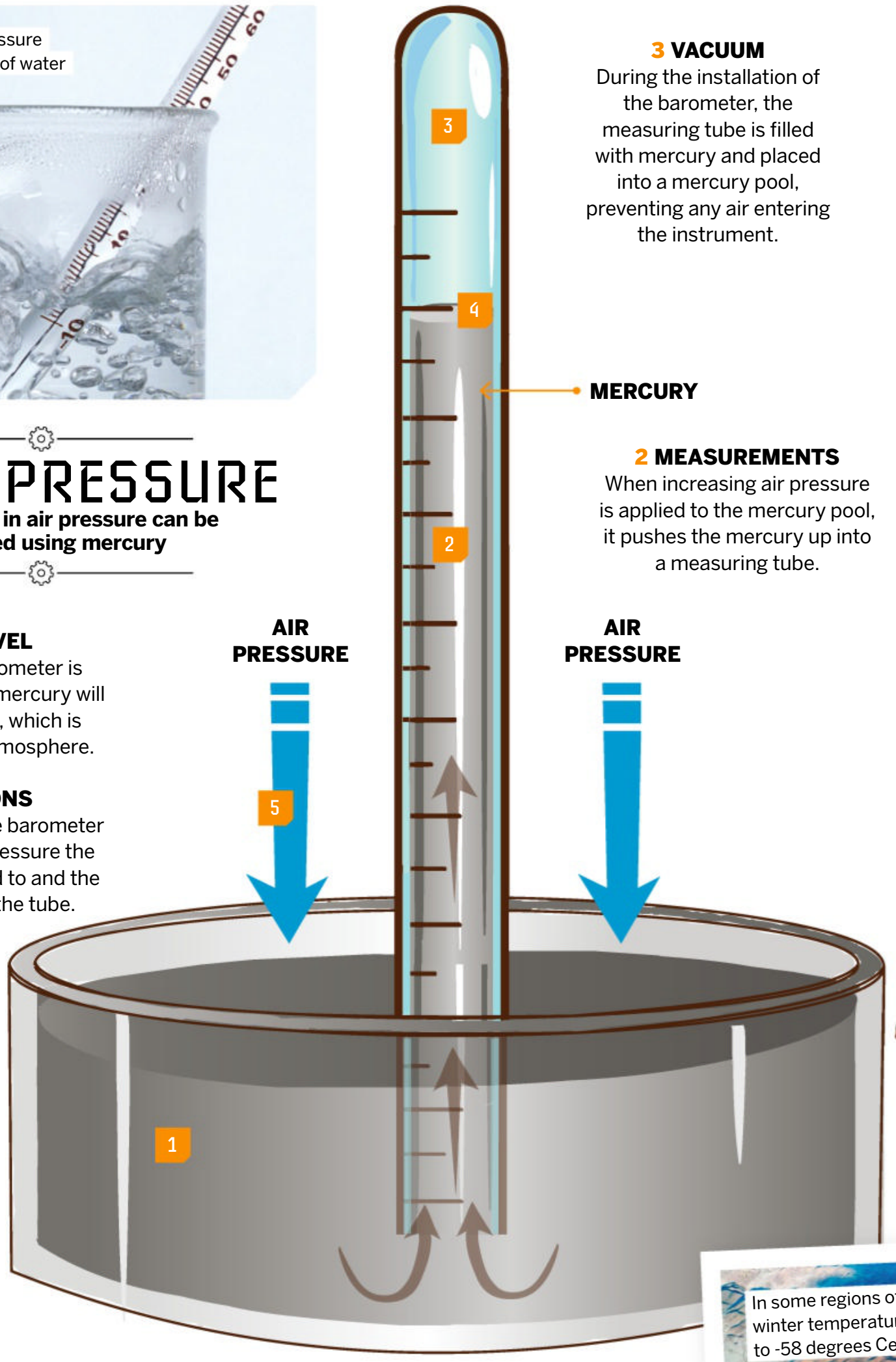


SEEING PRESSURE

How changes in air pressure can be measured using mercury

4 AT SEA LEVEL
When a mercury barometer is placed at sea level the mercury will sit at 76 centimetres, which is equal to one unit of atmosphere.

5 FLUCTUATIONS
The higher in altitude the barometer is moved, the less air pressure the mercury pool is exposed to and the lower the reading on the tube.

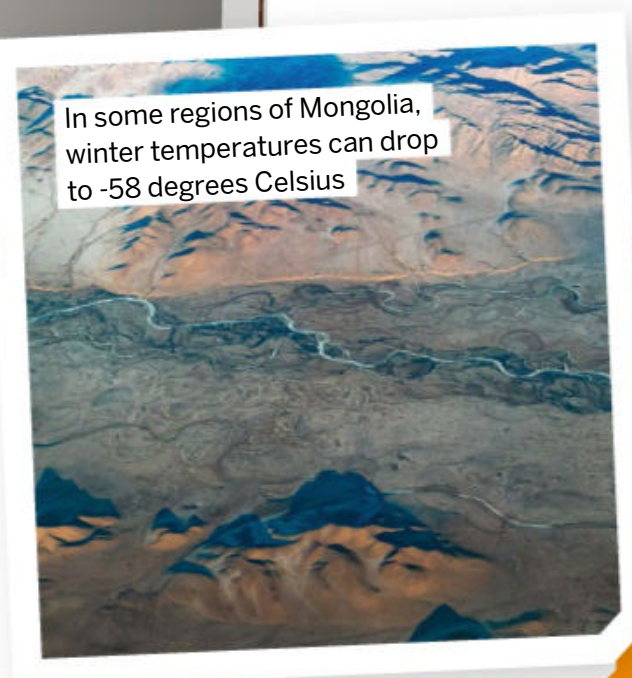


3 VACUUM
During the installation of the barometer, the measuring tube is filled with mercury and placed into a mercury pool, preventing any air entering the instrument.

2 MEASUREMENTS
When increasing air pressure is applied to the mercury pool, it pushes the mercury up into a measuring tube.

1 MERCURY POOL
At the base of the barometer is a pool of mercury in a reservoir that's exposed to the atmosphere.

An example of an antique wooden mercury barometer



In some regions of Mongolia, winter temperatures can drop to -58 degrees Celsius

RECORD-BREAKING PRESSURE

The highest recorded air pressure was set in 2020, when researchers at a weather station in Tsetsen-Uul, Mongolia, recorded sea-level air pressures of 1,094.3 hectopascals. On the day of the recording, the temperature was a bone-chilling -45 degrees Celsius. The previous record, also set in Mongolia, was recorded in 2004, when researchers recorded an air pressure of 1,089.4 hectopascals. In the UK the highest air pressure was recorded in Aberdeen, Scotland, in 1902, topping 1,053.6 hectopascals. 2020 saw air pressures of 1,053.6 hectopascals being recorded in Swansea, Wales, which were the highest on record since 1957.

A hormone called melatonin is largely responsible for signalling to our body that it's time to sleep

WHY WE DREAM

The science behind your slumber and the benefits of drifting off to dreamland

WORDS **SCOTT DUTFIELD**

On average, we spend about a third of our lives – or around 26 years – sleeping, six years of which are spent drifting off to dreamland. During an optimal seven-hour sleep at night, the body experiences sleep cycles with four stages, which together take between 90 and 110 minutes to complete. The first two stages, called NREM 1 and NREM 2 (non-rapid eye movement) involve light sleep that lasts up to around 25 minutes.

NREM 3 is the stage of deepest sleep and lasts for up to 40 minutes. Around 75 per cent of a person's sleep is spent in NREM sleep. Dreams can occur through each of these stages, but during the final REM stage in the cycle, brain activity picks up, and we begin to vividly dream. In each of the four to five sleep cycles that occur in one night, the REM sleep stage increases in duration with each new cycle, starting at only ten minutes and increasing up to an hour long. The REM sleep stage is also when people are most likely to spontaneously wake up in the morning.

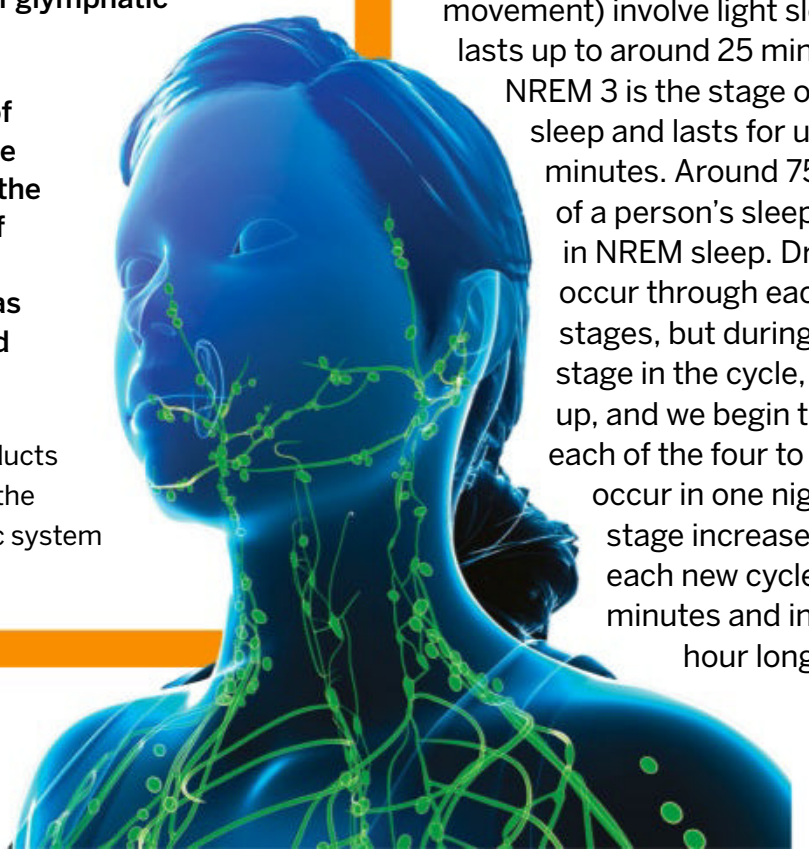
Three parts of the brain play a key role during REM sleep and allow us to dream: the hippocampus, amygdala and cortex. Each of these regions of the brain allows us to tap into the emotional, visual and memory content of a dream. As for the purpose of dreams, scientists still aren't entirely sure. Scientists think that they help us process emotions, retain information and cement new memories. Studies have shown that during sleep, those that spend more time in REM sleep have lower fear-related brain activity the next day and may be less prone to developing post-traumatic stress disorder (PTSD). But don't worry if you don't remember your dreams – not everyone does. Around 1 in 250 people report having never remembered a dream in their lives. On average, a person will experience between four and six dreams per night. This is because the memory storage region of the brain, called the hypothalamus, is inhibited during the REM stage and doesn't record your dreams.

Did you know?

Humans are the only mammals that willingly delay sleep

RESTORATIVE SLEEP

During sleep, the brain undergoes a period of rejuvenation: the brain's cells form, reorganise and repair themselves to cement memories and knowledge. It's also quickly working to remove all the waste that's built up within it. During the day our brains are naturally flooded with all sorts of molecules, such as proteins and carbon dioxide, which scientists call interstitial metabolic waste products. These can be harmful to the brain if they're not removed. That's where the brain's drainage system comes into play. Known as a glymphatic clearance, this evicts waste products from the brain and drains them away through the body's lymphatic system. This process is most effective while we sleep, with some studies suggesting that twice the amount of waste proteins are cleared from the brain during sleep. Studies have also linked a reduction in the effectiveness of glymphatic clearance, and subsequent accumulation of metabolic waste products, with the development of neurological diseases such as Alzheimer's and dementia.



Brain waste products are drained into the body's lymphatic system while you sleep

DID YOU KNOW? The ideal room temperature for sleep is between 15.6 and 20 degrees Celsius

THE CONSEQUENCES OF DREAM DEPRIVATION

How our bodies respond to being denied access to REM sleep

1 MENTAL HEALTH DISORDERS
The development of anxiety, depression and other mental health disorders have all been linked to poor dreaming.

2 HORMONE IMBALANCE
Sleep deprivation can lead to hormonal imbalances and disrupt the endocrine system. This can affect mood, cognitive function and even future sleep cycles.

3 CARDIOVASCULAR DISEASE
Those that suffer from obstructive sleep apnea, a condition associated with a reduction in REM dreaming, also have an increased risk of developing cardiovascular disease and diabetes.

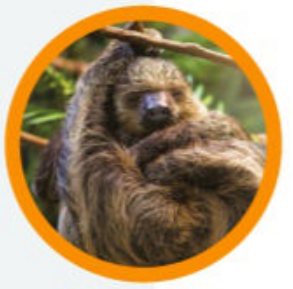
4 PAIN SENSITIVITY
Some studies have shown that a reduction of REM sleep and dream deprivation may increase a person's sensitivity to pain.

5 OBESITY
When people haven't had enough REM sleep, it can increase the production of ghrelin, also known as the hunger hormone, which affects our appetite.

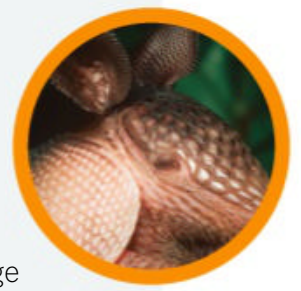
6 IMMUNE SYSTEM
Generally, sleep promotes a healthy immune system. However, some studies have found a reduction in REM sleep leads to an increase in inflammation in the body.

5 HEAVY SLEEPERS OF THE NATURAL WORLD

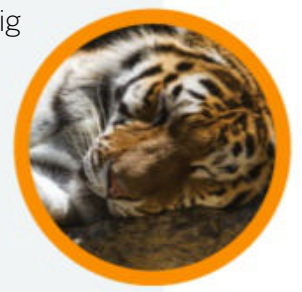
1 SLOTHS
Living up to their stereotype, sloths are keen sleepers. For up to 15 hours of the day, sloths are nestled in the treetops asleep, leaving them with around nine hours to find food.



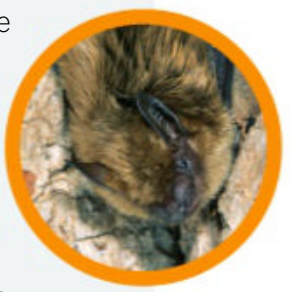
2 ARMADILLOS
While they are curled up in their burrows, most species of armadillos spend around 16 hours per day asleep before they emerge in the morning to forage for insects.



3 SUMATRAN TIGER
Like many other big cats, Sumatran tigers spend the majority of their day – around 18 hours of it – asleep to conserve their energy.



4 LITTLE BROWN BATS
For around 20 hours of the day, brown bats are snoozing upside down waiting for night to fall. As nocturnal creatures, bats roost until dusk, when they emerge to hunt insect prey.



5 KOALA
These iconic Australian marsupials sleep for 20 to 22 hours per day. What little time they do send awake is spent eating around a kilogram of eucalyptus leaves for energy.

HOW FOOD IS FERMENTED

This ancient preservation technique transforms foods' taste and appearance

WORDS **AILSA HARVEY**

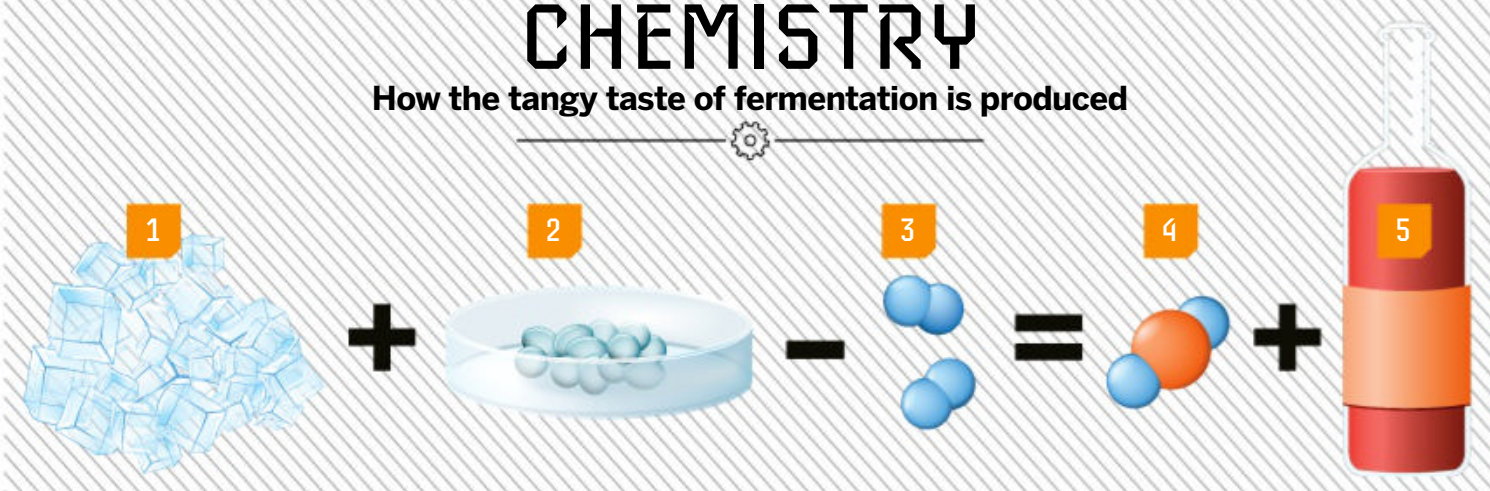
Did you know?

Surströmming is banned by many airlines

When some species of yeast and bacteria are added to certain foodstuffs, these microorganisms digest carbohydrates like starch and sugar and convert them into acidic and alcoholic compounds. The flavours of fermentation can be divisive, but for those who are fans of distinctive fermented foods such as kimchi, kombucha and yoghurt, the transformation that takes place in the fermentation process has both taste and health benefits – boosting your immune and digestive systems. The earliest record of fermentation dates back to 6000 BCE, used as a vital method to preserve food for long periods. In other instances, such as the fermentation of garri in Western Africa, the process began as a vital safety precaution. Garri is a product made from the root vegetable cassava. Cassava contains poisonous cyanides, but the five-day process of fermenting the cassava pulp in sealed bags converts it into a safely edible product.

ALTERING FLAVOUR CHEMISTRY

How the tangy taste of fermentation is produced



1 SUGAR
Sugar is the yeast's nutrition. As the enzymes in yeast consume the sugar, they produce carbon dioxide.

2 YEAST
Saccharomyces cerevisiae yeast is commonly used in fruit and vegetable fermentation.

3 ANOXIC
To break down sugars in foods, fermentation takes place in conditions with no oxygen. Any oxygen will encourage unwanted microorganisms to accumulate and change the taste.

4 CARBON DIOXIDE
This gas is a waste product of fermentation, but it adds to the flavour, creates the bubbles in beer and makes fermented bread rise.

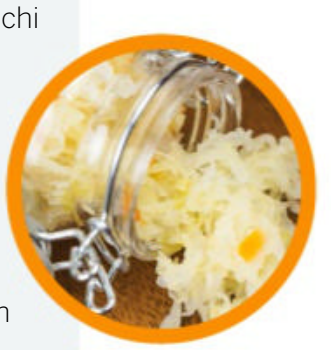
5 ALCOHOL
Yeast converts sugar into alcohol, producing a tart flavour and serving as a natural food preservative.

5 FACTS FERMENTED DELICACIES

1 CURED MEATS
Meats such as salami, bresaola, bologna and pepperoni are pressed, dried and fermented with salt or sugar. They are then dried so that the meat can be preserved for months.

2 MISO
Soybeans are fermented with kōji mould and salt to produce miso. Miso is a Japanese seasoning paste with an umami salty-sweet flavour.

3 VEGETABLES
Sauerkraut and kimchi are examples of fermented vegetables. Sauerkraut is pickled and fermented cabbage, often complementing sausages in German cuisine. Kimchi is Korean and is a result of fermenting cabbage in spicy brine.



4 SOURDOUGH
Wild yeast and bacteria are used to make sourdough bread rather than typical baker's yeast. Fermentation of the bread takes between six and eight hours.

5 SURSTRÖMMING
Swedish fermented herring has a reputation for being stinky. It is illegal to carry it on many forms of public transport. They are transported in special vehicles with sealed doors.

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HISTORY

ANCIENT EGYPTIAN INVENTIONS

Discover the weird and wonderful technological accomplishments of one of the earliest civilisations

WORDS **SCOTT DUTFIELD**

DID YOU KNOW? Each of the great pyramids would have taken between 15 and 30 years to construct

Did you know?

There are more than 700 hieroglyphic symbols

An ancient Egyptian wig, popular during the period of the New Kingdom

WEAVING THE FIRST WIGS

The earliest known wig dates back to around 3400 BCE, found in a female burial site at Hierakonpolis, also known as the City of the Hawk. Typically worn among the elite of ancient Egyptian high society, wigs served as a way for both men and women to show status and wealth within the social hierarchy. They also offered some protection against the Sun's heat for members of the nobility that shaved their heads. Wigs were also used for cleanliness and the prevention of head lice.

Wigs were made from human hair, either taken from the wearer's head or traded for, before a coating of beeswax or plant resin was applied for protection. Locks of hair could then be twisted, plaited or curled into shape by ancient hairdressers. To form the netted base of the wig, fine strands of plaited hair were woven together, often incorporating string and leather straps. Each lock of hair could be individually attached to the net to form the overall wig. Like any fashion trend, the style and appearance of wigs changed throughout the 3,000-year history of ancient Egyptian civilisation. From the short chin-length bobs that were favoured during the Old Kingdom, which lasted from 2649 to 2130 BCE, to the divided upper curl and lower shoulder-length plaits often worn during the New Kingdom, from 1550 to 1070 BCE, the ancient Egyptians wore a range of styles, which also included elaborate gold hair accessories.

As the predominant writing material, papyrus was used to produce academic scrolls, correspondences and legal documents

PUTTING PEN TO PAPYRUS

The first evidence of the ancient Egyptians using papyrus to document life in their early civilisation was excavated from the tomb at Saqqara, south of Cairo, and dates back to around 2900 BC A tall, fibrous plant called papyrus (*Cyperus papyrus*) once lined the banks of the Nile and filled the marshes that encapsulated the river. By slicing the pith (lining) of the plant lengthways, they created strips of plant matter that, when soaked, stuck together rather well and dried into a robust sheet. Although papyrus paper was typically made in individual sheets for record-keeping and list-making, the majority of papyrus paper was glued together to form long scrolls, which were then rolled around wooden sticks. Ancient text, hieroglyphs and scripture were painted on the scrolls with naturally sourced ink. Originally, red and black inks which were made from the soot of burnt vegetables or hydrated iron oxide were used to paint papyrus.

Papyrus was adopted throughout Europe, particularly in ancient Rome and Greece, before parchment swept the continent. However, it wasn't until around 2,000 years ago, during the Chinese Han dynasty, that court official Cai Lun invented paper-making. With its invention, after around 4,000 years of service, papyrus was slowly phased out of mainstream use.

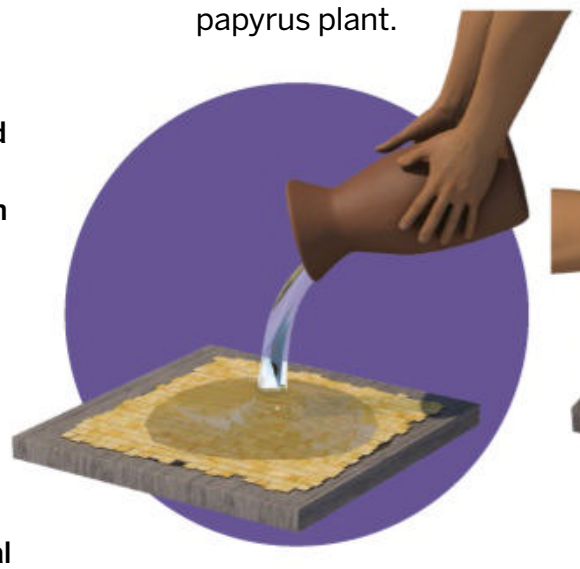
HOW TO MAKE PAPYRUS PAPER

Turning river plants into ancient scrolls

1 PLANT
Along the marshy banks of the River Nile grew the papyrus plant.

2 CUTTING
The triangular stalk of the papyrus plant was cut into long strips.

3 LAYERING
Papyrus strips were layered in alternating orientations, horizontally then vertically.



4 SOAKING
Strips were soaked in water to release the natural glue-like chemicals found in papyrus.

5 PRESSING
The sheets were pressed to remove excess water and left to completely dry out.

6 SCROLL
Papyrus sheets were joined end to end using natural gum to form a rolling scroll.

DID YOU KNOW? The first policing organisation was created by the ancient Egyptians around 3000 BCE

An Egyptian bowling ball on display in Bristol Museum & Art Gallery

THE BIRTH OF BOWLING

In 1930, British anthropologist Sir Flinders Petrie discovered the contents of a child's grave dating back to 3200 BCE. Among the objects uncovered was a ball and set of pins, reminiscent of those used in bowls. Unlike the dense plastic balls of today, the ancient Egyptians used a variety of materials to make their balls. Some were formed from husks of grain and leather, bound together with string, while others were made of polished rock and porcelain. Corn husk balls may have been thrown to knock down pins.

Ancient toothpaste called for many charred and burnt ingredients

THE FIRST TOOTHPASTES

Clean teeth have been a concern for thousands of years, but it was the ancient Egyptians that created one item you're sure to have: toothpaste. Unlike the minty-fresh feeling you get after scrubbing your teeth today, the recipe for toothpaste around 5000 BCE didn't have quite the same taste. It was packed with some unusual ingredients, combining several abrasive materials to remove plaque and debris, including ground pumice stone and charred eggshells. Add some ox hoof ashes, dried iris flower, water, rock salt and pepper, and you've got yourself a toothpaste fit for a pharaoh.

THE WORLD'S OLDEST DRESS

Uncovered by Egyptologists in 1977 following the excavation of a First Dynasty tomb in Tarkhan, the world's oldest dress is a linen garment that would have fit a young teenage girl. The dress comes in three parts, including pleated sleeves and a bodice. However, the hem of the dress is missing, and therefore its exact length remains unknown. To date the dress, researchers at the University of Oxford used radiocarbon dating on a 2.24-milligram sample of the fabric. By measuring the amount of decay experienced by the carbon atoms within the linen, scientists have estimated that the dress was created between 3482 and 3102 BCE.

Did you know?

Cleopatra bathed in milk to reduce her wrinkles

The remains of the earliest known dress, dating back to the First Dynasty

5 FAB COSMETIC CREATIONS

1 EYESHADOW
A vibrant-green copper carbonate mineral called malachite was crushed and turned into a paint that was applied to the eyelids around 4,000 years ago.

2 EYELINER
Powder eyeliner called kohl was made from a dark concoction that included a lead sulphide mineral called galena and soot.

3 LIPSTICK
Also applied as cheek rouge, ancient Egyptians used a natural clay called red ochre, along with flowers, beeswax and even fish scales, to make vibrant red lipsticks.

4 HAIR DYE
Mummies have been unearthed with hair samples dyed using the henna shrub (*Lawsonia inermis*). When the henna interacted with the hair's keratin, it turned the hair a red colour.

5 PERFUME
Hieroglyphics suggest that around 5,000 years ago, ancient Egyptians made sweet-scented perfumes from ingredients such as frankincense, myrrh and cinnamon.

An example of the first wooden door locks made in ancient Egypt

Did you know?

