THE MAGAZINE THAT FEEDS MINDS

HOW IT WORKS

SCIENCE ENVIRONMENT TECHNOLOGY TRANSPORT HISTORY SPACE

INSIDE

COWS ARE MAGNETIC

AND 24 OTHER WEIRD SCIENCE FACTS

7 NATURAL WONDERS

The science behind Earth's most amazing phenomena

LAWS OF THE UNIVERSE

Learn about the physics which governs space

Taranis completed its first test flight in 2013

Tiny radar profile for maximum stealth on covert missions

Will include autonomous elements with no need for human input

DRONE AIRCRAFT

INSIDE THE PILOTLESS PLANES OF THE FUTURE

LIFESAVERS • AERIAL SPIES • STEALTH WEAPONS • SCIENTIFIC TOOLS

PULSARS UNCOVERED

What causes neutron stars to get in a spin?

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Inside the devices that go far beyond taking photos

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Discover how insects are trained to find explosives

DAM BUILDING EXPLAINED

The engineering that can defy water and gravity

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ISSUE 54

WELCOME

The magazine that feeds minds!

Page 22
Ever wondered how the tallest mountain range in the world got there?

There's a new trend in the field of aviation that once upon a time would barely have been conceivable: aircraft without pilots. That is, full-sized planes and helicopters zooming around the sky without anyone up there in the cockpit.

They go by a number of names, including drones and unmanned aerial vehicles (UAVs), neither of which really does these amazing pieces of engineering justice. And what's similarly unfair is that they seem to have acquired a reputation as only being good for one thing: death and destruction. This issue we shed some more light on these incredible flying machines, introducing a few of the most advanced currently taking to the air and exploring the many other roles UAVs perform with aplomb, including scientific research and even – believe it or not – *saving* lives.

Enjoy the issue.

Adam Millward
Deputy Editor

Meet the team...

Marcus
Senior Designer
As a Brit I love to moan about the weather so learning about the future tech set to help control it really piqued my interest!

Erlingur
Sub Editor
I love lists of all types, so the fantastically varied list of 25 weird science facts is right up my Geekville alley.

Jackie
Research Editor
I enjoyed the 'Laws of the universe' feature. It's amazing to think that the entire cosmos is governed by just four fundamental forces.

Helen
Senior Art Editor
I've loved looking at the '7 natural wonders' feature; it just reminds me of what a mind-blowingly awesome planet we live on.

What's in store...

The huge amount of information in each issue of How It Works is organised into these key sections:

Science
Uncover the world's most amazing physics, chemistry and biology

Technology
Discover the inner workings of cool gadgets and engineering marvels

Transport
Everything from the fastest cars to the most advanced aircraft

Space
Learn about all things cosmic in the section that's truly out of this world

Environment
Explore the amazing natural wonders to be found on planet Earth

History
Step back in time and find out how things used to work in the past

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Meet the experts...

Vivienne Raper
Weather control
Geophysics expert Vivienne explores the technology – both currently in operation and that on the drawing board – with the power to change Earth's climate, including how cloud seeding is used to induce rain.

Rob Jones
7 natural wonders
From the biggest volcano to the stunning polar auroras and the tallest tree to grow on Earth, Rob takes an in-depth look at the science and geology of nature's most spectacular phenomena.

Giles Sparrow
Laws of the universe
How It Works' regular space contributor Giles is on hand to help you get to grips with the fundamental physics that affect every object in the cosmos.

Alexandra Cheung
Weird science
Did you know we weigh less when the Moon is directly overhead? Or that light can trigger a sneeze? Alex explains some of the most mind-bending facts in science.

Rik Sargent
Dam engineering
This month Rik explores the core structure of a dam. Which natural forces help hold back great bodies of water, and how do the major types of dam differ in shape and building materials?

Why is lava not the most deadly thing to come out of a volcano? Find out on pg 32

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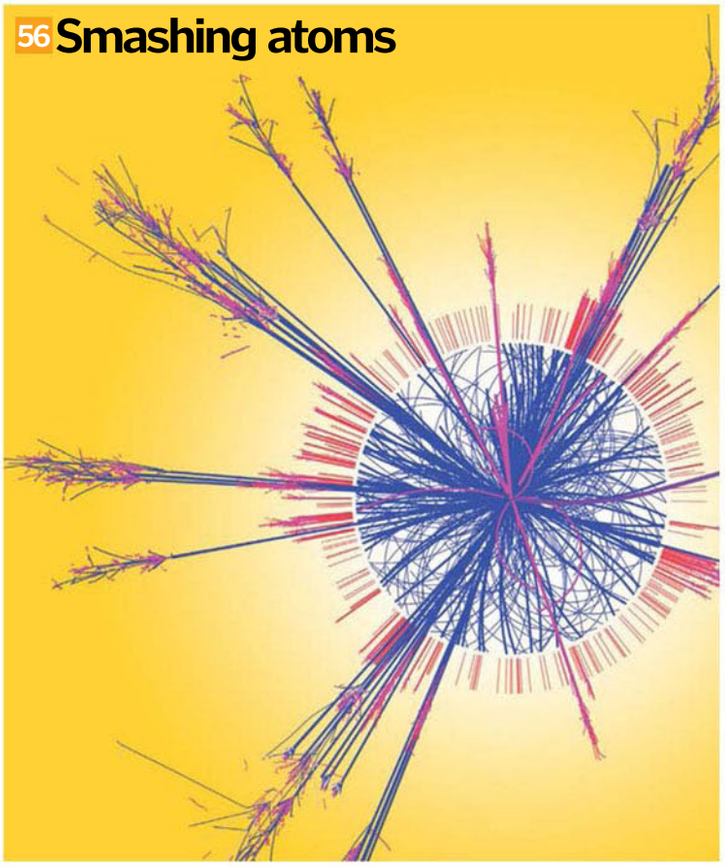

56 Smashing atoms

39 Google Trekker

20 Spaghetti Junction

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Not only towns and cities were devastated by the typhoon but many acres of farmland too

Mega-storm hits South-east Asia

What could be the largest typhoon in history has caused mass destruction in the Philippines

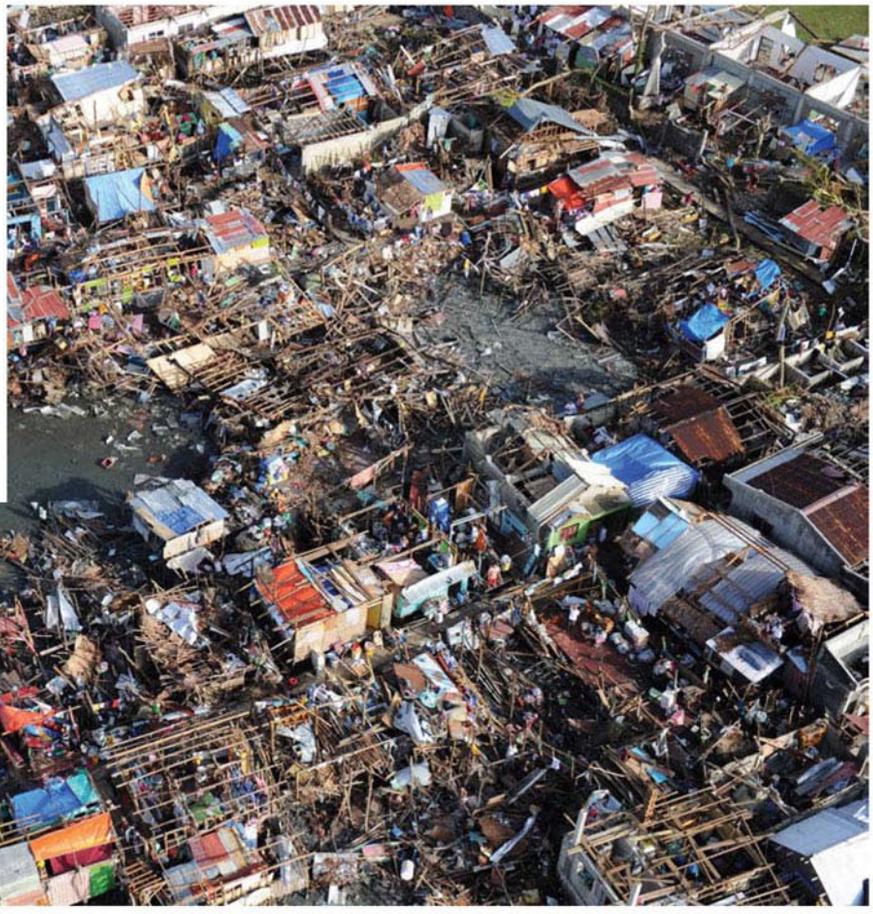
One of the biggest-ever storms to make landfall – perhaps even the biggest – has sparked a humanitarian crisis in the Philippines. Over ten million residents have been affected by Super-typhoon Haiyan – also called Yolanda by Filipino authorities – and the death toll, although yet to be confirmed, is known to be in the thousands.

At its peak, Haiyan was equivalent to a Category 5 hurricane and tragically, at the time of writing, official figures indicate it could have claimed some 4,000 lives. The casualty rates could rise as aid workers move in to start the recovery operation, though this process is taking longer than anticipated because of the extent of the damage across the hundreds of islands that make up the nation.

The monster storm hit the Philippines on 8 November with winds reaching up to 379 kilometres (235 miles) per hour and bringing with it waves as high as 15 metres (50 feet). In its wake, it left buildings in ruins, power lines and trees ripped from the ground and landslides

"It left many buildings in ruins, power lines and trees ripped from the ground and landslides making roads impassable"

Super-typhoon Haiyan is considered by some to be the biggest storm to ever make landfall



making roads impassable. The country's interior secretary, Mar Roxas, commented: "The devastation is… I don't have words for it, it is really horrific. It's a great human tragedy."

Also known as hurricanes and cyclones in other parts of the world, a typhoon is a clockwise-rotating storm system (they spin anticlockwise north of the equator) that develops as warm, moist air rises from tropical seas to form rainclouds. The low pressure this leaves draws in cooler air, which itself heats up and rises. Eventually this cycle causes the storm to spin at high velocity, with a calm region – the eye – emerging at the centre. In order for a typhoon to become a 'super-typhoon' it must have sustained gusts of over 240 kilometres (150 miles) per hour.

There were fears that Haiyan could once again pick up pace as it moved across the South China Sea but on making landfall in Vietnam its power had been diminished, reducing its classification to a severe tropical storm.

Kepler might be coming out of its short-lived retirement

Kepler back on planet hunt?

There is renewed hope that NASA's Kepler telescope, which was retired in August, could get a new lease of life.

In May 2013 the second of Kepler's four reaction wheels which help keep the spacecraft steady malfunctioned. This seemed to herald the end of its planet-hunting days, because it could no longer counter solar pressure, causing it to spin.

But now engineers have suggested a way to work around the issue, manoeuvring Kepler to a certain tipping point where sunlight falls evenly over it. "It's like balancing a pencil on your finger," explains deputy project manager, Charlie Sobeck. "As long as you can keep that pencil balanced with your finger below, it's not going to tip over."

The suggested 'K2' mission wouldn't work quite the same as before, as Kepler would not be able to focus on a specific region for as long. This means it would only be able to detect planets with very short orbits around their stars. Already considered a huge success, since it launched in 2009 Kepler has spotted 3,538 candidate planets outside our Solar System, with 167 confirmed to date.

See your photos in World of Animals!

With the first edition of new wildlife magazine **World of Animals** now on the shelves, there is a fantastic opportunity for you to get involved. Each issue includes a section dedicated to readers' best wildlife photography, from the bugs in your back garden to the Big Five on the African savannah.

Just send your snaps to **animals@imagine-publishing.co.uk** and you could win a free subscription to the magazine! **World of Animals** is available from WH Smith, all good newsagents and digitally on iTunes and Google Play. For lots more wildlife goodness, check out its companion site **www.animalanswers.co.uk**.

Mach 6 hyperplane revealed

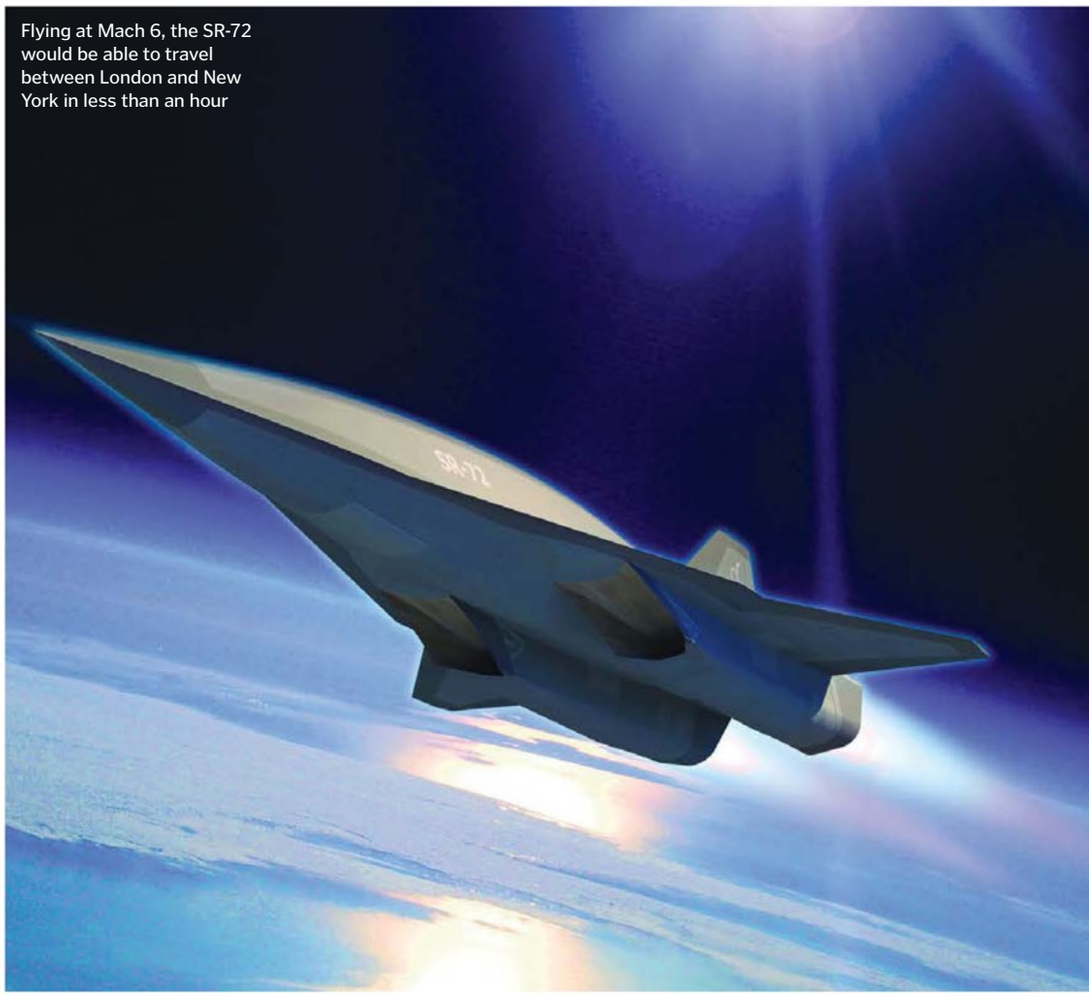
The 'Son of Blackbird' spy plane – the reinvented SR-71 – could take off by 2030

According to leading aerospace company Lockheed Martin its latest hypersonic plane design – capable of flying at six times the speed of sound – could be in the air as soon as 2030. The SR-72 is the evolution of Lockheed's much-celebrated SR-71 Blackbird which made its debut flight in 1962 and the following year had surpassed Mach 3 (that is, 3,675 kilometres/2,284 miles per hour).

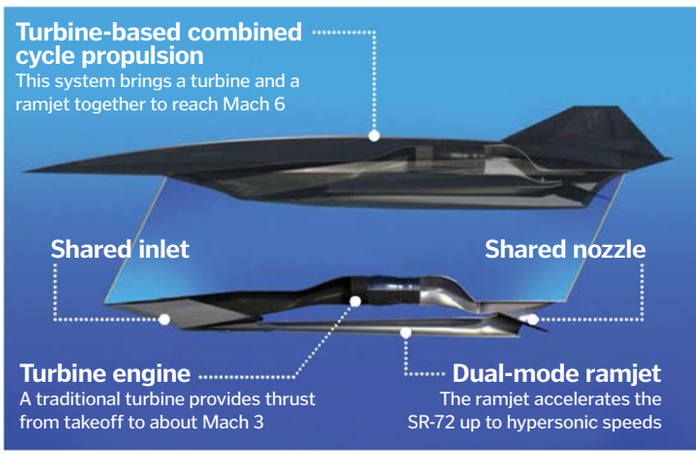
The SR-72, dubbed 'Son of Blackbird', would offer many of the same benefits of its forebear, like reconnaissance behind enemy lines at a high altitude – only at double the speed. Indeed, Brad Leland from Lockheed's Hypersonics division said: "Speed is the next aviation advancement to counter emerging threats in the next several decades. The technology would be a game-changer in theatre, similar to how stealth is changing the battlespace today."

To reach such blistering speeds, the SR-72 will use a new form of combined cycle propulsion. This involves the marriage of a traditional jet turbine and a dual mode ramjet, which are explained in the diagram to the right.

Another major difference in the new-and-improved Blackbird could be that it is unmanned. To learn more about the drone aircraft already performing incredible feats today, check out our feature on page 12.

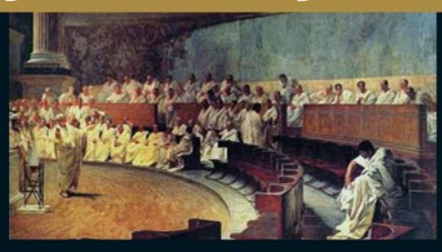


Flying at Mach 6, the SR-72 would be able to travel between London and New York in less than an hour



This day in history 05/12/13: How It Works issue 54 goes on sale, but what else

63 BCE
Closing statement
Roman lawyer, orator and consul, Marcus Cicero, delivers his final speech against the Catiline Plot.



771 CE
To be Frank
After his sibling dies, Charlemagne becomes the sole ruler of the Franks.

1082
Brotherly hate
Joint count of Barcelona, Ramon Berenguer II is killed while hunting, many suspect by his own twin brother.

1492
New World
Christopher Columbus takes his first step onto the island of Hispaniola (now Haiti and the Dominican Republic).

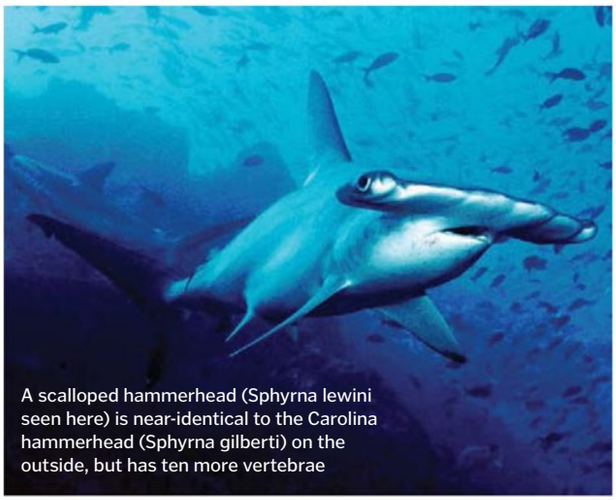
India set to join Mars exploration party

India has made history by becoming the first Asian country to send a spacecraft to the Red Planet. Launched on a PSLV (Polar Satellite Launch Vehicle) rocket on 5 November the Mars Orbiter Mission (MOM) successfully arrived in Earth's orbit, where it is currently performing a series of thruster firings, having recovered from a minor glitch in an early manoeuvre.

Opting for a more economical route known as the Hohmann Transfer Orbit, rather than a direct exit from Earth, the probe will increase its velocity and its distance from us little by little until it is far enough to escape our planet's gravity. By 1 December, it is expected to be en route to Mars. If all goes to plan, MOM is scheduled to arrive at the Red Planet in September 2014, when it can start analysing the Martian atmosphere and photographing the surface with the host of cameras and measuring tools included in its scientific payload.

Not long after it arrives in Mars's orbit, MOM will be joined by NASA's Mars Atmosphere and Volatile EvolutioN (MAVEN) probe, which successfully launched on an Atlas V rocket on 18 November from Florida.

India's Mars Orbiter Mission is the first Asian spacecraft sent to the Red Planet



A scalloped hammerhead (Sphyrna lewini seen here) is near-identical to the Carolina hammerhead (Sphyrna gilberti) on the outside, but has ten more vertebrae

New species of shark found off US coast

A research team has discovered a unique species of shark off South Carolina that has been in plain sight for years. Ichthyologist Joe Quattro has been conducting an extensive survey of river fish – as well as ocean fish in estuaries – on the US East coast for nearly 20 years. It was while studying hammerhead pups that a discrepancy was picked up in their genetic code.

This unusual finding corroborated an earlier anomaly recorded back in the Sixties of a shark with fewer vertebrae than other hammerheads. After several more years of research and classification, the new species – Sphyrna gilberti – has now been fully described in the journal *Zootaxa*.

The reason the Carolina hammerhead has gone undetected for so long is its virtually identical appearance to the common scalloped hammerhead; the only notable anatomical differences are internal.

Robotic arm grabs top tech prize

A mechanical arm designed by four engineering students from the University of Pennsylvania has scooped 2013's James Dyson Award, which celebrates new tech that solves a problem.

The Titan Arm is an exoskeleton device that can be used to boost strength for lifting – granting the ability to pick up an additional 18 kilograms (40 pounds) – or as a mechanical aid for those with back problems.

It is comprised of a brace to improve posture, a shoulder piece with movable joints, plus sensors which can log movements and send information wirelessly to doctors. At the moment it is controlled by a joystick, but the students think it could be adapted to detect electrical activity in muscles, like more advanced biomechanical tech around today.

Even more remarkable is the tiny budget the team managed to stick to, building a prototype for just £1,200 ($1,900). Nick Parrotta, one of the students who built the Titan Arm, explains why keeping costs down was a priority: "We wanted Titan Arm to be affordable, as exoskeletons are rarely covered by health insurance. This informed our design decisions and the materials we used. Most structural components are machined from inexpensive aluminium."

happened on this day in history?

1766
Going, going... gone
Famous London auction house Christie's holds its first ever sale.

1839
Custer's birthday
George Armstrong Custer, most well known for his epic defeat at Little Bighorn, is born.

1848
There be gold...
US President James K Polk verifies the discovery of gold deposits in California, sparking a gold rush.

1933
Raise a glass
After 13 years of alcohol being illegal, the 18th Amendment is repealed, ending the Prohibition.

1945
Lost squadron
Five US Navy planes take off from Florida only to vanish in the Bermuda Triangle after reporting failing instruments.

10 COOL THINGS WE LEARNED THIS MONTH

Videogames are good for your brain

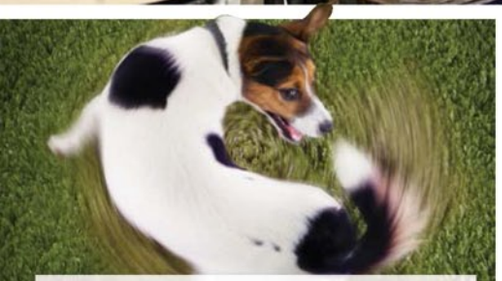
They get a lot of criticism for dumbing down the young generation, but new research by the Max Planck Institute suggests a short daily dose of gaming can actually boost our brain power. A group of adults were asked to play *Super Mario 64* for 30 minutes a day for two months, with before and after scans taken with an MRI machine. In comparison with a control group who didn't play videogames over the same period, the scientists found increases in grey matter, including those associated with memory formation and strategic planning. It's even thought that videogames might be used as a complementary therapy to treat some mental disorders.

Robots are taking over rock

The music world is famous for its advanced technology, but if you thought iPods, high-end speakers and recording studios were impressive, you should take a look at the Z-Machines. Debuting this year in Tokyo, three robots – named Cosmo, Ashura and Mach – make up the band and between them they boast some impressive skills. Guitarist Mach has 78 fingers and 12 picks, with the ability to play over 1,180 beats per minute, drummer Ashura can play 22 drums simultaneously, while keyboardist Cosmo shoots lasers from his eyes. Now that sounds like a gig worth seeing!

We can see in the dark

A new cognitive science study has revealed that many of us are able to see our body without any source of light. Participants were fitted with eye trackers before being put in a pitch-black room and asked to wave their hand, and more than 50 per cent were able to accurately follow the movement. The researchers believe these findings confirm we use far more sensory data than optical information to see, and that our brains play an equally important role as our eyes – especially when it comes to perceiving self-motion. Interestingly, those with the condition synaesthesia, where sensory perceptions overlap, performed particularly well in this test.

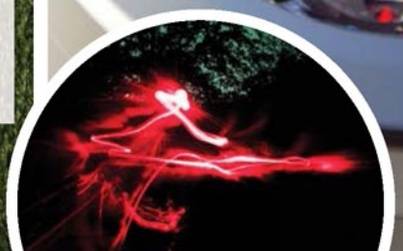


Waggy tails express mixed feelings

A new study into man's best friend has shown that dogs can gauge each other's moods by the way they wag their tails. Building on other research that showed happier dogs wagged to the right, while nervous dogs more to the left, researchers set out to confirm if other dogs can read these 'tell-tail' signs. A trial group were presented with videos and moving silhouettes of tail-wagging dogs, with their behaviour and heart rate monitored. The results showed dogs generally remained relaxed on seeing tails move right, but grew more anxious on seeing tails swing to the left.

Lighting is evolving

Tech that combines lasers and a motorised faceted crystal to refract light into amazing patterns has been used in the art world for some time. Now a prototype – called the Laserpod 2 – has scaled down this tech for a more domestic environment. The Laserpod can create stunning effects, either on a wall or in midair if projected onto atmospheric haze (see inset image), but it's seeking funding before it can be mass-produced.



Global warming could shrink all life on Earth

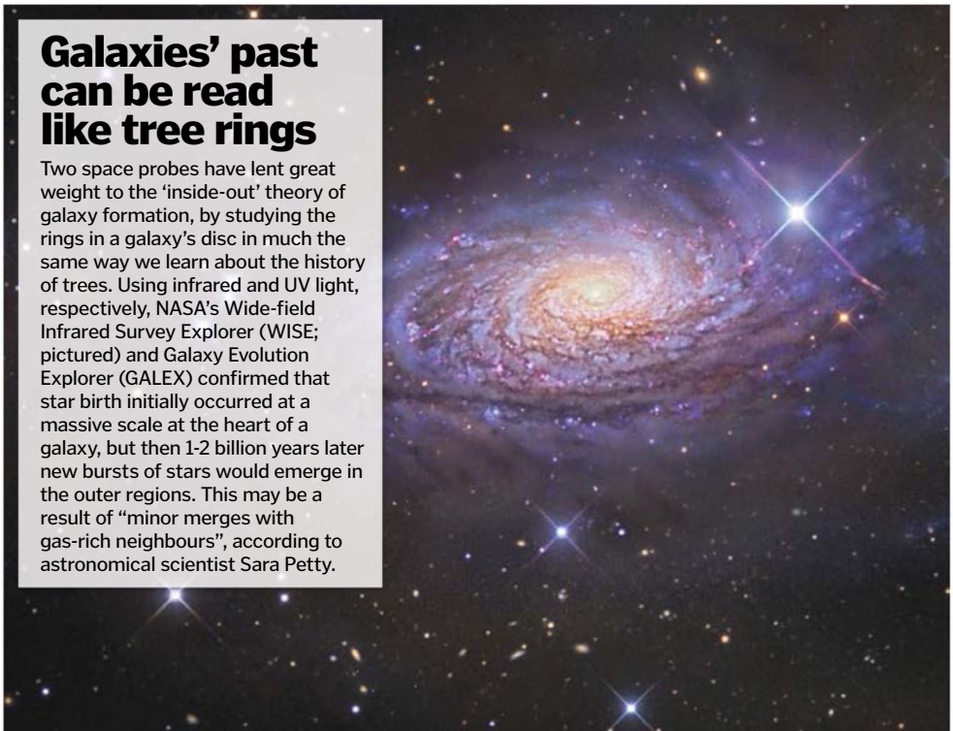
New research into a global warming event 53 million years ago has confirmed animals get smaller as the world heats up. Fossilised teeth and jaws of several species, including horses and primates, got ever-more diminutive during the Eocene Thermal Maximum 2. If global warming trends continue, species may shrink once again – including us!

We're a step closer to dino locomotion

Scientists have re-created the movements of the largest animal ever to walk the Earth in unprecedented detail. An Argentinosaurus skeleton dating from the Cretaceous era (which lasted from around 142 to 65 million years ago) was laser scanned before the data was fed into a bespoke simulation program with the processing power equivalent to 30,000 desktop computers. Estimated to have reached 40 metres (130 feet) long and weigh in the region of 80 tons, there have been some who doubt such a large creature could ever have got around on land, but this new virtual reconstruction suggests it could have moved at up to eight kilometres (five miles) per hour. The team are now hoping to re-create the locomotion of other famous dinos like T-rex.

Driverless pods will be public transport by 2015

Fed up of having to wait for a late-running bus or fork out for a pricey taxi? Well, in Milton Keynes, Buckinghamshire, a new type of driverless pod (similar to these pictured) is set to revolutionise public transport. Powered by electric motors, the 100 two-seater pods scheduled to be deployed in 2015 will travel at about 19 kilometres (12 miles) per hour in their own lanes around the city centre. You'll be able to use a special app to hail a pod or book one in advance and, even better, journeys are expected to cost just £2 ($3.20) – what a bargain!



Galaxies' past can be read like tree rings

Two space probes have lent great weight to the 'inside-out' theory of galaxy formation, by studying the rings in a galaxy's disc in much the same way we learn about the history of trees. Using infrared and UV light, respectively, NASA's Wide-field Infrared Survey Explorer (WISE; pictured) and Galaxy Evolution Explorer (GALEX) confirmed that star birth initially occurred at a massive scale at the heart of a galaxy, but then 1-2 billion years later new bursts of stars would emerge in the outer regions. This may be a result of "minor merges with gas-rich neighbours", according to astronomical scientist Sara Petty.

Our planet has a hot exo-twin

NASA has found a rocky exoplanet very similar to Earth in size and composition. Designated Kepler-78b, it is 1.2 times the size of our world and 1.7 times its mass (thought to be made largely of rock and iron). It is located about 400 light years away. But despite the similarities, this planet isn't considered a candidate for potential life because of its scorchingly close proximity to its star, which it orbits every eight and a half hours.

BAE's Taranis is an advanced technology demonstrator seeking to push the boundaries of unmanned military aircraft. It made its maiden flight in October 2013

DRONE AIRCRAFT

High-velocity, super-efficient and – if necessary – armed to the teeth, the unmanned aerial vehicle could be the future of both military and civilian aviation

KEY DATES
UAVS IN PROGRESS

1916
English engineer Archibald Low fails to fly a powered unmanned aerial vehicle.

1951
The Ryan Firebee series becomes one of the first jet-propelled drones to be mass-produced.

1973
The Tadiran Mastiff is considered the first modern combat UAV as it features a data link.

1994
General Atomics introduces the next generation of drones with the MQ-1 Predator.

2002
UAVs go small-scale with the AeroVironment RQ-11 Raven, which is launched by hand.

DID YOU KNOW? *A single MQ-9 Reaper costs £10.5mn ($16.9mn) to buy*

Today one aerial vehicle reigns above all others in grabbing the news headlines on almost a weekly basis: the unmanned aerial vehicle (UAV). These pilotless planes, or drones, are being used in an ever-growing range of roles, with national militaries now fielding vast remote-controlled squadrons across all theatres of war.

You only have to look at images of the General Atomics MQ-9 Reaper, a combat-centred UAV considered one of the most advanced hunter-killer aircraft ever built, and it's not hard to see why some have claimed that drone technology is something to be feared. Indeed, as its name would suggest, the Reaper specialises in long-endurance, high-altitude strikes at enemy targets with a variety of armaments, including a combination of highly accurate AGM-114 Hellfire missiles and GBU-12 Paveway II laser-guided bombs.

However this militarisation of UAV tech and the frequent bad press it gets fails to give credit to its many other applications, and arguably shrouds its true importance in the future of aviation, which is seeing incredibly successful results across all current fields.

Just to take one example out of many, the US National Oceanic and Atmospheric Administration (NOAA) currently uses the Aerosonde UAV as a hurricane hunter and weather monitor. The reason? Because this drone is an incredibly advanced piece of kit more than capable of out-sensing and outperforming any manned aircraft in the role of collecting atmospheric data. Indeed, the Aerosonde is able to record temperature, atmospheric pressure, humidity and wind measurements over oceans and remote areas with ease, remaining airborne up to a range of 3,000 kilometres (1,864 miles), at an altitude of 4,500 metres (15,000 feet) and a speed of 148 kilometres (92 miles) per hour. This performance is delivered through the partnership of the Aerosonde's modified Enya R120 engine and sleek, aerodynamic chassis – while its endurance is guaranteed by the lack of

F-16 fighter jets are being retrofitted to be used as training UAVs

Drone conversion

Currently, military contractor Boeing is retrofitting retired F-16 fighter jets with equipment that allows them to be flown remotely as a UAV. The jets, which have been obsolete for 15 years, were chosen due to their excellent handling characteristics and small radar profile. Early tests saw the first of these drone F-16s attaining speeds north of Mach 1.47 and successfully completing a series of complex manoeuvres.

The reason for the conversion of the F-16s, which from now on will be designated QF-16s, is to create a fleet of mission-capable unmanned vehicles that can be used to help train pilots and act as dummy targets for live fire tests. Currently, only six of these drone QF-16s are operational, but due to the programme's success, a production schedule is pencilled in to begin in late 2013, with the aircraft ready for deployment by 2015.

Main drone uses

COMBAT

MQ-9 Reaper; Guizhou WZ-2000

A rapidly expanding sub-section of the UAV field, combat drones specialise in delivering guided missiles and bombs to enemy targets without risking a pilot's life. Combat drones have recently seen much use in the Afghanistan and Iraq wars, patrolling battlefields for hostile infantry, vehicles and strongholds. Their high speed and small size make them excellent stealth vehicles too, capable of performing covert strikes behind enemy lines.

EMERGENCY

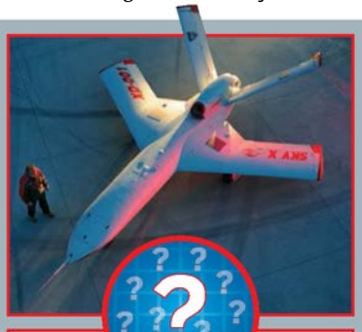
Draganflyer X6; Casper 250

From combating forest fires to exploring natural disaster zones, UAVs are increasingly seeing a large uptake across emergency services across the globe. Microdrones are often used to explore earthquake-struck buildings, thereby not risking a human life to a potential collapse. Radiation spills are also often initially explored by remote-controlled drones, with the unmanned vehicle impervious to any harmful side effects.

RECON

Elbit Hermes 450; RQ-4 Global Hawk

The bread-and-butter routine of the UAV sector, reconnaissance is being taken to new levels of omniscience with drone deployment across the world. With UAVs capable of remaining in the air for well over 24 hours without landing, thanks to the absence of pilots on board, and being fitted with next-generation sensing and recording equipment, they can deliver constant high-fidelity data streaming for far longer than any human could.



SCIENCE/RESEARCH

Sky-X; SIERRA; RQ-4 Global Hawk

Many UAV aircraft built today are done so purely for research and development, with their small size and unmanned nature making them ideal test vehicles for new aviation technologies or aircraft designs. Historically, experimental aircraft were piloted by expert pilots, with many lives lost when things went wrong. They are also perfect for conducting scientific research around the world, analysing weather and geological features – NASA uses several.

"The speed, agility and reconnaissance capabilities far outstrip those of any single human"

human pilot. In fact, prior to the use of drones as weather monitors and early warning systems, many lives were lost or endangered when piloted aircraft were brought down by bad weather. The arrival of drones such as the Aerosonde has removed that risk.

Indeed, what is not reported is that today, UAVs are used in many useful, non-military applications (see 'Main drone uses' on page 13), ranging from fighting forest fires to saving trapped civilians from disaster zones, and all without further endangering human life. The speed, agility and reconnaissance capabilities far outstrip those of any single human, and their deployment is seeing ever greater success across all fields.

So, why the hostility? Admittedly, the notion of a computer-controlled aircraft, which if militarised could carry high-explosive weapons, is a daunting one, but when you start to consider that these aircraft are the product of the most advanced aviation companies, with each dedicating many of their best teams to their creation – you have to question whether those concerns are justified.

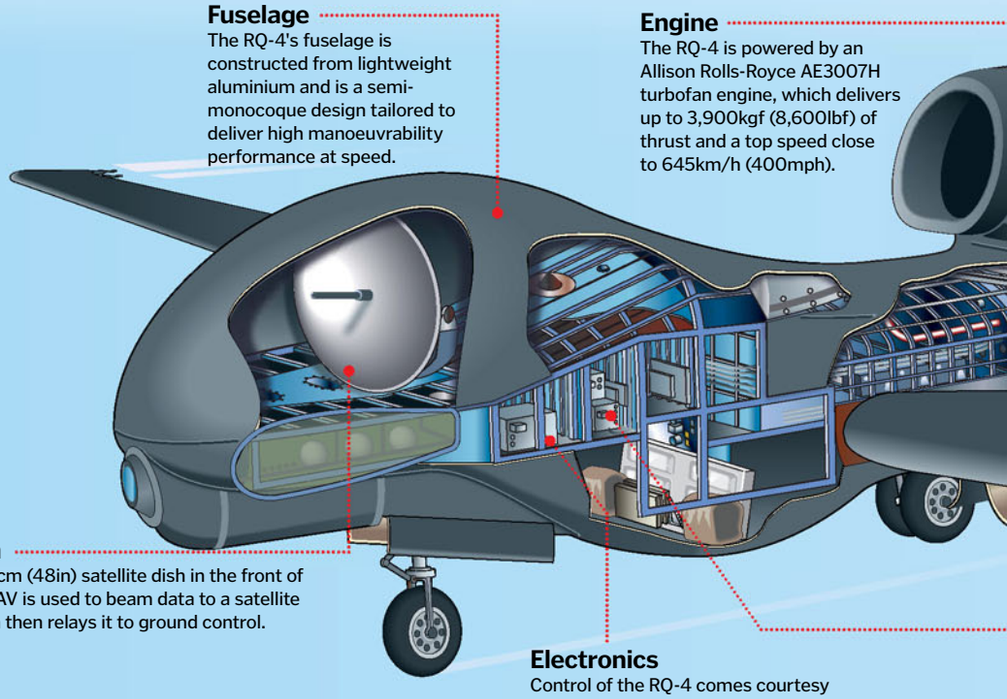
In fact, a quick browse of the world's top plane manufacturers, be it the British BAE Systems, the American General Atomics, Lockheed Martin and Northrop Grumman, or the French Dassault Aviation, shows each is pouring its most bleeding-edge technology into researching and developing UAVs.

Dassault Aviation, for example, is currently building a drone aircraft, nicknamed the 'nEUROn'. It's cloaked, has a delta wing design and is capable of hitting a top speed of 980 kilometres (608 miles) per hour. It is, in many respects, as advanced as today's most competent manned aircraft. However, the nEUROn's main purpose is not to enter production, but to trial out technology and – critically – safety features which can then be adopted into future production aircraft. This trend of stringent testing of UAVs and potential technology is at the forefront of the industry; the nEUROn did not fly when displayed at the 2013 Paris Air Show as it's not yet cleared to fly in civilian airspace – something that will likely only happen after all its flight trials in late-2015.

In fact, UAV aircraft are among the safest and most advanced on the planet, with many of their technologies pioneering and, importantly, readily transferable to other vehicles. Today, UAVs are fairly small

Inside the RQ-4 Global Hawk

Check out the key components of this state-of-the-art surveillance UAV



Fuselage
The RQ-4's fuselage is constructed from lightweight aluminium and is a semi-monocoque design tailored to deliver high manoeuvrability performance at speed.

