2 MOON POSTERS

5 FREE GIFTS

DIGITAL BOOKS
> ALL ABOUT SPACE: THE ANNUAL
> ASTRONOMY FOR BEGINNERS
> THE SPACE RACE

[WORTH] £30

All About Space

[12] TED TALKS TO WATCH RIGHT NOW

WHAT IS DARK ENERGY?
THE AMBITIOUS PLAN TO SHED LIGHT ON THE DARK UNIVERSE

WELCOME TO THE HOLOGRAPHIC UNIVERSE

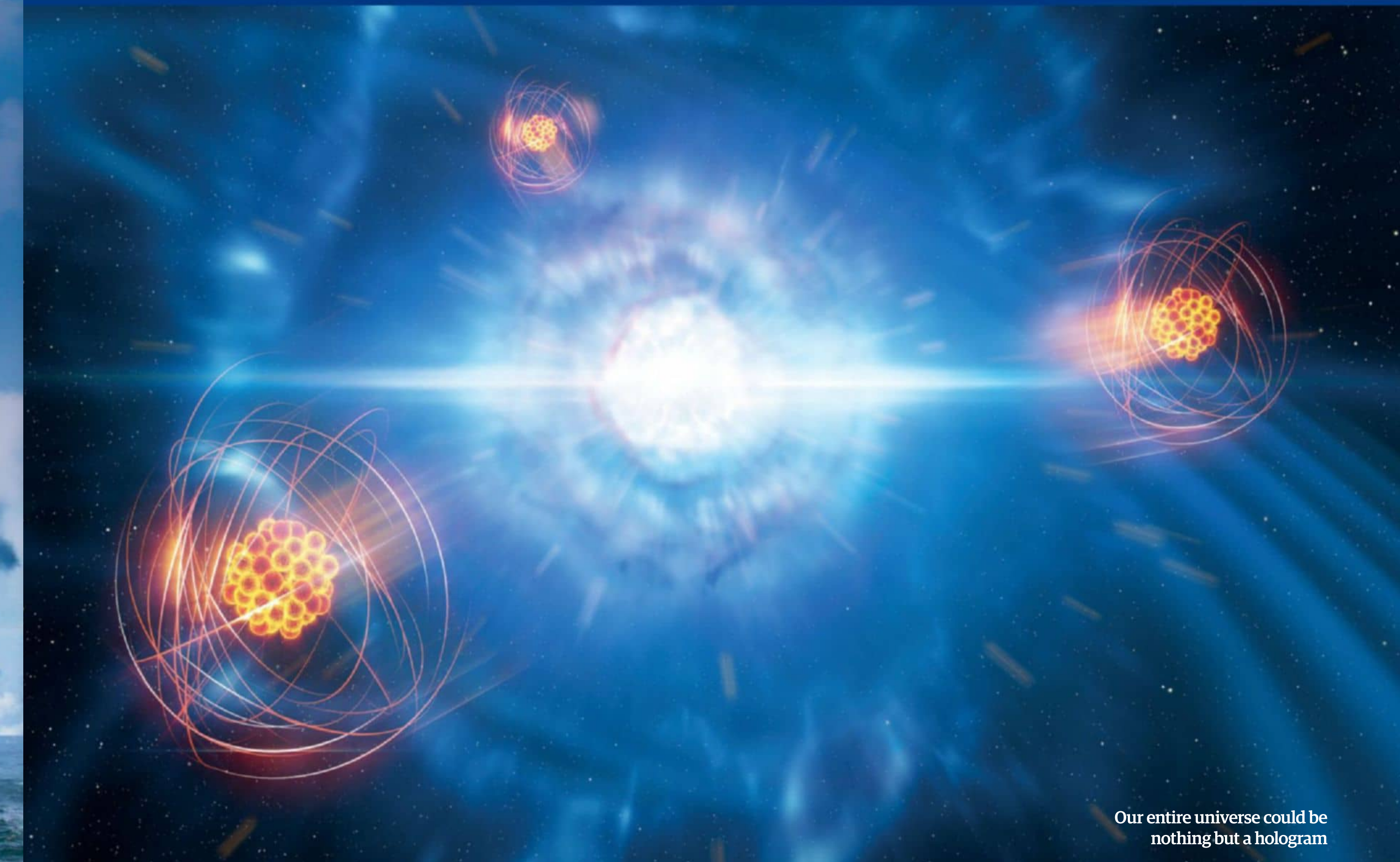
Why the reality of the cosmos might be stranger than we thought

EXCLUSIVE ANN DRUYAN INTERVIEW
"IT FEELS LIKE THERE'S A WAR AGAINST SCIENCE"

SATURN: INSIDE THE RINGED PLANET
HOW TO BUILD A ROCKET
WHAT HAPPENS IN SPACE'S BERMUDA TRIANGLE?
55 THINGS NASA HAS DONE FOR YOU

FUTURE
ISSUE 103

GET FREE ALL ABOUT SPACE BONUS CONTENT
SIGN UP ONLINE AT SPACEANSWERS.COM/NEWSLETTER



Our entire universe could be nothing but a hologram

Welcome

During these unprecedented times, I hope that you're keeping well and are making the most of isolation by reading the book you've always wanted to read, safely keeping in touch with friends and family, watching your favourite shows or even just making sure that you're making the most of your daily outdoor allowance by keeping fit or going for a stroll to clear your mind.

The **All About Space** team have been making sure that we're still bringing you the latest news in space science and space exploration, ensuring that your magazine is delivered directly to your door. What's more, we've also included three free digital eBooks to keep you and your family entertained over the next few weeks or months. We hope that you enjoy them.

If you're wanting a change of pace to reading, then how about watching some of the most inspiring TED talks on space? Turn over to page 24 for our top 12 - and be sure to share them with family and friends over the coming weeks.

If you need a hands-on activity, then we've got plenty to keep you entertained with our advice on which planets and naked-eye objects to best observe with your household, the latest telescope to buy and, of course, our monthly tour of our natural satellite, the Moon.

Before I sign off, I wanted to thank you for your loyalty to the brand and to remind you to stay safe. I'll see you next month - take care!

Gemma Lavender
Editor-in-Chief

Our contributors include...

Colin Stuart
Space science writer
Welcome to the holographic universe! Colin speaks to the researchers who have discovered that the cosmos is even stranger than we thought!

Libby Plummer
Science writer
While you're in isolation, watch some inspiring TED talks about the universe! From black holes to exoplanets, turn to page 24 for our top 12.

© Getty

Ann Druyan
Writer, producer and director
With *Cosmos: Possible Worlds* a fixture on our screens over the past few weeks, Carl Sagan's wife gives us a behind-the-scenes look.

Lee Cavendish
Staff writer
Lee reveals three new exciting projects that will help us to solve dark energy once and for all. Turn to page 38 for his full report on space's unusual substance.

ALL ABOUT SPACE ISSUE 104 ON SALE 21 MAY!
Single issues and subscriptions available at: myfavouritemagazines.co.uk

© ESO

Keep up to date

Online www.spaceanswers.com
Facebook /AllAboutSpaceMagazine
Twitter @spaceanswers

CONTENTS

www.spaceanswers.com

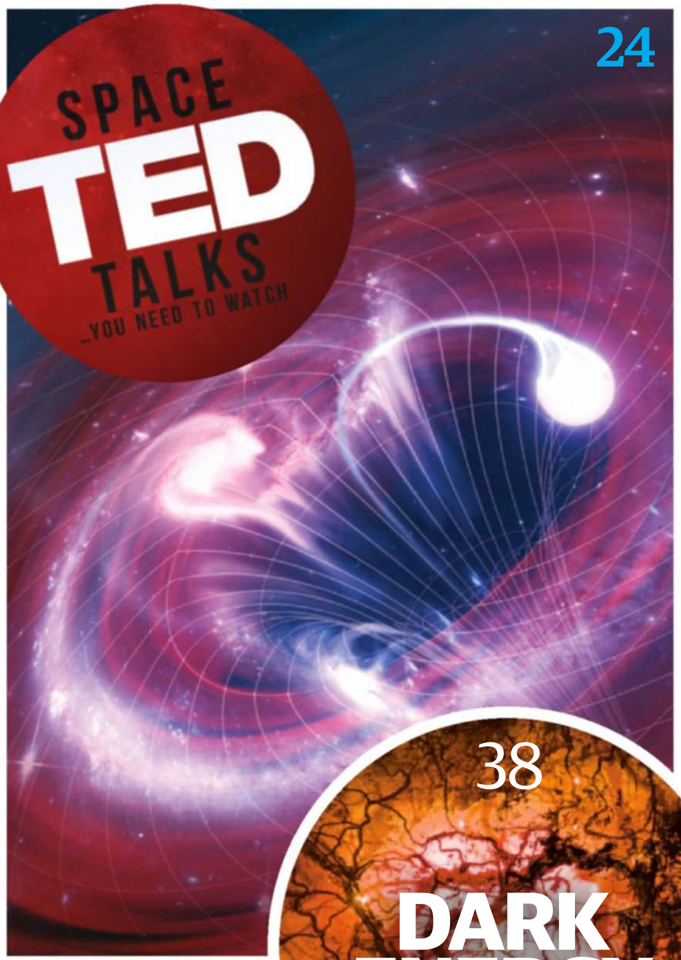
TWEET US
@spaceanswers
POST ON FACEBOOK
/AllAboutSpaceMagazine
SEND US AN EMAIL
space@spaceanswers.com

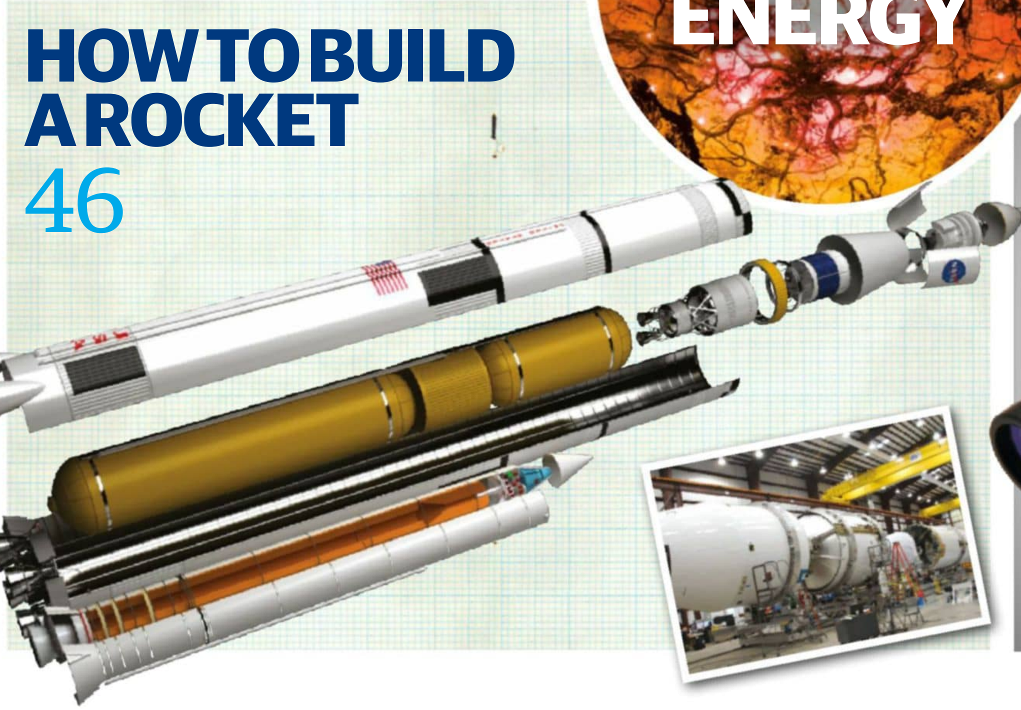
"There is a chance to get to a much better future"
28 Ann Druyan
Writer and executive producer of *Cosmos: Possible Worlds*

LAUNCH PAD
YOUR FIRST CONTACT WITH THE UNIVERSE

FEATURES

TURN TO PAGE 44 FOR DETAILS



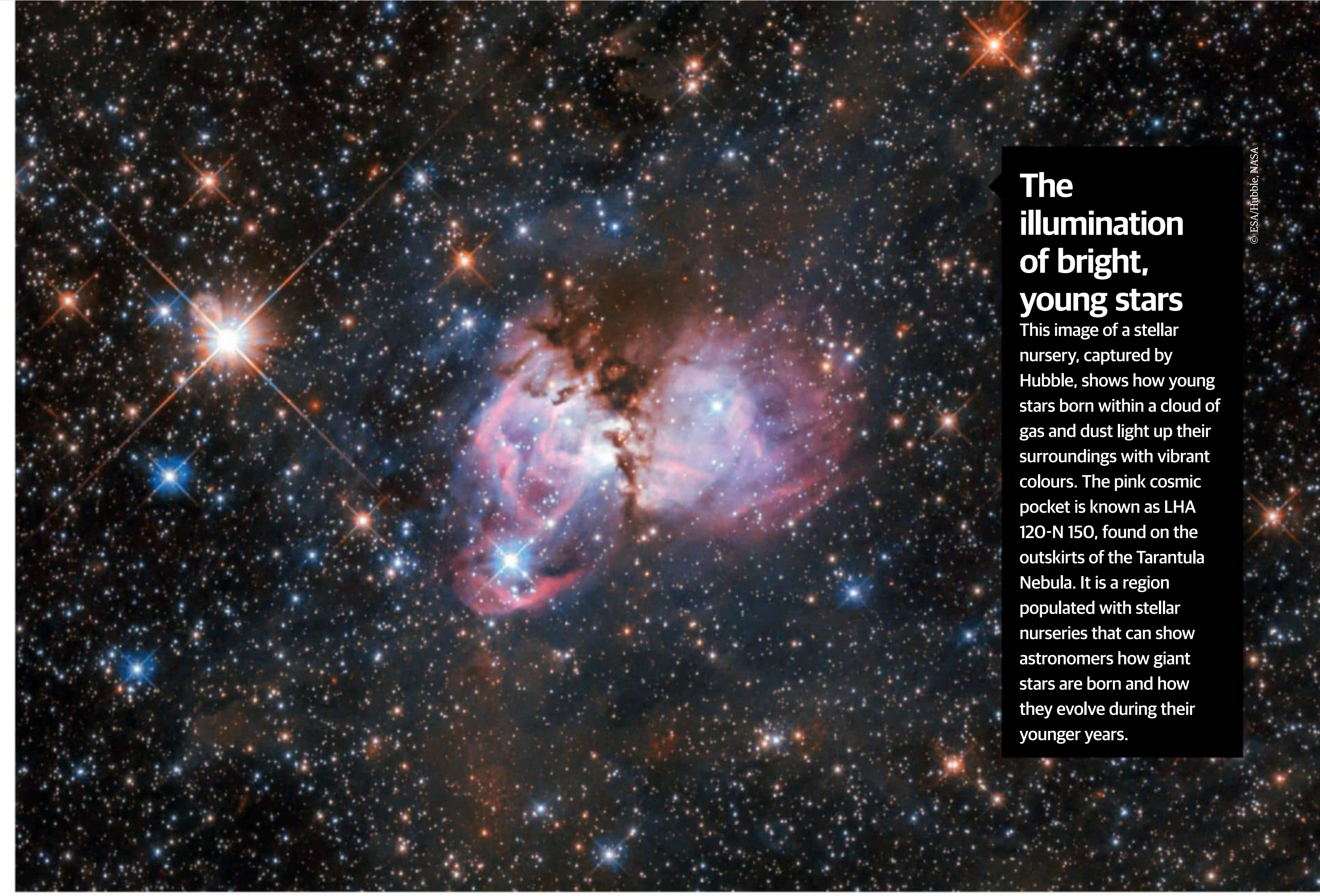


STARGAZER
Your complete guide to the night sky

Picture perfect: when the Milky Way aligns

The European Southern Observatory's Paranal Observatory is situated in a perfect part of the world for observing the night sky. In the Chilean Atacama Desert the sky is generally cloudless, and so the stars sparkle in clear heavens for most of the year. This gave one astrophotographer the chance to capture the Milky Way's band appearing to emerge from the VLT Survey Telescope. For our more eagle-eyed readers, some may have spotted the Orion constellation – with Betelgeuse shining bright – above the telescope too.

© ESO



The illumination of bright, young stars

This image of a stellar nursery, captured by Hubble, shows how young stars born within a cloud of gas and dust light up their surroundings with vibrant colours. The pink cosmic pocket is known as LHA 120-N 150, found on the outskirts of the Tarantula Nebula. It is a region populated with stellar nurseries that can show astronomers how giant stars are born and how they evolve during their younger years.

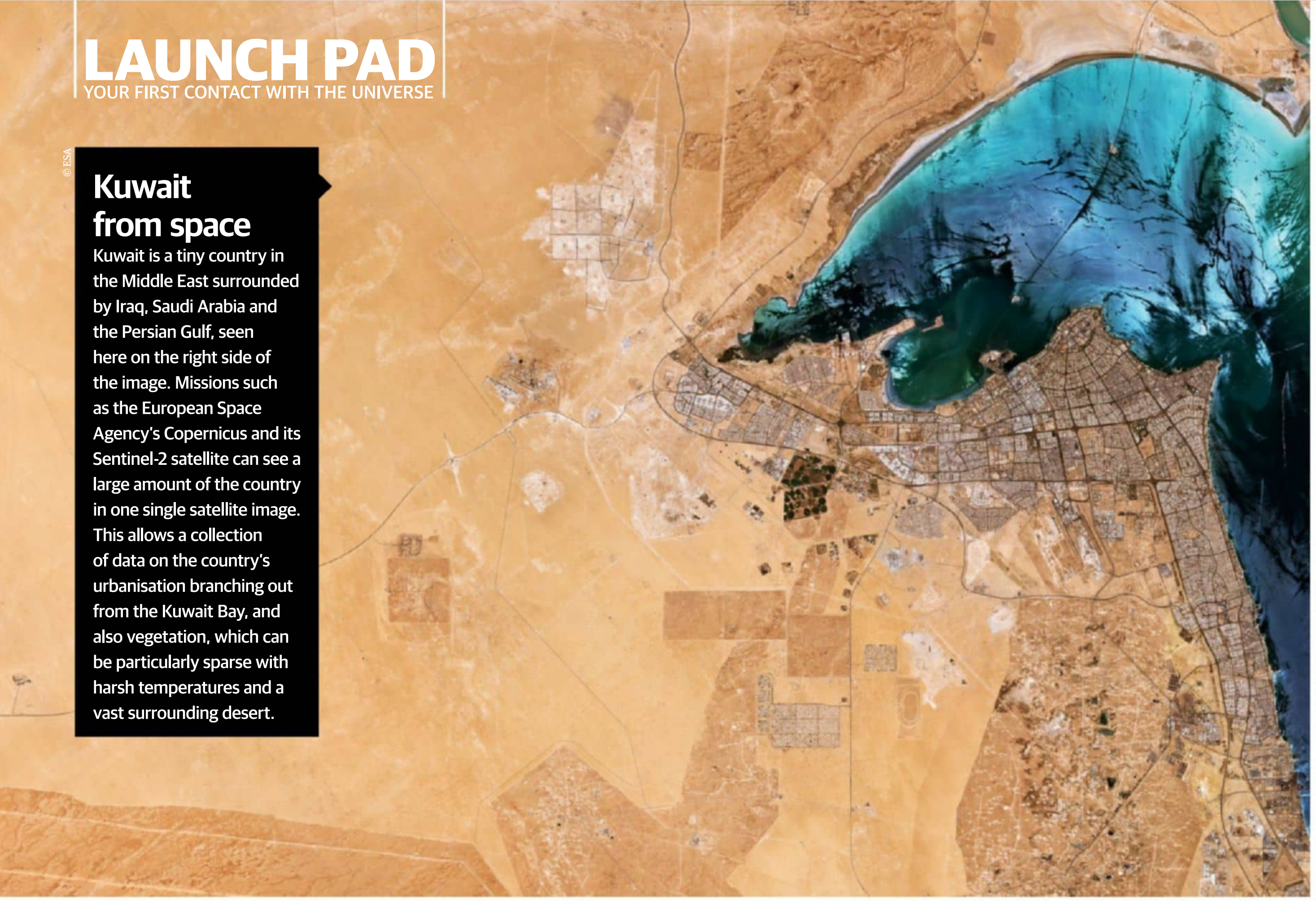
© ESA/Hubble, NASA

Psychedelic view of our black hole

This impressive shot is an unusual view of the centre of our Milky Way. Astronomers are devising new ways to study the enormous black hole at the centre of our galaxy, known as Sagittarius A*.

This image is a result of a new technique, as scientists look to study the exotic areas around our black hole, singling out neutron stars, white dwarfs and clouds of gas heated to millions of degrees. Blue and green represents X-ray data collected by NASA's Chandra X-ray Observatory and the red reveals radio data collected by the MeerKAT telescope in South Africa.

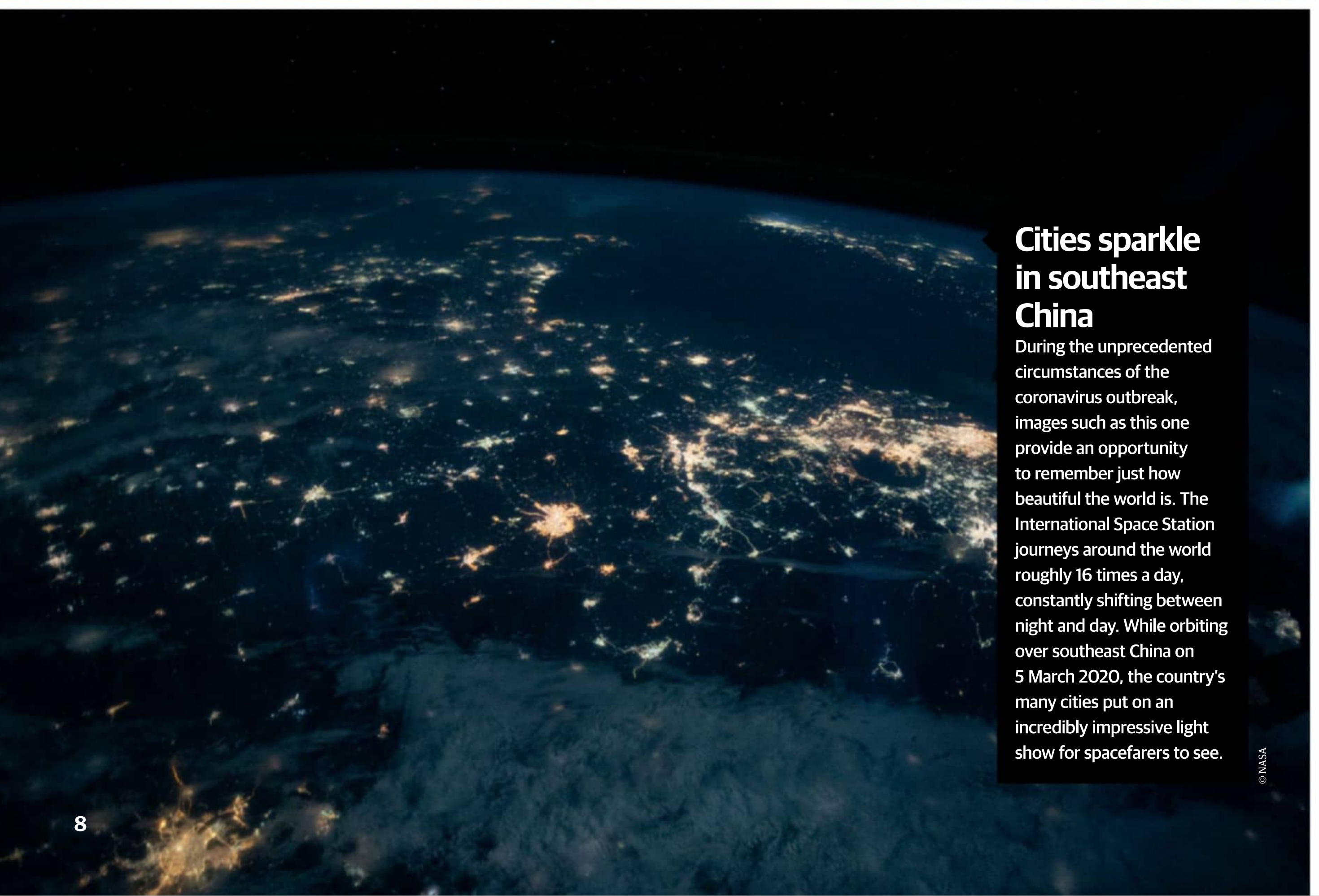
© NASA



© ESA

Kuwait from space

Kuwait is a tiny country in the Middle East surrounded by Iraq, Saudi Arabia and the Persian Gulf, seen here on the right side of the image. Missions such as the European Space Agency's Copernicus and its Sentinel-2 satellite can see a large amount of the country in one single satellite image. This allows a collection of data on the country's urbanisation branching out from the Kuwait Bay, and also vegetation, which can be particularly sparse with harsh temperatures and a vast surrounding desert.



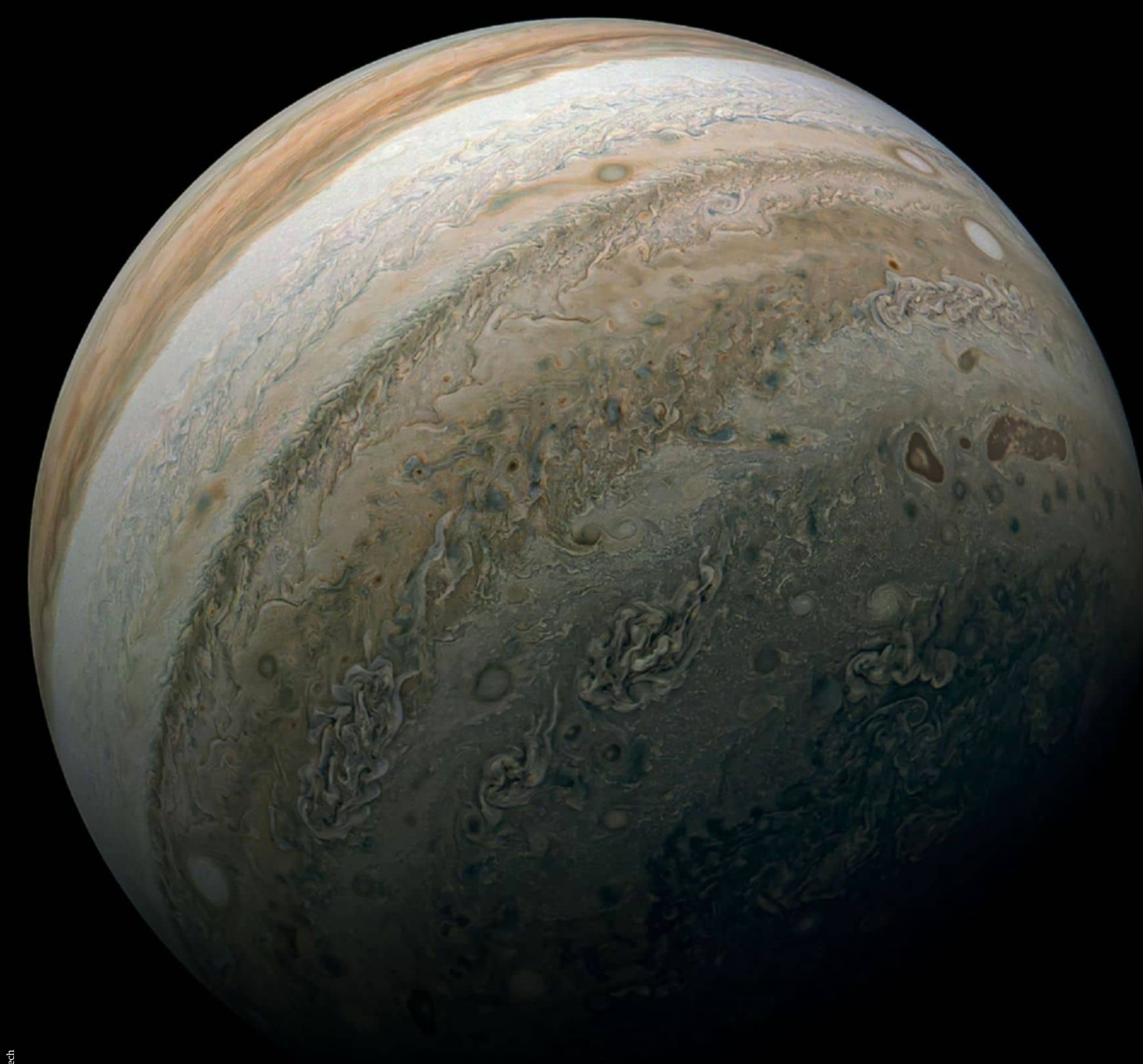
Cities sparkle in southeast China

During the unprecedented circumstances of the coronavirus outbreak, images such as this one provide an opportunity to remember just how beautiful the world is. The International Space Station journeys around the world roughly 16 times a day, constantly shifting between night and day. While orbiting over southeast China on 5 March 2020, the country's many cities put on an incredibly impressive light show for spacefarers to see.

© NASA

The magnificent marble

NASA's Juno spacecraft is always beaming back its latest up-close snapshots of the Solar System's grandest planet. However, it takes a while to see pictures like this because it requires the help of citizen scientists. In this case, the image was taken during the spacecraft's last flyby on 17 February 2020, but it wasn't released until after citizen scientist Kevin M. Gill untapped its beauty. Gill was able to emphasise the tempestuous and banded nature of the gas giant's southern hemisphere.



© NASA, JPL-Caltech

A halo of dark matter is believed to surround our home galaxy

Source: Wikipedia Commons

Our Milky Way is being used to hunt for dark matter

Words by Chelsea Gohd

Scientists studying a mysterious signal from far-off galaxies didn't find dark matter as they'd hoped. But the inventive new technique they used to detect this strange signal, which uses our own galaxy to hunt for dark matter, could elevate the hunt for the elusive material.