The mummification process took 70 days to compete

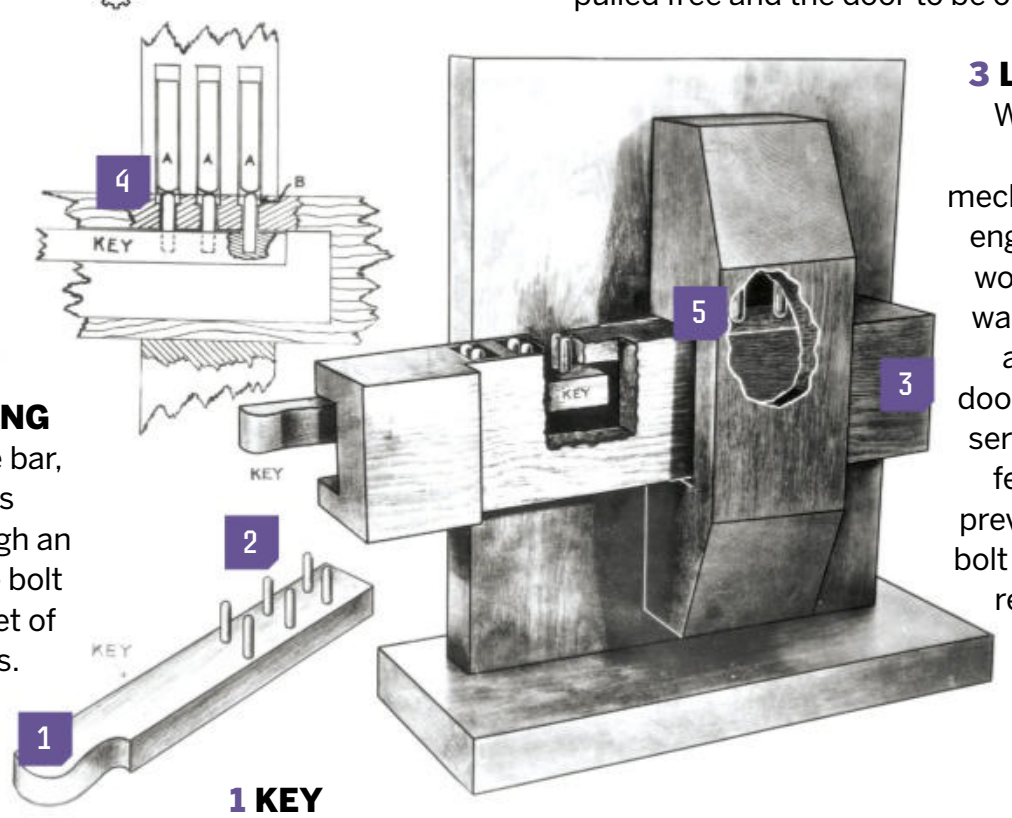
EGYPT UNDER LOCK AND KEY

The origins of the modern-day lock date back to both ancient Mesopotamia and Egypt around 4000 BCE. One of the first locking systems ever created was a pin tumbler lock, commonly known as the Egyptian lock. Assembled completely from wood, this lock used a series of moving pins that, when positioned correctly, fell into the gaps of a wooden bar or bolt that had been placed across the gap of a door and a wall. When a toothbrush-like key with the corresponding pegs was inserted into the bolt, the key pegs lifted the pins from the bar and released them from the lock. The bar could then slide out and the door could be opened.

There was a second design for the Egyptian lock that used the same locking system, but instead of inserting the key directly into the bolt, it was placed in a slot above it to lift an initial set of pins, which in turn lifted a secondary set holding the bolt in place. This simple yet effective mechanical device was used by ancient civilisations in much the same way as it is today, to secure personal belongings and to protect homes and places of worship. Over time, pin-timber locks spread through Europe, and around 200 CE the Romans adapted the Egyptian design to create new pin-tumbler locks made from bronze and iron.

INSIDE A LOCK

The locking mechanism used in ancient Egypt was basic, but effective



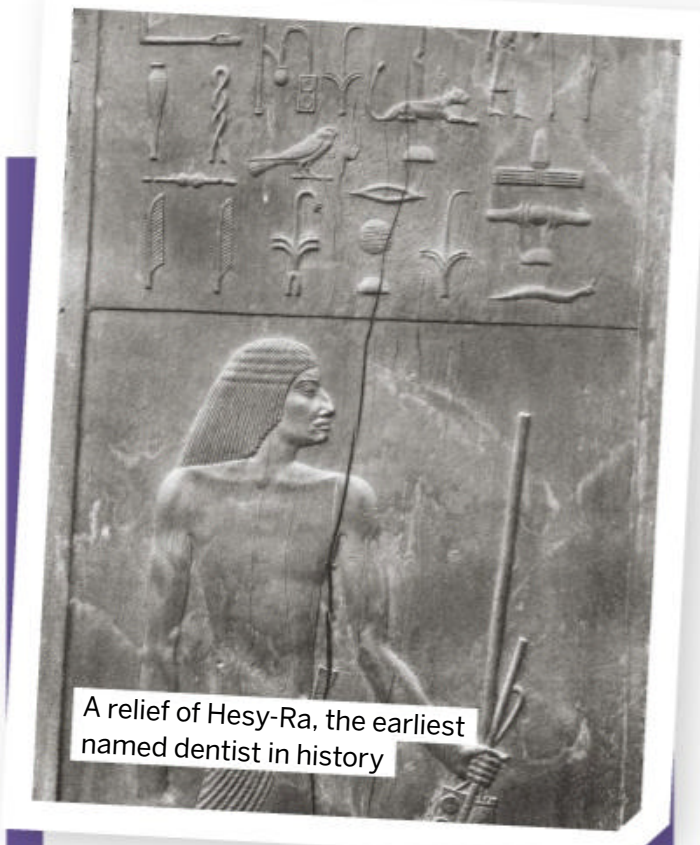
4 UNLOCKING
To remove the bar, the key was inserted through an opening in the bolt to meet the set of locking pins.

3 LOCKING
When the locking mechanism was engaged, the wooden bolt was inserted across a doorway and a series of pins fell into it, preventing the bolt from being removed.

5 FREEING THE BOLT
Once the key was lifted slightly, it would move the lock's pins upwards and out of the bolt, allowing it to be pulled free and the door to be opened.

1 KEY
Like any good lock, a paired key was used to unlock the mechanism.

2 PINS
The long-handled key sported a series of pegs that corresponded to the position of a series of pins within the lock.



A relief of Hesy-Ra, the earliest named dentist in history

ANCIENT DENTISTS

The first recorded dentist was an ancient Egyptian by the name of Hesy-Ra, a high-ranking officer to Pharaoh Djoser around 2600 BCE. Hesy-Ra was bestowed many titles during his life, including the 'chief of dentists and physicians'. Studies have shown that the majority of ancient Egyptians, both rich and poor, were subject to heavy tooth wear and decay. This may have been the result of abrasion caused by eating certain high-fibre foods, along with desert sand contamination of their favourite food, bread. In the Ebers Papyrus, the oldest medical scroll of ancient Egypt, the recipe for an 'itchy tooth' consisted of one part cumin, one part resin of incense and one part dark fruit, crushed together and applied to the tooth.

Dental samples taken from different tombs revealed that the ancient Egyptians engaged in several dental surgical procedures, including tooth extractions and potentially prosthetic work. One of the best known examples of ancient Egyptian prosthetics is commonly known as the Giza Bridge, which dates back to 2500 BCE. Archaeologists discovered a pair of molars that had been connected by a piece of gold wire at a burial site in Giza in 1914. Researchers originally believed that the wire twisted around the teeth was used to hold one of the teeth in the jaw. However, further analysis in 2013 suggested that the Giza Bridge may have been constructed after the teeth had fallen out or been removed. The binding may have been a way to hold the teeth together or as a way to wear them as an amulet for protection.

DID YOU KNOW? The oldest description of cancer can be found in the 5,000-year-old Edwin Smith Papyrus

5 WAYS ANCIENT EGYPTIAN MEDICINE IS USED TODAY

1 FEELING A PULSE
Ancient Egyptian and Chinese civilisations were some of the first to make the connection between the body's circulatory system and heartbeat by feeling a pulse.

2 TAMPONS
The earliest evidence of tampons is found in ancient Egypt, which were made from cloth and often referred to as a 'tyet', or the 'knot of Isis'.

3 OPIOIDS
Made from poppy seeds, ancient physicians produced poppy juice to tackle pain relief and use in surgery. However, this potent cocktail would not have been as concentrated as modern-day opioids.

4 LEECHING
The use of leeches to remove blood from the human body has been around for thousands of years. The practice of bloodletting was seen in the paintings within an Egyptian tomb dating to around 1500 BCE.

5 TRANSSPHENOIDAL SURGERY
Originally created to extract the brain through the nose during mummification, this technique is now used to cut away tumours growing on the pituitary gland.

MEDICAL RECORD

The Temple of Kom Ombo in Upper Egypt contains this relief depicting ancient medical instruments

1 NEEDLES
Wounds and incisions were stitched together with needles and plant or wool-fibre threads.

2 HOOKS
Used to extract foreign objects from wounds or from within the body during surgery.

3 FORCEPS
These were used to grip objects within the body, such as bones or arrowheads.

4 CUPPING VESSELS
These devices brought blood to the skin's surface to draw out impurities using suction.

5 SCALPELS
Used to make incisions during surgery or during the embalming process.

6 SAW BLADES
Deployed when a surgeon needed to cut through tough material, such as bone.

7 CATHETERS
Reeds, bronze tubes and curled-up palm leaves were used as catheters to treat urinary retention in males.

A painting of a physician treating a patient in ancient Egypt

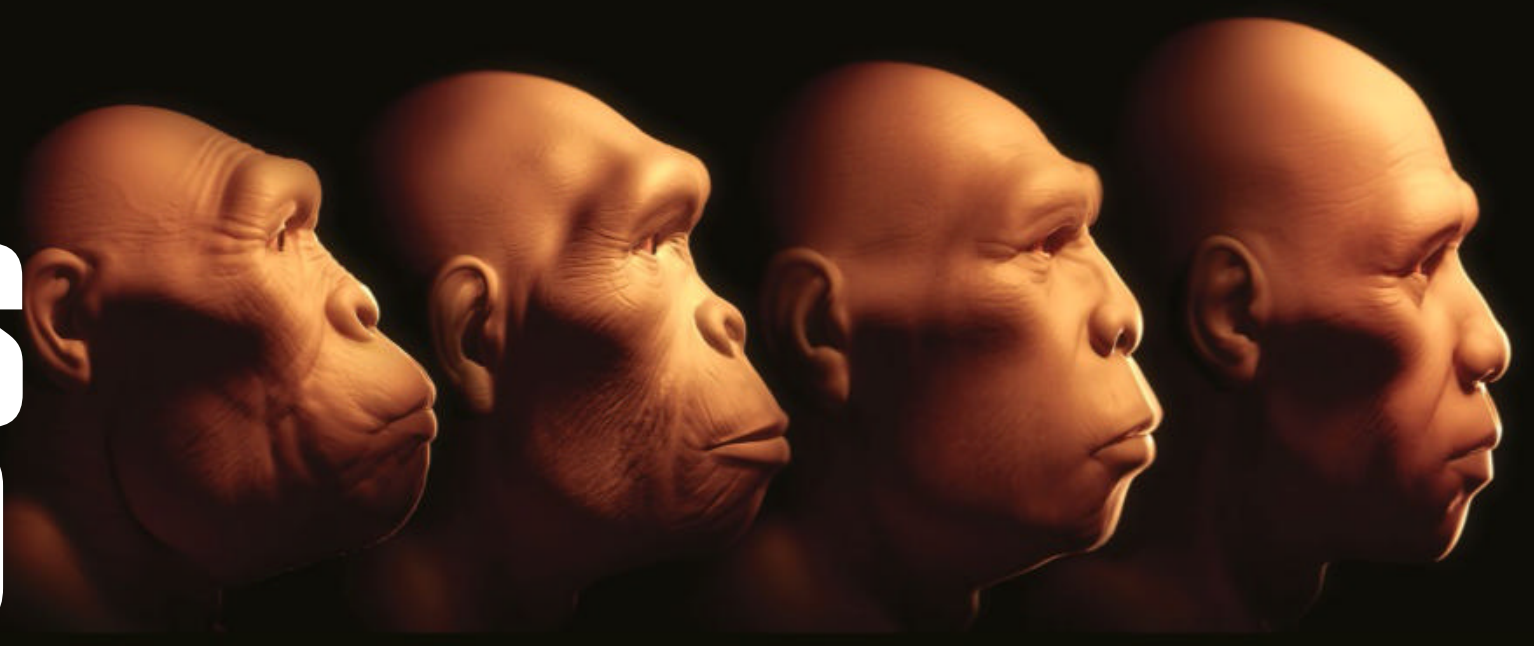
THE START OF MODERN-DAY MEDICINE

The ancient Egyptians were some of the earliest pioneers of healthcare and surgery. The first account of a practising physician was made in 3533 BCE, when the Fifth Dynasty Pharaoh Sahure was treated for a disease in his nostrils by a chief physician named Sekhet'enanch. Throughout their history, ancient physicians like Sekhet'enanch created and practised a whole host of remedies for ailments and illnesses, such as using plant resin to heal wounds or metals as antimicrobials. Researchers have also uncovered the use of many medicines, such as laxatives made from castor oils, and rubefacients to stimulate blood flow.

Prosthetics also found their way into the world through ancient Egypt. One of the earliest examples of a prosthetic was found strapped to the foot of a 3,000-year-old mummy. In place of the remains of a big toe, the mummy sported a wooden toe prosthetic attached to a wax and leather strapping. It's believed that the wearer of the wooden toe was the daughter of a high-status priest.

Ancient Egyptian and Greek civilisations were also the first to use organised medical kits. Within the Temple of Kom Ombo, an ancient medical centre used between 180 and 30 BC near the city of Aswan in Egypt, are several hieroglyphic walls that outline the many fields of medicine, as well as the tools ancient doctors used to treat their patients.

HOW HUMANS EVOLVED



Step through history, from the first walking humans to the *Homo sapiens* of today

WORDS AILSA HARVEY

People are complex animals who navigate the world on two feet, have advanced thoughts and form varied social groups. The species we all belong to is *Homo sapiens*, and to understand this specialised taxonomic group we've evolved into, we need to look back at more than 20 hominid species that form our family tree. *Homo sapiens* evolved from these species over millions of years, and since the first *Homo sapiens* emerged around 300,000 years ago in Africa, our lives and characteristics have adapted to new circumstances.

One of the oldest early human species is *Orrorin tugenensis*. This species was about the same size as a chimpanzee and would climb trees to get around its habitat in Eastern Africa. When the fossils of *Orrorin tugenensis* were discovered in Kenya in 2001, the upper femur had skeletal similarities to typical upright-walking humans. Its features were more ape-like than human, but it was evidence of one of the first species that combined the ability to climb and walk.

The first species to be categorised in the same genus as today's humans was *Homo habilis*. Evidence of this species was found in East Africa, living between 2.8 and 1.5 million years ago. They made stone tools and had round skulls like modern humans. *Homo erectus* evolved directly from *Homo habilis*. This species was the first to specialise completely in walking, using their larger brains to make advanced tools and control fire. *Homo erectus* became extinct around 100,000 years ago.

A similar species to *Homo sapiens* was *Homo neanderthalensis*, or Neanderthals. However, they didn't evolve from the same species that produced modern humans. The Neanderthals did share a common ancestor with *Homo sapiens*, though: *Homo heidelbergensis*, which lived around 800,000 years ago. Modern humans evolved in Africa, while some members of *Homo heidelbergensis* ventured out of Africa and evolved into Neanderthals. When modern humans migrated out of Africa, they interbred with Neanderthals, and many people today can trace a small percentage of their DNA to this ancient species.

The earliest ancestors of *Homo sapiens* were hunter gatherers, and our species developed much lighter skeletons. One of the most noteworthy adaptations of early humans, which also helped *Homo sapiens* become the only surviving human species today, were skull adaptations. With flat foreheads, thin walls and a high vault – the area which houses the brain – the human brain was able to grow larger, leading to more intelligent beings. In turn, this adaptation in *Homo sapiens* meant that the species could interact with new surroundings and problem-solve by creating tools when climate change produced unpredictable environments.

Did you know?

The appendix was likely a digestive organ in human ancestors

BECOMING HUMAN

The milestones that made you the person you are today

6 MILLION YEARS AGO

UPRIGHT POSTURE

Early humans' short legs evolved to support the body in an upright posture. This was likely an adaptation to the retreating forests and more open landscapes.

4.1 MILLION YEARS AGO

BIPEDAL WALKING

To accommodate this new method of mobility, humans developed a wider knee joint to support body weight.

3.6 MILLION YEARS AGO

FOOTPRINTS

Preserved footprints from one of *Homo sapiens*' earliest ancestors, *Australopithecus afarensis*, were made in wet volcanic ash. They prove that these early humans also walked in a heel-toe motion.

DID YOU KNOW? Human and ape evolutionary paths separated 6 million years ago

800,000 YEARS AGO

BIGGER BRAINS

The most rapid increase in early human brain size began, fuelled by high-energy foods such as meat.

1.8 MILLION YEARS AGO

OUT OF AFRICA

Homo erectus moved to Asia from Africa as droughts forced them to find new sources of food and water. All fossils discovered from before this point have been found in Africa.

1.9 MILLION YEARS AGO

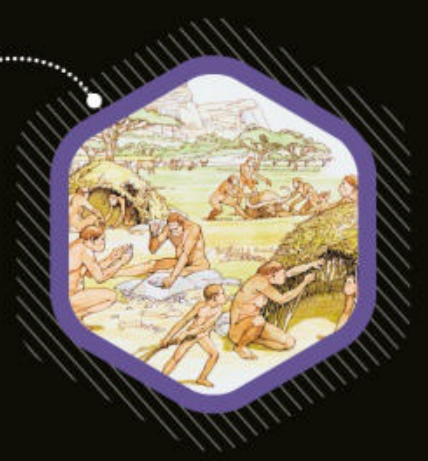
WALKING STAMINA

As humans began to walk further and faster, the hip bones became stronger and thigh bones longer.

2.6 MILLION YEARS AGO

TOOL-MAKING

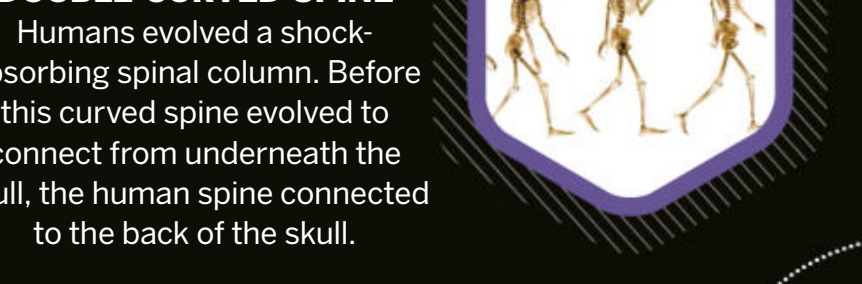
In the early Stone Age, humans learned to build basic tools and hunted large animals for meat.



2.5 MILLION YEARS AGO

DOUBLE-CURVED SPINE

Humans evolved a shock-absorbing spinal column. Before this curved spine evolved to connect from underneath the skull, the human spine connected to the back of the skull.



200,000 TO 300,000 YEARS AGO

FIRST HOMO SAPIENS

The first modern humans evolved. Modern humans have a large, round braincase, a chin, narrow pelvis and no brow ridge.

160,000 YEARS AGO

CHILDHOOD GROWTH

Big brains require more energy. Because of this, human childhood is much longer than in other species. The age of reproduction became delayed, as found in humans today.

60,000 YEARS AGO

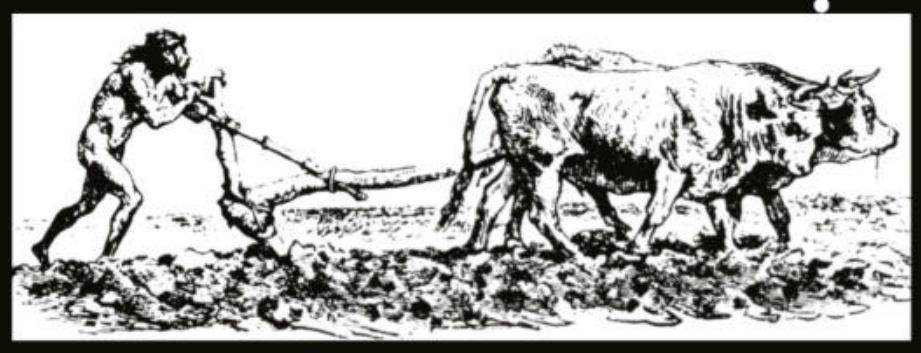
WORLDWIDE MIGRATION

Homo sapiens began a migration out of Africa 60,000 years ago. Many groups continued to travel and explore until humans lived across the entire globe.

12,000 YEARS AGO

TURNING POINT

The Agricultural Revolution was a turning point for human life on Earth. Humans started to control the growth of plant life and breeding of animals. This also impacted where communities settled.



"When modern humans migrated out of Africa, they interbred with Neanderthals"

8,000 YEARS AGO

RISE OF WORDS

By this stage, modern humans were using symbols for different words and communicating different concepts. Humans had become complex beings.

104,000 YEARS AGO

FAST HUNTING

By this stage, humans were able to catch fast prey. Instead of relying on hand axes, humans had stone-tipped spears made of bone, ivory or antler.

74,000 YEARS AGO

NEAR-EXTINCTION

The population of *Homo sapiens* reduced from 10,000 to an estimated 600 adults. Scientists thought that this dramatic reduction was due to the Toba volcanic eruption significantly altering the climate, but recent studies debunk this.

WHO DISCOVERED THE SOLAR SYSTEM?

How mathematical masterminds and innovative technology helped unveil what was beyond Earth

WORDS **AILSA HARVEY**

The extensive knowledge we hold about the Solar System today has come from direct observations of space or theories based on these observations. Through the lenses of telescopes, astronomers have discovered hundreds of moons, supermassive black holes, billions of rocky chunks that make up Saturn's rings and clouds indicating a toxic atmosphere on Venus, among other things. These detailed features of planets and space objects were once unviewable. And before this, having definitive knowledge of any world outside our own was completely unfathomable. Different cultures made up their own far-flung theories of what the glistening dots that took up the night sky could be.

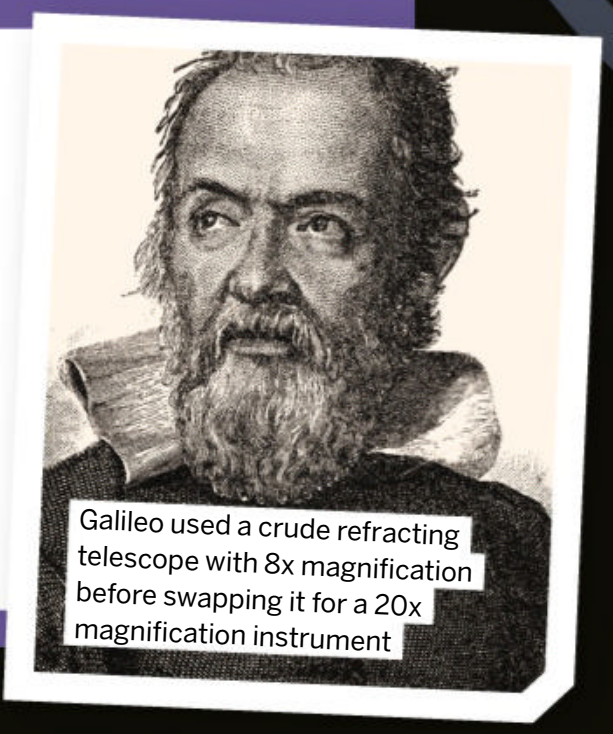
In the 1500s, around the time that people were coming to terms with the fact that Earth was round, Polish astronomer and mathematician Nicolaus Copernicus stated his theory that we revolve around the Sun. Before this finding, people generally thought that Earth was at centre of the universe. In 1515, Copernicus changed people's understanding of our place in the Solar System by explaining how Earth was a planet like Venus or Saturn. His theory was made by observing the shift of visible stars over the course of many months, as Earth moved from one side of its orbit to the other. But Copernicus' theory wasn't widely accepted until a century later. In the 1600s, German mathematician Johannes Kepler began working on mathematical laws that could explain the orbits of different planets around the Sun. Kepler's first law stated that the planets move in an ellipse, an imperfect circle, with the Sun at one focus point. The second law was that a planet covers the same area of space in the same amount of time at any point in its orbit. The final law was that a planet's orbital time is proportional to the size of the orbit. Mathematicians and scientists of this time were crucial in beginning to uncover the fundamental workings of the Solar System. Thanks to the invention and evolution of the telescope from the 1600s onwards, revelations about worlds beyond Earth continue to emerge to this day.

Did you know?

Galileo was imprisoned for saying Earth orbits the Sun

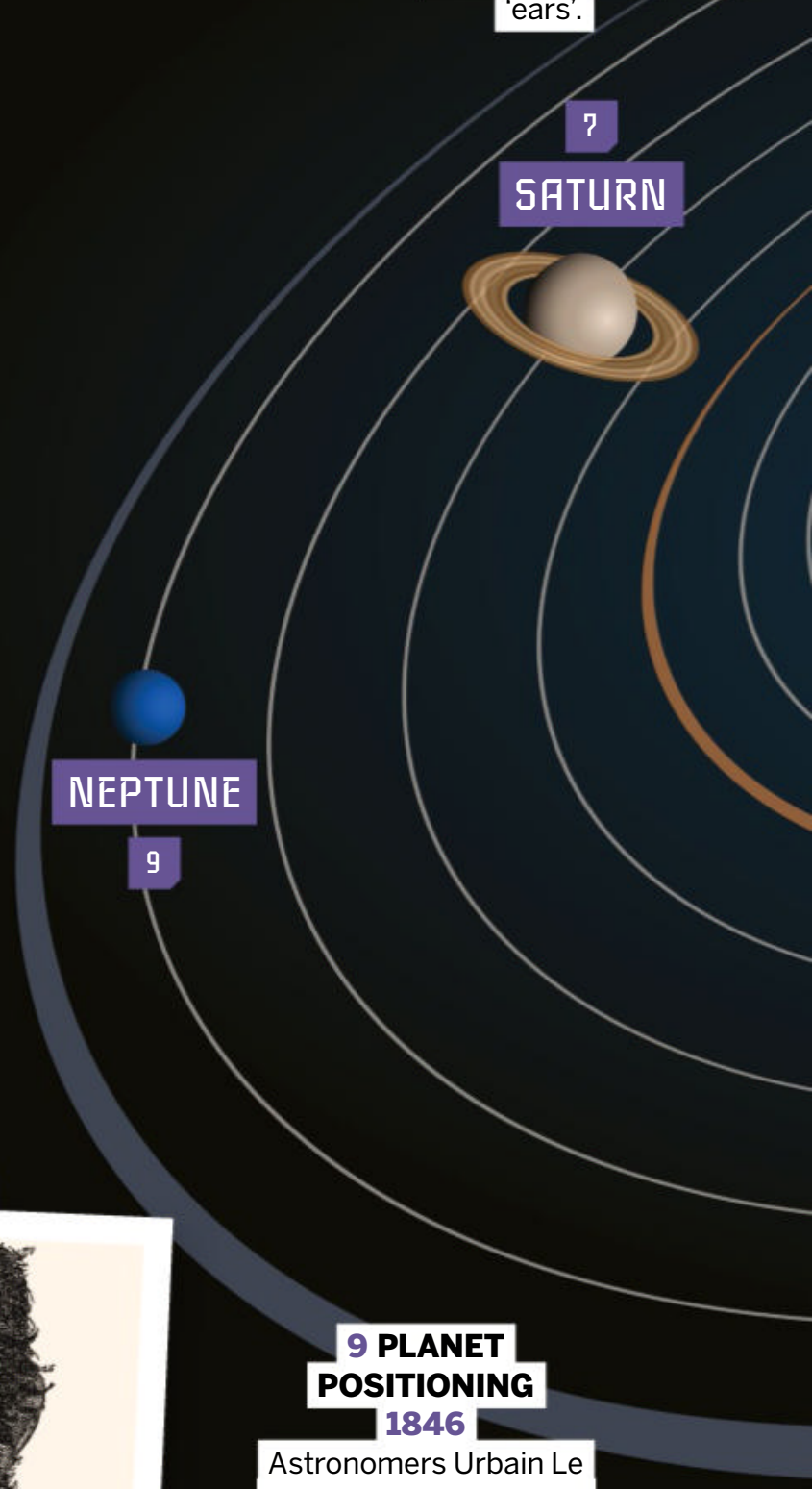
STUDYING THE MILKY WAY

Unlike scientists before him, who could only study space with the naked eye, Italian astronomer Galileo Galilei was the first to study the night sky and view the Milky Way using a telescope in 1610. The invention of the telescope enabled him to see objects in outer space clearer than ever before. Copernicus had only been able to see the Milky Way as a massive band of 'cloud', while Galileo could focus on the many individual stars that make up our galaxy and its spiral arms. Galileo made notes of every observation and became the first person to discover that the Milky Way is a large group of stars, planets and other celestial objects. Following further study of the Solar System, Galileo was also the first to see sunspots, Moon craters and to record the phases of Venus.