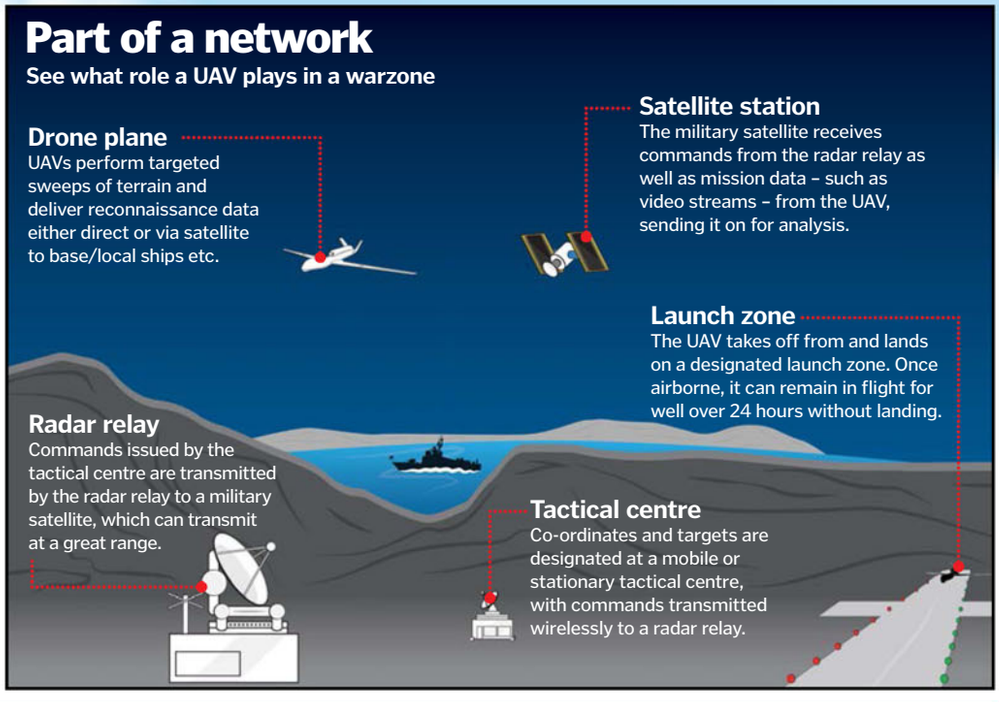
Engine
The RQ-4 is powered by an Allison Rolls-Royce AE3007H turbofan engine, which delivers up to 3,900kgf (8,600lbf) of thrust and a top speed close to 645km/h (400mph).

Dish
A 122cm (48in) satellite dish in the front of the UAV is used to beam data to a satellite which then relays it to ground control.

Electronics
Control of the RQ-4 comes courtesy of a Mission Control Element (MCE) system, which is used for mission planning, command and control of the vehicle, as well as harvested image processing and dissemination.

Part of a network

See what role a UAV plays in a warzone



Drone plane
UAVs perform targeted sweeps of terrain and deliver reconnaissance data either direct or via satellite to base/local ships etc.

Satellite station
The military satellite receives commands from the radar relay as well as mission data – such as video streams – from the UAV, sending it on for analysis.

Launch zone
The UAV takes off from and lands on a designated launch zone. Once airborne, it can remain in flight for well over 24 hours without landing.

Radar relay
Commands issued by the tactical centre are transmitted by the radar relay to a military satellite, which can transmit at a great range.

Tactical centre
Co-ordinates and targets are designated at a mobile or stationary tactical centre, with commands transmitted wirelessly to a radar relay.

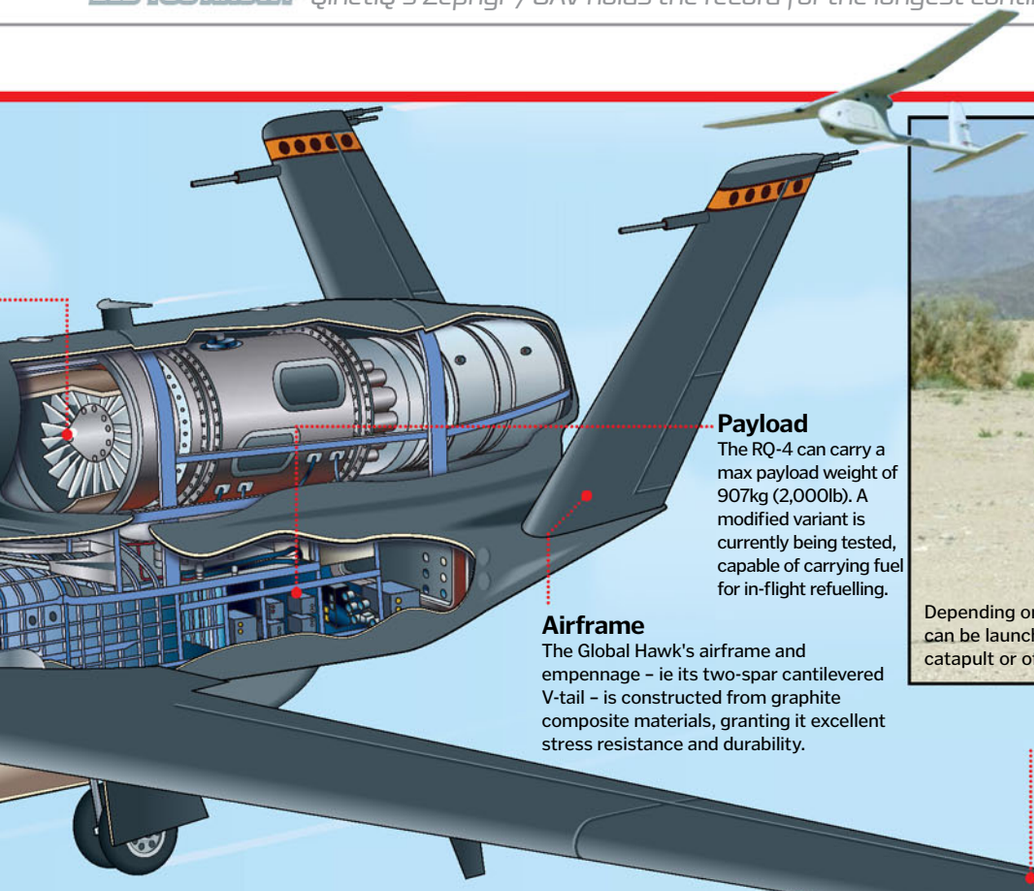
AMAZING VIDEO!

SCAN THE QR CODE FOR A QUICK LINK

Get up close with the amazing MQ-9 Reaper

www.howitworksdaily.com

DID YOU KNOW? *QinetiQ's Zephyr 7 UAV holds the record for the longest continuous unmanned flight at over 336 hours*



Payload

The RQ-4 can carry a max payload weight of 907kg (2,000lb). A modified variant is currently being tested, capable of carrying fuel for in-flight refuelling.

Airframe

The Global Hawk's airframe and empennage – ie its two-spar cantilevered V-tail – is constructed from graphite composite materials, granting it excellent stress resistance and durability.

Depending on their size, UAVs can be launched by hand, catapult or off a runway

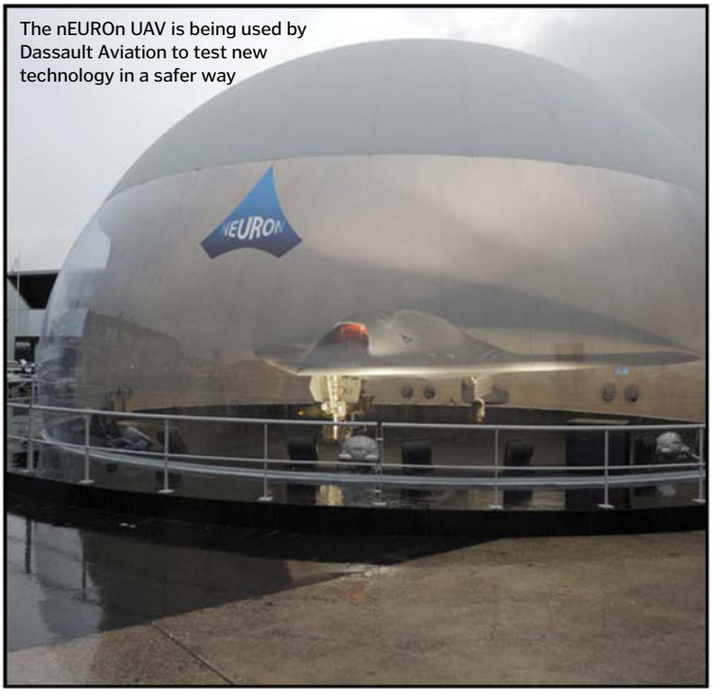
Wings

The thin tapered wings of the RQ-4 are constructed from lightweight carbon fibre and help grant the drone a service ceiling of 19,812m (65,000ft).

Sensors

An Enhanced Integrated Sensor Suite (EISS) provides the Global Hawk with a synthetic aperture radar (SAR), an electro-optical (EO) sensor and infrared (IR) sensor. The EO and IR sensors can operate simultaneously with the SAR.

Ground control at NASA's Dryden Flight Research Center; inset, NASA's Global Hawk is used to perform scientific research and Earth observation



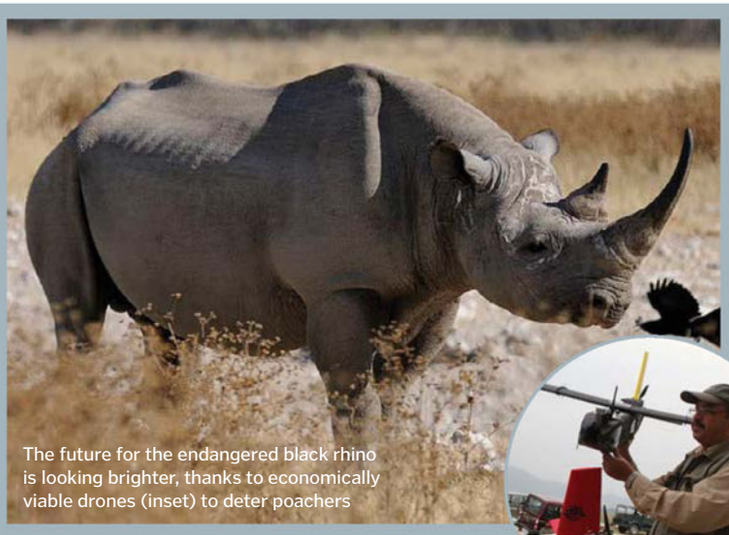
The nEUROn UAV is being used by Dassault Aviation to test new technology in a safer way

"If UAVs are the future of flight, then a clear roadmap needs to be laid down for their development"

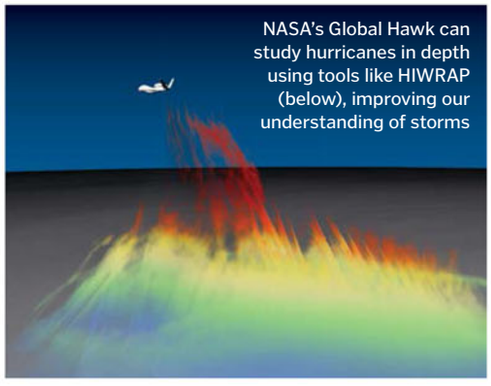
The eco-warrior drones

One of the biggest challenges environmental conservation organisations face today is monitoring large swathes of land where endangered species are at risk from a lethal combination of deforestation, poaching and illegal development. This problem is particularly acute when the protected landscape itself is largely inaccessible, with it often taking conservationists days to trek through areas to monitor a particular area or species. The rise of UAVs, however, is radically transforming the process of environmental monitoring, with small-scale, low-cost drones capable of being deployed over vast areas of rainforests and savannas and reporting back in a fraction of the time it would take a ground team to do so.

From skimming over Indonesia's jungle canopy photographing orangutans, through to deterring rhino poachers in Nepal and on to studying elephants in Malaysia, UAVs are ushering in a new era of drone ecology, where even cash-strapped charities and environmental organisations can benefit. Indeed, the current rise of UAV technology means that small operational drones can be bought and assembled for a couple of thousand of dollars, rather than the hundreds of thousands it would take to pilot, fuel and operate a manned aircraft. As a quick case study, the use of drones in South Africa, where rhino poaching has been a serious issue for decades, has seen a marked decline in the illegal activity since they were deployed.



The future for the endangered black rhino is looking brighter, thanks to economically viable drones (inset) to deter poachers



NASA's Global Hawk can study hurricanes in depth using tools like HIWRAP (below), improving our understanding of storms

It's not all about planes – the K-MAX unmanned helicopter is designed to deliver cargo behind enemy lines and can carry up to 2,720kg (6,000lb)

machines, but in the future, thanks to their autopilot systems now being more advanced than any other aircraft due to state-of-the-art R&D efforts, larger pilotless cargo or even passenger aircraft could be built, with faster, more frequent flights possible, and with far less chance of human error. What's more, it's not just future drone aircraft that will benefit from UAV development, but traditional piloted aircraft bound to see many upgrades too.

Despite increasing numbers of drones set to be used over the next 50 years, there will naturally still remain a huge demand for piloted aircraft. With the help of sensory, communication and autopilot systems delivered by drone technology, these flights will be achieved more efficiently and with greater safety than ever before.

Just because the history of unmanned aerial vehicles is largely militarised, with efforts to create a drone aircraft beginning as far back as World War I, that does not mean its future has to be. The wider air industry needs to evolve rapidly if it is to keep pace with the ever-increasing population's travel needs, and for that, drones are a key component.

If UAVs are the future of flight, then a clear roadmap needs to be laid down for their development. Currently, UAVs are split into six functional categories including target and decoy, reconnaissance, combat, logistics, research and development, and commercial, with the latter only being granted a licence to operate in most nations' airspace on a case-by-case basis. This limited form of categorisation is fine to a point, but as the number of drone

THE STATS
TARANIS NUMBERS

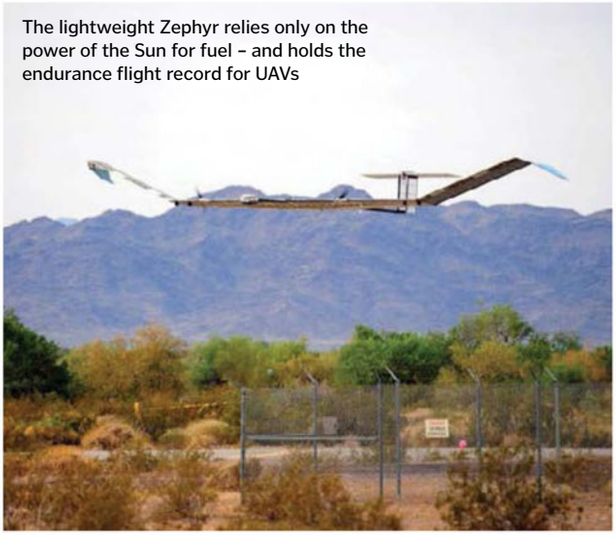
HEIGHT 4m | WINGSPAN **9.1m** | THRUST 2,939kgf
LENGTH **11.4m** | WEIGHT 8,164kg | WEAPON BAYS **2**

DID YOU KNOW? *Lockheed's K-MAX drones have been used by the US military to deliver battlefield cargo since 2007*

The liquid hydrogen-powered Boeing Phantom Eye taking off for a test flight

The Airspace Operations Challenge

The Airspace Operations Challenge (AOC) is a competition currently being run by NASA to help foster and develop technologies that will help advance UAV use in US airspace. The AOC's focus is very much on safety, with competitors asked to create aircraft that can demonstrate a series of controlled operations in complex air traffic environments. The AOC is currently in the registration phase for competitors, with phase 1 scheduled for April 2014. Anyone who meets the AOC's criteria can enter and there's a $500,000 prize pool for the winners!



The lightweight Zephyr relies only on the power of the Sun for fuel – and holds the endurance flight record for UAVs

aircraft and their applications increase, more refined and flexible criteria will have to be set.

For example, government use today largely revolves around emergency services, such as fire brigades using drones to detect forest fires – but as more and more services enter the private sector, then laws – like the ones slowly emerging for driverless cars – will need to be amended to account for the fact that many future vehicles will not have a pilot on board. This sort of change needs to be partnered with greater monitoring over private UAV manufacturers, as with great technology comes greater responsibility and accountability.

While certain UAVs are being scaled up, others are going the other way, with some experimental models even launchable by hand like a paper plane (like the RQ-11 Raven). If this sort of cutting-edge development continues, then soon UAVs might not just be carrying weapons, cameras and disaster relief, but performing more everyday tasks. That said, it will probably be some time yet before drones are delivering your weekly food shop!

Ones to watch...

1 Taranis
Technically referred to as a UCAV, an Unmanned Combat Air Vehicle, BAE Systems' Taranis is an experimental drone currently undergoing trials in the UK. The project is led by BAE, but also involves Rolls-Royce, GE Aviation Systems, QinetiQ and the British Ministry of Defence (MoD). The prototype cost £143 million ($230 million) to develop and is designed with fully autonomous elements in mind, though a trained operator will always be in control on the ground.

2 Phantom Eye
The Boeing-made Phantom Eye is a high-altitude, long-endurance UAV designed by the defence contractor's secretive Phantom Works. It's powered by liquid hydrogen and has been designed as a spy plane, remaining in flight at high altitude for several days without having to return to a base station. The Phantom Eye recently reached an altitude of 8,530 metres (28,000 feet) and remained there for four and a half hours while carrying a payload from the Missile Defense Agency.

3 Tempest
The Tempest is an unmanned aircraft system (UAS) designed for in-situ sensing and observation of severe storms and supercell thunderstorms. The aircraft is launched manually via radio control and is switched to autonomous mode once airborne, where it then operates via autopilot within a designated airspace region. Atmospheric data gathered by Tempest is then streamed back to a mobile base station for processing, with any early warnings instantly shared.

4 Zephyr
A lightweight solar-powered UAV that currently holds the official record for an unmanned aerial vehicle – spending 336 hours and 22 minutes airborne without landing – the QinetiQ Zephyr is an experimental drone designed to explore the possibilities of solar-powered UAVs. Made from carbon fibre, the Zephyr uses harvested sunlight to charge a lithium-sulphur battery, which in turn powers a permanent-magnet synchronous motor.

5 TOP FACTS:
Avro Lancaster B.III

On the night of the 16th May 1943, 19 Lancaster Bombers took part in the raid, with 11 returning. 53 Allied airmen were killed with 3 taken prisoner.

The project was code-named Chastise. The dams supplied water and power to the German industrial areas so were very important targets.

The Möhne dam was attacked first and breached, with the Eder and Sorpe being attacked later. The resulting flood waters killed an estimated 1,650 people.

The bigger effect though was felt on production, with 20,000 men having to be diverted from other tasks to repair the dams and lots of farm land damaged by the flood waters.

The raid was masterminded by Barnes Wallis, responsible also for the famous bouncing bomb used in the attacked.

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HOW IT WORKS

A50138
The Dambusters Avro Lancaster B.III (Special) 'Operation Chastise'

While the Lancaster saw the vast majority of its service as a high altitude night bomber, attacking strategic targets deep within Germany, notably its involvement in the battles of the Ruhr, Hamburg and Berlin, it was a daring low level raid that gave the Lancaster arguably its finest hour. The Dambusters raid, as it has since become known, was one of the most famous operations of the war. Led by Wing Commander Guy Gibson, the nineteen specially modified Lancaster bombers attacked the Möhne, Eder, Sorpe, and Ennepe dams, with the Möhne and Eder dams being breached.

Operation Chastise was the official name for the attacks on the German dams, which occured on 17th May 1943 during the Second World War. The attack was carried out by 617 Squadron RAF, specially formed for this unique and highly dangerous mission. The squadron subsequently became known as the legendary Dambusters.

Scan this QR code with your smartphone to find out more!

A50138 1:72 Scale The Dambusters Avro Lancaster B.III (Special) 'Operation Chastise' Gift Set

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RECORD BREAKERS
MARINE GIANT

85,000

LARGEST FLOATING DRY DOCK

The Zhonghai Emeishan is the largest floating dry dock in the world, measuring 410m (1,345ft) long with a hoisting capacity of about 85,000 tons – more than any other dry dock in the maritime sector.

DID YOU KNOW? *Heat wraps slowly degrade components, whereas barrier coatings and plasma sprays protect engine parts*

Thermal barrier coatings

The special paint that helps keep an engine cool even under immense pressure

Thermal barrier coatings are an efficient form of exhaust heat management, keeping a car's engine cool by stopping exhaust heat from spreading to other areas of the engine. This is important as excessive heat can damage components.

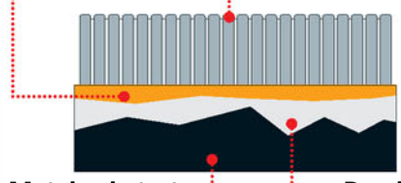
Usually a ceramic-based paint, this coating is found on anything from turbo casings through to manifolds and even entire exhaust systems, insulating the areas concerned thanks to their low thermal conductivity.

Thermal barrier coatings typically consist of four layers: the metal substrate, metallic bond coat, thermally grown oxide and the ceramic top coat. Historically, engine parts would simply be wrapped in a fabric heat wrap to insulate them, but today there are many options including plasma spray where micro-particles are applied with a super-hot torch. The latter process is often used on composite materials in high-end motorsport as this protects against physical degradation from friction, and the material bonds with the composite instead of sitting on top.

Minimising exhaust heat in an engine bay ensures racing cars hit peak performance

Thermal coating layer by layer

How ceramic paint insulates vital motoring components up close



Oxides
Thermally grown oxides act as an oxygen diffuser to prevent any damage occurring.

Ceramic top coat
The external coat protects the substrate by keeping other layers at a lower temperature.

Metal substrate
This is the original engine part that gives off lots of heat when in use, eg an exhaust.

Bond coat
This helps the ceramic coating stick to the metal substrate, much like an undercoat layer on a wall.

How floating dry docks work

Explore the platforms that are crucial for building and repairing massive boats on water

With seagoing vessels constantly exposed to the harsh elements of the ocean, building, repairs and maintenance are crucial to their longevity. Here, floating dry docks come into play by lifting a vessel from its immediate sea environment to grant workers access to underwater sections, such as the hull.

A floating dry dock's cross-section is akin to that of the letter 'U', with buoyancy chambers on both sides of the dock. The dock can simply drop into the sea with the opening of a series of valves that flood these buoyancy chambers with water. With the dock partially submerged, a vessel is free to float into the middle of the dock and rest on its specially designed platform. Next, pumps are used to drain water from the chambers, lifting the dry dock – along with the ship – to the surface again.

Usually made from steel and built in a series of 'U' cross-sections, floating dry docks can also be towed anywhere, and some even have their own steering mechanism, adding to their appeal over a stationary land-based dock.

Using powerful pumps and the laws of buoyancy floating dry docks can support even the largest vessels

"The landmark covers 12 hectares (30 acres) and comprises over four kilometres (2.5 miles) of slip roads"

Spaghetti Junction

How was this tangle of roads in the UK built and how is it maintained?

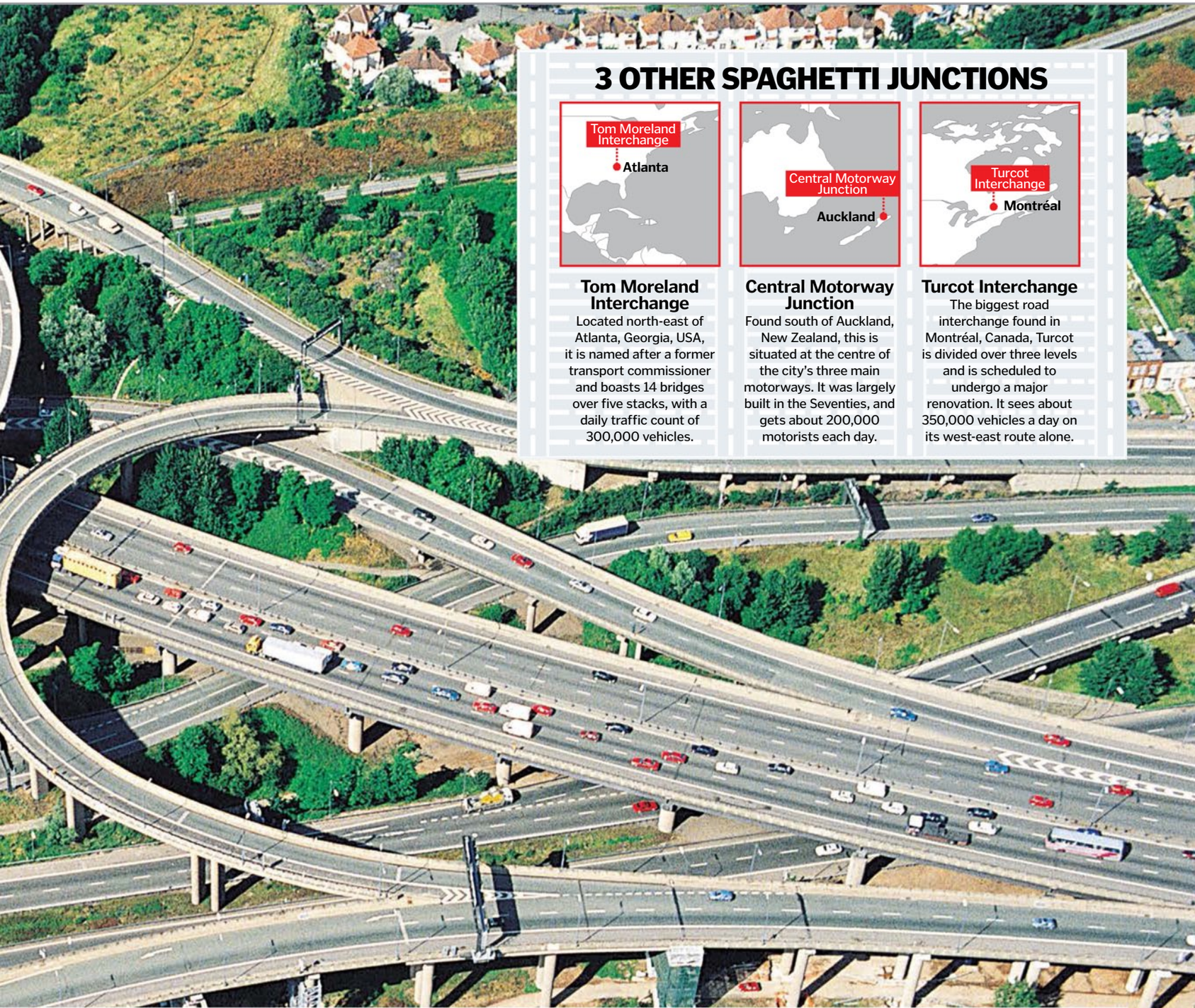
'Spaghetti junction' has become something of a common term that's used to describe a number of complicated road interchanges around the world, but originally it was coined back in the Sixties as a nickname for the Gravelly Hill Interchange in Birmingham in the Midlands of England. Indeed, this particular Spaghetti Junction has earned its place in the *Guinness Book Of Records* for being the 'most complex interchange on the British road system'.

THE STATS
GRAVELLY HILL INTERCHANGE

OPENING DATE 24/5/1972 | CONCRETE COLUMNS 559 | STEEL REINFORCEMENT 13,000+ tons

AVERAGE TRAFFIC IN 1972 40,000 | YEARS TO CONSTRUCT 4 | AVERAGE TRAFFIC IN 2012 210,000

DID YOU KNOW? *In 2007, Spaghetti Junction was voted the best-known sight on British motorways by motorists*



3 OTHER SPAGHETTI JUNCTIONS

Tom Moreland Interchange
Located north-east of Atlanta, Georgia, USA, it is named after a former transport commissioner and boasts 14 bridges over five stacks, with a daily traffic count of 300,000 vehicles.

Central Motorway Junction
Found south of Auckland, New Zealand, this is situated at the centre of the city's three main motorways. It was largely built in the Seventies, and gets about 200,000 motorists each day.

Turcot Interchange
The biggest road interchange found in Montréal, Canada, Turcot is divided over three levels and is scheduled to undergo a major renovation. It sees about 350,000 vehicles a day on its west-east route alone.

Costing approximately £10 million ($16 million) to build over a four-year period, Spaghetti Junction was the crowning glory of the Midland Links project, which was set up with the aim of easing access to Birmingham's city centre. The reason that so much of the interchange is raised up was in order to work around existing features (both natural and man-made) on the ground, such as rivers, canals, railway lines and other utilities like gas pipes and electricity lines. Despite some issues with structural checks that ultimately pushed back its opening date by a few months, the first public cars used it on 24 May 1972.

The local landmark covers an area of 12 hectares (30 acres) and comprises over four kilometres (2.5 miles) of slip roads arranged over five different levels. More than 550 concrete columns are used to support the road network, some of which reach over 24 metres (80 feet) in height. Serving 18 different routes, the interchange is renowned for its high volume of traffic, with estimates indicating it sees over 210,000 motorists every day.

Over the years, Spaghetti Junction has undergone a number of repairs, typically using high-pressure jets of water to blast away structurally compromised sections of concrete, which are then replaced with new steel and concrete. Because of these ongoing repairs and continual monitoring by the Highways Agency, it's hoped that Spaghetti Junction will be functional for many decades to come.

For centuries people were taught that the forces which shaped our planet and the wider universe were beyond their reach and comprehension, with but mere glimpses of insight available to only the most learned scientists and scholars.

Today, however, thanks to the diligent work of natural scientists worldwide, this legacy of ignorance is being eroded. Now more than ever before we are discovering the true nature of Earth and the physics, chemistry and biology that lay behind it. From how its mightiest mountains emerged as a result of tectonic activity, through to how water sculpted caves and valleys, as well as how tiny particles in the atmosphere create stunning light shows in the night sky, far from explaining away these wonders, we are now able to appreciate them at a whole new level, learning the truth about the planet's past, present and even future.

When you gaze upon the natural wonders of our planet – from its mightiest waterfall to its biggest volcano – we do so now not just in awe of their beauty and power, but with an understanding unparalleled throughout history. Here we pick out seven of the most incredible features on Earth, revealing not just why they are so special, but also the fundamental processes that without they would never have come to be...

7 NATURAL WONDERS

From huge mountains stretching into the sky to kaleidoscopic light shows that put man-made displays to shame, discover the science behind some of our planet's most amazing phenomena

5 TOP FACTS
CORAL REEFS

Widespread
1 Coral reefs are estimated to cover 284,300 square kilometres (109,800 square miles) of the world's ocean surface area. 91.9 per cent are in the Indo-Pacific region.

Most diverse
2 The reefs of the Philippines are the most diverse in terms of species, with more than 915 reef fish and 400 scleractinian coral species (ie stony corals) identified so far.

Prehistoric habitat
3 The peak reef development time was in the Middle Cambrian era (513-501 million years ago). Not all reefs were formed from coral, with some made of calcareous algae.

Not all the same
4 There are many types of reef depending on their location, shape and composition. Atoll reefs, for example, are circular in form and are set around a central lagoon.

Pollution is the enemy
5 Reefs are in decline worldwide due to human development and expansion. Indeed, a report in 2013 indicated that rising air pollution levels were stunting their growth.

DID YOU KNOW? *When first measured, Mount Everest was listed as 8m (26.2ft) shorter than it actually is*

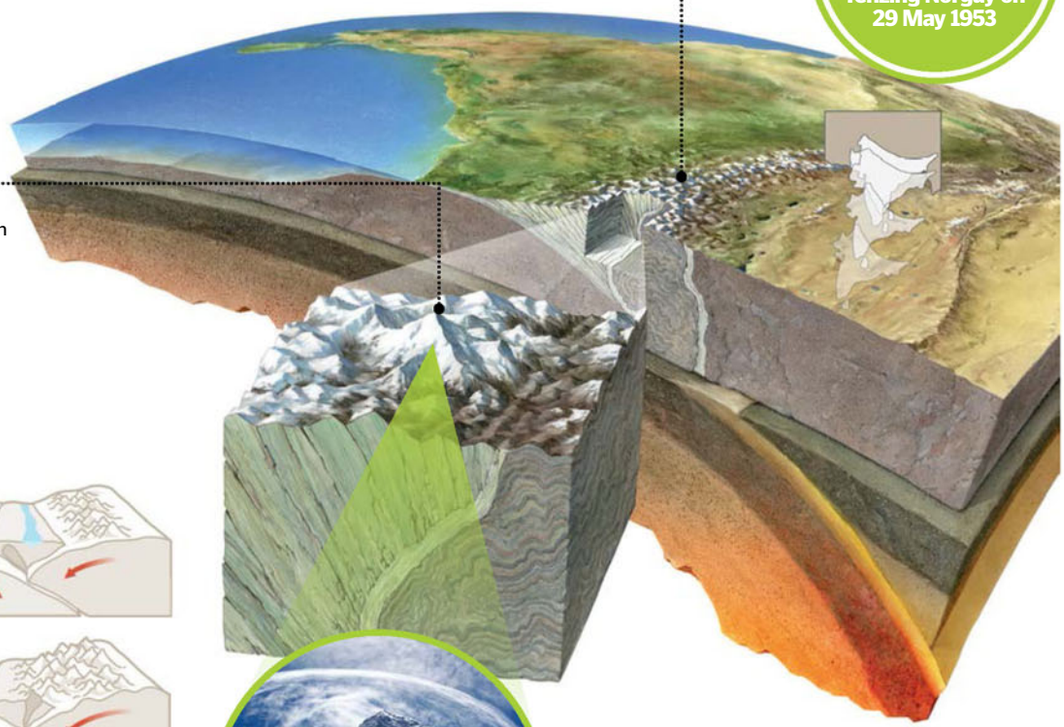
Himalayas in the making
How did Earth's highest mountain range develop?

Formation
The Himalayas were formed through the collision of the Indo-Australian and Eurasian continental tectonic plates, a process that began around 60 million years ago.

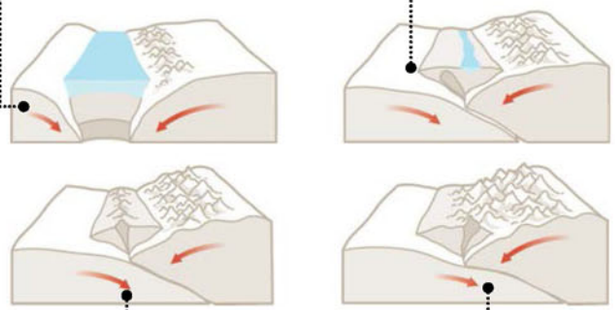
Range
Mount Everest is part of the Himalayas range in Asia, which separates the plains of the Indian subcontinent from the Tibetan Plateau. In total the range is about 2,300km (1,400mi) long.

The first recorded mountaineers to scale Everest were Edmund Hillary and Tenzing Norgay on 29 May 1953

Highest peak
Rock upthrust generated by the plate collision and the high altitude of the surrounding plateau results in Everest.



Tectonics
The collision of these two plates started a process known as thrust tectonics where the crust deforms.



Layering
The thrust tectonic process caused layers of rock strata to slide over each other over millions of years, forcing them and a lot of sediment to rise.

Folding
Today the Indian and Asiatic plates under Everest continue to collide and fold the Earth's crust, with the lands of Nepal shrinking.

Distortion
As the crust is subjected to sustained horizontal tectonic forces, its rock layers become deformed, with outer rigid layers fracturing and forming faults.

1 Biggest mountain on Earth

Mount Everest, Nepal/China

If you truly wanted evidence of the awe-inspiring majesty of the natural world along with the processes that have created it and continue to evolve it, then you need look no further than Mount Everest, the tallest mountain on Earth. Standing at a whopping 8,848 metres (29,029 feet) above sea level in the Mahalangur area of the Himalayas mountain range, Mount Everest's peak is the highest place a human can stand anywhere on our planet, offering brave and strong climbers the view of all views.

For centuries, the sheer height of Everest led to the question of just how such a biblical structure could have been created, with its presence either misguidedly explained away or simply taken for granted. Now though, with science's new-found understanding of plate tectonics and the epic geological processes the developing Earth underwent to lead us to today's crustal landmasses, Everest's formation is much better understood (see 'Himalayas in the making' box for more) – and even more spectacular for it.

For the record, the highest building in the world, the Burj Khalifa in Dubai, is 829.8 metres (2,722 feet) high at its very tip. So for the time being, nature is trumping man by over ten times as far as tall structures go!

Mounting controversy

While Mount Everest has for decades been referred to as the highest mountain on Earth, its status is determined solely by how and from where it is measured. There are, in fact, other mountains that are taller.

For example, Everest sits atop the Tibetan Plateau, which already has a very high elevation. As such, base elevations for Everest begin at 4,200 metres (13,800 feet) and end at 5,200 metres (17,100 feet), granting it an overall base-to-peak height range of 3,650-4,650 metres (12,000-15,300 feet).

In contrast, Mauna Kea in Hawaii has its base deep below sea level rather than atop a plateau, with its above-sea segment only measuring in at 4,207 metres (13,803 feet). However, if Kea is measured from its base, then it has a height of 10,200 metres (33,465 feet), which is over twice the base-to-peak height of Everest.

"Coral reefs account for 25 per cent of all marine species on Earth"

5 amazing waterfalls

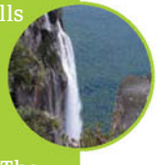
1 Niagara Falls

Technically the name for three waterfalls that sit along the border between Canada and the USA, Niagara Falls are one of the most famous natural attractions on Earth.

2 Iguazu Falls

Situated on the border of Brazil and Argentina, Iguazu Falls is a series of cascades that divide the upper and lower Iguazu River. The falls have an average flow rate of 1,756m³/s (62,010ft³/s) and a staggering 275 drops.

3 Angel Falls

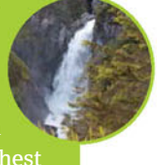


Often referred to as Parakupá Vená ('Fall from the Highest Point'), Angel Falls in Venezuela is the highest uninterrupted waterfall, with a height of 979m (3,212ft) and a plunge of 807m (2,648ft). The falls are part of the Canaima National Park, which is a UNESCO World Heritage Site.

4 Tugela Falls

Located in South Africa's Drakensberg (Dragon Mountains), Tugela Falls is considered the second tallest waterfall on Earth, consisting of five free-leaping falls that, combined, deliver a total drop of 948m (3,110ft). It's possible to walk to the very top.

5 Reichenbach Falls



A series of waterfalls on the Reichenbach Stream in Switzerland, the Reichenbach Falls have a total drop of 250m (820ft) and one of the highest cataracts in the Alps.

2 Most powerful waterfall

Victoria Falls, Zambia/Zimbabwe

If you had not considered how immensely powerful water can be, then it is time to take a look at the world's most powerful waterfall. Victoria Falls, named by Scottish explorer David Livingstone in honour of Queen Victoria in 1855, is not only testament to H_2O's awesome power but also to how beautiful Earth's natural wonders can be.

At 1,708 metres (5,604 feet) wide, 108 metres (355 feet) high and boasting a whopping average flow rate of 1,088 cubic metres (38,430 cubic feet) per second, Victoria Falls is unsurpassed by any other waterfall, dwarfing other famous examples like Niagara Falls with ease. In fact, there is only one other waterfall in the world that approaches the sheer immensity of Victoria, and that is Iguazu Falls in Brazil (see 'Five amazing waterfalls' for more).

The power of Victoria Falls is so immense that it is currently cutting furiously into the basalt and sandstone terrain that surrounds it, feeding Zambezi River, forever hollowing out new gorges and chasms. Currently there are six primary gorges at Victoria, but these are constantly being extended and are only set to increase in number as time goes on.