For decades scientists have been searching for dark matter, an invisible material that doesn't interact with light but which permeates our entire universe, influencing it with its gravity. And a signal coming from a nearby galaxy spotted in a 2014 study gave scientists hope that this was the long-sought evidence for dark matter.

Some current models predict that dark matter particles slowly decay into ordinary matter, a process that would produce faint photon emissions that X-ray telescopes could detect. And in 2014 scientists spotted an X-ray emission from a galaxy in a dark matter hunt, as it's known that dark matter collects around galaxies.

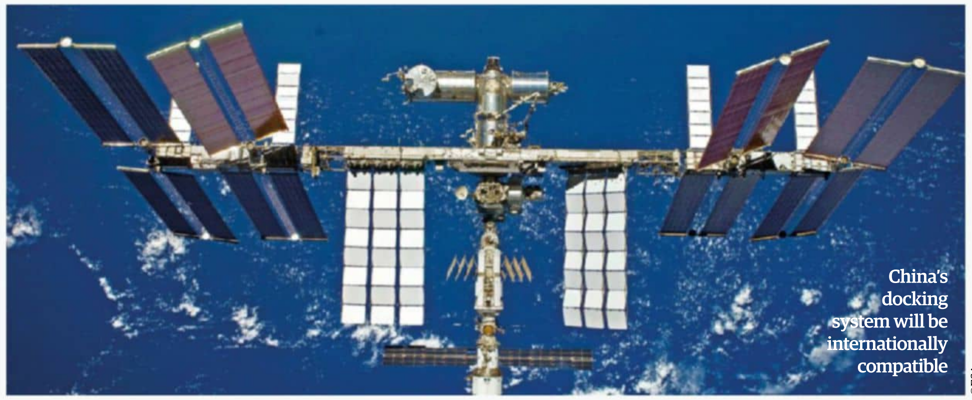
Researchers think that the emission, known as the '3.5 keV (kilo-electronvolt) line', is likely made of sterile neutrinos, which have long been thought of as a candidate for dark matter, study co-author Chris Dessert of the University of Michigan said.

Sterile neutrinos are hypothetical particles that are a close relative of the neutrino, a neutral subatomic particle with a mass very close to zero. They are released in nuclear reactions like those in nuclear plants on Earth and in the Sun. Because the tiny amount of mass in neutrinos can't be explained by the Standard Model of particle physics, some think that sterile neutrinos could make up this mystery mass that is actually dark matter.

To come to this conclusion, researchers looked for the 3.5 keV line in the sky. Since we live in the Milky Way's dark matter halo, any observation made through the halo must have dark matter in it. So when the team found no trace of a 3.5 keV line in the data, they determined that "the 3.5 keV line isn't due to dark matter," Dessert said.

While the 3.5 keV signature is most likely caused by sterile neutrinos, this might seem to rule out the hypothetical particle as a candidate for dark matter. But it's still possible that different mass sterile neutrinos, which wouldn't put out the same signal, could explain the elusive material. While Dessert admitted it was fairly disappointing that the researchers didn't observe a 3.5 keV line, the technique they developed could further the search for the elusive material.

"While this work does throw cold water on what looked like what might have been the first evidence for the microscopic nature of dark matter, it does open up a whole new approach to looking for dark matter, which could lead to a discovery in the near future," said Ben Safdi, an assistant professor of physics at the University of Michigan. "In the past people have said, 'Well let's look at a part of the sky that has a huge amount of dark matter in it and let's see if we see [dark matter] there,'" said Kerstin Perez of the Massachusetts Institute of Technology.



China's docking system will be internationally compatible

©ESA

China's new crew spacecraft to dock with Space Station

Words by Andrew Jones

A next-generation crew spacecraft that China is preparing for a flight test this spring appears to be capable of docking with the International Space Station (ISS). An image posted by the Shanghai Academy of Spaceflight Technology (SAST) shows the new spacecraft's docking system, which appears compatible with the International Docking System Standard (IDSS). NASA, the European Space Agency and Russia's federal space agency, known as Roscosmos, use IDSS-compatible systems or adapters. These are in use on the ISS to facilitate rendezvous and docking with spacecraft.

The new craft is designed to boost China's capabilities in sending humans into orbit, reduce costs through partial reusability and allow astronauts to survive the radiation environment and high-speed re-entries of deep-space missions. It will be capable of carrying six astronauts or three astronauts and 500 kilograms of cargo to China's planned space station. A prototype is being prepared at the Wenchang Spacecraft Launch Site.

The IDSS docking mechanism is androgynous. The first such system was developed and used for the 1975 Apollo-Soyuz Test Project, meaning that neither the US nor Soviet spacecraft had 'male' or 'female' mechanisms.

China has demonstrated rendezvous and docking capabilities with Shenzhou crewed spacecraft and the Tiangong-1 and Tiangong-2 space labs, as well as with the Tianzhou cargo spacecraft.

The rendezvous systems on spacecraft, which facilitate the manoeuvring and matching of vectors and velocities for close approaches, may, however, need to be adapted to be compatible.

Old gas blob from Uranus found in Voyager 2 data

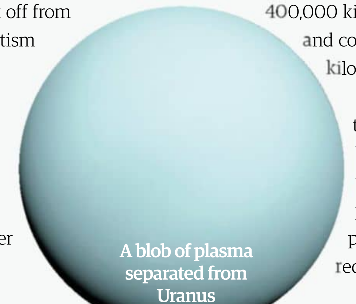
Words by Meghan Bartels

Buried inside data that NASA's iconic Voyager 2 gathered at Uranus more than 30 years ago is the signature of a massive bubble that may have stolen a blob of the planet's gassy atmosphere. The tiny wobble in the Voyager 2 data represents something much larger since the spacecraft was flying so fast.

Scientists behind the new research believe the zigzag marks a plasmoid, a type of structure that wasn't understood particularly well at the time of the flyby in January 1986. A plasmoid is a massive bubble of plasma, a soup of charged particles. Plasmoids can break off from the tip of the sleeve of magnetism surrounding a planet like a teardrop. Scientists have studied plasmoids at Earth and nearby planets, but never at Uranus or its neighbour Neptune, since Voyager 2 is the only spacecraft to date ever to visit those planets.

Scientists want to know about plasmoids because these structures can pull charged particles out of a planet's atmosphere and fling them into space, and if you change a planet's atmosphere, you change the planet itself. Uranus' situation is particularly complicated because the planet rotates on its side and its magnetic field is skewed from both that axis and the plane all the planets lie in. Because Voyager 2 flew straight through this plasmoid, scientists could use the archived data to measure the structure, which they believe was about 400,000 kilometres (250,000 miles) across and could have stretched 204,000 kilometres (127,000 miles) long.

Ideally scientists would piece together more observations of Uranus' magnetic field, enough to better understand how this phenomenon has shaped the planet over time. But that will require another spacecraft visit.



A blob of plasma separated from Uranus

©NASA

© ESO

Neutron star crash helped form our Solar System

Words by Nola Taylor Redd

Astronomers are on the hunt for the remnants of the neutron-star collision that gave Earth its precious metals. When neutron stars merge they spew a wealth of short-lived elements into their surroundings, and these materials become part of later-forming solar systems. Now scientists are trying to close in on the merger that seeded our Solar System by tracing the elements produced by the original decaying material. From that work they believe the responsible merger occurred 100 million years before and 1,000 light years away from the birth of our Solar System.

"It was close," the project's lead scientist Szabolcs Marka, who is a physicist at Columbia University, said. "If you look up at the sky and you see a neutron-star merger 1,000 light years away, it would outshine the entire night sky."

Marka and his colleague Imre Bartos, an astrophysicist at the University of Florida, used meteorites from the dawn of the Solar System to track down the collision. They analysed the isotopes - flavours of elements with different numbers of neutrons in their atoms - in these rocks.

First they calculated the quantity of radioactive isotopes in the early Solar System; then the researchers compared their measurements with the amount of isotopes produced by neutron-star mergers.

The universe's heavy elements, such as gold, platinum and plutonium, form when neutrons bombard existing atoms. During such collisions, a neutral neutron can emit a negatively charged electron, becoming a positively charged proton and changing the atom's identity.

This process, known as rapid neutron capture, occurs only during the most powerful explosions, such as supernovae and neutron-star mergers. But scientists continue to debate which of these extreme events is responsible for the bulk of heavy elements in the universe.

Above: A collision would have provided the heavier elements found in our Solar System

Distant 'quasar tsunamis' are ripping their own galaxies apart

Words by Brandon Specktor

At the centre of almost every galaxy in the universe is a supermassive black hole, gobbling up incredible amounts of matter and belching out incredible amounts of radiation. The biggest and hungriest of these gobblers - called quasars, or quasi-stellar objects, because they look deceptively like stars when seen through most telescopes - are some of the most energetic objects in the universe.

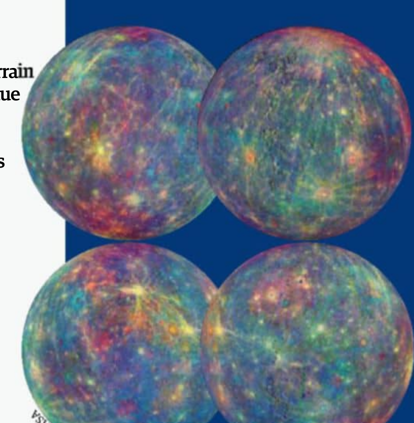
© ESO

As infalling matter swirls around the quasar's maw at near-light speed, that matter heats up and flies outwards, propelled by the incredible force of its own radiation. All that intergalactic indigestion makes a quasar an awesome sight, capable of shining a thousand-times brighter than a galaxy of 100 billion stars. However, a series of new papers suggests the very same radiation that puts quasars on our maps of the universe may be devastating the galaxies that host the insatiable objects.

In six studies, astronomers used Hubble to spy on 13 quasar outflows - gusts of high-speed radiation pouring out of distant quasars. By observing the outflows over several years and in many wavelengths across the electromagnetic spectrum, the team found that the wind and gas gushing out of a quasar can travel at more than 64 million kilometres (40 million miles) per hour and reach billions of degrees in temperature, rampaging through the galaxy's disc like a tsunami.

Left: Powerful quasars are tearing through their host

Right: Mercury's chaotic terrain could be due to the presence of volatiles



© NASA

IN COOPERATION WITH SPACE.com

Mercury might have had the ingredients for life

Words by Chelsea Gohd

In 1974 NASA's Mariner 10 probe flew by Mercury and observed a cracked, cratered landscape. Now, according to one new theory, Mercury's fractured 'chaotic terrain' could've been formed by volatiles - elements and compounds that can easily jump from a gas to a liquid or solid - under the surface. Volatiles, a chemical category that includes water, are essential for sparking and supporting life as we know it, so their potential presence on Mercury is intriguing.

The study, led by Alexis P. Rodriguez, a researcher at the Planetary Science Institute in Arizona, took a closer look at Mercury's chaotic terrain and the possibility that volatiles once shaped a planet with surface temperatures hot enough to melt lead - a planet that has forever been thought of as being 'completely inhospitable'. "A key to the discovery was the finding that the development of Mercury's chaotic terrains persisted until approximately 1.8 billion years ago, 2 billion years after the Caloris basin formed," said Dan Berman, also of the Planetary Science Institute.

WIN

HELIOS 10x50 SOLANA BINOCULARS

These porro-prism binoculars are waiting to unveil some glorious sights - whether it's spotting stars or nature watching

Thanks to Optical Vision Ltd, **All About Space** is able to offer one lucky winner a pair of 10x50 Solana binoculars, perfect for both terrestrial and astronomical observations. These binoculars are made with high-quality BK-7 porro prisms, offering excellent magnification and light-capturing ability, and are encased within a rubber armour for protection and comfort.

By combining excellent, lightweight performance, the Solana 10x50 binoculars are great to take on any adventure. With spring now in full force, there's a fine selection of constellations and targets to explore. Whether it's planets or some of the brighter celestial sights listed in Messier's catalogue, these binoculars will provide an engaging and high-definition experience.

To be in with a chance of winning, answer this question:

Which of the Apollo missions was first to bring a rover to the lunar surface?

A: Apollo 11 **B:** Apollo 15 **C:** Apollo 17

Competition ends on 23 May 2020

Enter online at **spaceanswers.com** or by post to
All About Space competitions, Richmond House, 33 Richmond Hill, Bournemouth, BH2 6EZ

Visit the website for full terms and conditions at **futureplc.com/terms-conditions/**

Holographic universe

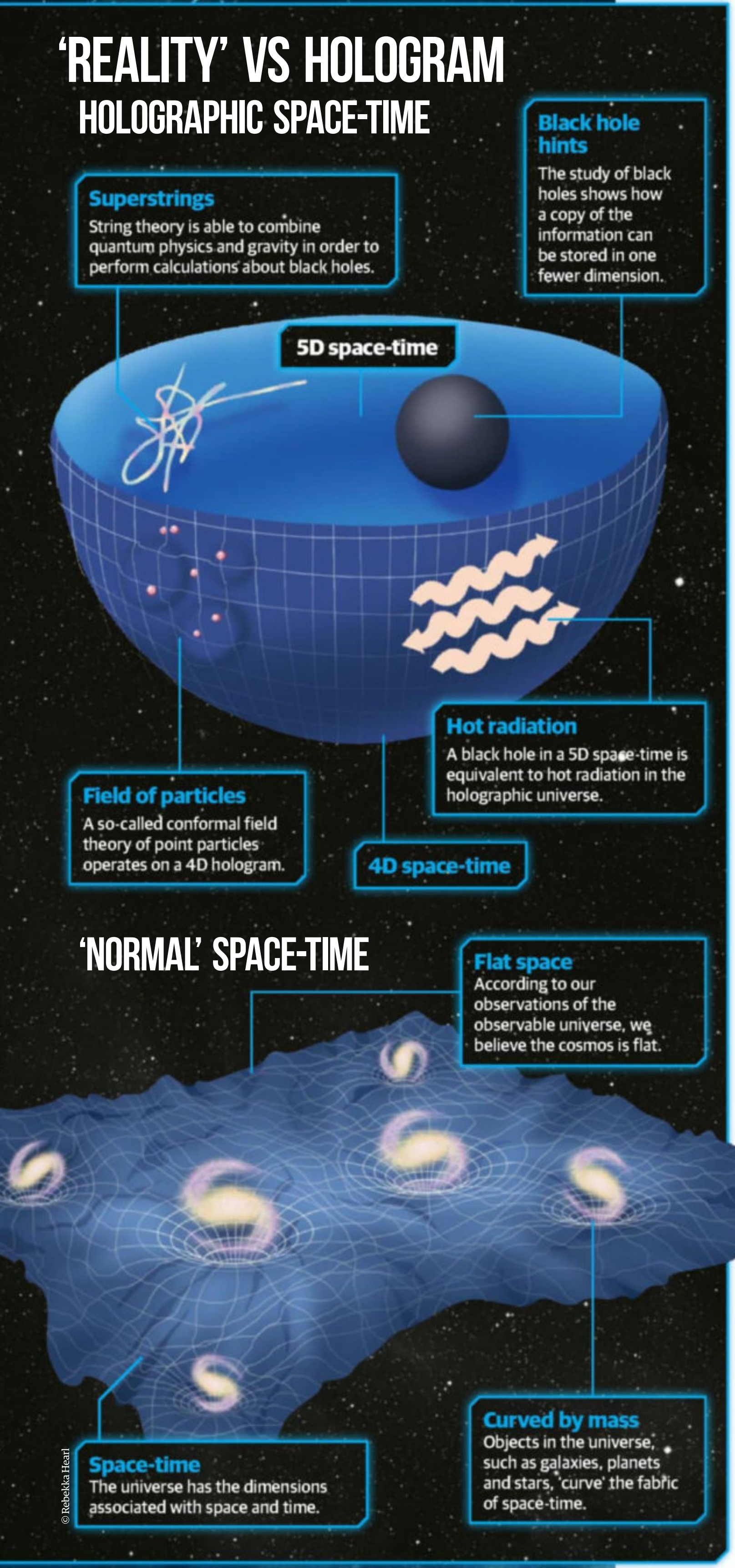
WELCOME TO THE HOLOGRAPHIC UNIVERSE

According to current research, the reality of the cosmos may be stranger than you think

Reported by Colin Stuart

Picture a room filled with books. Then imagine that all the books suddenly disappear. All the information they contained would be lost, right? All the plot lines, characters and happy endings would vanish into thin air. But this library is different. Here all the information inside the room is also encoded on the floor, the walls and the ceiling. Even though the books themselves are gone, you can still retrieve all of the details they contained by looking at the surfaces that once enclosed them. Want to know how that story ended? Read the wallpaper. Whodunnit? Consult the carpet. Sounds downright weird, doesn't it?

Our imaginary library gets stranger though. If the books disappeared, but the information in them didn't, did the books even exist at all? Or were they just a projection of the information on the walls, carpet and ceiling? After all, holograms like the ones found on credit cards work in a similar fashion. Viewed in one way they look three dimensional, but all the information they contain is actually encoded in only two dimensions. It is the same information presented differently.



© Rebekka Hearl

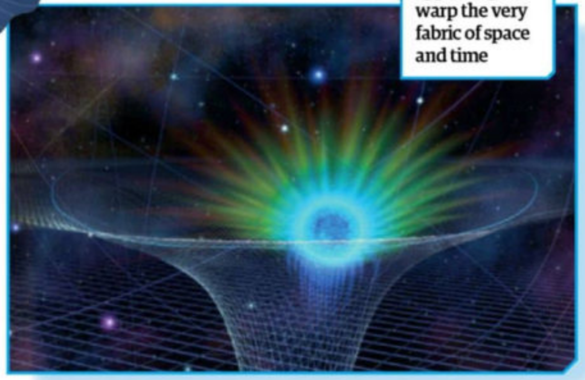
The remarkable thing is that there is growing evidence our universe behaves just like this bizarre library, and that everything we see within it might just be a holographic projection of information encoded on some far-distant boundary. "Even gravity might be an illusion," says Daniel Grumiller, an associate professor from the Vienna University of Technology in Austria.

As with many of the universe's greatest mysteries, this one starts with black holes. A black hole is what you get when a really big star dies. At the end of its life, the star's dense iron core collapses and rips a hole in space into which nearby objects irretrievably fall. These extreme objects are at the centre of physics' ultimate quest: to unite the theories of quantum physics and general relativity. The former is our best description of atoms and the very small; the latter is our most successful explanation of gravity and the very big. However, Stephen Hawking applied both quantum physics and general relativity to black holes in the 1970s and suggested that if both theories were right then information is destroyed inside black holes. This so-called 'black hole information paradox' is something many physicists just can't accept. The reason the idea is so abhorrent is that it goes against a fundamental principle of quantum physics called determinism. It says that if you have a complete set of information about an object at a given time, you should be able to work out what it was up to before. However, if that information is destroyed then this is no longer possible.

Imagine that you set fire to a page in a book. The information it contained would not be entirely destroyed. While it would be insanely impractical to do so, in theory you could collect all of the ashes and retrieve the original information written on the page because, to a physicist's eyes at least, that original information hasn't vanished from the universe. "It would be nearly impossible to get back in any practical sense, but provided you traced all the ash particles you could do it, at least in principle," says Grumiller. There's still a way you can reconstruct the system's earlier state from its present state. However, Hawking's initial conclusion from applying quantum physics and general relativity to black holes was that information about matter falling in is destroyed – it is impossible to ever get it back.

Then physicists came up with a way to potentially spare their blushes. They realised that just like our library, a copy of all the information about the objects inside a black hole might also be encoded on its two-dimensional perimeter, known as the 'event horizon'. "We call this idea the holographic principle," says Grumiller. There are some problems with this idea, however, and physicists are still frantically trying to sort out the details. Perhaps the biggest stumbling block is the so-called 'firewall paradox', a theory that says that information isn't lost if it is left imprinted on the event horizon – a black hole's point of no return.

But why stop at black holes? If every three-dimensional object inside a black hole can be equivalently described by information on an external two-dimensional surface, why can't the same be true of the universe as a whole? Perhaps



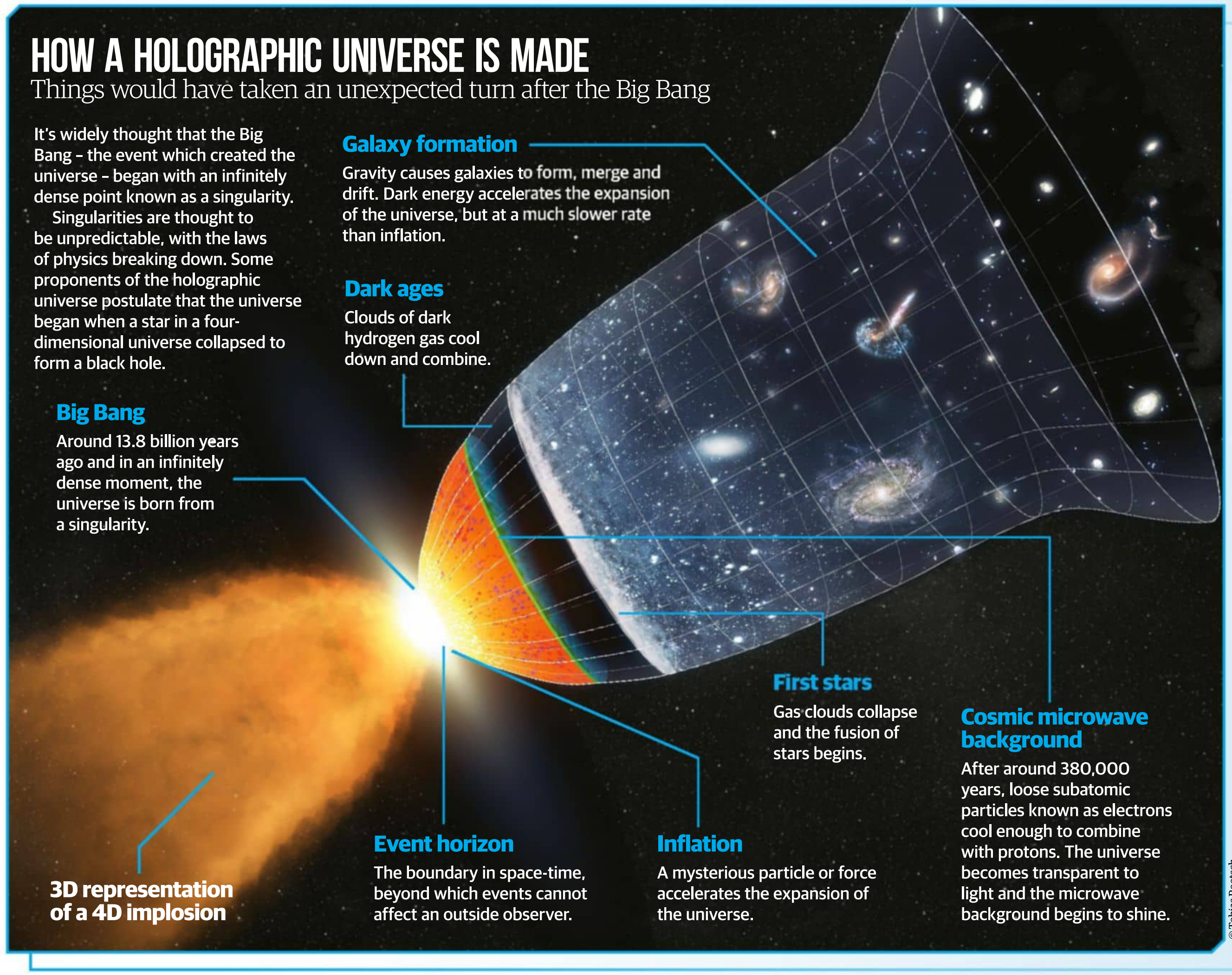
Below: An artist's impression of a black hole, appearing to warp the very fabric of space and time

© Nicolle Fuller/National Science Foundation

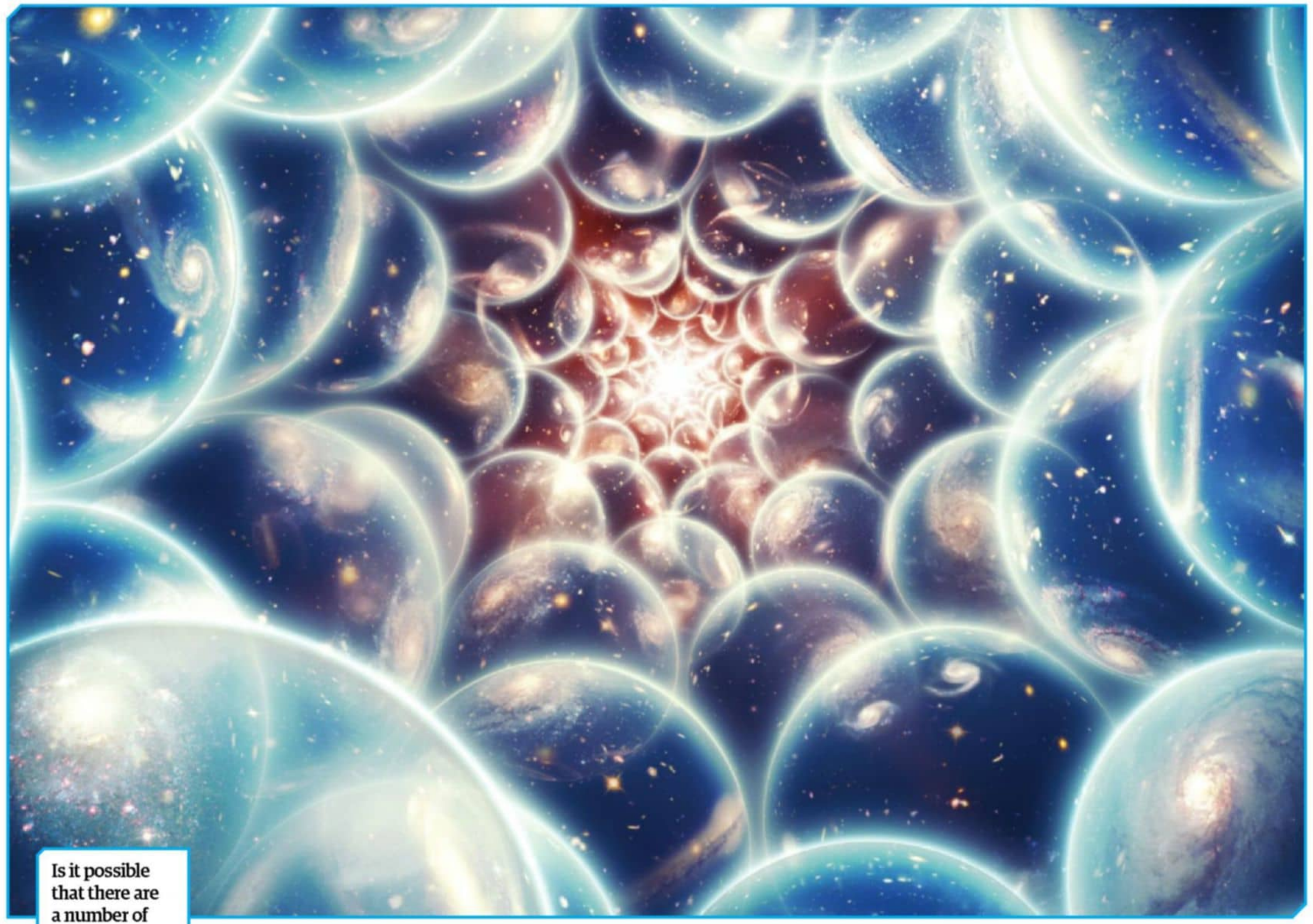
"A COPY OF ALL THE INFORMATION ABOUT THE OBJECTS INSIDE A BLACK HOLE MIGHT ALSO BE ENCODED ON ITS TWO-DIMENSIONAL PERIMETER"

An interferometer is using laser beams and mirrors to test the holographic principle

© Fermilab



© Tobias Roetsch



© Tobias Roetsch

Is it possible that there are a number of holographic universes?

what we perceive as our three-dimensional existence is merely a projection of information residing on some distant two-dimensional surface, just like the books were a projection of information that was actually on the walls and ceiling of the library. For some this is a very powerful idea, one that might lead to a successful theory of quantum gravity. That theory is so sought after because it would be able to explain the very small and the very big at the same time – a one-size-fits-all description of the entire universe. The big issue with uniting quantum physics and general relativity into one coherent theory is that they seem like pieces from two different puzzles – they refuse to neatly fit together. For decades physicists have been working on ways to get them to play nice, with string theory a leading contender.

This idea basically says that subatomic particles – those that in turn build atoms – are actually made up of tiny vibrating strings. Just as you can play strings on a musical instrument in different ways to produce different notes, so different particles are formed by these strings vibrating in different ways. The trouble is that this theory can only join the puzzle pieces together if the universe has substantially more dimensions than we experience. To reconcile that with what we see around us, these additional dimensions are – rather conveniently – said to be curled up really small, and so remain out of sight.

But in 1997, theoretical physicist Juan Maldacena made a breakthrough. He invoked the holographic principle, proposing that the messy world of string theory might just be a projection of a much simpler reality. If string theory is the hologram, we should be looking for the equivalent rules in fewer dimensions – the walls instead of the books. Then, rather than inventing multiple unseen dimensions to get quantum gravity to work, we could accept that one of the dimensions we experience is an illusion. "Some aspects of quantum gravity are much easier to calculate using this alternative picture," says Grumiller.

It took until 2013 for these rules to be found. A team of Japanese physicists led by Yoshifumi Hyakutake calculated some properties of a black hole using string theory with all its extra dimensions. They then did the same calculation using quantum physics, but in one fewer spatial dimension than we're used to. Remarkably, the two sets of calculations matched, so their work says that string theory is equivalent to quantum physics, albeit in fewer dimensions. Perhaps what we perceive as the universe is just a hologram based on the rules of quantum physics playing out on some distant surface with one fewer dimension. As the latter makes no mention of gravity, this implies that gravity is part of the hologram.