Galileo used a crude refracting telescope with 8x magnification before swapping it for a 20x magnification instrument

7 SEEING SATURN'S RINGS
1610
Galileo spotted Saturn's rings over 400 years ago. He described the planet as having 'ears'.



9 PLANET POSITIONING
1846
Astronomers Urbain Le Verrier and John Couch Adams calculated Neptune's position correctly using mathematics. It was then identified as a planet by Johann Gottfried Galle.

DID YOU KNOW? Copernicus died shortly after publishing his heliocentric theory of the Solar System in 1543

2,500 YEARS IN THE MAKING

How have past discoveries shaped our understanding of the Solar System?

1 CENTRAL STAR
450 BCE
Greek philosopher Anaxagoras conceived the earliest known theory that the Sun is a nearby star.

2 ROTATION SPEED
1965
Scientists discovered that Mercury rotates three times in two orbits. Before this it was believed that the same side of the planet always faced the Sun.

3 VENUS IN FOCUS
1610
Galileo was the first person to see Venus up close through a telescope. By studying its phases, he could prove that Venus travelled around the Sun, not Earth.

4 RED PLANET ICE CAP
1672
Dutch astronomer Christiaan Huygens made the earliest observations of Mars' southern polar cap.

5 VISITING THE BELT
1972
Pioneer 10 was the first spacecraft to reach and pass through the asteroid belt.

6 REACHING JUPITER
1974
Pioneer 10 made the first close Jupiter approach from 80,998 miles away. It captured the detail of Jupiter's Great Red Spot as part of 500 pictures.

8 COMET OR PLANET?
1781
Uranus was first observed by astronomer William Herschel, but he thought it was a comet or star.

10 PLOTTING PLUTO
1930
Clyde Tombaugh of Lowell Observatory noticed that one star in a pictured starfield was moving. He had discovered Pluto, which was reclassified as a dwarf planet in 2006.

5 COOL COSMIC REVELATIONS

1 UNIVERSE COMPLEXITY
American astronomer Edwin Hubble proved that the Milky Way is just one of many galaxies, all moving away from each other.

2 NEBULAE VELOCITY
By 1917, American astronomer Vesto Slipher had recorded the velocities of 25 spiral nebulae, which were later proven to be galaxies.

3 COSMIC DISTANCES
Henrietta Swan Leavitt's study of Cepheid variable stars was published in 1912, allowing astronomers to measure cosmic distances and revealing the huge scale of the universe.

4 FATHER OF THE BIG BANG
Belgian physicist and priest Georges Lemaître was first to propose the Big Bang theory, which he named the 'hypothesis of the primeval atom', in 1927.

5 THE EXPANDING UNIVERSE
Georges Lemaître and other scientists worked out that the universe is continually expanding, but it wasn't until Hubble published this in 1929 that it became public knowledge.

DID YOU KNOW? London Heathrow is the UK's busiest airport – around 191,200 passengers pass through it every day

HOW AIRCRAFT GO MISSING

The disappearance of Flight MH370 shows that even with today's technology, planes can simply vanish. But why is that, and how can we stop it happening?

WORDS TIM HARDWICK

Kuala Lumpur International Airport is home to one of the busiest terminal complexes in Southeast Asia and handles almost 40 million passengers a year. Boarding the chartered Boeing 777 at around midnight, the 239 passengers on Malaysia Airlines Flight MH370 would have believed they were headed for Beijing, China, along a routine flight path on one of the safest commercial jets in operation. But just 40 minutes after takeoff, the pilots made their last contact with air traffic control and all signals from the aircraft were lost. The flight was never heard from again.

It seems unthinkable that a passenger jet could vanish into thin air, especially when technology such as GPS and satellite communications are available. Aircraft are fitted with GPS systems, which pilots use for navigation. However, relaying this location data to air traffic control would be prohibitively expensive, so many aviation authorities rely on a different tracking system, the origins of which date back to the 1930s.

Did you know?

Around 100,000 flights take place globally every day

Radar stations enable air traffic controllers to continually survey the skies by providing two essential tracking functions. The first is served by the biggest revolving antenna in a ground station, known as the primary radar. This system was devised before and during World War II to detect enemy aircraft, and works by sending out pulses of electromagnetic waves that

"It seems unthinkable that a jet could vanish into thin air when GPS and satellite communications are available"

© Getty

HOW RADAR WORKS

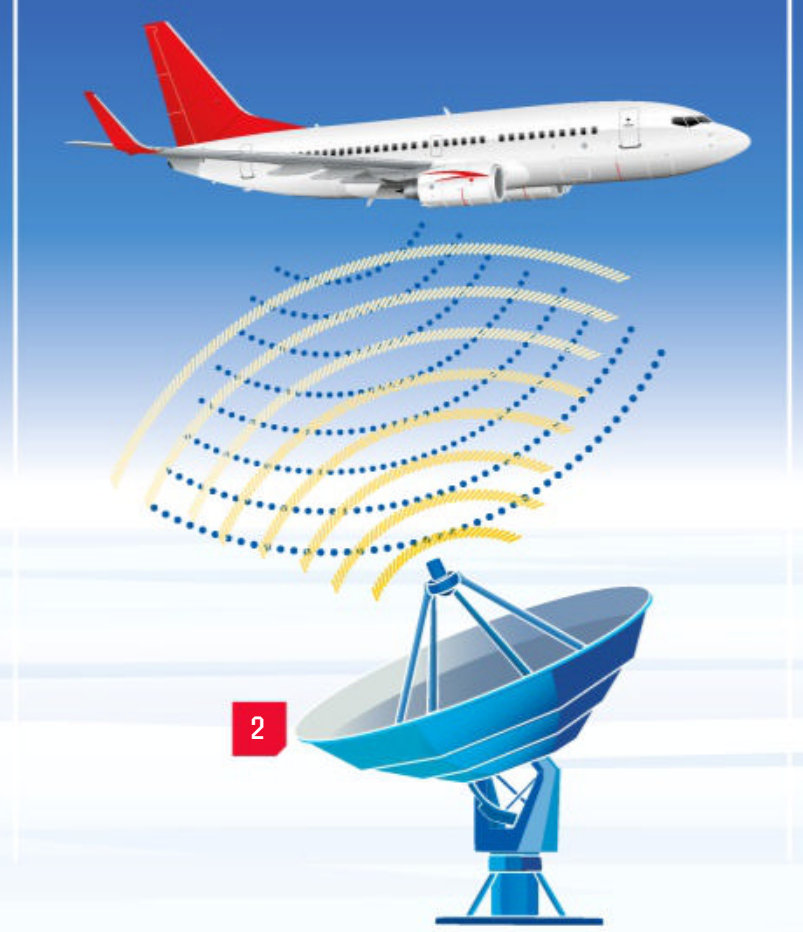
Our primary means of tracking aircraft relies upon the reflection of radio waves

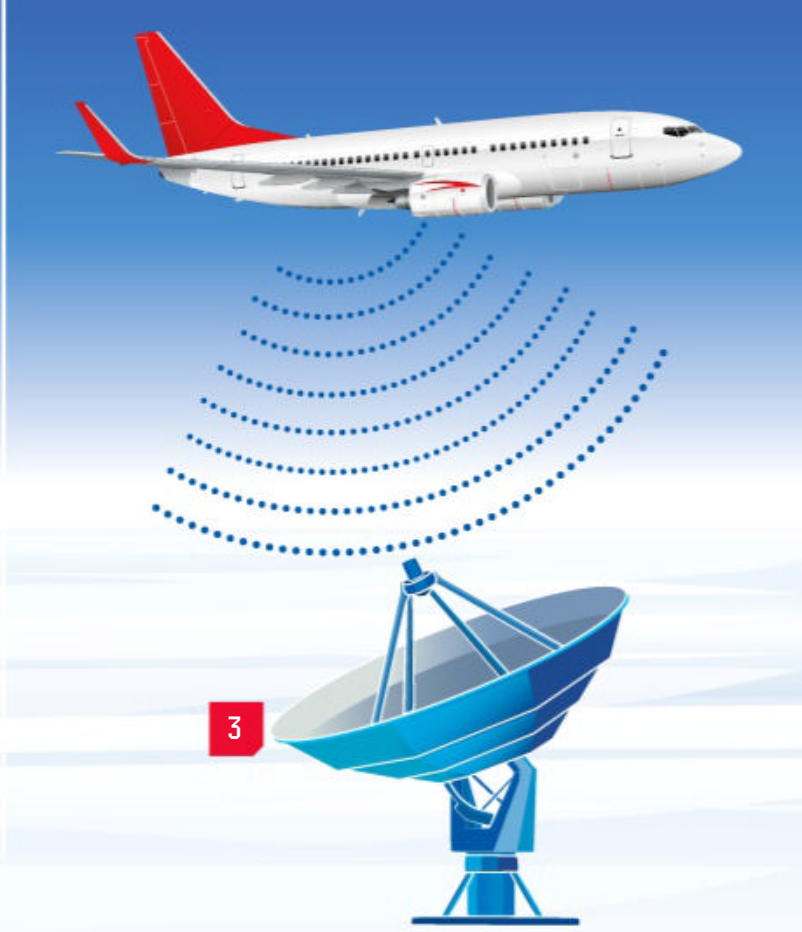
Ground staff track the movements of aircraft using radar – RAdio Detection And Ranging. This system measures the reflection of radio waves to pinpoint an aircraft. Radio waves are used because they travel close to the speed of light, making it easier for ground staff to respond to sudden changes. But once a plane is roughly 150 miles out to sea, coverage fades and air control must rely on either satellite communications or high-frequency radio waves capable of travelling further to stay in touch.

1 TRANSMISSION
Antennae on the ground work as transmitters, intermittently beaming high-frequency radio waves into the air. The curved shape of the dishes allows them to focus the waves into a precise beam, like a torch. The radio waves continue through the air until they hit something, such as an aircraft. This object then reflects the waves back to the ground.

2 LISTENING
The antennae alternate between transmitting radio waves – typically for a few thousandths of a second – and 'listening' for their return for up to a few seconds.

3 ANALYSIS
Received waves are processed and converted into a graphic on a visual display that's monitored by air traffic control staff on the ground. Basic radar can only tell us so much about what's in the sky, though, so aircraft fitted with transponders beam back additional information, such as the plane's identity and altitude.





bounce off any objects they come into contact with. These reflected echoes are in turn detected by the radar and appear as moving points on surveillance displays watched by staff in airport control towers.

Primary radar is effective at locating large metal objects and relaying their distance from the transmitter, as well as their 'azimuth' – their angle in relation to the observer and a reference point, usually north. However, the altitude of the located object remains unknown, as does its identity. In fact, there's no telling what a blip on a primary radar is – be it a tree, a hill or a flock of birds – without supplementary data, which is why secondary surveillance radar has become a mainstay of air traffic control since the 1950s.

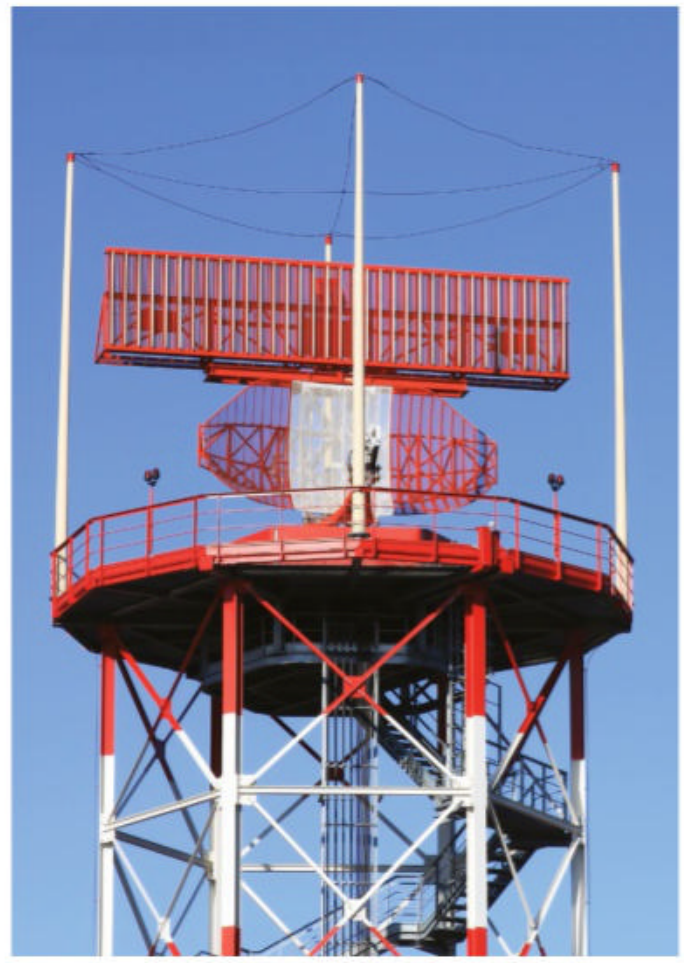
Based on military identification technology also developed during World War II, the secondary radar used at a ground station features a bar-shaped antenna that transmits another high-frequency signal over the primary one. If an aircraft fitted with a transponder flies into range, the secondary signal communicates with, or 'interrogates', the device, which then relays the requested information to the ground station. Usually this includes a four-digit identification code called a 'squawk', assigned by ground control via radio transmission, along with a readout from the aircraft's barometric altimeter. The pilot can also use the transponder to communicate an emergency message if needed.

Did you know?

MH370 still hasn't been found after nine years

Each sweep of the radar beacon registers a new block of data from the transponder to provide an up-to-date rendering of the aircraft's current position and status. But the system does have its limitations. Ground radar coverage can only cover about 149 miles out to sea, so if an aircraft passes beyond this, or if its transponder is turned off – as in the case of Flight MH370 – then the aircraft becomes invisible to radar.

Turning off a transponder isn't something that could happen by accident – it involves



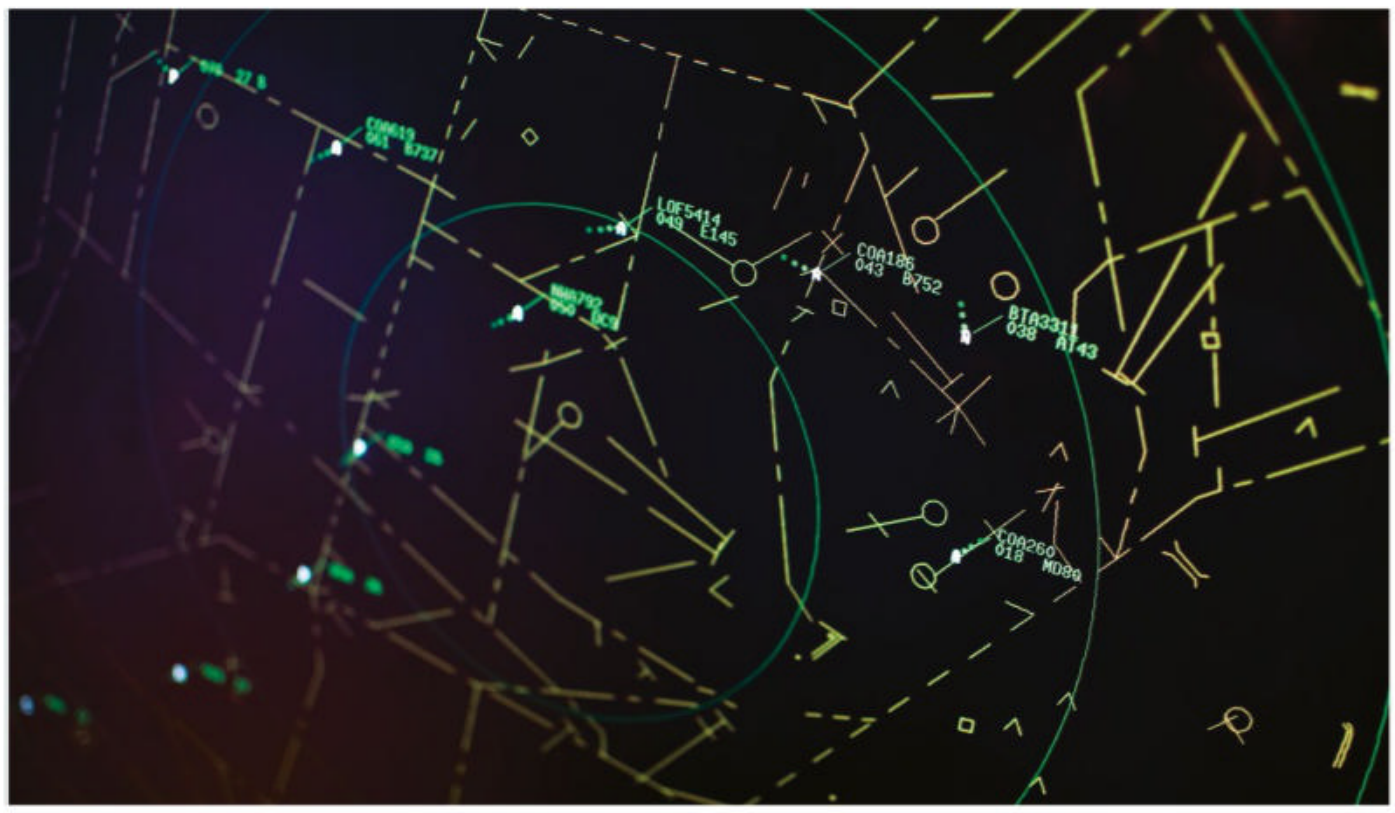
DID YOU KNOW? The acronym ‘radar’, initially proposed by the United States Navy, was first used in 1940

switching a number of cockpit controls in specific sequence to activate a touchscreen keyboard, before inputting the final command to switch off. But why would a pilot ever need to perform such an operation – one that could put the aircraft at extreme risk? “In the interests of safety – namely fire and electrical system protection – it’s important to have the ability to isolate a piece of equipment,” says pilot Patrick Smith, who runs the website **askthepilot.com**. “Also, transponders occasionally malfunction and transmit erroneous or incomplete data, at which point the crew will switch the device off and then on again, or swap to another unit.”

Evidence suggests that primary radar managed to track the missing Malaysian jet for at least an hour after its transponder had been turned off. The fact that it continued to fly in this fashion suggests that the flight was deliberately diverted by the pilot - which is one popular and controversial theory - or someone else on board. What it fails to explain, though, is why the aircraft ‘dropped off the map’ so easily in the first place.

The limitations of ground radar tracking led aviation authorities to adopt a digital datalink system in the 1970s, allowing pilots to transmit short, simple messages to ground control – similar to text messages – via satellite. But such a system becomes equally useless if, for whatever reason, the pilot doesn’t transmit those messages. The ideal solution would be for aviation authorities to find a cost-effective way for aircraft to automatically transmit their location to the ground using data from satellites.

An Automatic Dependent Surveillance-Broadcast (ADS-B) system does exactly this. Here an aircraft’s location is determined



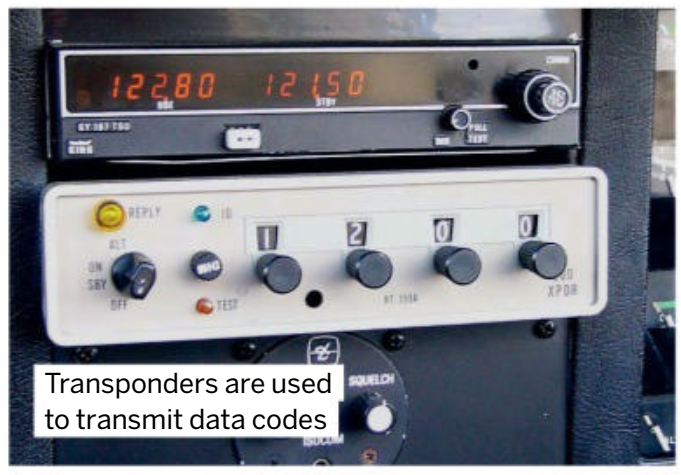
Top: Air traffic control staff are largely reliant upon radar to track aircraft

Above: Detailed information about aircraft is garnered through a combination of primary and secondary radar

© Getty

FLYHT's AFIRS device can stream live data on demand

The Boeing 777 Flight MH730: the flight that disappeared



Transponders are used to transmit data codes

using GPS. This information, along with other data such as the plane's flight number and speed, is transmitted using another kind of transponder that's usually attached to the underside of the aircraft "With ADS-B you get much more data at a lower cost," says Mikael Robertsson, co-founder and chief product officer of **flightradar24.com**, a flight-tracking website that has deployed over 3,200 ADS-B receivers globally. "Australia was the first country to use ADS-B, but any change in the aviation industry takes a very long time."

Uptake has been slow over the years, although the US Federal Aviation Authority mandated that the majority of aircraft operating in most US Federal Aviation Administration-controlled airspace had to be equipped with ADS-B by 2020. Richard Hayden, director of Canadian aviation company FLYHT Aerospace Solutions, warns that while the technology exists, "it just hasn't been employed on most planes."

Another solution, developed by FLYHT, is Automated Flight Information Reporting Systems (AFIRS), technology capable of streaming live data via satellites. Constantly transmitting data, as ADS-B does, requires significant bandwidth, which is costly. However, AFIRS is programmed to stream only when it's really needed, using event-driven triggered data transmission. Triggers might be a plane deviating from its flight plan, for example, or instruments and warning klaxons suggesting that there's a problem.

Did you know?

There are over 100 transponder codes used

The general reluctance of the aviation industry to roll out this technology has been blamed on the expense involved, but Hayden argues that this argument is based on a false premise – that data would need to be constantly streamed. "All AFIRS does is detect exceeded limits," says Hayden. "And there is no infrastructure investment associated with having such a capability. The infrastructure is already in place, and the only investment required is a computer that can access the internet."

The cost of the new technology isn't necessarily high. But until all aviation authorities around the world insist on these technology upgrades, it will be up to individual airlines to adopt the sort of satellite technology that will ensure that aircraft like Flight MH370 don't just disappear off the radar.

BLACK BOX RECORDERS

All modern commercial aircraft are required by law to carry a flight data recorder (FDR). These so-called 'black boxes' are actually painted in heat-resistant, high-visibility orange, and their recovery serves a critical function in helping investigators piece together the final moments of an aircraft in the event of a major incident. An FDR is hooked up to a plane's flight data acquisition unit. This unit has sensors wired to various areas on the aircraft recording flight performance parameters such as pressure, altitude and rudder pedal position. Modern black boxes also record cockpit crew conversations and radio communications. Typically, FDRs are located in the tail section of a plane, where they stand the best chance of surviving a crash. They are also equipped with underwater locator beacons that have a battery life of approximately 30 days.

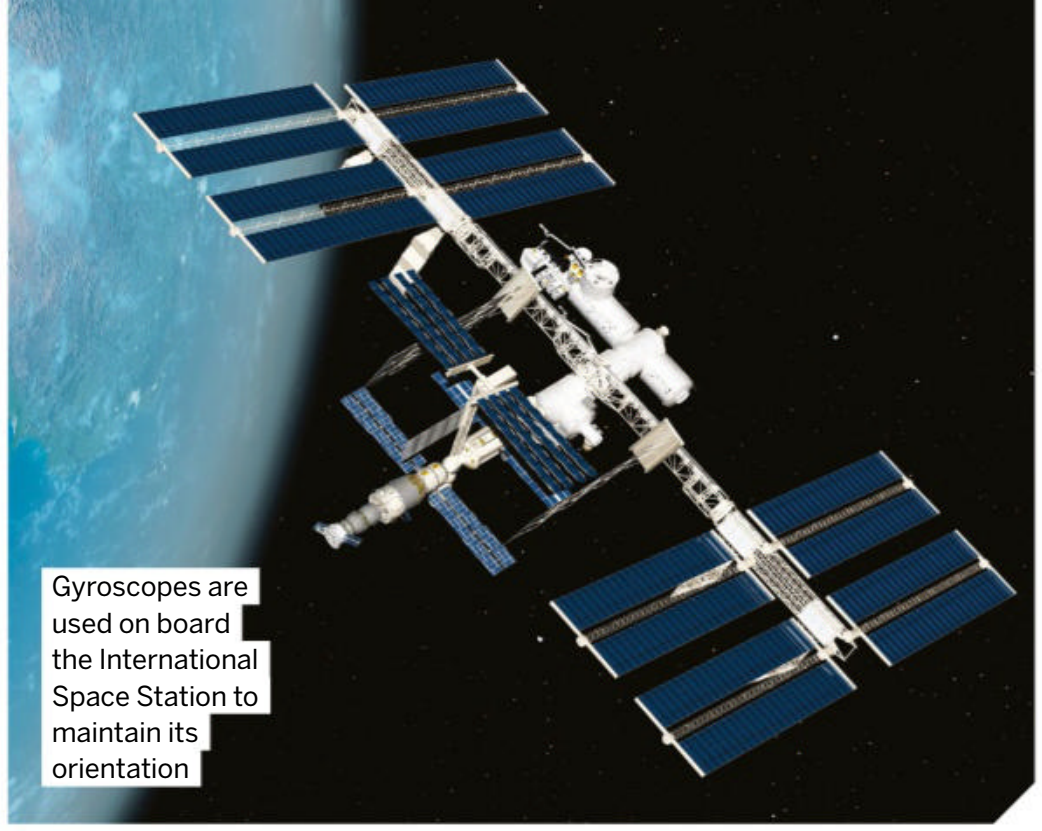
FDRs are able to survive temperatures over 1,000 degrees Celsius

DID YOU KNOW? The first gyroscope was invented in 1812

WHAT IS A GYROSCOPE?

Here's how this peculiar instrument seemingly defies gravity

WORDS **SCOTT DUTFIELD**



Gyroscopes are used on board the International Space Station to maintain its orientation

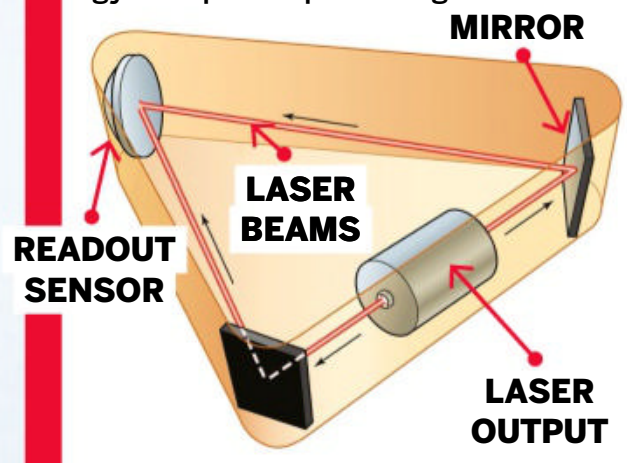
Gyroscopes are perplexing instruments, commonly used in stabilising ships and navigation systems. At its heart, a mechanical gyroscope is a central, spinning wheel that stays on its axis even when the rest of the instrument is moving around, making it appear as though the wheel is defying gravity.