THE STATS VICTORIA FALLS

HEIGHT 108m
AVERAGE FLOW RATE 1,088m³/s
NUMBER OF DROPS 1
WIDTH 1,708m
SPRAY HEIGHT 400m
MADE WORLD HERITAGE SITE 1989

DID YOU KNOW? *The Crannell Creek giant redwood tree was estimated to be 20 per cent bigger than General Sherman*

3 Largest living structure

Great Barrier Reef, Australia

The Great Barrier Reef is home to over 1,500 species of fish, 5,000 species of mollusc, 14 species of seasnake, 330 species of sea squirts, 500 species of bryozoans, numerous marine mammals such as whales and dolphins, as well as countless other rare animals.

Coral reefs are formed from structures made from the calcium carbonate secreted by corals over hundreds of years. Most coral reefs are composed from stony corals, which consist of millions of tiny polyps, and grow best in warm, shallow waters – hence why most are found in equatorial seas. Despite covering less than 0.1 per cent of the world's ocean surface, they make up 25 per cent of all marine species on Earth.

Human impact on reefs

Despite Aboriginal Australians inhabiting the area of the Great Barrier Reef as long ago as 38,000 BCE, sympathetically using the surrounding waters to fish and the corals for decoration, today the human impact on the reef is much more destructive. Chief among these issues are water pollution and tourism.

Reefs like the Great Barrier have incredibly delicate ecosystems and environments, so the increased introduction of industrial chemicals and farming fertilisers from Australian businesses has left many component reefs unbalanced or, in extreme cases, abandoned. Tourism, on the other hand, has exploded over the past 50 years, with hundreds of thousands of visitors passing through each year.

To combat these damaging activities, the Australian government has established the Great Barrier Reef Marine Park Authority, an organisation set up to preserve this natural wonder, educate visitors and ensure its survival.

4 Tallest tree in the world

General Sherman Giant Sequoia, USA

There are trees and then there are giant sequoias, with the latter an order of magnitude greater than anything growing in your back garden. Of all the giant sequoias in the world, the nicknamed 'General Sherman' in the Californian Sequoia National Park is the biggest of them all, with a volume so great that it is officially the largest known living tree on Earth.

So how big? How about 83.8 metres (274.9 foot) high, 11.1 metres (36.5 foot) in diameter and over 1,250 tons in weight? Yes, it's stats are truly colossal. In fact, when you compare it to other supposedly large objects, they suddenly don't seem so large. For instance, Nelson's Column in Trafalgar Square in London is beaten by over 30 metres (98 feet). Think the iconic red London double-decker bus is heavy? Well, you better think again, as the General weighs in over 100 times heavier.

Interestingly, despite their massive size – something generated by their rapid growth speed and long lives – the giant sequoia is sadly in decline – as we consider in greater detail below.

Tough at the top

Despite a fully matured giant sequoia producing on average in excess of 11,000 cones and dispersing an estimated 300,000-400,000 seeds annually, the tree is currently listed as endangered on the International Union for Conservation of Nature's Red List of Threatened Species, with numbers falling consistently over the last 100 years.

While human expansion and development has no doubt had an impact, the primary reason for their population decrease is due to the great difficulty the trees have generating the next generation, with seeds only being able to grow successfully in full and consistent sunlight and mineral-rich soils free from other vegetation. This last point is particularly important, with total vegetation clearances only typically occurring after wildfires (which also introduce lots of minerals to the soil).

Scientists think that the increased fire-suppression activities of humans in the early to mid-20th century in many sequoia groves has actually led to the slump in their numbers, with controlled burns now instigated periodically by environmental agencies in an attempt to help the next generation of these mega-trees.

Giant sequoias grow really fast as far as trees go, producing 1m³ (35ft³) of wood each year!

"The Mauna Loa volcano is so heavy that its mass actually depresses the Earth's crust by 8km (5mi)"

Most auroras occur within the auroral zone, an area 10-20 degrees from the Earth's magnetic poles

5 Nature's amazing light show

Aurora borealis, auroral zone (above Earth's polar regions)

Undoubtedly one of Earth's most amazing natural wonders, the polar auroras – otherwise known as the northern and southern lights – are a naturally occurring light display that takes place in the high latitude regions of the poles. They are characterised by diffuse coloured streaks through the night sky, winding and twisting like a liquid stream made of light.

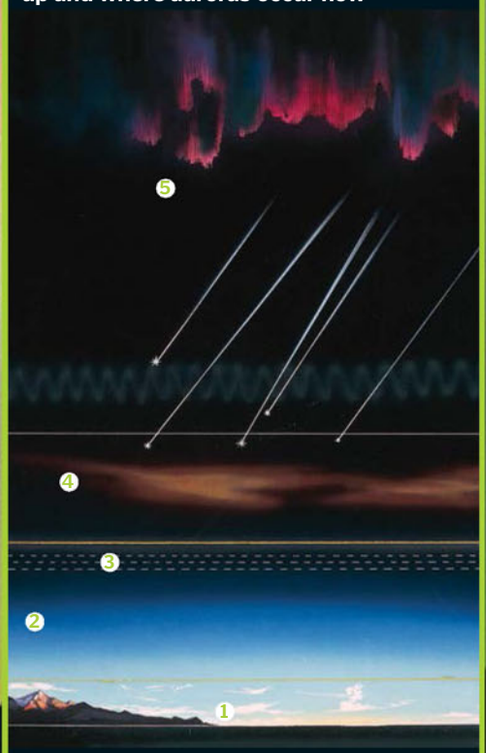
Far from anything supernatural, auroras like this are actually the result of the collision of energetic charged particles with atoms in Earth's thermosphere, the highest layer of the atmosphere (see 'Auroras in context' boxout). These charged particles originate in the Earth's magnetosphere where solar winds from the Sun bombard the thermosphere, triggering the auroral mechanism.

The light results from the charged particles colliding with and ionising nitrogen atoms – ie the nitrogen atoms gain an electron – as well as oxygen and nitrogen atoms returning from an excited to a ground state, thereby forcing the emission of photons (quanta of light). The path and structure of the emitted photons are determined by the direction of the Earth's magnetic field lines, with the charged particles funnelled down and accelerated along them, hence the location of auroras around the north and south magnetic poles.

Interestingly, it's possible to determine the type of emissions reacting in the sky by studying the colour of an aurora, with oxygen emissions generating a green or brownish-hued illumination, while nitrogen emissions produce a blue or red display.

Auroras in context

See how Earth's atmospheric layers stack up and where auroras occur now



1 Troposphere
The lowest part of Earth's atmosphere, this is the region where weather takes place. It is characterised by rising and falling pockets of air, with the air pressure at its top only ten per cent that at sea level.

2 Stratosphere
Above the troposphere, which ends after 12km (7.5mi), is the stratosphere – known for its high-speed horizontal air movements. It extends upwards for a distance of 50km (31mi), where it ends near the planet's ozone layer.

3 Ozone layer
The ozone layer is situated at the top end of the stratosphere and consists of a thin area of highly reactive oxygen. Due to ozone being particularly reactive, it is the primary layer in the atmosphere that absorbs UV radiation from the Sun.

4 Mesosphere
Home to the coldest part of Earth's atmosphere, the mesopause, the mesosphere is a region that extends from about 50km (31mi) up to 85km (53mi). It is characterised by atmospheric tides, internal gravity waves and noctilucent polar clouds.

5 Ionosphere
The inner region of the thermosphere, the ionosphere is named after the ionisation of atoms and absorption of energetic photons from the Sun which occur here. Charged particles interact with the magnetic fields to produce stunning auroras.

AMAZING VIDEO! SCAN THE QR CODE FOR A QUICK LINK

Ranger Matt Fagan talks about General Sherman

www.howitworksdaily.com

DID YOU KNOW? *Despite being referred to as the Pacific 'Ring of Fire', it is actually more of a horseshoe shape*

6 Largest surface volcano

Mauna Loa, Hawaii

Mauna Loa is one of five volcanoes that form the island chain of Hawaii in the Pacific Ocean. It is also the largest surface volcano, both in mass and volume, in the world and for centuries has been renowned for its epic eruptions, with it regularly spewing lava into the local environment.

Mauna Loa is an active shield volcano – this means it is almost entirely built from lava flows – with successive eruptions over thousands of years slowly growing Loa's profile into the gargantuan proportions we see today, and the silica-poor lava creating its shallow slopes.

Indeed, the immense scale of Loa is hard to comprehend at first, as it covers a land area of 5,271 square kilometres (2,035 square miles). In fact, composed of up to 80,000 cubic kilometres (19,200 cubic miles) of solid rock, Mauna Loa makes up over 50 per cent of Hawaii's entire surface area, and is so heavy that its mass depresses the Earth's crust by eight kilometres (five miles), creating an inverse mountain.

If the height of Mauna Loa and its inverse mountain are combined, the true height of this epic volcano taken from the start of its eruptive history is a staggering 17,170 metres (56,000 feet)!

The almost constantly active Mauna Loa makes up over half of Hawaii's surface area

The Mauna Loa volcano has been erupting on and off for the last 700,000 years

7 Most beautiful caves

Marble Caves, Chile

In ancient times, marble was chosen by architects and the elite for both its strength and beauty, with buildings made of the metamorphic rock a sign of wealth and prestige. However, just as artists throughout history have carved and sculpted the amazing material with man-made tools, so too have the elements of the Chilean lake of General Carrera – but on a much larger scale and over a far longer time frame.

And today we are left with the Marble Caves or, as the locals have dubbed them, the Marble Cathedral. Positioned on the Chilean side of the great lake, which is the second largest freshwater lake in South America, the Carrera marble cave network has been sculpted entirely by the action of the infiltrating ice and waters over many millennia.

At first glance of the caves, with the colourful walls, ethereal light and super-clear water – the latter the result of a high concentration of ground glacial silt – it's hard to believe such a structure could be totally natural. But as environmental scientists have now revealed, at one time the entire area around the Marble Caves was covered with vast glacial ice fields, making this almost supernatural structure even more awe-inspiring.

The best of the rest

1 Grand Canyon

When listing Earth's natural wonders, you have to include the Grand Canyon. 446km (277mi) long, 29km (18mi) wide and over 1,600m (5,250ft) deep, this canyon of canyons is a spectacular natural site.

2 Salar de Uyuni

There are many salt flats on Earth, but none is as wondrous as the Salar de Uyuni in Bolivia. Measuring over 10,000km² (6,200mi²), Salar de Uyuni is also the largest on Earth, containing up to 70 per cent of the planet's lithium reserves.

3 Mariana Trench

The deepest trench in the deepest part of the planet's oceans, the Mariana Trench is biblical in scale, clocking in at just under 11km (7mi) below the sea's surface. At the very bottom of the marine trench the pressure is around 1,000 times that at the surface.

4 Sahara Desert

Nicknamed 'The Great Desert' for good reason, the Sahara holds the record of the hottest desert in the world, and is also the third largest. It features enormous sand dunes that measure over 180m (590ft) in height.

5 River Nile

Passing through over ten countries on its 6,695km (4,160mi) course, the Nile is the planet's longest river. It emanates from two sources – the Blue Nile and the White Nile – which join in Sudan to form this awesome waterway that brings life to the desert.

"Epiphytes can only grow in places that are constantly moist, so they are most common in tropical rainforests"

How do air plants survive?

Learn about epiphytes, the remarkable plants that grow without any need for soil

Garden centres often call them 'air plants' because they seem to grow in mid-air. Dangling roots help them to develop without any need for soil – however, these fascinating plants do need to be watered: they live *in* air, not *on* air.

In nature, these plants grow as epiphytes (derived from the Greek for 'upon plant'). That means they essentially piggyback on other plants, typically growing on the branches of trees high above the ground, with no direct connection to the earth. Without any soil to store water, epiphytes can only grow in places that are constantly moist, so they are most common in tropical rainforests.

They take nothing from the host tree, in contrast to parasitic plants. Instead they rely on nutrients from dead leaves falling from above. They use their roots only as anchors and to gather water. Many ferns and mosses also grow as epiphytes on damp, shady tree trunks, even in more temperate countries.

Plants that like the high life

Pink quill *Ecuador*
Tillandsia species are the classic air plants. So many pink quills were collected from the rainforest as houseplants that they became endangered. Thankfully, most can now be mass cultivated, even in temperate regions.

Cattleya orchid
South America
The beautiful flowers of Cattleya orchids are a horticulturalist's favourite. Most of the 70 species live as epiphytes on trees and they take great skill to grow.

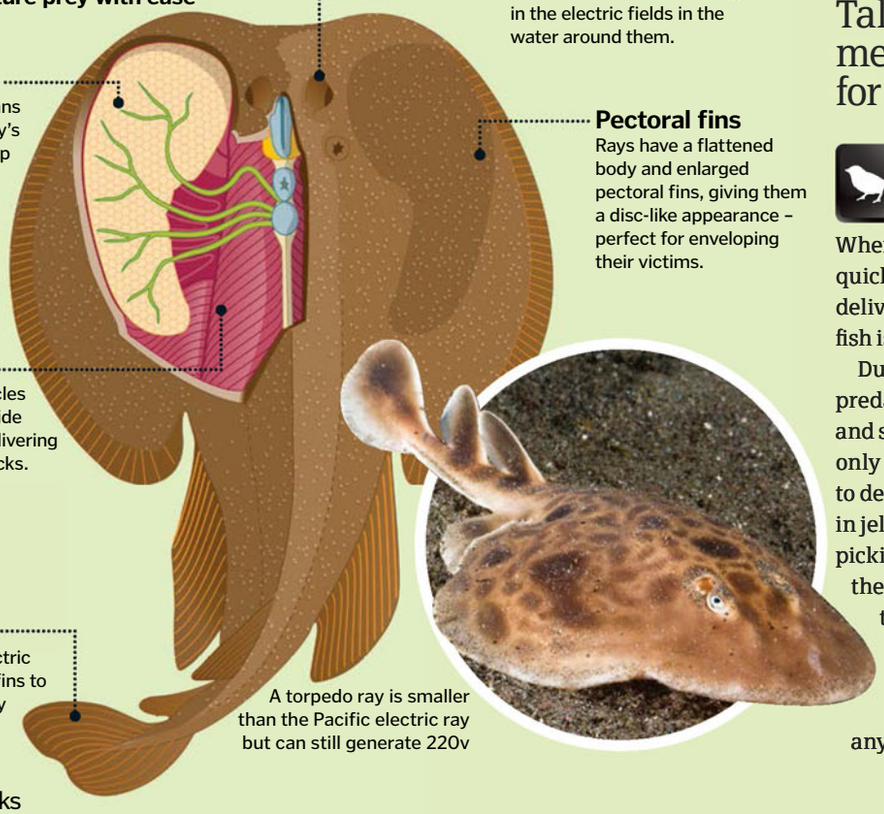
Bromeliads
Tropical Americas
The narrow leaves of bromeliad plants typically form a cup shape, which sometimes traps water at its base. They can even grow on telephone lines.

Mosses
Worldwide
Mosses often live on tree trunks. To keep moist, they grow on the side away from the Sun's heat – eg the north side in the northern hemisphere.

Basket fern
South-east Asia/Australia
Small fronds wither into a brown basket that protects the green fertile fronds and collects leaf litter to feed the fern.

Stunning biology

The unique anatomy of the electric ray enables it to capture prey with ease



A torpedo ray is smaller than the Pacific electric ray but can still generate 220v

Electric rays

Take a look at the shocking mechanism this flatfish uses for both defence and attack

The Pacific electric ray, which grows up to 1.5 metres (five feet) long, uses its electrical ability to ambush prey. When a fish comes within range, the ray quickly wraps its huge fin disc around it, delivering rapid pulses of electricity. Once the fish is stunned, the ray will swallow it whole.

Due to its size the Pacific electric ray has few predators, but smaller rays, like numbfishes and sleeper rays, use their electrical organs only in self-defence. Electric rays are also able to detect electricity. They have electroreceptors in jelly-filled pores on their heads, capable of picking up changes in the electrical fields in the water. When another fish swims past, the contraction of its muscles generates electricity, which the ray can sense. Not only does this alert the ray to nearby predators, but it also enables it to locate any prey that may be hiding in the sand.

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"Their small size also means that, unlike dogs, they are not at risk of setting off an undetonated mine"

Mammatus clouds

Why these distinctive clouds may warn of tornadoes...

Clouds form when the atmosphere becomes saturated and moisture condenses out around tiny particles of dust, salt or ice, collectively referred to as condensation nuclei. The shape of the cloud reflects the turbulence of the atmosphere and signals what is happening with the weather.

Mammatus (or mammatocumulus) clouds are puffy and rounded, with a distinctive protuberance on their undersides. Their name reflects their appearance, coming from the Latin word for breasts, while 'cumulus' is the Latin for pile or heap. Their formation is not fully understood, but it is thought that they are the result of sinking air, usually after a storm.

If a bad storm is brewing, clouds often pile up high; the top of the pile drifts in the strong winds of the upper atmosphere so the pile becomes shaped like an anvil. This kind of cloud is called cumulonimbus and it can warn of torrential rain or snow, hail, thunderstorms or even tornadoes to follow. Mammatus clouds often form the underside of cumulonimbus clouds and so are associated with storms.

Mammatus clouds can pile up to great heights, forming an anvil shape

Bees have an excellent sense of smell, so can sniff out buried explosives

Training anti-mine bees

Swarms of bees have been taught to locate TNT and identify land mines, but how do they do it?

During the Croatian war of independence in the early-Nineties, more than 1.5 million land mines were laid across the country. Although the remaining minefields are marked, de-mining is not yet complete, and over 500 people have been killed and many more injured by land mines since the war ended.

Even once a field has been de-mined and checked, there is a chance that remaining land mines could still be hidden beneath the soil. However, Croatian scientists have developed a rather novel solution to uncovering the remaining mines: bees.

These insects have an exceptionally good sense of smell, which means they can be trained to sniff out trinitrotoluene (TNT) – the explosive used in these devices.

A sugar solution is placed into a glass to simulate nectar and this is placed in soil containing traces of TNT. As the bees fly towards their sugary drink, they smell the TNT and, over a period of three or four days, gradually learn to associate the smell of explosives with the promise of food.

Once the bees are trained, they can be transported to fields and released into the air. Bees are incredibly hard to track visually, but they emit a lot of heat as they fly, and so can be followed with an infrared camera. Their small size also means that, unlike trained mine-detecting dogs, they are not at risk of setting off an undetonated mine.

The research has yet to be completed, but it is hoped the bees will be able to help confirm if fields have been properly de-mined.

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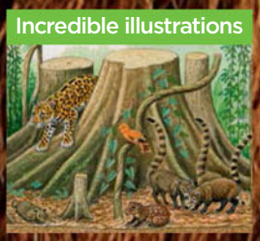

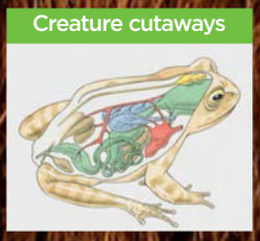

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"Pyroclastic flows can move at astonishing speeds of over 50 metres (164 feet) per second"

Pyroclastic flows

Learn about the fiery avalanches that pose the deadliest volcanic hazard

Pyroclastic flows have been responsible for around 55,000 deaths over the last 400 years – almost half of all volcano-related fatalities. These ground-hugging avalanches of rock fragments and volcanic gases destroy everything in their path. As they cascade downhill from an erupting volcano, they burn farmland, houses, livestock and people. Indeed, these fiery avalanches can reach extreme temperatures of up to 1,000 degrees Celsius (1,800 degrees Fahrenheit).

The Roman towns of Pompeii and Herculaneum were famously destroyed in 79 CE by pyroclastic flows caused by the eruption of Mount Vesuvius. As the volcano lost pressure, the powerful plume of gas and ash blasted from the vent collapsed. The plume rolled down the mountainside, burying Herculaneum refugees sheltering in seashore arcades with their gold and jewels; later flows struck Pompeii. Nearly 8,000 people died in the towns, many buried for thousands of years beneath several metres of ash and rock.

Pyroclastic flows can move at astonishing speeds of over 50 metres (164 feet) per second, as far as 200 kilometres (120 miles) from the eruption site – that's faster than a car travelling at over 180 kilometres (110 miles) per hour! Their extraordinary range and speed is thanks to the rock fragments flowing like a liquid inside a cushion of hot gas.

Pumice flows are pyroclastic flows caused by the collapse of an eruption column – for example, during the famous Pompeii eruption. They are mostly made of air and light pumice rock and are dumped as deposits called ignimbrites. Flows caused by hot blocks breaking off a growing lava dome are called nuées ardentes, which are denser than pumice flows. Nuée ardente translates as 'glowing cloud' and is named after the incandescent ash cloud that accompanies the flow.

Volcanic hazard distances

How do pyroclastic flows compare to other volcanic ejecta?

- Lava flow
- Pyroclastic flow
- Mud flow
- Ash fall

2,000km

200km

AMAZING VIDEO!

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A pyroclastic flow at Mount Paluweh, Indonesia

www.howitworksdaily.com

DID YOU KNOW? *Krakatoa's 1883 pyroclastic flows travelled 40km (25mi) over the Sunda Strait, even engulfing ships in flames*

A space radar image of Mount Unzen, Japan

Unzen tragedy

On 3 June 1991, journalists and volcanologists waited to photograph pyroclastic flows from Mount Unzen in Japan when a cloud of ash from a pyroclastic flow engulfed them. It demolished trees, wooden houses and electric poles – 43 people died.

Seismographs recorded 9,500 pyroclastic flows during the 1990-1995 Unzen eruption. They happened as a mound-shaped lava dome grew on the volcano's steep north-eastern flank. Hot lava blocks broke off the dome, collapsed down the steep slope and formed pyroclastic flows that travelled up to five kilometres (three miles).

CONTROLLING THE WEATHER

DISCOVER HOW WE MAKE RAIN AND THE AMBITIOUS PLANS BEING HATCHED TO TACKLE CLIMATE CHANGE

Superhero Storm in the *X-Men* comics can conjure rain, end droughts and create hurricanes with the power of her mind. Now, scientists and meteorological technology are opening more and more opportunities for us mere mortals to manipulate weather and Earth's climate.

In 2009, Chinese meteorologists from the Beijing Weather Modification Office claimed to be responsible for the city's earliest snowfall since 1987. Around 16 million tons of snow reportedly fell over drought-afflicted northern China after workers fired rockets carrying pellets of silver iodide into heavy clouds.

The rockets were cloud seeding, a process invented in the late-Forties. Supporters claim it can reduce hail damage, increase rainfall and disperse fog among other things. There are cloud-seeding projects in at least 20 countries worldwide, from Israel to Australia; in 2003, in the US alone, ten states were conducting at least 66 cloud-seeding programmes. In China, around 32,000-35,000 people are employed in the weather modification industry.

The big question in cloud seeding is: how effective is it? A 2003 US National Academies report concluded there was no concrete scientific proof it worked. According to Professor Michael Garstang from the University of Virginia, who chaired the report, the situation hasn't changed much since; there remains "a lack of definitive evidence," he says.

Even cloud-seeding supporters admit it doesn't currently lead to a huge rise in rain and snowfall. "It doesn't increase precipitation by 50 per cent in most cases," says Bruce Boe from Weather Modification Inc, a private weather control company based in North Dakota, USA.

US enthusiasm for weather modification research waned in the late-20th century, with funding falling to less than five per cent of its Seventies peak. But there are signs of fresh interest in the field. The US National Science Foundation (NSF) is funding a cloud-seeding project in the Wyoming mountains, operated by Weather Modification Inc. New technology, such as advanced computer models and radar instruments that can see inside clouds is driving the resurgence of interest, says Boe: "We're bringing a lot of new tools to bear on the question. These tools weren't available before and they're starting to bear fruit."

The Wyoming project, launched in 2005, uses aircraft-mounted radar and ground-based

5 TOP FACTS MYTHS BUSTED

1 Geoengineering is ready
Today's geoengineering ideas are untested or small-scale experiments. Cooling Earth by one degree Celsius would require a minimum five years of military-scale effort.

2 One tech is enough
No single 'magic technology' can cool the Earth. Future geoengineers might use many fixes, like reflective buildings, a space-based deflector and encouraging reforestation.

3 It solves climate change
Geoengineering doesn't stop greenhouse gas emissions – the root cause of man-made climate change. It's a 'plaster', pausing harmful warming to give us time to cut emissions.

4 We can't create rain
There's emerging evidence that cloud seeding *can* make rain. An Australian project in 2005-2009 found that rainfall increased in suitable clouds by an average 14 per cent.

5 It's all a conspiracy
There's no scientific evidence behind claims that HAARP, a US facility studying Earth's ionosphere, is a secret conspiracy for creating hurricanes as weapons.

DID YOU KNOW? *A global survey in 2010 found 72 per cent of us supported research into reflecting sunlight to cool the planet*

instruments. It tests the effectiveness of seeding winter orographic clouds – which are cold clouds formed when air rises over mountains – with silver iodide.

"In the mountains of the American West, these types of storms are the main target for cloud seeding. Often the clouds are not efficient at generating snow, so cloud seeding is used to enhance snow production," says Dan Breed from the US National Center for Atmospheric Research (NCAR), who is evaluating the project.

Another aim of the experiment is to increase snowfall by perhaps ten per cent a year, building up the winter snowpack so it's available for use. The extra water running off the mountains each spring would be worth an estimated £1.5-3 million ($2.4-$4.9 million).

Cloud seeding affects the weather in a local region, but there are other technologies being devised to alter climate on a much bigger scale. Space mirrors and giant floating hosepipes might sound far-fetched, but they're two proposals for geoengineering. Geoengineering is deliberate global modification of Earth's climate to counter man-made climate change.

Geoengineering may sound impossible, but serious scientists are investigating how it might cool down the planet. In the last few years, billionaire Bill Gates reportedly donated £2.8 million ($4.5 million) to geoengineering research, and the UN IPCC report, a summary of what most scientists agree we know about climate change, mentioned geoengineering for the first time this year.

Geoengineering is essentially 'Plan B' in case we reduce greenhouse gas emissions 'too little, too late' to avoid dangerous climate change, argues a 2009 report by the UK's Royal Society. A temperature rise of just two degrees Celsius (3.6 degrees Fahrenheit) could melt the Greenland ice sheet and cause a long-term sea level rise of seven metres (23 feet). That's enough water to submerge both London and Los Angeles.

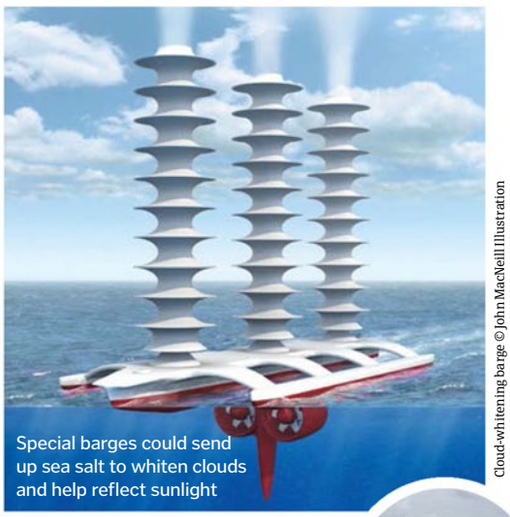
To avoid this wide-scale warming, we'd need to cut global carbon dioxide emissions by 50 per cent of 1990 levels by 2050, according to the Royal Society. Yet emissions are still rising – by 1.4 per cent during 2012. Even if we cut carbon emissions today, temperatures will continue rising for decades. The climate system is like an oil tanker – ie slow to turn around.

Dr Hugh Hunt is an engineer from Cambridge University working on SPICE (Stratospheric Particle Injection for Climate Engineering) – a UK government-funded geoengineering research project: "We don't know what the scale of unabated climate change will be," he says. "You've got to think in advance what emergency measures you might need, and then hope you won't need them."

There are two types of geoengineering. Solar radiation management (SRM) cools the Earth by reflecting the Sun's heat back into space, while carbon dioxide removal (CDR) scrubs CO_2 – the primary greenhouse gas causing man-made climate change – from the atmosphere.

Examples of SRM include space mirrors, injecting sulphate aerosols into the atmosphere through giant hosepipes and painting urban roofs white. One idea uses cloud seeding to make clouds more reflective. Fleets of unmanned 3,000-ton barges could sail the oceans, spraying clouds with saltwater. Salt particles should create more water droplets in the clouds, whitening them. Proposals for CDR include fertilising tiny marine plants with iron, growing new forests or fast-growing crops and burying charcoal, all of which lock up CO_2 and remove it from the air. Most geoengineering proposals remain in the lab at this stage. "We can do very little right now because the ▶


Geoengineering plans include ideas for orbiting sunlight reflectors in space


Special barges could send up sea salt to whiten clouds and help reflect sunlight

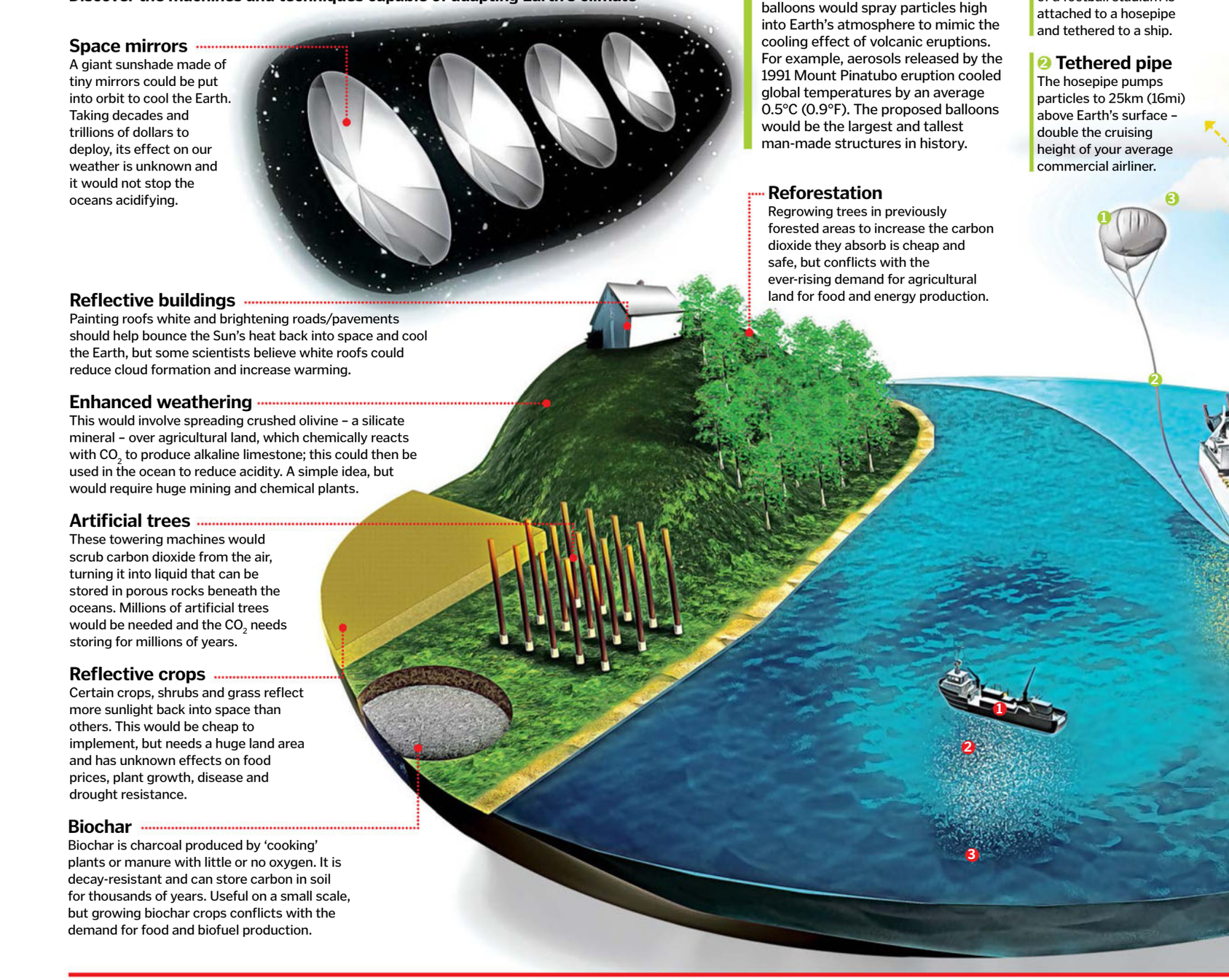
Cloud-whitening barge © John MacNeill Illustration


New technology has led to a resurgence in cloud-seeding projects

"Reflecting sunlight back into space with aerosols is the fastest geoengineering method"

Weather-changing tech in action

Discover the machines and techniques capable of adapting Earth's climate



Space mirrors
A giant sunshade made of tiny mirrors could be put into orbit to cool the Earth. Taking decades and trillions of dollars to deploy, its effect on our weather is unknown and it would not stop the oceans acidifying.

Reflective buildings
Painting roofs white and brightening roads/pavements should help bounce the Sun's heat back into space and cool the Earth, but some scientists believe white roofs could reduce cloud formation and increase warming.

Enhanced weathering
This would involve spreading crushed olivine – a silicate mineral – over agricultural land, which chemically reacts with CO_2 to produce alkaline limestone; this could then be used in the ocean to reduce acidity. A simple idea, but would require huge mining and chemical plants.

Artificial trees
These towering machines would scrub carbon dioxide from the air, turning it into liquid that can be stored in porous rocks beneath the oceans. Millions of artificial trees would be needed and the CO_2 needs storing for millions of years.

Reflective crops
Certain crops, shrubs and grass reflect more sunlight back into space than others. This would be cheap to implement, but needs a huge land area and has unknown effects on food prices, plant growth, disease and drought resistance.

Biochar
Biochar is charcoal produced by 'cooking' plants or manure with little or no oxygen. It is decay-resistant and can store carbon in soil for thousands of years. Useful on a small scale, but growing biochar crops conflicts with the demand for food and biofuel production.

Volcano balloons

Hosepipes attached to giant helium balloons would spray particles high into Earth's atmosphere to mimic the cooling effect of volcanic eruptions. For example, aerosols released by the 1991 Mount Pinatubo eruption cooled global temperatures by an average 0.5°C (0.9°F). The proposed balloons would be the largest and tallest man-made structures in history.

Reforestation
Regrowing trees in previously forested areas to increase the carbon dioxide they absorb is cheap and safe, but conflicts with the ever-rising demand for agricultural land for food and energy production.

1 Helium balloon
A helium balloon the size of a football stadium is attached to a hosepipe and tethered to a ship.

2 Tethered pipe
The hosepipe pumps particles to 25km (16mi) above Earth's surface – double the cruising height of your average commercial airliner.

technology hasn't been developed to intervene on a planetary scale," notes Andy Parker.

Still, there are a few examples of outdoor field tests. The SPICE project included a plan, later abandoned, to pump water one kilometre (0.6 miles) vertically through a pipe attached to a helium balloon. Its aim was to test the feasibility of squirting sulphate aerosols through a giant hosepipe 20 kilometres (12 miles) above the ground. "We don't know if it's technically possible," continues Dr Hunt. "No one has built a 20-kilometre (12-mile) pipe that goes vertically upwards." Among his unanswered questions are, firstly, can we build and launch a balloon big enough, and secondly, can we build a pipe strong enough?

Other geoengineering proposals rely on pre-existing technology. Fertilising oceans with iron, for example, has already happened on a small scale although not necessarily legally. It needs lots of tanker ships, chemical plants and iron. "There's nothing technically difficult about that," says Professor Andy Ridgwell from Bristol University.

It would take hundreds of years to see results from iron fertilisation and other CDR technologies though. They rely on slow natural processes, such as fertilising tiny marine plants that transport carbon into the deep ocean when they die. "You can't suddenly pull loads of

KEY DATES
MAN-MADE WEATHER

1891
Rainmaker Robert Dyrenforth tries proving noise causes downpours by exploding dynamite kites over Texas.

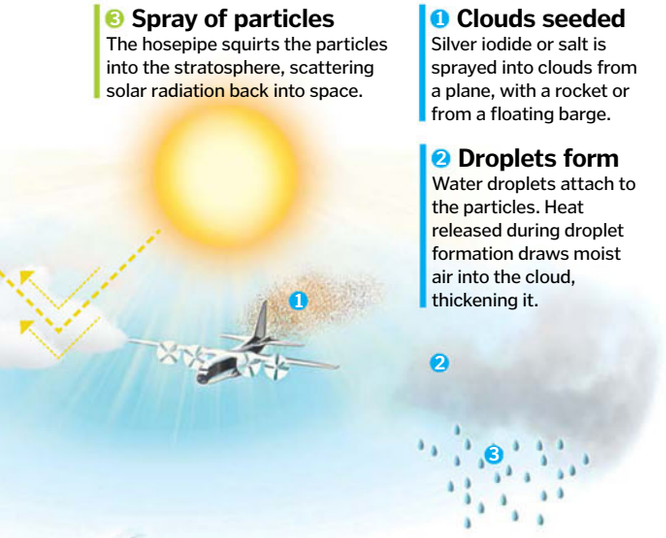
1946
Vincent Schaefer performs the first cloud-seeding experiments, dropping dry ice pellets into clouds.

1952
34 die in a flood in Lynmouth, England. The UK cloud-seeding Operation Cumulus is blamed.

1967
Operation Popeye, a secret US cloud-seeding project, seeks to deluge enemy troops in Vietnam.

2008
The Chinese government tries to prevent rain at the 2008 Beijing Olympics by launching 1,104 rockets.

DID YOU KNOW? *Global temperatures could rise by more than 1°C by the end of this century, even if we reduce carbon emissions*



3 Spray of particles
The hosepipe squirts the particles into the stratosphere, scattering solar radiation back into space.

1 Clouds seeded
Silver iodide or salt is sprayed into clouds from a plane, with a rocket or from a floating barge.

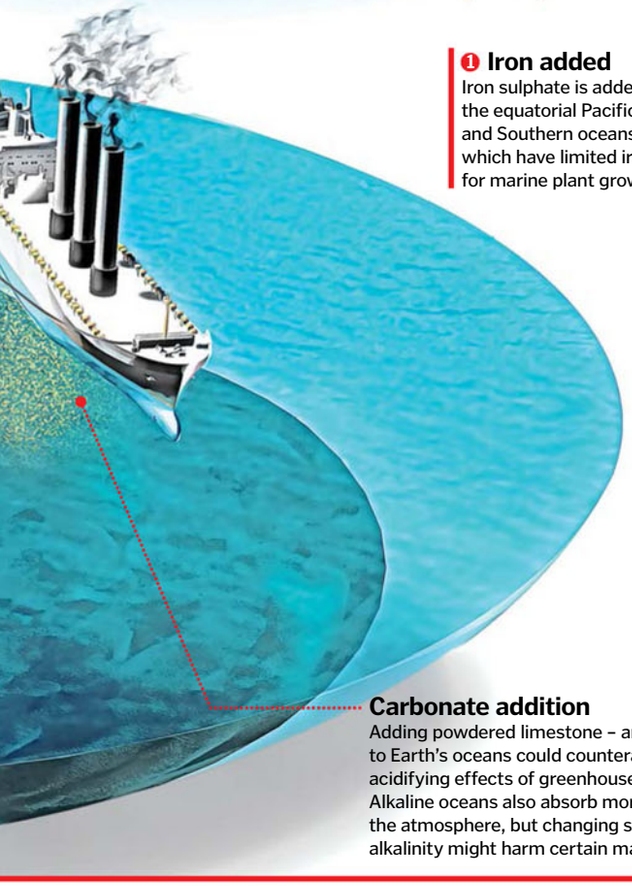
2 Droplets form
Water droplets attach to the particles. Heat released during droplet formation draws moist air into the cloud, thickening it.

Cloud seeding

Cloud seeding is a technique for man-made rainmaking already used around the world to varying degrees of success. Rainfall naturally occurs when water droplets attach to sand, dust or salt particles. Cloud seeding squirts extra particles into clouds to spawn new raindrops. Salt is used in warm tropical clouds, while silver iodide is added to cold clouds to create extra ice crystals.

Some scientists believe cloud seeding can brighten clouds to counteract climate warming too. The extra particles make the clouds denser, whiter and more reflective, deflecting more sunlight back into space.