"PERHAPS WHAT WE PERCEIVE AS OUR THREE-DIMENSIONAL EXISTENCE IS MERELY A PROJECTION OF INFORMATION RESIDING ON SOME DISTANT TWO-DIMENSIONAL SURFACE"

Holographic universe

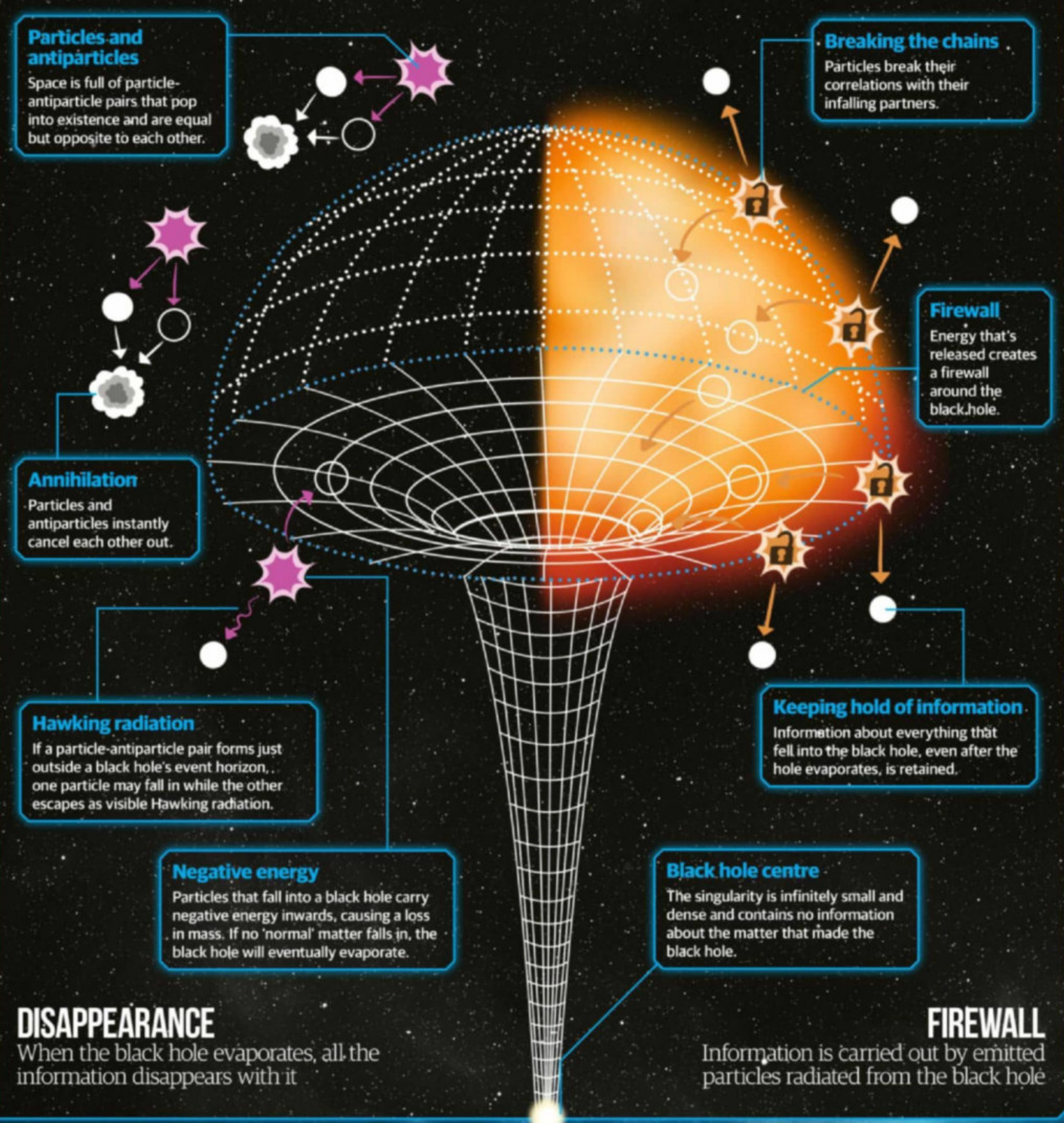
A scientist works on the technology behind Fermilab's Holometer experiment, which is looking for tiny jitters in space itself

© Fermilab

THE FIREWALL PARADOX

How black holes could hint at a holographic universe

Physicists get around the problem of information being lost if a copy of that data is left imprinted on the event horizon. In quantum physics, two copies of the same information technically shouldn't exist. However, you can dodge that bullet by saying that a person inside the black hole can't see the information on the event horizon and a person outside the event horizon can't see the information inside it. Complications then arise due to black hole evaporation, predicted by Stephen Hawking. Once roughly half of the black hole has evaporated, there is no longer enough data on the edge of the black hole to match the information inside it. General relativity predicts that anyone passing through the event horizon would hit a 'firewall' and be burnt to a crisp. This goes against the normal prediction of general relativity that says you shouldn't notice anything different when passing this imaginary line – but you would certainly notice getting fried!



Although Grumiller notes that "if you run over the edge of a cliff you'll still fall down".

However, as is often the case, there is a catch. Both Maldacena and Hyakutake's teams performed their calculations in a hypothetical universe in which the overall shape of space does not match our own. Cosmologists believe that our local universe is flat. That is to say it has no overall curvature and the angles of a triangle drawn between three points add up to 180 degrees, just as on a sheet of paper. But both Maldacena and Hyakutake's work was based on a universe with 'negative curvature' as the calculations were easier to solve. Such universes are saddle shaped and triangles drawn on the surface have angles adding up to less than 180 degrees.

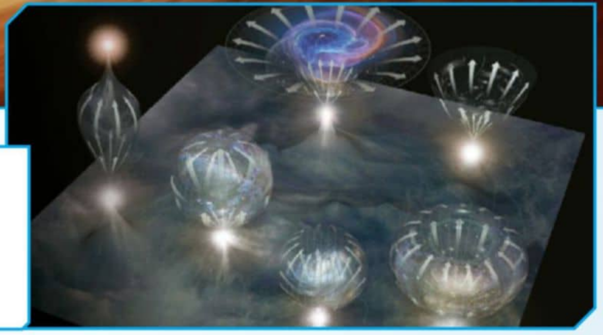
For the holographic principle to be taken seriously by physicists, it would have to be shown to apply to flat universes too. Inspired by this problem, Grumiller and colleagues spent three years trying to get it to work, and they announced their findings in early 2015. "We found that the holographic principle can indeed be applied to flat space too," he says. Suddenly the idea of our three-dimensional experience of the universe being a hologram was back on the table. As things stand the case for the holographic principle is on a firm theoretical basis. It seems – at least on paper – that we can explain everything we see around us in fewer dimensions than are apparent. But that's only half the battle. Like any scientific theory, it needs experimental proof to back it up. The theory needs to make a prediction that researchers can go out and test.

Such a prediction is currently being tested by Craig Hogan with his 'Holometer' experiment at the Fermilab particle physics facility in the US. If the universe can be explained purely in quantum physics terms, then all the rules you'd normally associate with the theory don't just apply to atoms, but also to space itself. The quantum realm is notoriously counter-intuitive. It is possible for a subatomic particle to be in two places at once simultaneously. Similarly, you can never pin down the precise location of an atom – you can only assign probabilities to where it is most likely to be. "The holographic principle is telling us that this uncertainty should also apply to the fabric of space," says Hogan. This means that on the smallest scales, space itself should be blurry. Picture it like a photograph. Seen on a computer screen the photo looks continuous. But zoom in enough and you see it is actually made of discrete chunks – its constituent pixels. On the smallest scales, the photograph is actually blurry. The same could be true of space.

Hogan set up the Holometer experiment to test this idea. His equipment is what physicists call an interferometer. Laser beams are bounced off mirrors along two equal paths – or 'arms' – that are at right angles to each other. The laser beams then meet in the middle and a detector picks up this combined beam. But the laser beams only combine perfectly if they take exactly the same time to travel along each arm. If one is delayed along the way then it will lag behind the other and they won't join up properly. "If the holographic principle holds then the quantum uncertainty associated with space should cause 'jitters' in the experiment," says Hogan. These jitters would cause a delay of around 10 to 25 seconds in the arrival time of one of the beams. That's just one ten trillionth of a trillionth of a second.

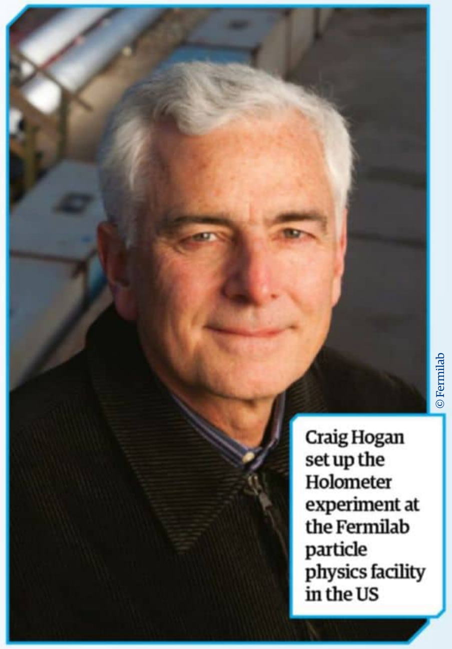
The bad news is that Hogan's experiment ran for 140 hours and found no such jitters. "But it's not over," Hogan says. "We've only ruled out one particular type of blurriness." Undeterred, he has reconfigured the experiment to look for evidence of a slightly different version of the holographic principle. The quest to find out whether what we see around us – including gravity itself – is an illusion continues. But if experiments like Hogan's are successful, we might have to completely re-evaluate everything we thought we knew.

Astronomers are struggling to answer the 'black hole information paradox'



Three-dimensional universes could exist on a two-dimensional plane

"THE HOLOGRAPHIC PRINCIPLE IS TELLING US THAT THIS UNCERTAINTY SHOULD ALSO APPLY TO THE FABRIC OF SPACE" **CRAIG HOGAN**



Craig Hogan set up the Holometer experiment at the Fermilab particle physics facility in the US

NAUTILUS-X

The artificial-gravity spacecraft that could take humans to the Moon and beyond

When it comes to manned missions into deep space there is no shortage of proposals. People have dreamt up spacecraft with various fantastical elements, from futuristic propulsion engines to somewhat ambitious aesthetic designs, but one proposal that warrants a serious glance is Nautilus-X. It's a spacecraft that builds largely on existing technology to make human exploration of the Solar System a realistic possibility, and at a reasonable price too.

Drawn up by NASA engineers Mark Holderman and Edward Henderson, the name stands for Non-Atmospheric Universal Transport Intended for Lengthy United States Exploration. Nautilus-X would be capable of supporting a crew of six for missions lasting from one month to two years. Although it might look like a mini space station, the whole thing is designed to be able to travel throughout the Solar System, be it near the Moon or Mars. Although incapable of descending to the surface of another world itself, it has docking ports to which landing craft can be attached.

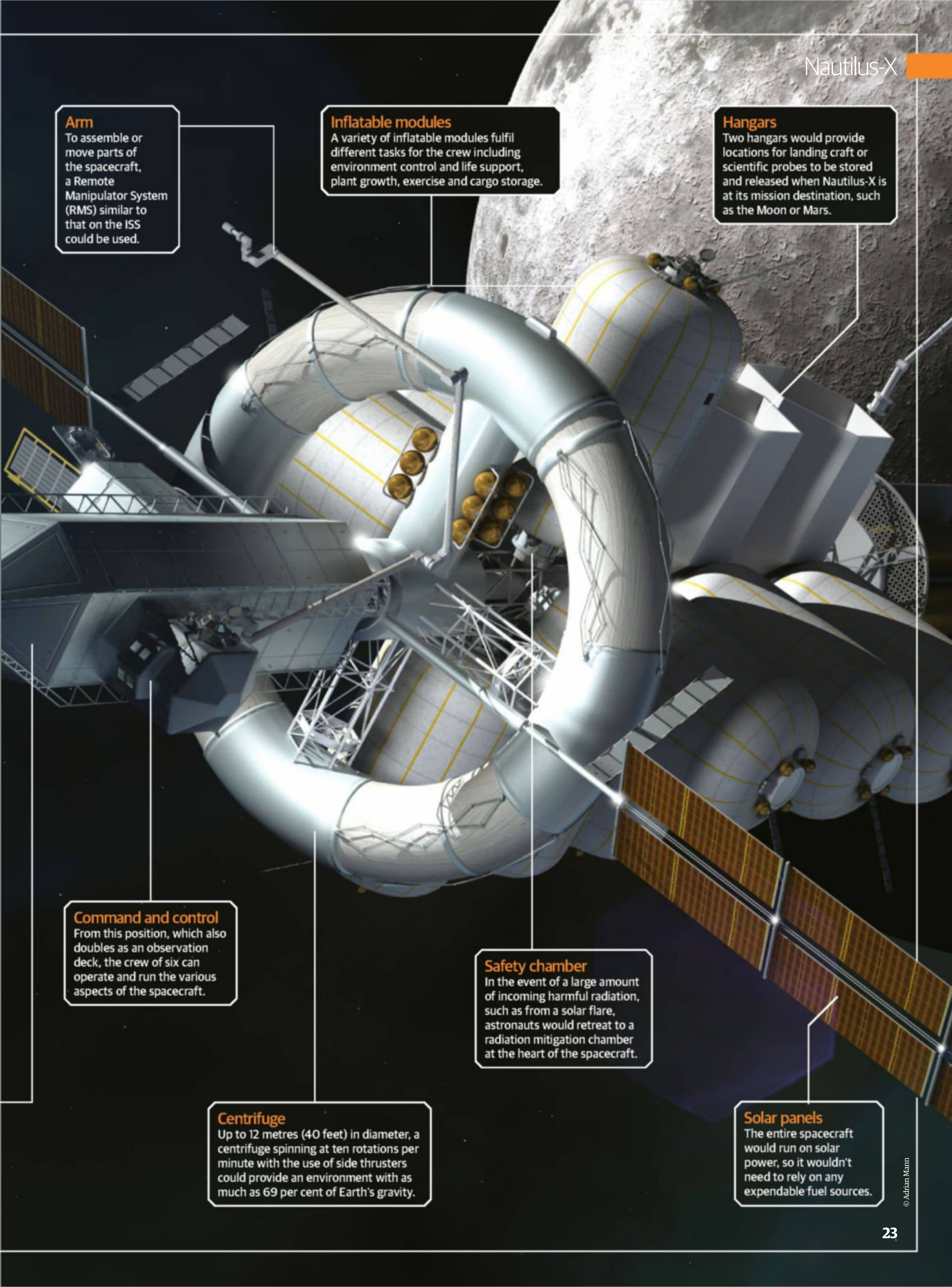
The design of the spacecraft means that it could remain in space for many years, with several different crews utilising it. For example, one crew could travel to Nautilus-X in an Orion spacecraft and then take the entire spacecraft onwards to Mars for a mission lasting up to a year. They would then return in Nautilus-X at the conclusion of the mission and leave the spacecraft near Earth orbit, ready and waiting for another crew, while they travel back to the surface of Earth in their Orion capsule.

Such an implementation would allow multiple rotating crews to make use of the spacecraft on a variety of missions. Solar panels would make the station almost entirely self-sustainable, while onboard farms could provide astronauts with food. At the outset of a mission, however, it's likely astronauts would need to bring some supplies with them, perhaps on a separate spacecraft such as SpaceX's Dragon.

Another key feature of Nautilus-X is the centrifuge. It is well documented that prolonged exposure to space can have a debilitating effect on an astronaut's health, in particular their muscle and bone strength. It is estimated that as much as two per cent of bone mass is lost for every month an astronaut is weightless in space, so providing an artificial-gravity environment could be essential for long-term exploration missions. The centrifuge on Nautilus-X would provide between 0.51 and 0.69 of Earth's gravity, allowing astronauts to recuperate bone mass they may have lost while on other parts of the spacecraft or outside on a mission. Such a centrifuge had been suggested as an additional module for the International Space Station to test the technology, but unfortunately that now seems to be on hold due to budgets.

On the subject of money, Nautilus-X carries with it a rather alluring price tag. The brains behind the project estimate it would cost around $3.7 billion (£2.3 billion) - not even double the price of NASA's Curiosity rover - while development could be completed in just over five years. Such figures are attractive, especially for the money-conscious top dogs at NASA, so there is a chance that after further research this spacecraft may come to fruition.

So when could we expect to see work on Nautilus-X begin? At the moment NASA's manned exploration funding is tied up in a number of projects, namely Orion, Commercial Crew Development - which includes funding for SpaceX, Boeing and Sierra Nevada Corporation's upcoming manned vehicles - the ISS and the Space Launch System heavy-lift rocket. The latter would be essential for launching and assembling the various components of this spacecraft in Earth orbit. Whether we will ever see Nautilus-X fly is up for debate, but it's good to know that NASA has a sound proposal for a deep-space exploration vehicle if it ever decides to go down that route.



SPACE TED TALKS …YOU NEED TO WATCH

*Be even more inspired by the universe with **All About Space**'s top picks of ideas worth spreading*

Reported by Libby Plummer

© NASA, Getty

IS OUR UNIVERSE THE ONLY UNIVERSE?

Professor Brian Greene, professor of mathematics and physics, Columbia University

This action-packed talk explores the possibility that our universe is part of a vast complex of universes called the multiverse. The animated lecture is given by theoretical physicist Brian Greene, perhaps the best-known proponent of superstring theory, the idea that tiny strands of energy vibrating in a higher dimensional space-time create every single particle and force in the universe. He breaks down the complicated idea into three parts, starting with the idea that space is expanding and how Nobel Prize-winning research in the 1990s discovered that rather than slowing down, this expansion rate is getting faster. The talk reveals how this is driven by mysterious 'dark energy' and explains how string theory fits into all this. Touching on the possibility of additional dimensions in space that we have not yet detected because of their tiny scale, Greene ends on some startling revelations about what future astronomers will observe and conclude based on the idea that other galaxies are rushing away from our own, and will eventually be too far away to see.

© NASA, ESA & Hubble

YOUR KIDS MIGHT LIVE ON MARS. HERE'S HOW THEY'LL SURVIVE

Stephen Petranek, editor-in-chief of Breakthrough Technology Alert

Will we all be living on Mars in the near future? Award-winning journalist Stephen Petranek firmly believes it's not a question of if, but when. His future-gazing talk looks at how we might survive on the Red Planet, and makes some pretty bold predictions about when this might actually become a reality. As well as reviewing the reasons why humans need to make the long journey to Mars, he discusses the physical differences between it and our home planet, comparing the size, temperature, atmosphere and gravity.

ADVENTURES OF AN ASTEROID HUNTER

Dr Carrie Nugent, professor of computational physics at Odin College of Engineering

This enlightening talk centres on our oldest cosmic neighbours - asteroids - and their importance to us here on Earth. Not only can asteroids shed light on the beginnings of the Solar System, they also pose a massive risk to our safety. For example, in 2013 the Chelyabinsk asteroid entered Earth's atmosphere over a remote area of Russia and created a shock wave that shattered windows, rocked buildings and caused hundreds of injuries. A similar incident, though on a much larger scale, is thought to be related to the fate of the dinosaurs. As a result, near-Earth asteroids are now constantly monitored in order to try and prevent another catastrophic strike on Earth. Nugent is part of the team that uses NASA's NEOWISE telescope, a very valuable telescope that was pulled out of retirement and reprogrammed to search the skies for asteroids and catalogue them. In her talk she reveals some breathtaking details about the size of the asteroid that wiped out the dinosaurs. She also explains what else is already being done to prevent another potentially deadly asteroid strike, and what needs to be done in future.

© Tobias Roetsch

OTHER TALKS WORTH WATCHING RIGHT NOW

How LIGO discovered gravitational waves – and what might be next

Professor Gabriela González

The Argentinian astrophysicist explains the Nobel Prize-winning confirmation of Einstein's prediction and what it means for our understanding of the universe.

Teach arts and sciences together

Former NASA astronaut Mae Jemison

A compelling case for reintegrating STEM subjects and the arts put forward by the former NASA astronaut and the first African-American woman in space.

The untapped genius that could change science for the better

Astrophysicist Jedidah Isler

The first African-American woman to earn a PhD in astrophysics from Yale spells out the value of diversity and intersectionality in STEM fields.

What I learned from going blind in space

Former CSA and NASA astronaut Chris Hadfield

An incredible tale of how facing fears enables astronauts to deal with the dangers of spaceflight by the *Space Oddity*-singing Canadian astronaut.

Why we need the explorers

Professor Brian Cox

The popular physicist explains the importance of investment in exploratory space programs and curiosity-driven science.

FOR MORE SPACE TED TALKS VISIT

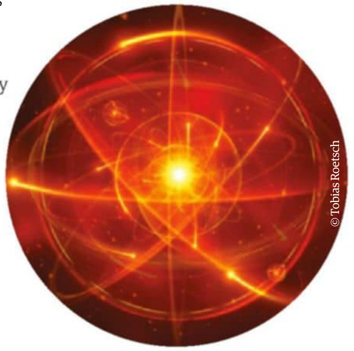
TED.COM

OR YOU CAN ALSO DOWNLOAD THE APP FOR FREE

HAVE WE REACHED THE END OF PHYSICS?

Dr Harry Cliff, particle physicist at CERN and Science Museum Fellow of Modern Science

As a scientist working on the Large Hadron Collider, Cliff is well placed to run through the basics of Einstein's general theory of relativity and quantum mechanics and how these ideas have transformed our understanding of the universe. Over 100 years on from Einstein's theory, physics is at another turning point. Could the laws of physics prevent us from making further discoveries and stop us from every truly understanding why there is something rather than nothing? CERN's discovery of the Higgs Boson may have proved the existence of a cosmic energy field, but the Higgs field is still not fully understood. What's more, the mysteries of dark energy, string theory and the concept of the multiverse are all compelling concepts, but Cliff questions whether we will ever be able to explain or definitively prove their existence.



© Tobias Roetsch

THE SEARCH FOR PLANETS BEYOND OUR SOLAR SYSTEM

Professor Sara Seager, astrophysicist at the Massachusetts Institute of Technology

Astrophysicist and planetary scientist Sara Seager's research led to the first discovery of an atmosphere on a planet outside our Solar System. In this inspiring talk, the exoplanet expert speaks about the search for potentially habitable worlds beyond our own. Thousands of exoplanets have been pinpointed during the last couple of decades, but that's just the tip of the iceberg. The astonishing variety of exoplanets already discovered includes gas giants that would be far too hot to support life, in contrast with Kepler-186f, so far considered to be one of the most likely spots for discovering life. This Earth 2.0 is a so-called 'Goldilocks' planet, not too hot or too cold, but just the right temperature. However, what's really important in the search for potentially habitable exoplanets is examining their atmospheres. While the Hubble Space Telescope has been used to study the atmospheres of larger exoplanets, we still don't have the technology to study smaller planets. This intriguing talk highlights the importance of assessing the amount of gases present in these distant worlds, and how that could lead to the discovery of intelligent alien life.

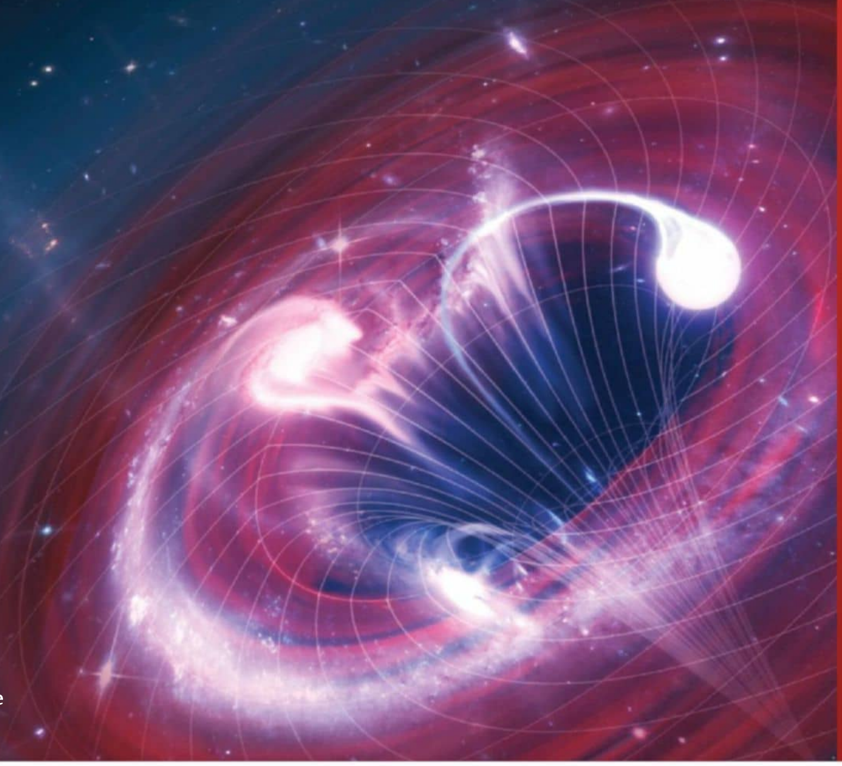
© Tobias Roetsch

HOW TO TAKE A PICTURE OF A BLACK HOLE

Dr Katie Bouman, assistant professor of computing, Caltech

© NSF

For years we had only been able to see what the inside of a black hole might look like thanks to computer graphic rendering, like those seen in the film *Interstellar*. Despite Einstein's prediction of black holes in his theory of general relativity more than 100 years ago, we still hadn't managed to successfully image one. That all changed last year when the black hole at the centre of Messier 87 was snapped. A telescope capable of capturing images of a black hole needs to be as big as the Earth itself, making this feat extremely difficult. However, Bouman worked as part of a team of international experts to produce a giant computational telescope – known as the Event Horizon Telescope – combining the power of telescopes around the world with imaging algorithms to fill in the gaps. In this talk she reveals the extraordinary process of developing these algorithms based on what experts believe a black hole should look like, using pieces of images from everyday life in order to avoid bias. Viewers will get a glimpse at how astronomers, physicists, mathematicians and engineers came together to solve a seemingly impossible quandary, pushing the boundaries of science.



© Tobias Roetsch

"I NEVER SAW A TRULY DARK NIGHT SKY UNTIL I WAS 15"

LUCIANNE WALKOWICZ

© NASA/JPL-Caltech

LOOK UP FOR A CHANGE

Lucianne Walkowicz, stellar astronomer on NASA's Kepler mission

The night sky provides an incredible view, but what if we're not able to see it? In this talk, Lucianne Walkowicz speaks about how light pollution is ruining our extraordinary view of space. While there is a tendency to believe that this loss is an inevitable result of technological progress, Walkowicz, who works on NASA's exoplanet-hunting Kepler mission, says that this need not be the case, and that the night sky should be treated as a natural resource that must be preserved. The intense light from urban settlements around the globe is so distinct it can be photographed from space. But most of the energy used to light outdoor spaces is wasted, says Walkowicz, leaving plenty of room for improvement. She also explains how people can learn more about the night sky thanks to a range of 'citizen science projects'. These involve organisations sharing their data online and teaching people how to interact with it so they can make contributions to research. Some projects involve asking people to help classify photos from space, while new exoplanets were discovered by participants as part of the Kepler project.

BIO

Ann Druyan

Ann Druyan co-wrote, along with her late husband Carl Sagan, arguably the most popular scientific series ever with *Cosmos: A Personal Voyage* in 1980. She returned to *Cosmos* in 2014 with Neil deGrasse Tyson and created, wrote and produced the latest two seasons.

Druyan's unique ability to communicate science has won her Emmy and Peabody awards, and she was also the creative director of NASA's Voyager Interstellar Message Project. This message was inputted on two golden discs that were then attached to NASA's Voyager spacecraft.

NAT GEO EXCLUSIVE: PART TWO

ANN DRUYAN TALKS COSMOS POSSIBLE WORLDS

Ann Druyan speaks to **All About Space** about the significant scientific impact of the *Cosmos* series, Carl Sagan and NASA's historic Voyager missions

Reported by Lee Cavendish

The original *Cosmos* TV series was released almost 40 years ago. Has peoples' interest in science and the universe increased in this time?

I feel that there's been a kind of war against science in the US. I certainly can't speak for other countries, but what has changed is in 1980, when Carl Sagan and I did the original *Cosmos*, there was still a kind of great dream of a wonderful future. In episode four of the original series, we talked about climate change. The scientists well knew what we are all experiencing now. It was a different atmosphere because the respect for science, and I can only really speak for the US, was much higher.

That was a big difference, and we felt that in 2014 for *Cosmos: a Spacetime Odyssey*, and for this season we wanted to not only be truthful about the predicament we find ourselves in, but also to create a great dream of the future. The dream that we'd lost. This season of *Cosmos* is not only many stories of heroes that perhaps you've never heard of before, but also a vision of the future, because I believe that dreams are maps, and without a dream of the future, just with the kind of gloomy, long shadow that we all feel, it's really difficult to motivate people. Especially the young, who have the hard work of becoming scientists, mathematicians and technicians so that we can get to a better future, because I believe that it's not too late. That we can still awaken from this sleepwalking that we're all doing. That there is a chance to get to a much better future.

> "IT WAS A DIFFERENT ATMOSPHERE BECAUSE THE RESPECT FOR SCIENCE WAS MUCH HIGHER" ANN DRUYAN

Looking at all of the topics you cover in the programme, how do you select and decide what topics are the ones that the general public should know about?

Well, that's not so much the decision. For me, the way that this season and the previous season were created was when I'm sitting at home. As I say, I'm not a scientist. I'm a hunter-gatherer of stories. I'm sitting at home, and I'm reading. I'm scanning the headlines from *Nature* and *Science*, and some other scientific journals. I'm reading articles, and I'm creating a kind of collection of stories. And for a story to really qualify for *Cosmos*, it has to work on many different levels. It has to be a way in for everyone who's not a scientist or not even aware that they're interested in science.