Newton's first law states that an object will travel in a linear motion in the same direction until it's subjected to another force. In the case of a gyroscope, the linear motion is replaced by rotating angular momentum. When a gyroscope is spun, it remains spinning on the same axis until an external force called torque is applied. When placed in a free-moving gimbal, a spinning wheel can continue to spin under angular momentum, on its axis, without being affected by external torque.

Another property of a gyroscope is a phenomenon in physics called precession. When torque is applied to a spinning gyroscope, the angular momentum increases towards the source of the torque at a perpendicular angle of 90 degrees. These competing forces cause the gyroscope to not only spin on its axis, but also rotate, much like how the Moon spins on its axis but also orbits Earth. There's an experiment you can do at home to visualise precession – all you need is a string and bicycle wheel. When you tie a piece of string to the centre of the wheel and hang it in the air, it will naturally hang under the force of gravity. However, if you lift the wheel into a vertical position, quickly spin it and let go, it won't return to its horizontal position and will instead continue to spin vertically and rotate around the string.

LASER-POWERED

A ring laser gyroscope spins on a rotating wheel but is replaced with optical fibre coils. Gyroscopes are a handy tool for measuring the direction of movement in navigation, as they can maintain a fixed orientation. Using two counter-rotating laser beams and a photodetector, these gyroscopes measure the changes in how the laser beam reaches a sensor while the gyroscope is rotating, a phenomenon known as the Sagnac effect. The difference in the distance that each beam travels to reach the sensor is proportional to the rate of rotation the gyroscope is experiencing.



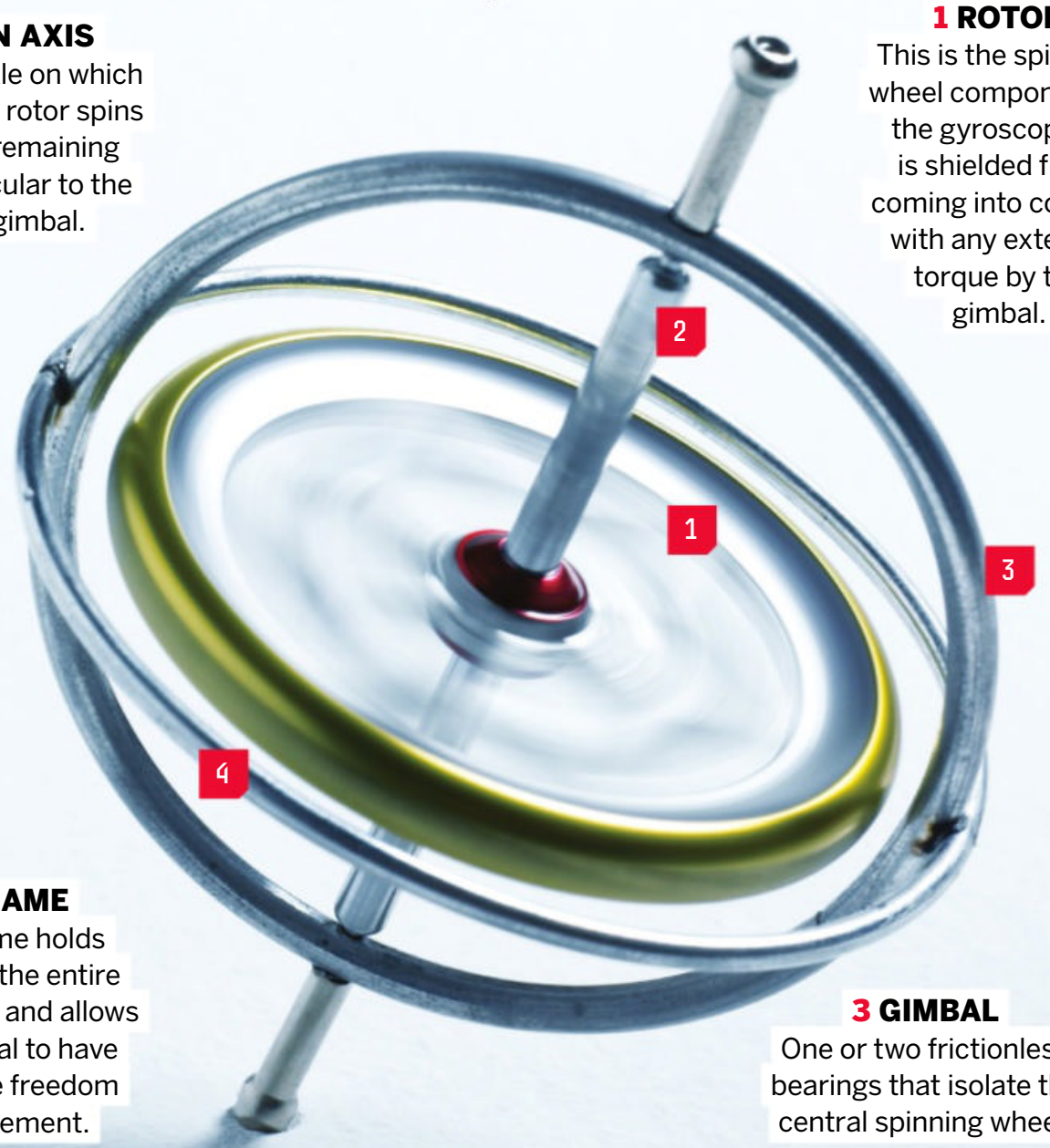
An illustration of the internal laser and mirror components of a laser gyroscope

GYROSCOPE ANATOMY

The components that keep these instruments spinning

2 SPIN AXIS
A rod or axle on which the central rotor spins around, remaining perpendicular to the inner gimbal.

1 ROTOR
This is the spinning wheel component of the gyroscope. It is shielded from coming into contact with any external torque by the gimbal.



4 FRAME
The frame holds together the entire gyroscope and allows the gimbal to have complete freedom of movement.

3 GIMBAL
One or two frictionless bearings that isolate the central spinning wheel.

INSIDE A BATTERY FACTORY

WORDS **AILSA HARVEY**

We visited a gigafactory to find out how the world's greenest car batteries are made

The combustion of fossil fuels is still responsible for producing 80 per cent of the world's energy. Producing electricity from fossil fuels involves burning coal, gas or oil to create heat that ultimately rotates an electricity-generating turbine. After being used to power countries around the world for over 150 years, fossil fuels are running out. They are also detrimental to the environment, producing 34 billion tonnes of carbon dioxide in just one year.

But in automotive and power industries there's an alternative to burning fossil fuels: lithium-ion batteries charged from green energy sources. Northvolt runs one of Europe's largest battery factories, producing batteries while being powered by 100 per cent renewable energy. Just 124 miles south of the Arctic Circle, the location of Northvolt's factory in Skellefteå, Sweden, was specially chosen for its geography. It's coastal, flat, remote and well-connected by road and sea, so the location ensures the potential of using hydroelectric, wind and solar power without compromising on the essential logistics for a factory.

Northvolt began battery production for commercial use in 2022 and primarily manufactures car batteries to assist with the expanding electric car market. In 2022, more than 10 million electric cars were sold worldwide, and these sales are estimated to increase by 35 per cent to 14 million in 2023. To tackle the problem of the availability of renewable energy, Northvolt's large cells are being installed into storage devices to capture excess solar energy. Battery-powered technology in vehicles is better for the planet than the old combustion engine we still rely upon. However, battery factories can still produce between 3,120 and 15,680 kilograms of carbon dioxide emissions for every lithium-ion car battery they manufacture. The process in Sweden's new gigafactory demonstrates how this doesn't need to be the case.

Did you know?

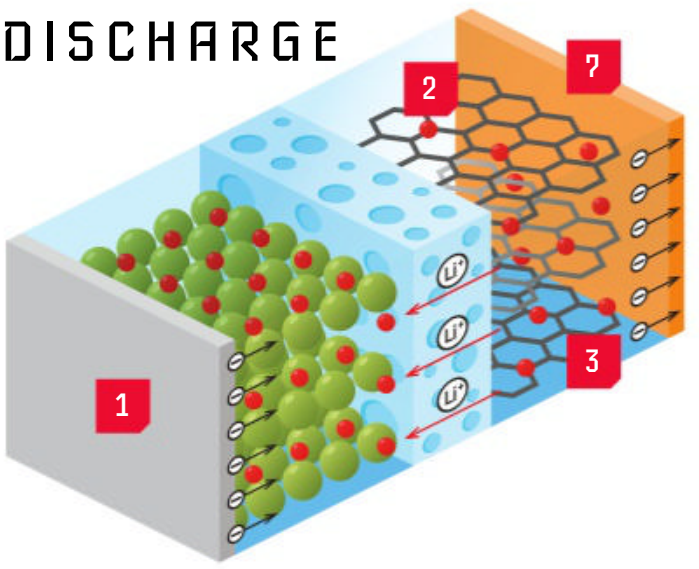
Five per cent of lithium-ion batteries are recycled

DID YOU KNOW? Lithium-ion batteries have a weight just one-third that of lead-acid batteries

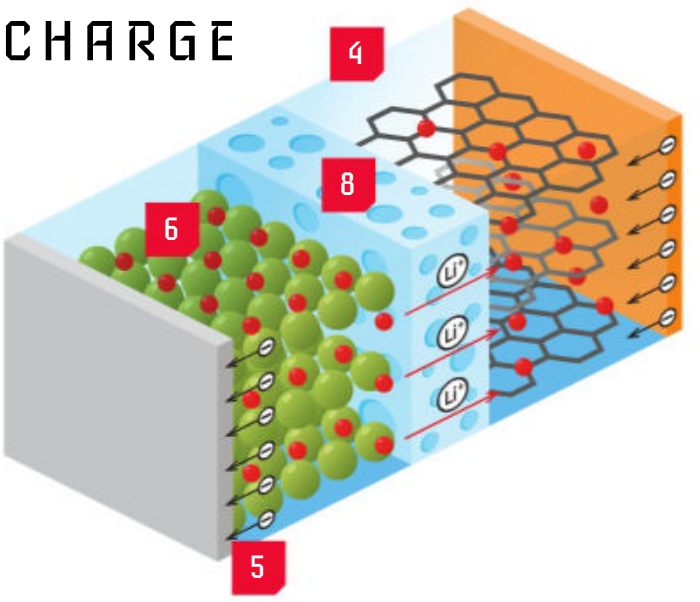
HOW LITHIUM-ION BATTERIES WORK

What makes these batteries long-lasting and rechargeable?

DISCHARGE



CHARGE



1 CATHODE
The positive side attracts negative electrons, removing them from the lithium atoms.

2 LITHIUM IONS
These ions are positively charged after losing electrons.

3 LI-METAL CARBON
The lithium ions reach this graphite sheet and become trapped. At this point the battery is fully charged.

4 ELECTROLYTE
This is a solution that positively charged ions can travel through, but electrons can't.

5 ELECTRON
The electrons can't move through the separator. Instead they move through the connected circuit towards the opposite end of the battery, as they are attracted to their unstable ions.

6 LI-METAL OXIDES
The ions are unstable when separated from the lithium metal oxide.

7 ANODE
To release electricity from the battery, lithium ions are released from the anode to the cathode electrode when the power source is removed and a device is connected. As they return, the electrons move through the circuit, releasing electricity.

8 SEPARATOR
Only lithium ions can pass through this central guard.

CYLINDRICAL AND PRISMATIC

Lithium-ion batteries are produced to power a range of products – from small handheld remote controls to sizable vehicles and even larger devices. For this reason, different types of batteries are produced in factories. Northvolt has multiple facilities, but at its gigafactory in Skellefteå, the batteries produced are prismatic.

Compared to the more commonly encountered cylindrical cells, which are small, long and rounded, prismatic cells are rectangular and flattened. Their components are stacked into layers inside a steel or aluminium casing. Their narrow shape helps them reduce the space taken up in electric or hybrid vehicles while maintaining a size that allows them to store more energy than cylindrical batteries.

Northvolt produce both cylindrical and prismatic batteries

5 USES FOR LITHIUM-ION BATTERIES

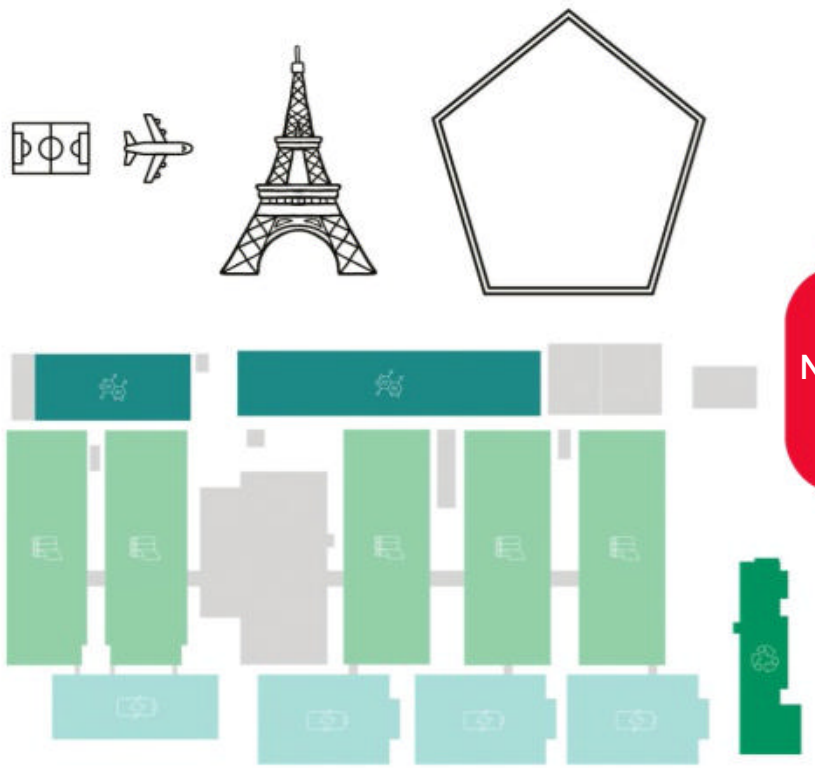
1 ELECTRIC VEHICLES
A lithium-ion battery has a high power-to-weight ratio, increasing efficiency and replacing combustion engines.

2 SOLAR ENERGY STORAGE
When solar panels produce more energy than is needed, these batteries can store the excess. On less sunny days, the energy in the batteries can be utilised.

3 HEART PACEMAKERS
The lithium-ion batteries found in pacemakers can last up to eight years and weigh less than 30 grams.

4 PERSONAL ELECTRONICS
With high energy densities, durability and the ability to recharge from any percentage of discharge, lithium-ion batteries are used for laptops, smartphones and other electronic devices.

5 WATCHES
Small lithium-ion batteries with a capacity of just three volts can be continually recharged for a decade.



Did you know?

Northvolt's factory is around three times the size of the Pentagon

PRODUCTION PROCESS

Over 3,000 employees work at Northvolt to manufacture batteries of consistent quality

2 SLURRY MIXING
Anode and cathode materials are mixed separately here to make a negative and a positive electrode. Carbon-based materials are added to the anode slurry, which are much cheaper than the metal oxides mixed into the cathode. The active material is preserved by chemicals that prevent it from breaking down.

5 CELL PRODUCTION
The electrode sheets, which have been collected in a large roll, are fed into machines to be cut for individual battery cells. The electrode sheets are stacked into small packages to fit into a metal can.

6 FORMATION AND AGEING
The final stage involves charging up the battery and discharging it multiple times. This ensures the batteries are working effectively.

3 ELECTRODE PRODUCTION
The two slurry mixes are spread evenly onto copper and aluminium foils.

4 OVEN DRYING
The anode and cathode electrodes are taken along separate lines into ovens where they are dried. The electrode production and drying processes take place in one long building, as each step needs to occur immediately after the last.

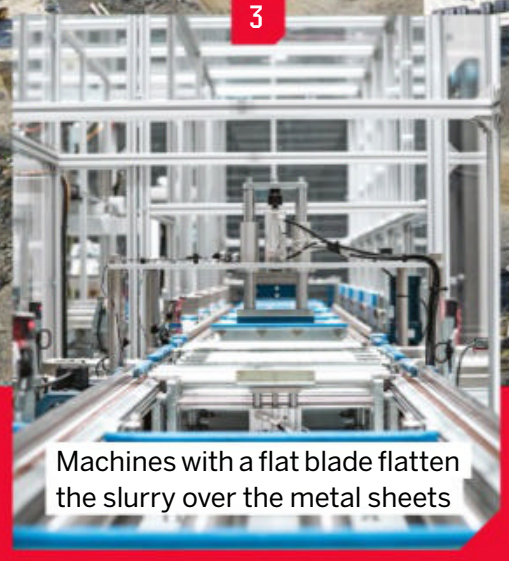
1

Batteries' raw materials include lithium, nickel, manganese and cobalt

2

Slurry mixers produce a highly viscous mixture, enabling a thick electrode coating

3



Machines with a flat blade flatten the slurry over the metal sheets

4

Drying the coated foil in these ovens helps the anode and cathode stick to the foil

DID YOU KNOW? Recycling the materials in a battery's cathode reduces its carbon footprint by 80 per cent

SUSTAINABLE BATTERY-MAKING

The metal resources used to produce batteries are typically mined every time new batches of batteries are required. However, it's possible to recycle used batteries that can no longer be recharged, as well as the trimmings and byproducts that are otherwise wasted at the factories. As the world becomes more electric, it's estimated that by 2030 the global demand for batteries will have increased to 14 times the demand of today. At the Northvolt factory site, a recycling facility is currently being built so that as much of the material used as possible can be taken from old batteries. By 2030, Northvolt aims to recycle at least half of the material used for its batteries.

When the recycling facility is built, the factory will have the capacity to recycle 125,000 tonnes of battery materials

1 UPSTREAM
The process starts here, with the raw materials combined to produce the active material of the cathode electrodes in the batteries.

5
Metal cans are filled with electrolyte before being sealed

6
The controlled charging of new batteries makes the flow of ions steadier and more reliable

BATTERY BOSS

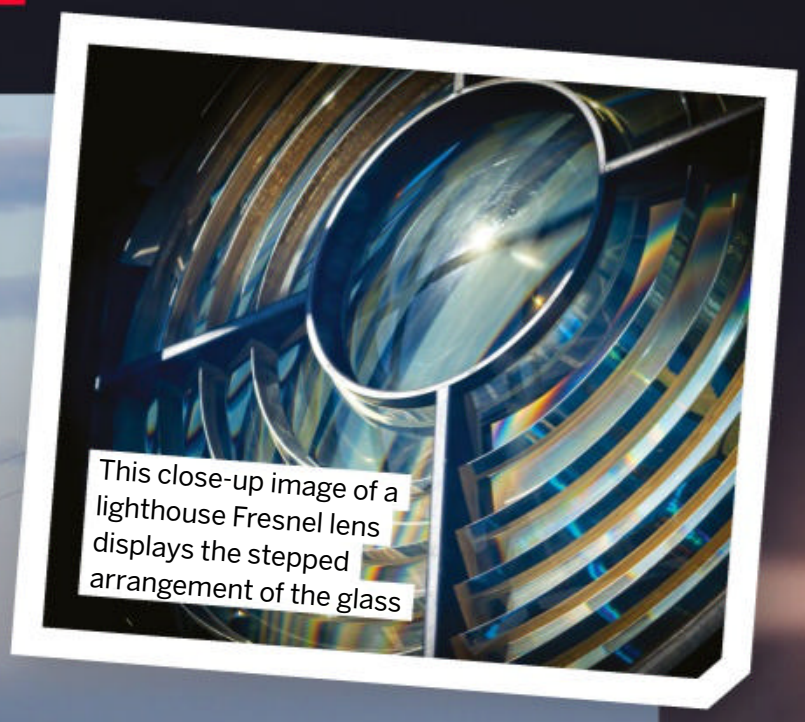
Thor of Northvolt explains how the green battery gigafactory came about

How did the idea for the factory form?
Northvolt was founded by Carl-Erik Lagercrantz and Harald Mix after seeing this mass need for European batteries. The lithium-ion battery was invented in Japan by Japanese and American researchers for Sony Walkmans and similar applications. The production of these batteries was based mainly in Asia, so the idea was to be the first European producer of these battery cells, which at that stage was a pretty explosive idea. Our challenge right now is to go from building one gigafactory to building multiple gigafactories. We are working as fast as we can.

What is it that sets Northvolt apart from other battery factories?
Several characteristics of Northvolt set it apart from others, in particular powering battery manufacturing with fossil-free energy. Batteries so far have been produced primarily by coal power, in which massive amounts of energy is consumed. If we used coal power, we would repeat the mistakes of the past. Using renewable energy, recycling and creating a circular production means that Northvolt has been able to cut emissions roughly by 70 per cent so far compared to previous batteries. Several technologies have been installed to support circularity of waste and resources. Rather than relying on third parties for chemical production of battery materials, Northvolt does this in-house, controlling the sourcing of all raw materials being used. Lastly, while Northvolt is a battery manufacturer, it's also a battery recycler. By establishing recycling capacity, Northvolt intends to source up to 50 per cent of its raw material needs from the recycling of end-of-life batteries and production waste.

How easy are lithium-ion batteries to recycle?
Northvolt is involved in several kinds of battery chemistry, but lithium-ion batteries are generally the preferred choice within the electric vehicle industry, favoured for performance characteristics such as lifetime and energy density. With Northvolt's recycling approach, as much as 95 per cent of the nickel, manganese and cobalt can be recovered to battery-grade levels of purity and used to replace freshly mined metals. The copper, aluminium, plastic and steel used in batteries can also be recycled.

What are Northvolt batteries used for?
80 per cent of the market for our batteries are cars and trucks. We also supply boxes called Voltpacks which are kind of like LEGO. You can stack them together and generate energy off the grid. These can be used on construction sites, or are often sold to festivals.



This close-up image of a lighthouse Fresnel lens displays the stepped arrangement of the glass

INSIDE A LIGHTHOUSE

Discover the tried-and-tested technology behind these maritime navigational beacons

WORDS **AILSA HARVEY**

Before GPS technology simplified the navigation process for voyagers at sea, sailors relied wholly on lighthouses to sail in and out of harbours and safely navigate rocks at night. Today, thousands of these towers still act as vital guides around the world's coasts.

At the top of a lighthouse is a large, rotating light. Instead of scattering the light in all directions, light exits the beacon in a single beam. The lens placed in front of the lamp has stepped sections that focus the light into the centre. Altering the curved lens into steps makes the centre of the lens thinner. Without this stepped arrangement, the thick lens would absorb too much of the light, dimming its luminance and reducing its effectiveness. The focused light is better able to penetrate the dark, and rotating the light means it's visible to sailors approaching from all directions. This powerful beam can even cut through fog for maximum effectiveness. Early lighthouse buildings were typically made from stone and contained wood or coal fires, but more modern versions use concrete and steel, which don't require as much upkeep.

I HOLLOW WALL
Many taller lighthouses have hollow walls to reduce their weight. These gaps can also be used for ventilation.

F SPIRAL STAIRS
Most lighthouses have a spiral staircase running from ground level to the lantern room.

G ROOMS
A storeroom, bedroom and living room are utilised by lighthouse operators.

Did you know?
There are around 18,700 lighthouses in the world

H POWER ROOM
Most lighthouses are powered by diesel electric generators.

5 FACTS ABOUT LIGHTHOUSES

1 FIRST LIGHTHOUSE
The Lighthouse of Alexandria, built in the 3rd century BCE, is believed to be the oldest lighthouse in the world.

2 LIGHTSHIP INVENTION
In the 1730s, beacon lights were anchored to the tops of ships in regions where lighthouses couldn't be built.

3 BISHOP ROCK RECORD
Four miles off Cornwall, England, the lighthouse on the 16-metre Bishop Rock holds the record of 'smallest island with a building on it'.

4 NUCLEAR-POWERED TOWERS
In the 1990s, Russia had at least 132 lighthouses powered by nuclear reactors along its north coast.

5 AMERICA'S AUTOMATION
For 30 years, all lighthouses along the US coastline have been automated.

DID YOU KNOW? A lighthouse in Michigan becomes completely covered in ice during freezing winters and rough seas

BEAMING PHYSICS

How do lighthouse lenses produce their guiding light?

A SUN VALVE
A black rod inside this tube absorbs heat from the Sun, causing it to expand. The expanded rod switches off the gas supply so that the light only shines at night.

B CUPOLA
The top of a lighthouse is usually curved to allow wind to travel around it smoothly.

C FRESNEL LENS
The lens in a lighthouse consists of hundreds of pieces of cut glass, angled to focus the light in one direction as a bright beam.

D LANTERN ROOM
Glass windows called storm panes surround the central light.

E GALLERY
This platform circles the tower. Lighthouse keepers can stand here to look out at approaching ships.

AUTOMATION IN ILLUMINATION

Before the 1960s, lighthouses couldn't run without a lighthouse keeper based at the tower to turn the lamp on and off, wind up the lamp so that it would move horizontally, keep watch and carry out regular maintenance work. Lighthouse keepers and their immediate family would live in the lighthouse, often in remote and unsheltered regions. Today, lighthouses are electrified, and their lights operate automatically on a timed motor. In the event that the power fails, self-sustained lighthouses are equipped with a backup energy source. When assistance is needed to monitor and operate the machinery, this can be done remotely via landline, satellite and radio links.

Before automation, lighthouse keepers had to wind up the lamp's flashing mechanism every day

The main entrance of a lighthouse is usually high up to remain out of reach of rising tides and waves

THE WEIRD WORLD OF MOULD

The strangest, deadliest, most disgusting and useful moulds found on Earth

WORDS SCOTT DUTFIELD

Much like a bell-shaped mushroom that you might find growing on a forest floor, the world's mould species belong to the fungi kingdom. However, the two are distinctly different. Most fungi can be either multicellular or unicellular organisms, feasting on organic matter such as the carbon and glucose content found in decaying leaves. Moulds, on the other hand, are only ever multicellular organisms, which tend to extract nutrition from many different sources, such as decaying material, paper, wood and even paints.

There are more than 100,000 different species of moulds on Earth, many of which can be found in your home. As part of their reproductive cycle, moulds release their version of seeds, called spores. Moulds release hundreds of thousands of these microscopic spores, which measure between 1.0 and 40 micrometres, into the air – for comparison, the diameter of a human hair is 70 micrometres. Some will find a new home and grow under the correct conditions.

Moisture is a key ingredient for a mould's development. Damp walls, leaky roofs and spoiling fruit are all excellent sites for a mould spore to land. Once the spore has landed it develops into fine threads called hyphae. These threads then intertwine and form a mould network collectively called a mycelium. Unlike plants, mould mycelium cannot produce its energy from photosynthesis, and so draws nutrition from its surroundings by releasing digestive enzymes to extract carbon and sugars and convert them into energy.

Did you know?