3 Rain falls
The droplets or ice crystals collide, growing bigger and heavier until eventually they fall as precipitation.



1 Iron added
Iron sulphate is added to the equatorial Pacific and Southern oceans, which have limited iron for marine plant growth.

Ocean fertilisation

Marine plant life is at the core of the ocean food chain. The plants are a source of food for other marine life, and happen to take up and bind carbon dioxide as well. They rely on the availability of nutrients to grow – most commonly nitrogen or iron. Fertilising the oceans with iron sulphate is believed to increase their growth and reproduction, which would in turn increase the amount of carbon dioxide they take up, reducing the effect of carbon emissions. Some scientists also believe that the increased marine plant life may increase the number of fish in the sea, in turn improving our food supply.

2 Microalgae bloom
The rich iron supply creates vast blooms of tiny marine plants, which take up CO_2 as they grow.

3 Carbon locked away
As the plants die, some fall to the ocean floor, taking locked-up carbon dioxide with them which becomes buried as sedimentary rock.

Carbonate addition
Adding powdered limestone – an alkali – to Earth's oceans could counteract the acidifying effects of greenhouse gases. Alkaline oceans also absorb more CO_2 from the atmosphere, but changing seawater alkalinity might harm certain marine life.

Can we stop a hurricane?

Hurricane Katrina in 2005 was arguably the worst natural disaster in American history, and many scientists believe hurricanes will only worsen with climate change.

So there's no shortage of ideas for stopping these devastating storms. In 2009, Bill Gates backed a proposal to halt hurricanes by towing tub-like barges into their path. These would cool the warm ocean waters fuelling the storm.

Most plans underestimate a hurricane's power though; according to the NOAA Hurricane Research Division, one storm can release the energy of 10,000 nuclear bombs. For example, to fight a hurricane with water-absorbent powder you'd need hundreds of planes to make sorties every one and a half hours.

Some therefore argue that it's cheaper and more practical to adapt to hurricanes by, for instance, building stronger houses.

The risks of geoengineering

Geoengineering is controversial because it involves large-scale changes to Earth's climate. Critics discuss possible negative side effects, like that ocean fertilisation might cause toxic algal blooms, or that geoengineering gives industry and government excuses not to cut carbon emissions.

Geoengineering also raises issues of ethics. Cooling the climate with sulphate aerosols "is potentially cheap enough for single countries to do", says Professor Andy Ridgwell, Bristol University, but could impact other countries' climates as well.

Others fear 'rogue' geoengineers. For example, an American businessman dumped 100 tons of iron sulphate into the Pacific in July 2012 in an unauthorised ocean fertilisation scheme.

carbon dioxide out of the atmosphere with any of them," explains Professor Ridgwell. "They lend themselves to gradual mitigation."

Growing vast new forests or fast-growing crops competes with existing land uses, explains Dr Tim Lenton from Exeter University. The idea is to repeatedly harvest fast-growing crops like eucalyptus, which capture the carbon dioxide they use to grow. Crops growing on the best soils take up the most carbon, but you want to use those soils to grow food. "The plausibility problem is that you're in potential competition with other land uses in a world where dietary demands are rocketing."

Reflecting sunlight back into space with aerosols is the fastest geoengineering method. It mimics the rapid cooling effect of a large volcanic eruption. "Once you start blocking out some sunlight, temperatures drop quite quickly," explains Andy Parker. For example, in the two years following the eruption of Mount Pinatubo in the Philippines in 1991, global temperatures cooled by about 0.5 degrees Celsius (0.9 degrees Fahrenheit) on average.

So realistically how fast could we cool the planet? Dr Hunt concludes: "Let's suppose the Greenland ice sheet completely melts and we get a one-metre [3.2-foot] sea-level rise. It could be done in five years – if we've got time to think about it, 20-30 years from now."

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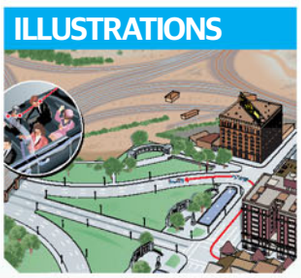

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LARGEST KEY IN THE WORLD

According to the Guinness World Records, the biggest key ever made is 5.5 metres (18 feet) tall and 2.6 metres (8.5 feet) wide. It was manufactured by Cypriot Georgiou Evagoras and measured in 2006.

DID YOU KNOW? *Google has mapped over 8mn km (5mn mi) in the six years since Street View launched*

Key-cutting machines create exact copies by tracing the design of the original key onto the new one

How keys are made

Discover how the unique notches and grooves are added to fit bespoke locks

Simple locks have keys based on a series of larger teeth, so many locks can tolerate a degree of inaccuracy, and a lot of key duplication is still done using a manual key-cutting machine. The original key is clamped on top of the new one, forming a template. Using this as a guide, the operator traces the outline with a cutting blade, producing a duplicate pattern in the new key below.

A skilled operator can produce keys that are nearly identical, but it is very time-consuming, and for high-security locks greater precision is required. Automated key-cutting machines allow keys to be replicated with a finer degree of accuracy.

These machines use the same principle as manual key cutting in that the original is used as a template, although the keys are clamped separately. A stylus traces the outline of the original and the machine transfers it to the copy using a cutting blade. For higher-security keys, a laser-cutting device is used, allowing for extremely high precision. This technique introduces a series of tiny pits into the surface of the metal, increasing the lock's complexity.

Some keys are not copied at all. So-called 'code keys' use a predefined map stored on a memory device. In order to replicate these, all that is needed is the code, which contains all of the instructions about the locations and dimensions of the grooves.

Trekker cameras

Google Street View can now venture into city centres and the remote wilderness with its tough camera backpacks

A fleet of Google Street View cars – alongside a few trikes, snowmobiles and boats – has been capturing panoramic images of our roads and buildings for some time now, but there are certain areas they haven't been able to reach. Well, until now.

The solution lies in a 1.2-metre (four-foot)-tall, backpack-mounted camera called the Trekker. Kitted out with 15 lenses – each attached to a five-megapixel camera – it takes a photograph every two-and-a-half seconds, sweeping in a full panorama above the user's head.

It weighs a hefty 19 kilograms (42 pounds), but volunteers seem very keen to take the equipment into the wilderness. Charitable organisations, research institutions and the tourism industry are all eligible to apply to borrow the Trekker equipment, giving Google access to areas unreachable by their car-mounted cameras, and eventually allowing people to virtually explore national parks, ruined buildings and other difficult-to-reach areas like canyons and caves.

The equipment has already been used to map several hiking trails, including the Grand Canyon, and in the UK the complex network of canals and waterways that runs up and down the country has been recorded.

Using a backpack-mounted camera, Google Street View explores parts of the world only accessible on foot

Making maps

Google is extremely selective when it comes to imagery and aims to ensure that photographs are captured when the weather is clear and the view is as unobstructed as possible. Images are recorded alongside GPS information in order to ensure that their exact location is accurately mapped.

Google's camera technology uses a series of lasers to measure the distance from the lens to the subject of the image. These in turn create 3D models of the landscape that enable the best image to be selected depending on where the user is virtually positioned within Street View.

"4K TVs work in much the same way as an HD TV – they use either liquid crystal display or plasma screens"

Next-gen TVs explored

How 4K televisions and other new tech are changing the way we watch the box

The next big thing in TV, 4K is a type of ultra-high definition video. 4K refers to the resolution, clocking in at around 4,000 horizontal pixels across. We say 'around' 4,000 because there are two types of video being called 4K. Originally, it was developed to improve cinema: Sony introduced equipment with double the horizontal pixels of its 2K format (2,048 x 1,080 pixels), logically calling it 4K.

For television, high-definition video is technically 1,920 pixels wide, and ultra-HD TV is 3,840 pixels. It's approximately 4,000 – hence the 4K label – but its more accurate name is Quad Full High Definition (QFHD).

4K TVs work in much the same way as an HD TV – they can use either LCD (liquid crystal display) or plasma screens. Plasma screens are filled with tiny cells of neon and xenon. When an electric charge is applied, the gas will emit UV light, which goes on to activate phosphorescent material inside the cell to glow red, green and blue in any combination.

LCDs, on the other hand, are a layer of liquid crystals sandwiched between two sheets of polarised glass, back- or side-lit by light-emitting diodes. When an electric charge is applied here the twisted crystal molecules untwist and change how light passes through so an image can be generated on the screen.

Essentially the more pixels you have the sharper the pictures will appear. Resolution is listed as the number of horizontal pixels plus 'i' or 'p' – ie 1080i or 1080p. The letter tells you the method the machine uses to send the picture to the screen: i for interlaced or p for progressive scan. Generally, progressive scan TVs have a better picture because the signals are sent all at once, whereas interlaced TVs send data twice, as odd and even lines.

So the technology's ready. Broadcasters are ready. And as data storage gets smaller and cheaper, filmmakers are 4K ready. But it'll be some time yet before we're ready, since many of us are only just upgrading to HD TV!

110in

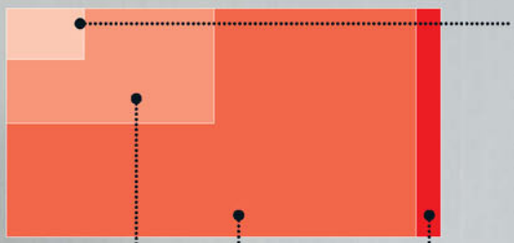
BIGGEST 4K TV TO BE BUILT

In 2013, Samsung announced plans for 241-centimetre (95-inch) and 279-centimetre (110-inch) 4K TVs. If you fancy one, you might want to check you've got enough space – that's a diagonal of 2.7 metres (nine feet)!

DID YOU KNOW? *The smallest programmable part of a screen, the word 'pixel' was made up from picture and element*

Definition in pixels

The more pixels, the clearer the picture. Here's a quick guide to how the various video resolutions measure up



SD: 720 x 480px
SD is today's 'normal' Standard Definition TV. In analogue, it was formats like NTSC, PAL and SECAM, and in digital, it varies around the world and by device but it's either 704 or 720 pixels wide.

Full HD: 1,920 x 1,080px
Today's 'High Definition' – the HD video format being broadcast in the UK, and the highest resolution most HD TVs are capable of.

Quad HD: 3,840 x 2,160px
QFHD (Quad Full High Definition) is four times the pixel size of a normal HD TV – the pixel size you'd get if you put together four HD TVs.

4K HD: 4,096 x 2,160px
Sony has defined 4K as double the horizontal pixel size of its '2K' cinema resolution, making it 256 pixels wider than QFHD.

Is this the end for cinema?

On a screen of 152 centimetres (60 inches) or less, you're unlikely to see much difference between HD and 4K TV. So your home HD TV is about as good as it gets. For larger screens, it depends how far away from it you're sitting. Get closer and 4K's noticeably sharper.

With home TVs this good, will anyone still go out to the pictures? Yes – at least while film-makers still distribute their latest movies to cinemas first. But now TVs are smarter, with cinema-quality sound and resolution, how long before new films are 'released' straight to home systems?

More new TV tech

1 LG Magic Remote
The latest remote control tech in an all-in-one zapper: you can point and scroll like a mouse, wave it around like a Wii controller and speak into it instead of typing.

2 Samsung Quadmatic Picture Engine
This is Samsung's technology that converts SD, HD or QFHD content into ultra-HD size. It uses noise reduction and detail enhancement that helps to produce a smooth and sharpened picture that is very close to 4K quality.

3 Sony Magnetic Fluid Speakers
Rather than the mechanical system used to move speaker cones up and down, Sony is using a magnetic fluid – it's smoother, more energy-efficient and requires less space. Sony is already making slimmed-down speakers and this tech is evolving TV audio.

Samsung's 216cm (85in) S9 Series Ultra HD TV costs £35,000 ($45,000)!

Television evolution

How TV has changed over 100 years

1907 – Birth of modern TV
Boris Rosing is the first to use a cathode ray tube (CRT) – a vacuum tube and an electron gun that produces images when an electron beam strikes the phosphorescent surface.

1946 – Colour introduced
Manufacturers add a red-blue-green wheel in front of a CRT. Some of the first colour broadcasts in the US are medical operations; they are so 'real', many viewers faint!

1981 – The first HD TV
Japanese company NHK demonstrates its analogue HD TV system with 1,125 lines of resolution, but it isn't until 1991 that Japan transmits in HD. The US is behind by seven years.

1990s – Liquid crystal tech
In 1964, George Heilmeier invents colour LCD, but it isn't until 1996 that this technology has developed enough to build TVs. NEC and Hitachi pioneer large flat-screen LCD TVs.

2004 – LEDs arrive on the scene
Sony uses LEDs instead of CCFLs (cold-cathode fluorescent lamps) to light LCD displays, offering long life, energy efficiency and quicker switching.

2007 – Digital switchover
UK broadcasters begin a phased shutdown of analogue transmissions – this 'digital switchover' runs until 2012. Now Brits need a digital TV or set-top box to watch.

2009 – Quantum dots
Nanoco develops 'quantum dots' for LED screens which produce more accurate colours.

2012 – Rise of 4k
In 2012, the BBC tests ultra-hi-def kit while filming the Olympics. In 2013, an average 4K TV will set you back – aptly – £4,000 ($6,400).

"Using the light in the camera, a doctor can see inside the ear and an app can be used to capture images"

How do we examine ears?

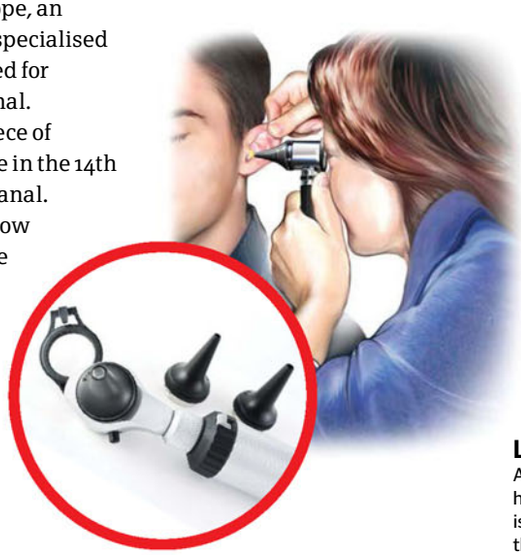
Otoscopes allow doctors to see inside the ear using a mix of magnifying lenses and lights

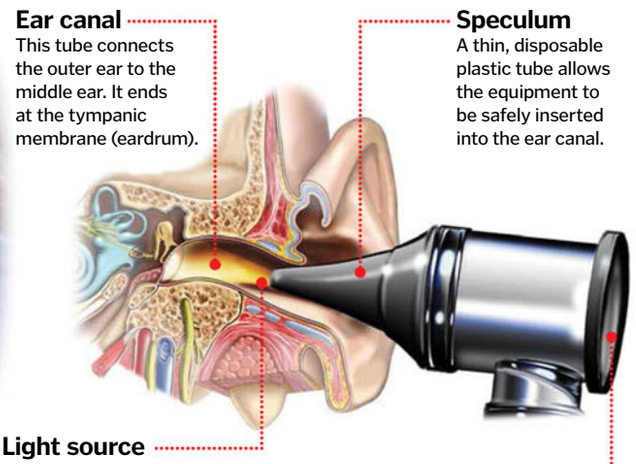
Also known as an auriscope, an otoscope is essentially a specialised magnifying glass designed for medical examination of the ear canal.

The otoscope itself is a simple piece of technology, first designed in France in the 14th century as a tool to widen the ear canal. Modern otoscopes consist of a narrow speculum, designed to fit inside the ear canal, along with magnifying lenses and a halogen or fibre-optic light source. This enables doctors to examine the ear canal and the cone-shaped membrane that forms the eardrum. They can also be used for examining inside the nose and back of the throat.

This tool is used in general practice to diagnose infection and inflammation. Some otoscopes also allow a puff of air to be administered – a technique used to test for changes in flexibility due to a buildup of fluid

New technology also allows an otoscope to be fitted to a smartphone for low-cost digital imaging. Using the light provided by the camera, a doctor can see inside the ear and an app can be used to capture images, record video and store data for further analysis.





Ear canal
This tube connects the outer ear to the middle ear. It ends at the tympanic membrane (eardrum).

Speculum
A thin, disposable plastic tube allows the equipment to be safely inserted into the ear canal.

Light source
A fibre-optic or halogen light source is used to illuminate the dark ear canal.

Lenses
Optical lenses within the otoscope typically grant up to 8x magnification.

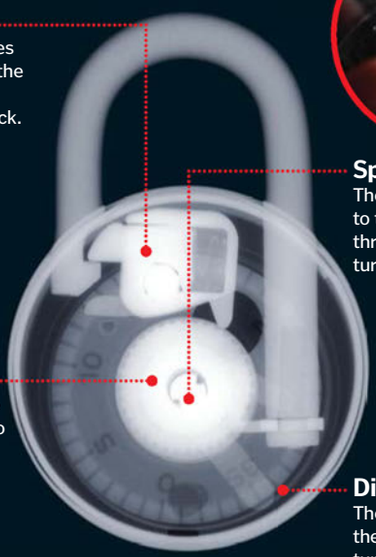
Why we have earwax

Earwax is produced by the outer section of the ear canal and is a combination of dead skin cells and secretions from specialised gland cells. Its sticky consistency lubricates the ear canal, preventing it from drying out, and also traps any particles that enter the ear. The cells of the ear canal begin at the eardrum and move outwards as they age and die, carrying earwax with them. Excess earwax can cause discomfort and hearing problems, but removing it with a cotton swab is not advised, due to the risk of painfully compacting the wax or even perforating the eardrum.

Medically known as cerumen, earwax helps to protect the body

Combination locks

Discover what is going on at the heart of these traditional security devices...



Latch
When all of the notches in the wheels line up, the latch fits down into them, releasing the lock.

Spindle
The spindle is attached to the dial and runs through the wheels and turns the drive cam.

Wheel pack
The wheels each have a pin, allowing them to turn as a group.

Dial
The external dial moves the drive cam, which in turn spins the wheels.

A combination lock contains three notched wheels, which must be lined up to release the latch. The wheels have a pin on either side so at certain points in their rotation one wheel will 'catch' the next one, moving the two in unison.

To open it, the dial must first be turned clockwise for two rotations – this moves the first wheel, which spins until its pin comes into contact with the second wheel. When the pins collide, the first wheel starts to rotate the second, which in turn picks up the third.

Continuing to turn the dial clockwise to the first number lines the notch on the third wheel up with the latch. The dial is then twisted anticlockwise, pushing the first and second wheels away from the pin on the third wheel. The notch on the second wheel is lined up with the latch and the dial turned clockwise again, moving the first wheel to its position and opening the lock.

THE STATS
GALAXY NX

MP COUNT 20.3 DIMENSIONS 136.5 x 101.2 x 25.7mm

SENSOR SIZE 23.4 x 15.7mm SCREEN RESOLUTION 1,280 x 720 (HD)

DID YOU KNOW? *The Galaxy NX features the largest sensor available in a mirrorless interchangeable lens camera*

Learn more

To find out more about three web-connected cameras on the market and how they compare, check out this issue's group test on **page 88**.

The ability to download apps means you can share and edit with the camera

Connected cameras

How the latest smart cameras enable us to do much more than take photos

A new wave of cameras, like the Samsung Galaxy NX, is bringing the functionality of smartphones to the world of cameras, with the ability to get online and use apps via the Android operating system.

As well as allowing you to connect to the internet via Wi-Fi, where data is transmitted between the camera and a nearby router using radio frequency bands, the Galaxy NX can also use the 3G and 4G Long Term Evolution (LTE) and Evolved High Speed Packet Access (HSPA+) standards for wireless communication. If you insert a SIM card into the camera, you can upload your photos to the internet by sending packets of data between the card and a local mobile signal tower in the form of radio waves. This means you can access the web anywhere, so long as you have network coverage.

Most modern cameras require you to use your smartphone or tablet as a wireless network access point and transfer your shots to your device before you can share them. However, the ability to download apps straight onto models like the Galaxy NX means you can upload directly using social network apps.

This also opens up scope for perfecting your shots before you share them with editing apps from Google Play. The 12.1-centimetre (4.77-inch) scLCD capacitive touchscreen contains a layer of glass coated with a conductor that senses your fingertips, allowing you to interact with photos in detail to apply effects and edits.

Re-inventing the cameraphone

The poor quality of cameraphone images in comparison to the hi-res photos produced by digital cameras has seen Sony launch the QX10 and QX100. These 'lens-style cameras' connect to your smartphone via Wi-Fi or near-field communication (NFC) to replace your phone's built-in camera and produce higher-quality shots.

Both models feature an optical zoom lens and image sensor, and are powered by a lithium-ion battery. They can attach to your phone via a mount, or be used independently, allowing for more creative framing of your photos. Your phone's screen then becomes the viewfinder, letting you control the lens via the Sony PlayMemories Mobile app.

"Arch dams, like the Hoover Dam in the USA, use their curved shape to balance out the pressure"

Dam engineering

How these structures are built to withstand immense natural forces

Building any dam presents a unique engineering challenge, since no landscape or water system is exactly the same. One of the best sites to build a dam is in a narrow river valley with steep rocky sides strong enough to support the structure. The first step is to divert the water around the area you want to build, and for large dams in rocky environments, explosives are used to blast a new channel through the terrain. A temporary barrier is needed to keep water out of the area normally submerged. Traditionally, a wet concrete mixture is poured into moulds, hardening to form the shape of the intended dam. Gravity dams, meanwhile, like the Three Gorges Dam in China have walls with steep slopes, and rely solely on their immense weight to hold the water back. Arch dams, like the Hoover Dam in the USA, use their curved shape to balance out the pressure. Buttress dams get their strength from concrete pillars lined along the face of the structure, and embankment dams slope gradually and are made from compacted earth. The world's largest dams weigh millions of tons, making strong foundations that reach deep below the original ground level essential.

History of dams

The first dams were simple gravity dams made of masonry. The Ancient Egyptians were the first to realise dams could alleviate floods. In 2650 BCE, work began on a large embankment dam called Sadd el-Kafara. At 110 metres (360 feet) long and 14 metres (46 feet) tall, it would have been the largest in the world, but a flood destroyed it before it was finished. Marduk Dam in Mesopotamia, from circa 2000 BCE, was the first embankment dam, built to prevent flooding and to irrigate crops.

The Romans embraced dam building, using them to transport, store and distribute water in new ways – and at least two Roman dams are still used today. Modern dam construction took off in the mid-19th century as knowledge of structural theory and materials science came to light.

THE STATS
THREE GORGES

WEIGHT 65mn tons HEIGHT **185m** STARTED OPERATING 2003

BREADTH **2km** BUILD TIME 17yrs OUTPUT **22,500MW**

DID YOU KNOW? *Building the Three Gorges Dam raised so much water that the Earth's rotation slowed slightly*

Reservoir
1,050km² (405mi²) of water covers once inhabited land. It called for the relocation of 1.3 million people.

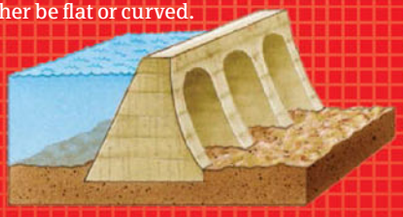
Ship lock
A two-way, five-stage lock enables large vessels weighing up to 10,000 tons to pass.

Ship lift
A 113m (370ft) 'elevator' for smaller ships that weigh around 3,000 tons is due to be completed in 2015.

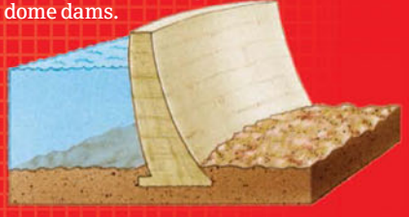
Three major types of dam

Embankment dam
Made from a bank of earth, these dams rely on their intense weight and sloped shape to hold the water back. There may be an impervious layer of concrete, plastic or other material on the upstream face if the particle sizes in the earth are big enough for water to seep through. Earth-filled dams can be made completely from one type of material, but may need a layer that collects and drains seep-water to ensure the structure stays intact.

Buttress dam
Buttress dams are used when the surrounding rock is not strong enough to provide a solid foundation. A series of solid concrete buttresses lined along the downstream face of the dam provide the strength needed to hold it in place. Buttresses add weight to the structure, pushing towards the ground and anchoring the dam even further. Since most of the support comes from the buttresses, the dam wall can either be flat or curved.



Arch dam
Best for narrow rocky ravines with steep walls strong enough to support the structure, these are solid concrete structures that curve upstream, forming an arch. The pressure from the water is distributed evenly for structural integrity, similar to an arch bridge. The weight of the dam pushes it into the ground, helping to reinforce it. Examples that are double-curved horizontally and vertically are referred to as dome dams.



COWS ARE MAGNETIC AND 24 OTHER WEIRD SCIENCE FACTS

NO POWER LINES

Bovine north-south tendency
Cows were most likely to be found with their heads pointing due north or south, aligned with geomagnetic fields.

NEAR POWER LINES

Disorder
In the vicinity of power lines the north-south alignment went awry, presumably because the cables' own weak electric fields disrupt magnetoreception.

Science is full of surprises. From the bizarre habits of fruit bats to the average colour of our universe (believe it or not, it isn't black), the weird discoveries uncovered by researchers across all fields of science are a constant reminder that we know far less than we sometimes assume.

Our world, and indeed the cosmos beyond, still has the capacity to shock us, and what's more, it's these anomalies that keep science moving forward, challenging our assumptions and forcing our understanding to new levels. Just think, once upon a time, even cornerstones of the scientific institution like gravity would have seemed crazy.

Funny, intriguing or just plain jaw-dropping, here are 25 of science's strangest findings, from marine biology to mathematics and astronomy. You'll never see the world in quite the same way again...

1. Cows are magnetic

Well, technically they're more like compass needles. Studying satellite imagery from Google Earth, researchers found that cattle (and deer) often align themselves with the Earth's magnetic field lines between the north and south poles. They aren't the only ones believed to sense magnetic fields: bacteria, molluscs and mole rats also display a magnetic 'sixth sense'. But while magnetoreception has a clear advantage for migratory animals, it's not obvious how it could benefit cows. One hypothesis is that it may help them to map their local surroundings.

5 TOP FACTS
JELLYFISH TRIVIA

Ancient jellies
1 The first jellyfish species are believed to have appeared on Earth around 650 million years ago, predating primitive dinosaurs by over 400 million years.

Jumbo jellyfish
2 Native to Japan, Nomura's jellyfish is the largest known jellyfish species, weighing 200 kilograms (440 pounds) and measuring up to two metres (6.6 feet) in diameter.

Beautiful but deadly
3 The box jellyfish's venom is one of the most potent animal poisons, containing toxins that attack the heart and nervous system to kill its victims in as little as three minutes.

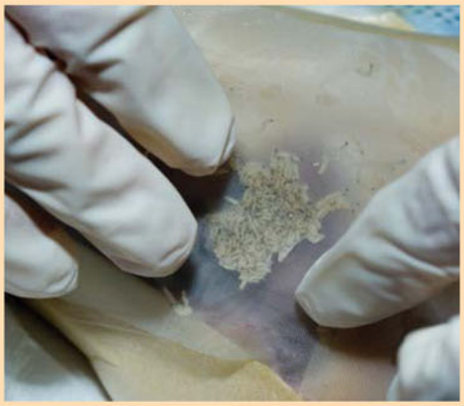
Heartless critter
4 Comprising over 90 per cent water, jellyfish have no bones, brain, heart or respiratory system. Sensory nerves on their tentacles let them see, smell and orient themselves.

Deep-sea glow
5 Some jellyfish species make their own light, known as bioluminescence. Most jellyfish use this light to put off predators, although some also use it to entice prey.

DID YOU KNOW? *Ancient Mayans and Aboriginal Australians are thought to be the first to use maggots to treat wounds*

2. Wounds filled with maggots heal faster

In deep wounds and ulcers, dead or dying tissue needs to be cut out at regular intervals to prevent infection – a process called debridement. Eating dead tissue but sparing healthy tissue, applying maggots to the wound can achieve more precise results than the surgeon's knife in a shorter time. On top of that, maggot secretions have a wide range of benefits, from improving the flow of nutrients to healing tissues to raising the wound's pH level to limit pathogenic bacteria growth.



1 Body
Measuring around a centimetre (0.4in) long, about six maggots are applied for each square centimetre of the wound.

2 Mouth hooks
Maggots use these two modified mandibles to probe and scratch away at dead tissue.

3 Secretions
Enzymes in its saliva and secretions help it to break down its food.

Maggots have proved to be very effective at cleaning wounds

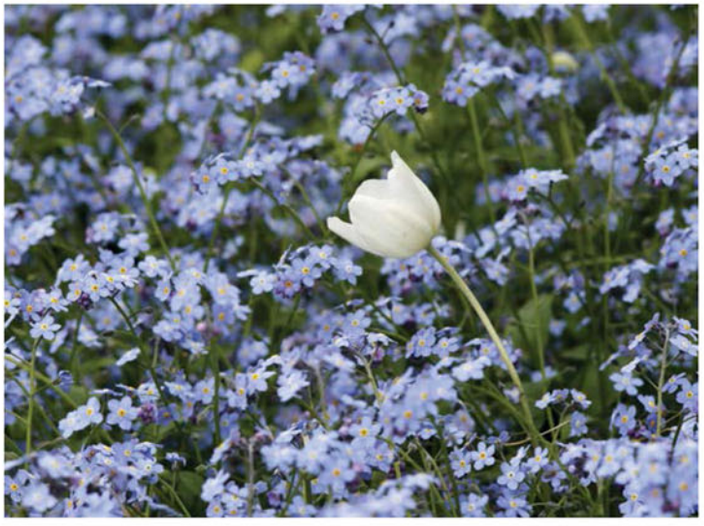
3. Hot water can sometimes freeze quicker than cold water

Observed by scientists as far back as 400 BCE, this uncanny phenomenon is called the Mpemba effect. Several theories attempt to explain it. Concentrations of solutes (which evaporate from hot water) could play a part, or it could be that frost forming on cold water insulates it from further cooling. Convection is also a likely culprit. Inside the freezer, the water touching the container walls cools quicker than water in the centre. This creates convection currents as warmer, less dense water rises. These currents are much stronger in heated water, where the temperature gradient is more extreme, helping it cool faster.

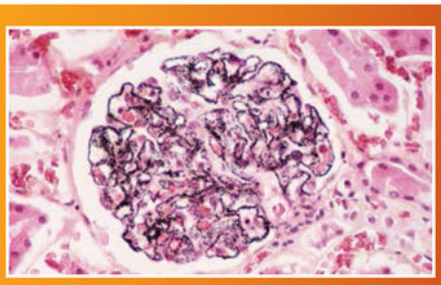
More recent research has implicated that supercooling – the phenomenon in which water doesn't always freeze at 0 degrees Celsius, but continues to cool by several degrees before ice appears – may play a role too. Some believe that initially cold water supercools more than hot water, although why that may be remains to be confirmed.

4. Plants have friends and enemies

Recent studies suggest that plants behave differently depending on who their neighbours are. When surrounded by 'friendly' plants, including genetic relatives or helpful species that limit pests and weeds, they grow slowly, perhaps to share resources. But when they detect a rival such as fennel, which secretes chemicals to inhibit other plants, they grow far more aggressively. Plants recognise these friends and foes thanks to chemical signals emitted from their leaves or roots, and some studies even imply that plants can detect sounds produced by their neighbours. Plants can also alert their fellow flora to attacks from herbivores or parasites. When a tomato plant is attacked by aphids, for instance, it releases volatile chemicals into the air. The plants that pick up on these signals respond by producing their own chemicals to repel the parasites and even attract wasps that prey on aphids. Other species use symbiotic fungi living on their roots as messengers.



"The Turriopsis dohrnii jellyfish has a remarkable life cycle... it could theoretically live for ever"



5. Too much silver can turn skin blue

Argyria is a condition in which skin turns a blue-grey shade, provoked by ingesting silver. Broken down in the stomach, silver enters the bloodstream as a salt and is deposited in the skin. Light oxidises it, producing blue or grey-silver compounds. Sufferers have usually taken colloidal silver supplements – an alternative remedy with no known benefits.

6. Honey has no expiry date

Honey's low moisture content and high acidity create an inhospitable environment for the bacteria and other microbes that cause food to spoil. It also has traces of hydrogen peroxide, an effective antibacterial agent. If exposed to air, though, moisture can get in, so it needs to be kept in a sealed container to last indefinitely.

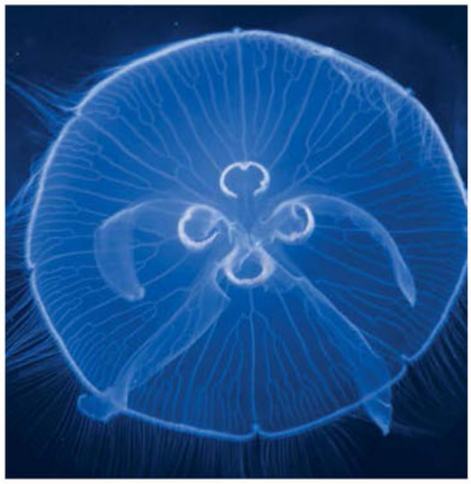
7. Straight hair has more knots than curly

After counting the tangles on hair salon customers' heads, mathematicians found that straight-haired people averaged over five knots, while curly-haired customers had only three. Mathematical models of tangling suggest that although curly hairs brush against each other more often, the angle at which straight hairs meet makes them more likely to become entwined.

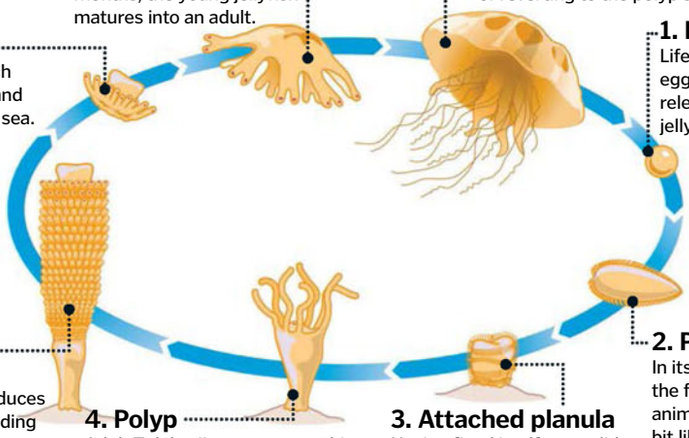
8. The colour of the universe is beige

After adding up the light emitted by 200,000 galaxies, two astrophysicists determined the average colour of universe: a rather bland shade of beige that they nicknamed 'Cosmic Latte'. Ten billion years ago, the universe would have had a pale blue hue, but its colour has shifted with the increasing number of redder stars.

9. Some jellyfish are immortal



The tiny Turritopsis dohrnii jellyfish has a remarkable life cycle: after reaching sexual maturity it can revert back to a juvenile state. There is no apparent limit to how many times it can do this, meaning it could theoretically live for ever. While most T dohrnii die in the conventional manner, in times of crisis they can transform into a polyp state, a process called transdifferentiation. This lets them reproduce asexually to start a new colony. Unique in the animal world, this has helped them spread to oceans across the world.



1. Fertilisation
Life begins when eggs and sperm released by mature jellyfish meet.

2. Planula
In its larval stage, the free-swimming animal is shaped a bit like a miniature flattened pear.

3. Attached planula
Having fixed itself to a solid surface, the planula develops a mouth and tentacles.

4. Polyp
Adult T dohrnii can return to this stage of development through cell transdifferentiation.

5. Budding polyp
The polyp reproduces asexually by dividing in half repeatedly to produce genetically identical copies.

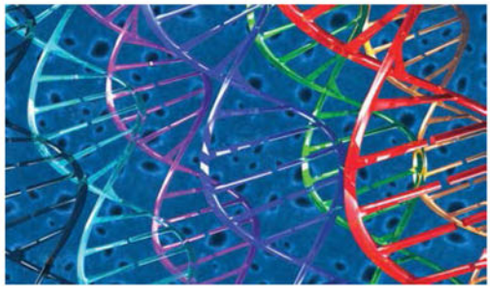
6. Ephyra
Segments detach from the polyp and drift off into the sea.

7. Juvenile
Over a few weeks or months, the young jellyfish matures into an adult.

8. Adult
As it reaches sexual maturity, the T dohrnii jellyfish has the option of reverting to the polyp stage.

10. There is 0.2mg of gold inside us

We absorb small amounts of gold from our environment, but it serves no known purpose. Largely inert, it is non-toxic in small doses. Gold compound sodium aurothiomalate can, however, reduce inflammation in arthritis patients, although its mechanism of action isn't fully understood. Researchers are currently investigating the use of nanoparticles equipped with antibodies which could latch on to cancer cells to help speed up diagnosis.



11. We can have more than one set of DNA

Known as chimerism, this condition can arise when two eggs are fertilised inside the mother. Instead of developing independently to produce non-identical twins, one absorbs the other, taking on its cells and DNA. The outcome is one individual combining cells with two different genotypes. Most chimeras are oblivious to their genetic makeup, but it can create some strange results. Indeed, they may have two blood types or even organs with different genotypes.

RECORD BREAKERS
EGYPTIAN SNACK

3,300yrs

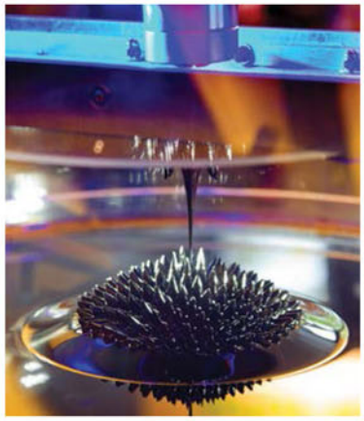
WORLD'S OLDEST EDIBLE HONEY

A jar of honey found in the tomb of Ancient Egyptian pharaoh Tutankhamun is believed to be well over 3,000 years old. And thanks to honey's antimicrobial properties, it's still edible!

DID YOU KNOW? *The water boatman is the loudest creature relative to body size, producing sounds of up to 99dB*

12. A candle flame is full of diamonds

Within a candle's flickering flame, hydrocarbon molecules are converted into carbon dioxide. During this process, the carbon briefly takes the form of diamond nanoparticles. A whopping 1.5 million of these minuscule gems are created every second, but are burnt up almost instantly. Although harvesting these diamonds would be impossible, this recent discovery could lead to new methods for producing cheap jewels. Alongside diamonds, researchers were surprised to find the three other forms of carbon (fullerenic particles, graphitic and amorphous carbon) in the flame.

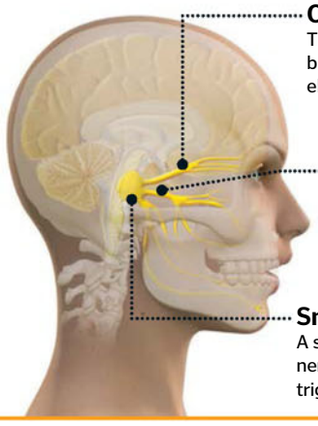


13. Liquids can defy gravity

When cooled down to near absolute zero temperatures, certain substances such as helium become superfluids with zero viscosity, capable of climbing walls or seeping through microscopic cracks. This occurs thanks to a weird quantum effect which makes individual atoms act as one, flouting both gravity and surface tension. Ferrofluid (pictured) is just as mind-blowing; made by suspending tiny magnetic particles of iron in oil, these magnetic liquids form intricate patterns of peaks and troughs when they are placed in a magnetic field.

14. Light can make some people sneeze

In about a quarter of people, sudden exposure to bright light can bring on a sneezing fit known as the photic sneeze reflex. Normal sneezes happen when something irritates the nose lining. This stimulates the trigeminal nerve and the body expels the irritant with a sneeze. The nearby optic nerve, meanwhile, alerts the brain to changes in light levels, to which it responds by constricting or enlarging the pupils. In photic sneezers, a flood of light creates electric signals in the optic nerve sensed by the trigeminal nerve, triggering a sneeze.



Optic nerve
The optic nerve responds to bright light by sending an electric signal to the brain.