That is because we're a story-driven species. If a story is both a way into a scientific concept, but also has its own human drama – as well as a way of finally giving you that soaring uplift that I get from science as a non-scientist – then it's worthy of *Cosmos*.

"IT HAS TO BE A WAY IN FOR EVERYONE WHO'S NOT A SCIENTIST OR NOT EVEN AWARE THAT THEY'RE INTERESTED IN SCIENCE" ANN DRUYAN

Bottom: The visual effects shown in the new *Cosmos* series are a wonderful spectacle

Below: Tyson and Druyan both attended the screening of *Cosmos: A Spacetime Odyssey* in 2014

© Getty

What was Carl Sagan's favourite episode of his own series?

Carl's favourite episode was episode two, which was about life. [It's called] One Voice in the Cosmic Fugue, and that was our favourite. We always felt that with anything that you create, there are always some things in it that when you look at it again, you wince. You think I wish I'd done that differently. But in episode two, that gave us the fewest amount of winces. We really felt like we told the story adequately.

What was it like preparing the Voyager Golden Record and sending Beethoven into space?

Beethoven and Chuck Berry and Blind Willie Johnson and so much more. That was the greatest experience imaginable. Because I was 27, and try to imagine, it was 1977 – a woman doesn't even get to finish a sentence. Forget about other things. To be constantly interrupted. To be constantly told that you're unworthy because you're not a man. And at that point, when we began work on the Voyager Record, Carl and I had worked on a previous project which never came to fruition. But we had the experience of thinking together, which was just a divine experience.


© Cosmos Studios

14816962


© Cosmos Studios


© NASA/ESA


© Getty

Top (clockwise): *Cosmos: Possible Worlds* explores the alien and exotic scenarios humanity could find itself in

NASA's Voyager missions still receive overwhelming public attention

Druyan and Sagan got married in 1981, a year after the release of the original *Cosmos*

I was really excited a few years ago. I was at the Jet Propulsion Laboratory [in Pasadena, California], and the same people who had been really, almost offended by the Javanese Gamelan music – they were like, "What is this? Why is this? Why not Frank Sinatra? What's going on?" – the public information officer told me that the Voyager mission is the most beloved, and not only is the Voyager mission itself, but the 'Pale Blue Dot' picture that Carl fought for from 1981 to the time of its taking in 1990. Every day, by far, the most inquiries received about anything NASA has ever done was the Voyager record.

That was completely thrilling. We only had six months. The entire project came in for $18,000 (£13,800). So all of us, the six of us, the primary people who are working on it all the time, wanted nothing except the honour of conferring kind of immortality on the musicians. Someone like Blind Willie Johnson, who died of such extreme poverty. He had no shelter. No one thought his music was of any value. And yet we now know him to be one of the great innovators in the history of music, and his music has a shelf life now of one to five billion years. And so, the honour of creating this Noah's ark of human culture was a joy that still gives me goosebumps.

You began your work on *Cosmos* with your husband, and now you work with Neil deGrasse Tyson. Can you compare them and what it's like to work with them both?

Well, it was wonderful to work with both of them. I mean, I can't really compare them because Carl was the love of my life, so that's one thing, but also Carl was involved. He led the creation of the first one. And so on the second two [seasons], it's been slightly different in that Neil wasn't involved in the actual writing.

But I have to say that I admire Neil's performance in this [season]; it is even greater than in the second season. He was a pleasure to work with and had great stamina. We had all kinds of storms and things that we had to deal with, and even at midnight Neil was perfect and really excellent.

WATCH *COSMOS*: POSSIBLE WORLDS

Cosmos: Possible Worlds can be caught on Sundays at 7pm on National Geographic

WHAT HAS NASA DONE FOR YOU?

Hundreds of billions of dollars have been spent on space exploration - here's what we got in return

Reported by Laura Mears

Space exploration is expensive. The Soviet Union kick-started the Space Race in 1957 when it placed the first-ever artificial satellite into orbit. According to NASA historians, the beachball-sized Sputnik 1 caused a "full-scale crisis". The idea of falling behind with technology in the middle of the Cold War frightened the American public, and the US government responded with heavy investment. By the end of 1958, NASA had been formed.

Over the next decade the government poured more than $25 billion (£20 billion) into the space program to ensure that the first man on the Moon was American. In the decades that followed, hundreds of billions of dollars would be spent pushing the boundaries of science and technology. This phenomenal investment won the US the Space Race and completely changed our understanding of the universe, but with NASA currently operating on a budget of about $22.6 billion (£18.4 billion) a year, and estimated to have spent at least $650 billion (£529 billion) in the last 62 years, what does it mean for average people? What has NASA done for us?

The obvious answers would involve satellites, weather monitoring, communications, navigation and aeroplane travel, but even the Apollo missions, the Space Shuttle program and the exploration of Mars have benefitted the general public.

When NASA was formed, part of the conditions of its funding included a requirement to share new advancements with industry, and behind the dramatic launches and the mind-blowing photographs, NASA spin-off products have been taking space technology and adapting it to solve everyday problems. One of the most notable is memory foam, developed at the Ames Research Center in 1966 to protect aircraft pilots and passengers in the event of a crash. It is now a household item used in sports helmets, protective clothing, high-end mattresses and prosthetic limbs. But there have been thousands of others.

The Mercury missions, which took American astronauts into orbit around Earth for the first time, brought innovations in waste disposal. The Gemini missions, which developed the technology required for the moonshot, inspired anti-glare coatings for television screens and computer monitors, equipment to measure patient oxygen and carbon dioxide levels and advances in oil mining technologies. The Apollo program itself spawned dozens of new ideas. The heat-shielding technology used to protect the Apollo spacecraft was adapted to develop paints and foams to protect aircraft, and later used to create layers of insulation inside public buildings. These materials slow the rate of fire damage, allowing people more time to get out before buildings collapse.

The digital image processing software developed to allow Apollo astronauts to land safely on the Moon was later used as the basis for the first of the Landsat satellites. Together this series of satellites have been capturing images of Earth for over 45 years, tracking changes in the landscape, the environment and the atmosphere. More recently the images have been made easily accessible via Google Earth.

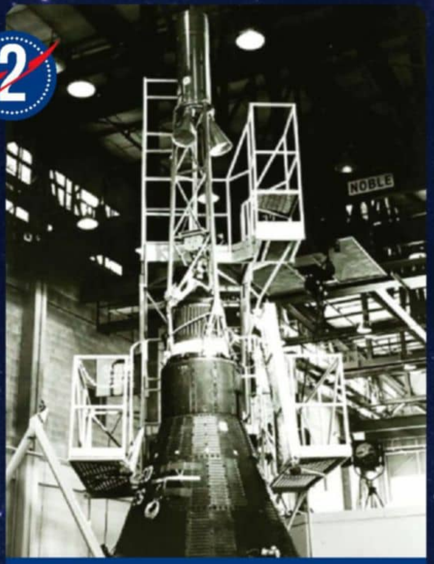
The Apollo digital image processing technology was also famously used in MRI scanners, although NASA had nothing to do with actually inventing the medical equipment itself. Freeze-drying techniques used to preserve space food passed over into industry, and so too did water purification technology. And the materials developed to protect Apollo astronauts in space and on the surface of the Moon also found their way into everyday life.

1

SPACESUIT MATERIALS PROTECT FIREFIGHTERS

The launch pad fire disaster that killed the three crew members of Apollo 1 triggered an intense period of investigation into new flame-retardant materials for spacesuits and vehicles to protect the future Apollo astronauts. This new technology rapidly made its way into industry and into the suits of firefighters, soldiers and racing car drivers.

What has NASA done for you?



SPACECRAFT DESIGN SOFTWARE IS USED TO PROTOTYPE ROLLERCOASTERS

The 1968 computer program NASTRAN was originally written to help NASA engineers design spacecraft, but it was released to the public in 1971 and has since been used for a number of different applications. It's ability to test elastic properties of structures made it perfect for modelling car suspension, bridges and even rollercoasters.

ORION TECHNOLOGY IS PROTECTING DEEP-SEA DIVERS

NASA's new Orion spacecraft has only made it off the launch pad for a test flight, but it has already sparked a number of spin-off technologies. The company behind Orion's life support has adapted the same systems for use by divers working in extreme and dangerous environments.

VIKING PARACHUTE COVERS MAKE HARD-WEARING TYRES

The two Viking landers were sent to the surface of Mars in the 1970s, and their parachutes needed protection on the journey. The stronger-than-steel fibres designed to protect the Viking descent gear were later incorporated into car tyres by Goodyear, extending their life span by thousands of miles.

HUBBLE OPTICS TOOL HELPS ICE SKATERS AT THE OLYMPICS

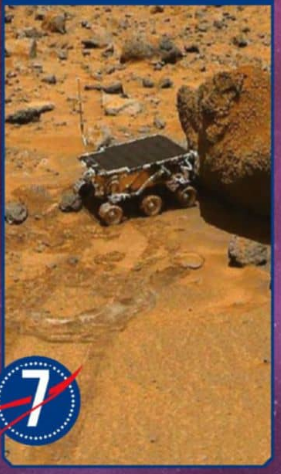
The technology used to create the optics for the Hubble Space Telescope was adapted, in collaboration with the US Olympic Committee, to develop a sharpening tool for ice skate blades. The sharp skates outperformed traditional versions, and were used by Chris Witty when she won gold and set a world record at the 2002 Winter Olympics.

SPACE SHUTTLE SHOCK ABSORBERS PROTECT BUILDINGS FROM EARTHQUAKES

Shock absorbers designed for use during the launch of NASA's Space Shuttle missions formed the basis for technology that now protects more than 500 buildings in earthquake-prone areas across the world. Known as 'fluidic dampers', the shock absorbers contain oil to absorb the impact.

MARS-INSPIRED ROVERS EXPLORE WAR ZONES

The PackBot Tactical Mobile Robot was developed by iRobot engineers and inspired by a prototype Mars rover. It accompanies US troops in Iraq and Afghanistan, using tracks to climb over rugged terrain. It has a pair of flippers that allow it to climb stairs and to flip itself back the right way up if it is knocked over on the battlefield.



APOLLO HEAT SHIELDING PROTECTS BUILDINGS FROM FIRE

The Apollo heat shielding was specifically designed to burn as it reentered the atmosphere, forming a protective layer around the returning spacecraft, but NASA also funded research to apply this technology elsewhere. An adapted version has been used to coat steel frames supporting large buildings. They survive for longer in a fire, giving people more time to evacuate.

SPACE STATION ROBOTS COULD BUILD CARS

Working with General Motors, NASA has been developing Robonaut 2 (R2): a robotic ISS crew member. It is being designed to be able to work safely alongside people both in space and on Earth. Not only could the technology have uses on the ground in safer manufacturing, but associated products, like exoskeletons and gloves, could have medical uses.

Sports shoes have been made using the techniques behind space boots, and the lightweight, moisture-resistant fibreglass designed for use in spacesuits was used to build the first retractable cover at an NFL football stadium. It was strong, but still allowed enough light through to reach the grass on the pitch below. The Apollo life-support systems were adapted to form the basis for breathing apparatus to protect firefighters from smoke inhalation, and the suit cooling systems, designed to make the astronauts more comfortable, were adapted for emergency service and medical use.

Even the computer program designed to minimise the power usage of a portable Moon drill found its way back down to Earth, and was later used to create the iconic 1980s cordless vacuum cleaner, the Black and Decker Dustbuster. After this flurry of innovation, NASA set up its Skylab in the 1970s - Skylab was the first American space station. This allowed experiments to be conducted in orbit around Earth.

Innovations sparked by Skylab included new techniques for helping newborn babies to breathe, computerised solar water heaters and self-powering signs that glowed without the need for electricity. These self-powering signs are now used to light the way in emergencies.

> "EVEN THE APOLLO MISSIONS, THE SPACE SHUTTLE PROGRAM AND THE EXPLORATION OF MARS HAVE BENEFITTED THE GENERAL PUBLIC"

The Space Race ended in 1975 when the United States and the Soviet Union teamed up to dock a NASA Apollo Command Module to a Soviet Soyuz 7K-TM. Investment slowed, but it marked a new era in international space exploration and cooperation, and innovations continued. Since 1976 NASA has been keeping track of the best innovations in a magazine known as *Spinoff*.

The Space Shuttle missions began in 1981, and required another vast financial investment from the government. A single Space Shuttle launch cost an average of $450 million (£363 million), and each of the 130 or so flights set the space agency back around $1.5 billion (£1.21 billion). However, with this spending came another wave of innovation and, according to NASA, over 100 technology spin-offs. The visors developed for the astronauts on the Space Shuttle program inspired scratch-resistant reading glasses, and an iodine-based purification system designed to recycle water was later adapted for use in disaster relief efforts. LED panels designed to grow plants on board the shuttles have been adapted for medical uses, Space Shuttle shock-absorber technology is now being used to protect buildings against earthquakes and imaging technology developed to measure surface damage on the shuttles can capture and analyse pictures of crime-scene evidence.

At the same time, other NASA projects were also making a difference in the wider world. In 1985 grooved surfaces that NASA had developed to reduce slipping on runways was adapted for use on steps and in car parks to protect pedestrians in the wet. Later in the same decade, technology used by NASA satellites to study the ozone layer was repurposed to create lasers capable of breaking down blockages in human arteries. In 1990 NASA launched another major mission: the $2.5 billion (£2.2 billion) Hubble Space Telescope. It had an unnoticed fault in its optics and required a heroic - and expensive - repair in order to function properly, but since then it has more than made up for its cost.

Not only has the Hubble Space Telescope provided an incredible window out into the universe, its advanced optics and imaging technologies have inspired other industries, providing the basis for improved microsurgery techniques and tumour biopsies and advancements in the manufacture of semiconductors.

The Hubble Space Telescope was followed in 1993 by one of the biggest contributors to scientific and technological advancements made in space - the International Space Station (ISS). This orbiting laboratory has been permanently occupied by teams of astronauts and cosmonauts since 2000, and over the course of its life span has racked up a bill in excess of $150 billion (£123 billion) - although NASA is only responsible in part.

The microgravity environment on the ISS allows unique experiments to be conducted, and data has been gathered in a vast number of fields from materials science to biology to robotics. Superconductors and nanomaterials have been tested aboard the station, plants and animals have been studied and the human body has been monitored. Thanks to the International Space Station we now have a robotic arm that can perform surgery inside an MRI scanner, a new method of delivering cancer-fighting drugs and even some high-performance golf clubs.

The technology used to build the ISS itself, and the equipment on board, has also been useful back on Earth. The imaging software designed to help robots to assemble the space station is now used to analyse the damage to crash test dummies, helping to improve safety in cars. Handheld warning systems designed to detect falling pressure in parts of the station are now used to monitor cabin pressure on planes. Back on the ground, NASA continued to pioneer research in other areas. A major focus throughout its history has been understanding contamination and developing clean rooms within which to assemble spacecraft. These innovations have since found their way into medicine, manufacturing and industry.

NASA technology developed to measure the airflow in wind tunnels is now used to monitor the polluting emissions from industrial smokestacks, and colour-changing optical fibres designed to detect dangerous chemicals on aircraft are now being used as a warning system for industrial accidents or chemical warfare.

Precision GPS designed to test Einstein's theory of relativity is being used to drive remote-controlled tractors, and supercomputers normally used to analyse the flow of fuel in rocket engines have been used to design a device that can keep blood flowing through the body while a patient waits for a transplant. Even excess rocket fuel has found a new use, providing the basis for demining device flares, which destroy land mines by burning away the explosives inside.

NASA has made many significant technological advancements that have had a real impact on the everyday lives of people across the world. It continues to push the boundaries of human achievement, including pioneering ambitious and expensive missions to explore our potentially habitable neighbour, Mars.

'NASA-INVENTED' MYTHS

- ✘ Tang (drink)
- ✘ Velcro
- ✘ Teflon
- ✘ Barcodes
- ✘ Quartz clocks
- ✘ Smoke detectors
- ✘ Cordless power tools
- ✘ MRI scanners
- ✘ Microchips
- ✘ Space pen

The 1997 Mars Pathfinder mission and the 2012 Curiosity rover set the American space agency back by billions of dollars, but the scientific and technological advancements made along the way have been huge - and they don't stop here.

The technology used to weave the tough Pathfinder parachutes has been used to make stab- and impact-resistant vests, and the Martian rovers themselves have been adapted to create reconnaissance robots to seek out explosive devices in war zones. These military rovers can climb steep slopes, function under water and even navigate stairs.

Technology designed to search for water on Mars has been adapted for use on aircraft, allowing them to detect water in the air for weather forecasting, and technology developed to search for life on Mars is being used to monitor for biological threats.

Mineral analysers are being used in pharmaceuticals and forensics, and the techniques used to develop new methods of growing plants in space and on Mars are being adapted for use in other biological experiments, like drug development. The Mars rovers have revealed a planet that could be habitable by humans and that could even be home to extraterrestrial life, and the technology being prepared for the next phases of exploration is already set to have important uses back on Earth.

By 2016 over 2,000 different NASA spin-off products had already been catalogued, and this is just the tip of the iceberg. NASA has inspired scientists, engineers, thinkers, inventors and entrepreneurs, and their innovations and scientific advancements contribute to a growing base of human knowledge that will form the platform for advances that we can't even dream about today. NASA may be expensive, but speaking in 1974, science-fiction writer and scientist Isaac Asimov explained the core of the argument: "If we refuse to take those steps because we don't see what the future holds, all we're making certain of is that the future won't exist".

NASA AROUND YOU

A great deal of space-inspired innovations can be found in your city and even at home

MANUFACTURING
- Powdered lubricants
- Improved welding
- Power plant design
- Smokestack monitors
- Rapid prototyping
- Chemical detection
- Improved mine safety

SPORTS & RECREATION
- Shock-absorbing athletic shoes
- Protective padding
- Ingestible thermometers
- Protective cool vests
- Heart rate monitors
- Tennis rackets

MEDICAL
- Light-Emitting Diodes (LEDs)
- ER infrared ear thermometers
- Automatic insulin pumps
- Artificial limbs
- Clean room apparel
- Precision dialysis pumps and fibres
- Invisible braces
- Diamond coatings: artificial hip joints

©Adrian Mann

HOUSEHOLD
- Ingestible toothpaste
- Cosmetics
- Memory metal alloys
- Environmentally safe sewage treatment
- Polished-brass finish
- Memory foam mattresses

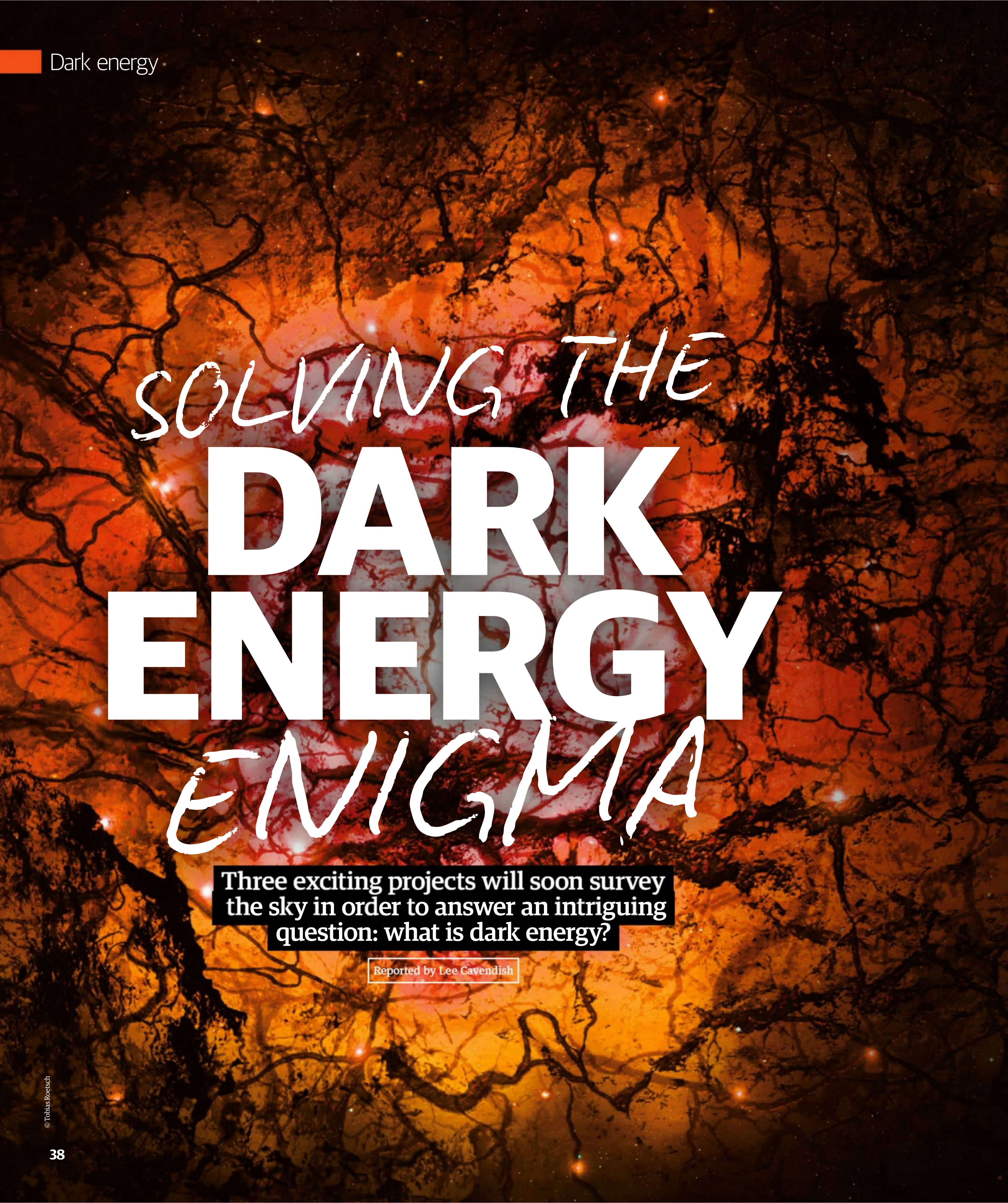
PUBLIC SAFETY
- Fire-resistant reinforcement
- Video enhancing and analysis systems
- Fire sensors
- Face masks and fire suits
- Land mine removal
- Anthrax detection
- Flame-retardant materials
- Self-illuminating materials
- Lifeshears
- Breathing systems

AIR TRAVEL
- Collision avoidance systems
- Clean-burning engines
- Nitrogen oxide reduction
- Anti-icing systems
- Virtual biofeedback training
- Cabin pressure devices
- Parachute systems
- Voltage controllers

INFRARED SATELLITE TECHNOLOGY INSPIRED AN IN-EAR THERMOMETER

Infrared satellite imaging technology developed at the Jet Propulsion Lab in California for the Infrared Astronomical Satellite was originally designed to measure the temperature of distant stars. In 1991 it was transformed into a thermometer that could measure body temperature using infrared light.

© NASA Getty



Solving the DARK ENERGY enigma

Three exciting projects will soon survey the sky in order to answer an intriguing question: what is dark energy?

Reported by Lee Cavendish

© Tobias Roetsch

The universe is a funny thing. Astronomers work their whole careers to understand what it's made of, yet they are also open to the idea that they could be as far away from the truth as possible. The key to understanding the large-scale structure of the universe is figuring out what dark energy is. This mysterious form of energy is related to the expansion of the universe. After conducting experiments related to this expansion, astronomers have at least been able to determine that dark energy makes up 68 per cent of the universe. The rest is dark matter - the equally mysterious matter that cannot be directly observed but interacts gravitationally with regular matter - and baryonic matter. This we can observe; it is what makes up galaxies and everything within them.

"Dark energy has two noticeable effects in the universe. The first effect is on the expansion history of the universe. Dark energy has caused the expansion of the universe to accelerate in the last few billion years. Observing supernovae that have occurred in the last 10 billion years gives us a very good measure of the expansion of the universe," Dr Jason Rhodes, project scientist of NASA's Wide Field Infrared Survey Telescope (WFIRST) space observatory, tells **All About Space**. "The second effect dark energy has is on the distribution of matter in the universe. This distribution, and how that distribution changes over time, is given by an interplay between the attractive force of gravity pulling things together and the repulsive nature of dark energy pushing things apart."

Living in a universe predominantly made up of dark energy and not knowing much about it seems strange. However, there are some exciting projects on the way that are looking to scrutinise this currently theoretical substance. Three notable candidates will take our most recent findings, apply it to state-of-the-art engineering and analytical techniques and delve headfirst into the dark universe in an attempt to understand what dark energy is.

© NASA/ESA

Left: The universe is made up of countless objects spanning across billions of light years

This trio consists of NASA's WFIRST space observatory, the European Space Agency's (ESA) Euclid space observatory and the Dark Energy Spectroscopic Instrument (DESI) attached to the Mayall Telescope at Kitt Peak National Observatory in Arizona. Together these three dark energy surveyors will use a variety of techniques to understand the distances between galaxies and the acceleration of their expansion and construct an accurate three-dimensional model of what our universe looks like.

"So far all observations indicate a relatively straightforward cosmology: the universe contains cold dark matter which evolves according to the theory of general relativity with a cosmological constant lambda - the famous lambda-CDM concordance model," Euclid's project scientist Dr René Laureijs explains to **All About Space**. "Unfortunately, this model of the universe cannot be unified with the Standard Model of elementary particles that is quantum theory. There is a fundamental problem. I hope that these missions can shed some light on this."

Our currently accepted theory is that the universe consists of 'cold dark matter' and a cosmological constant. Cold dark matter, or CDM, is dark matter that moves slowly compared to

What is the universe made of?

There is much more to the cosmos than what meets the eye

68%

Dark energy

Dark energy makes up most of the universe. It is believed that this is the driving force behind the expansion of the universe, which Edwin Hubble observed in 1929.

27%

Dark matter

Dark matter refuses to be seen, but astronomers have observed its gravitational effects on galaxies and other astronomical observations.

5%

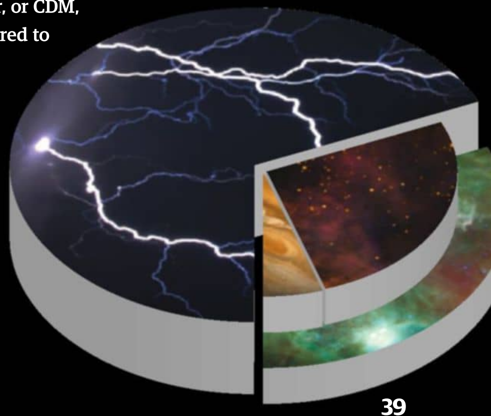
Baryonic matter

This is regular matter that can be seen and is composed of particles called baryons, but it only makes up a minute five per cent of the universe.

32%

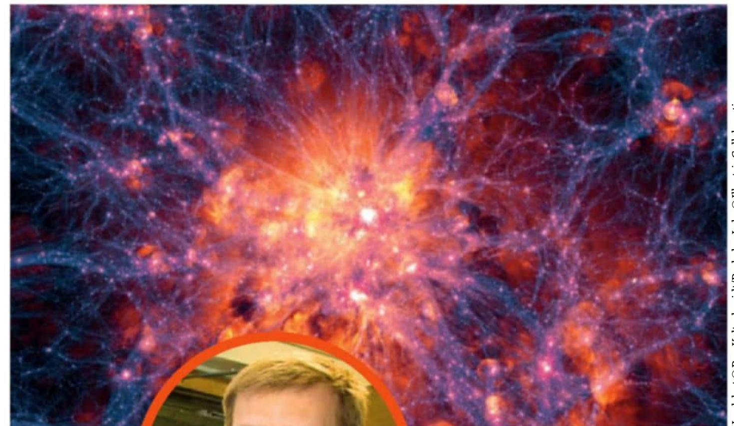
All matter

Even when you combine all matter, it still only makes up a third of the entire universe. This shows the overwhelming bias towards dark energy.



the speed of light, and a cosmological constant, or lambda, is the simplest form of dark energy proposed by Albert Einstein in 1917. It was included in Einstein's equations as an 'anti-gravity' constant to explain why the universe expands as opposed to collapsing under its own gravity. However, as Laureijs explains, this theory has trouble explaining the behaviour of the cosmos' smallest particles. Before cosmologists can begin to intertwine the two theories, they need to construct a large-scale map of the universe.

The DESI instrument is operated by the Lawrence Berkeley National Laboratory in California, and it achieved first light on 22 October 2019. DESI's host is a modest telescope, but has been active in the scientific community since 1973, and was the second-largest telescope in the world at the time. The Mayall Telescope has now been fitted with an innovative instrument that consists of 5,000 fibre-optic 'eyes'. Each cable is capable of capturing the light of a single galaxy and splitting it into a spectrum of light for astronomers to carefully analyse. Within a 20-minute observing time, this instrument is capable of gaining spectroscopic data on 5,000 galaxies simultaneously. "The size of this survey will be huge. In the first five years of operation we will have measured the distance to more galaxies than previously measured by all other telescopes in the world combined," says DESI's project scientist David Schlegel of Lawrence Berkeley National Laboratory.