Fungi first appeared around a billion years ago

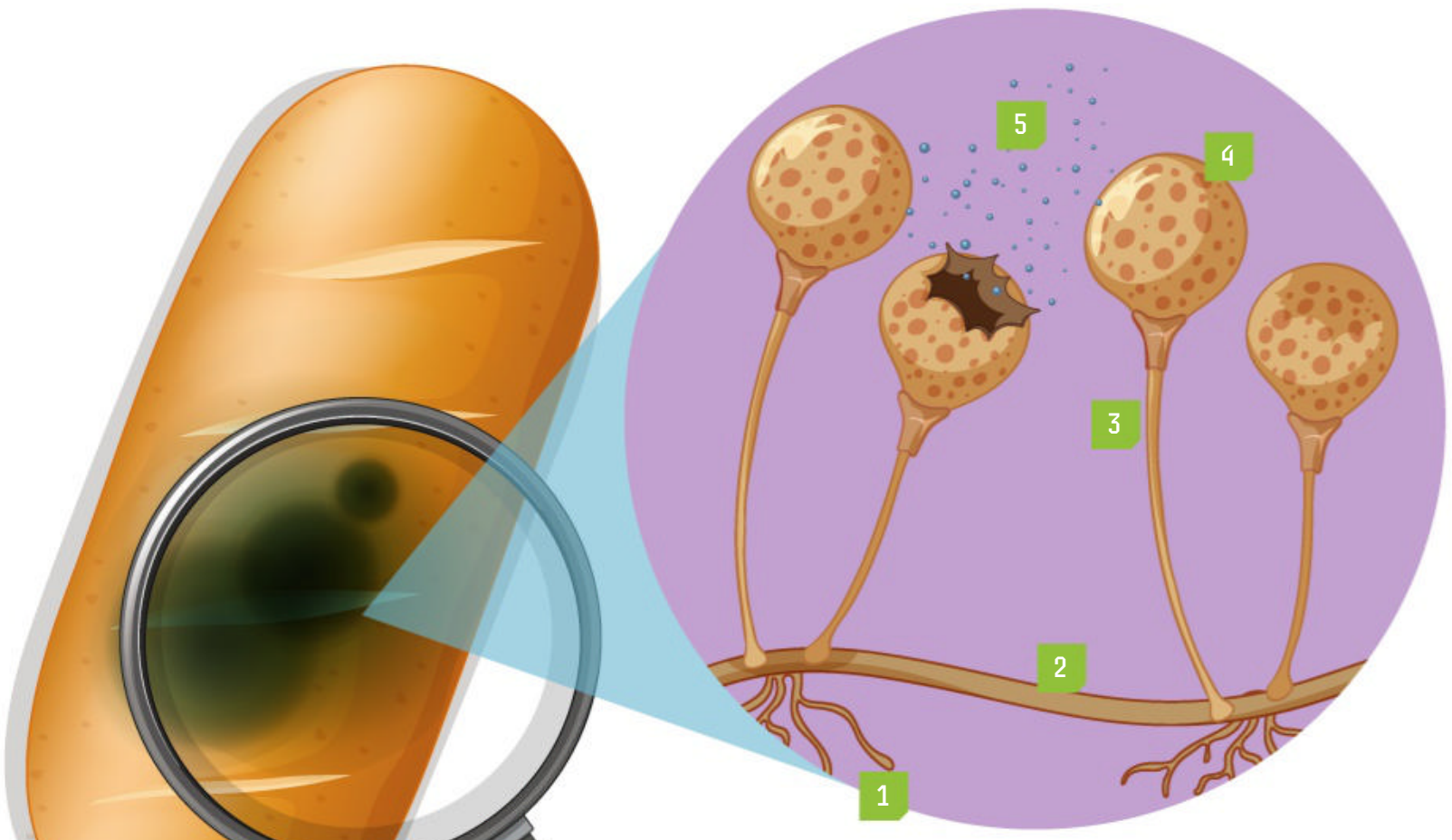
DID YOU KNOW? The largest single fungus, *Armillaria ostoyae*, covers around 3.7 square miles

BREAD BINGER

***Rhizopus stolonifer* is a common mould found on bread**

5 SPORES
The spores are the mould's reproductive cells. They float through the air, land on more bread to multiply and form new mould.

4 SPORANGIA
At the apex of the sporangiophores are the spherical 'fruits' that house the mould spores.




A close-up view of a bread mould's sporangia

1 RHIZOID
The root-like anchor of the mould, this releases digestive enzymes into the substance below.

2 STOLON
The horizontal network of hyphae from which spore-carrying bodies emerge.

3 SPORANGIOPHORES
The stalks that hold the spore nurseries, called sporangia.

THE MIRACLE FUNGUS

If you've ever had a serious bacterial infection, you're likely to have been treated with a little white pill made from mould. Discovered by chance in 1928, *Penicillium chrysogenum* can fight invading bacterial forces and prevent them from regrowing. While studying *Staphylococcus* bacteria, Dr Alexander Fleming discovered that after some time away, mould had grown in his study Petri dishes that were filled with bacteria. He witnessed that no bacteria were growing around the mould, soon concluding that it must produce a chemical defence to ward off the bacteria. He called it penicillin. Scientists now know that what Fleming observed was penicillin's ability to break down the membrane of bacteria, allowing it to be tackled more easily by the body's immune system. More than ten years after his discovery, a group of scientists uncovered Fleming's work – which had been shelved by Fleming – and produced a pure penicillin drug to fight bacterial infections.


An artist's illustration of *Penicillium chrysogenum*

4 NASTY MOULDS THAT MAKE YOU SICK

1 CLADOSPORIUM
A common mould found on plants, in soil and on many household surfaces, the spores of this mould can trigger allergies and asthma symptoms after long-term exposure.

2 FUSARIUM
Mycotoxins released by this mould can affect the performance of its host's immune system and negatively impact gastrointestinal cell lining if ingested.

3 ASPERGILLUS
A common mould that doesn't affect the majority of people. However, its spores can cause allergic reactions and lung infections in people with weakened immune systems.

4 PENICILLIUM
Although it's used to make medicines, this mould can also trigger asthma symptoms among sufferers and surface infections such as keratitis, an inflammation of the eyes' corneae.

THE DARK SIDE

Many moulds are harmless to humans – some are even used to enrich the flavour of some cheeses, such as Stilton and Roquefort. However, the inhalation or ingestion of some mould spores can be hazardous. Black mould (*Stachybotrys chartarum*) is one of the worst that can find its way into your home. Needing only 12 to 24 hours to grow, it's prolific under the right conditions. Once it's established itself, the spores can trigger the body's immune responses, resulting in symptoms such as sneezing and a runny nose. However, in extreme cases, long-term exposure to black mould has been linked with a potentially life-threatening condition in infants called acute pulmonary haemorrhage, though further research is required.

Black mould, like many other mould and fungi species, can release mycotoxins that can disrupt or damage different systems in the body. For example, *Byssochlamys* is often found on rotting apples and releases a mycotoxin called patulin. When consumed, these toxins can cause vomiting and gastrointestinal issues in humans, but can lead to kidney or liver damage in some animals. To avoid the hazardous effects of mould exposure, ensure that your home stays as dry as possible to prevent growth and seal off areas that are infested until they are cleaned. Toss any food that has begun to grow a mould colony and don't just scrape it off the top... mould mycelium can burrow much deeper into food than you think.

It can take less than a day for black mould to appear on damp walls

Did you know?

There are around 1,000 species of slime moulds

SYMPTOMS OF BLACK MOULD EXPOSURE

1 SNEEZING
This is the body's way of removing trapped spores from the mucus in the nose.

2 COUGHING
Spores trapped in the mucus lining of the lungs can be removed through coughing.

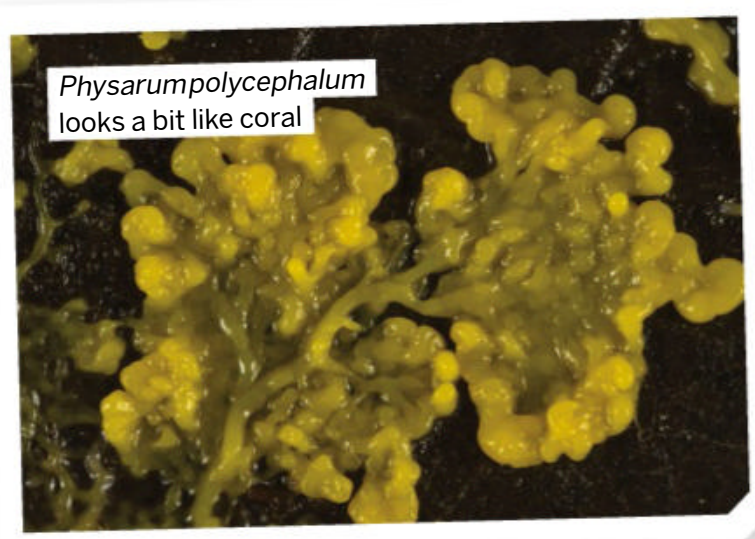
3 RED EYE
Spores and mycotoxins can irritate the eyes, causing them to appear bloodshot.

4 POSTNASAL DRIP
Part of the body's immune response to spore infiltration is overproducing mucus, which can drip to the back of the throat.

5 WHEEZING
Symptoms of existing respiratory conditions such as asthma can be worsened, including shortness of breath.

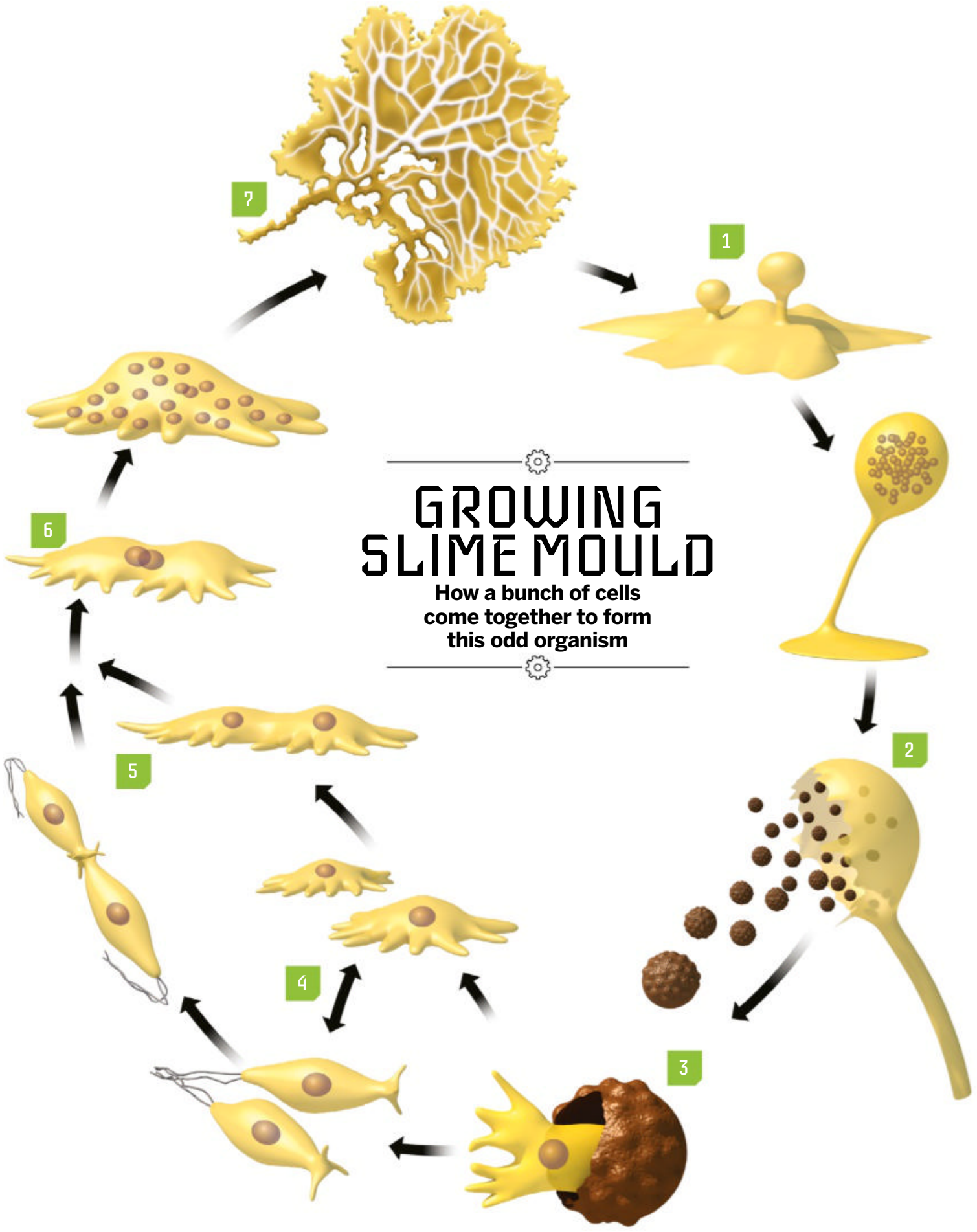
SLIMY MYSTERY

Slowly crawling along the forest floor are a diverse group of organisms we've come to know as slime mould. These unusual life forms were once thought to be a type of fungus. However, scientists have discovered that they belong to another group called Protozoa. This group of organisms includes free-moving single-celled organisms such as amoebae. Once slime mould has matured, it will cease to move and bear sporangia 'fruits', similar to moulds. These fruits will then release spores that will go on to grow into new slime moulds. However, unlike mould and other fungi, slime moulds don't have penetrating hyphae to dig into wood and extract nutrients. Instead their amoeba-like movements allow them to freely crawl their way along the surfaces of plants and trees, engulfing bacteria along the way. One slime mould, *Physarum polycephalum* – nicknamed 'the blob' – has piqued the interest of scientists. Despite not having a brain or nerve cells, scientists have discovered that this strange slime remembers things and can solve mazes. It's not yet fully understood how the slime mould retains this kind of information.



Physarum polycephalum looks a bit like coral

DID YOU KNOW? Slime moulds have been recorded travelling at speeds of up to 1.35 millimetres per second



GROWING SLIME MOULD

How a bunch of cells come together to form this odd organism

1 SPORANGIA EMERGE
The spore-bearing structures begin to sprout from a mature mass of slime mould, called a plasmodium.

2 SPORE RELEASE
Once a sporangium is fully formed and filled with spores it ruptures, releasing them onto nearby decaying wood.

3 GERMINATION
From these spores, one or two new cells emerge – either an amoeboid cell under dry conditions or a flagellating cell under wet conditions.

4 CONVERSION
If necessary, either the amoeboid cells or flagellated cells can transform into the other to suit a change in their environment.

5 FEEDING
During the amoeba stage of their lives, slime moulds will feed on bacteria until food becomes scarce.

6 PLASMOGAMY
When their food runs out and the amoebae begin to starve, they fuse together, rapidly multiplying and forming a larger body known as a plasmodium.

7 MATURITY
When mature, the multicellular plasmodium will begin to spread out into a netting shape in preparation to grow sporangia and release spores.


Tubulifera arachnoidea slime mould in its plasmodium stage

5 FACTS STRANGE SLIMES

1 FALSE PUFFBALL (*ENTERIDIUM LYCOPERDON*)
This slime mould looks similar to the fungal giant puffball (*Calvatia gigantea*) during its reproductive stage of life. False puffballs are often found hanging from dead trees.

2 CARNIVAL CANDY (*ARCYRIA DENUDATA*)
The vibrant red 'fruits' of this slime mould resemble sponge-like loofahs. They release their spores onto nearby decaying wood for their amoeba hatchlings to feast on the bacteria within.

3 RED RASPBERRY (*TUBIFERA FERRUGINOSA*)
The sporangia of this slime mould are so tightly packed together that they resemble a raspberry. The vibrant sporangia eventually turn a purplish-brown before releasing spores.

4 CORAL SLIME (*CERATIOMYXA FRUTICULOSA*)
Found in forests around the world, this slime mould transforms its body into icicle-like stalks that bear the mould's spores.

5 *COMATRICHA NIGRA*
When this mould is ready to release its spores, it grows individual lollipop-like sporangia.

WHY MOSQUITOES BITE

How a tiny blood meal sustains these insects

WORDS **AILSA HARVEY**

Have you ever felt a sudden urge to itch your skin before looking down to see a puffy red bump? Although the offender is probably nowhere to be seen by this point, it's likely that you have been bitten by an insect. If this insect was a mosquito, the lump will become harder and form a hive-like bump over the next 24 hours.

These small flying insects can be found all over the world, and usually their bites prove to be little more than a minor skin irritation. In some countries, however, their bite can be fatal. As mosquitoes feed from the blood of a variety of hosts, they can pick up diseases from infected animals and people, transmitting the disease to whatever they bite next. Most diseases caused by mosquito bites occur in Africa, Southeast Asia and South America. They include malaria and yellow fever, both of which can be deadly.

Not all mosquitoes have a taste for blood. Only the females can bite through skin, as they need the proteins in animal blood to produce eggs for reproduction. Studies show that the number of eggs a female mosquito will lay directly correlates with the volume of blood she has ingested. When they bite, they suck up between 0.001 and 0.01 millilitres. This small meal is an insignificant loss for our bodies, but a mighty feast for an insect just a few millimetres long. It's the equivalent of a person drinking the volume of an entire bathtub.

A close up of a *Culex pipiens* mosquito in which the long, covered proboscis can be seen outstretched

Did you know?

Mosquito saliva contains an anti-coagulant to stop blood clotting

TYPES OF MOSQUITO

Although there are over 3,000 unique species of mosquitoes in the world, these species can be grouped into three main genera. The most common mosquitoes are *Aedes*, *Culex* and *Anopheles*. Mosquitoes in the *Aedes* genus inhabit tropical locations and have a reputation for being the biggest disease spreaders. Some of the diseases *Aedes* mosquitoes spread are yellow fever, dengue, West Nile, Chikungunya and Zika. *Aedes* are active biters during the day and aim mainly for human blood.

Meanwhile, *Culex* mosquitoes prefer to bite birds. However, they won't decline a human meal. They're most active at night and breed in freshwater environments. Some of the diseases they spread are West Nile virus and western and Eastern equine encephalitis. The third genus, *Anopheles*, is made up of about 460 species. These mosquitoes are responsible for most malaria transmissions and have caused millions of human deaths. Mammals are their usual victims, and these mosquitoes bite between dusk and dawn.

Anopheles (top), *Culex* (middle) and *Aedes* (bottom) mosquitoes have subtle physical differences

DID YOU KNOW? Some people's bodies produce chemicals that prevent mosquitos from finding them

BITING ANATOMY

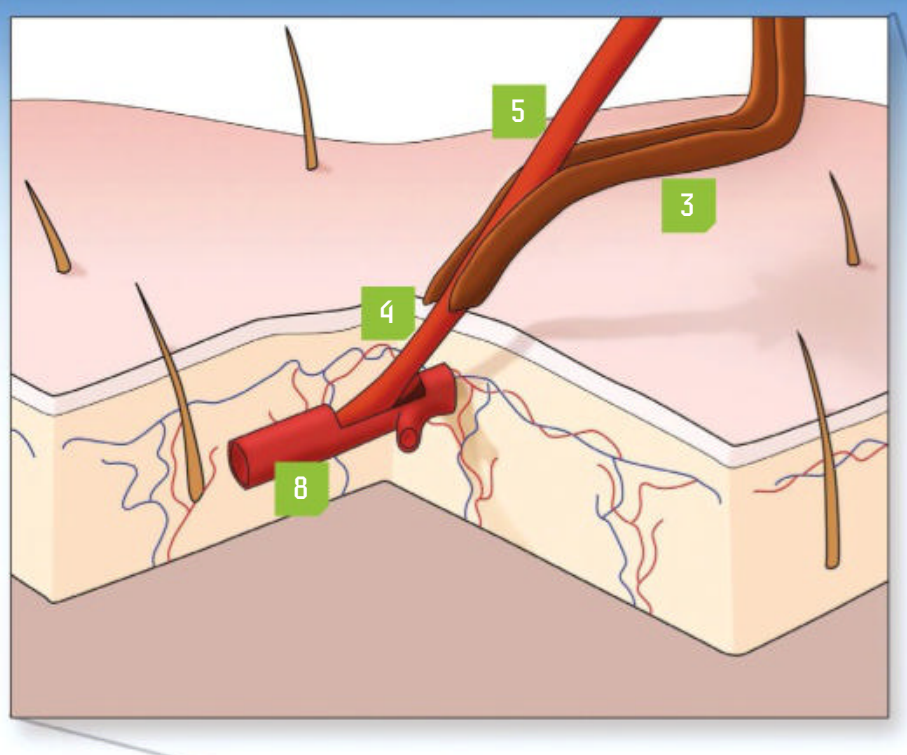
How a mosquito's body has evolved to steal your blood

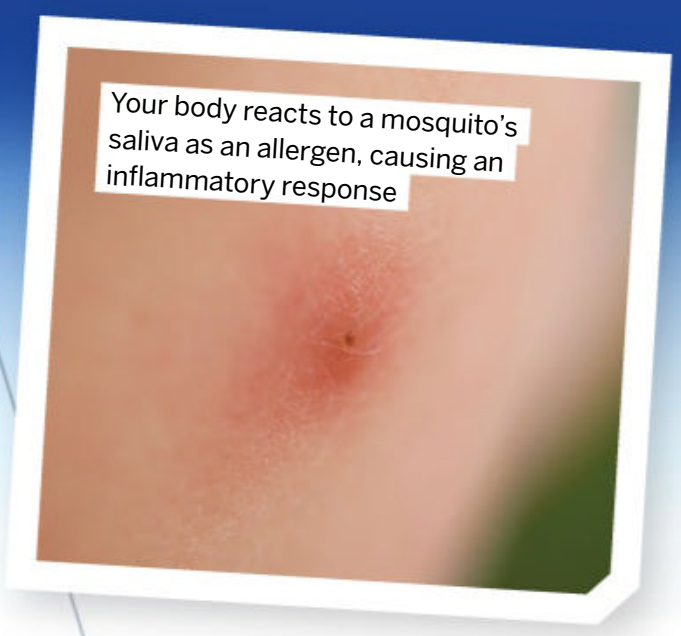
1 PROBOSCIS
Female mosquitoes use this long, flexible tube to pierce the skin and suck up blood. The male's proboscis isn't strong enough and is used to feed on flower nectar and fruit instead.

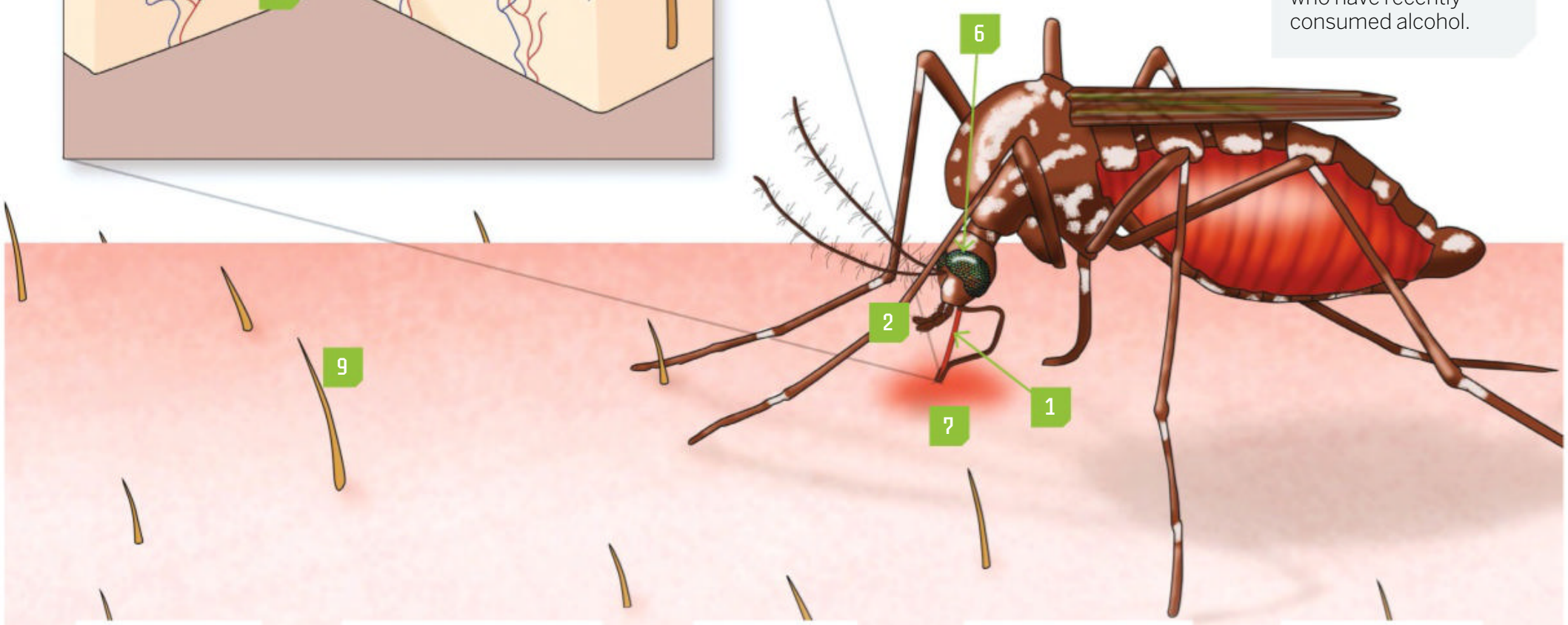
2 PALPS
These small organs between the antennae can sense the scent of humans and animals.

3 LABIUM
The protective outer sheath of the proboscis slides back just before a mosquito bites.

4 MAXILLA
Tiny teeth at the tip of the mouthparts help the proboscis cut through the skin's surface.







5 MANDIBLES
The jaws push outwards to spread the tissue. This gives easier access to blood vessels.

6 COMPOUND EYES
On the sides of a mosquito's head, large eyes with multiple lenses provide a large field of view. Each lens can focus in a different direction, scanning for animals.

7 SWELLING
A swollen red bump can appear a few minutes after the bite. The mosquito has a numbing agent in its saliva, so you don't feel the bite as it's happening.

8 BLOOD VESSEL
Sensors at the top of the mouthpiece guide it towards chemicals in the blood vessels. The capillary heals quickly after a bite.

9 HUMAN HAIR
Human hairs are much less sensitive to vibrations than a mosquito's. This means that often our hairs don't detect an approaching mosquito.

5 BLOOD-SUCKING FACTS

1 BREATH DETECTION
Mosquitoes can detect the carbon dioxide in a human or animal's breath from 22 metres away.

2 THIRSTY WORK
These insects drink up to three times their body weight in blood.

3 BLOOD LOSS
To drain all the blood from your body, you would need to be bitten 1.2 million times by mosquitoes.

4 HEAT GIVEAWAY
Mosquitoes are drawn towards body heat when they fly nearby.

5 BOOZY BUGS
Studies show that mosquitoes are more likely to bite people who have recently consumed alcohol.

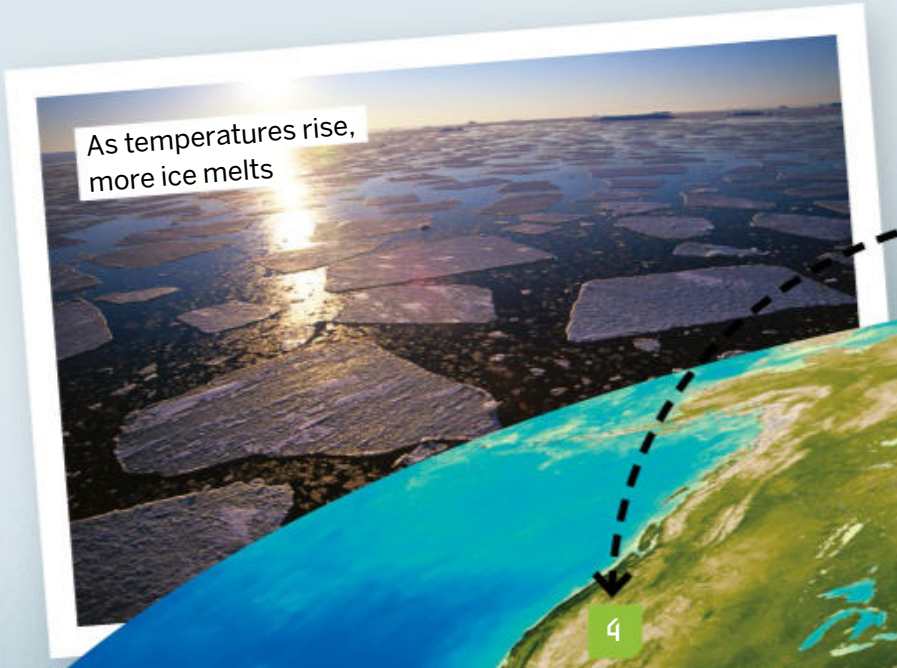
WHAT IS THE CLIMATE TIPPING POINT?