Trigeminal nerve
In close proximity, the central branch of the trigeminal nerve detects irritation in the nose.

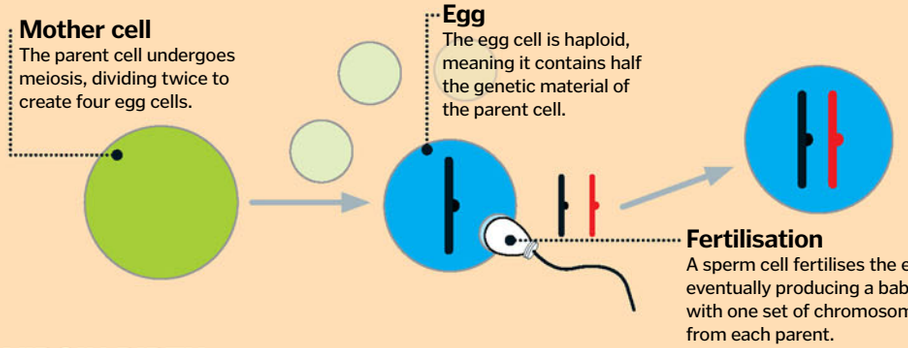
Sneeze
A signal fired through the optic nerve can stimulate a signal in the trigeminal nerve, triggering a sneeze.

15. Virgin births are not a myth

In some species, a female's egg cell can develop into an embryo without being fertilised. This form of asexual reproduction is called parthenogenesis (Greek for 'virgin birth') and occurs in many plants and insects, as well as certain fish and reptiles, including Komodo dragons and hammerhead sharks. Some species reproduce exclusively through parthenogenesis, while others use it as a back-up option when there are no males. In most species, parthenogenesis produces offspring with two identical sets of chromosomes, making them half-clones of their mother.

NORMAL FERTILISATION

Chromosome key Female Male

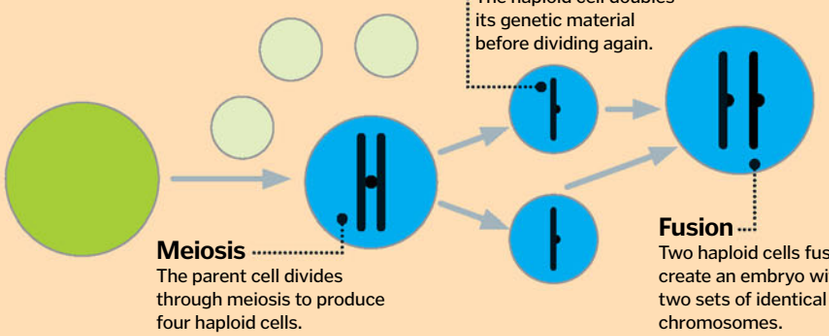


Mother cell
The parent cell undergoes meiosis, dividing twice to create four egg cells.

Egg
The egg cell is haploid, meaning it contains half the genetic material of the parent cell.

Fertilisation
A sperm cell fertilises the egg, eventually producing a baby with one set of chromosomes from each parent.

VIRGIN BIRTH (PARTHENOGENESIS)



Division
The haploid cell doubles its genetic material before dividing again.

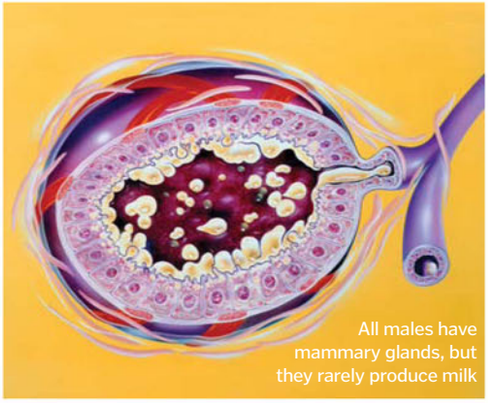
Meiosis
The parent cell divides through meiosis to produce four haploid cells.

Fusion
Two haploid cells fuse to create an embryo with two sets of identical chromosomes.

"Although they originate from the same fertilised egg, identical twins carry small differences in their genes"

16. Men can lactate too

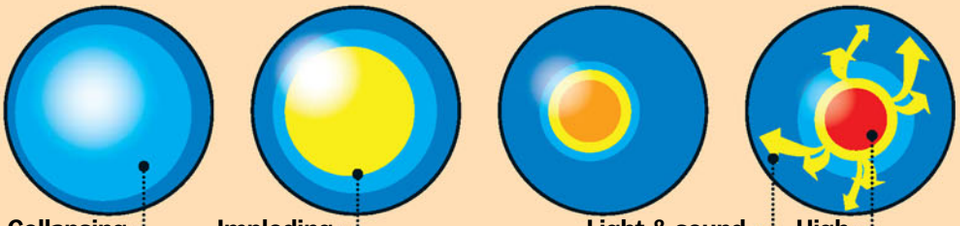
Male mammals possess mammary glands and can produce milk, although this is rare. Certain disorders involving the pituitary gland, for example, cause it to produce prolactin, which stimulates milk production. The Dayak fruit bat is the only species in which male lactation is widespread. It's unclear whether they actually breast feed or if milk production is a side-effect of a diet rich in phytoestrogens – plant molecules that mimic female hormones.



All males have mammary glands, but they rarely produce milk

17. Pistol shrimp snap their claws louder than Concorde

The diminutive pistol shrimp can snap one of its claws so hard that it tears water apart, creating a high-pressure bubble of gas called a cavitation bubble. As it collapses, the bubble creates a deafening pop as loud as 218 decibels, lasting for just one millisecond. Just before it bursts, the temperature inside the bubble soars to 4,700 degrees Celsius (8,500 degrees Fahrenheit), creating an intense flash of light (see diagram below). The shrimp uses this trick to stun prey.



This map shows how the magnetic north pole has moved over time due to secular variation (ie drift)

18. There is more than one north pole

True (or geodetic) north is a fixed point, located where the Earth's axis of rotation meets the planet's surface, diametrically opposite the south pole. However if you look at a compass needle, it doesn't point to the north pole, but rather to a place a few hundred kilometres south-east: magnetic north. Earth acts like a giant magnet, and the magnetic north is one of its poles. The planet's magnetic field is created by churning molten iron in the planet's outer core. As these currents change, so does the location of the magnetic north pole, which is currently wandering at a speed of about 55 kilometres (34 miles) a year. After drifting through northern Canada, magnetic north is now heading towards Siberia. More dramatic changes could, however, be afoot. In the past, Earth's magnetic poles have switched places every 500,000 years. The reason behind these flips is unknown, but geophysicists predict that the next one could be coming up in a few thousand years.

19. Identical twins are not identical

Although they originate from the same fertilised egg, identical twins still carry small differences in their genes. Examining twin genomes closely, researchers found variations in the numbers of copies of a given gene, possibly caused by mutations during early development. This variation could explain why sometimes one twin develops a genetic disorder while the other is spared.

1 Fertilisation
A sperm cell fertilises an egg, producing a cell called a zygote which combines the parent cells' DNA.

2 Zygote
The zygote soon divides to form a small bunch of cells called a blastocyst.

3 Split
The blastocyst can split into two between one and nine days after fertilisation.

4 Mutations
As the foetuses develop, 'copy errors' in cell division create small variations in the twins' genetic material.

DID YOU KNOW? *The magnetic north pole has drifted approximately 1,100 kilometres (684 miles) over the last 150 years*

20. The faster you move, the heavier you get

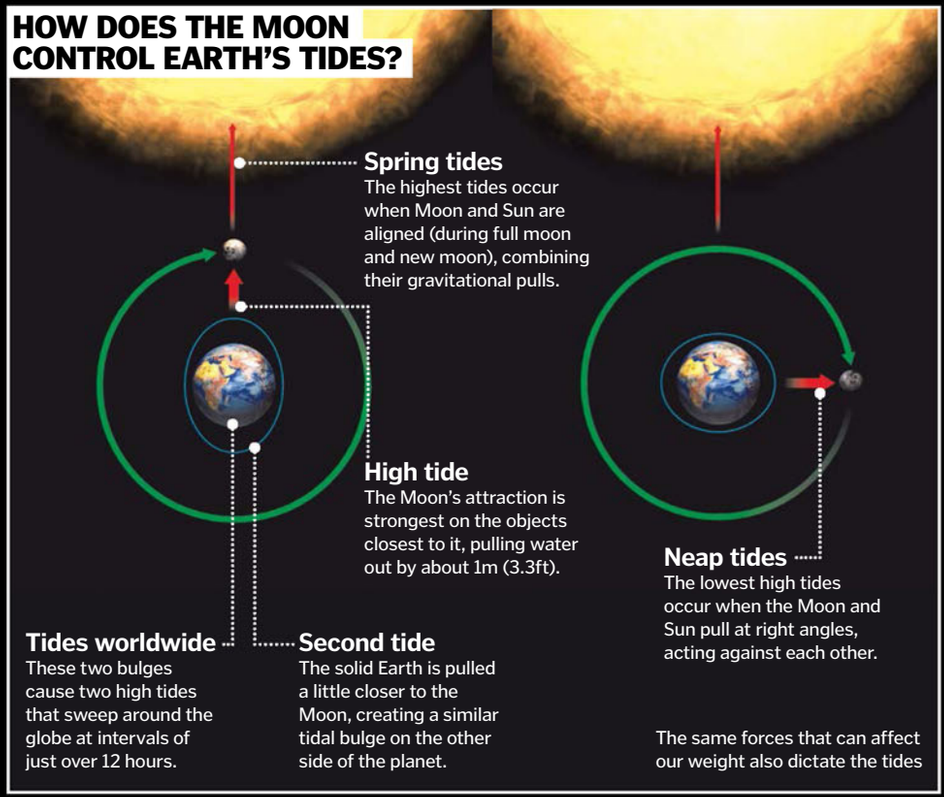
Einstein discovered this with his theory of special relativity. As an object picks up speed it gains kinetic energy, which causes its mass to increase, as described by his famous $E=mc^2$ equation. At the speeds humans travel at the change in mass goes unnoticed, but as an object comes close to the speed of light the effect is undeniable. Particle accelerators like the Large Hadron Collider propelling protons at almost the speed of light, for instance, need to take their increased mass into account. One consequence of this is that no object can travel at the speed of light – the faster it gets, the more mass it acquires and the more energy it needs. In other words, you'd need infinite energy to push it to light speed.

When travelling at high speeds, you become noticeably heavier

21. We weigh less when the Moon is overhead

What we call weight is the downward force resulting from Earth's gravitational pull on our mass. But Earth isn't the only one pulling us towards it. The Moon also exerts a force on us, cancelling out some of Earth's attraction when it is directly overhead. Being much smaller and also farther away from us, the Moon's magnetic field is much weaker, meaning the effect is almost imperceptible: ie a 100-kilogram (220-pound) person would weigh just 0.5 grams (0.02 ounces) less. Conversely, when the Moon is on the opposite side of Earth to you, you weigh a fraction more.

HOW DOES THE MOON CONTROL EARTH'S TIDES?



The same forces that can affect our weight also dictate the tides

22. A mobile phone has more computing power than used on the Apollo missions

The Apollo guidance system that successfully landed man on the Moon had just 64 kilobytes of memory and operated at 0.043 megahertz. Modern-day smartphones, meanwhile, average one to two gigahertz, meaning that they are around 40,000 times faster.

23. There are more molecules in a cup of water than cups of water in the oceans

Earth's oceans contain approximately 1.3 billion cubic kilometres (312 million cubic miles) of water, which equates to 5.2×10^{21} 250-millilitre cups. A cup of water, meanwhile, contains a jaw-dropping 8.4×10^{24} H_2O molecules – that's over 1,000 times more molecules than cups!

24. NASA has a building so big that it can rain inside

NASA's Vehicle Assembly Building's vast interior extends over a whopping 3,665,000 cubic metres (129,428,000 cubic feet). On humid days, it can accumulate enough moisture to form clouds – although in practice 125 ventilators keep humidity levels in check.

25. A single-celled organism can be up to 20cm across

Syringammina fragilissima's one cell branches out into a network of tubes extending over ten centimetres (3.9 inches). As it grows, the deep sea-dwelling creature oozes slime onto the sediment, solidifying its structure.

"Launched in the Philippines in 2011, the project has brought solar bottle bulbs to 140,000 homes in the country"

Bottling light

Solar bottle bulbs are brightening up thousands of homes in the developing world, but how do they work?

Invented by Brazilian mechanic Alfredo Moser and developed with a little help from MIT students, a solar bottle bulb (or Moser lamp) is simply a soda bottle filled with chlorinated water, fitted into a roof. Refracting and reflecting sunlight downwards during the day, it lights up homes far more effectively than a skylight. Adding a few drops of bleach to the water ensures that it stays clean and free of germs for years. When sunlight meets the water in the bottle it slows down, bending (that is, refracting) downwards. Depending on its angle, some of this light is channelled straight into the room below while some rays hit the opposite side of the bottle and are reflected back in.

This phenomenon, known as total internal reflection, causes light to bounce back and forth inside the bottle until its angle is great enough for it to escape. As light exits the bottle at various directions, it illuminates the home just like an electric light bulb of about 60 watts.

Total internal reflection can be used as a cheap and sustainable light source

What is the Liter of Light project?

The Liter of Light project, initiated by non-profit organisation MyShelter Foundation, aims to bring this sustainable, cheap, but life-changing technology to deprived communities across the world. Living in shantytowns where tightly packed dwellings let in very little natural light, many people are forced to live in near-complete darkness both day and night. Launched in the Philippines in 2011, the project has brought solar bottle bulbs to 140,000 homes in the country.

Creating an effective light bulb out of a soda bottle is surprisingly simple

Making a bottle of light step-by-step

1. Materials
First you need a 1.5-litre PET plastic bottle, a piece of corrugated iron, some rubber sealant, filtered water and bleach. You'll also need cutters to slice through the iron sheeting, sandpaper, a drill and rivets to fix the bottle. This is an adult-only project.

2. Cut
Trace two concentric circles onto the iron sheet: one with the same diameter as the bottle and one a centimetre (0.04 inches) smaller. Cut out the inner circle then make small incisions radiating out. The resulting strips will provide a snug fit for the bottle.

3. Stick
Sandpaper the upper third of the soda bottle to give the sealant a better grip. Then slide the bottle into the corrugated iron so that the smooth upper third sticks out at the very top. Glue firmly into place using the sealant and allow time to dry completely.

4. Fill
Fill the bottle with water, adding 10 millilitres of bleach before screwing on the cap. Mixed with water, the chlorine in bleach forms hypochlorous acid (HOCl). Breaching micro-organisms' cell walls, this damages cell proteins and prevents murky water.

5. Install
Cut a hole in the roof just slightly larger than the bottle's diameter and apply sealant. Push the base of the bottle through and make sure it is firmly in place. Drill holes into the roof on each side of the bulb and secure with rivets. Apply sealant to avoid leaks.

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"Some plants can produce pheromones that alter insect behaviour"

What are pheromones?

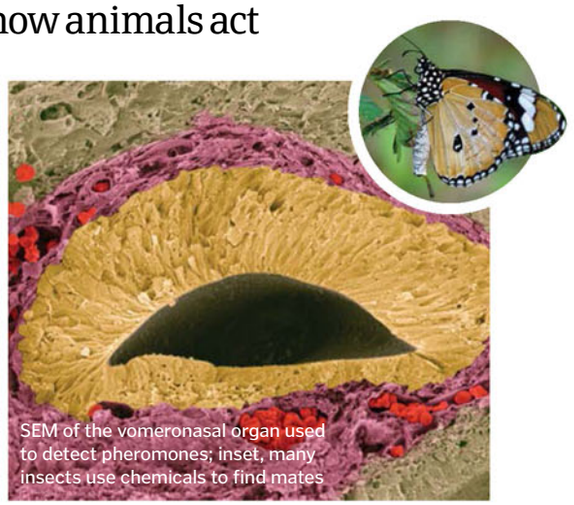
The science behind the chemicals which have a big effect on how animals act

Pheromones are a means of chemical communication between animals, allowing ants to form orderly lines in search of food, tigers to mark their territory and newborn rabbits to find their mother for milk.

Insects have multiple sense organs located on their antennae, while many animals have a specialist organ in the nose that is known as the vomeronasal organ (VNO). The VNO is linked by nerves to the hypothalamus – the region of the brain connecting the nervous system to the endocrine (hormone) system. Incoming signals can potentially affect a range of behaviours and physiologies, from aggression to reproduction.

Plants also use pheromones. For example, when an antelope eats the leaves of an acacia tree, it releases ethylene. This chemical alarm signal is effective for up to 45 metres (150 feet), and causes surrounding acacia trees to produce bitter-tasting tannin to discourage the antelope from grazing more. Some plants can also produce pheromones that alter insect behaviour.

Whether or not humans are sensitive to pheromones is debated. We don't always have a VNO, and our gene coding for the receptors look inactive. Still, in some animals normal nasal tissue can also detect pheromones, so there is a chance that humans might too.



SEM of the vomeronasal organ used to detect pheromones; inset, many insects use chemicals to find mates

What are pheromones used for in nature?

Raising the alarm
When certain species of insect or plant are under attack, they release alarm pheromones, alerting other members of their species to the danger. All individuals collectively respond to the alarm, either fleeing or mounting a unified defence.

Marking territory
Many animals use pheromones to mark the boundaries of their territory – a familiar trait of dogs. Some insects also use pheromones to signpost the location of their eggs, to prevent other females from laying in the same place.

Leaving a trail
A pheromone trail is the invisible road that guides ants. As more ants travel along the route, they add their own pheromones. Foraging ants will also leave trails to food but stop as the source is depleted, so the scent dissipates.

Recruitment
Bees scour large territories to find nectar, so in order to ensure they return to the hive, workers secrete a pheromone to direct them home. This powerful chemical messenger also attracts lone bees to join the colony as they fly past.

Finding a mate
Pheromones can be used to bring individuals together, whether for mating, defence or migration. Females often release pheromones to signal fertility, eg the female silkworm moth can lure a mate from up to 48 kilometres (30 miles) away!

Eczema explained

What causes the skin to react to otherwise harmless material?

Eczema is a broad term for a range of skin conditions, but the most common form is atopic dermatitis. People with this condition have very reactive skin, which mounts an inflammatory response when in contact with irritants and allergens. Mast cells release histamine, which can lead to itching and scratching, forming sores open to infection.

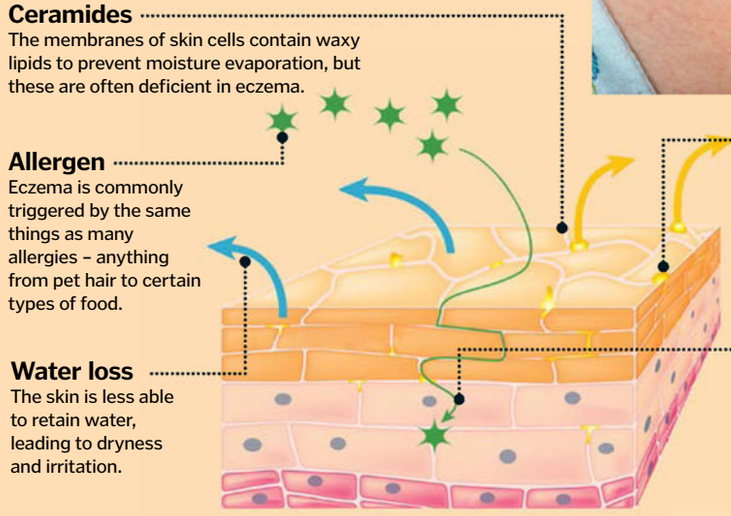
There is thought to be a genetic element to the disease and a gene involved in retaining water in the skin has been identified as a potential contributor, but there are many factors.

Eczema can be treated with steroids, which suppress immune system activity, dampening the inflammation so skin can heal. In serious cases, immunosuppressant drugs – used to prevent transplant rejection – can be used to weaken the immune system so it no longer causes inflammation in the skin.

The histamine increase can cause itching, leading to open sores

Under the skin

What happens inside the body when eczema flares up?



Ceramides
The membranes of skin cells contain waxy lipids to prevent moisture evaporation, but these are often deficient in eczema.

Allergen
Eczema is commonly triggered by the same things as many allergies – anything from pet hair to certain types of food.

Water loss
The skin is less able to retain water, leading to dryness and irritation.

Allergen entry route
The cells of the skin are normally tightly bound together to prevent contaminants from entering the body, but in eczema there are gaps.

Inflammatory response
The immune system produces a response to allergens beneath the skin, leading to redness, itching and inflammation.

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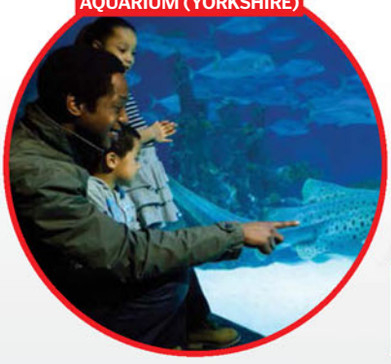

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"Atom smashers will continue to yield vital clues into the universe's most puzzling mysteries"

Smashing atoms

Slamming together tiny particles can uncover our universe's biggest secrets

High-energy particle collisions are a window into the subatomic world. Creating them, however, requires some of the most complex technology on the planet. First, particle accelerators use electric fields to boost charged particles to almost the speed of light, ramping up their kinetic energy. In a circular collider like the Large Hadron Collider (LHC), magnets steer and focus these particles into two beams no more than two millimetres (0.08 inches) wide, travelling in opposite directions. At designated points in the heart of particle detectors, the beams cross to produce head-on collisions.

As predicted by Einstein's famous $E=mc^2$, under the right conditions, mass can be transformed into energy and vice versa. And this is exactly what happens when two particles crash together. The colliding particles break in to their smallest subatomic constituents, shooting in all directions. As well as the usual suspects, some of these creations are rare, exotic particles whose very existence exposes the inner workings of our universe.

Short-lived particles such as the Higgs boson rapidly decay into other types. To determine their presence, physicists analyse the particles produced by each collision, looking for tell-tale signs. This work is accomplished thanks to advanced detectors, which identify various species of particle and record their speeds, energies and trajectories.

Particle research has shaped modern physics, providing evidence for current theories on what the universe is made of as well as the laws that govern it. In the last 50 years, colliders have glimpsed scores of previously unseen inhabitants of the subatomic world, from quarks – matter's fundamental building blocks – to the more recent famous Higgs boson.

But such discoveries are merely the tip of the iceberg. In the decades to come, atom smashers will continue to yield vital clues into the universe's most puzzling mysteries, from unmasking dark matter to perhaps revealing extra dimensions of space.

Know your particle machines

Particle physicists pick and mix different types of accelerators and colliders to do their research. Linear accelerators push particles in a straight line, whereas cyclotrons and synchrotrons set them whizzing around a circular path, building up top speeds by giving particles an extra nudge with each successive lap. Synchrotron light sources, meanwhile, take advantage of the electromagnetic radiation emitted by particles coursing around a synchrotron. Focusing this high-intensity light into a narrow beam, they can probe the molecular structure of anything from new drugs to historic paintings.

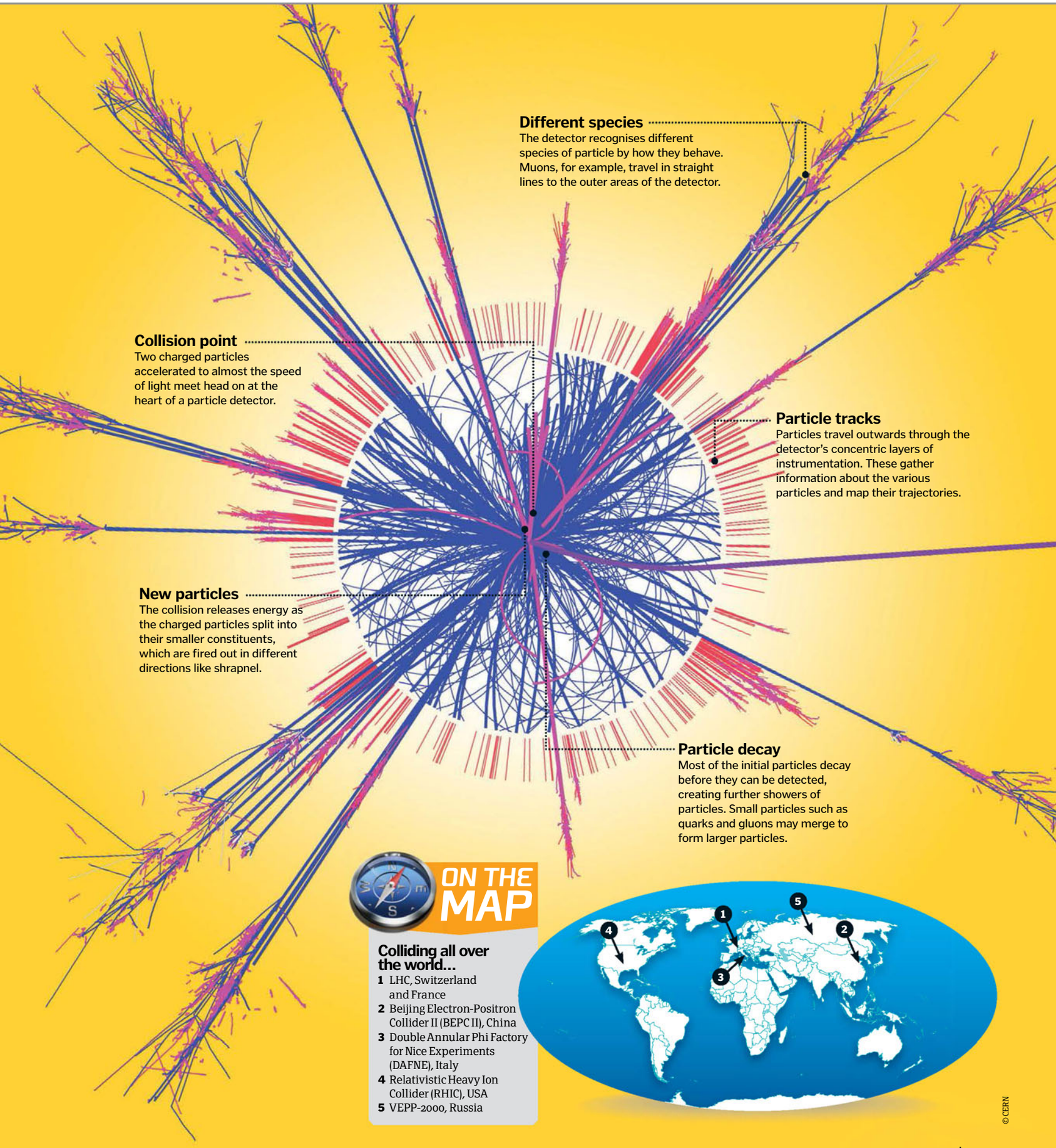
The LHC is currently shut for upgrades and is due to reopen in early-2015

75mn GB

THE LHC'S ENORMOUS DATA BANK

In the past three years, CERN has recorded 75 million gigabytes (75 petabytes) of data on the Large Hadron Collider's particle collisions. That's roughly equivalent to 525 years' worth of HD-quality films.

DID YOU KNOW? *Protons at full energy in the LHC complete over 11,000 laps of its 27km (16.7mi) ring per second*



Different species

The detector recognises different species of particle by how they behave. Muons, for example, travel in straight lines to the outer areas of the detector.

Collision point

Two charged particles accelerated to almost the speed of light meet head on at the heart of a particle detector.

Particle tracks

Particles travel outwards through the detector's concentric layers of instrumentation. These gather information about the various particles and map their trajectories.

New particles

The collision releases energy as the charged particles split into their smaller constituents, which are fired out in different directions like shrapnel.

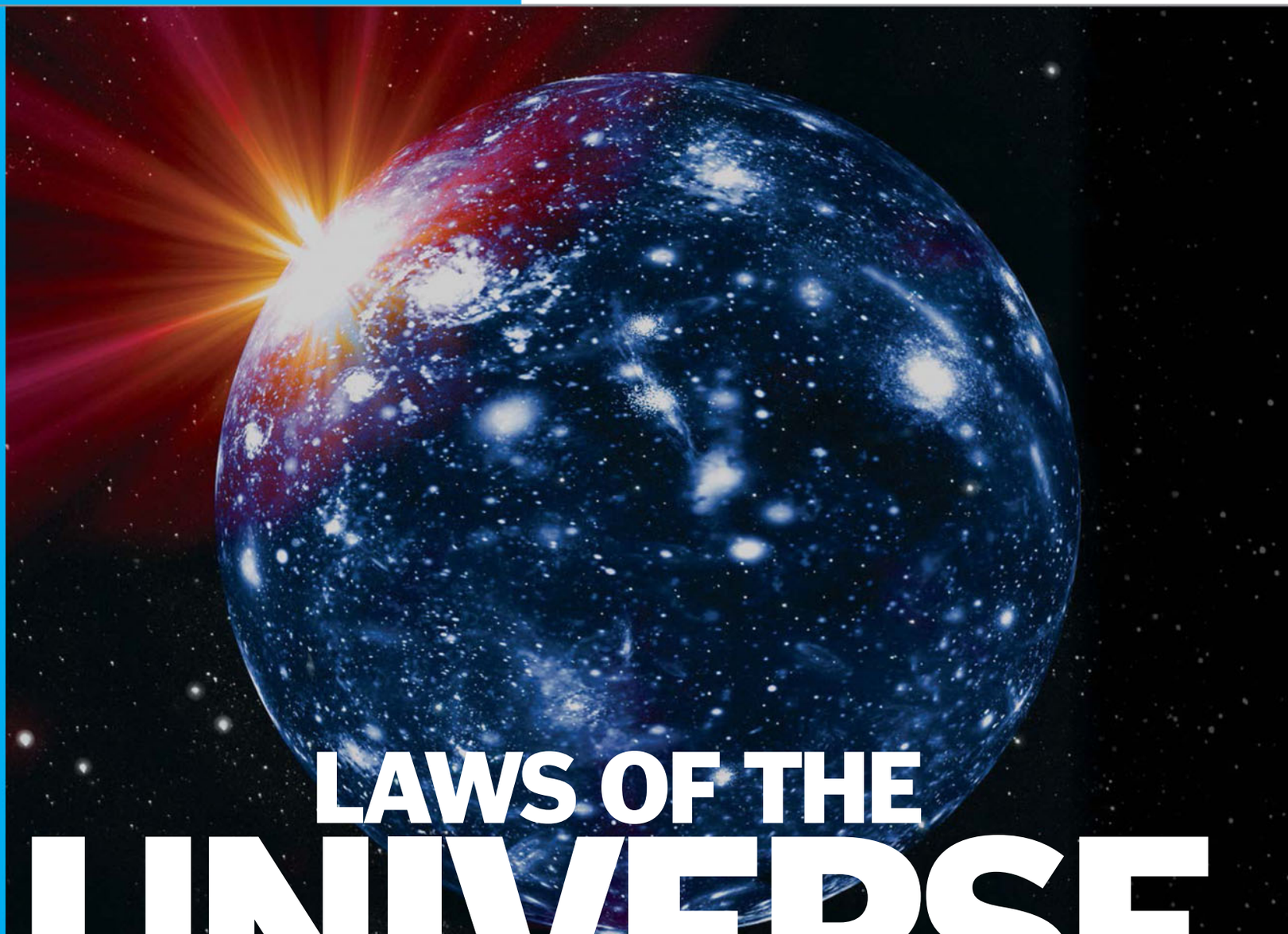
Particle decay

Most of the initial particles decay before they can be detected, creating further showers of particles. Small particles such as quarks and gluons may merge to form larger particles.

ON THE MAP

Colliding all over the world...

1. LHC, Switzerland and France
2. Beijing Electron-Positron Collider II (BEPC II), China
3. Double Annular Phi Factory for Nice Experiments (DAFNE), Italy
4. Relativistic Heavy Ion Collider (RHIC), USA
5. VEPP-2000, Russia



LAWS OF THE UNIVERSE

Learn about the amazingly universal physics which governs the history, present and future of the cosmos

From the intricate behaviour of subatomic particles to the gravitational dance of the largest galaxy clusters, our universe displays amazing, infinite complexity. Yet at heart it relies on just a small number of fundamental laws. Evidence points to just four forces – gravitation, electromagnetism, plus the weak and strong nuclear forces – governing every kind of interaction between matter. In effect, the large-scale universe is even simpler than that – the nuclear forces, as their name suggests, only make their influence felt over the tiny distances within atoms, while the infinite range of electromagnetism and gravity arguably make them the dominant powers.

All these laws, however, are required to make the cosmos behave in the way that we observe, and there's a good chance that if they, or the 'universal constants' that govern their influence, were just slightly different, the universe as we know it might not be here at all.

The laws that govern the universe have been gradually uncovered over several centuries. The effects of gravitation were first noted academically in the early-17th century, and the more fundamental laws that govern them towards the end of that century. The 19th century brought an improved understanding of energy and electromagnetism, while the 20th century revealed the quantum laws that govern atoms themselves, and transformed our understanding of gravity once again. ▶

5 TOP FACTS
UNIVERSAL LAWS

1 Orbits and beyond
While Kepler's laws define only the properties of objects in elliptical orbits, Newton's laws describe all forms of motion, and so are far more widely applicable.

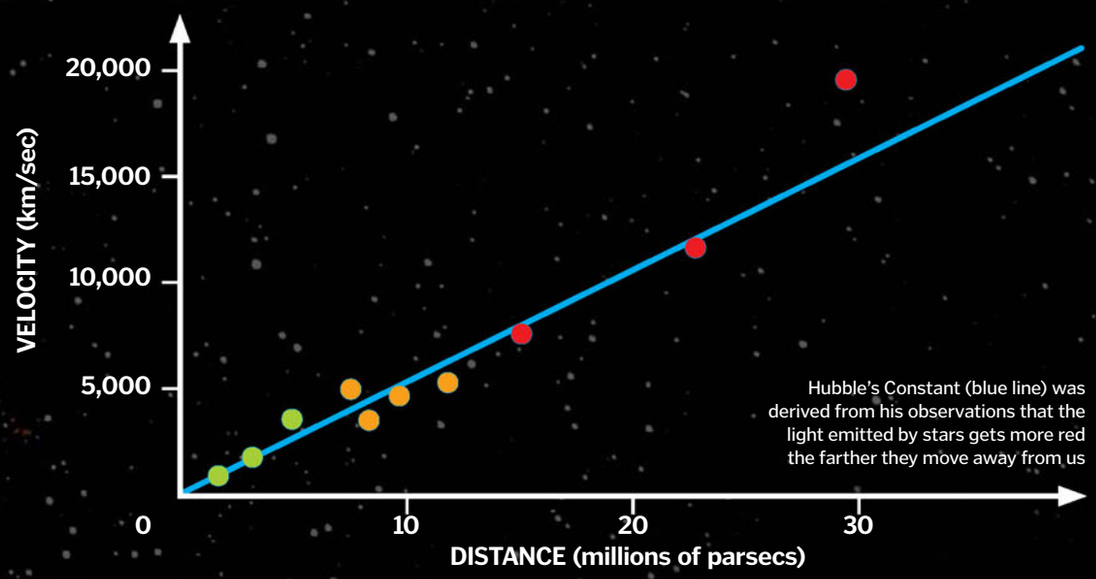
2 Slow burn out
The laws of thermodynamics predict that the universe will get more disorderly, and its energy thinly spread, as it gets older. It will slowly cool in a process called 'heat death'.

3 Special and general
Einstein's special theory of relativity addresses only the physics of high-speed motion, while his general theory looks at wider laws of the universe as a whole.

4 Quantum revolution
Quantum theory predicts that light and matter both show wave and particle-like properties, but no phenomenon will reveal both at the same time.

5 A matter of spin
The Standard Model of particle physics separates particles into fermions or bosons depending on 'spin' – a form of intrinsic angular momentum.

DID YOU KNOW? *The Big Bang theory predicts the development of the cosmos back to 10^{-43} seconds after its creation*



Hubble's Constant (blue line) was derived from his observations that the light emitted by stars gets more red the farther they move away from us

Cosmic expansion

In the mid-Twenties, astronomer Edwin Hubble used the behaviour of distant flickering variable stars to prove the 'spiral nebulas' in the sky were, in fact, galaxies millions of light years beyond our own. He went on to make an even more fundamental discovery. Light from many spiral nebulas was already known to be 'red shifted' – elongated in wavelength and shifted towards the red end of the spectrum due to the same Doppler effect that affects the pitch of a passing emergency siren. Hubble found that the farther away a distant galaxy was, the greater the red shift in its light. The only way to explain this was if the universe itself was expanding rapidly and dragging the galaxies apart.

Big Bang theory

Evidence including the expansion of the cosmos and an omnipresent 'afterglow' of radiation shows that the universe was created in an enormous explosion some 13.8 billion years ago. In the first moments of creation, the concentration of energy was so intense that the universe's fundamental forces acted as a single unified force – and indeed many cosmologists suspect that the separation of the forces helped drive a violent period of expansion known as inflation. Since that time, the cosmos has steadily expanded and cooled. For the first 380,000 years, the universe remained so dense and opaque that it was largely governed by electromagnetic interactions as light bounced back and forth between particles. Thereafter, the universe rapidly became transparent, and since then gravity has been the key factor that has shaped the cosmos.

KEY PLAYER
Edwin Hubble

US astronomer Edwin Hubble (1889-1953) used Cepheid variable stars to measure the distance to remote galaxies and prove they lay far beyond the Milky Way. He also devised a scheme for galaxy classification, and showed that the universe as a whole is expanding, paving the way for the Big Bang theory.

Evolution of the cosmos

Various forces and laws have made their influence felt at different points in the universe's long history...

1 Big Bang
The universe sprang into existence in a cataclysmic explosion some 13.8 billion years ago.

2 Matter and energy
In the intensely hot conditions of the new universe, mass and energy were interchangeable, with particles of matter continually popping in and out of existence.

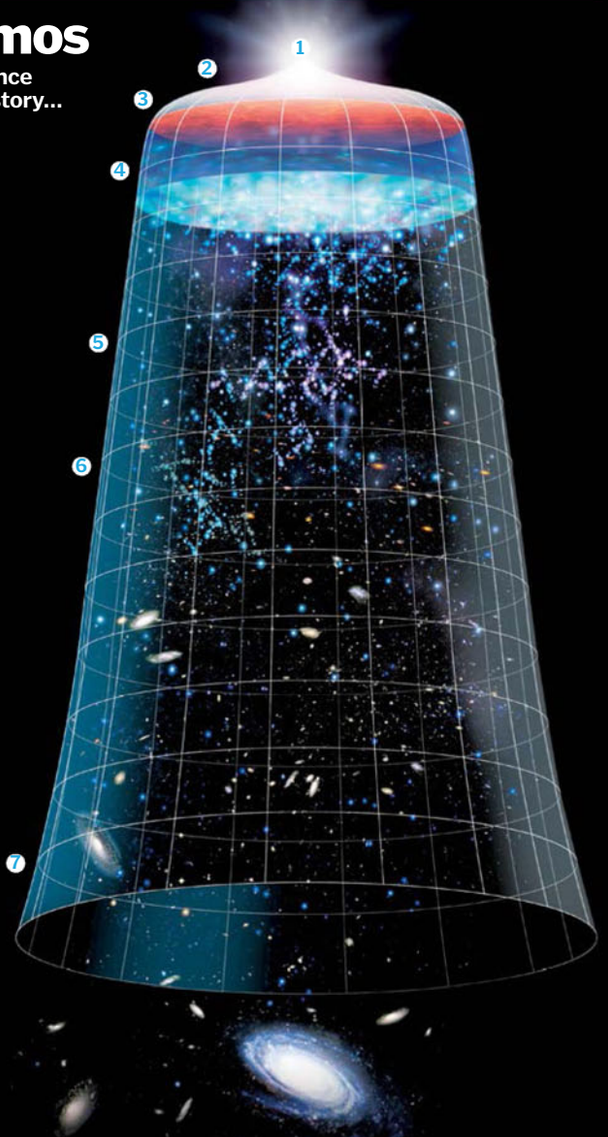
3 Inflation
Shortly after the initial explosion, separation of the four fundamental forces drove a brief period of sudden expansion and cooling known as inflation.