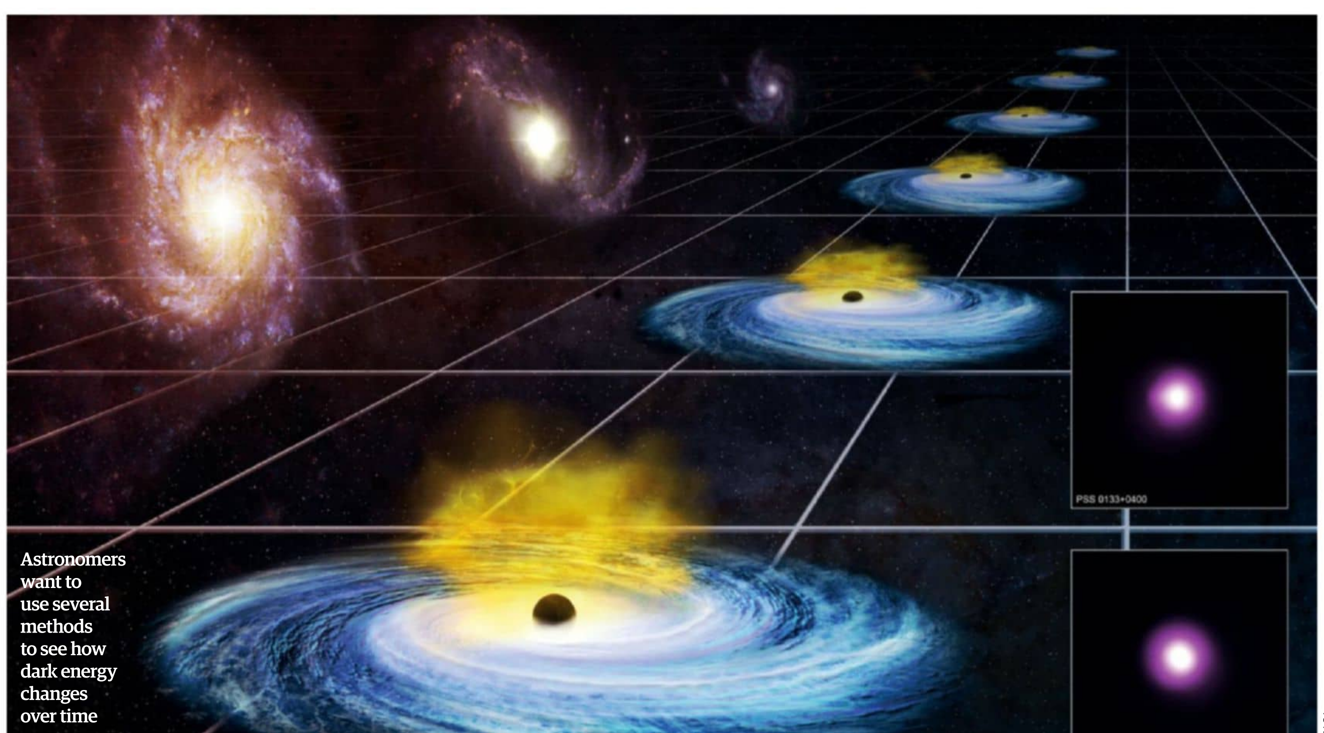


Right: The structure of galaxies and clusters appear as a 'cosmic web', which could be the key to understanding dark energy

Right: Schlegel is project scientist of DESI, which will analyse the spectra of millions of galaxies

Galaxies are key to grasping the universe and its past. Since the time of Edwin Hubble, astronomers have been studying distant galaxies and their spectra. By breaking up the light spectrum of a galaxy, astronomers are able to determine the shift of absorption or emission lines to reveal the galaxy's distance from Earth. It was with this technique, referred to as redshift, that Hubble and his space telescope namesake were able to determine that galaxies at farther distances are receding at a faster rate than nearer galaxies.

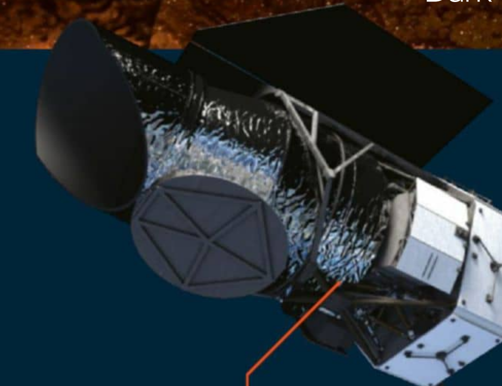
Now DESI is on a mission to collect data on as many as 35 million galaxies and 2.4 million quasars - extremely luminous and active galaxies - in one-third of the total sky area over a five-year period. This will allow astronomers to look back in time to roughly 11 billion years ago, approximately 2.8 billion years after the Big Bang. "DESI helps us understand the accelerating universe through the structure of this 3D map because the features on this - positions and clusters of galaxies - could vary significantly as we look deeper into the universe," explains Schlegel.



Astronomers want to use several methods to see how dark energy changes over time

A trio of cosmic pioneers

These three projects will each examine the universe in their own unique way

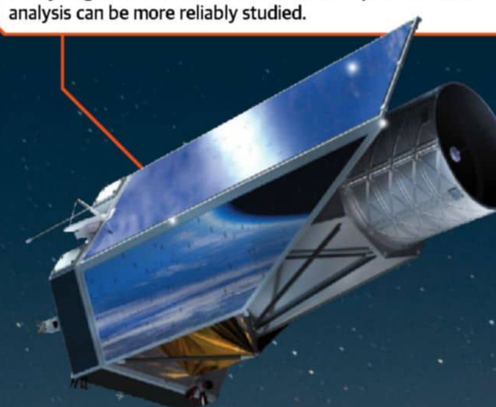


Euclid

Operator: ESA **Location:** Sun-Earth Lagrange point L_2

First light: 2022

Euclid is destined to study both dark matter and the dark universe by observing both weak gravitational lensing effects and baryonic acoustic oscillation 'standard rulers'. Euclid's ability to gather data via two reliable techniques means the analysis can be more reliably studied.

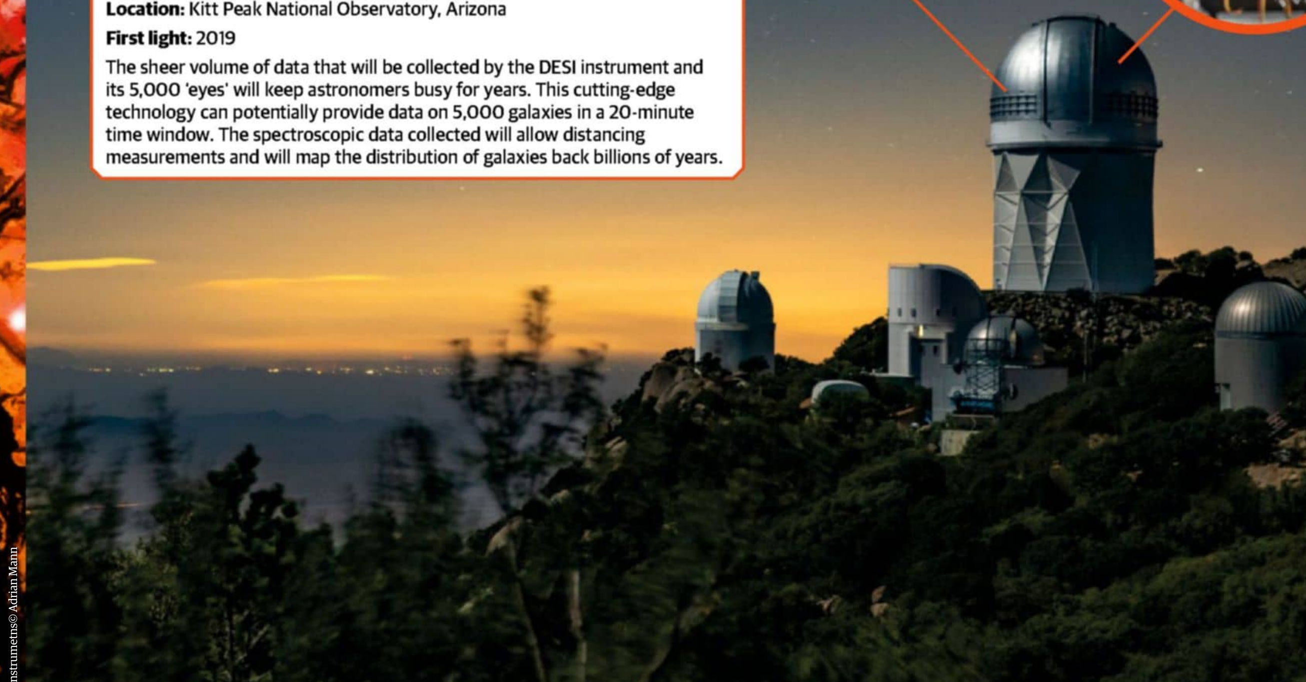


Wide Field Infrared Survey Telescope (WFIRST)

Operator: NASA **Location:** Sun-Earth Lagrange point L_2

First light: 2025

WFIRST is NASA's next flagship telescope and will devise a detailed map of the distribution of galaxies throughout the ages. This map will be compiled from data collected from supernovae, weak gravitational lensing and a variety of galaxy clusters.



Dark Energy Spectroscopic Instrument (DESI)

Operator: Lawrence Berkeley National Laboratory, University of California, Berkeley

Location: Kitt Peak National Observatory, Arizona

First light: 2019

The sheer volume of data that will be collected by the DESI instrument and its 5,000 'eyes' will keep astronomers busy for years. This cutting-edge technology can potentially provide data on 5,000 galaxies in a 20-minute time window. The spectroscopic data collected will allow distancing measurements and will map the distribution of galaxies back billions of years.


© ESA

Left: As the project scientist of Euclid, Laureijs is helping to unlock the secrets of dark energy

"For instance, the map close to us is stretched out a lot more than it should be because of this acceleration due to dark energy. And then in the early universe, when there's not as much dark energy, it shouldn't be as stretched out, but this is where we don't have much data yet. Depending on when dark energy was pushing the universe apart, it will push apart different parts of the map. This data will help us eliminate a number of theories about the way dark energy works."

Next to receive first light will be the ESA's Euclid mission, which will focus its efforts on the grander dark universe - both dark matter and dark energy. This space telescope is planned for launch in 2022. Its equipment includes a 1.2-metre (four-foot) primary mirror, fitted in a Korsch telescope, which will explore the cosmos in visible and near-infrared light. The mission duration is set at six years, and in this time it "will measure the expansion of the universe starting at a redshift of z=2, which corresponds to a look-back time of some 10 billion years ago, until now. The measurement will cover the period that the universe turned from a decelerating expansion caused by the gravity of the dark and ordinary matter into an accelerating expansion due to the growing prominence of the dark energy," explains Laureijs.

Euclid will measure the universal expansion and the distribution of dark matter using two different methods: weak gravitational lensing and baryonic acoustic oscillations. Weak gravitational lensing is better suited to understanding dark matter because by observing the visual dysmorphia of a background galaxy - an example being the famous Einstein Ring - astronomers can determine the amount of dark matter in the foreground galaxy cluster as it uses its influential gravity to bend light. However, baryonic acoustic oscillations are better suited for probing dark energy by seeing how the same fluctuation oddities seen in the cosmic microwave background (CMB) have influenced the spatial distribution of galaxies and clusters. This technique will provide measurements of enormous cosmic structures that are influenced by the opposing forces of gravity and dark energy.

The baryonic acoustic oscillations' spatial distribution originates from when the universe was a ball of hot and dense plasma, even before when neutral hydrogen began to form, which is also known as the epoch of recombination and is the predicted source of the CMB. The baryonic acoustic oscillation technique is referred to as a 'standard ruler' due to the reliably constant distance between galaxies, and can be a powerful tool when measuring the growth of cosmic structures within the overall expansion of the universe.

"The presence of a force related to a substance named dark energy is theory, but Euclid will provide sufficient observational accuracy to prove the validity of the theory. In addition we will have sufficient accuracy to determine whether the acceleration is constant", says Laureijs.

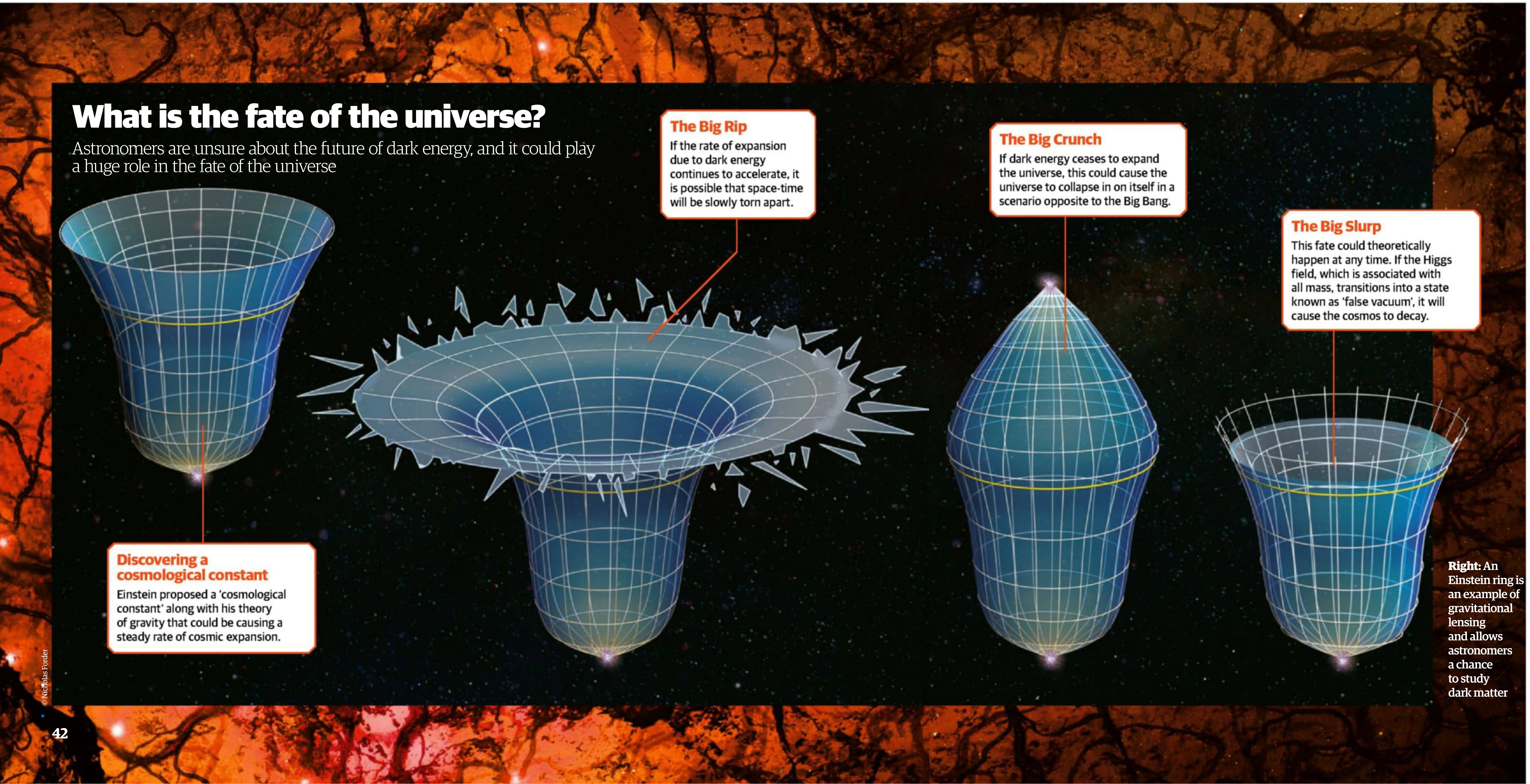
Lastly, the telescope that completes this triad - if Trump's administration doesn't scrap it first - will be WFIRST, due to launch in 2025. This is one of the successors of the Hubble Space Telescope; its build looks similar, but it is much more powerful. "The near-infrared camera on the venerable Hubble has one megapixel," explains Rhodes. "Each of WFIRST's 18 near-infrared detectors has 16 megapixels, giving WFIRST an astounding 288 megapixels. Given that the WFIRST telescope is the same size as Hubble, WFIRST will have the same resolution and light-collecting power, but with a camera that can view nearly 300 times as much sky in a single image."

The WFIRST team plans to utilise three different scientific methods in an attempt to finally prove the existence of dark energy: "Using supernovae as standard candles to measure the expansion history of the universe, using weak gravitational lensing and using the clustering of galaxies," Rhodes divulges. "WFIRST will use all three of these techniques to make multiple measurements of both the time evolution of the distribution of matter and the expansion history of the universe. Using multiple techniques allows us to have independent cross-checks of our results. Measuring both the matter distribution and expansion history allows us to distinguish between many different dark energy theories."

However, this dark energy inspector may not be able to cast its gaze upon the cosmos for a while yet. Although the designated launch date is 2025, this project is dependent on the construction, completion and launch of the James Webb Space Telescope (JWST), which has had delays in droves. With WFIRST estimated to cost a maximum of almost £3.4 billion ($4 billion), it may take a while to reap the benefits.

When the time comes that these projects are up and running - and most likely in the case of DESI, have already finished their observing - we could be living in a world where dark energy is less elusive and less mysterious. This may sound optimistic, but with this many dedicated and technologically advanced instruments scanning the sky in remarkable detail, astronomers may have a better understanding of what dark energy is, how the universe was born and also how it will end.

"Based on our current understanding of dark energy, we think the universe will end in a Big Rip in the very distant future. However, we are still in the early days of studying dark energy and we don't even know if the dark energy evolves over time," says Rhodes. "Our guesses now are just that… guesses, until we have a lot more data that helps us distinguish between the many theories of dark energy that fit the limited data we have now."



© Nicholas Forder


© ESA/Hubble & NASA

Right: An Einstein ring is an example of gravitational lensing and allows astronomers a chance to study dark matter

HOW TO BUILD A ROCKET

From concept to launch, the life cycle of a modern rocket is a fascinating journey that involves hundreds of engineers and billions of dollars

Reported by Dominic Reseigh-Lincoln

From their humble origins in the Chinese invention of gunpowder and fireworks in 700 CE to the towering behemoths that hurtle astronauts and satellites alike into space, the rocket remains the centrepiece of modern space travel. Whether they're models designed and used by the biggest space agencies in the world or those constructed in the private sector to deliver parts and supplies to sites such as the International Space Station (ISS), the genesis and eventual launch of a rocket takes the involvement of hundreds of engineers and years of careful planning.

So where does it all begin? The main foundations of a rocket's life can be broken up into a handful of key phases: formulation, detailed design and manufacturing and operations. During the formulation phase, the broad brushstrokes of the architecture and development plans are put into place. As part of making these decisions, a large number of potential concepts and variations are considered by multiple teams working in unison. "The conceptual studies on heavy-lift systems have been going on at a low level for decades in support of various initiatives," says Tyler Nester, an associate chief engineer working on NASA's hotly anticipated new Space Launch System (SLS). "The conceptual studies that helped shape the SLS started in earnest in the 2011 time period, so there are a number of people that are involved in an effort like designing, developing and operating the SLS as the program evolves."

Early in the design of a new rocket, the emphasis is firmly on conceptual ideas. During this phase of preproduction, programs typically need a lower level of staffing. The detail of the design and analysis work increases as the number of concepts under study gets narrowed down to a smaller figure. "The number of people that need to be involved can vary depending on the planned flight rate," reveals Nester. "As programs transition between phases, people's jobs tend to evolve based on what is needed during that phase. The original plans showed a desired first flight date a little less than seven years after the [Space Launch System] program started in 2011."

At this stage an important decision has to be made regarding a rocket's future: will it aim to operate as a reusable vehicle – where its components are directed back into the sea or

Above: NASA workmen lower the nose cone into place on a solid rocket booster at the Marshall Space Flight Center, Alabama

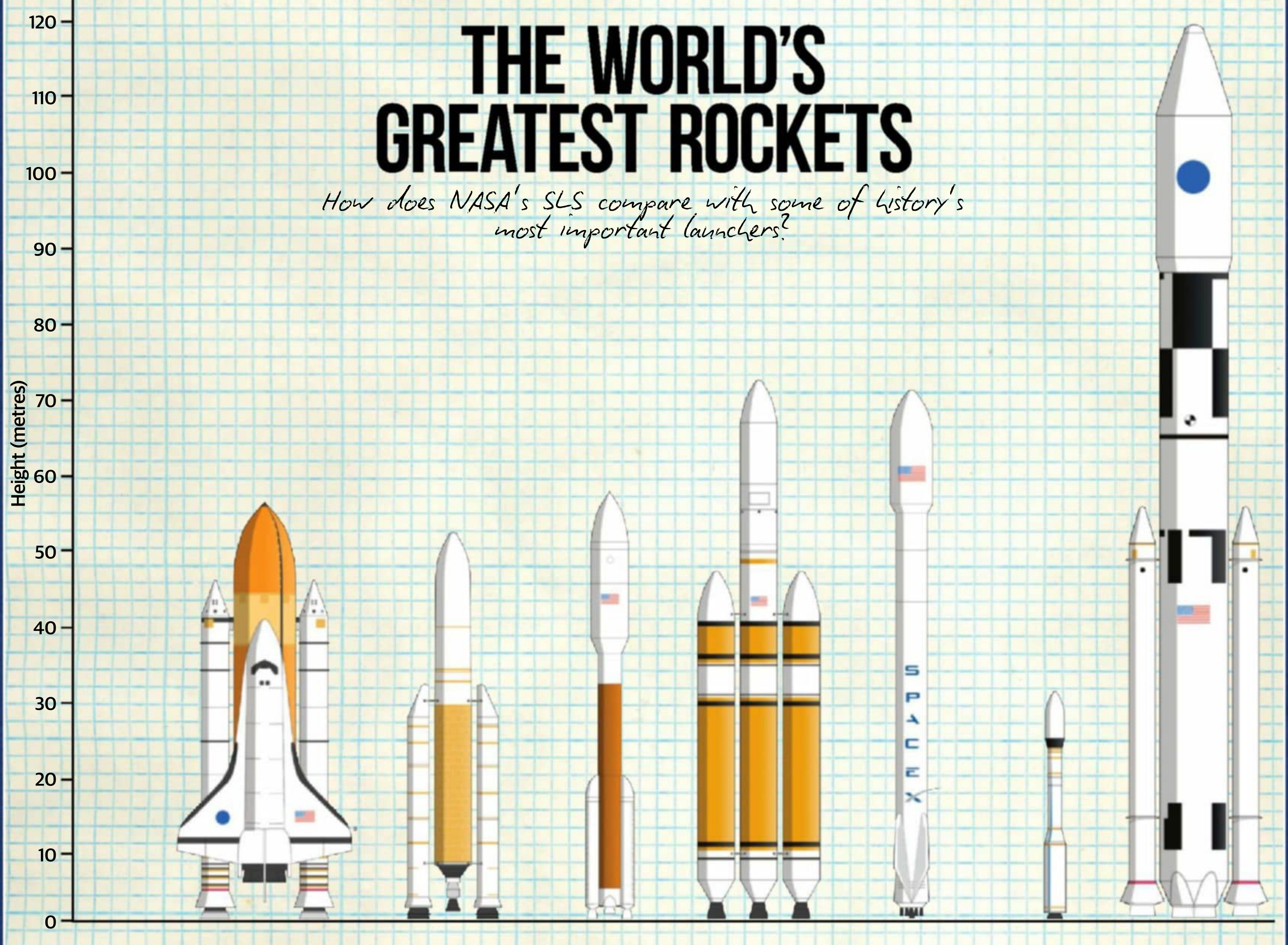
Right: In order to test the heat stress the rocket will endure during its launch, scientists often build scale models, such as this one of the SLS


© NASA


© NASA

THE WORLD'S GREATEST ROCKETS

How does NASA's SLS compare with some of history's most important launchers?



NAME	SPACE SHUTTLE	ARIANE 5	ATLAS V	DELTA IV HEAVY	FALCON 9	VEGA	SLS
YEARS IN OPERATION	1981 to 2011	1996 to present	2002 to present	2002 to present	2010 to present	2012 to present	From 2021
HEIGHT (M)	56	52	58	72	70	30	117
FUEL TYPE	LOX/LH2	LOX/LH2	RP-1/LOX	LH2/LOX	LOX/RP-1	HTPB (Solid)	LH2/LOX
THRUST (LBF)	7,800,000	310,000	860,000	710,000	1,700,000	680,000	9,400,000
PAYLOAD TO LEO (TN)	27.5	21	18.5	29	22.8	1.5	130
USED FOR	Satellites, probes and manned missions	Satellites	Satellites	Satellites	Satellites	Satellites	Manned missions
DESTINATIONS	Hubble Space Telescope, International Space Station	Geostationary transfer orbit and long-term orbit	Low-Earth orbit, geostationary transfer orbit	Low-Earth and Sun-synchronous orbit	Low-Earth orbit	Low-Earth, Sun-synchronous and polar orbits	Beyond low-Earth orbit, asteroids, Mars

© Ed Crooks; Getty

How to build a rocket

onto specialised platforms – or will it aim for the more traditional one-use system, where a rocket's many parts are usually lost in re-entry or left to drift in space. Such a decision was a key point of discussion at the earliest formulation stages of the SLS program. In the end, like many other rocket programs operated by NASA and the European Space Agency (ESA), the expendable route was decided upon.

But what's the rationale behind such a decision? Interestingly, the most obvious factor of cost isn't as one-sided as you might think. "The decision on expendable versus reusable hinges on how reusability impacts performance, cost and reliability," says Nester. "For the cost piece of the puzzle, the recurring, non-recurring, fixed and variable portions of the cost need to be considered. Reusability is a great concept, and the Shuttle program realised some cost savings via reusability.

"For the SLS, even though some of the hardware is the same hardware as the Shuttle, the differences in flight rate and application are such that reusing these components was predicted to result in an increase in program cost [as opposed to generating a savings on the Shuttle program]. For our application, the balance of considerations showed that the 'costs' of reuse weren't justified by the benefits," he adds.

Once the main elements of a new rocket's design have been formulated, then a more detailed design is needed. NASA's Space Launch Initiative, unlike almost any other modern rocket program, makes this specific design process even more complicated. The plan was made to split the rocket's program into three separate phases, known as 'blocks'. These phases, called 'Block 1', 'Block 1B' and 'Block 2', are all based on the same central core and set of four rockets, but each one has unique characteristics that will define each stage of the program's post-launch life cycle.

For instance, the second phase, 1B, will employ a more powerful second segment known as an Exploration Upper Stage that will aim to take teams of human astronauts farther into space than ever before, most notably those that will man NASA's Orion spacecraft. The decision to design three iterations of the same rocket may seem a strange one, but it's emblematic of the desire to take manned missions beyond the Moon.

"For programs like the SLS, the designs solidify as they progress through the detailed design phase," says Nester on whether these designs are set in stone from the start or shift as new developments are made. "Based on when the system's blocks are projected to be needed, the different blocks are at different phases in the typical program life cycle. For each block we assess the potential implications on the parts that will be common across the blocks. For the evolutions that could occur in the nearer term, more and more of the details are being finalised each day. These details will all be finalised as we get closer to manufacturing the different elements of the evolved configurations."

In many cases, a new rocket's design will often draw upon certain characteristics from previous programs, taking inspiration from them. While this practice is there to ensure the advances made elsewhere are retained and refined upon, it's also a vital way to keep costs from spiralling out of control. In some cases it's not just the amalgamation of previous developments, but the inclusion of actual components from cancelled or retired projects. Since a new rocket program is often designed as much for its cost effectiveness in comparison to current launch programs as it is the potential scientific possibilities, using existing parts has become quite commonplace.

A total of 16 RS-25 engines from the defunct Space Shuttle program have been incorporated into the SLS's design. Elsewhere, a majority of the metal hardware used for the program's five-segment rocket boosters was also used on the Shuttles, whereas the interim cryogenic propulsion system – which will be located in the upper stage of the rocket, propelling the Orion spacecraft above it – has been incorporated from the Delta IV rocket, a vehicle that's still in use today. In fact, the SLS has even integrated the booster avionics, engine controller and core stage systems from the Ares program. It's a common practice in both national space agencies and private manufacturers such as SpaceX, and one that's driven rocket design since the earliest iterations.

> *"The decision on expendable versus reusable hinges on how reusability impacts performance, cost and reliability"* **TYLER NESTER**


Right: A close up of the rocket engine and exhaust pipes of NASA's Saturn V rocket

© Getty

How to build a rocket

BUILDING THE SLS

What makes the Space Launch System the most powerful rocket ever made?

1 RS-25 engines
Previously used as the main engine of the Space Shuttle, four RS-25 engines will power the core stage of the SLS.

2 Core stage
The largest element of the SLS, the core stage is 65 metres (212 feet) tall and contains cryogenic liquid hydrogen and liquid oxygen that will mix and feed the four RS-25 boosters beneath it.

3 LH2 tank
The largest of the components in the core stage, this tank contains the other element needed to fuel the RS-25 rockets below – cryogenic liquid hydrogen.

4 Intertank
One of a number of components incorporated from the defunct Space Shuttle program, the intertank feeds fuel loads between the LOX and LH2 tanks.

5 Forward skirt
Built by Orbital ATK, this element connects the core stage of the rocket with its twin rocket boosters on either side.

6 Spacecraft adaptor
The final element of the Orion spacecraft, the spacecraft adaptor is designed to create an airtight lock between the craft and the remainder of the rocket.

7 Encapsulated service module panels
These panels, comprised mainly of reinforced fibreglass, are jettisoned once the final stage of the rocket's launch is initiated.

8 Launch abort system
Built purely for emergencies during launch, the escape rocket is there to propel a manned crew to safety in the early stages of launch.

9 Crew module
This element of the Orion Multi-Purpose Crew Vehicle holds the crew itself, providing space for up to four astronauts to live and operate.