Discover what might happen if we reach this critical threshold, and how we can prevent it

WORDS **AILSA HARVEY**

There's a limit to how much greenhouse gases our planet can absorb without a drastic change to the climate worldwide. The point at which this can no longer be reversed is called the tipping point. For each element of climate change – from melting glaciers to declining coral reefs – there is a point of no return. One way to envisage this is to think about a child on a slide. There is a crucial point in this journey in which someone has committed to going down the slide, and they can't go back up. This transforms their state from being at the top to being at the bottom.

It's important to learn about and act on the impact of global warming on the planet before it becomes irreversible, but when will this be? In the early 2000s, scientists estimated that when human activity has increased the global temperature by four degrees Celsius, the climate system would reach its tipping point and undergo radical changes. More recently, this increase has been revised, and the planet could reach its critical threshold after a rise of just 1.5 degrees Celsius. According to the World Meteorological Organization, there's a 66 per cent chance that one year between 2023 and 2027, the global near-surface temperature will hit this threshold. But despite major changes in Earth's climate due to human activity, it isn't too late. Leaders from countries all over the world are working to find solutions for reducing the greenhouse gases we emit and avoiding the tipping point.


As temperatures rise, more ice melts

THE DOMINO EFFECT

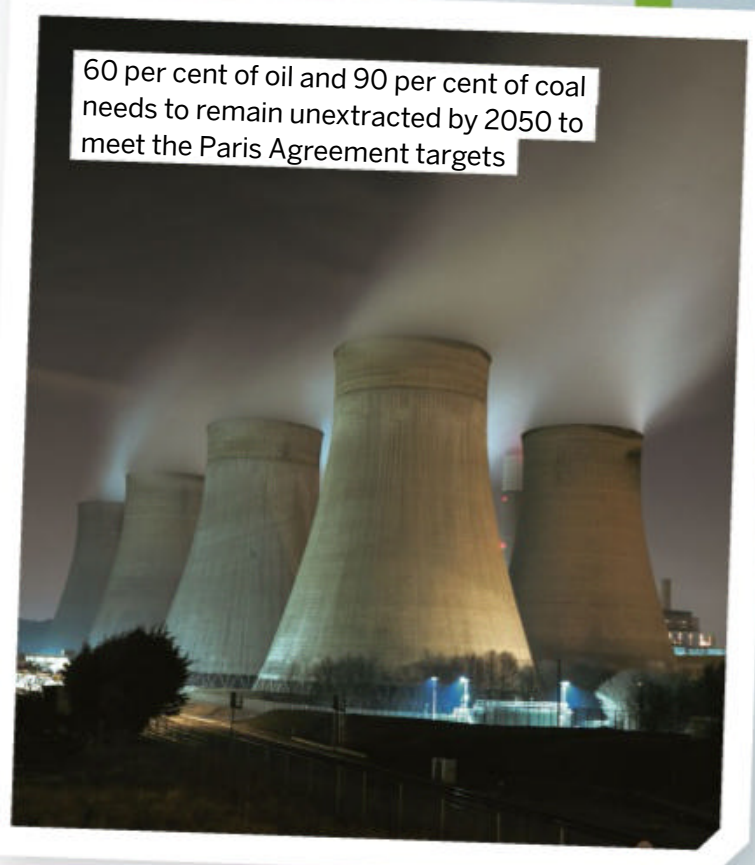
These are some of the places where tipping points can lead to a chain reaction of extreme weather

TIPPING POINTS

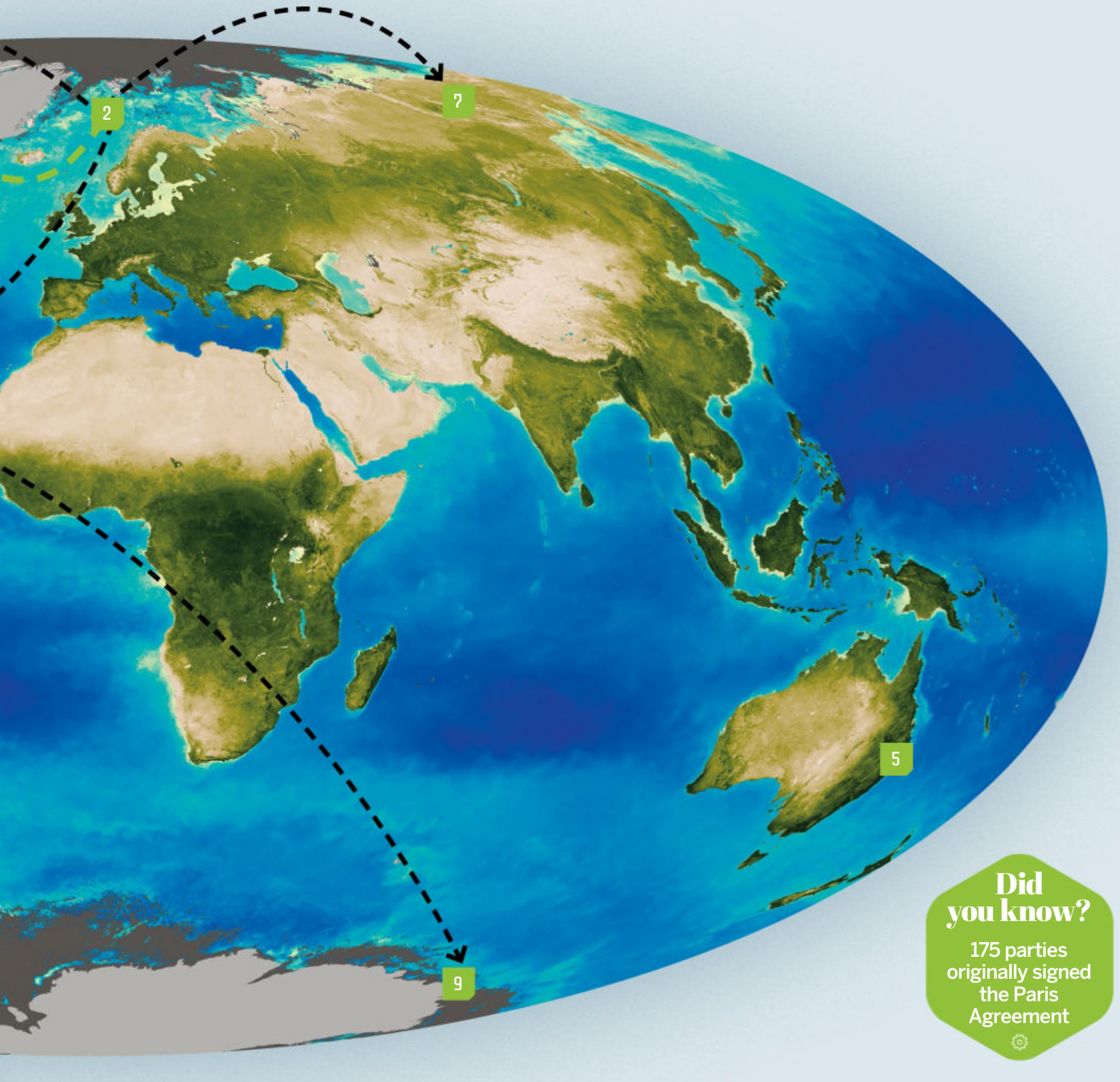
CONNECTIVITY

THE PARIS AGREEMENT

This international treaty came into effect in November 2016 and aims to reduce the global temperature rise. It's the world's first internationally binding agreement, which means that governments all over the world have agreed to make contributions towards limiting their country's greenhouse gas emissions. 194 countries are part of this agreement, which requires each to submit their plans to support the environment, as well as being transparent about their impact on the planet by relaying data of their produced emissions. Since the world's focus on pulling back from the climate tipping point, more than 130 countries now aim to reduce their greenhouse gas emissions to net zero by 2050. Eight have declared that they've already met this target. This is achieved by introducing renewable energy systems and absorbing existing carbon dioxide from the atmosphere.


60 per cent of oil and 90 per cent of coal needs to remain unextracted by 2050 to meet the Paris Agreement targets

DID YOU KNOW? The planet is currently warming at the quickest rate in 10,000 years



5 FACTS CRITICAL CLIMATE INDICATORS

1 RISING GLOBAL TEMPERATURES
If the global temperature reaches 1.5 degrees Celsius higher than pre-industrial levels by 2027, the unnatural warming is estimated to trigger other climate tipping points.

2 MELTING ICE CAPS
The mass reduction in sea ice caused by global warming impacts the temperature of the oceans as sunlight is no longer reflected off the ice. Water below this ice is denser and sinks to cause ocean circulation. This reduces as the ice melts.

3 EXTREME WEATHER EVENTS
Life-threatening weather events such as intense heat waves, uncontrollable wildfires, hurricanes, storms, droughts and floods become more common as greenhouse gases accumulate in the atmosphere.

4 GREENHOUSE GAS CONCENTRATION
The more carbon dioxide and other greenhouse gases are released by burning fossil fuels, the more of the Sun's heat is trapped in the atmosphere by the thick blanket of gas.

5 OCEAN ACIDIFICATION
The ocean absorbs a third of carbon dioxide produced by human activity. This makes the waters more acidic and hostile to sea life.

Did you know?
175 parties originally signed the Paris Agreement

1 AMAZON RAINFOREST
Climate change causes droughts in the Amazon. The reduced Atlantic circulation carries less precipitation to the area.

2 ARCTIC SEA ICE
Warmer global temperatures increase the melting rate of Arctic ice. This reduces the ocean's temperature contrast, weakening currents. It also weakens jet streams in the atmosphere, which can lead to wildfires on other continents.

3 ATLANTIC CIRCULATION
As the ocean's circulation is reduced, the northern Atlantic experiences cooling, while the southern Atlantic experiences warming.

4 BOREAL FOREST
Warmer conditions cause more frequent wildfires here. It also increases the prevalence of invasive pests such as Siberian moths or mountain pine beetles. These can wipe out some species of trees.

5 CORAL REEF REDUCTION
Fluctuations in water temperature cause coral to lose the algae that covers it in a process called coral bleaching. Coral relies on algae to produce its food, and bleaching can be irreversible when the coral dies.

6 GREENLAND ICE SHEET
Carbon stored in the ice sheet is released when it melts. It has released 500 gigatonnes of carbon so far and is halfway towards the tipping point for the southern portion of the sheet.

7 PERMAFROST
As Arctic temperatures are increasing, frozen land thaws and breaks apart. This releases greenhouse gases that are stored in the permafrost.

8 WEST ANTARCTIC ICE SHEET
The reduction in this ice sheet is considered a tipping point because if temperatures rise to 1.5 degrees above pre-industrial levels, the sheet will suffer from irreversible melting, increasing global sea levels.

9 WILKES BASIN
This area of East Antarctica will reach its tipping point at a temperature increase of three degrees.

Win!

A DIGITAL WATER BLASTER SET

WORTH **£300**

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A: 7 DAYS B: 24 DAYS C: 200 DAYS

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Terms and Conditions: Competition closes at 00:00 BST on 5 October 2023. By taking part in this competition you agree to be bound by these terms and conditions and the Competition Rules: **www.futuretcs.com**. Entries must be received by 00:00 BST on 05/10/2023. Open to all UK residents aged 18 years or over. The winner will be drawn at random from all valid entries received, and shall be notified by email or telephone. The prize is non-transferable and non-refundable. There is no cash alternative.

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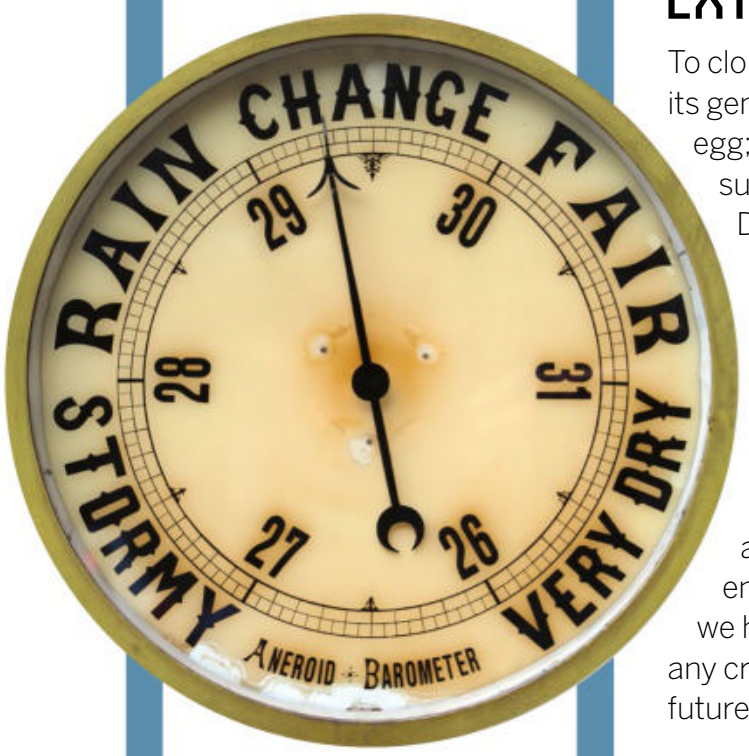
BRAINDUMP

Amazing answers to curious questions

Why is electricity blue?

Electricity only looks blue because we usually see electrical energy as it passes through air. Electrons in each atom of air gain energy from the electricity and jump to a more excited state. As the electrons return to their original energy level they release a photon of light. In air this photon appears blue, but other gases would produce different colours. The gases argon, phosphor, mercury and neon are used in this way to make the various colours in 'neon' lights.



WHO INVENTED THE BAROMETER?

Evangelista Torricelli became court scientist to the Duke of Tuscany in 1642. He experimented with fountains in Florence and a long tube over ten metres high filled with water that was in his house. In 1644 Torricelli described how he took a glass tube about one metre long, sealed at one end, and completely filled it with mercury, which is much denser than water. Then, holding his finger over the open end of the tube, he inverted it under the mercury contained in a large bowl and removed his finger. The mercury fell to a height of about 76 centimetres above the mercury level in the bowl and stayed there. This is still called Torricelli's experiment, and the space at the top of the tube above the mercury in barometers is known as a Torricellian vacuum.

CAN WE CLONE EXTINCT ANIMALS?

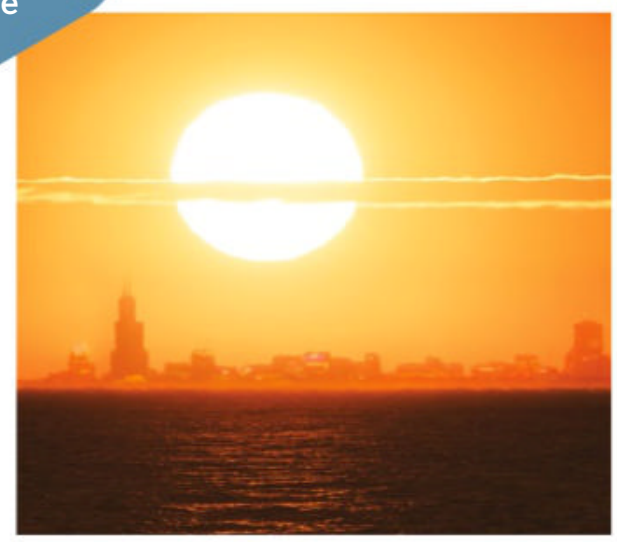
To clone an animal you must extract its genetic material to form a cloned egg; this is then implanted in a surrogate mother. Extracting DNA from long-extinct animals, like dinosaurs, is hard, as it's often damaged and incomplete. For more recently extinct animals it may be possible to find well-preserved DNA and use it to clone the animal. Scientists are now preserving the DNA of endangered species, so although we have not been able to resurrect any creatures yet, one day in the future it may be possible.

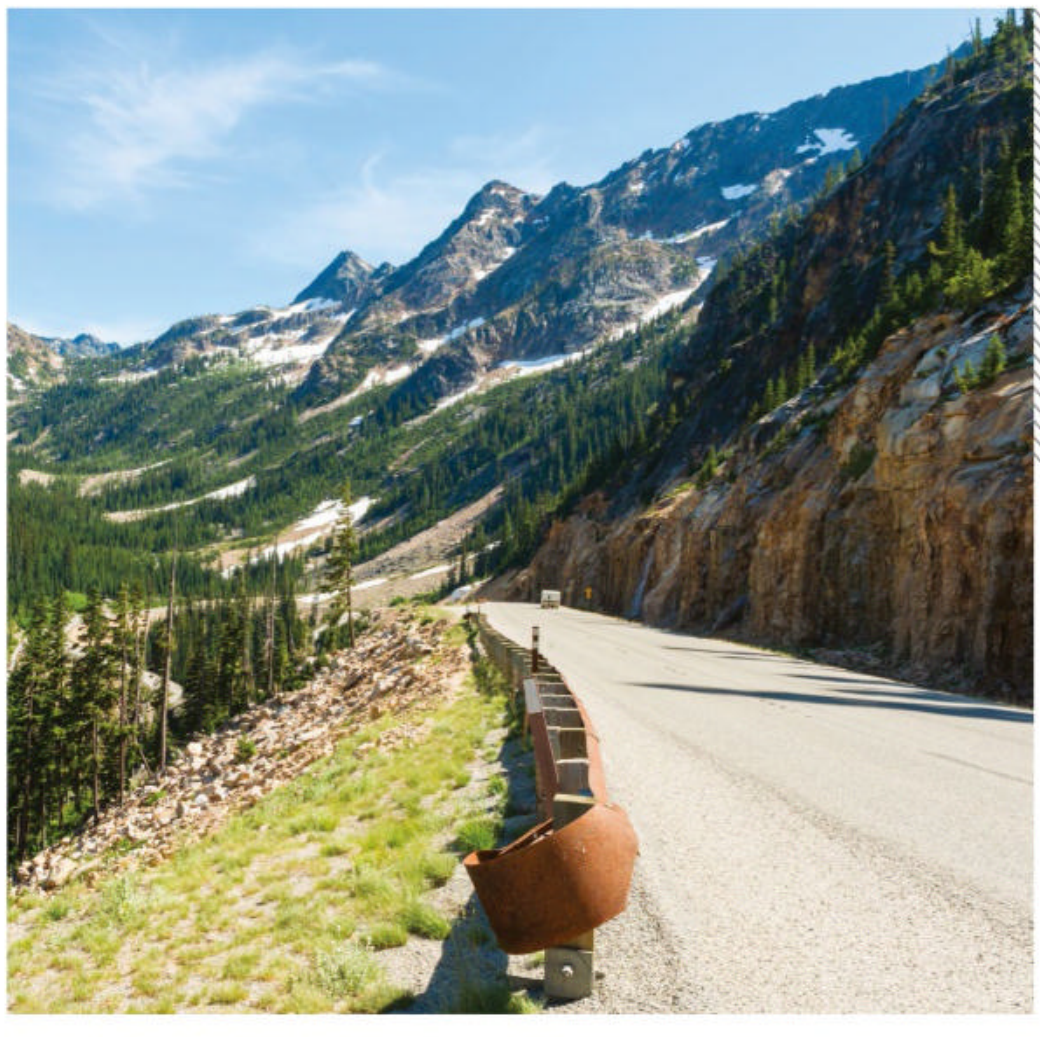
Did you know?

Over 5 billion species have gone extinct in Earth's lifetime

IS THERE A MAXIMUM TEMPERATURE?

All particles vibrate, and the more energy they have, the more they vibrate. We experience this as heat, which we measure with temperature scales. Nobody really knows if there is a maximum temperature, as it has never been reached. Some scientists suggest that the Planck temperature of 1.41679×10^{32} Kelvin may be the hottest possible temperature as, according to Max Planck, above that the laws of physics stop working. However, in theory there could be no limit to how hot something can get.





What's the biggest road in the US?

Spanning a whopping 3,365 miles, Route 20 is the longest road in North America. Route 20 runs east to west from Boston, Massachusetts, at Kenmore Square, right through to Newport, Oregon, where it merges at an intersection with Route 101 just a mile from the Pacific Ocean. Interestingly, the route passes by the famous Yellowstone National Park – up until 1940, this is where the road terminated.

BRAINDUMP

HOW DO YOU CUT DIAMONDS?

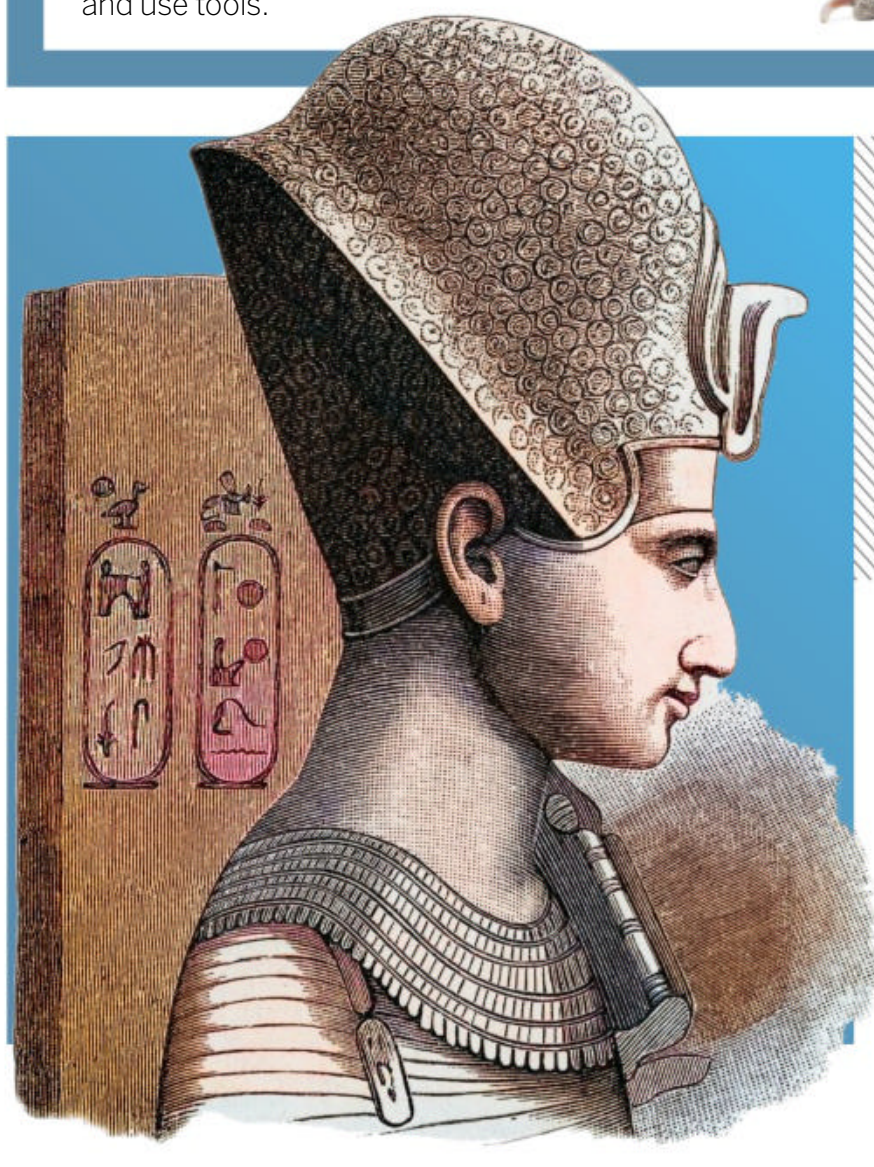
Diamonds are hewn from a rough stone to a multi-sided gem so that they reflect light in a beautiful way. But diamonds are extremely hard, which makes them difficult to cut. First, a 3D computer model is made of the diamond so the final shape can be planned out. The gem is then cut up using a diamond saw or a laser. After this, the facets of the stone are ground flat against another diamond, and finally the facets are polished. The stone is then cleaned in acid to give a brilliant finish.

WHY ARE MUMMIES BROWN?

The ancient Egyptians preserved the human body by drying it out with a salt-like substance called natron and applying plant resins to the skin. Both processes darken the colour of the skin and the few Egyptian paintings that depict mummification show mummies as entirely black. Osiris, god of the dead and rebirth, is often portrayed with black skin – a colour also likened to the dark fertile mud of the River Nile. Arabs associated the dark resins with tar-like bitumen, which they called mummia – this is the origin of the word mummy.

WHAT'S THE SMARTEST BIRD?

Intelligence is subjective, but in general, parrots and crows are considered the most intelligent birds. Studies with an African grey parrot called Alex have shown that parrots can associate words with their meanings and form simple sentences. He could vocally label more than 100 objects by colour and shape and quantify numbers of them. Studies have shown that crows such as the New Caledonian crow are also very bright. They can problem solve, as well as make and use tools.



Who was the longest serving pharaoh of Egypt?

According to later lists of Egyptian kings, Pepi II ruled for 94 years around 2200 BCE. However, contemporary documents only go up to the seventh decade of his reign, and so it's not certain that he really ruled for that long. The longest fully documented reign is the 67 years of Ramesses II, who came to the throne around 1279 BCE and built more temples than any other pharaoh. Third place is a tie between Thutmose III and Psamtik I, both of whom ruled for 54 years.

What is terminal velocity?

When a skydiver jumps from a plane, the pull of gravity causes them to go faster and faster as they fall. At the same time, air resistance creates a slowing force called drag. The faster the skydiver falls, the more drag they experience. At some point the speeding-up force of gravity and the resistance force of drag would be exactly equal and balance each other out. This means that the skydiver cannot gain any more speed, and this is known as terminal velocity. Terminal velocity also applies to vehicles such as aircraft, trains and cars. There's no point having a really powerful engine if the drag is going to stop it from propelling the vehicle, hence why aerodynamics is a major design consideration.

Did you know?

Squirrels can survive a fall thanks to a low terminal velocity

WHY ARE PLANETS AND STARS SPHERICAL?

Planets and stars are spherical as this is the most efficient shape for an even distribution of force. Stars and planets have a huge mass, which results in a very strong gravitational force. The easiest way to evenly spread this force in all directions is for the star or planet to be ball-shaped. Smaller asteroids don't have this large gravitational force, and so they aren't forced into a sphere.

Is the Sun fixed in space?

By tracking the motion of sunspots across the Sun, we can see it has rotational motion. It takes the Sun 31 days to rotate at its poles, but at its equator it moves faster, taking just 27 days to turn one revolution. This type of differential rotation is also present on the gas giants Jupiter and Saturn. The lack of a rigidly defined surface and a largely flowing composition means that objects like the Sun can have varying rotational speeds as the whole body is not held together in the same way rocky planets like Earth are. But the Sun is also moving in two other ways. First, it's not stationary in the Solar System – it's actually in orbit around every body that is also in orbit around it, such as all the planets. However, as the Sun is so massive, its orbit is nominal. Indeed, the centre of mass of these orbital systems is often found within the Sun itself, so it only wobbles very slightly compared to the huge orbits of other celestial bodies. Beyond this, the Sun is also moving around the centre of the Milky Way, along with the entire Solar System. One complete orbit takes about 230 million years.