4 Radiation era
For some 380,000 years, the universe was opaque, and electromagnetic interactions governed the behaviour of visible matter.

5 Matter era
Once the cosmos became transparent, matter began to collapse as a result of gravity.

6 First stars
After around 300 million years, the first stars began to develop from collapsing gas clouds, transforming the lightweight elements created in the Big Bang into heavier ones.

7 The universe today
Today, the expansion of the universe continues on a grand scale, and is even accelerating thanks to the influence of mysterious dark energy.



"Newton showed that planetary orbits were just one manifestation of more fundamental laws of motion"

KEY PLAYER

Johannes Kepler

Kepler (1571-1630) was a student of the astronomer Tycho Brahe, and used his observations of planetary motions to form his revolutionary theory of elliptical planetary orbits. Despite being remembered as a scientific pioneer, he was also a keen astrologer.

Kepler's laws decoded

Three laws of planetary motion describe the movement of planets or any object in orbit around another under the influence of gravity

KEY

- Law 1: Law of ellipses
- Law 2: Law of equal areas
- Law 3: Law of harmonies

Shorter orbit
Objects close to the Sun have short periods not only because their orbits are themselves shorter, but also because they move more rapidly along them.

Solar focus
The object being orbited – in this case the Sun – sits at one of two focus points along the ellipse's long 'major' axis.

Perihelion
When the planet is at its closest point to the Sun, it moves fast and sweeps out a broad, short triangle.

Equal areas rule
Kepler's second law states that a triangle connecting points on the orbit to the focus sweeps out equal areas in equal times.

Elliptical orbit
According to Kepler's first law, one object in orbit around another follows an elliptical path. Circular orbits are just a special type of ellipse.

The first great physical laws to be discovered were those governing planetary motion. In the early-16th century, Nicolaus Copernicus had been the first modern astronomer to suggest the planets orbited the Sun, and evidence to support this radical idea had mounted through the century. But one of the essential jobs for any good theory of the planets was that it should predict their motion and positions, and this was where the Copernican theory fell down, offering little more accuracy than the old Earth-centred theory of the universe.

In 1609, German astronomer Johannes Kepler made a daring conceptual leap. Earlier generations of stargazers had been wedded to the idea of 'perfect' circular motion, but Kepler suggested that instead, the planets followed elliptical paths – ovals stretched along one axis, with the Sun at one of two focus points.

The resulting laws of planetary motion proved successful, but the underlying force behind them wasn't described until 1687, when Isaac Newton published his *Mathematical Principles Of Natural Philosophy*. Here, Newton showed that planetary orbits were just one manifestation of more fundamental laws of motion: that an object will continue in a state of rest or motion in a straight line unless acted on by a force; that the acceleration (a) experienced by a body of mass (m) under the influence of a force (F) is given by the simple equation a = F/m; and that when one body exerts a force on a second, it experiences an equal and opposite force. Newton argued that even when objects were not in physical contact, they could influence each other through gravity. He argued that the same force which causes objects to fall to the ground on Earth extends into space in accordance with universal gravitation, and that its influence can be infinite, making gravity the governing force shaping the large-scale universe.

From planets to galaxies...

Newton's laws of motion and gravitation can extend beyond our Solar System to describe the structure of galaxies, and even their large-scale movement. In a spiral galaxy, stars orbiting in the outer disc are affected by the same rules as planets, so in general they move more slowly at greater distances from the centre – a phenomenon called differential rotation that means galaxies don't spin like solid objects.

Galaxies are also affected by the gravity of their neighbours, often concentrating in loose groups or denser clusters. Sometimes, however, galactic rotation and cluster dynamics fail to match the behaviour we might expect from visible matter, and this is a major clue indicating the existence of unseen 'dark matter' that is both invisible and transparent, making its presence felt only through its gravity.

KEY DATES
SPACE PHYSICS

1609
Johannes Kepler publishes his *Astronomia Nova*, putting forward his first two laws of planetary motion.

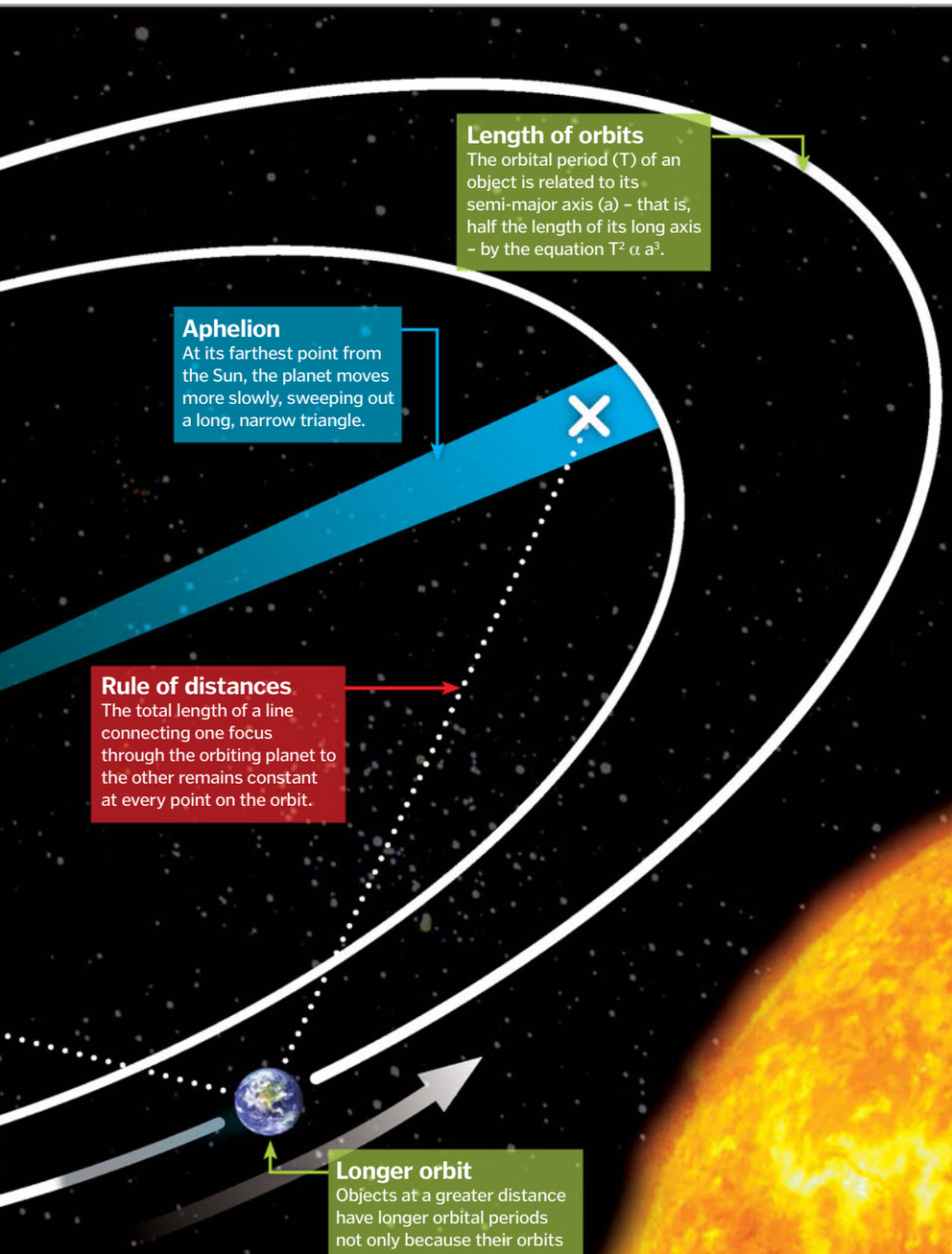
1687
Isaac Newton develops Kepler's laws into general laws describing all forms of motion and gravity.

1900
Max Planck suggests that light is packaged in tiny but distinct packets of energy called quanta.

1916
Einstein publishes his general theory of relativity, explaining gravity as a distortion of space and time.

1924
Louis de Broglie suggests matter may display wavelike properties – the beginning of the field of quantum mechanics.

DID YOU KNOW? *Despite Newton's laws, physicists still struggle to predict results when three or more bodies are involved*



Length of orbits
The orbital period (T) of an object is related to its semi-major axis (a) – that is, half the length of its long axis – by the equation $T^2 \propto a^3$.

Aphelion
At its farthest point from the Sun, the planet moves more slowly, sweeping out a long, narrow triangle.

Rule of distances
The total length of a line connecting one focus through the orbiting planet to the other remains constant at every point on the orbit.

Longer orbit
Objects at a greater distance have longer orbital periods not only because their orbits are longer, but also because they move more slowly through space.

Thermodynamics: the rules of heat and energy

The science of thermodynamics studies the properties of heat and how it can be transferred. Temperature is, in essence, the random motion of particles within matter, and heat is the flow of energy by which this motion is transferred from one object to another. So stellar interiors can be modelled in terms of the different processes – conduction, convection and radiation – that transfer energy through them. Several important laws, largely developed in the 19th century, define the behaviour of thermodynamic systems, but the most important for cosmologists is the second law, which states that the entropy of a closed system (a measure of its disorganisation and the way heat energy is evenly spread across it) inevitably increases. Since in thermodynamic terms the universe is a closed system, this means that its entropy too will inevitably increase; in other words, heat will eventually become evenly spread out, dooming the cosmos to a long, cold death unless other factors intervene beforehand.

KEY PLAYER
Isaac Newton

Mathematician and physicist Isaac Newton (1643-1727) devised the laws of motion and universal gravitation and the maths of calculus. He also contributed to the study of optics, building the first practical reflecting telescope and showing that white light consisted of many colours.

"Einstein's theory of relativity recast gravity as a distortion in the fabric of four-dimensional space-time"

While the 18th and 19th centuries saw important developments in the theories of heat and energy (like thermodynamics), the early-20th century saw twin revolutions in the science of the very large and the very small. Albert Einstein's general theory of relativity, published in 1915, recast gravity as a distortion in the fabric of a four-dimensional 'space-time', created by large concentrations of mass.

It described and predicted phenomena that couldn't be accounted for by Newtonian gravity alone, such as gravitational lensing (the way that beams of light, which have no mass and therefore should be immune to the influence of gravity, are deflected when they pass close to massive objects). Meanwhile, Edwin Hubble's key observations proved that the universe as a whole is expanding, pointing to a much denser, hotter origin in the distant past: the Big Bang.

Einstein also played a key role in the formation of quantum theory – the idea that on the smallest scales, all phenomena display simultaneously wave-like and particle-like characteristics, and that matter and energy are interchangeable. First posed by Max Planck in 1900, and subsequently developed in the Twenties and Thirties by figures such as Louis de Broglie, Niels Bohr and Werner Heisenberg, quantum physics has provided the key to unlocking both the nature of light and other electromagnetic radiation and the structure of matter itself. The unpredictable nature of quantum-scale system helps to explain phenomena such as radioactive decay, but also poses some troubling philosophical questions.

Building on the success of quantum theory, physics in the late-20th century got to grips with the way forces work on the quantum scale, successfully developing 'gauge theories' that show how electromagnetism and the weak and strong nuclear forces are transmitted through the exchange of messenger particles called bosons between susceptible particles of matter. Based on this Standard Model of particle physics, and ideas such as the equivalence of mass and energy (embodied in Einstein's famous equation $E=mc^2$), cosmologists have been able to show how the energy released in the Big Bang could give rise to the raw materials that make up the universe.

Today, theoretical physicists are largely concerned with the pursuit to unify the fundamental forces of the cosmos in a simplified single model. But although these efforts have shown some positive results, a 'Theory of Everything' which describes all the laws of the universe in a neat unified equation remain some way off realisation.

KEY PLAYER

Albert Einstein

Physicist Albert Einstein (1879-1955) shaped 20th-century physics more than any other. His special and general theories of relativity revealed the interchangeability of mass and energy and the true natures of space, time and gravity. He also played a major role in developing quantum theory.

The nature of space-time

According to general relativity, our perceptions of space and time are aspects of a single four-dimensional space-time...

Pinched or warped?
In three dimensions, we might imagine that space-time is, in fact, 'pinched in' around large masses, a little like the waist of an hourglass.

Gravitational well
Distorted space-time around the larger object creates a 'well'. Objects in orbit roll around the edge of this well at a distance determined by their speed.

Flat space
Space-time is only flat and uniform in regions that are far away from any mass or gravitational influence.

Smaller distortion
Smaller masses such as the Moon create smaller dents in the 'sheet' of space-time.

Distorting mass
Large masses such as the Earth distort space-time around them, warping it in a way that we perceive as gravity.

Depicting space-time
One common way of visualising the true nature of space-time is to depict space as a two-dimensional 'rubber sheet'.

AMAZING VIDEO!

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An amazing simulation of gravitational lensing

www.howitworksdaily.com

DID YOU KNOW? *Since 1986, astronomers have found evidence that there may be a possible fifth fundamental force*

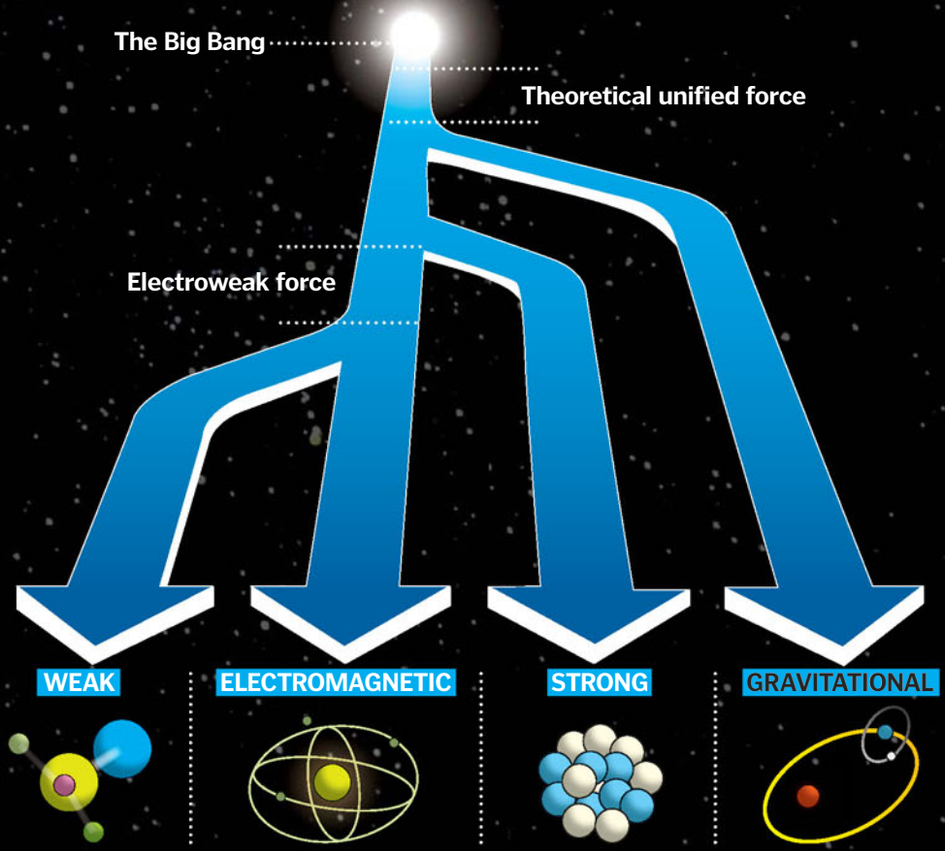
A focus on fundamental forces

Four fundamental forces shape the universe: gravitation, electromagnetism and weak and strong nuclear forces. Electromagnetism is probably the simplest to understand; it acts on any object with an electric charge, felt as a force of attraction or repulsion. It transmits between objects by force-carrying particles called photons and 'virtual' photons.

The two nuclear forces are confined within the heart of atoms, where they bind subatomic particles together. The strong force acts on particles called quarks, binding them in groups of three (through force-carrying gluon particles) to create hadrons such as protons and neutrons, and binding these particles together in turn to make complete atomic nuclei. The weak force, meanwhile, is carried by two different types of particle – known as the W and Z bosons – and can trigger the spontaneous changes in atomic nuclei that are linked to radioactive decay.

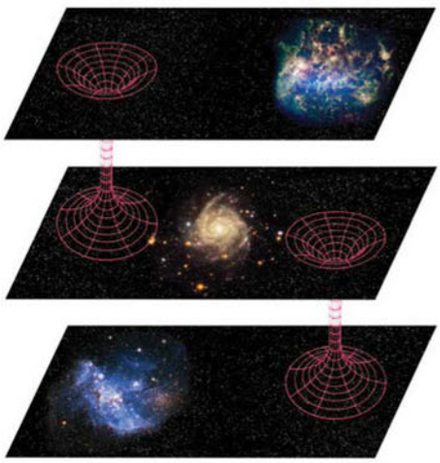
Gravitation is the most mysterious force of all – much weaker than the others, but influential over an infinite range. Although general relativity describes it as a distortion of space-time, some scientists still speculate that it may be transmitted by theorised particles referred to as gravitons.

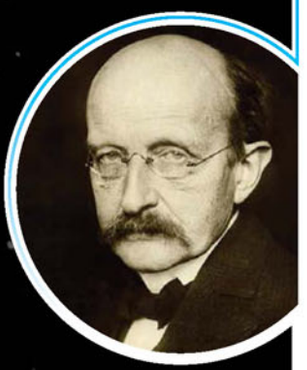
In recent decades, physicists have begun to uncover deep connections between these apparently different forces. At high enough energies, electromagnetism and the weak force merge into a single electroweak force, and there are hopes that at even higher energies the strong force may eventually be combined with them to create a so-called 'Grand Unified Theory'.



Parallel possibilities?

Parallel universes may sound like science fiction, but the laws of physics as we understand them permit them to exist in various ways. One possibility is that the universe is infinite and stretches beyond the region of space we can see, in which case we could expect every possible set of conditions and 'universe' to occur somewhere, and might even be able to reach some of them via theoretical shortcuts called wormholes (illustrated below). Another theory is that our cosmos is one of many four-dimensional 'branes' floating like sheets in multidimensional space, with parallel universes existing on similar sheets that may be out of reach.





KEY PLAYER
Max Planck

Physicist Max Planck (1858-1947) is widely recognised as the founder of quantum theory thanks to his suggestion that light and other forms of electromagnetic radiation might be found in discrete packets of energy, or quanta. He argued against the wider implications of quantum physics.

KEY PLAYER
Stephen Hawking

Physicist and cosmologist Stephen Hawking (born 1942) dedicated his early career to understanding the gravitational laws governing black holes. In more recent years, he has developed cosmological theories that offer hope for unifying the theories of general relativity and quantum theory.

Challenging universal laws

While many believe the laws of physics work in the same way throughout the universe, there's evidence that their effects might vary. Equations like Newton's laws of universal gravitation contain elements called constants, which determine, for example, the strength of gravitational force exerted at a certain distance. But a 2010 survey has found evidence that these so-called 'constants' are nothing of the kind, hinting that the 'fine structure' constant might be different from one part of the universe to another, dictating the strength of the electromagnetic force. Similarly, recent measurements suggest the strength of the universal gravitational constant may also be changing, weakening gravity. While the fluctuations we can see are tiny, it's possible the constants vary more elsewhere.

Data from the Keck Observatory has cast doubt on what was believed to be a natural constant

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1. HIGH

Indian Astronomical Observatory

The highest optical telescope in the world in Hanle, India, is 4,500 metres (14,750 feet) up.

2. HIGHER

Large Millimeter Telescope

The Large Millimeter Telescope is found some 4,600 metres (15,092 feet) above sea level in Sierra Negra, Mexico.

3. HIGHEST

Atacama Observatory

The University of Tokyo Atacama Observatory in Chile wins – a staggering 5,640 metres (18,500 feet) above sea level!

DID YOU KNOW? *The thin air at high locations makes for less distortion in astronomical observations*

The Sphinx Observatory

What science is performed at the highest observatory in Europe?

Lying over 3,560 metres (11,716 feet) above sea level in the Bernese Alps in Switzerland is the Sphinx Observatory. Reachable only by an elevator from the highest train station in Europe at Jungfraujoch, this observatory is the 14th highest in the world and the highest in Europe. Completed in 1937, the observatory's location affords it optimal conditions to perform a variety of research such as meteorology, cosmic ray studies, glaciology and astronomy. Although no longer used primarily for astronomy today, when it was, the high altitude enabled it to observe the universe with much less atmospheric interference than is encountered at sea level.

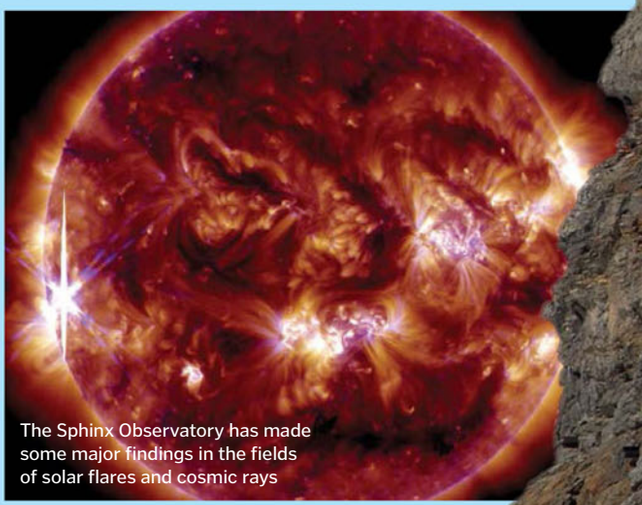
The observatory hosts several laboratories to complement research, nowadays mainly in the field of climate and environmental sciences related to the Montréal and Kyoto Protocols. These research projects are part of international networks and programmes like the Global Atmosphere Watch (GAW), which aims to better understand the composition of Earth's atmosphere and how it interacts with our planet's oceans and biosphere.

Two terraces are also present at the observatory where further scientific experiments can be carried out. The observatory even has its own weather observation station, with its high-up location making it a prime spot for meteorological studies.

New experiments are regularly run at the Sphinx Observatory, with its rare location being a popular destination for scientists. Recent investment has offered more possibilities for short-term experiments and ground-breaking research at this observatory, which is sometimes called 'the top of Europe'.

Making history at the Sphinx

Since 1937 many important discoveries and breakthroughs have been made at the Sphinx Observatory. Back in 1950, a team from the Université de Liège in Belgium measured the spectroscopy of sunlight, providing a reference still used today. Cosmic ray research in 1951 helped to usher in an era of high-energy experiments, while in 1982, a cosmic ray detector proved for the first time that high-energy solar neutrons are in Earth's atmosphere after a solar flare. Over the years the observatory has changed the focus of its research from glaciology to astrophysics to, now, atmospheric studies and environmental sciences.



The Sphinx Observatory has made some major findings in the fields of solar flares and cosmic rays

The stunning location of the Sphinx Observatory provides a unique opportunity for groundbreaking science

"Pulsars are believed to form when supernovas compress the core of a massive star"

Secrets of pulsars

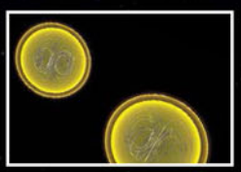
Find out everything you need to know about these amazing pulsing stars

From our perspective a pulsar is reminiscent of a lighthouse's beam, with flashes of radiation viewed from Earth as the emission is pointed our way. These highly magnetised stars were first discovered in 1967 as astronomers searched for a source for these regular pulsing lights from space that had no other explanation. Determined to be rotating neutron stars, pulsars are believed to form when supernovas compress the core of a massive star. They have the same angular momentum as the original star, but since they are much smaller, pulsars rotate at high speeds – some at hundreds of times a second! They emit beams of radiation along their magnetic axis, which is not the same as the rotational axis. For every rotation of the pulsar, the beam is seen once or twice (depending on its alignment with Earth), making it appear to flash. As its electromagnetic power is emitted, the pulsar's rotation slows down and eventually stops pulsing. This seems to occur anywhere between 10-100 million years after the formation of the star.

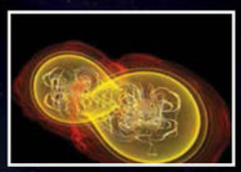
One of the nearest pulsars to Earth is also one of the oldest to be detected with X-rays. An isolated pulsar – meaning that it is not in a binary star or other system – PSR J0108-1431 is estimated to be about 200 million years old and about 770 light years away. Due to its age, J0108 is also one of the faintest, and spins only a little faster than one revolution per second.

Pulsars have many different applications. Millisecond pulsars can rival the accuracy of atomic clocks, and may be used to detect gravitational waves that pass Earth. Pulsars have also been used to create maps that could be used in space. Such maps were included on the Pioneer and Voyager spacecrafts.

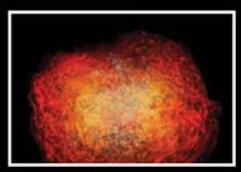
What happens when neutron stars collide?



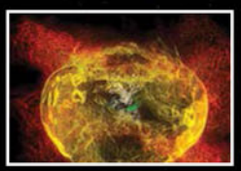
1. Neutron stars have greater mass than the Sun, contained in spheres that are less than 29km (18mi) across. A collision between them lasts just 35 thousandths of a second.



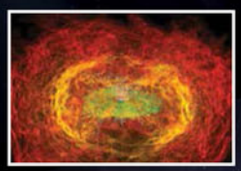
2. As you'd expect, mergers between these stars are chaotic. The merged magnetic fields that are created are a trillion times greater than that of our Sun.



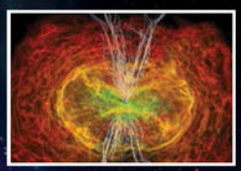
3. The stars become one swirling, dense and incredibly hot cloud of matter. Huge amounts of energy are released during this process, so much so that it's visible from Earth.



4. Next, the new structure develops a black hole at its centre, surrounded by super-heated plasma. The black hole continues to draw in any material that ventures too close.



5. The matter and the magnetic fields (shown here in the image in white) begin to organise. The matter takes on the formation of a high-energy plasma jet.



6. The jet-like magnetic field produces very short gamma-ray bursts – some of the brightest events in the universe. Satellites record these bursts almost every single day.

Crab Nebula in focus

The Crab Nebula, located in the Taurus constellation, contains the Crab Pulsar at its centre. Discovered in 1968, this pulsar is a very young neutron star about 20 kilometres (12.4 miles) across. It emits gamma rays through to radio waves, with a spin rate of about 30 times per second. It was the first pulsar discovered to be the result of a supernova remnant. The nebula is very bright in X-rays and, with the exception of the pulsar, it's considered to be very regular in spectrum and density. This means it's often used as a calibration source in X-ray astronomy.

Pulsars were only discovered by astronomers in the Sixties

716Hz

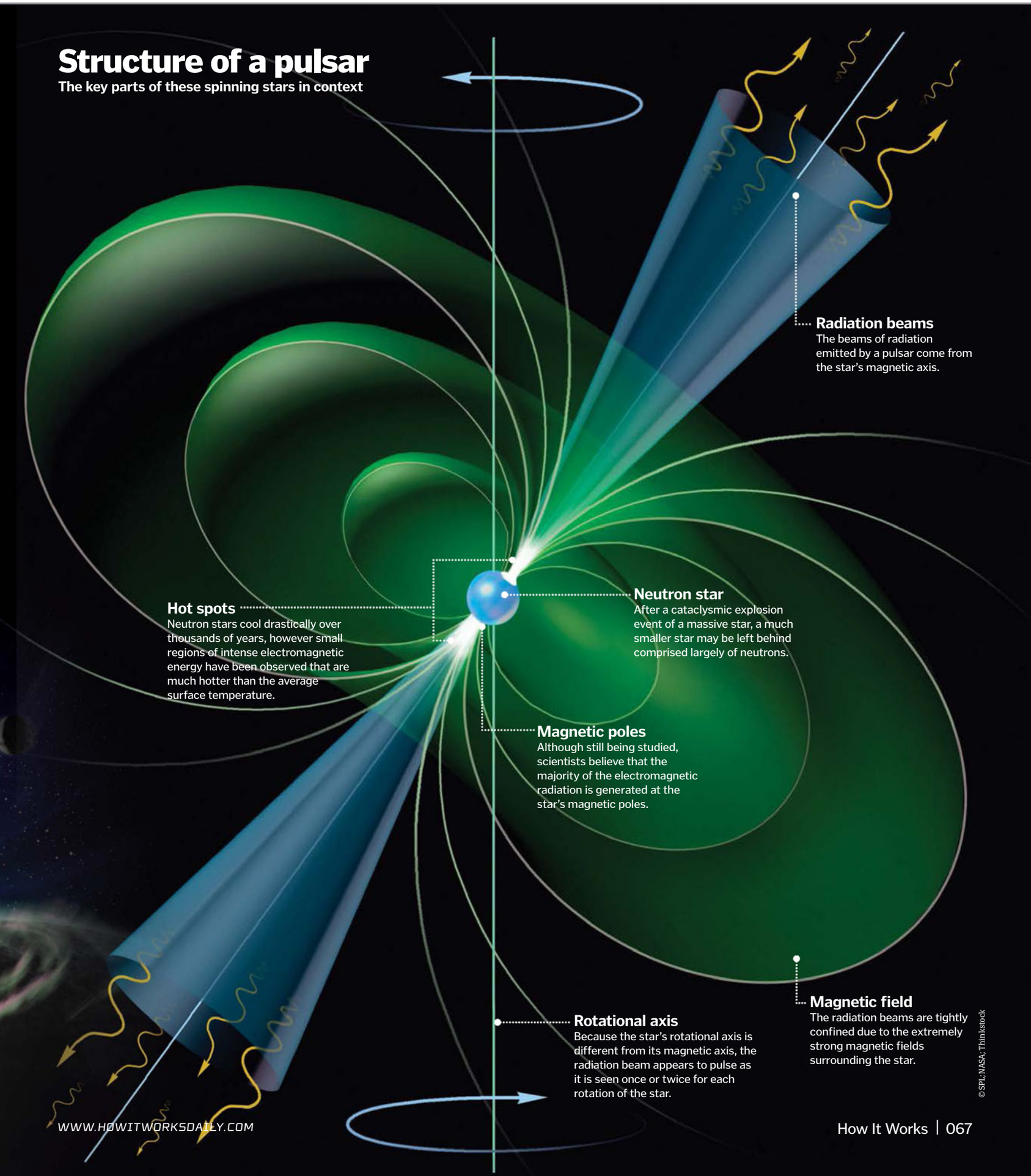
SHORTEST SPIN PERIOD

The pulsar PSR J1748-2446ad has the shortest spin period of any pulsar discovered so far, estimated to rotate over 700 times a second (ie 716 Hertz). The fastest kitchen blenders only spin at 250-500 Hertz.

DID YOU KNOW? *There is still no consensus to explain how pulsars emit their radiation, over 40 years since their discovery*

Structure of a pulsar

The key parts of these spinning stars in context



KEY DATES
SPACE COMMS

1957
The first signals from space come from Sputnik 1, which broadcasts radio pulses back to Earth.

1958
Project SCORE is the first communications satellite, space communications relay and first voice transmission.

1963
The Apollo 7 mission includes the first live television broadcast from an American spacecraft.

1975
Russian probe Venera 9 lands on Venus, becoming the first spacecraft to transmit images of another planet's surface.

2013
NASA announces Voyager 1 as the first manmade object to enter interstellar space. It is still sending back data.

DID YOU KNOW? *Alexander Graham Bell believed the photophone – a device that transmits speech via light – was his best invention*

Laser communications

Find out how the LADEE probe is experimenting with a new-and-improved way to keep in touch with astronomers on Earth as it studies the Moon

During its time in the Moon's orbit, NASA's LADEE (Lunar Atmosphere and Dust Environment Explorer) spacecraft is carrying a Lunar Laser Communication Demonstration (LLCD) as part of its payload. This space terminal is designed to perform much better than traditional radio communications systems, beaming signals five times faster from the Moon to Earth.

On the spacecraft end, there's a 0.5-watt laser that fires through a ten-centimetre (3.9-inch) telescope, sending a laser beam encoded with data the 384,400 kilometres (238,855 miles) back to Earth. This works in much the same way as data is transmitted via infrared lasers in fibre-optic cables on the ground. The main station, or Lunar Lasercom Ground Terminal, is located in White Sands, New Mexico, and houses eight telescopes: four 15-centimetre (six-inch) refracting telescopes to send data and four 40-centimetre (16-inch) reflecting telescopes to collect and focus the beam.

LADEE launched on 6 September 2013 from NASA's Wallops Flight Facility, Virginia, and a series of LLCD experiments are scheduled to begin in late-2013 and continue into early-2014. If the LLCD is successful, laser communications could become the new standard, leading to faster, more cost-effective and more efficient communication throughout space.

No one-trick pony

In addition to the LLCD, LADEE carries three scientific instruments. The LDEX, or Lunar Dust EXperiment, will measure dust on the Moon. The Neutral Mass Spectrometer (NMS) will study the composition, density and time variability of the exosphere, and the Ultraviolet and Visible Light Spectrometer (UVS) will look at the composition of the lunar atmosphere.

LADEE's mission goals include documenting the dust environment in order to help design future missions and also attempt to solve the mystery of whether the Apollo astronaut sightings of diffuse emissions above the surface were lunar dust, or an electrically charged sodium glow. The spacecraft will orbit around the Moon's equator for 100 days.

LADEE's payload

LADEE has three scientific instruments along with the LLCD, which will interact with a terrestrial terminal

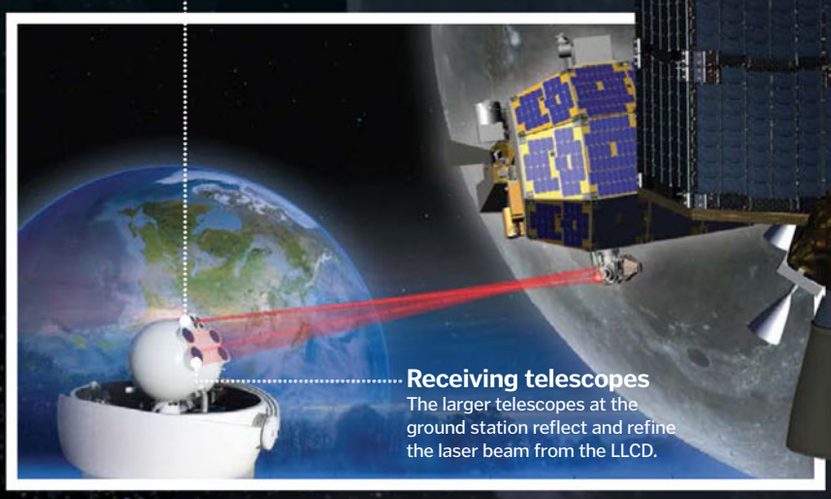
LDEX
The Lunar Dust EXperiment (LDEX) directly collects and analyses dust from the Moon's outer atmosphere.

UVS
The UV-Vis Spectrometer (UVS) looks to pin down the composition of the lunar atmosphere by studying light signatures.

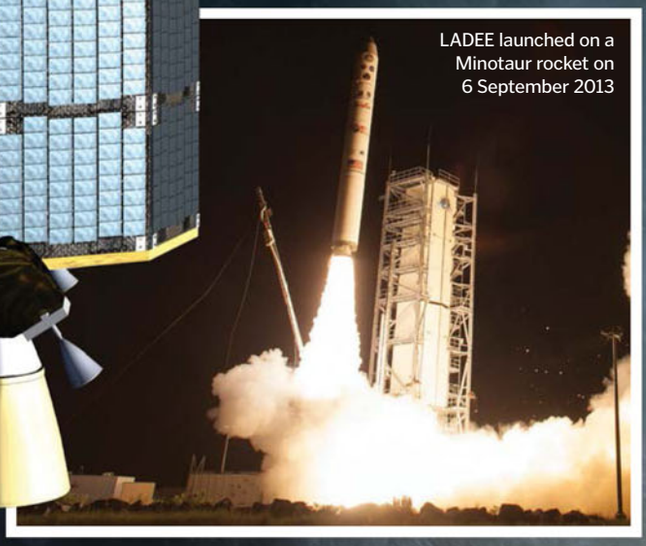
LLCD
The LLCD experiment sends and receives data using pulsed beams of light, much faster than radio signals.

NMS
The Neutral Mass Spectrometer (NMS) measures fluctuations in the exosphere of the Moon across different orbits.

Transmitting telescopes
Smaller telescopes on the ground refract the laser beam to transmit data back to the LLCD.



Receiving telescopes
The larger telescopes at the ground station reflect and refine the laser beam from the LLCD.



LADEE launched on a Minotaur rocket on 6 September 2013

"It may be that a planetary system like our own, where all the planets are in stable orbits, is a rare occurrence"

Planet formation

Why new discoveries have challenged our thinking of how different worlds develop across the universe

The long-standing theory of how our Solar System was created is that the planets and the Sun were born out of a nebula that flattened into a rotating disc. At the heart of this disc formed our Sun, while the dust and gas surrounding it slowly coalesced into the planets and other objects such as asteroids and comets. However, more recent observations suggest that our current theories may not be wholly applicable to other planetary systems.

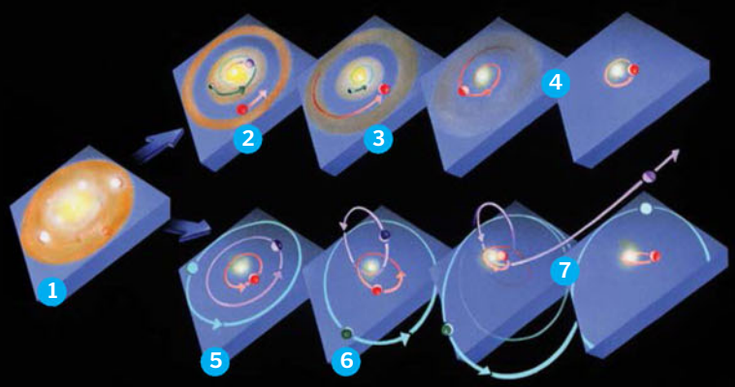
Over the past decade we have found a treasure trove of exoplanets in the Milky Way, and a lot of these do not conform to our current understanding of planetary formation. Unlike our Solar System, where all the major planets orbit within the same plane, we've found systems where planets are flung in highly eccentric orbits away from the plane of the other planets. Similarly, we thought no gas giant planets would be able to form near stars, but 'hot Jupiters' have been found orbiting their host stars in tight orbits.

It is likely that planets found incredibly close to their host star migrated there after being influenced by other planets within their own systems (see the diagram below). Indeed, it may be that a planetary system like our own, where all the planets are in stable orbits, is a rare occurrence.

However, while our theories of how planetary systems form may need to be rewritten, our understanding of how planets themselves form is thought to be fairly sound. It is believed that as the dust and gas within a protoplanetary disc begin to clump together, they become the dominating force within their orbit and begin to attract more and more material. Over a period of hundreds of millions or billions of years, these 'building blocks' of planets, known as planetesimals, gradually grow into the fully-fledged planets that we can see in our own Solar System today. Those planetesimals that do not become a planet remain in a system as asteroids and, in some instances, comets.

Tidal parades vs jumping Jupiters

A closer look at the main stages in two formation theories



1. Formation
Systems are thought to begin with a rotating disc of dust and gas that forms a star and planets.

2. Tidal parade
In a tidal parade system, multiple planets, like the three here, form in orbit around their host star.

3. Destruction
The farthest and largest planet slows the orbits of the inner planets so they fall into the star.

4. Close orbit
The larger planet is in turn pulled towards the centre, but its orbit then stabilises around the star.

5. Jumping Jupiters
However, an unbalanced system can send planets into disarray.

6. No stability
Here, the orbits and masses of the planets influence each other and make them unstable.

7. Thrown out
The result is that one or more planets are thrown out of the system, while the rest remain in highly eccentric orbits.