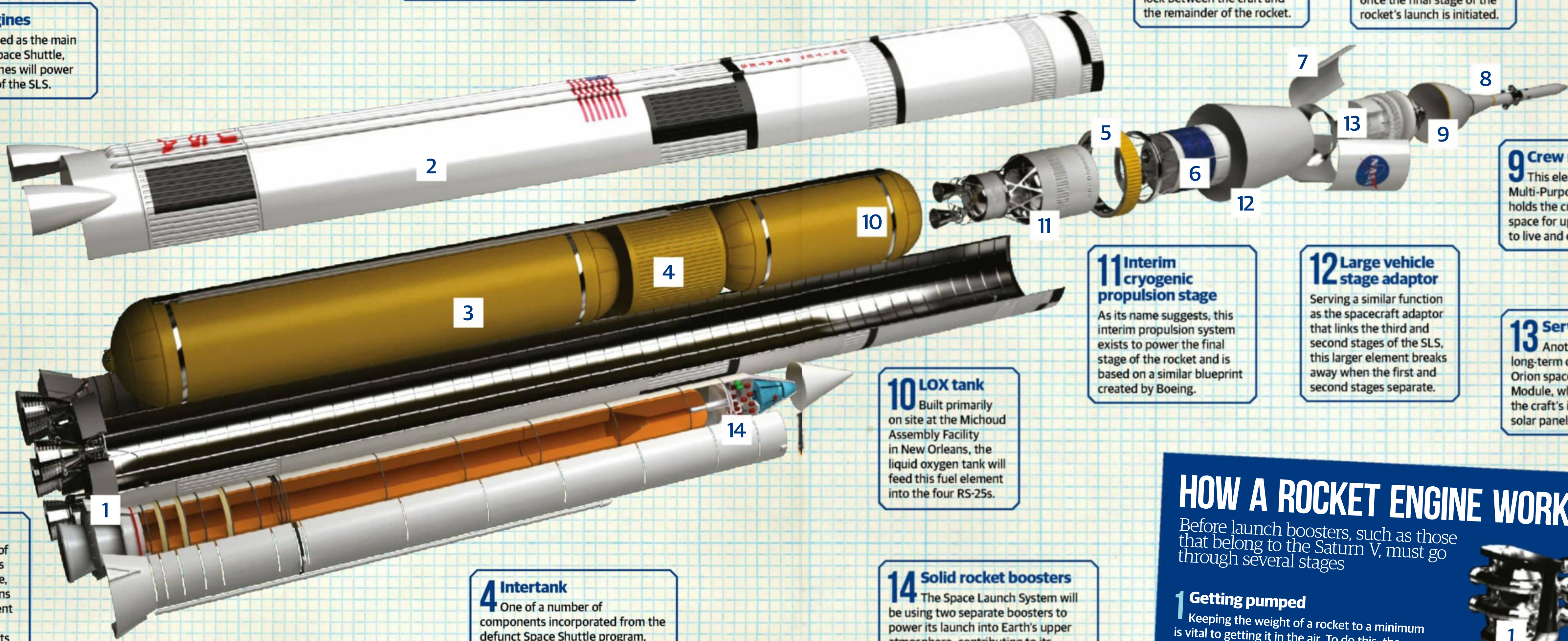
10 LOX tank
Built primarily on site at the Michoud Assembly Facility in New Orleans, the liquid oxygen tank will feed this fuel element into the four RS-25s.

11 Interim cryogenic propulsion stage
As its name suggests, this interim propulsion system exists to power the final stage of the rocket and is based on a similar blueprint created by Boeing.

12 Large vehicle stage adaptor
Serving a similar function as the spacecraft adaptor that links the third and second stages of the SLS, this larger element breaks away when the first and second stages separate.

13 Service module
Another main and long-term component of the Orion spacecraft is the Service Module, which hosts most of the craft's instruments, fuel and solar panels.

14 Solid rocket boosters
The Space Launch System will be using two separate boosters to power its launch into Earth's upper atmosphere, contributing to its 70-tonne capability.



It's now that a rocket enters the manufacturing and operations stage of its life cycle. The definitive blueprints for the rocket are now sacrosanct, detailed down to every last bolt, cut and wire. Everything from materials required to the amount of man-hours needed to construct, test and eventually launch the rocket are determined years in advance so construction of its composite parts can begin. And for Nester and the rest of the team working on the SLS, learning from past projects is key to building the composite parts of a rocket. "We are using a lot of lessons learned from previous programs in our efforts to streamline the development and manufacturing processes. For example, in many areas we have applied lessons from lean manufacturing to improve our manufacturing operations and reduce our manufacturing costs."

In some cases, rockets are built and tested in completely different locations, with multiple teams assembling payload constructs while others test and refine boosters. For projects with the magnitude of the SLS, every facet of the rocket is being constructed and rigorously tested on one huge site, namely the Michoud Assembly Facility in New Orleans, Louisiana. The facility itself is one of the largest of its kind in the world, with a staggering 17 hectares (43 acres) housed under one roof. It's so big, in fact, that engineers such as Nester have to use bicycles just to reach different divisions.

And many of those divisions are now using new advancements to create the most resilient and affordable materials for everything from the rocket's outer shell to its internal circuitry. "One of the most important considerations is understanding the environments in which the system will need to operate and designing the system to operate in those environments," explains Nester. "This is true for the ascent-phase portions of the mission

HOW A ROCKET ENGINE WORKS

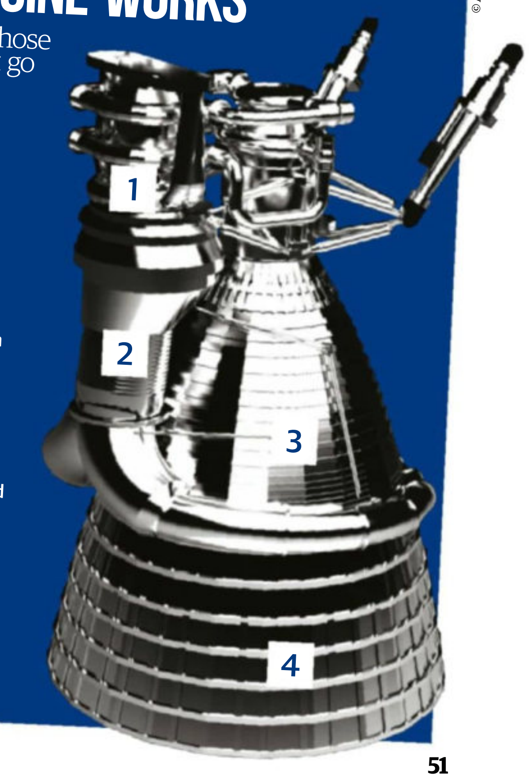
Before launch boosters, such as those that belong to the Saturn V, must go through several stages

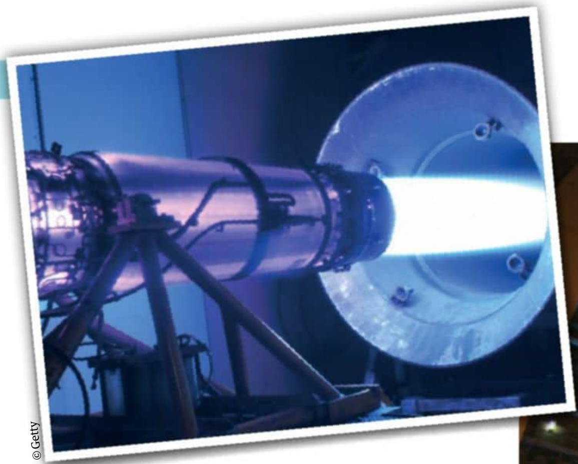
1 Getting pumped
Keeping the weight of a rocket to a minimum is vital to getting it in the air. To do this, the fuel and oxygen propellants are liquefied with extreme cooling. The pumps begin by sending these to the combustion chamber.

2 Fuel injection
On its way to the turbo pump, the fuel is then siphoned through coolant passages. The newly pressurised fuel then passes over the turbine, causing it to rotate.

3 Fired up
The fuel and oxidiser components are pumped into the combustion chamber proper where they're superheated into a high-pressure gas.

4 Chain reaction
As the gas is squeezed through the throat of the combustion chamber and out of the nozzle it creates thrust, which pushes back up towards the chamber lifting the rocket.





©Getty

©: NASA; Getty

and for the in-space portions of the mission. The analytical and testing tools that are being used are critical to making this process work. The advances in computer-aided design (CAD) and computer-aided engineering (CAE) technology have been a key enabler in enabling us to design and analyse the system."

According to Nester, the new elements of the system are being designed to take advantage of developing manufacturing technologies, such as new joining and assembly innovations and additive manufacturing, as well as the use of 3D printing, as "the combination of new design technologies and the new manufacturing technologies enables us to consider things that were previously not possible".

Modern rockets capable of carrying everything from supplies to a manned mission are composed of multiple 'stages' that are designed to systematically power a given payload out of Earth's atmosphere and towards a designated region of space, or point of orbit. The lower stage is the largest, containing the biggest thrusters and thousands of litres of fuel - types of fuel differ, but most use a mixture of liquid oxygen and kerosene. The first stage is designed to produce a gargantuan amount of thrust in order to lift a rocket off the ground and into our atmosphere.

For rockets designed to carry multiple types of payloads over their life cycle, ensuring the lower stage is capable of lifting the varying weight, and the forces this generates, is a key factor for consideration. "Depending on the needs of a particular payload, we may change the fuel loading to optimise for a specific case," adds Nester. "In some cases, options for adding small amounts of propulsive capability as part of the payload are possible. The different 'blocks' realise increased capability by incorporating groups of upgrades as a 'block' changes."

Many rockets, including the Delta IV, are composed of one additional segment, with the second stage - or upper stage - constructed of additional boosters, a structural shell and the payload itself within; these are mostly used to send satellites into orbit and are far easier and inexpensive to build and launch. For larger and more ambitious projects such as the SLS, a special three-part set-up has been used. While the factor of cost will always temper the fires of innovation to a degree, many scientists and engineers working in the field believe three-stage rockets such as the Space Launch System are key to taking manned missions beyond the Moon and out into the Solar System, with Mars their next aim.

And so, after years of research, testing and manufacturing, the multiple stages of a rocket are constructed, and the rocket itself is prepared for launch. Launch sites such as NASA's Kennedy Space Center (KSC) in Florida and the ESA's Guiana Space Centre in French Guiana house multiple platforms that can be customised to meet the dimensions of a given vehicle, although private manufacturers such as SpaceX have been testing the feasibility of sea-based launch platforms.

For something as monolithic as the SLS, NASA engineers had to go as far as building a brand-new one in preparation. "Our partners in the Ground Systems Development and Operations (GSDO) project at KSC are putting in place the facilities to assemble and launch the SLS," adds Nester on the subject. "They are basing their designs and plans on a careful study of best practices from across the industry." The launches themselves take years of planning, but often turn out to be the swiftest phase of a rocket's life cycle thanks to rigorous test flight initiatives.

Thankfully, the rate of astronaut fatalities caused by malfunctioning rockets has steadily reduced as advances in safety measures take hold. Projects such as the Space Launch System, and others such as the Vega, Ariane and Atlas rockets, are ushering in a new era of spaceflight as humankind reaches further and further into the heavens.

> "New design and manufacturing technologies enable us to consider things that were previously not possible" TYLER NESTER

Top left: A gas turbine aerospace engine running in a test cell with afterburners on. High thrust creates extreme vibration of engine

Left: New advancements in manufacturing, such as NASA's 51.8 metre (170 foot) Vertical Assembly Center, have helped build rockets faster and safer

planet profile Saturn

Saturn is famous for its rings, but there is more to it than meets the eye

The Ringed Planet is not only a fan favourite among astronomers because of its consistent visibility in the night sky, but also because it offers an enticing uniqueness. Along with Jupiter, Uranus and Neptune, Saturn is one of the gas giants - also known as Jovian planets - that sit in the outer regions of the Solar System. What is most intriguing about the two largest planets in our Solar System, Jupiter and Saturn, is that they are the bridge to understanding stars like our Sun. Although they are classified as planets, they have a more similar composition to the Sun than they do to Earth.

Saturn is one of the brightest objects in the night sky, with an apparent magnitude that swings from -0.55 to +1.17. Magnitude varies with the distances between Saturn, Earth and the Sun. The ringed gas giant is nine-times further away from the Sun than Earth is, as well as over nine times the Earth's diameter. As the second-largest planet Saturn also has an enormous volume capacity, which is capable of fitting 764 Earths inside it.

As it is an extremely bright celestial object, Saturn has been observed for centuries, and as such its discovery date can't be pinned down. However, the Italian astronomer Galileo Galilei observed Saturn through his telescope in 1610, at first believing that Saturn's rings were actually moons. Over years of observation the moons would change shape and sometimes disappear, which was due to the planet's inclination with respect to Earth. Galileo's error wasn't realised until 45 years later when Dutch astronomer Christiaan Huygens used a telescope with a higher resolution to resolve the rings.

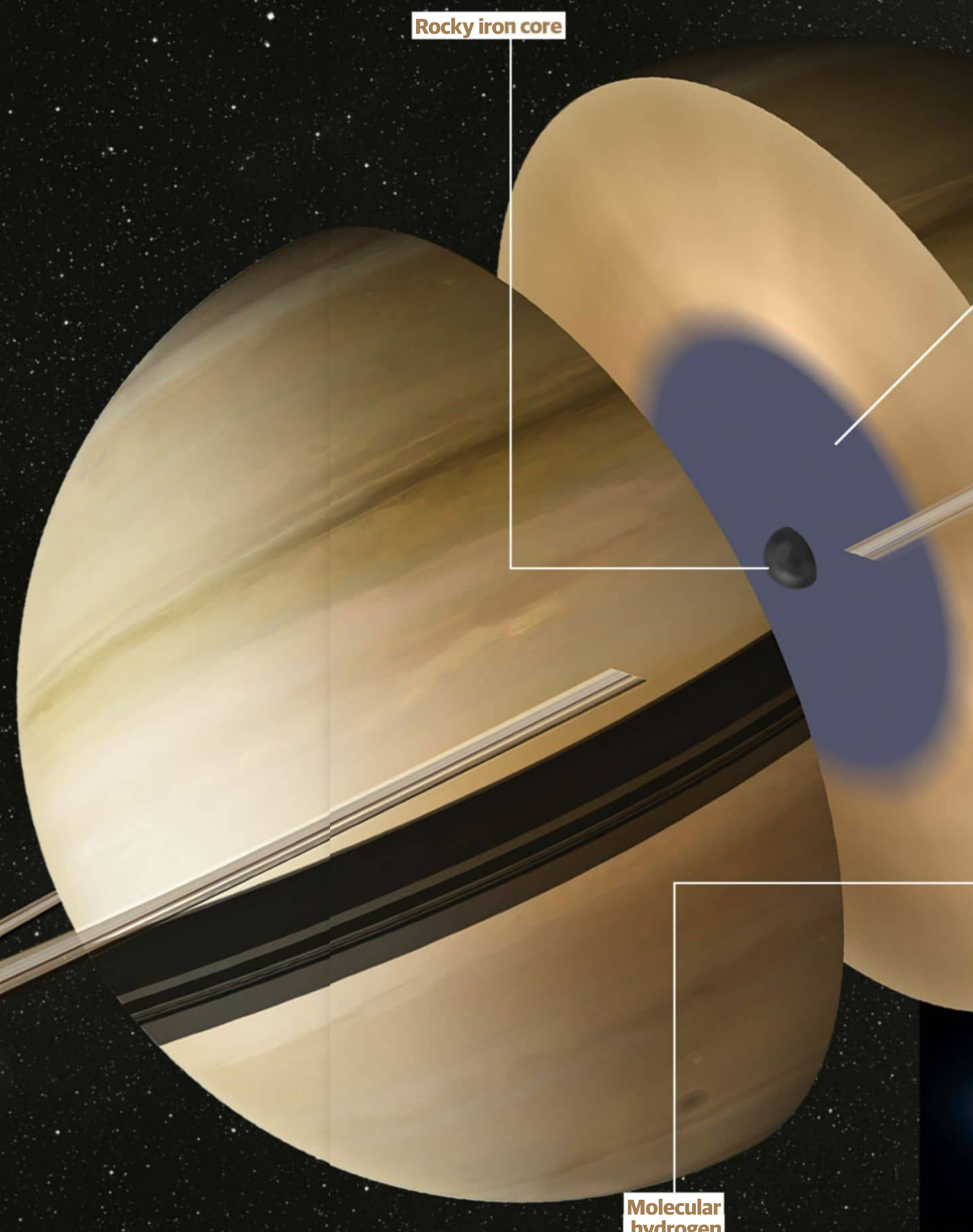
In modern times space probes have been able to get a much closer look at the planet and its ring structure, the most prominent example being NASA's Cassini spacecraft. Cassini's flybys showed that Saturn's rings are made up of mostly water-ice particles and some rocky meteoroids, sized from tiny grains of sand to as large as mountains and extending up to 282,000 kilometres (175,000 miles) from the planet.

There is much more to Saturn than just its rings though. It has 53 confirmed moons, with a further 29 provisional moons that are just awaiting confirmation. The most intriguing moons are Titan and Enceladus, which exhibit exciting astrobiological prospects. Titan shows Earth-like weather cycles and lakes, but with hydrocarbons, and Enceladus has a subsurface ocean of liquid salty water. Saturn in itself is an enormous and fascinating structure that has become more and more understood since the days of Galileo and Huygens.

As mentioned previously, Saturn is more similar to the Sun than it is the Earth. The planet's composition is 94 per cent hydrogen and six per cent helium, with trace amounts of methane and ammonia. While astronomers can't physically dig down into Saturn and see its internal structure, they can build computer models showing how the planet formed 4.6 billion years ago. These models show that as temperatures and pressures rise as you get closer to the core, gaseous hydrogen is squashed into liquid metallic hydrogen. At the core of Saturn is a rocky ball of denser elements, including iron and nickel.

"Space probes have been able to get a much closer look at the planet and its ring structure"

The Cassini space probe spent 13 glorious years scrutinising the Saturnian system



Saturn composition

94% Hydrogen

6% Helium

+

Traces of ammonia and methane

This is the famous image titled 'The Day the Earth Smiled'

The latest news from Saturn

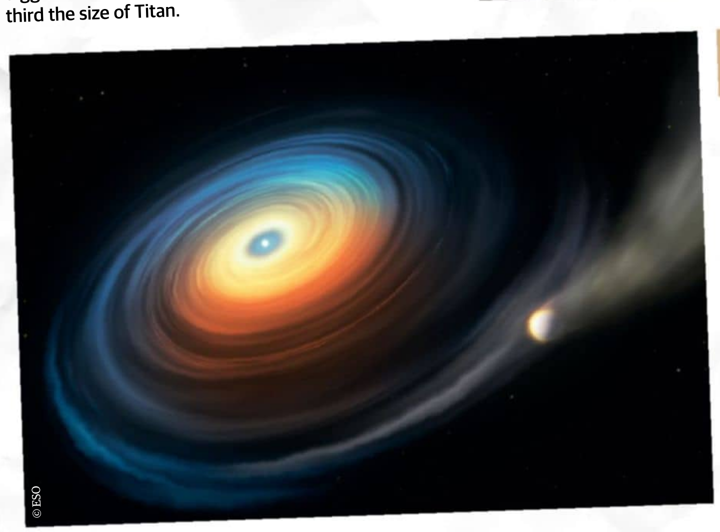
Titan survived Saturn's ancient feeding frenzy


© Nagoya University

It's likely that when Saturn was in its younger years, it was accreting whatever mass it could to become the enormous size it is now. In this primordial feeding frenzy, natural satellites orbiting close to the surface were likely engulfed on account of Saturn's gravity. Yet Titan, the second-largest natural satellite in the Solar System behind Jupiter's Ganymede, has remained in orbit.

Yuri Fujii, a designated assistant professor at Nagoya University, and Masahiro Ogihara, a project assistant professor at the National Astronomical Observatory of Japan (NAOJ) have recently proposed that Titan was spared from this frenzy due to a 'safety zone' created by the warmer and closer gas. In this scenario, the inner gas pushes a large moon away from Saturn and stops it from being consumed.

"We demonstrated for the first time that a system with only one large moon around a giant planet can form," said Fujii. "This is an important milestone to understand the origin of Titan." Not only does it help explain the origin of Titan, but it also helps explain why Saturn only has the one relatively huge moon. The next biggest Saturnian moon is Rhea, which is less than a third the size of Titan.


© ESO

What happens to Saturn when the Sun turns into a white dwarf?

In approximately 5 billion years our Sun will have swallowed the rocky terrestrial planets, including Earth, as it entered the red supergiant phase of its lifetime. After a further 3 billion years the supergiant star will have shed its outer layers and left behind a white dwarf star. This is the dense, scorching-hot remnant of the star we know now.

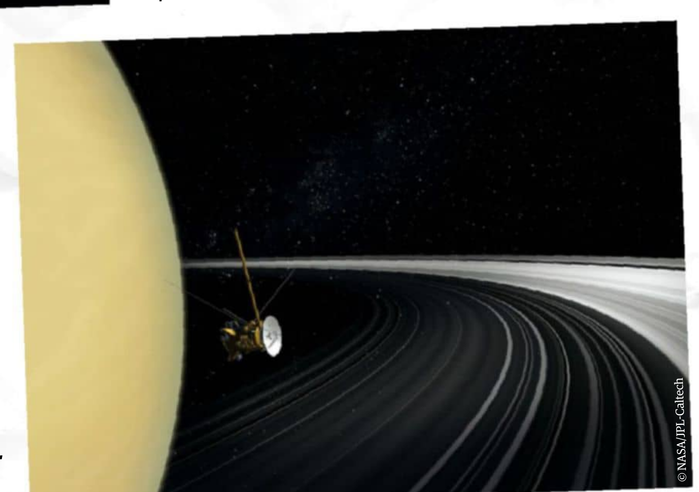
Recent research conducted by Matthias Schreiber, an astrophysicist at the Universidad de Valparaíso in Chile, suggests that once a Sun-like star has transformed into a white dwarf, it would be able to accrete the evaporated layers of its surrounding gas giant planets. This research has very intriguing implications for the future evolution of the Solar System, and in particular the ability to spot signs of Saturn in a white dwarf star.

As Schreiber said, "The white dwarf will accrete a fraction of the evaporated material, and this will result in detectable signatures, so future generations of alien astronomers, if they exist, can potentially investigate the chemical composition of Jupiter, Saturn, Neptune and Uranus."

Lord of the rings: the two explanations

The origin of Saturn's rings has been subject to constant debate since their discovery. While some believe they formed during the formation of the planet 4.6 billion years ago, others think they could have arisen within the last couple of hundred million years. Recent research by Aurélien Crida of the Observatoire de la Côte d'Azur argues that they are most likely ancient, based on data taken during the Cassini mission's 'Grand Finale', which consisted of a series of dives through Saturn's rings before vaporising in the atmosphere. During this time Cassini measured the mass of the ring system as about 15.4 million billion tonnes. That's equivalent to about 40 per cent the mass of Saturn's moon Mimas, which is 400 kilometres (250 miles) wide.

Some argue that because the rings are more than 95 per cent water ice, they should be more contaminated if they are ancient. However, Crida has provided evidence that suggests the mass of Saturn's rings is consistent with 4.6 billion years of very dynamic evolution. "I think that, objectively, [this theory] forms a much more consistent picture, with a convincing model of their formation at the same time as Saturn, plus formation and outward migration of the satellites in agreement with the observations", said Crida.


© NASA/JPL-Caltech

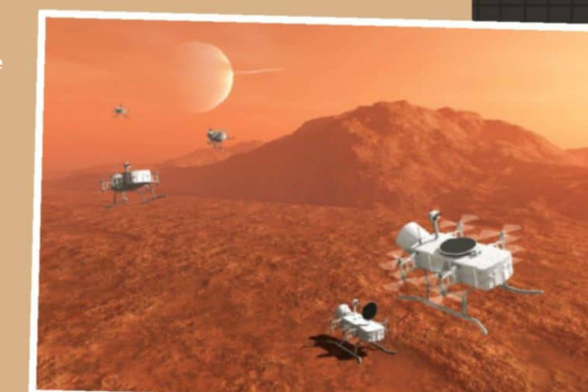
The history of Saturnian exploration

Saturn has been extensively studied across centuries. When Galileo used his telescope in the early 17th century, the rings of Saturn became apparent. Fast forward to 2020 and there is a host of commercially available telescopes to see the planet in amazing clarity. There is also a team of ground- and space-based observatories that frequently capture observations of the planet to provide regular updates.

In regards to space probe missions to Saturn, it has had a handful of human-made mechanical visitors over the last few decades. The first interplanetary investigator was NASA's Pioneer 11 spacecraft; it became the first probe to encounter Saturn on 1 September 1979. After that were NASA's two Voyager probes, which returned historic images of the outer Solar System, discovering moons and revealing surface features that had never been seen before. Voyager 1 flew past Saturn on 12 November 1980 and Voyager 2 followed suit on 26 August 1981.

The most fruitful mission to Saturn arrived there on 1 July 2004. The Cassini space probe – created in a collaboration between NASA, the European Space Agency (ESA) and the Agenzia Spaziale Italiana (ASI) – stayed in orbit around the Ringed Planet for 13 years, and the ESA-built Huygens lander arrived on the surface of Titan on 14 January 2005. For over a decade this probe took magnificent images, collected pivotal data and even took the first dive through the planet's rings. During this 'Grand Finale', as it was known, the space probe was able to collect unprecedented data on the Cassini Division, which is the wide gap between rings A and B.

This mission is still fresh in the memory of astronomers, as they are still examining heaps of data collected during Cassini's stay at Saturn. This means that we're unlikely to see a Saturn-specific mission in the foreseeable future. Do not give up hope though, as there are certainly talks of returning to its moons. For example, NASA's Dragonfly mission is hoping to launch a drone to the surface of Titan by 2026.

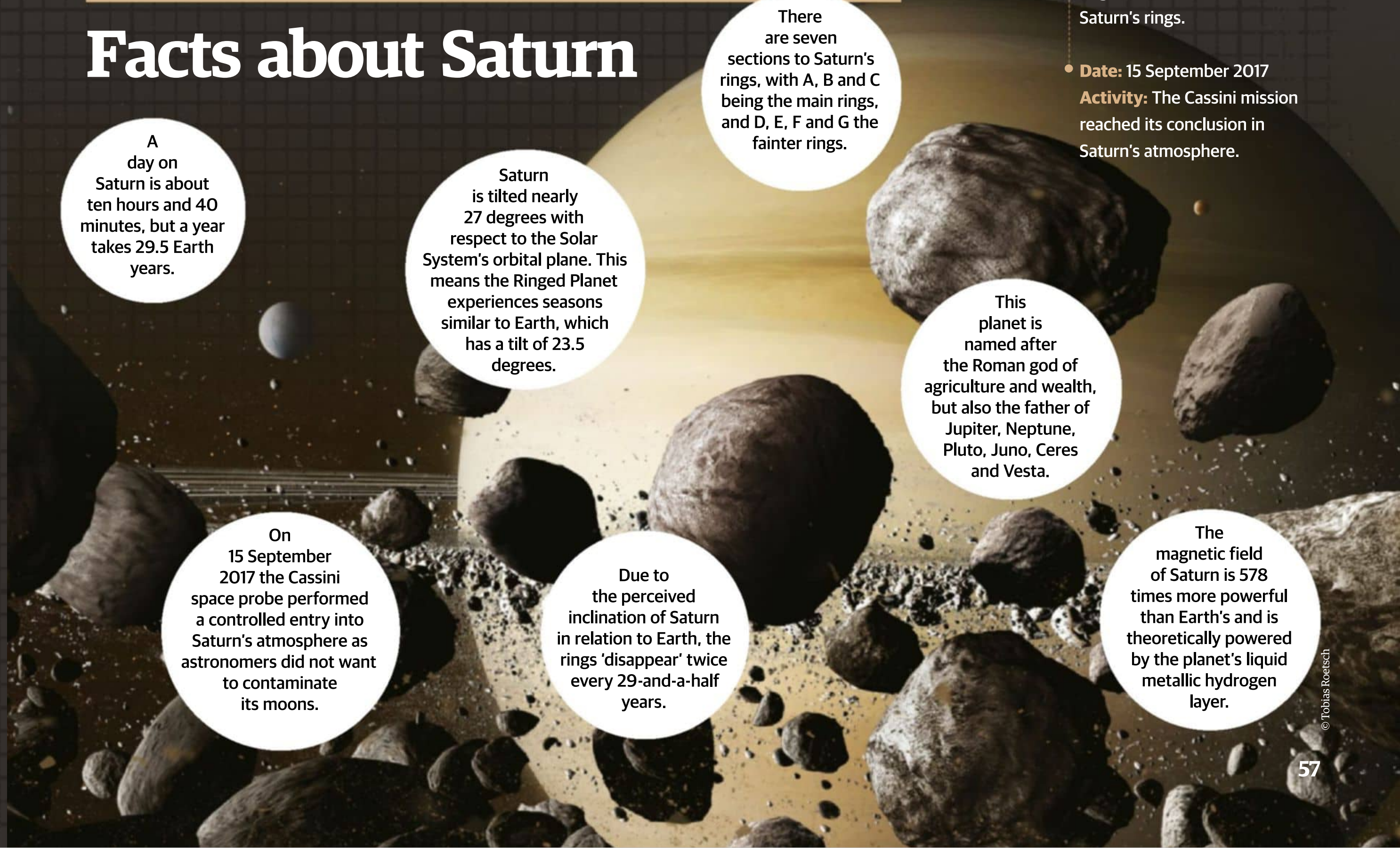

© Adrian Mann

Below: The Dragonfly mission will examine Saturn's largest moon, Titan

A timeline of Cassini-Huygens' voyage to Saturn

- **Date:** 15 October 1997
  Activity: Cassini-Huygens was launched from Cape Canaveral.
- **Date:** 30 December 2000
  Activity: The spacecraft passed Jupiter to conduct a gravity-assist manoeuvre.
- **Date:** 1 July 2004
  Activity: The Cassini-Huygens space probe arrived at Saturn.
- **Date:** 14 January 2005
  Activity: The Huygens probe separated from Cassini and landed on the surface of the moon Titan.
- **Date:** 19 July 2013
  Activity: Cassini took the historic picture of Earth from Saturn titled 'The Day the Earth Smiled'.
- **Date:** 29 November 2016
  Activity: The Grand Finale began as Cassini dove into Saturn's rings.
- **Date:** 15 September 2017
  Activity: The Cassini mission reached its conclusion in Saturn's atmosphere.