Did you know?

Carrots were originally white in colour

DO CARROTS HELP YOU SEE IN THE DARK?

This isn't quite true, but the story of how this myth came about is quite interesting. First of all, carrots are rich in vitamin A, which itself has been linked with many health benefits. However, various tests and studies have conclusively proved that eating carrots will not improve your eyesight if it is already good. That being said, if you have a vitamin A deficiency then it's likely that eating carrots will improve your night vision. The origin of this myth stems from World War II.

During the war, Britain developed a new way to determine the location of Nazi bombers before they reached England, known as airborne interception radar. However, not wanting to alert the enemy to their new technology, the British government released various pieces of propaganda through the Ministry of Food stating that the new detection method was the result of pilots eating more carrots and being able to see the bombers more clearly in the dark. As well as fooling the Nazis, this story also encouraged British people to grow and eat more vegetables at a time when other goods such as meat were scarce due to rationing.

WHICH ANIMALS HAVE THE LONGEST LEGS?

The land animal with the longest legs is the giraffe, whose legs can be 1.8 to 2.1 metres long – taller than most humans. These towering animals can reach six metres overall and weigh four tonnes, with a sprint speed of 37 miles per hour. When galloping, the giraffe's front and hind legs work in pairs. Ostriches are the longest legged birds, at 1.2 to 1.5 metres long. However, both of these are dwarfed by the feeding tentacles of the giant squid, which can reach 8.2 metres long.

HOW LONG DOES IT TAKE FOR BONES TO BECOME FOSSILS?

Some palaeontologists regard all bones more than 10,000 years old to be fossils. How a bone is fossilised very much depends on the environment it's buried in. The organic parts usually decay quickly after the animal dies – though there's controversial evidence that proteins and red blood cells have survived in 67-million-year-old *Tyrannosaurus rex* bones. The non-organic parts of the bone may be replaced by minerals, such as silica, to become stone. The time for this to happen can vary between a few months to hundreds of thousands of years depending on environmental conditions.

HOW MANY YEARS CAN MUMMIES LAST?

A mummy is a body from which most of the moisture has been removed by the use of a mixture of sodium salts known as natron, named after the valley in Egypt where it is found, and then wrapped in linen bandages. If kept dry, it can theoretically last forever – many have been found in perfect condition after up to 4,000 years. However, if they get damp they can rot down to bare bones. This happened to the pharaoh Psusennes I, in spite of his tomb never having been touched by robbers.

Why do rabbits have long ears?

The rabbit's long ears serve two main functions. The first is so they can catch sound from any direction. Rabbits can move their ears independently, so they can hear in two directions at once. The second is that they give off heat from the body through a vast network of blood vessels to keep the bunny cool, since these animals can't sweat or pant. However, not all rabbits have big ears – some domesticated breeds, like the Netherland Dwarf, have short ones.

THE LIBRARY

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AUTHOR **DK**
ILLUSTRATOR **DK**
PUBLISHER **DK**
PRICE **£25 / $29.99**
RELEASE **7 SEPTEMBER**

As a **How It Works** reader, you should be able to fully appreciate the *Eyewitness Encyclopedia of Everything*. It's full of science facts for the sake of it – our favourite flavour of science facts – covering categories such as space, weather, prehistoric and modern life, vehicles, physical forces... pretty much any category you'd expect to see in a hefty hardback encyclopedia whose title claims to cover 'everything'.

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Crucially, it's bursting with as much in the way of photos and annotated illustrations as there is text. That would make the *Eyewitness Encyclopedia of Everything* very easy to pick up and leaf through for a casual read, if the hardback wasn't such a whopping tome nearly 400 pages long. It is an encyclopedia, after all, so you know you're getting value for money here. To pick just a few of our favourite annotated images out, 'under the microscope' shows the scale of tiny organisms, from the flu virus to a sugar crystal, and 'magnificent Moon' details features of the Moon's surface on a panoramic photo taken on one of the Apollo missions. There's also a thoroughly detailed modern periodic table of the elements, which really satisfies the science nerds in us.

"It's bursting with photos and annotated illustrations"

From a practical point of view, the *Eyewitness Encyclopedia of Everything* could be a useful reference for any school project and inspire the student with ideas of how to present their project, too. But it's a captivating read in itself that any of our subscribers will enjoy and consume in the same way they do **How It Works**.

AWESOME HUMAN BODY SCIENCE EXPERIMENTS FOR KIDS

40 AMAZING PROJECTS TO EXPLORE

AUTHOR **ORLENA KEREK**
PUBLISHER **CALLISTO MEDIA**
PRICE **£11.99 / $14.99**
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From studying saliva to building an articulating hand, this children's book of science experiments has everything a school student needs to know about the human body. Before delving into its 40 exciting activities, the book lays down the scientific groundwork for how the human body works and the many organs and systems that help it function. The difficulty and duration of each experiment and activity are helpfully labelled and don't require heaps of special equipment to complete. Many experiments utilise everyday items, such as laundry detergent and egg shells to study enzymes and a pair of tights and socks to understand digestion. Although some experiments require the help of an adult, the instructions for each experiment are child-friendly and simple to follow.

SHIPWRECKED!

DIVING FOR TIME CAPSULES ON THE OCEAN FLOOR

AUTHOR **MARTIN W. SANDLER**
PUBLISHER **ASTRA PUBLISHING HOUSE**
PRICE **£22.99 / $24.99**
RELEASE **31 OCTOBER**

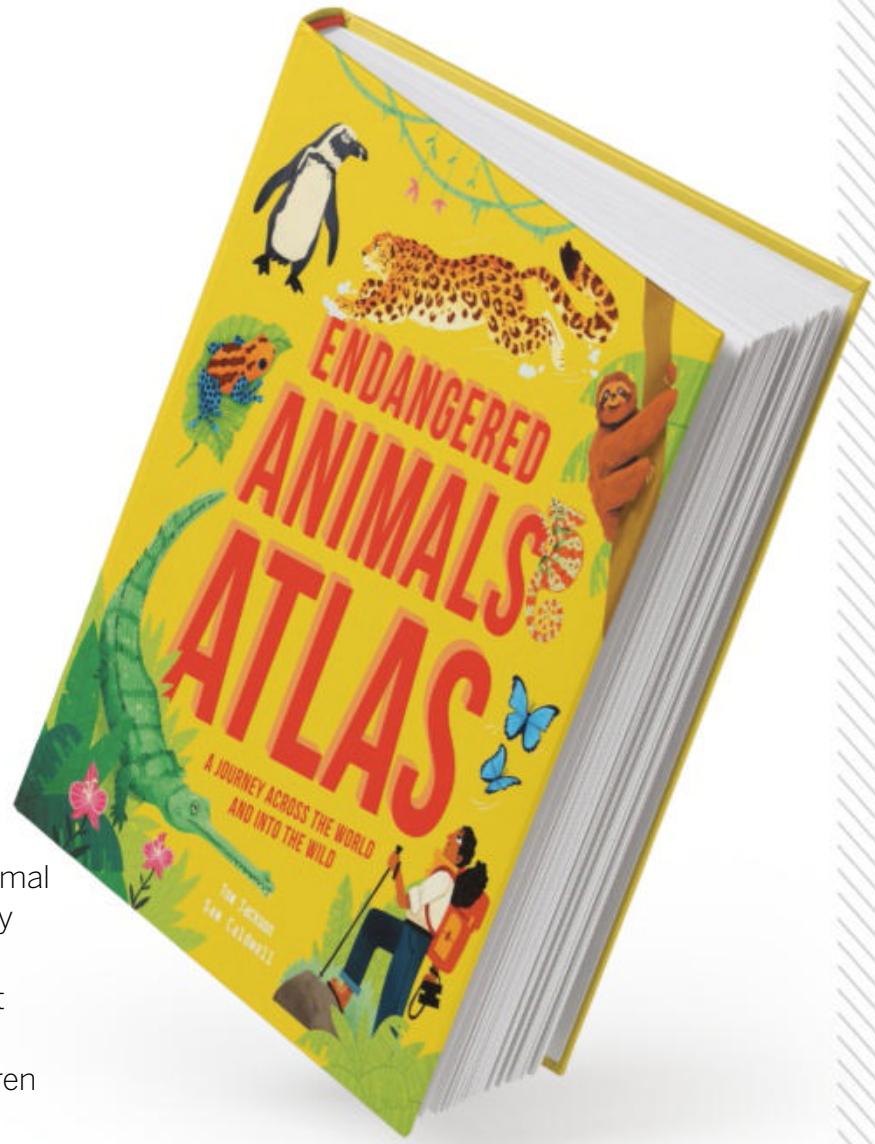
Dive deep below the surface and discover the treasures and tales hidden within the broken wreckages of ships in this intriguing and adventure-filled book. It's estimated that there are more than 3 million shipwrecks at the bottom of the sea around the world. Throughout seven chapters, National Book Award-winning author Martin W. Sandler highlights the discovery of just a few of history's most interesting examples. From the well-known wreckages of the Mary Rose warship of Tudor times to the lesser known tale of a 14th-century Chinese merchant ship carrying 28 tonnes of gold and a pair of polar exploration ships that mysteriously vanished in the early 1800s, this is a fascinating read for any budding explorers who are enthralled by treasure hunting and uncovering the secrets of the past.

ENDANGERED ANIMALS ATLAS

A JOURNEY ACROSS THE WORLD AND INTO THE WILD

AUTHOR **TOM JACKSON**
ILLUSTRATOR **SAM CALDWELL**
PUBLISHER **QUARTO PUBLISHING**
PRICE **£12.99 / $16.99**
RELEASE **5 OCTOBER**

There are millions of species living on our planet, and by taking a journey through this book, you'll get to see some of the world's most amazing creatures. However, what makes some of these animals so spectacular is their rarity. You may have never seen an animal like them before, and this book will explain why there are so few to spot. Delivering both awareness of the human impact on the planet and incredible facts about life on Earth, the *Endangered Animals Atlas* is perfect for children between seven and nine to read in awe while learning valuable lessons. In each immersive illustrated section, you'll uncover an impressive variety of animals, how they came to be, how their habitats have changed, which animals are at risk from invasive species and each animal's status of endangerment. Covering the diverse landscapes of India, the Australian Outback, tropical seas and the Arctic, each page features a selection of incredible wildlife. At the end of the *Endangered Animals Atlas*, readers are told about the ways we can conserve endangered species and learn about the extinct animals that roamed the planet before any of us were born.

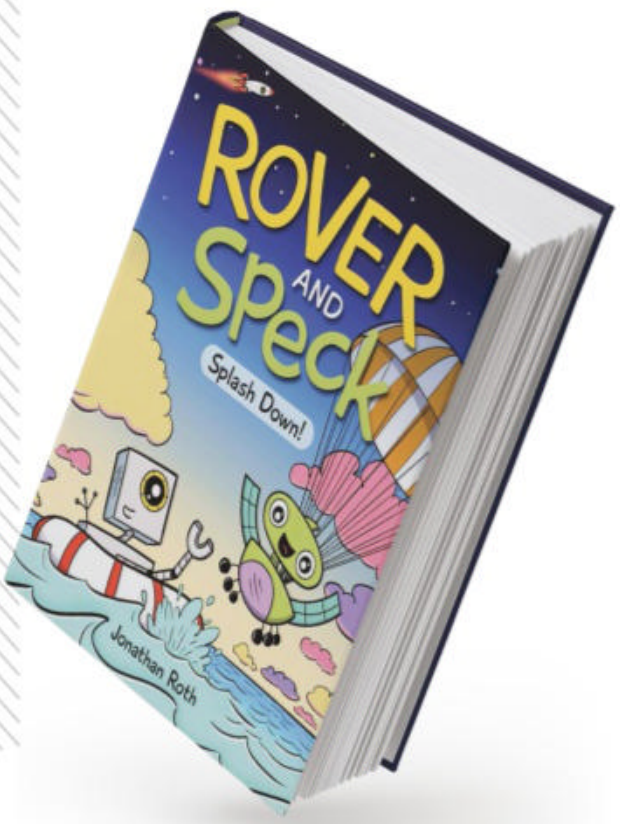


ROVER AND SPECK: SPLASH DOWN!

THESE SPACE EXPLORERS TAKE ON A DANGEROUS RESCUE MISSION

AUTHOR AND ILLUSTRATOR
JONATHAN ROTH
PUBLISHER **KIDS CAN PRESS**
PRICE **£16.99 / $16.99**
RELEASE **3 OCTOBER**

Rover and Speck are always eager for a mission, and this adventure is sure to have young children amused and intrigued. When the two adorably illustrated rovers embark on an adventure to the unexplored planet K2-18 b, they end up in the jaws of a gigantic beast. The comedic interactions between the characters are coupled with fun science fact boxes, providing clever balance between fact and fiction. The action-packed story is easy to follow and is presented in a comic-book style, with illustrations providing entertaining little details for readers to spot. Rover and Speck place themselves in further danger as they work as a team to save one of the planet's local creatures. Rover, being the more experienced of the two, explains the science behind various technologies and life forms that are encountered throughout the adventure, teaching Speck and the reader along the way. By the end of their day, the rovers have learned about water worlds, digestion, ocean creature anatomy and even helped to form a symbiotic relationship on the planet.



BRAIN GYM

Give your brain a puzzle workout

Sudoku

Complete the grid so that each row, column and 3x3 box contains the numbers 1 to 9

EASY

1			6		7	3		
9			1		8		2	
4	8	7		2	9	5		6
7		8		6				1
6	4			1				8
5			8	3				
8		9		7	1	2		
	7	4			6	1	9	
	1	5					6	7

MEDIUM

7	2		9		8		4	1
4					3		8	2
1			6		2	7	5	
							7	
	5							9
6				7		4		
3	4	9			7			8
8	7			6	5	1		
		6	8					

HARD

6		9					2	
3		2		8	4	7	9	5
8	7				2	6		
					5		8	
		6				9	1	
		8		9				
	5		8					2
				1				9

Word search

Find the following words

SOLAR
JUPITER
RESCUE
MOULD
MOSQUITO
TIPPING
SEA
EGYPT
DREAM
HUMAN
FLARE
BATTERY

S	C	U	E	Q	M	O	L	D	Y	G	P	R	O	A
O	T	Y	H	U	M	A	N	E	L	W	Z	E	O	T
L	R	E	S	Q	U	E	R	D	R	E	B	S	X	I
A	L	S	A	E	T	A	I	P	P	I	A	C	C	P
R	F	J	U	P	L	T	E	R	H	M	T	U	S	P
H	U	M	E	F	E	G	R	Y	P	A	T	E	F	I
I	H	P	O	T	I	S	E	A	N	Q	E	M	L	N
E	G	Y	P	T	O	L	T	J	U	P	R	T	E	G
J	D	F	A	B	Z	Q	I	B	A	T	Y	T	E	R
Y	R	S	O	I	A	R	P	M	O	U	L	B	S	I
N	I	K	R	O	B	G	U	F	J	M	U	Q	H	L
A	M	C	V	E	F	R	J	H	I	X	A	L	B	N
M	O	S	Q	U	I	T	O	P	Q	G	S	E	T	U
D	W	K	Y	Z	T	I	P	D	I	N	G	P	R	O
I	N	T	E	G	Y	D	L	U	O	M	Q	Y	Z	D

What is it?

Hint:

This bug wants to be a deer

A

Spot the difference

See if you can find all six changes between the images below

QUICKFIRE QUESTIONS

Q1 Which of these Australian mammals lays eggs?

- Kangaroo
- Echidna
- Koala
- Dingo

Q2 What force keeps the planets orbiting the Sun?

- Gravity
- Tension
- Magnetism
- Air resistance

Q3 In what century was radioactivity discovered?

- 18th
- 19th
- 20th
- 21st

Q4 What reflex is triggered by your arrector pili muscles?

- Gag
- Knee jerk
- Goosebumps
- Sneeze

Q5 What does WWW stand for in a website address?

- World Web Widget
- World Wide Web
- Working Web Widget
- Wonderful World Web

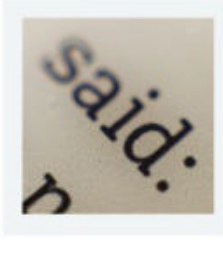
Q6 Who became the first US president in 1789?

- Benjamin Franklin
- George Washington
- Benedict Arnold
- Thomas Jefferson

Answers

Find the solutions to last issue's puzzle pages

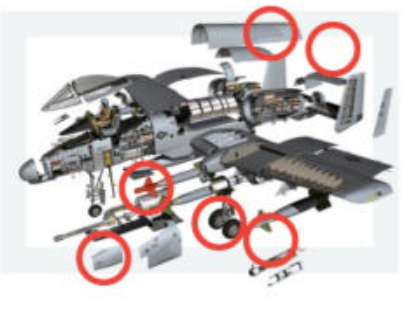
Q1 IONISING RADIATION
Q2 CENTRAL PROCESSING UNIT
Q3 11
Q4 2.0 GRAMS
Q5 PACIFIC
Q6 LIVER



What is it?

E-INK

Spot the difference



HOW TO...

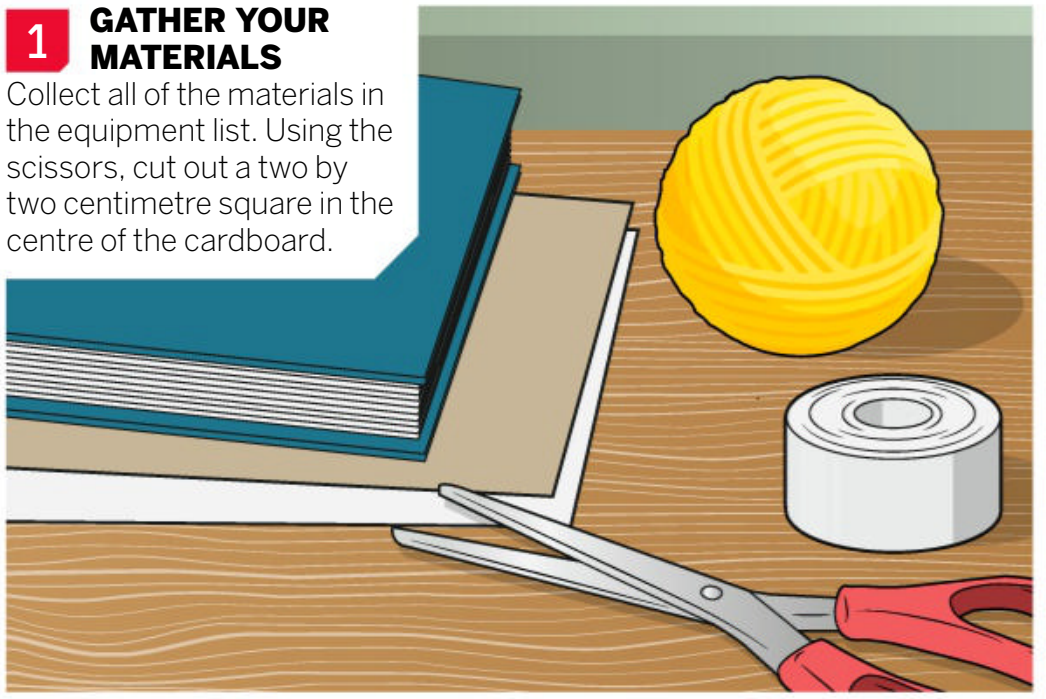
Practical projects to try at home

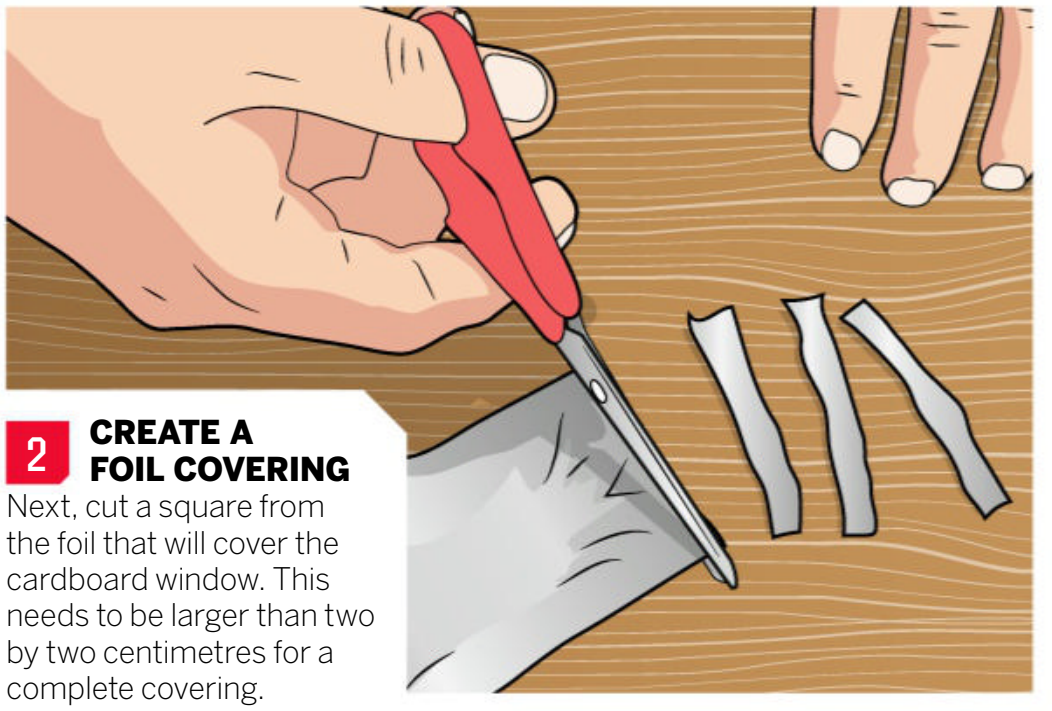
MEASURE THE SUN'S DIAMETER

With this simple pinhole viewer, you can calculate the size of our Solar System's star

1 GATHER YOUR MATERIALS

Collect all of the materials in the equipment list. Using the scissors, cut out a two by two centimetre square in the centre of the cardboard.



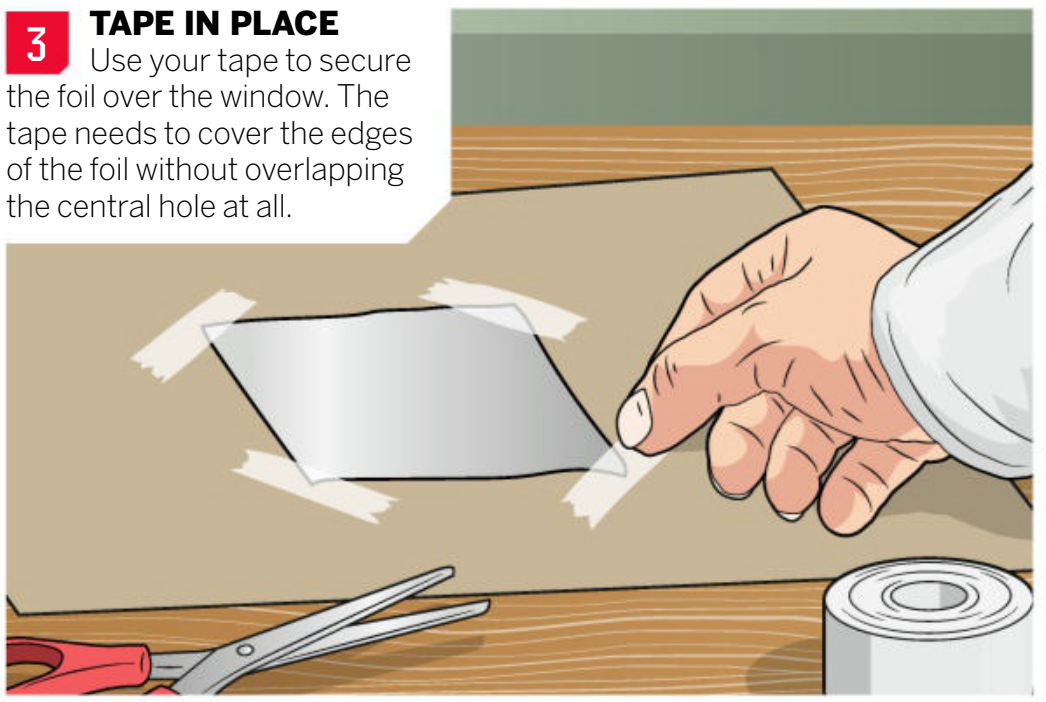


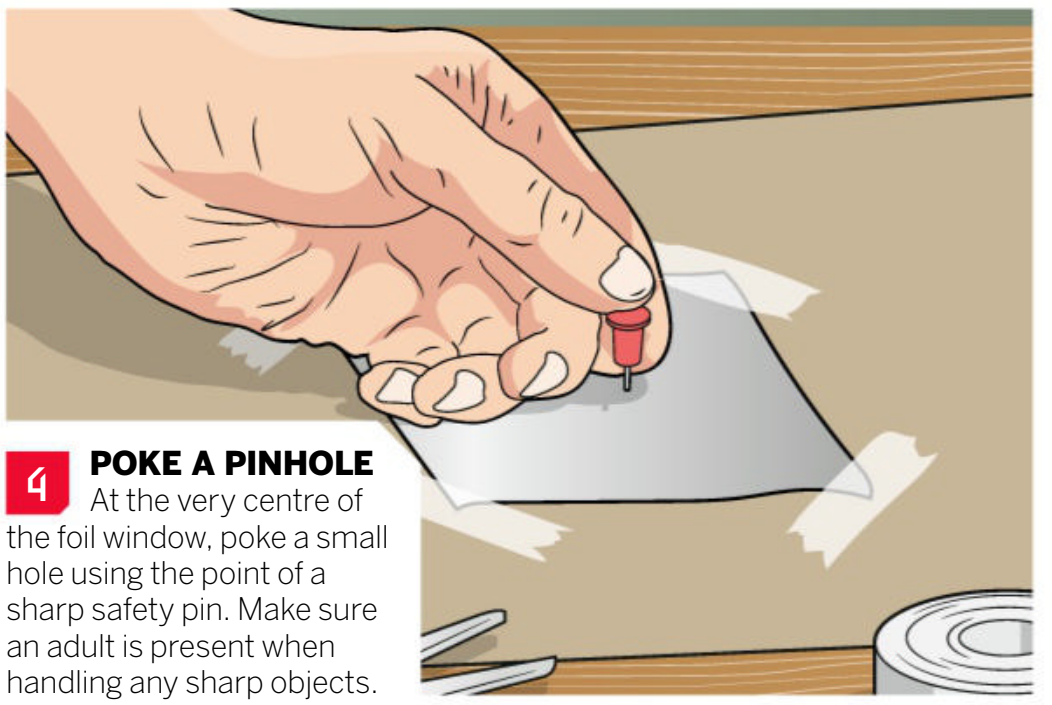
2 CREATE A FOIL COVERING

Next, cut a square from the foil that will cover the cardboard window. This needs to be larger than two by two centimetres for a complete covering.

3 TAPE IN PLACE

Use your tape to secure the foil over the window. The tape needs to cover the edges of the foil without overlapping the central hole at all.