Most formation theories start with a disc of dust and gas that eventually coalesces into planets

5 TOP FACTS
PLANET SYSTEMS

Solar System
1 Our own Solar System provides the basis of our planetary system knowledge; we've got four terrestrial planets and four gas giants in stable orbits around the Sun.

Seven-planet system
2 The next richest planetary system we know of is that around the dwarf star KIC 11442793, 2,500 light years away, which comprises seven planets in tight orbits.

Best bet for life
3 The Gliese 581 system, located about 22 light years away, contains at least four planets, and we think that one or two of these might be potentially habitable.

Triple-star system
4 The planetary system around Gliese 667 is interesting in that it is a triple-star system around which at least six planets are in orbit, and possibly one more.

Still in progress
5 A debris disc similar to what we think was present in the early Solar System suggests the Eta Corvi system is a prime example of a planetary system still in formation.

DID YOU KNOW? *The first exoplanet was discovered in 1992 – a bizarre world in orbit around a pulsar*

Planets in the making

We speak to astrophysicist Eric Ford from Pennsylvania State University about current hypotheses in the field

Can you explain the current understanding of how planets form?
When gas collapses to form a star, a portion of the gas forms into a disc. As the disc cools, some of the iron, silicon, carbon, oxygen and water condenses to form grains. When grains collide, they can stick and grow into pebbles. We're still unsure of the details, but somehow the pebbles become incorporated into larger bodies that grow to become asteroids, rocky planets and the cores of giant planets.

How has the discovery of exoplanets changed our theories of planetary formation?
The discovery of exoplanets very different to our own has opened our mind to the diversity of planetary systems that nature can produce. The observations have inspired a wide range of theories about how planets of various masses and sizes could be arranged into the configurations that we observe today.

Could our understanding of how the planets formed in the Solar System be wrong?
NASA's Kepler mission has demonstrated that most planetary systems are unlike our Solar System. Instead of designing planet formation to reproduce our Solar System, now we must develop theories that make a wide variety of planetary systems and only occasionally produce something similar to our system.

What future observations are needed to better understand planetary formation?
We'll need lots more observations. Fortunately, there are several new facilities in the works that will lead to major advances in our ability to directly image large planets far away from their star and to resolve structures in the protoplanetary discs.

Hopefully, the major space agencies can co-operate to develop at least two more generations of major space-based observatories, so we'll be able to discover and characterise Earth-like planets.

Eccentric orbits

The less circular a planet's orbit is, the more eccentric it is said to be. Earth's orbit, with the Sun at its centre, has an eccentricity of 0.0167, with 0 being a circular orbit and 1 being parabolic. Some exoplanets, however, have highly eccentric orbits, with their host star focused towards one end. One of the most eccentric planets we know of is HD 80606b, located in the constellation of Ursa Major, at 0.93. Its orbit takes it from a distance of just 5 million kilometres (3.1 million miles) from its host star right out to 130 million kilometres (80 million miles), with its speed increasing as it gets closer and vice versa.

How has Warwick Castle evolved?

One of the most famous fortresses in England, Warwick Castle is a medieval masterpiece brimming with impressive architecture

Commissioned by William the Conqueror two years after his victory at the Battle of Hastings, Warwick Castle is one of the most impressive, well-visited and best-preserved medieval castles in England. From humble origins as a Norman motte-and-bailey fortress in 1068 through to becoming one of the largest military structures of the 14th century, and on to its transformation into one of the most prestigious country houses in Europe, Warwick has changed a great deal over its 945-year history.

The castle itself is located on a sandstone bluff in the town of Warwick, England, where it hugs the River Avon. Its position was chosen due to its central location within the Midlands, granting easy access to the surrounding regions – something that was critical to William in order to put down any rebellions. In addition, the castle's high elevation made attacking it incredibly difficult. As such, from 1068 onwards the castle continued to remain a key defensive structure – even centuries after William's death – with it slowly being bolstered with more towers, new buildings and walls.

As a castle this culminated in the late-15th century. By this time, far from a simple motte and bailey, Warwick was a colossal complex consisting of vast metres-thick stone walls, many parapet-lined towers, comprehensive domestic facilities and even a fully functional gaol and dungeon. It was, in many respects, a fully operational town, with facilities like a working mill, stable and market making it far more than just a defensive stronghold but also a hub for trade and commerce.

Following centuries of decline, Warwick Castle was turned into a country home and estate in the early-17th century, which it remained up until 1978, when it was bought and turned into a tourist attraction. Since then Warwick has been largely returned to a castle state, with a series of renovations and reconstruction celebrating its heritage.

Warwick Castle is one of the best preserved medieval castles in England

Warwick's weapons

While Warwick Castle has seen its walls besieged a number of times, any long-range offensive will only occur in the defence of the fortress, with Britain's largest siege engine and the world's largest trebuchet found here.

Since its construction in 2005 based on notes and drawings from the 13th century, the Warwick trebuchet has been fired over 6,500 times and is a very popular attraction. The machine – made in Wiltshire, England – requires eight people to operate and can fire projectiles weighing up to 150 kilograms (330 pounds) over a distance of 300 metres (980 feet)!

Warwick over time

Check out some of this fortification's key milestones throughout its history now

1068
William the Conqueror begins the castle's construction, building a motte-and-bailey fort.

1264
Simon de Montfort, the leader of a group of rebellious barons at odds with the monarchy, captures the castle.

1395
The castle's second tallest tower today, Guy's Tower, is built towards the end of the 14th century. It stands at 39m (128ft) tall.

1572
Following a series of improvements and extensions, the castle is visited by Queen Elizabeth I.

5 TOP FACTS
WARWICK CASTLE

1 Grand estate
Warwick Castle's landscape gardens were designed in the 1750s by Lancelot Brown. He spent £2,293 on the project, which today equates to about £260,000 ($420,600).

2 Crown property
As well as being owned by 37 individuals to date since its construction, Warwick Castle has also fallen under the control of the British Crown on no less than four occasions.

3 Parliamentarian era
During the English Civil War of 1642-51 Warwick Castle saw much action, including a full-blown siege instigated by Royalist forces which it successfully withstood.

4 Anglo-Saxon burh
Prior to William the Conqueror ordering the construction of Warwick Castle, an Anglo-Saxon burh – a fortified town – lay on the site, emerging circa 914.

5 Family home
Warwick Castle was converted into a country house and estate by Sir Fulke Greville in 1604. The estate remained in his family's hands right up until 1978.

DID YOU KNOW? *Over £6mn ($9.6mn) has been spent maintaining Warwick Castle over the past ten years*

Tour of a medieval stronghold

Explore the main features that make up Warwick Castle in this illustration

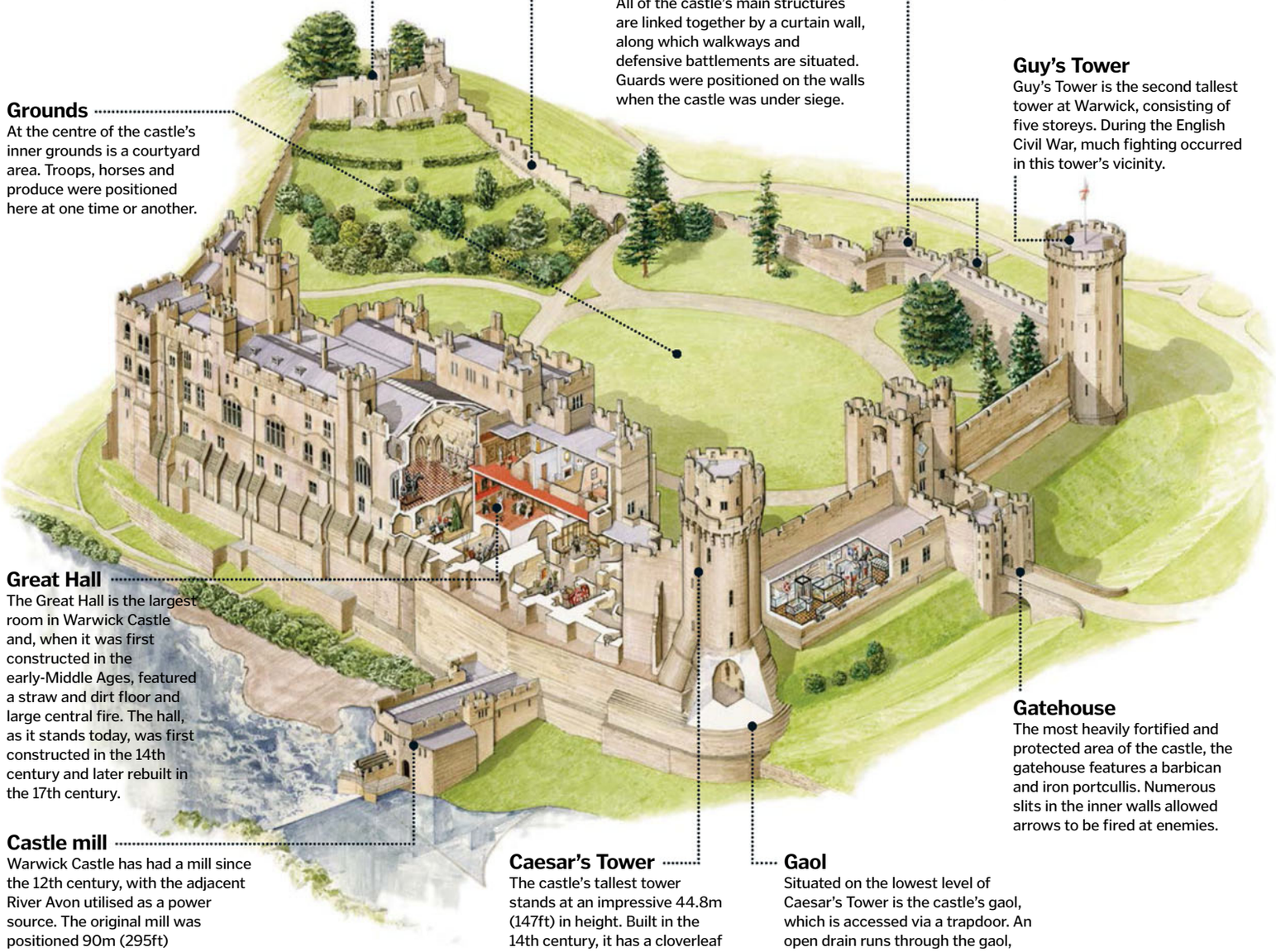
Castle Mound
This is the oldest part of Warwick Castle, being first built in 1068 under the orders of William the Conqueror. It was an ideal defensive lookout.

Curtain wall
All of the castle's main structures are linked together by a curtain wall, along which walkways and defensive battlements are situated. Guards were positioned on the walls when the castle was under siege.

Bear and Clarence Towers
Positioned in the centre of the north wall are the short Bear and Clarence Towers. Their construction started in the 15th century, but they were never completed due to their commissioner, King Richard III, dying at the Battle of Bosworth.

Guy's Tower
Guy's Tower is the second tallest tower at Warwick, consisting of five storeys. During the English Civil War, much fighting occurred in this tower's vicinity.

Grounds
At the centre of the castle's inner grounds is a courtyard area. Troops, horses and produce were positioned here at one time or another.



Great Hall
The Great Hall is the largest room in Warwick Castle and, when it was first constructed in the early-Middle Ages, featured a straw and dirt floor and large central fire. The hall, as it stands today, was first constructed in the 14th century and later rebuilt in the 17th century.

Gatehouse
The most heavily fortified and protected area of the castle, the gatehouse features a barbican and iron portcullis. Numerous slits in the inner walls allowed arrows to be fired at enemies.

Castle mill
Warwick Castle has had a mill since the 12th century, with the adjacent River Avon utilised as a power source. The original mill was positioned 90m (295ft) downstream, with this one built later towards the end of the 14th century.

Caesar's Tower
The castle's tallest tower stands at an impressive 44.8m (147ft) in height. Built in the 14th century, it has a cloverleaf shape and is topped with a crenellated parapet.

Gaol
Situated on the lowest level of Caesar's Tower is the castle's gaol, which is accessed via a trapdoor. An open drain runs through the gaol, and there is only one narrow slit in its walls to act as a window.

1628
The owner of the castle, Sir Fulke Greville, is murdered by a disgruntled servant.

1759
Francis Greville (right) petitions for the title of the Earl of Warwick, reuniting the earldom and the castle.

1871
A massive fire consumes the eastern wing of Warwick Castle.

1890
The Countess of Warwick uses the castle to keep deer, geese, an emu and raccoons, among other unusual animals.

2013
Four new areas are opened to the public for the first time, including Bear Tower, where a bear was once kept.

"Prior to the 20th century, salt mining was an incredibly difficult and hazardous undertaking"

How was salt mined?

Learn how this valuable mineral was harvested before the Industrial Age

Salt is one of the earliest resources mining was used for, with the industry dating back thousands of years. Salt, as we know it, comes from halite in evaporated deposits (see 'Salt of the Earth' for more detail), which are usually – though not always – located underground. As a result it requires an extensive mining operation to both retrieve and process it for use in cooking and beyond.

While today we have advanced mining machines, electrical lighting systems, air filtration networks and super-efficient processing facilities worldwide, prior to the 20th century, salt mining was an incredibly difficult and hazardous undertaking, with conditions, tools and techniques requiring expert knowledge and a good deal of luck!

Lighting was delivered by tallow candles or flaming torches, for example, while halite extraction relied on a mix of manual pickaxe labour and the use of black powder explosives – the latter often resulting in cave-ins.

One of the biggest killers in salt mines prior to the 20th century, however, was dehydration. Due to the miners' constant contact with salt, both physically while digging for it and also via inhalation, rapid dehydration and excess sodium intake were common, with many miners passing out through exhaustion. This dehydration was heightened by the intensity of the labour, with long cave networks to navigate, colossal deposits to be broken down with just pickaxes, towering wooden scaffolds to be climbed and heavy barrels to haul.

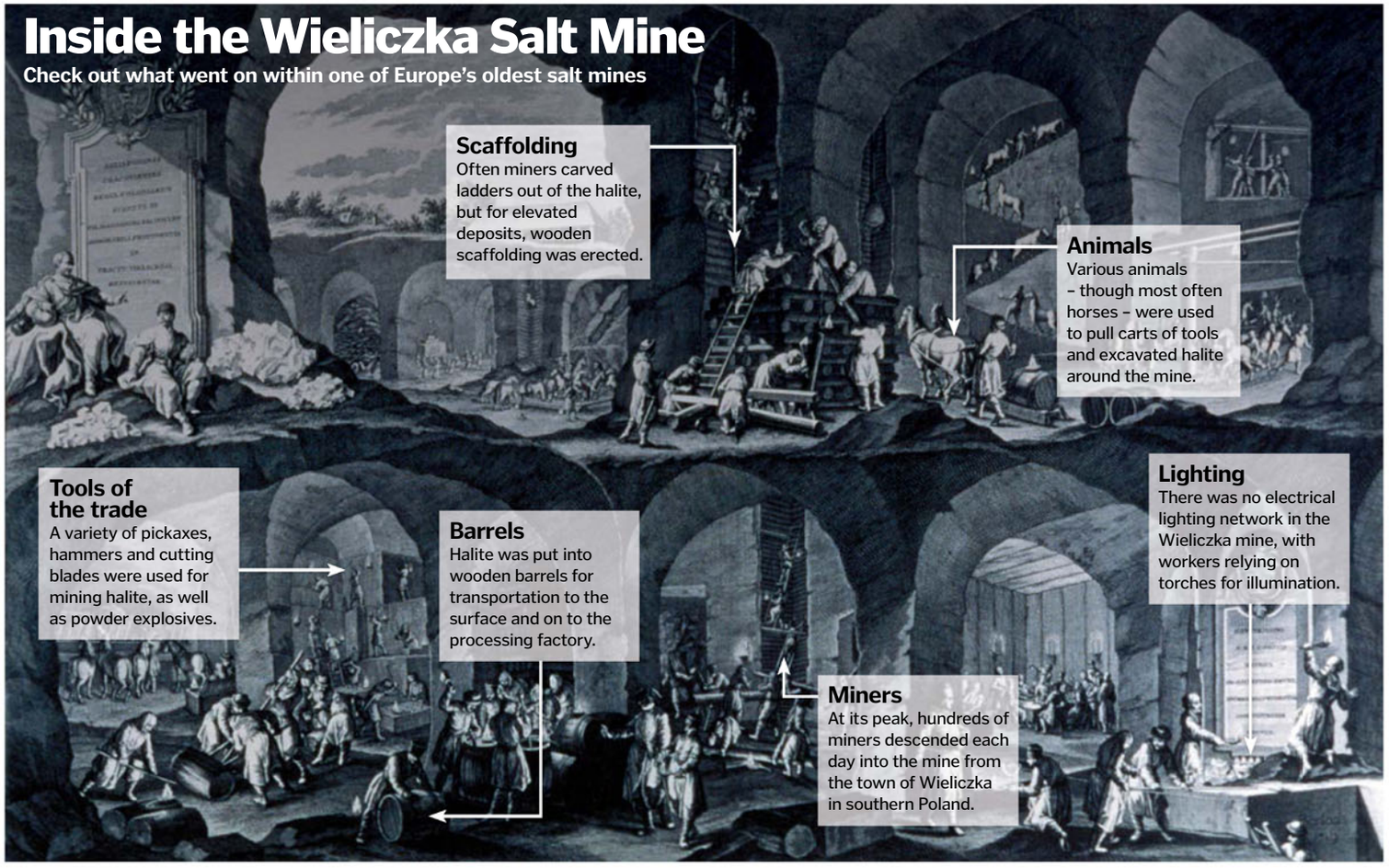
Indeed, in many countries, salt mining was used as a form of punishment or slave labour until the 1900s, with the life expectancy of those sentenced to this work very low.

Salt of the Earth

Salt – or to be precise, rock salt – is the common name for the mineral halite (pictured), which has the chemical formula NaCl. Halite is formed by the evaporation of salty water – like that found in the Earth's seas, which contains large quantities of dissolved Na^+ and Cl^- ions – over long geological time frames. Due to epic changes in our planet's structure and atmosphere over time, today halite deposits can be found underground, with the lighter salt deposits driven upwards by movements in the denser rocky crust below.

Inside the Wieliczka Salt Mine

Check out what went on within one of Europe's oldest salt mines



Scaffolding
Often miners carved ladders out of the halite, but for elevated deposits, wooden scaffolding was erected.

Animals
Various animals – though most often horses – were used to pull carts of tools and excavated halite around the mine.

Tools of the trade
A variety of pickaxes, hammers and cutting blades were used for mining halite, as well as powder explosives.

Barrels
Halite was put into wooden barrels for transportation to the surface and on to the processing factory.

Lighting
There was no electrical lighting network in the Wieliczka mine, with workers relying on torches for illumination.

Miners
At its peak, hundreds of miners descended each day into the mine from the town of Wieliczka in southern Poland.

What was Humpty Dumpty from the famous nursery rhyme?

A An egg **B** A cannon **C** A battering ram

Answer:
Well, despite being depicted as an egg traditionally, nobody really knows, with various theories about what he was in real life supported. Some believe it was a cannon used in the English Civil War, while another story goes it was a battering ram used in the Siege of Gloucester in 1643.

DID YOU KNOW? *Rams were often capped with steel heads, many resembling the faces of fierce creatures*

Brutal battering rams

How were these powerful siege engines built and used?

Battering rams were one of the most common pieces of siege equipment from antiquity right through to the Middle Ages, often granting offensive forces access to an enemy's fortified stronghold or city.

A typical battering ram consisted of a rectangular wheeled frame from which a large tree trunk was slung via ropes or chains. The suspended trunk would then be rocked backwards and forwards within the frame until it swung with great force. By placing an obstacle – such as a wooden gate – in the ram's path, it could transfer a vast amount of energy into the target, often shattering the defence.

However, for a ram to get up to speed, a team of soldiers was required to first place it in position and also control its swinging – both of which are difficult when under fire by ranged weapons. To counter this, battering rams often featured triangular wooden coverings stretched with wet animal hides. This shielding not only protected the soldiers from direct missile strikes but also the risk of fire, with the hides extinguishing any flaming arrows.

The age of the battering ram came to a close largely due to the proliferation of gunpowder and explosives in the late-Middle Ages, with army sappers using these incendiary devices to bring down gates and walls much faster.

Roof
A wooden board covered with wet animal skins protected soldiers below from missiles and also snuffed out fire arrows.

Chains
Due to the immense weight of the ramming trunk, thick rope or large metal chains were typically used to take most of the burden.

Cap
The tree trunk was capped with a pointed steel plate. This helped prevent splitting in the ram when pounding through gates/doors.

Grips
Bolted into the side of the trunk was a series of metal bars, which enabled the operators to better direct the ram and increase its swing.

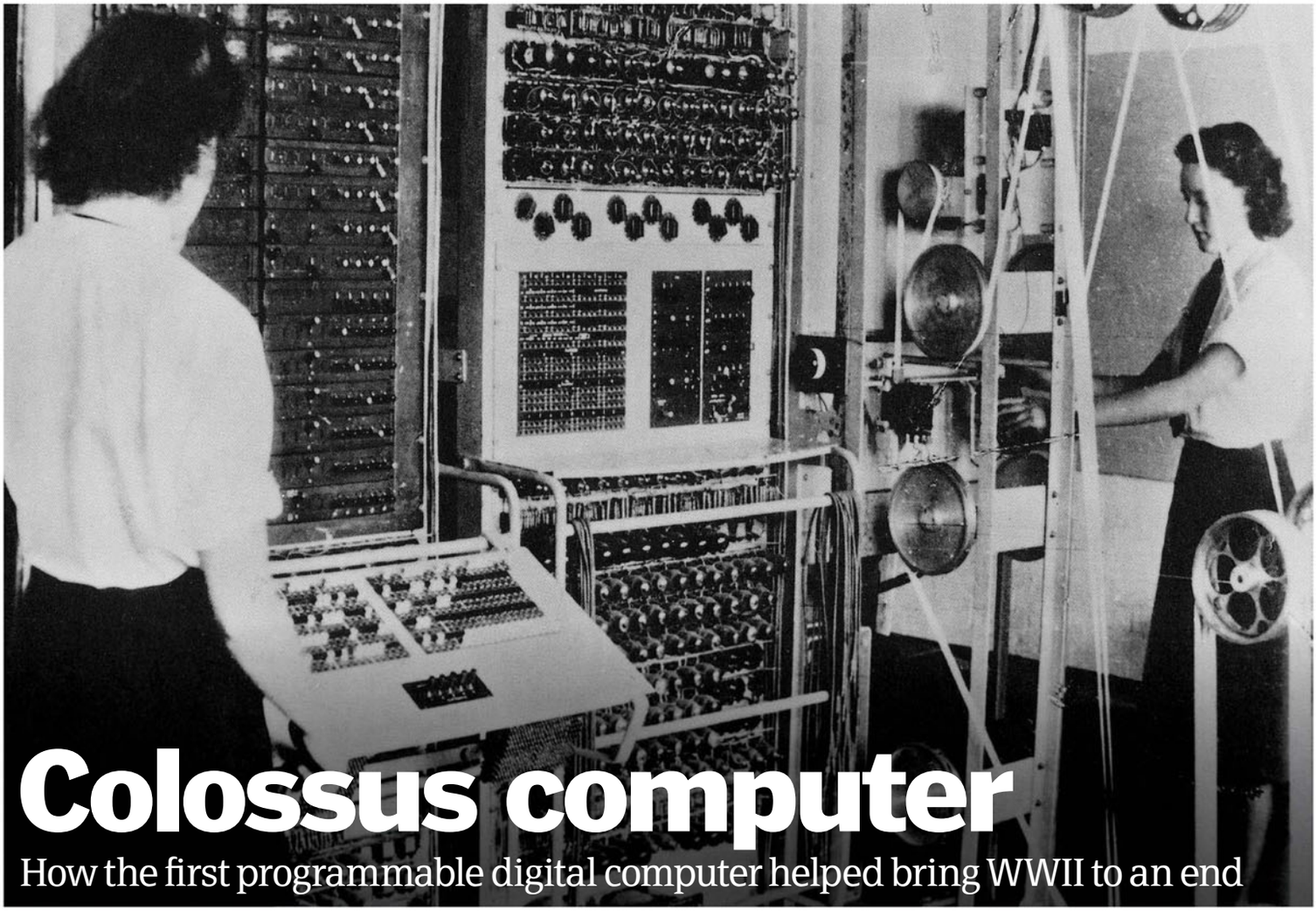
What other weapons were used in siege warfare?

Trebuchet
One of the most useful siege weapons ever to be created, the catapult-style trebuchet allowed an army to bombard a city's walls and interior buildings with huge stones, flaming balls of earth and even dead animals (the latter spreading disease and panic throughout the inhabitants). On the downside, trebuchets required a large team to operate effectively.

Ballista
A large missile-throwing weapon, the ballista was an excellent choice when you wanted to disrupt infantry columns. Developed first by the Ancient Greeks, the ballista worked via torsion springs, with huge wooden spikes propelled at great speed when released over large distances. The ballista would be scaled down over the centuries until eventually it could be handheld.

Tower
A simple yet devastatingly effective siege weapon if used correctly, the tower was literally a mobile wooden turret on wheels that enabled troops to scale enemy walls in relative safety. After climbing up through the shielded internal cavity, soldiers would then be released with the dropping of a small drawbridge, enabling them to charge over enemy battlements.

"Colossus proved to be a colossal success, with the intelligence used to counter the Nazis' movements"



Colossus computer

How the first programmable digital computer helped bring WWII to an end

The Colossus computer was a machine used by the British intelligence service during World War II to analyse and decrypt teleprinter orders and messages enciphered with a Lorenz SZ40/42 encryption machine by the Nazi Germany High Command. The contents of the messages were of incredible value to the Allies, as they often contained key orders for German generals, including troop movements and tactics.

Prior to the German use of the Lorenz cipher, the Allies had successfully cracked their Enigma code and had for years held the ability to decode messages thanks to Alan Turing's electromechanical Bombe machine. The Lorenz cipher was much more complex, however, with the SZ40/42 enciphering a message by combining its characters with a keystream of characters generated by 12 mechanical pinwheels. As such, without knowing the key characters – ie the position of the pinwheels – no decryption could take place.

The Colossus solved this issue by finding the Lorenz key settings, rather than actually decoding the message – the latter part done manually by cryptologists. The computerised process involved the Colossus analysing the inputted encoded message's characters and then counting a statistic based on a programmable logic function (such as whether an individual character is true or false). By analysing a cipher text in this way a number of times, the initial position of the Lorenz machine's 12 pinwheels could be determined and the keystream established.

Historically, the Colossus proved to be a colossal success, with the Allies decoding many war-changing messages throughout 1944 and 1945 and the generated intelligence used to counter the Nazis' movements in Europe. In addition, after the war, the technological advancements in computing brought about by Colossus led to Britain becoming a pioneering centre for computer science.

A colossal reconstruction

As part of the transformation of Bletchley Park into a museum, a fully functional replica of the Mark 2 Colossus was completed in 2007 by a team of engineers led by electrical engineer Tony Sale. Unfortunately, this was nowhere near as simple as six decades' worth of technological advancement since the war might make you think, with many blueprints and original hardware being destroyed after WWII, leaving those responsible for its reconstruction severely lacking in workable information.

Luckily though, after a dedicated research campaign, many of the Bletchley team's original notebooks were acquired, which when collated delivered a surprising amount of information. As such, by using the notebooks and consulting several original members of the Bletchley team, including the designer of the Colossus's optical tape reader – Dr Arnold Lynch – the reconstruction was completed successfully and is today situated in exactly the same position of the original Colossus at Bletchley Park, where it can be used to crack codes once more.

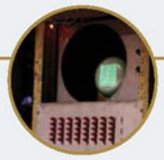
KEY DATES
COMPUTING MILESTONES

1837
Charles Babbage describes his design for the first mechanical computer – the Analytical Engine.

1936
German engineer Konrad Zuse builds the Z1 (right), which is the first programmable computer.

1943
The original Colossus, the world's first programmable electronic digital computer, is built by Tommy Flowers.

1948
The Small-Scale Experimental Machine (right) is built in Manchester. It can store and run a program from memory.



1975
The first machine to be sold to the public as a 'personal computer' is the Altair 8800.

DID YOU KNOW? *The Colossus was not made public knowledge until the 1970s due to the Official Secrets Act*

A sculpture to commemorate Flowers, with his son (left)

Flowers in focus

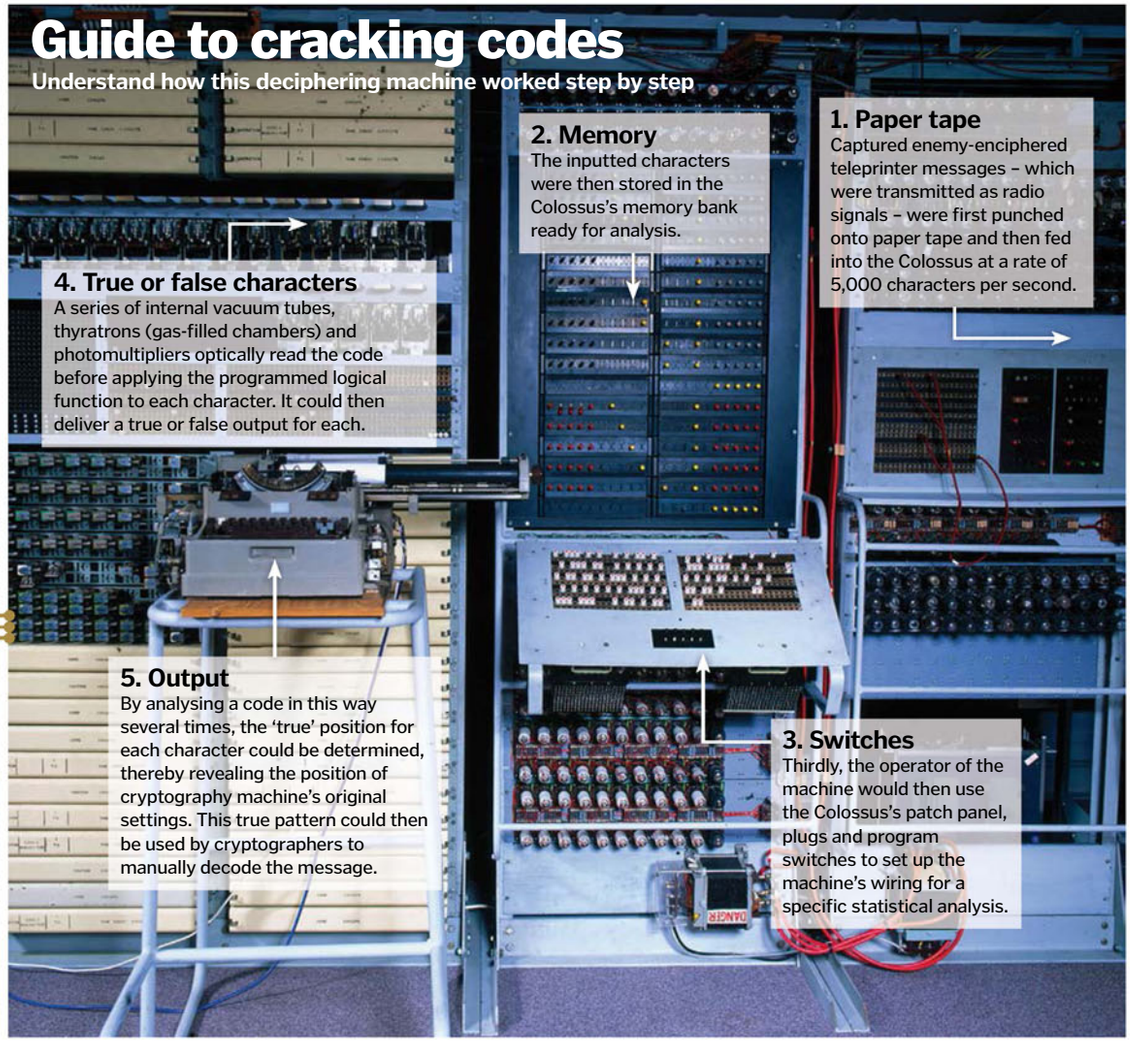
Thomas (Tommy) Flowers was the British engineer behind the design and construction of the Colossus computer. After graduating from the University of London with a degree in electrical engineering, Flowers went on to join the telecommunications branch of the General Post Office, where he explored the use of electronics for telephone exchanges.

Off the back of this work, Flowers was invited to help code-breaking expert Alan Turing to build a machine that could help automate part of the cryptanalysis of Nazi Germany's Lorenz cipher – a high-level cipher used to communicate important orders from the high command.

By 1943 Flowers had built the Colossus, and soon after received funding to create a second improved variant, which went into active service in June 1944. Despite his key role in helping the Allies to victory, Flowers could not talk about his work for decades as he was sworn to secrecy.

Guide to cracking codes

Understand how this deciphering machine worked step by step



1. Paper tape
Captured enemy-enciphered teleprinter messages – which were transmitted as radio signals – were first punched onto paper tape and then fed into the Colossus at a rate of 5,000 characters per second.

2. Memory
The inputted characters were then stored in the Colossus's memory bank ready for analysis.

3. Switches
Thirdly, the operator of the machine would then use the Colossus's patch panel, plugs and program switches to set up the machine's wiring for a specific statistical analysis.

4. True or false characters
A series of internal vacuum tubes, thyratrons (gas-filled chambers) and photomultipliers optically read the code before applying the programmed logical function to each character. It could then deliver a true or false output for each.

5. Output
By analysing a code in this way several times, the 'true' position for each character could be determined, thereby revealing the position of cryptography machine's original settings. This true pattern could then be used by cryptographers to manually decode the message.

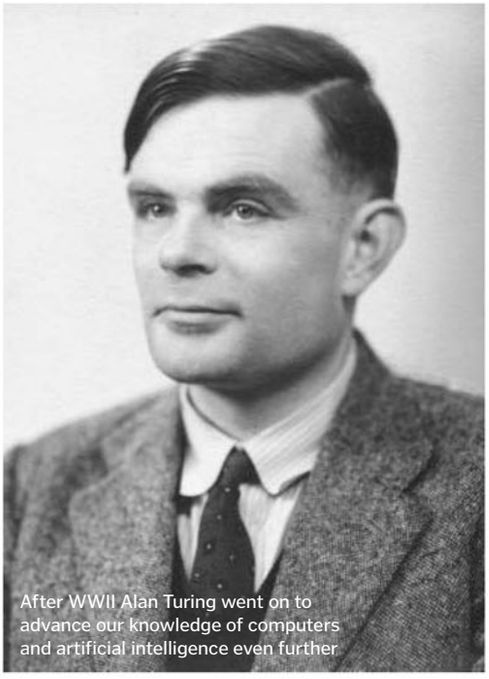
In 1993 Bletchley Park was re-opened as a museum devoted to code breakers

Bletchley's role in WWII

Bletchley Park was the British government's main decryption headquarters throughout World War II. Located in Milton Keynes, Buckinghamshire, England, Bletchley was a top-secret facility for Allied communications, with a diverse team of engineers, electricians and mathematicians working manually – and later with the help of decryption machines – to break the various enemy codes used to disguise orders and private communiqués.

Among the many decoders – also known as cryptanalysts – working at Bletchley, Alan Turing became by far the most famous, with his work in breaking the Enigma and then Lorenz codes earning him the nickname the 'Father of Computer Science'. Indeed, between them Turing, Flowers and the rest of the Bletchley team's efforts arguably were crucial to the Allies' eventual victory in 1945, with the intelligence gathered by them – intel which was code-named 'Ultra' – speculated by some to have shortened the war by up to four years.

Today Bletchley Park is run by the Bletchley Park Trust, which maintains the estate as a museum and tourist attraction, with thousands of people visiting the site every year. Among the Trust's many activities is the reconstruction of many of the machines that helped to break the Axis codes – as discussed in more detail in 'A colossal reconstruction' opposite.



After WWII Alan Turing went on to advance our knowledge of computers and artificial intelligence even further

BRAIN DUMP

Because enquiring minds need to know...

Want answers?

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How It Works magazine @HowItWorksmag

howitworks@imagine-publishing.co.uk

Overall rocket launches are less damaging to the environment than more everyday transport

Does launching rockets harm the environment?

Wendy

In theory, yes. There are various ways a rocket launch can cause environmental damage, but in practice, they make a very minor contribution to such damage compared to things we do in our everyday lives. Any rocket engine is powered by a chemical reaction of some sort, which may produce some polluting gases (although the most efficient reaction of all, combustion of liquid hydrogen and liquid oxygen to make steam, is also the 'cleanest' in environmental terms). Gases left behind as the rocket blasts through the atmosphere make no substantial contribution to the greenhouse effect compared to cars and ground-based industry. Although these exhaust gases can damage the protective ozone layer about 20 kilometres (12.4 miles) up, recent research suggests they are only responsible for about one per cent of human-inflicted damage at most. All in all, the harm caused is insignificant compared to how much satellites and space experiments have taught us about the environment and how we can better take care of it. **GS**

Meet the experts...

Luis Villazon
Luis has a degree in zoology and another in real-time computing. He's been writing about science and technology since before the web. His science-fiction novel, *A Jar Of Wasps*, is published by Anarchy Books.

Giles Sparrow
Giles studied Astronomy at UCL and Science Communication at Imperial College, before embarking on a career in space writing. His latest book, published by Quercus, is *The Universe: In 100 Key Discoveries*.

Vivienne Raper
Vivienne gained a PhD in climate change monitoring before becoming a science journalist. She likes to write sci-fi, go on country walks with her dog and play with her collection of 200 board games.

Mike Simpson
Michael has a doctorate in moss as well as teaching awards from the University of Alberta. While not working as a botanist or environmental consultant, he writes for magazines and online.

Dave Roos
A freelance writer based in the USA, Dave has written about every conceivable topic, from the history of baseball to the expansion of the universe. He has an insatiable curiosity for all things science and tech.

How fast does the Sun spin?

It was very hard getting it to stay still for this photo...

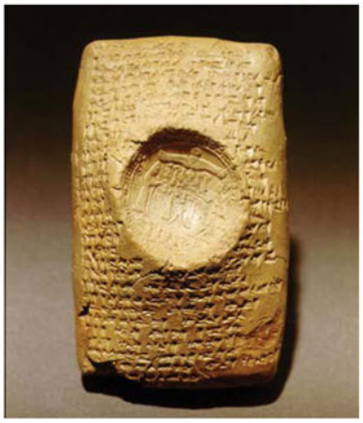
Jake Phillips

■ It actually depends on which bit of the Sun you're talking about! Because the Sun is an enormous mass of gas without any solid surface, it spins very differently from a solid object like the Earth – an effect that scientists call 'differential rotation'. This makes the equator rotate roughly once every 25 days, middle latitudes in both hemispheres roughly once every 27 days, and polar areas once every 30-36 days. Once you get deep enough inside the Sun, however, the gas is so dense that it behaves like a solid body, and rotates once every 27 days or so. **GS**

Which is the planet's most invasive plant?

Valerie

■ Several plants could claim this title, but the world's worst water weed is undoubtedly the water hyacinth. Found in 50 countries on five continents, this free-floating South American plant can double in mass every five days. It forms dense mats which rapidly clog waterways, limit boat traffic and stop sunlight and oxygen reaching underwater. 50 million tons of water hyacinth are removed each year from the White Nile alone. This exotic plant can escape into the wild from ornamental ponds where it is prized for its beautiful purple-blue flowers and attractive shiny dark-green leaves. **VR**



Who was the first chemist?

Laura Dale

■ Humans started using fire to extract precious metals from natural ore as far back as 40,000 BCE, but the first written record of an individual chemist comes from ancient cuneiform tablets found in Mesopotamia dating from 1200 BCE (pictured left). Her name was Tapputi and she was the royal perfume maker in Babylon. Tapputi, whose title was 'palace overseer', is considered the first chemist because she was the first to use specialised equipment – eg a distiller – to extract and purify essential oils from plants and flowers. Unlike other ancient thinkers who merely philosophised the nature of matter, Tapputi used a systematic method to experiment with the base properties of nature. **DR**

5-SECOND FACTS

Not all liquids are on a level

If the liquid molecules have a strong electrical attraction for the container's molecules, they pull up the sides, causing a concave surface (a meniscus). If the liquid pulls inwards to itself more strongly than the sides, it creates a convex meniscus.