Facts about Saturn


© Tobias Roetsch

A day on Saturn is about ten hours and 40 minutes, but a year takes 29.5 Earth years.

Saturn is tilted nearly 27 degrees with respect to the Solar System's orbital plane. This means the Ringed Planet experiences seasons similar to Earth, which has a tilt of 23.5 degrees.

There are seven sections to Saturn's rings, with A, B and C being the main rings, and D, E, F and G the fainter rings.

This planet is named after the Roman god of agriculture and wealth, but also the father of Jupiter, Neptune, Pluto, Juno, Ceres and Vesta.

On 15 September 2017 the Cassini space probe performed a controlled entry into Saturn's atmosphere as astronomers did not want to contaminate its moons.

Due to the perceived inclination of Saturn in relation to Earth, the rings 'disappear' twice every 29-and-a-half years.

The magnetic field of Saturn is 578 times more powerful than Earth's and is theoretically powered by the planet's liquid metallic hydrogen layer.

MYSTERIES OF THE UNIVERSE

THE BERMUDA TRIANGLE OF SPACE

There's a portion of space above Earth where protection from high doses of radiation is significantly weaker

Reported by David Crookes

There's a region in the western part of the North Atlantic Ocean where mysterious disappearances of ships, aeroplanes and people have been reported. It's long been known as the Bermuda Triangle, and it has led to much speculation over the years over what exactly may be causing it.

Could it be extraterrestrials, some force pulling objects under the sea or a link to the fabled lost city of Atlantis? Or could it simply be bad weather, human error or heavy traffic in the region? In truth, no one knows for certain, but more than 50 ships and 20 planes are understood to have vanished since the mid-19th century. In reality that's not of a greater frequency than any other well-travelled area of the ocean, but still the conspiracy theories persist.

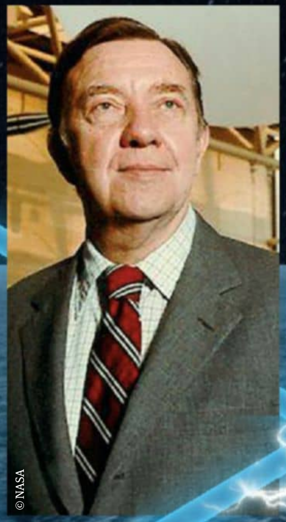
If we look skywards we can explore another separate phenomenon dubbed the 'Bermuda Triangle of space'. It is so-called because of the havoc a vast region above Earth has been causing to spacecraft that happen to enter the area. They're not suddenly vanishing into thin air, but the disruption that is being caused is nevertheless serious, and it poses problems for both equipment and astronauts.

The area in question lies above the South Atlantic, stretching from Chile to Zimbabwe, and it's the point where the inner Van Allen radiation belt comes closest to Earth's surface. To explain, you can imagine the radiation belts as being two doughnut-shaped rings of charged particles that surround our planet, held in place by Earth's magnetic field. The inner part consists mainly of high-energy protons and the outer part is mainly electrons. More crucially, since the belts trap the particles that are shooting from the surface of the Sun, they end up protecting the surface of the planet from harmful radiation.

At the location of the Bermuda Triangle of space, or the South Atlantic Anomaly (SAA) as it is formally known, Earth's magnetic field is particularly weak. This means the particles of solar cosmic rays are not being held back to the same extent as they are elsewhere above the planet. As a result they come as close as 200 kilometres (124 miles) to the Earth's surface - as nearby as they are observed to get. This means there's an increased flux of energetic particles in this area, with radiation shot from the surface of the Sun proving to be much stronger.

"I'm not fond of the nickname, but in that region, the lower geomagnetic field intensity eventually results in a greater vulnerability of satellites to energetic particles, to the point that spacecraft damage could occur as they traverse the area," explains John Tarduno, professor of geophysics at the University of Rochester. "This is something that concerns anybody planning or embarking upon a space mission because it can so easily cause millions of dollars and hours upon hours of time to be wasted.

"The lower magnetic field intensity allows Earth's radiation belt - technically the inner



Right: The discovery of the belts is credited to American space scientist James Van Allen

© NASA

SPACE'S BERMUDA TRIANGLE BY THE NUMBERS

1958
The year the South Atlantic Anomaly was discovered

200KM
The closest the Van Allen belt comes to the surface

0.3
Degree at which the highest intensity part of the SAA drifts west

11
Degree the Van Allen belts are offset from Earth

15
Percentage of time that Hubble orbits within the SAA

3,000
The rate of proton hits on a spacecraft per square centimetre per second

10,000,000
Amount of energy, in eV, of the protons that bombard spacecraft in the SAA

170
Number of years a weak patch of Earth's magnetic field has grown in size

© Getty

Left: The Hubble Space Telescope, which passes through the South Atlantic Anomaly ten times a day

belt - to come closer to Earth's surface," Tarduno continues. "Thus satellites passing through this region will experience higher amounts of radiation to the point that damage could occur. Think about an electrical discharge or arc. With more incoming radiation, a satellite can become charged, and attendant arcs can result in serious damage."

Ordinarily the belts stretch at an altitude of between 1,000 and 60,000 kilometres (620 and 37,000 miles) above Earth's surface. The low altitude of the radiation hotspot, however, puts it within the orbit of certain satellites, which are promptly bombarded by protons that exceed energies of 10 million electron volts (eV) at a rate of 3,000 'hits' per square centimetre per second.

This affects the onboard electronic systems, which hampers the operation of these objects and forces space agencies and other satellite operators to power them down. The same goes for Hubble, which passes through the SAA ten times a day, spending a good 15 per cent of its time there. It is also prevented from collecting astronomical data during these moments, which is obviously not ideal.

Failing to take precautions, however, would likely lead to system failure - something astronauts have already witnessed with computers on board craft that fly in the vicinity of the SAA. The only option is to take protective measures. "Putting equipment into a 'safe mode' means operations that are more vulnerable to radiation are curtailed," Tarduno says. But it's either that or no operation at all.

The more complex electronics become, the more potential there is for problems to emerge. Any satellites that use the microwave tracking system DORIS - which stands for Doppler Orbitography and Radiopositioning Integrated by Satellite - for example, see a resulting shift of the onboard oscillator frequency. The SAA can also prove very costly, seen most starkly when it helped to bring the Japanese satellite Hitomi crashing down to Earth.

Hitomi, or ASTRO-H, was commissioned by the Japan Aerospace Exploration Agency (JAXA) to study extremely energetic processes in the universe. Just over a month after its launch, its operators lost contact and it was found to have broken into several pieces. The problem, it later transpired, was due to the spacecraft's inertial reference unit reporting a rotation of 21.7 degrees per hour when it was actually stable. When the attitude control system sought to counteract the supposed spin, a succession of events caused it to break.

Had those on the ground been able to spot this, they could have corrected it. But it happened while the satellite was travelling through the SAA, so communication was lost. There is also a possibility that the large dose of radiation affected the electronics. In any case, the whole sorry saga lost JAXA £191 million ($273 million) as well as three years of prepared studies.

Astronauts can be affected by the SAA too. Some have reported seeing odd white lights flashing before their eyes, and steps have therefore been taken to protect them on board the International Space Station (ISS). Strong shielding is used in the most frequently occupied parts of the ISS such as the gallery and the sleeping quarters to reduce the amount of radiation the astronauts are exposed to. Astronauts also wear dosimeters that measure their personal exposure to ionising radiation in real time, sending out a warning if they increase towards dangerous levels.

But just why is the magnetic field less strong above the South Atlantic? This is to do with the shape of Earth, which despite common perceptions is not completely round. It bulges slightly in the middle, and the planet's magnetic dipole field is offset from its centre by about 500 kilometres (300 miles). Where the dip lies, the charged particles and cosmic rays are closer to Earth's surface and provide less insulation from interplanetary space. Even so, this magnetic bubble prevents the solar wind from reaching the surface.

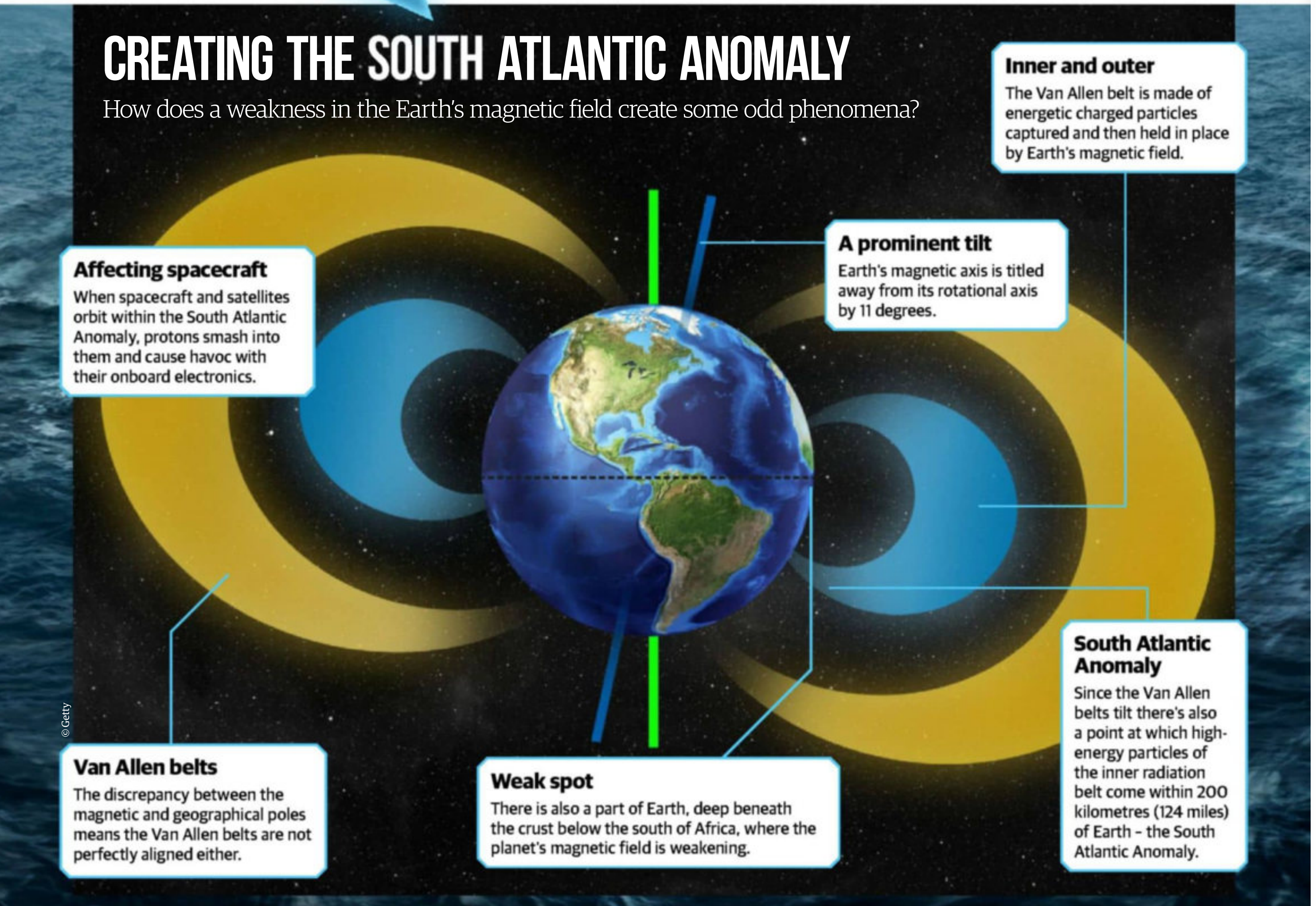
The magnetic field is being sustained by a dynamo process. Earth's outer core has flowing liquid metal, and this generates electric currents. When the planet rotates on its axis, the turbulent motions form the magnetic field, and this gives us the north and south poles. Yet the magnetic field is weakening, and the area of the SAA is growing.

In 2018 Tarduno sought to examine just how long the SAA has been active. As luck would have it, he was helped by Bantu farmers who lived in the Limpopo River Valley in Africa 1,000 years ago. They would perform a cleansing ritual which involved burning their villages during droughts to start afresh and encourage the rain. But this also resulted in the freeing of magnetic minerals in the clay that would align with Earth's magnetic field before cooling and providing a stunning snapshot of what was happening at that time.

"We found something unusual about the core-mantle boundary under Africa," Tarduno says, and

CREATING THE SOUTH ATLANTIC ANOMALY

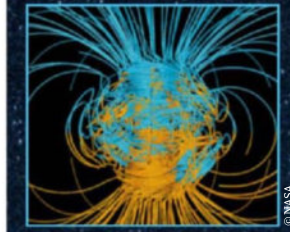
How does a weakness in the Earth's magnetic field create some odd phenomena?



THE THEORIES

What is happening and what are the possible consequences?

The Van Allen belt is at a low altitude



We know that Earth's magnetic poles are titled and we know that as a result the Van Allen radiation belt is tilted too. It's also accepted through evidence that the South Atlantic Anomaly is at the spot where the Van Allen radiation belt is closest to the surface of our planet and that in that location there is a low magnetic field. This is the explanation for the so-called Bermuda Triangle of space, and we know it is growing as the magnetic field weakens.

The answer could be deep underground

Studies into why Earth's magnetic field is weakening are important because the field offers us protection from solar wind and cosmic radiation. There's evidence we've seen such weakening before, with pointers to many past fluctuations. A strong theory is that it is being caused in the core-mantle boundary 2,900 kilometres (1,800 miles) under Africa. However, the biggest danger right now is posed to spacecraft and satellites rather than life on Earth.

The poles may be about to reverse

It's a controversial theory, but dipole decay and the development of the South Atlantic Anomaly could well be pointing to an impending reversal. Recent results and studies, however, don't appear to be indicating such an occurrence. Indeed, when scientists have sought to reconstruct the geomagnetic field evolution around the time of the last field excursion, some time intervals resembled the present SAA, but the anomalies disappeared.

Below: The Van Allen Probes (VAP) were launched in 2012 and operated for seven years to better understand the radiation belts

this, he surmises, could be affecting the global magnetic field. He says it shows that the SAA is the most current manifestation of a recurring phenomenon. "My colleagues and I have proposed that it is related to an unusual core-mantle boundary structure under Africa that promotes the formation of reversed flux patches," he tells us.

He is not alone in thinking this. "I am among a group of scientists who believe there is a direct relationship," he continues. "Under Africa, at the core-mantle boundary just above the liquid-iron core, the field is reversed. This is something we call a reversed flux patch. It is this patch that seems to be causing most of the weak field and the SAA."

The growing area of the SAA caused by the weakening of the magnetic field, however, could spell bad news over time. Not only could it cause havoc with computers and other electronic equipment on Earth, it could even lead to a greater prevalence of cancer. Scientists have also looked into whether this will mean the magnetic field is about to flip, but studies based on observations of the past 50,000 years suggest the SAA is not a sign of this.

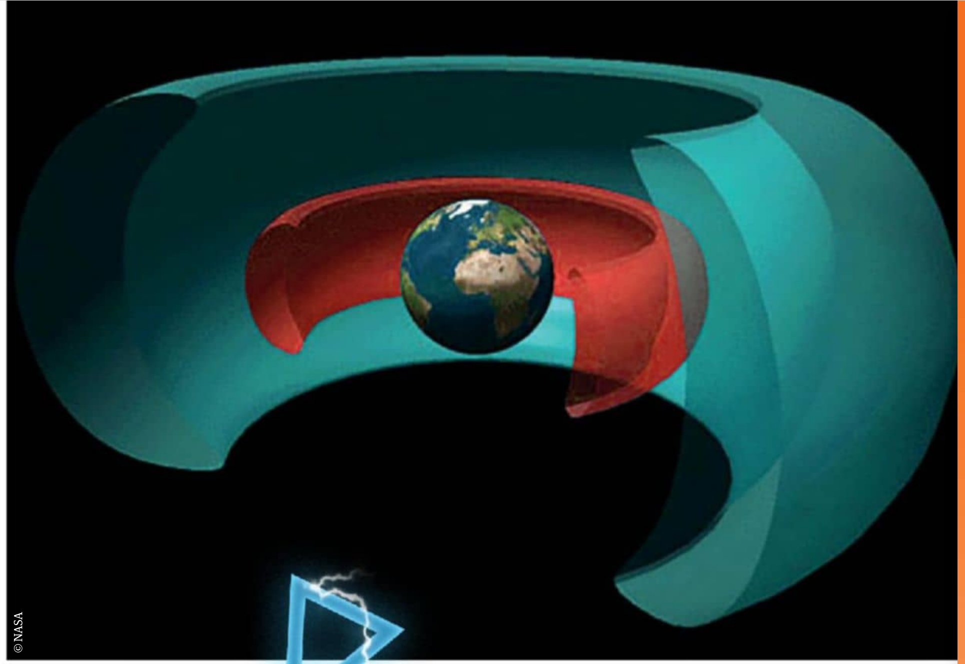
Further studies have also looked into how hazardous the radiation in the SAA could be at different levels. Riccardo Campana at the National Institute for Astrophysics in Bologna, Italy, for example, analysed radiation data from the Italian-Dutch satellite for X-ray astronomy BeppoSAX, which frequently journeyed through the lower edge of the SAA between 1996 and 2003. He found the radiation levels to be lower than in the upper layers.

Still, as the European Space Agency points out, the magnetic field has lost about 15 per cent of its strength over the past 150 years. Before 1994, it says, the magnetic north pole was moving at ten kilometres (6.2 miles) per year, but this has sped up to some 65 kilometres (40 miles) since 2001. Could the magnetic field ever disappear completely, leaving Earth wide open to radiation?

"This is not a concern until many billions of years into the future," says Tarduno. "Even during times of magnetic reversals, there is a magnetic field, albeit much weaker and much more complex in form than the present one.

"The debate now is whether we are in the early stages of a magnetic reversal. The rapid decline in dipole magnetic field strength over the last 160 years and the pattern of decay lend some support for consideration of this as a possibility, but the short time span of the observed decay still puts this into the realm of speculation."

For now the main concern is for space exploration, particularly given that the number of satellites and spacecraft carrying humans is set to increase. Knowing how the SAA behaves is crucial because it will end up covering a greater geographical region than today.



© NASA

Above: Here you can clearly see the wraparound of the proton-dominated inner belt in red and the outer belt that is dominated by electrons

MONIKA KORTE

Korte has closely studied the South Atlantic Anomaly as head of GFZ Potsdam's working group on geomagnetic field evolution in Germany

© Helmholtz Centre Potsdam

What is the SAA?

The SAA is a region stretching over parts of the southern Atlantic and South America where the geomagnetic field is weaker than at comparable latitudes by up to 40 per cent. As the dipole-dominated geomagnetic field is weakest in the equatorial regions anyway, the SAA is the region where field intensity is weakest anywhere on Earth.

Why does it cause problems with communications satellites and other equipment?

The geomagnetic field plays an important role in shielding Earth against the solar wind and cosmic radiation. The shielding is weakest in polar regions and where field intensity is weak - in the SAA. Satellites are more exposed to harmful influence from solar wind particles in the SAA and clearly more temporary outages of satellites are observed in the SAA region than elsewhere. Also, the dose of radiation that aircraft passengers receive is higher on routes through the SAA than elsewhere.

How can we protect craft from this pummelling of radiation?

Either by stronger technical shielding or by avoiding to fly through the area of the SAA. Both are not straightforward, though, as stronger shielding tends to be heavy, and in particular satellites are confined to orbits and cannot simply avoid just a small part of an orbit.

Your study in 2018 found the SAA was growing at the same time as Earth's magnetic field has been dwindling – how significant is this?

It had been noticed for years, even for some decades, by several researchers that the SAA was growing at the same time as Earth's global dipole field strength weakens. The growth of the SAA clearly seems linked to the dipole decrease, and there are theories that the growing of the SAA drives the dipole decay, but in my opinion it's not fully understood what is the cause and effect and what exactly the mechanism - or mechanisms - and link behind these two developments of the geomagnetic field are.

Our experts answer your questions

SOLAR SYSTEM

Do gas giants experience similar weather to Earth?

The giant planets have deep, cloud-filled atmospheres that behave in much the same ways as Earth's. Weather generally means storms and short-term cloud changes, and the driving physics are the same on any planet. The only differences are the lack of a solid surface and their large distance from the Sun.

For the giant planets, the weather is observed from above the cloud tops, which are ammonia ice for Jupiter and Saturn, and methane or hydrogen sulphide ice on Neptune and Uranus. The main driver for weather events is likely a water cycle, just as on Earth. As on Earth we observe thunderstorms, cyclones and waves in the clouds which form from disturbances in the atmosphere and cause changes in temperatures and local winds.

One major difference from Earth is that the most prominent round-looking storms are anticyclones, high-pressure storms that rotate in the opposite direction of a cyclone or hurricane. While storms on Earth last only hours to days, storms on the giant planets can be very stable. This is partly because there is no surface to cause them to dissipate. Storms that move towards the equator or poles will be torn apart, as we see on Earth; on Neptune storms typically do this and last only a few years. In contrast, on Jupiter and Saturn, the strong, alternating, east and west winds channel storms, preventing them from moving north or south, allowing them to stay stable for decades to centuries.

Dr Amy Simon is senior scientist for planetary atmospheres research in the Solar System exploration division at NASA's Goddard Space Flight Center

Above: Weather on Jupiter might not be so alien to us

© NASA/JPL-Caltech

Did you know?

Gas giants are believed to have some rocky material at the core, but it's hidden under layers of tumultus gases.

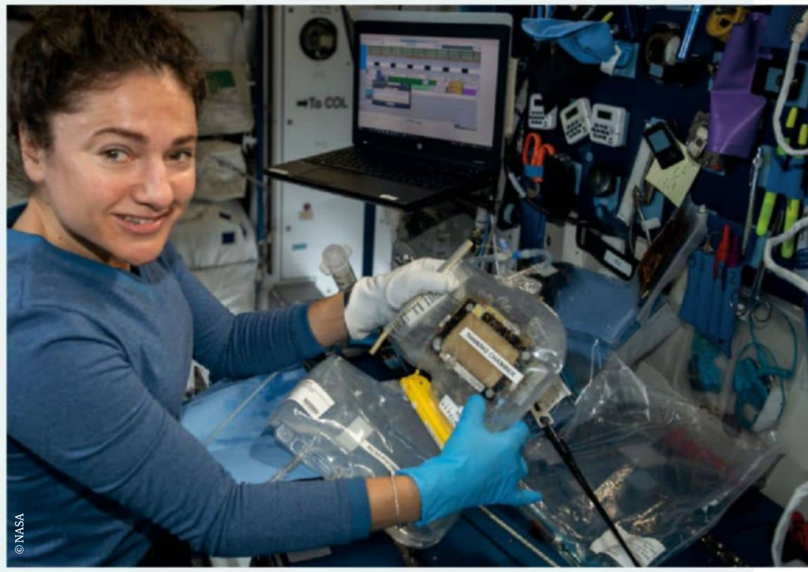
SPACE EXPLORATION

What is an astronaut's daily routine on the International Space Station?

An astronaut's day starts typically at 06:30 with breakfast followed by the typical morning ritual of getting ready for the day ahead. The working day always begins with a morning daily planning conference – audio only. All the astronauts and all the control centres around the world take part to synchronise on the schedule of the day ahead. Afterwards the astronaut gets busy with a number of activities – it could be science, medical or even some maintenance in the station – with a much-needed lunch break in the middle of the day.

A day is never dull, and one thing that is constant is exercise – two hours of exercise. This is vital to counterbalance the effects of weightlessness on the astronaut's body. On some days the astronaut will also take part in in-flight calls with schools or groups, or maybe record a message for us back on Earth. There are also those very special days when the astronaut has to go outside and check, fix or replace something. This is called an extravehicular activity, or EVA for short, though it's better known as a 'spacewalk'. Just as each morning, the astronaut joins his crew and control centres for the evening daily planning conference. Finally it's time for dinner, and hopefully also enough time to relax, call family, watch a film or, what all astronauts love, watch the Earth below with a camera on hand.

Romain Charles is lead of the Astronaut Operations Team at the European Astronaut Centre



Right: An astronaut must be well prepared to spend time living in space

© NASA

"It could be science, medical or even some maintenance"
Romain Charles

Below: The 'Roche limit' determines if an orbiting body is ripped apart into smaller debris

© NASA/JPL-Caltech

ASTROPHYSICS

What is the 'Roche limit'?

The Roche limit is the distance at which a moon's own gravity is in balance with the tidal forces working to pull the moon apart. If a moon wandered inside its planet's Roche limit, tides would rip it apart and turn it into a ring. While the basic concept of the Roche limit is straightforward, it turns out that its location depends on things that are different for every planet and every moon, such as how dense the moon and planet are relative to each other, what shape the moon has, how much the shape of the moon is changed during tidal effects and the strength of the material that makes it up.

Small moons can hold themselves together at closer distances than very large ones because internal strength is a more important factor in holding them together than gravity. After all, spacecraft in low-Earth orbit, like the International Space Station, orbit inside the Roche limit, but are not torn to shreds. It's more accurate to refer to the 'Roche zone' of a planet, which is where moons can 'potentially' be ripped apart, but only if they are large or weak enough that they behave more like a fluid and less like solid rock. The main rings of planets are mainly found inside the Roche zone, but there are some spectacular examples of moons and rings coexisting in the outer edges, such as the case of Pan and Atlas at Saturn, and Cordelia and Ophelia at Uranus.

Dr David Minton is an associate professor for the department of Earth, atmospheric and planetary sciences at Purdue University, Indiana

ASTROPHYSICS

Could a star have a ring like Saturn?

Stars can have rock and dust in orbit with gaps that resemble the rings of Saturn. Well-known stars like Vega and Fomalhaut have dusty debris discs, and this is likely a feature that most stars have during their lives. But there are also differences.

Soon after a star is born, gas and dust from the birth cloud will form a flat disc orbiting the star. This disc is the material from which planets form. If a gas giant planet similar to Jupiter forms from the gas and dust, its gravitational influence will clear out lanes in the disc. This is the same mechanism by which the moons in Saturn's rings have carved out lanes, producing multiple 'rings'.

The gas-rich phase for discs around stars is usually relatively short, less than 10 million years. Rocky bodies that have coalesced from the dust will slowly thin out over a longer time and eventually resemble the asteroid and Kuiper belts in the Solar System.

The main visual difference between the rings of Saturn and the 'rings' of debris around stars is that Saturn's rings are mostly ice, whereas debris discs around stars are mostly rock. Ice near the star would not last long.

Dr Mark Pecaut is associate professor of physics for Rockhurst University, Missouri

© ESO

Left: Discs around young stars are much harder to see than Saturn's rings due to their low reflectivity

SPACE EXPLORATION

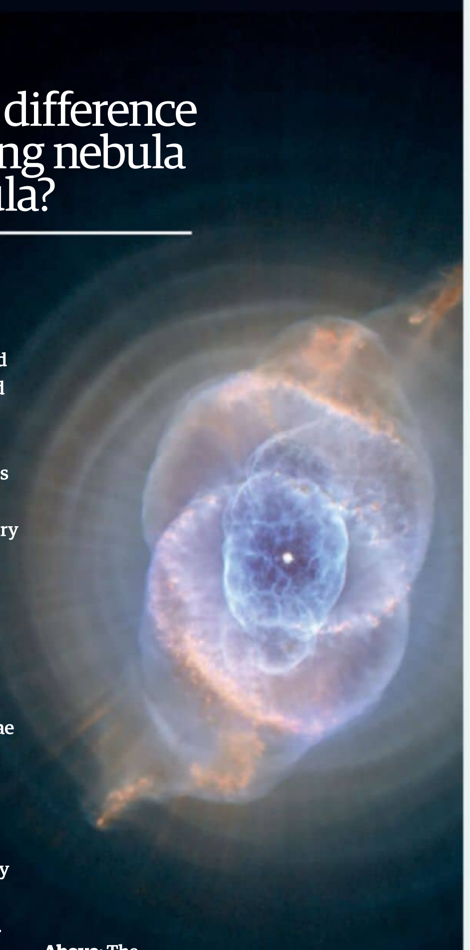
How can you tell the difference between a star-forming nebula and a planetary nebula?

A star-forming nebula is created by very bright young stars which are heating and ionising the leftover cloud of dust and gas from which they formed. A planetary nebula is formed at the end of the life of a star, after it has bloated into a red giant and run out of fuel. The central material from the red giant collapses to form a white dwarf star, and the heat and ionisation from this star blow the outer layers of material outwards.

Since some star-forming nebulae and planetary nebulae can look quite similar, astronomers must use a variety of clues to help differentiate them. The most obvious one is to see if you can identify a white dwarf at the centre of the nebula, in which case it is a planetary nebula. Also, the chemistry of the gas contained in the nebulae will be different, with planetary nebulae showing more highly processed chemicals that are forged in the interiors of the progenitor red giant stars.

The local environment of the nebulae can also be a clue; star-forming nebulae are typically found to be associated with clusters of young stars and found within dense molecular clouds. These types of diagnostics require astronomers to use data from multiple facilities and to look at multiple wavelengths to be sure they know what type of nebula they are dealing with.

Dr James De Buizer is senior scientist at the Stratospheric Observatory For Infrared Astronomy Science Center



© NASA/ESA/Hubble

Above: The white dwarf star at the centre of a planetary nebula can usually be spotted fairly easily

SOLAR SYSTEM

What if Earth had two moons?

© NASA

Right: What if the Moon had a twin?

Let's assume that they had the same mass as our Moon and that one formed twice as close to Earth as the other, with the closer moon initially ten-times closer than our Moon is today. Water tides on Earth from that closer moon would have initially been 1,000-times higher than the tides we experience today. Tides from the farther moon would have initially been 125-times higher than our tides today. The tidal force created by the two moons would also have caused an extensive earthquake and surface volcanic activity on Earth.

The young Earth, rotating much more rapidly than it is today, would pull the towering water tides around ahead of the moons that create them. The gravity from this water would pull the moons forward in their orbits, giving them energy and forcing them to spiral away from Earth.