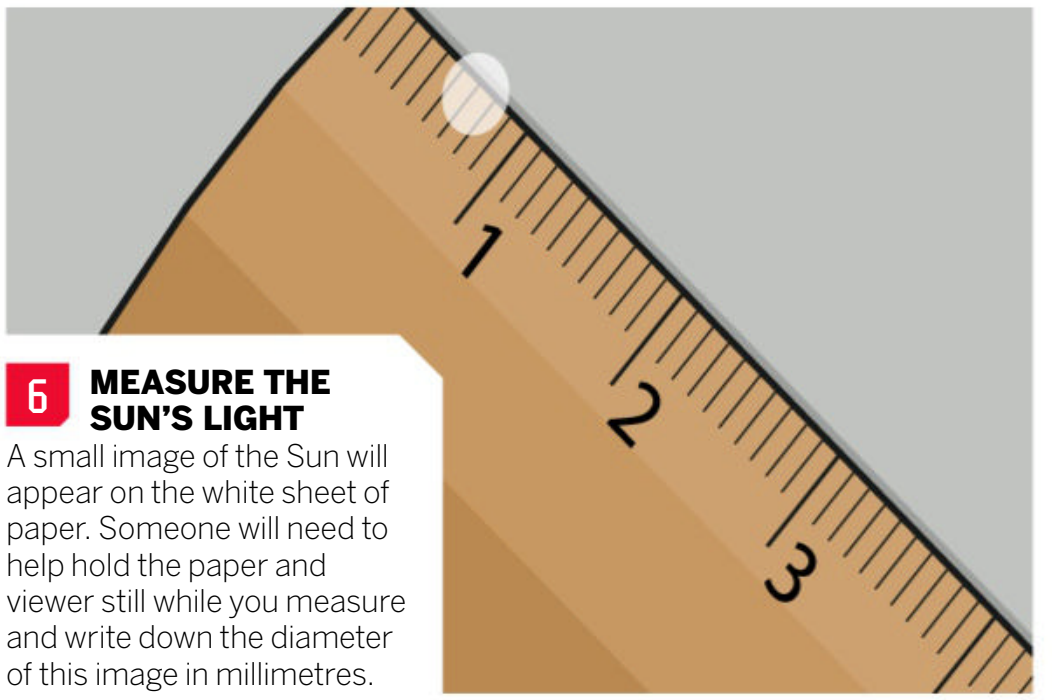


4 POKE A PINHOLE

At the very centre of the foil window, poke a small hole using the point of a sharp safety pin. Make sure an adult is present when handling any sharp objects.

5 SOLAR ALIGNMENT

Hold the pinhole viewer between the Sun and a piece of paper, with the hole directed towards the Sun. You might want to tape the paper to a book to keep it flat.



6 MEASURE THE SUN'S LIGHT

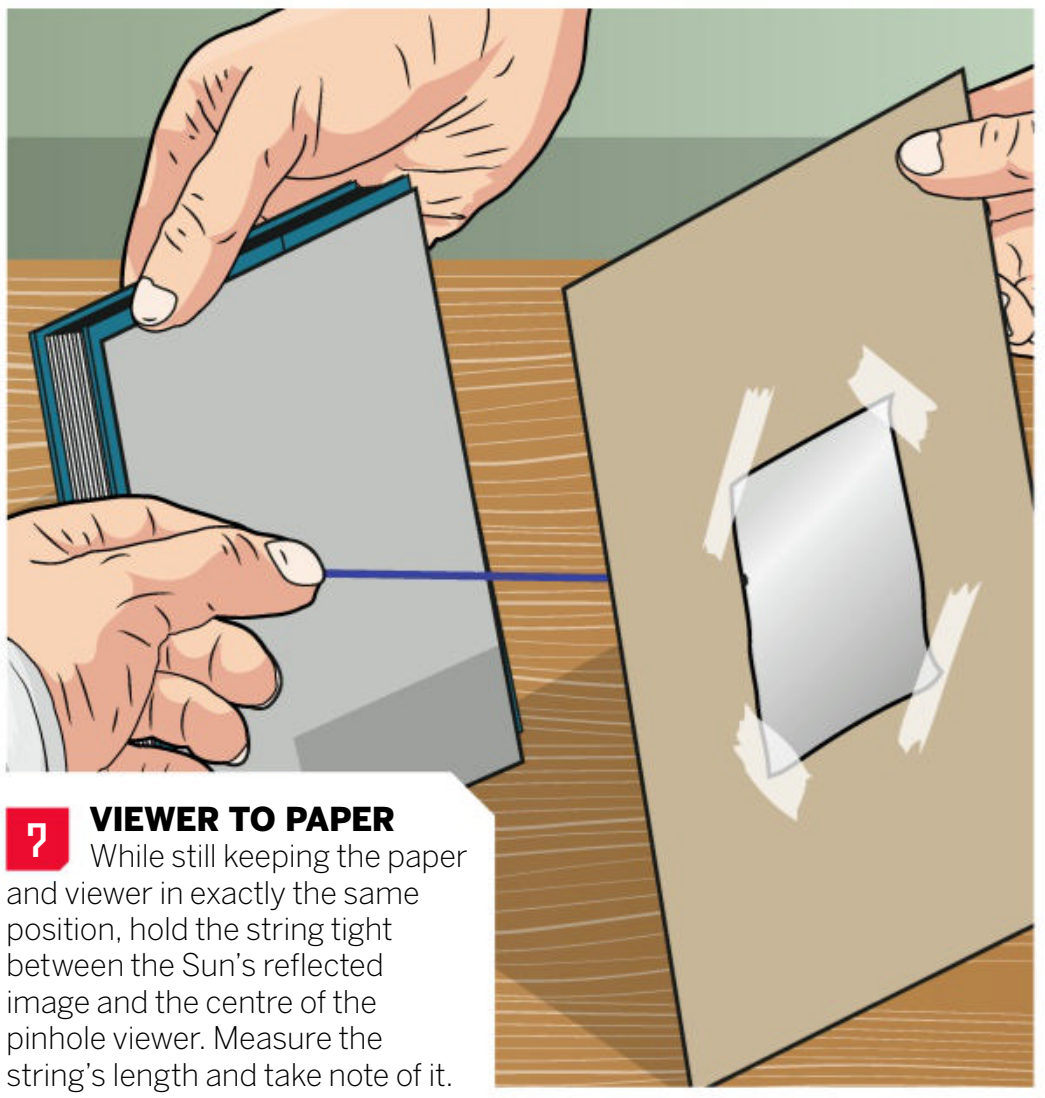
A small image of the Sun will appear on the white sheet of paper. Someone will need to help hold the paper and viewer still while you measure and write down the diameter of this image in millimetres.

NEXT ISSUE
MAKE YOUR OWN CANAL LOCK

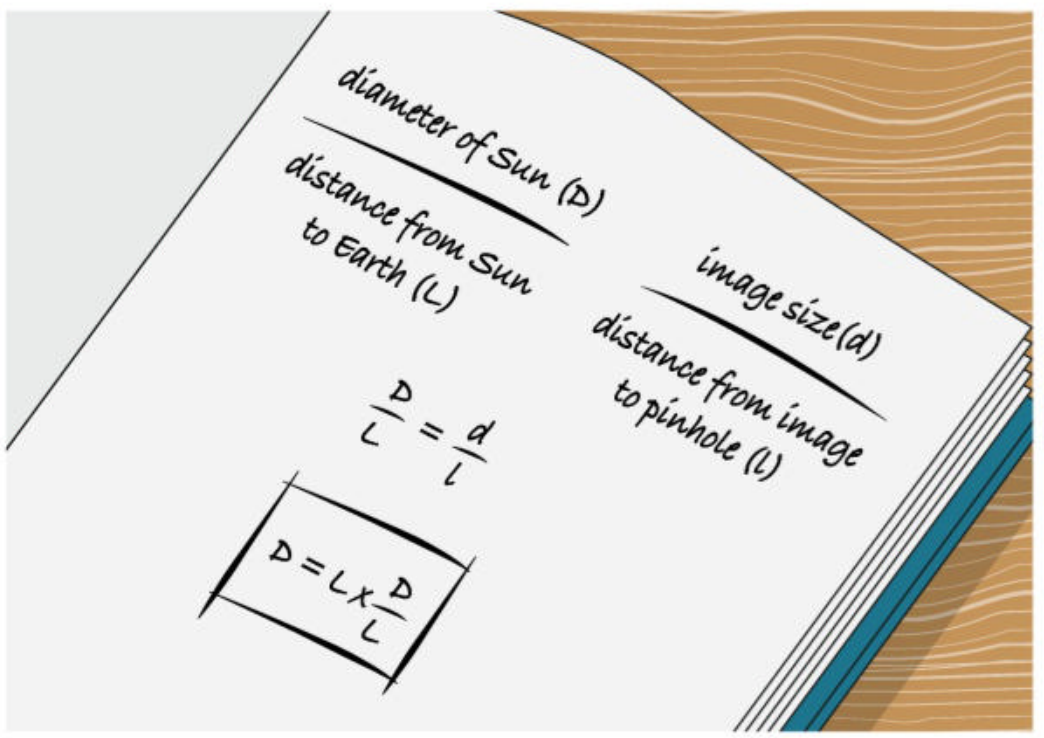
KIT LIST

- Piece of cardboard
- A4 paper
- Safety pin
- Masking tape
- Aluminium foil
- Scissors
- String
- Ruler
- Calculator

DON'T DO IT ALONE!
If you're under 16, make sure you have an adult with you



7 VIEWER TO PAPER
While still keeping the paper and viewer in exactly the same position, hold the string tight between the Sun's reflected image and the centre of the pinhole viewer. Measure the string's length and take note of it.



8 DATA TO DIAMETER
Write out this equation, but swap 'L' for 149,600,000, 'd' for the measurement of the light dot on the paper and 'l' for the measurement of the length of the string between the paper and pinhole. All measurements need to be in kilometres. To change millimetres to kilometres, divide the number by 1,000,000. To change centimetres to kilometres, divide the measurement by 100,000. Calculate L x d ÷ l to discover the diameter of the Sun.

SUMMARY

The pinhole viewer projects an image of the Sun onto the paper because every area of the Sun is radiating light. When this light travels through a small pinhole, less of the Sun's rays fit through, but light still travels from each visible point of the Sun. This creates an inverted image of the Sun on the paper. You can test this inside first by swapping the Sun with a lit candle. As every point on the flame emits some light, the paper behind the pinhole viewer will display the shape of the flame. The size of the flame's image will change depending on how far away from the viewer the paper is held.

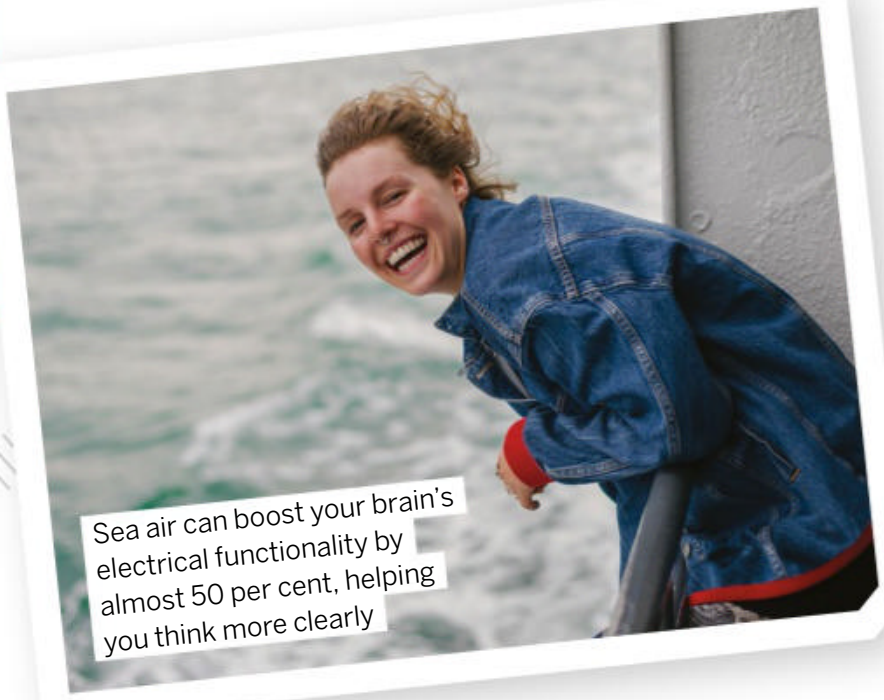
The ratio of the diameter of the Sun to its distance from Earth is proportional to the ratio of the diameter of the Sun's image on the paper and the distance between the paper and the pinhole viewer. As long as you have access to all the other measurements in the calculation – including the distance between Earth and the Sun – you can deduce the diameter of the Sun. At the end of the experiment, look up the actual diameter of the Sun and see how close you came to the right answer, simply by using household materials. You can also use the pinhole viewer to calculate the diameter of the Moon. Use the same equation to do this, but with the measurement for the distance between the Moon and Earth, and make sure you do the experiment when there's a full Moon.

Had a go? Let us know!

If you've tried out any of our experiments – or conducted some of your own – let us know! Share your photos or videos with us on social media.

INBOX

Speak your mind



Sea air can boost your brain's electrical functionality by almost 50 per cent, helping you think more clearly

SEA AIR SCIENCE

Dear **HIW**,
You always hear people referring to the 'sea air', but how different is the air at the coast? Does the wind pick up much salt, and if so, how far does the salt travel?
Saskia Ruhe

LETTER of the MONTH

This is a topical question as recent research has indicated that sea air is very different from the wind inland in its composition and has some health benefits. As the wind rushes past the waves, it picks up sea spray, including salt particles, which it carries across the shore. The salt concentration is very low, but salt can be deposited up to a few miles away from the ocean. Exactly how far the salt will travel in the air depends on the conditions that it was picked up in. A high wind speed increases the distance as the strong winds can lift the salt higher and further. When the water in the air eventually evaporates, the salt is suspended as small salt particles.

The salt concentration is just one thing that separates the sea breeze from inland wind. Because of the moisture being picked up by the wind, the air at the coast is often more humid. The temperature of the sea air is milder because the sea heats up and cools down slower than land does. As a result, winters and summers at the seaside can be a lot less extreme compared with inland conditions. However, it can be windier as sea breezes rush in from the sea and over the land.

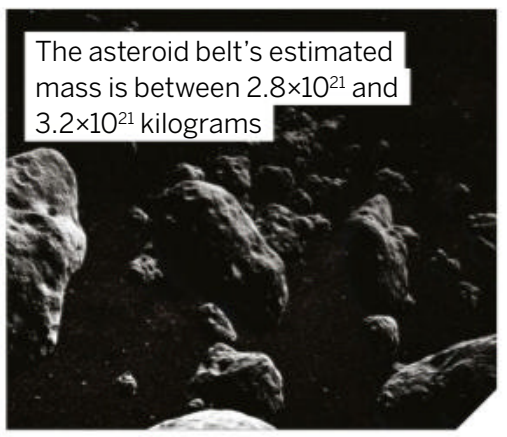
Finally, the concentration of negative ions in the sea breeze is a lot higher. As water from the ocean evaporates into the air, water molecules break apart and negative ions are released. There's also a high concentration of negative ions at the ocean's surface. When people at the seaside breathe in these ions, they benefit the electrical function of the brain and create more neural pathways. This means that breathing sea air can actually make you think clearer than city air can.

ASTEROID ACCUMULATION

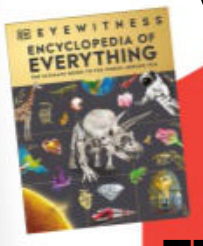
Dear **HIW**,
If you combined the mass of all the objects in the asteroid belt, how large a planet would be formed?
Alyn Scott

The main asteroid belt is between Mars and Jupiter and contains between 1.1 and 1.9 million asteroids that have a diameter larger than 1,000 metres. In addition to these space rocks, there are millions of smaller objects. Despite this huge collection of asteroids, the belt isn't as crowded as you might imagine. Instead they're relatively spaced out.

Almost half of the asteroid belt's entire mass is made up of the four largest objects: Ceres, Vesta, Pallas and Hygiea. Ceres is large enough to be considered a dwarf planet instead of an asteroid. Although we can't measure the exact mass of the entire asteroid belt, scientists have estimated that it is equivalent to four per cent of the Moon's mass.



The asteroid belt's estimated mass is between 2.8×10^{21} and 3.2×10^{21} kilograms



WIN!

AN AMAZING PRIZE FOR LETTER OF THE MONTH

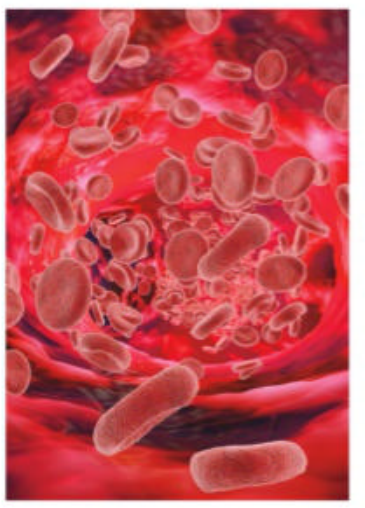
EYEWITNESS ENCYCLOPEDIA OF EVERYTHING

Experience the world's most incredible nature, science and history images and stories in one extraordinary book

THE BIOLOGY OF BLOOD

Dear **HIW**,
How long does a blood cell exist in the body and how quickly can the body make more when needed?
Dominic Hatfield

On average, a red blood cell in the human body has a life span of 120 days. As they reach the end of their time in circulation, their membranes become weaker. They are removed from the blood in the spleen, bone marrow and liver at an equal rate to the cells being made to replace them. This keeps your red blood cell count at a similar level consistently. Every second, your body completes production of about 2 million new red blood cells, and the formation of each one takes around two days.



Adults have 20 to 30 trillion red blood cells

Inland taipans carry enough venom to kill 100 people in one bite

DANGEROUS SPECIES

Dear **HIW**,
What's the most dangerous animal in Australia? I want to visit but the animals scare me.
Si Deyes

The dangers of Australian wildlife are well documented, but most people who visit the country spend much of their time in urban areas, where this danger is greatly reduced. Crocodiles, snakes, sharks and spiders are among the deadly and poisonous species, but the risk of being harmed by these creatures is generally low. The world's most venomous snake, the inland taipan, lives in Australia. More than 80 per cent of untreated bites from this snake result in death. However, they are timid creatures, live in remote areas and don't spend much time above ground during the day. Saltwater crocodiles are often considered more deadly, as they are more likely to be encountered. They grow up to seven metres in length and sometimes display aggressive behaviour. They are capable of taking down large prey, but by researching where known crocodile habitats are and following local guidelines, tourists can remain safe.

Firefighters need to consider their safety when tackling unpredictable wildfires.

RAGING WILDFIRES

Dear **HIW**,
What makes wildfires so destructive? Why can't they be quickly extinguished?
Peter Maschke

One of the biggest factors in the spreading of wildfires is the large availability of highly flammable fuel. Due to hot, dry conditions, plants are also dry and highly flammable. Firefighters may be able to tame one part of the blaze, but the scale of these fires can overwhelm emergency services and they can't extinguish the fires at all points. In rugged terrain and with the unpredictable nature of these fires, it's difficult enough to navigate close to the fire in the first place. Strong winds can cause embers from the fire to be carried to new areas, causing multiple blazes in a short space of time.

WE ASKED YOU

This month on social media, we asked you: What do you do to reduce your environmental impact?

@FATEMEH7FOR7

Using less plastic bags, eating less red meat and recycling

@JEANMCDOUGALL8333

Recycle

IAIN HUTCHISON

I use my bike more than my car

@MAIA_H3

I recycle my plastic

@DOODLENEWS

I have a plant-based diet and litter pick at my local beach occasionally

OLLY D

I've started trying to take shorter showers

© Getty

HOW IT WORKS

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FAST FACTS

Amazing trivia that will blow your mind

ICE CREAM IS A SOLID, A LIQUID AND A GAS

11,203 cubic miles

The magma reservoir under Yellowstone could fill the Grand Canyon 11 times

13.8 BILLION YEARS

The oldest known star, Methuselah, is inexplicably older than the universe

1928

This year, 15 countries signed an agreement to end all war

31 OCTOBER 2000

It's been over 20 years since the entire human race has been on Earth at the same time

300,000

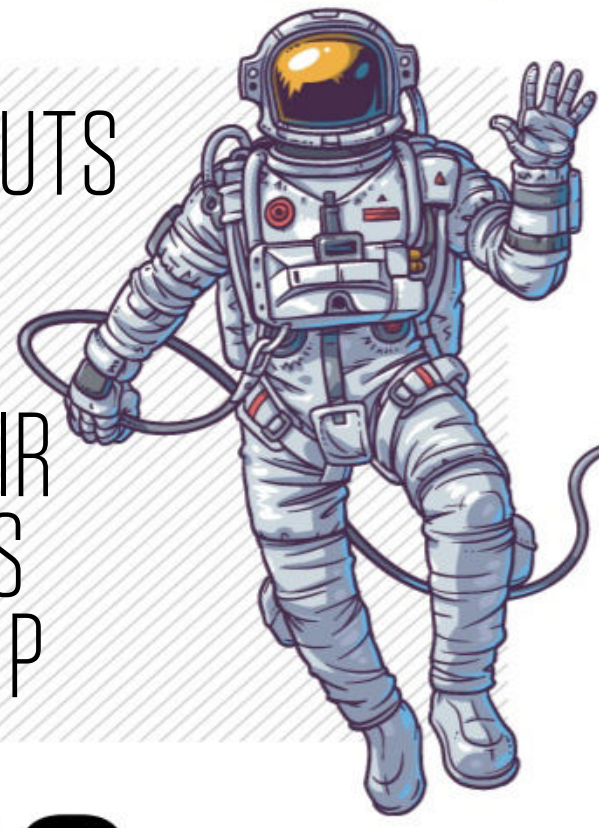
Three-quarters of the 400,000 species of plants are safe to eat

Apple founder Steve Jobs had koumpounophobia, a fear of buttons

8.4 MILLION

London has the most trees of any European capital

ASTRONAUTS WEAR BELTS TO STOP THEIR TROUSERS FALLING UP



TEN-TRILLIONTHS

A tiny fraction of your tan comes from stars beyond the Milky Way

IF I HAD SOMEWHERE TO LIVE...

I COULD GO ANYWHERE IN LIFE

When Abi's mum died, life got tough. She didn't get on with her dad and the arguments became violent. Abi felt her only choice was to leave home. With just the clothes on her back, and no idea where to go, she ended up sleeping on the streets in the freezing cold.

Right now, you could give a homeless young person like Abi somewhere to start their future

Abi's life changed when she was given a room at Centrepoint. A safe place to sleep and recover. A place to develop the skills and confidence she needed to rebuild her life – and leave homelessness behind for good. Now, Abi believes she can go anywhere.

Thousands of homeless young people like Abi are desperately trying to find their place in the world – but first they need a place to start again. **You could help right now by sponsoring a room at Centrepoint for just 40p a day.**

We know this support changes lives. 88% of the young people we help move on positively in life. So please, help someone like Abi today. Thank you.

Text PLACE to 78866 to donate £3
Call free on 0800 472 5798
Visit centrepoint.org.uk/place
Or complete and return the form below

SPONSOR A ROOM. HELP A HOMELESS YOUNG PERSON FIND THEIR PLACE.

YES, I WANT TO SPONSOR A ROOM FOR £12 A MONTH

Please collect my payment on the 1st/15th of every month (please circle preferred date).

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To the Manager:
Name and full address of your Bank or Building Society:

Originators Identification No. 6 5 9 1 0 7

_____ Postcode _____

Name(s) of Account Holder(s) _____

Bank Sort Code: ☐☐-☐☐-☐☐ Account Number: ☐☐☐☐☐☐☐☐

Instructions to your Bank or Building Society: Please pay Centrepoint Direct Debits from the account detailed in this instruction, subject to the safeguards assured by the Direct Debit Guarantee. I understand that this instruction may remain with Centrepoint and, if so, details will be passed electronically to my Bank/Building Society.

Signature(s) _____ Date _____

Banks and Building Societies may not accept Direct Debit Instructions for some types of account.

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Your name and address are needed to identify you as a current UK taxpayer.

Your donation will go towards funding Centrepoint's vital work with young people all year round providing accommodation and support. We sometimes use models and change the names of the young people we work with to protect their identity; however all stories are true and as told by the young person.

Full Name: _____

Address: _____

Postcode: _____ Telephone: _____

Email: _____

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☐ **Please contact me by email** ☐ **Please contact me by phone**

Last year our supporters helped us change the lives of over 15,000 homeless young people. By letting us know we can count on you, we can continue helping young people with a home and a future.

Your privacy is key.

We promise never to sell or swap your details, and will always keep them secure. You can view our Privacy Notice in full at www.centrepoint.org.uk/privacy. You can opt out of post and change how we communicate with you at any time. Please call 0800 232320 and speak to one of our friendly team or email supportercare@centrepoint.org to do this and ask us any questions.

Please return this form to: Freepost Plus RTXY-LBEA-UTJJ, Angel Fulfilment Services Ltd, Communication Centre, Par Moor Road, Par PL24 2SQ.

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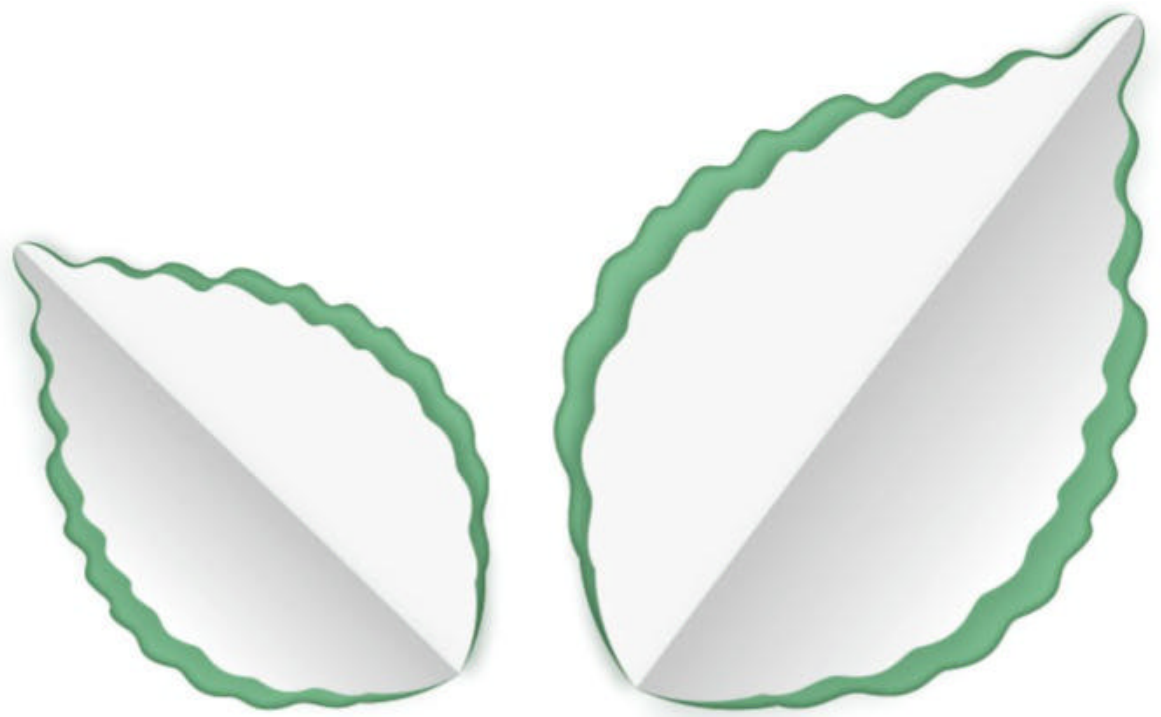

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