Red pandas were discovered before giant pandas

Zoologist Frédéric Cuvier was the first Westerner to discover the red panda, Ailurus fulgens ('fulgens' meaning 'shiny, fire-coloured cat'), in 1825, a full 48 years before the discovery of the black-and-white giant panda. Although fossil remains of red pandas have been found across the globe, the fluffy, striped-tail mammal lives exclusively in the high-altitude forests of China, India, Myanmar, Bhutan and Nepal.

Is there any way to improve concentration?

Holly Cooperfield

■ Researchers agree that one of the best ways to improve concentration is to stop multitasking. The brain is only able to successfully handle two tasks at the same time. When we try to juggle three or more tasks at once – say, emailing, talking on the phone and updating the shopping list – we actually train our brain to give less than its full attention to any single job. Instead of multitasking, break your day into smaller chunks of time, each dedicated to a single task. Other tips are to get more than seven hours sleep a night, to do aerobic exercise and to stay hydrated. **DR**

Does the night sky change over time? Find out on page 82

BRAIN DUMP

Want answers?

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howitworks@imagine-publishing.co.uk

5-SECOND FACTS

An episode of The Simpsons has over 17,000 frames

Like most modern animated TV shows, *The Simpsons* is filmed using a method called 'on twos'. In general, a second of film consists of 12 different frames, each of which is exposed twice. A 24-minute-long (1,440 seconds) episode therefore includes at least 17,280 frames.

Are star constellations permanent?

Shaun

Not quite – but it takes a long time for them to change! The patterns we think of as a constellation are (usually) made up of unrelated stars at different distances from Earth, travelling on their own paths in different directions through space. So over tens of thousands of years or even more, the constellation pattern can shift or change completely. What's more, in modern times, constellations have been officially defined as areas of sky rather than star patterns, so in theory a bright star from one constellation can wander off into another one altogether, given enough time. **GS**

What makes Australia's Blue Mountains blue?

Rich Naylor

The blue haze blanketing the Blue Mountains in New South Wales is commonly attributed to the area's eucalyptus forests. A popular theory is that airborne droplets of eucalyptus oil combine with dust particles and water vapour, refracting rays of mainly blue light. Another theory is they appear blue for the same reason the sky appears blue. Dust, water droplets and air particles scatter short wavelengths of blue light more than long wavelengths of red light. The air acts like a translucent plastic sheet, giving the mountains a blue tint. This explains why mountains without eucalyptus sometimes appear blue. **VR**

Which animal has the best sense of smell?

Charlie Downer

The bloodhound has the best sense of smell of any dog. Its nose has 40 times more scent receptors than a human nose – they have been referred to as 'a nose with a dog attached'. Bears have noses that trump even that. A polar bear can smell a seal that is buried under a metre (3.2 feet) of snow from over a kilometre (0.6 miles) away! Mammals generally have the best noses. But the best smeller of all doesn't have a nose at all. Male moths use their feathery antennae to comb scent molecules out of the air as they fly, rather than sucking it up through a nostril. Theirs is a highly specialised sense that has evolved to pick up just a single smell – the one emitted by female moths. The male Indian luna moth (pictured right) can detect a single molecule of sex pheromone from 11 kilometres (6.5 miles) away. **LV**

Does clicking your fingers increase your chances of getting arthritis?

Pierre Sangan

No. Rheumatoid arthritis, which is the kind that more commonly affects the hands and fingers, is a disease where your own immune system incorrectly begins attacking the cartilage of your joints. There's no evidence that this is affected by how much repetitive movement you do, whether it's finger clicking, typing or cracking your knuckles. Osteoarthritis *is* partly caused by mechanical stress of the joints but it normally requires a specific injury or a lifetime of hard work or obesity to do enough damage to trigger arthritis. No one clicks their fingers anywhere near enough to damage their joints like that, but it's still best not to overdo it. **LV**

Is there any way to fight baldness?

Tony Emery

Currently there are no scientifically proven ways to prevent baldness. The market for a means to retain an expansive topknot is lucrative, however, so researchers in academic institutions and private companies are keenly pursuing solutions. For example, scientists at the University of Pennsylvania announced earlier this year that they had identified a growth factor produced by gamma delta T-cells in the skin that made mice excessively hirsute. Unfortunately, it responds best to damaged skin so you might have to literally scratch your head to make it work. Nonetheless, their research has been licensed to an American firm that could develop it into a commercial product. **MS**

Pieces from the Staffordshire Hoard, the most valuable treasure ever found in the UK

What's the biggest treasure hoard ever found in the UK?

Simon Gilbride

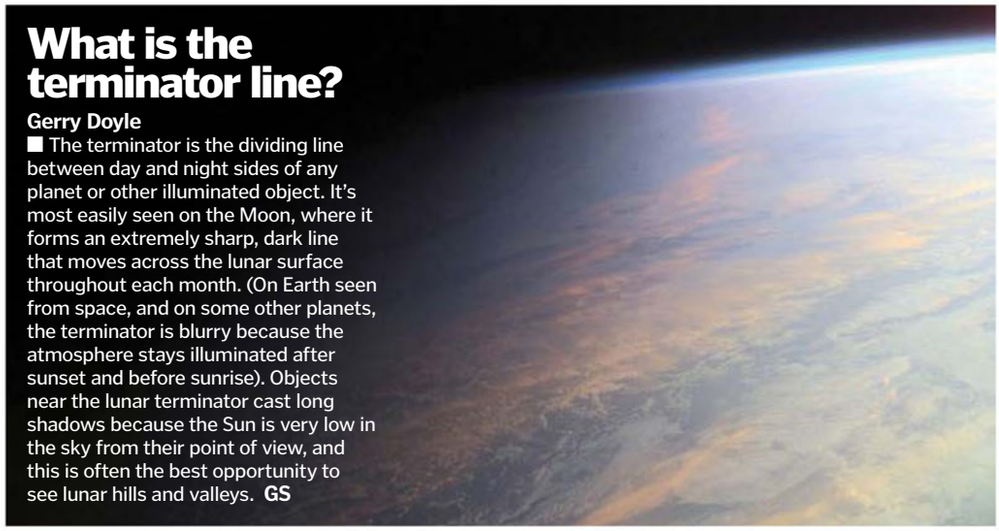
The Staffordshire Hoard, discovered on 5 July 2009, is the UK's most valuable treasure find. The 3,900 pieces of early Anglo-Saxon treasure found in a field near Lichfield, Staffordshire, were valued at an amazing £3.29 million ($5.3 million). The find contains five kilograms (11 pounds) of gold, 1.4 kilograms (three pounds) of silver, copper and 3,500 red cloisonné garnets – possibly from Sri Lanka. Experts have many theories for who buried the treasure, including soldiers and thieves. It mainly consists of richly decorated war gear from the seventh and eighth-century kingdom of Mercia. The sword hilts, filigree animals, processional crosses, helmet cheekpieces and other equipment are among the best Anglo-Saxon art ever discovered.

Metal detector fan Terry Herbert made the find, which contained three times more gold than the famous Sutton Hoo royal ship burial – a magnificent hoard unearthed in 1939. **VR**

What is the terminator line?

Gerry Doyle

The terminator is the dividing line between day and night sides of any planet or other illuminated object. It's most easily seen on the Moon, where it forms an extremely sharp, dark line that moves across the lunar surface throughout each month. (On Earth seen from space, and on some other planets, the terminator is blurry because the atmosphere stays illuminated after sunset and before sunrise). Objects near the lunar terminator cast long shadows because the Sun is very low in the sky from their point of view, and this is often the best opportunity to see lunar hills and valleys. **GS**



Can you think yourself into shape? Find out on page 84

BRAIN DUMP

A garter snake is not only the most common serpent, but also part of the largest family of snakes

Which is the world's most common snake?

Harry R

Reliable census figures don't generally exist for animals that aren't endangered, but it's probably the common garter snake (Thamnophis sirtalis). Garter snakes are members of the Colubridae, which is the largest family of snakes and contains almost 2,000 species and several dozen of these are species of garter snake. The common garter snake is found right across North America and is the only snake species native to Alaska. They are very thin – no thicker than your thumb – but can be over a metre (3.2 feet) long. They have a mildly venomous bite but it doesn't cause anything worse than an itchy swelling in humans. **LV**

5-SECOND FACTS

Blue moons are rare but not blue

Traditionally a 'blue moon' happens when there are two full moons in a calendar month. Full moons are separated by 29.5 days on average, so once every two or three years, you get a full moon at the start and again at the end of a month. That doesn't mean the Moon looks blue, though that can happen when fine particles in the air (eg from forest fires or volcanic ash) absorb the red part of its light.

Platinum is made by exploding stars

Platinum is rare in the Earth's crust for two major reasons. A heavy element, it's formed only during explosions of long-dead stars, unlike more abundant ones like carbon. Moreover there are few mineable deposits. Almost two-thirds of the world's platinum supplies come from South Africa.

Could we survive by just eating insects?

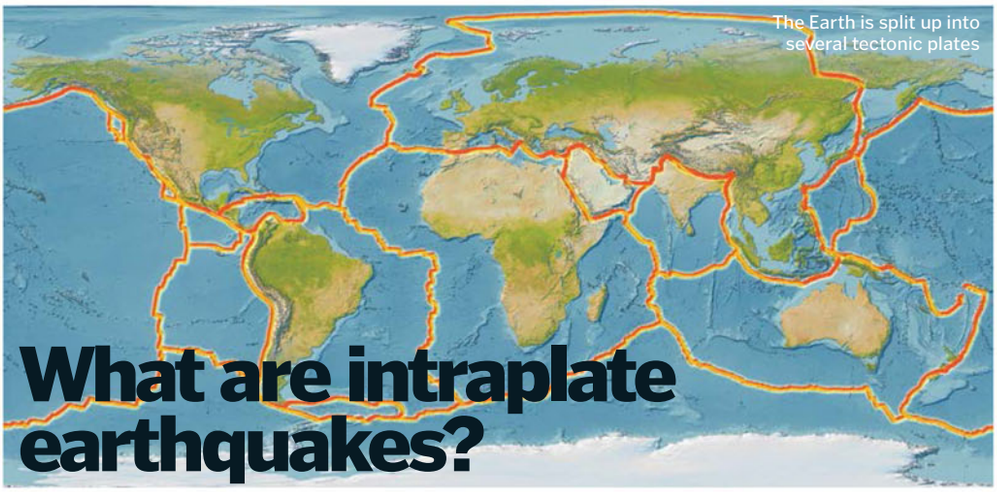
Paula Wilson

According to the United Nations' Food and Agriculture Organization beetles, caterpillars, bees, wasps and ants already contribute to the traditional diets of at least 2 billion people in the world. This is because at the right stage in their development some species can be excellent sources of fat, protein, vitamins, fibre and minerals. Insects are particularly favoured in developing nations where they are more sustainable and less resource-intensive than large mammals – the major components of Western diets. However, even communities that eat insects regularly on other foods too. For example, in parts of Africa where insects are eaten frequently people still get about 90 per cent of their protein from other sources, suggesting insects can't satisfy all our dietary needs. Also, to feed the world with bugs we'd have to overcome our aversion to them and resolve environmental concerns of mass production. **MS**

Does thinking hard burn calories?

Noel

Not many. Most of the energy your body requires is used just to power the basic processes of your metabolism. If you spend the day lying on the sofa, you'll still use about 1,300 calories, compared with 2,000-2,500 for a normal active day. Of those 1,300 calories, a fifth are used to power the brain, even if you're just watching daytime TV. That's because your brain is *always* thinking about something and idle daydreams use as much energy as algebra. **LV**


The Earth is split up into several tectonic plates

What are intraplate earthquakes?

Ellie Harrison

Intraplate earthquakes happen along shallow cracks within the floating rock slabs, called plates, which make up Earth's crust. This sets them apart from 98 per cent of earthquakes, which occur at boundaries between two or more plates. Intraplate quakes strike without warning and can reach magnitudes of more than 7.0. For example, an 1872 intraplate quake in California reached magnitude 7.7-7.9. Most earthquakes happen as plates grind past each other along cracks, called faults. Friction between the slabs causes them to lock together. Pressure builds up until the slabs shift, releasing their stored energy as an earthquake. However, intraplate faults seem to work differently. Scientists believe they are triggered by a sudden weakening of the Earth's crust or by the movement of other faults in the region. Other scientists think pressures build slower along intraplate faults than others, perhaps taking millennia. **VR**

Where was the biggest firework ever set off?

Max

Fireworks were invented in seventh-century China, but it's a small Japanese village north of Tokyo that boasts the largest single firework shell ever detonated. Every September, the residents of Ojiya City celebrate the Katakai Firework Festival. The climax of the celebration is the explosion of a massive round firework shell called the Yonshakudama. The largest on record measured 120 centimetres (47 inches) in diameter and weighed 450 kilograms (992 pounds). When detonated, the dozens of smaller shells implanted in the Yonshakudama created an ear-shattering explosion that stretched a staggering 800 metres (2,625 feet) across the sky. **DR**

How do blueprints work?

Ioanna Stamataki

In the cyanotype process paper coated with potassium ferricyanide and ferric ammonium citrate is clamped under the drawing being copied and exposed to ultraviolet light. The chemicals react and make blank areas turn blue while the lines under the original drawing stay white. In the similar diazotype method, the original is placed under paper coated in diazonium salt. Light exposure breaks down the salt outside the lines, causing the original to turn white. The copy is then exposed to ammonia, making the salt shielded by the lines turn blue. **MS**

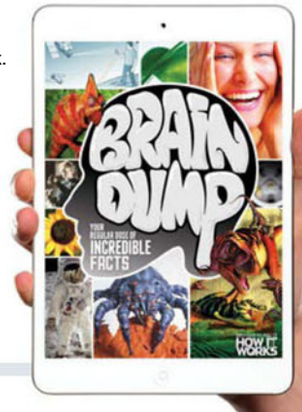
Where does the idea of telekinesis come from? Is it based in any fact?

M Holloway

One of the first uses of the term telekinesis was by American Henry Holt in his book *On The Cosmic Relations,* which discussed mysterious psycho-spiritual phenomena. Telekinesis first grabbed headlines in the late-19th century during séances. While a spiritualist medium spoke with the dead, objects appeared to move about the darkened room. This was later exposed as a hoax. Scientists and the military have conducted lengthy studies into telekinesis, including a 1930s Duke University study. It claimed to offer proof that individuals could use their minds to influence the outcome of a random number generator, but the results have never been successfully replicated. Physicists argue that brain waves are too weak to affect objects beyond a few centimetres from the skull, but admit that science still has a lot to learn about the behaviour of quantum particles. **DR**

Brain Dump on the go

If you can't get enough quick-fire trivia, be sure to download the latest edition of **Brain Dump** – Imagine's fact-packed, digital-only science magazine now available on Apple Newsstand and Google Play. It's the perfect way to while away some time, whether you're on a long journey or if you've just got a five-minute break, and you're guaranteed to learn something new every time you read it. Issue 7 explores a wide range of topics, from the everyday like what makes snow white, to the more epic, like how big is the Milky Way? It also explains how ejection seats work and the anatomy of the deadly T-rex. To read about all this and more, download the latest **Brain Dump** now. Check out the mag's Facebook page at **www.facebook.com/BraindumpMag** or follow @BrainDumpMag in the Twitterverse and share any perplexing quandaries that have been preying on your mind.



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REVIEWS
All the latest gear and gadgets

Gaming gear

Get ahead of the game with the peripherals and consoles enhancing the way we play

Checklist
- ✔ Headset
- ✔ Keyboard
- ✔ Mouse
- ✔ Arcade stick
- ✔ Portable console
- ✔ Android console

You may have noticed there's been talk of some brand-new consoles about to be released by Microsoft and Sony. The Xbox One and PlayStation 4 represent an amazing leap forward in the traditional console gaming space. But there's more to videogames than these big players. PC gaming is always at the cutting edge for a start, and mobile gaming is another sector on the rise. We're looking at the next generation of mobile games here, as well as PC-gaming accessories that will enhance your videogame experience.

1 Immersive audio

Sennheiser U 320
£109.99/$169.95
sennheiser.com

A good gaming headset is just a little different from a great pair of headphones, and not just because of the attached microphone. Gaming headsets should be a little more bass-heavy, allowing you to hear those ominous, approaching footsteps more easily. The U 320 headset, while providing this bass, also has a fantastic upper range when it comes to sound, meaning you won't miss out on a great musical score with your gaming experience. The microphone is automatically muted when not swung down and in use, and the overall quality is very high.

Verdict: ●●●○○

2 Tactile keyboard

Razer BlackWidow Ultimate Stealth
£124.99/$139.99
www.razerzone.com

Mechanical keyboards are one of the losses sustained by the move to newer, quieter keyboard technology. These devices are somewhat more practical in normal life, but for gaming, when your actions are dictated by audio and visual cues, the characteristic clackety-clack of an older-style keyboard can be key to better gameplay. The BlackWidow is one of the few remaining mechanical keyboards, but unlike other examples it doesn't come with a complicated array of extra buttons. It may have a simple layout, but it's one of the best standard keyboards we've used.

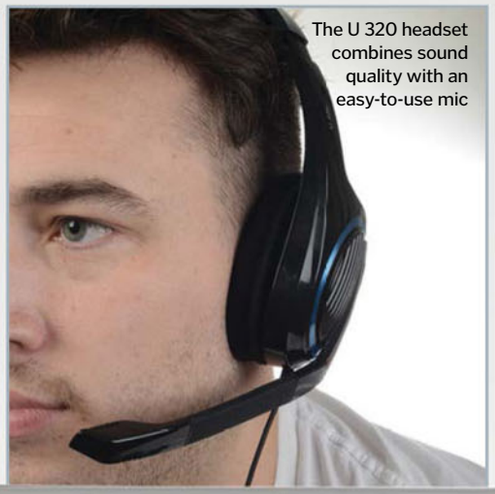
Verdict: ●●●●○

3 Ergonomic mouse

Razer Naga 2014
£69.99/$79.99
www.razerzone.com

Razer is the master of gaming mice, with a selection that has something for everyone. The original Naga included some of the Razer basics – great ergonomics, a highly precise laser and responsive buttons. It also features a 12-button pad on the thumb area of the device, making you look like a futuristic hacker as your thumb flies across the buttons. The new version has updated and improved the layout of these buttons, making them even more ergonomic and less prone to accidental depression, while still keeping the same fantastic quality.

Verdict: ●●●○○



The U 320 headset combines sound quality with an easy-to-use mic

An arcade stick made from real arcade parts – it doesn't get more authentic than that!

The only wire you need for the GameStick is the power cable, which can be plugged into the back of most TVs.

It's possible to plug the headset into some consoles with provided cables.

EXTRAS

Some top resources to help you become a gaming world citizen

BOOK

Critical Path: How To Review Videogames For A Living

Price: £11.50 / $17.99
Get it from: www.amazon.com
Think you know your stuff about games and feel the need to share? Veteran games writer Dan Amrich poured his vast experience into this vital book for any budding critic.

APP

Steam Mobile

Price: Free
Get it from: Google Play/iTunes
The Christmas Steam sale is coming up, and you might not always be near a PC to check out a flash sale. This Steam app allows you to keep tabs on bargains and to chat to Steam friends too.

WEBSITE

www.gamefaqs.com

Whether you're stuck in Carnival Night Zone or lost in Los Santos, someone at GameFAQs will have written a guide to help you out.

4 Open-source gaming

Ouya
£99.99/$99.99
www.amazon.co.uk
Starting off as one of the biggest-ever Kickstarter success stories, the Ouya came at a time when people were desperate for new games consoles. Due to an attractively low price, an OS based on Android and a promise of it being open, it piqued the interest of people from many walks of life. The Ouya has access to many of the best mobile games, and some exclusive titles of its own too, all for the same low cost. Each game also has a demo, meaning you can try before you buy to make sure you get the best experience out of the console.
Verdict: ★★★★★

5 Portable console

GameStick
£79.99/$TBA
www.gamestick.tv
If you didn't need a screen, battery or a way to connect to a mobile network, how big would a phone be? Pretty small, as the GameStick demonstrates by taking a modern mobile phone and sticking it into the form factor of a USB stick. This one plugs into your TV though, and connects via Bluetooth to its own controller. Four can be connected at once, and when you take it out of the TV you can store it in the top of the controller. The game selection is a bit slim right now, and the controller's not the most comfortable to use, but it's certainly a one-of-a-kind device.
Verdict: ★★☆☆☆

6 Retro controller

Razer Atrox
£179.99/$199.99
www.razerzone.com
The decline of the glorious arcades of yore has been very upsetting to a lot of older gamers. However, while the atmosphere may be gone, the control method lives on. Preferred by the best of the best for fighting games, a new breed of arcade sticks has been created, resulting in products like the Razer Atrox. Built using parts from actual arcade cabinets, the Atrox is a high-quality piece of gaming kit that also knows its audience. The box is straightforward to open and all the important parts are easy to customise to the exact way you want to play.
Verdict: ★★★★☆

Connected cameras

We put three devices blurring the line between traditional digital camera and smartphone to the test

1 Samsung Galaxy Camera EK-GC100

Price: £399/$499.99
Get it from: www.samsung.com

While the cameras on phones themselves have been getting better and better, they're still a long way off a proper digital camera or DSLR. The one advantage phones have over the camera is its easy connection to the internet and social media. As Android is fully customisable, Samsung took the logical step and outfitted a full digital camera with an Android operating system.

As one of the first Android-powered cameras, the Samsung Galaxy Camera had a lot to prove. Samsung's approach is interesting, not stripping anything away from the version of Android it has put on the camera, and including 3G connection so you can upload your snaps anywhere. The main difference is a custom camera app that gives you the range of options that any photographer would want to tweak. It's a touch sluggish and a little awkward to use with Android apps, but the camera takes great shots, and you can easily upload them to anywhere you normally would from your mobile phone without a go-between device – it's the best of both worlds.

Verdict: ★★★★☆

2 Nikon Coolpix S800c

Price: £279.99/$349
Get it from: www.nikon.com

The Nikon Coolpix came out around the same time as the original Galaxy Camera, and was based on a pre-existing Nikon point-and-shoot device. This version had its guts swapped out for more powerful components, and Android has been installed to give it the all-important connectivity.

Like the Galaxy, all the buttons you'd expect have been removed in favour of a custom-built app. It doesn't contain the same level of configuration, though, and if you like to really fine-tune your camera settings you may be disappointed.

Still, the small form factor is a bonus – both Samsung cameras here are as big as some DSLRs, so if you just want a normal camera then the Coolpix is a lighter, more reasonable option. The image quality is good, despite the lack of customisable controls, and the majority of what you'd want on the Android side is available.

It is a little sluggish to use, however, and as its version of Android is a bit dated, the S800c may not support all the apps you'll want to use.

Verdict: ★★★☆☆

3 Samsung Galaxy NX

Price: £1,299/$1,699.99 (with lens)
Get it from: www.samsung.com

The very latest connected camera is another in the Galaxy line, but where the original Galaxy was a good start, the Galaxy NX really steps things up a gear. Taking a more serious approach to the camera aspect, Samsung uses elements from one of its top ranges to create the NX. This includes having a proper viewfinder, interchangeable lenses and a few more traditional buttons and dials.

It still has the web-connected trappings you'd expect from it though, with a gorgeous high-resolution screen on the back. While it's not the latest version of Android, it's new enough to get by. All your favourite apps and social media sites are accessible in a flash, enabling you to share shots with little hassle.

The pictures themselves are excellent – topping out at an impressive 20.3 megapixels – using a sensor that the firm also has in its main camera line. Manual configuration is also comprehensive and similar to the original Galaxy Camera, letting you capture shots just the way you want. It costs a fair whack, but this is definitely a case where you get what you pay for.

Verdict: ★★★★★

Adaptable features
The Galaxy NX is compatible with the pre-existing Samsung NX line of camera lenses. This allows you to take different types of shots for varying subjects and conditions.

Settings galore
While lacking in physical buttons, all the manual configuring you might normally want to do with a camera is available on the custom app included with the Galaxy Camera.

Compact form factor
One of the Coolpix's big advantages is its diminutive size, making it much easier to slip into a small bag or even a pocket. As the lens is built in, you don't need extra space to accommodate this either.

GALAXY CAMERA
Dimensions: 128.7 x 70.8 x 19.1mm

NIKON S800C
Dimensions: 111.4 x 60.0 x 27.2mm

ON THE HORIZON

Three other cool gadgets we're keen to get our hands on...

iPad mini with Retina display

Hot on the heels of the seven-inch Android tablets, the original iPad mini seemed like a no-brainer – even if Steve Jobs had said it would never happen. While they were beaten to release by the second-gen Nexus 7, the new iPad mini is definitely a device worth checking out.

Nexus 5

Google's flagship phones are always important, and the latest Nexus is no different. Returning to LG, the Nexus 5 is a souped-up version of last year's Nexus 4. It boasts a better camera, 1080p screen and a more powerful processor – all for a fraction of the price of similar devices.

Samsung Galaxy Gear

Mankind has been obsessed with wrist-worn communicators for as long as we've had electronic communication, yet somehow it has taken this long for someone to actually make one. The Galaxy Gear may not be the first smartwatch, but it's the first that lets you take calls through a phone. Yes, it still needs a phone to actually be used, but it's one step closer to the dream.

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Winter-proof a garden

As the cold sets in, a few jobs will help see your garden through to the spring

1 Tidy up

Prune any broken stems back to the main plant in order to avoid damp and disease creeping in – however it's important to avoid excessive pruning if you're in for a hard frost. Make piles of leaves to create mulch for the spring, but don't go overboard on tidying up as some plants rely on their old leaves for insulation. In addition, remember to keep any seed heads attached as these are a vital source of food for birds during winter.

2 Treat the soil

Now's the perfect time to spread a generous layer of compost over your flowerbeds, or even better, mulch – which can be anything from bark chips to manure. Both of these will help to insulate the topsoil and the roots of your plants from the worst of the winter frost, but the mulch will also prevent any opportunist weeds growing and reduce the amount of soil erosion if it's a particularly wet winter.

3 Focus on the pond

Ponds should be thoroughly cleared of any fallen plant matter with a net to stop the water turning murky. A very simple way to ensure your pond doesn't completely freeze over is to float a plastic ball on the surface. This is particularly important if you have fish because they need a constant supply of fresh oxygen to survive, but it will also benefit any plants and other pond wildlife by keeping the water aerated.

4 Protect tender plants

Some plants can't manage when the lower temperatures kick in, so these need special attention. Once potted up, a greenhouse or conservatory make for ideal over-winter accommodation as both are warm, light and airy. Otherwise, a cold frame structure will suffice (as pictured), or if short on space you can even wrap the pots in bubble plastic or bin-liners and place in a sunny, sheltered spot against a wall.

5 Get planting

It might come as a surprise but there are quite a few plants out there that actually thrive in colder conditions, so your garden doesn't have to be bare. Vegetables include broccoli, Brussels sprouts and chard, while a few popular flowering plants are pansies, certain heathers and cyclamen. You can add straw over veg if you know a hard frost is on the way.

In summary...

When it comes to winter-proofing your garden it's all about striking the right balance. There's no harm in giving plants a trim, but don't over-prune them – especially in freezing weather – as this could do more harm than good. Don't forget that wildlife really benefits from old plant matter during these lean months too, so be sure to keep some leaves/seed heads etc.

NEXT ISSUE
- Pack a suitcase like a pro
- Treat a cold

Make your own Christmas pud

It's the staple way to end any Christmas dinner and it couldn't be simpler to make...

1 Prepare the contents

First of all, you need to decide which dried fruit you're going to put in your pudding. Traditional examples tend to include figs, currants, sultanas, apricots, dates, etc. To get that rich, moist finish which this cake is famous for, you need to soak the fruit in brandy and orange juice overnight in the fridge. At this stage you can also sterilise any coins you're putting in the pudding in boiling water or a little alcohol, such as vodka.

2 Make the cake mix

The next day, grease a pudding basin with butter and add a circle of greaseproof paper to the base. Combine the sugar, butter and eggs into a batter then stir in the soaked fruit and spices (eg cloves, cinnamon, nutmeg), followed by the flour; it should be fairly sloppy. Now's the time to add that lucky sixpence if you're using one. Pour the mix into the basin and add the lid, or use greaseproof paper and foil tied with string.

3 Cook and store

To cook your pud, you can use a dedicated steamer or place the basin into a large pan of boiling water; if doing the latter the water level should only come to about halfway up the pudding basin. Steam for four to five hours and remove very carefully to let it cool. The pudding is ready to eat now, but storing it in a cool, dark cupboard for a few days/weeks before Christmas Day will really help to intensify the flavours.

In summary...

You don't have to be a master chef to make a Christmas pudding and the homemade touch always goes down well. The longer in advance you can prepare your pud, the richer it will taste – and don't forget to warn guests if you have included any coins!

QUICK QUIZ

Test your well-fed mind with ten questions based on this month's content and win a model of the BAE Warrior tank!

Answer the questions below and then enter online at **www.howitworksdaily.com**

1. How much electricity can the organs in the head of the Pacific electric ray generate?
2. What weight of gold was found in the Staffordshire treasure hoard in 2009?
3. How many pyroclastic flows were recorded in the 1990-95 Unzen eruption?
4. What is the output of the Three Gorges hydroelectric dam in China (in MW)?
5. How high is the Swiss Sphinx Observatory above sea level (in metres)?
6. In what year was Guy's Tower at Warwick Castle constructed?
7. What was the average daily traffic on the UK's Spaghetti Junction in 1972?
8. How many times per second is the Crab Pulsar estimated to spin?
9. What is the name of the organ that snakes use to detect pheromones?
10. Who first came up with the idea to create solar light bulbs with water?

ISSUE 53 ANSWERS

1. Slovenia **2.** 315km/h **3.** Veliger **4.** 4,900LY **5.** 55
6. 1918 **7.** 13% **8.** 6 **9.** 1181 **10.** 300kg

INBOX
Speak your mind...

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WIN!

We enjoy reading your letters every month, so keep us entertained by sending in your questions and views on what you like or don't like about the mag. You may even bag an awesome prize for your efforts!

AMAZING PRIZE FOR NEXT ISSUE'S LETTER OF THE MONTH!

WIN A REMOTE-CONTROLLED CAR!

The winner of next issue's Letter of the Month will receive a Revellutions Road Rider RC street car, which can reach up to 20km/h (12mph)!

Letter of the Month

Scouting for stars

Hello HIW,

I have been reading your magazines for many months, and as always I enjoy each copy and read it back to back whenever I get the new issue.

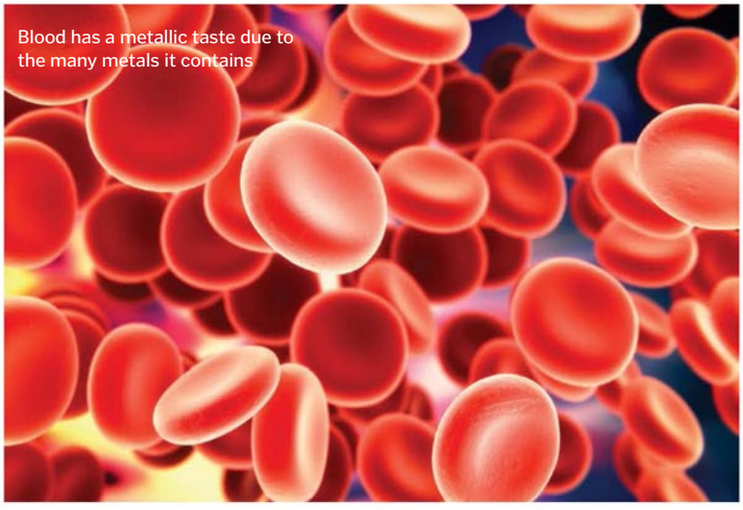
I'm a Scout leader and find this magazine a delight to talk about at our troop evenings. When I find a particularly interesting topic, I open up a discussion with the Scouts and see what they come up with.

They are interested in astronomy, as we are lucky to live in Devon and have areas where there is little light. We spend most of our winter nights going through the constellations and searching for planets.

Looking forward to the next issue,
Brendon Phillips, 21st Exeter Scouts

Hi Brendon, it's great to hear HIW is being used as a springboard for enlightening conversation at your Scout meetings. Based in Dorset, we too count ourselves lucky to get clear skies without much light pollution – when it's not cloudy, of course! Congratulations, you've won this month's Letter of the Month prize – a copy of *The Big Questions In Science*. Hopefully this will inspire many more interesting discussions at your troop evenings!

Remote areas have little light pollution, and in some spots you can even see one of the spiral 'arms' of the Milky Way



Blood has a metallic taste due to the many metals it contains

A taste for blood... and fizzy drinks

Hello,

This might seem like a bit of a vampirish question, but why does blood taste and smell like copper? I thought humans had iron in their blood? Spiders have copper in their blood, turning it blue.

On another subject, when you drink a can of coke, why does it kind of burn your tongue? If you don't know what I mean, try it and see. Why do computers get warm after using them for a while? Plus, is there a reason for people having different hair colours?

Love your magazine by the way – sorry for asking so many questions!
Ruth Tay

Hi Ruth, that is a lot of questions, but that's what we love, so keep them coming! Just to focus on the blood query, it's probably more accurate to say blood has a metallic taste rather than specifically copper because of the many metals it contains, including iron (used to bind oxygen in haemoglobin), copper, lead and even gold (see 'Weird science facts').

Facts better than fiction

Dear How It Works,

Thank you very much for the outstanding publication. Two years ago, I was struggling to help a family to find materials for their son to read to boost his vocabulary. This was a

"I have shared your magazine with parents struggling for engaging reading material"

particularly important task as the child was seeking admission to our school, where vocabulary and language fluency strengths can be differentiators in our competitive admissions pool. After a fruitless search through the local Barnes & Noble bookstore, I gave up on my task and stopped by the magazine section to pick up a little light reading for myself. It was here that I came across your magazine.

Purchasing a copy, I immediately knew that your magazine would be just the right resource for students who don't particularly like the types of books that are available in most schools, which are mostly fiction. I sent the magazine off to the child, and purchased a copy for my own son. Indeed, both boys loved the magazine and the other young man, in fact, increased his scores dramatically enough to gain admission to our school.

I immediately purchased subscriptions for my own son and my office, and then asked if our library would purchase copies for our students.

Since then, I have referred hundreds of families to your magazine, and keep a copy on the table in my office to share with other parents struggling for engaging reading material for what I call 'realist' children. These are the children who have no interest in fiction, but who are totally excited to read and learn about the real world around them. Thank you again for your work, I just want you to know how excited we are to have the magazine available in the States. I will continue to recommend your magazine, and look forward to your next issue.

Marjorie Mitchell
Atlanta, GA

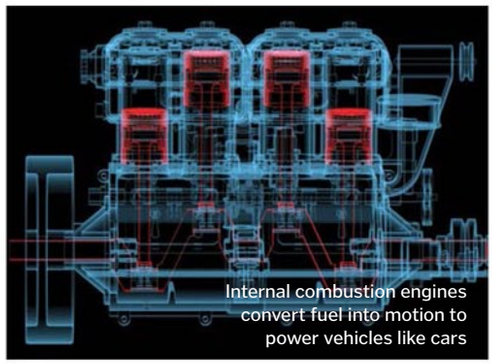
Thank you for your very kind letter, Marjorie. It's always a real pleasure for us to hear how children are enjoying HIW – and, indeed, adults too! We might be a science and tech title, but it just goes to show that reading about a subject you love has more benefits than you might first think.

Budding engineer

Hi,
I'm ten years old and I love your mag – my dad buys it for me every month and it is always interesting. I have a question: how does an engine work? I love science and engineering.

Thomas Joseph, Harlow, Essex

Hi Thomas – we're glad to hear of your interest in engineering and hope it stays with you all your life. Engines are very complicated pieces of kit to explain in just a few words, but essentially they are machines that convert fuel (eg petrol, coal or wood) into motion, which is used to power vehicles and more. Internal combustion engines, like the ones in most cars, create vast amounts of energy by squeezing fuel and air into a tight chamber and then setting it alight, using the generated gas to drive pistons. This movement is then converted into rotational energy to get the wheels rolling.



Internal combustion engines convert fuel into motion to power vehicles like cars

What's happening on... Twitter?

We love to hear from **How It Works'** dedicated followers. Here we pick a few tweets that caught our eye this month...

Rudi Kochanowski @rkocha
Howitworksdaily.com great site **@HowItWorksmag**

shane dorrian @shanedorrian3 **@HowItWorksmag** Wonder if any of Alfonso Cuarón's *Gravity* was inspired by Felix Baumgartner's space jump?

Matt Lathan @slicks1812 **@HowItWorksmag** – how can astronomers tell what kind of planet (rocky/gaseous) a distant planet is?

HP1 @HP987654321 **@HowItWorksmag** Love the helicopter part of #53 even though I prefer planes!

Nikita Hengbok @ihengbok
What does it take to sustain a whale shark? via **@HowItWorksmag**

Jennifer Denby @jennifer_denby
Great piece on @iFingerprinting's #drugtesting device in **@HowItWorksmag**

Miguel Davis @migs_1999 **@HowItWorksmag** is the best magazine ever

Monty McMont @monty_mcmont **@HowItWorksmag** 290dB isn't possible in air! Max SPL is 194dB before pressure wave peaks & valleys clip!

Rebecca Duckers @beckijayneholly Love reminding myself about #bonestructure in the **@HowItWorksmag** #bonegeek

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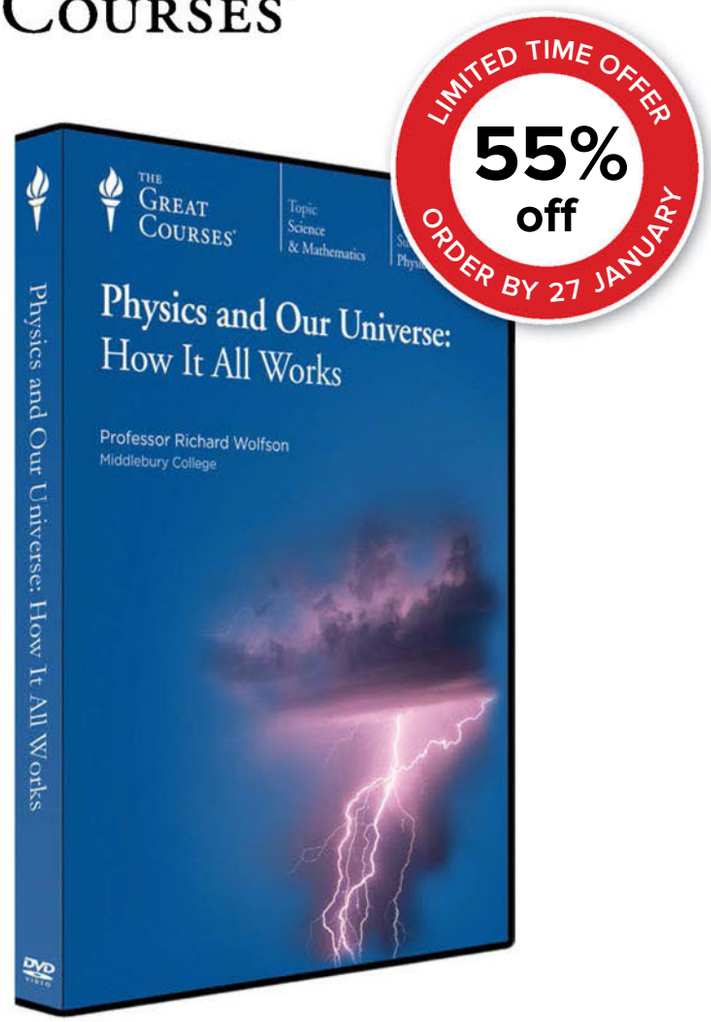

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