At the same time, friction between the water and Earth would cause Earth's rotation rate to slow, causing longer days, which is also happening today. The closer moon would feel more pull from the tides it created, and so it would spiral out faster than the farther moon. As a result, the inner moon would close the gap between the two moons until the gravitational interaction between them would cause them to collide and become one larger body.

Prof Neil Comins is professor of physics at the University of Maine, Orono, Maine

COSMOLOGY

What happened to antimatter after the Big Bang?

We do not know yet. This is one of the most fascinating open problems in physics. Antimatter particles were first discovered in cosmic rays almost 100 years ago and have since been called 'positrons', as they looked very similar to electrons, apart from the opposite electric charge. Since then, we understood that each particle of matter has an antimatter counterpart. When a particle meets its antiparticle, an annihilation occurs. This means the two particles are destroyed, and a flash of energetic light is produced.

According to our present understanding of the Big Bang, our cosmos started out with as much antimatter as matter. But the universe we see today, from planets to galaxies, reveals a matter-antimatter asymmetry, with an antimatter component less than one part in a billion. So what happened?

The main hypothesis is that this asymmetry was generated during the first instances after the Big Bang by interactions that proceed at a different rate for matter with respect to antimatter particles. This asymmetry then generated slightly larger amounts of matter in the primordial universe, where temperature and density were so high that particles and antiparticles were constantly created and annihilated. Some interactions producing such tiny asymmetry have been observed, but not yet enough to explain the observed matter domination.

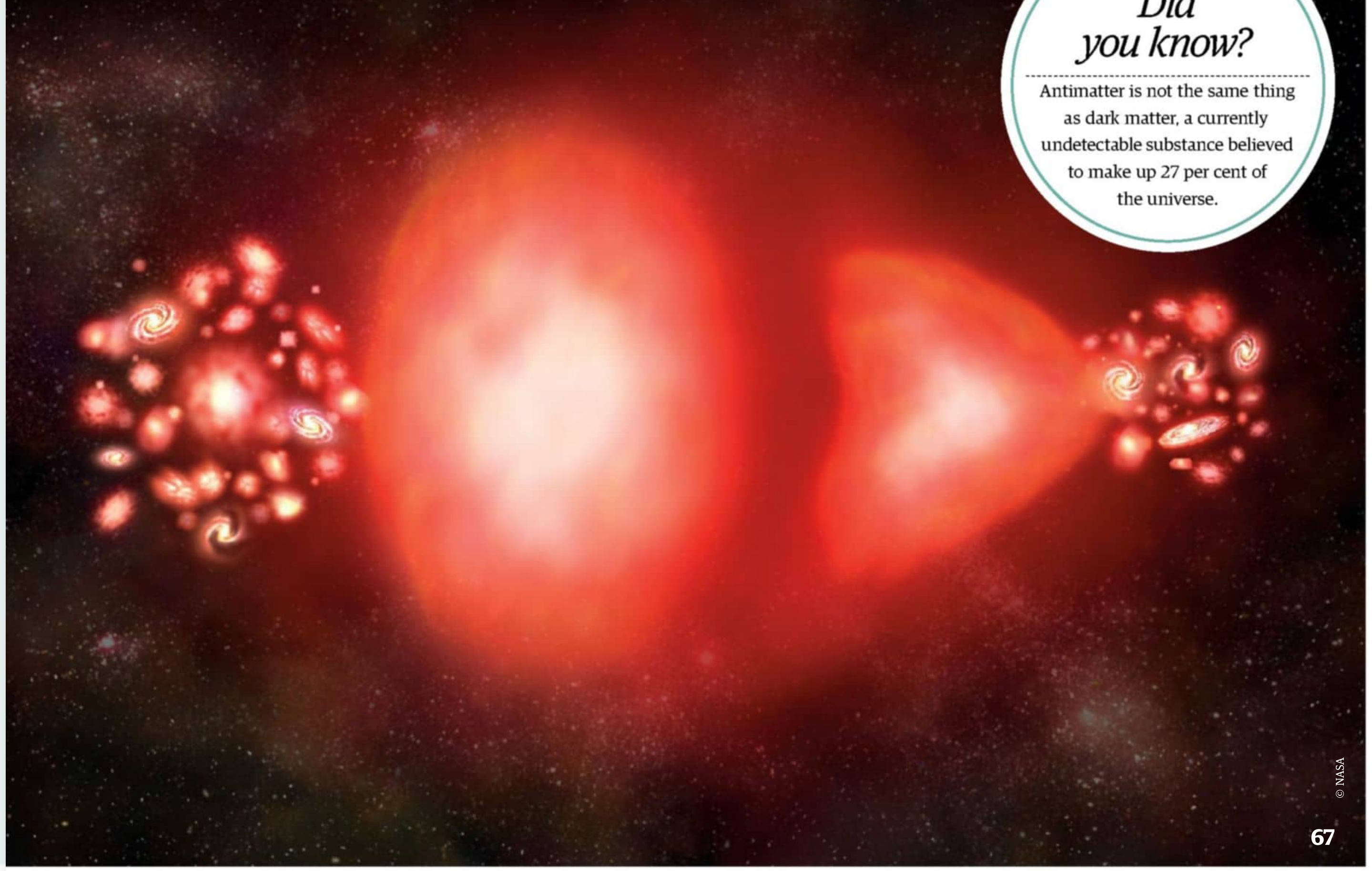
Another intriguing possibility is that the antimatter concentrates in anti-planets and anti-galaxies. But intense signals of energetic light coming from the annihilation with matter would be generated, which have not been observed. The explanation is still out there in the sky or in our laboratories, waiting for us to discover it.

Dr Silvia Manconi is a postdoctoral researcher in the theoretical particle physics and cosmology department at RWTH Aachen University in Germany

Below: If there were galaxies made of antimatter, astronomers would observe more flashes from constant annihilation

Did you know?

Antimatter is not the same thing as dark matter, a currently undetectable substance believed to make up 27 per cent of the universe.



© NASA

STARGAZER
ESSENTIAL GUIDES AND ADVICE FOR AMATEUR ASTRONOMERS

In this issue...

Red light friendly
In order to preserve your night vision, you should read our observing guide under red light

What's in the sky?

Jargon buster

Conjunction
A conjunction is an alignment of objects at the same celestial longitude. The conjunction of the Moon and the planets is determined with reference to the Sun. A planet is in conjunction with the Sun when it and Earth are aligned on opposite sides of the Sun.

Right Ascension (RA)
Right Ascension is to the sky what longitude is to the surface of the Earth, corresponding to east and west directions. It is measured in hours, minutes and seconds since, as the Earth rotates on its axis, we see different parts of the sky throughout the night.

Declination (Dec)
This tells you how high an object will rise in the sky. Like Earth's latitude, Dec measures north and south. It's measured in degrees, arcminutes and arcseconds. There are 60 arcseconds in an arcminute and there are 60 arcminutes in a degree.

Magnitude
An object's magnitude tells you how bright it appears from Earth. In astronomy, magnitudes are represented on a numbered scale. The lower the number, the brighter the object. So, a magnitude of -1 is brighter than an object with a magnitude of +2.

Opposition
When a celestial body is in line with the Earth and Sun. During opposition, an object is visible for the whole night, rising at sunset and setting at sunrise. At this point in its orbit, the celestial object is closest to Earth, making it appear bigger and brighter.

Greatest elongation
When the inner planets, Mercury and Venus, are at their maximum distance from the Sun. During greatest elongation, the inner planets can be observed as evening stars at greatest eastern elongations and as morning stars during western elongations.


© NASA, ESA & Hubble

23 APR (Medium telescope)
The Pinwheel Galaxy (M101) is well placed for observation in Ursa Major, glowing at +7.9

26 APR (Naked eye)
Conjunction between the Moon and Venus in Taurus

28 APR (Naked eye)
Venus is at greatest brightness, shining brightly at magnitude -4.5 in Taurus

4 MAY (Medium telescope)
Comet C/2017 T2 (PANSTARRS) makes its closest approach to the Sun

12 MAY (Binoculars)
Conjunction between the Moon and Jupiter in Sagittarius


© NASA, ESA & Hubble

12 MAY (Naked eye)
The Moon, Jupiter and Pluto pass within 2°14' of each other in Sagittarius

12 MAY (Naked eye)
Conjunction between the Moon and Saturn in Capricornus

12 MAY (Binoculars)
Globular cluster Messier 5 is well placed for observation in Serpens at magnitude +5.7

12 MAY (Naked eye)
The Moon and Saturn make a close approach within 2°38' of each other in Capricornus

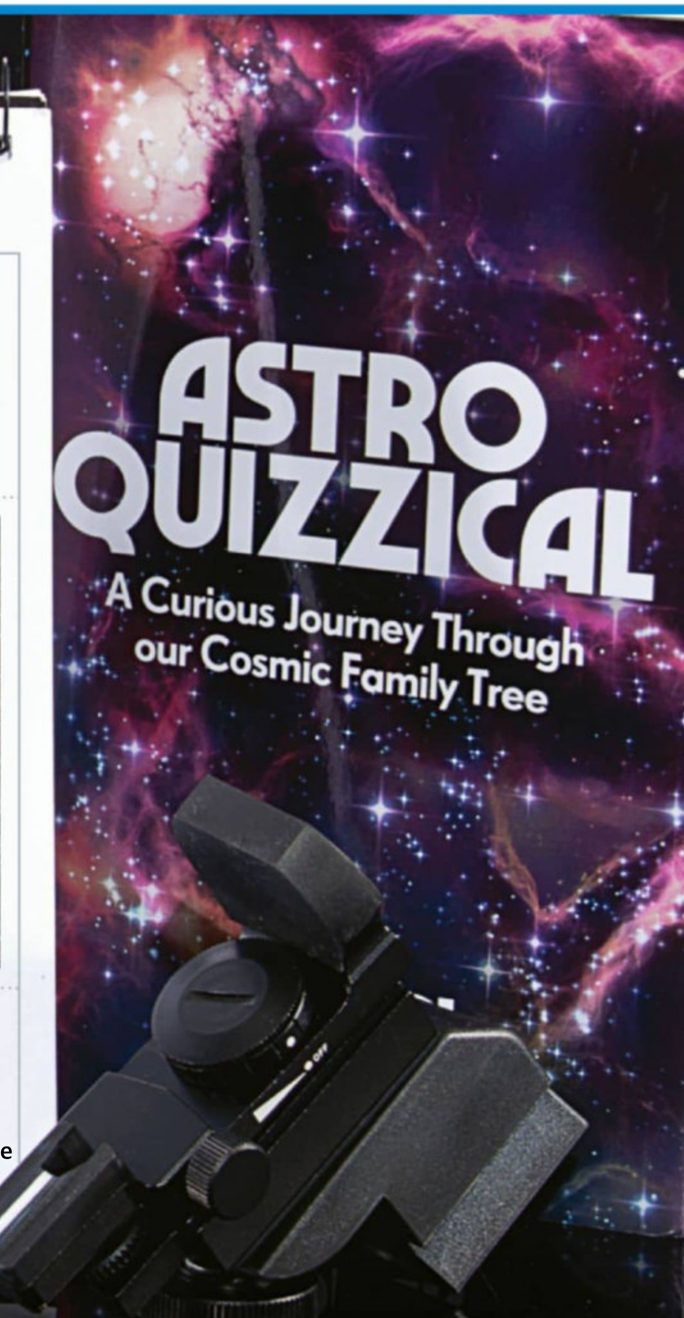
14 MAY (Medium telescope)
C/2017 T2 (PANSTARRS) is predicted to reach its brightest in Camelopardalis at +8.8

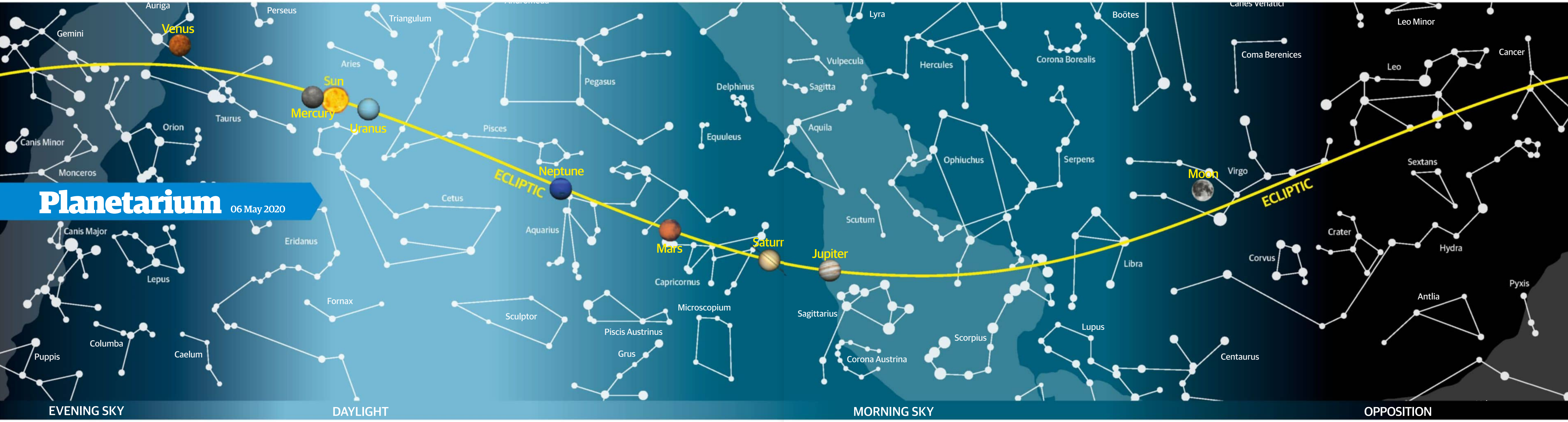
15 MAY (Naked eye)
Conjunction between the Moon and Mars in Aquarius

15 MAY (Naked eye)
The Moon and Mars make a close approach, passing within 2°36' of each other in Aquarius

18 MAY (Naked eye)
Jupiter and Saturn pass within 4°41' of each other in Sagittarius and Capricornus

Key:
- Naked eye
- Binoculars
- Small telescope
- Medium telescope
- Large telescope





Planetarium

06 May 2020

Moon calendar

Date	Phase	Illumination	Moonrise	Moonset
23 APR	NM	0.3%	06:23	20:34
24 APR		2.0%	06:42	21:43
25 APR		5.7%	07:04	22:52
26 APR		11.3%	07:31	23:59
27 APR		18.7%	08:07	--:--
28 APR		27.7%	08:52	01:02
29 APR		37.9%	09:49	01:58
30 APR	FQ	49.0%	10:57	02:44
1 MAY		60.5%	12:13	03:21
2 MAY		71.7%	13:34	03:51
3 MAY		82.0%	14:58	04:16
4 MAY		90.5%	16:23	04:37
5 MAY		96.5%	17:49	04:58
6 MAY		--:--%*	19:16	05:19
7 MAY	FM	99.6%	20:44	05:42
8 MAY		99.5%	22:09	06:09
9 MAY		96.3%	23:27	06:43
10 MAY		90.5%	--:--	07:26
11 MAY		82.7%	00:35	08:19
12 MAY		73.5%	01:29	09:20
13 MAY		63.6%	02:10	10:28
14 MAY	TQ	53.4%	02:42	11:38
15 MAY		43.3%	03:06	12:47
16 MAY		33.7%	03:26	13:55
17 MAY		24.8%	03:43	15:02
18 MAY		17.0%	03:59	16:08
19 MAY		10.3%	04:14	17:15
20 MAY		5.1%	04:30	18:23
21 MAY		1.7%	04:47	19:32

* The Moon does not pass the meridian on 6 May

% Illumination
Moonrise time
Moonset time

FM Full Moon
NM New Moon
FQ First quarter
TQ Third quarter

All figures are given for 00h at midnight (local times for London, UK)

Illumination percentage

	29 APR	6 MAY	13 MAY	20 MAY
MERCURY	100%	100%	90%	70%
VENUS	30%	20%	10%	100%
MARS	90%	90%	90%	90%
JUPITER	100%	100%	100%	100%
SATURN	100%	100%	100%	100%

Planet positions

All rise and set times are given in BST

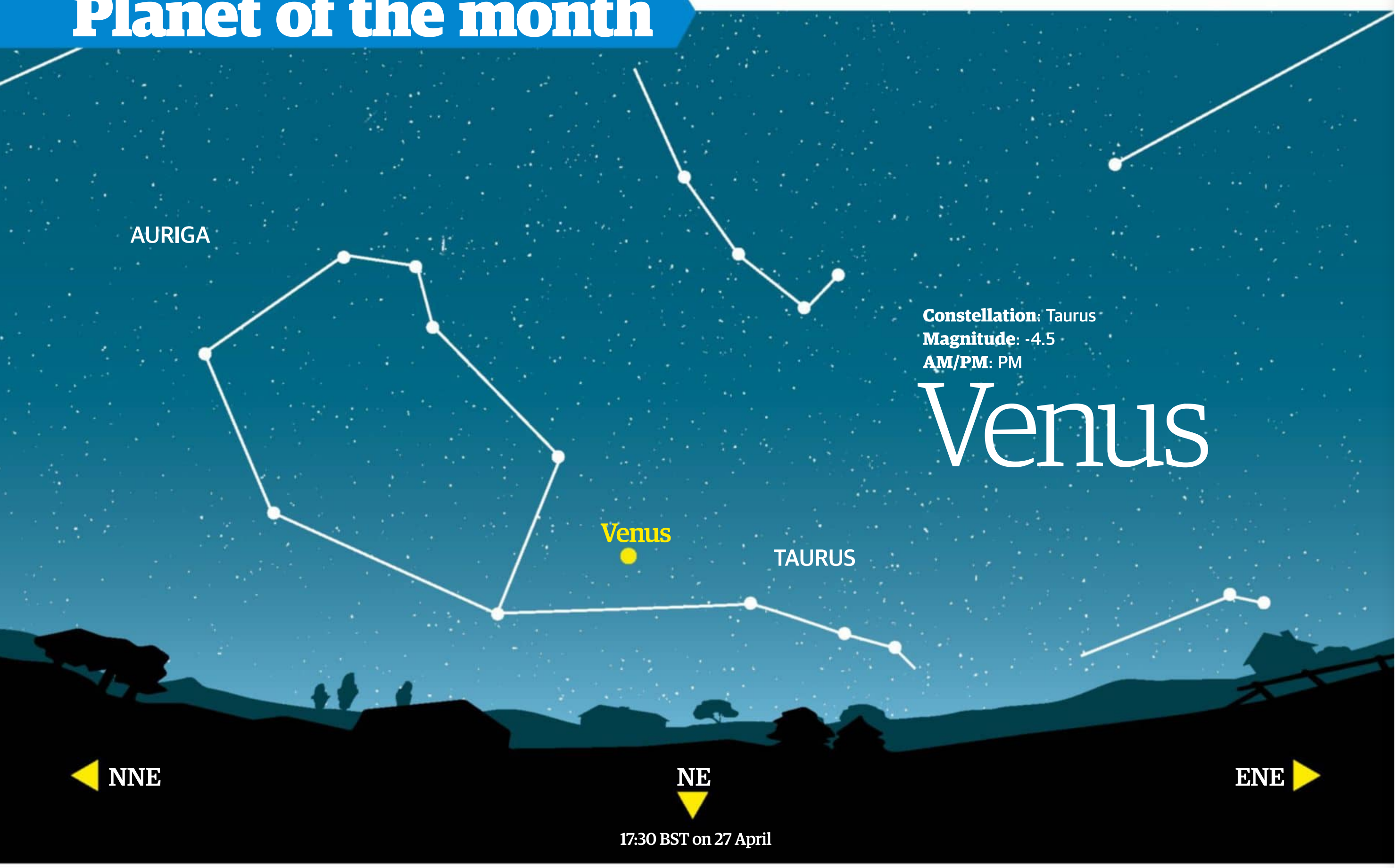
Planet	Date	RA	Dec	Constellation	Mag	Rise	Set
MERCURY	23 APR	01h 17m 38s	+06°11'50"	Pisces	-0.7	05:38	18:32
	29 APR	02h 01m 18s	+11°11'44"	Aries	-1.5	05:29	19:32
	6 MAY	02h 57m 57s	+16°59'15"	Aries	-2.3	05:25	20:34
	13 MAY	03h 58m 36s	+21°47'56"	Taurus	-1.4	05:28	21:38
	20 MAY	04h 57m 14s	+24°43'37"	Taurus	0.8	05:37	22:30
VENUS	23 APR	04h 50m 59s	+27°15'27"	Taurus	-4.5	06:57	00:35
	29 APR	05h 05m 37s	+27°40'52"	Taurus	-4.5	06:44	00:29
	6 MAY	05h 17m 26s	+27°46'44"	Taurus	-4.5	06:28	00:15
	13 MAY	05h 22m 01s	+27°25'23"	Taurus	-4.4	06:08	23:45
	20 MAY	05h 18m 15s	+26°33'06"	Taurus	-4.3	05:44	23:06
MARS	23 APR	21h 14m 56s	-17°27'48"	Capricornus	0.5	03:38	12:40
	29 APR	21h 31m 37s	-16°18'49"	Capricornus	0.4	03:24	12:40
	6 MAY	21h 50m 45s	-14°53'27"	Capricornus	0.3	03:08	12:39
	13 MAY	22h 09m 34s	-13°23'41"	Aquarius	0.3	02:51	12:39
	20 MAY	22h 28m 03s	-11°50'27"	Aquarius	0.2	02:33	12:38
JUPITER	23 APR	19h 53m 04s	-21°00'40"	Sagittarius	-2.3	02:38	10:56
	29 APR	19h 54m 31s	-20°57'36"	Sagittarius	-2.4	02:16	10:34
	6 MAY	19h 55m 38s	-20°55'35"	Sagittarius	-2.4	01:49	10:08
	13 MAY	19h 56m 08s	-20°55'21"	Sagittarius	-2.5	01:22	09:41
	20 MAY	19h 55m 58s	-20°56'56"	Sagittarius	-2.5	00:55	09:13
SATURN	23 APR	20h 14m 40s	-19°55'59"	Capricornus	0.6	02:53	11:25
	29 APR	20h 15m 17s	-19°54'34"	Capricornus	0.6	02:30	11:02
	6 MAY	20h 15m 42s	-19°53'53"	Capricornus	0.6	02:03	10:35
	13 MAY	20h 15m 47s	-19°54'17"	Capricornus	0.5	01:35	10:07
	20 MAY	20h 15m 33s	-19°55'45"	Capricornus	0.5	01:08	09:39

STARGAZER

This month's planets

You'll have to be an early riser this April through to May as the Solar System's spoils grace the dawn sky

Planet of the month



17:30 BST on 27 April

Venus is our 'Planet of the Month' this issue because it is just so ridiculously beautiful in the sky this month. During April and May it really will deserve its ages-old nickname of 'the evening star' because it will shine like a silvery lantern in the west after sunset, so bright it draws the eye away from everything else.

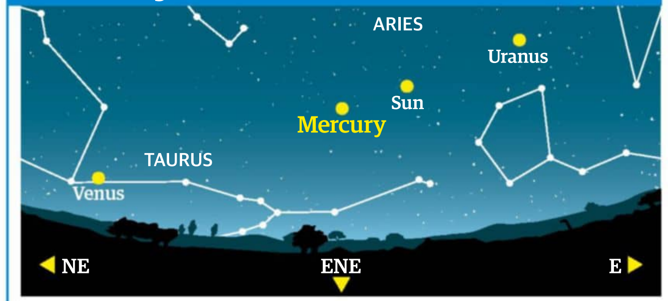
You'll first spot Venus out of the corner of your eye as soon as the western sky begins to darken after sunset, looking like a silvery spark in the purple-orange twilight. As the sky darkens Venus will get brighter and more obvious to the eye until it dominates the sky. Eventually the sky will be dark enough to see stars around Venus, and then you'll notice that it is shining to the upper right of the V-shaped Hyades star cluster, which represents the wickedly sharp horns of Taurus, the Bull.

Cross your fingers for clear skies during the last week of April because that's when Venus will be joined in the evening sky by the young crescent Moon, and the pair will make a beautiful sight in the twilight from around 21:00. After sunset on 25 April a very thin crescent Moon will shine 13 degrees directly below Venus. The following evening of the 26th, the Moon - by now a slightly bigger crescent - will have moved a little way along its path across the sky and will be shining to the lower left of Venus, just over six degrees - or 12 Moon widths - away from it.

On this evening you should also be able to see the subtle lavender-pink glow of 'Earthshine' on the dark part of the Moon's disc - what some call, with justifiable romance: 'the old Moon in the new Moon's arms.' 24 hours later, after sunset on 27 April, the Moon will have moved even further along its path and will be shining to the upper left of Venus, some 14 degrees away.

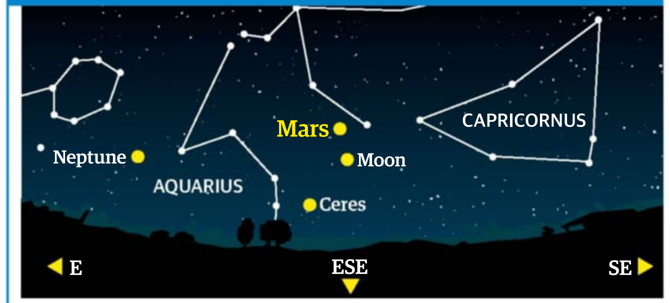
After the Moon has passed Venus, another celestial object will approach it. The planet Mercury will appear to the lower right of Venus from around 10 May, and will gradually climb up towards it as the evenings pass. By 20 May the two planets will be just three degrees - or six Moon widths - apart and will look like a 'double star' in the twilight sky. They'll be visible to the naked eye but will look more impressive through a pair of binoculars or a small telescope.

Mercury 07:00 BST on 10 May



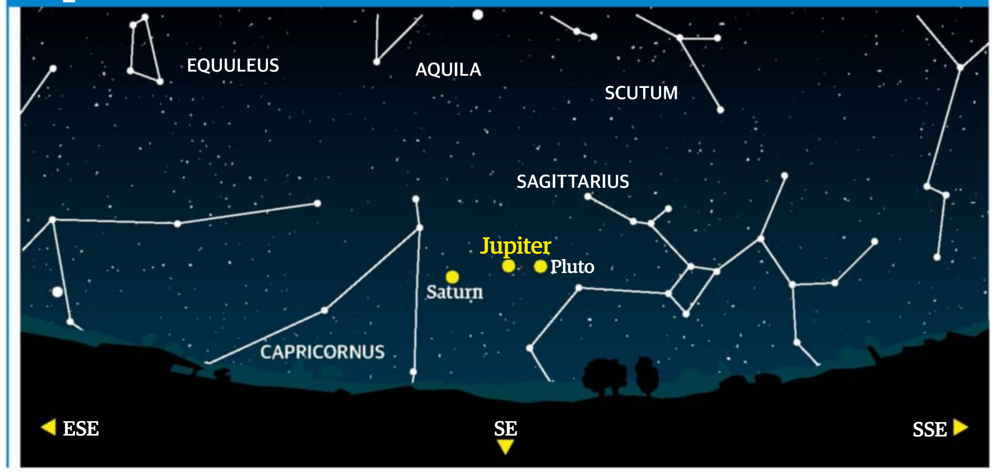
Constellation: Taurus
Magnitude: -1.3
AM/PM: PM
At the start of our observing period Mercury is technically a morning object, but in reality it's too close to the Sun to be seen. You'll have to wait until around 10 May to see it, when it emerges from the glare of the Sun and reappears low in the northwestern sky after sunset, to the lower right of brighter Venus.

Mars 04:00 BST on 15 May



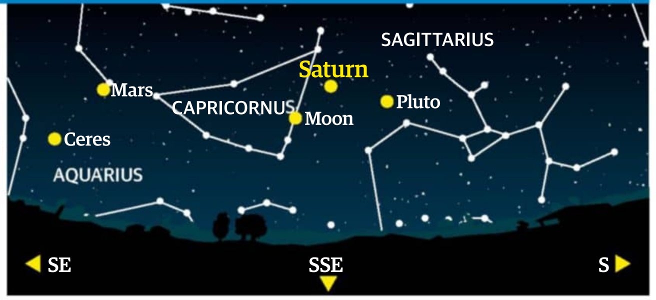
Constellation: Aquarius
Magnitude: -0.1
AM/PM: AM
Mars will be an easy naked-eye object in the pre-dawn sky, brightening steadily as the days pass. At the end of April it will drift out of Capricorn and into Aquarius, attaining negative magnitude at the same time. Mars is going to get a lot brighter over the coming months, and will be a stunning sight.

Jupiter 03:00 BST on 12 May



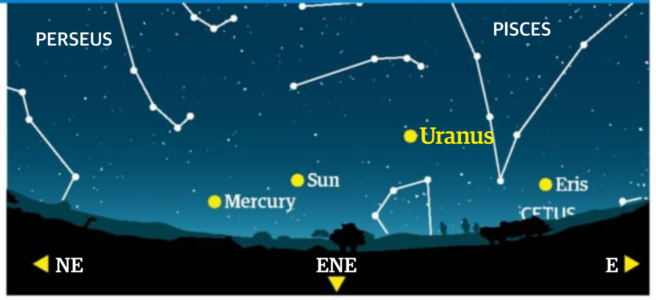
Constellation: Sagittarius
Magnitude: -2.3
AM/PM: AM
Jupiter will be on the western end of a three-link chain of worlds - with fainter Saturn and Mars to its lower left - all visible to the naked eye. During our observing period Jupiter will slowly close in on Saturn until they are a mere four degrees apart. The waning gibbous Moon will also get in on the action, shining five degrees to the lower right of Jupiter before dawn on the morning of 12 May and less than ten degrees to its lower left the following morning. A pair of binoculars will show you Jupiter's four largest moons as tiny 'stars' close to the planet.

Saturn 05:00 BST on 13 May

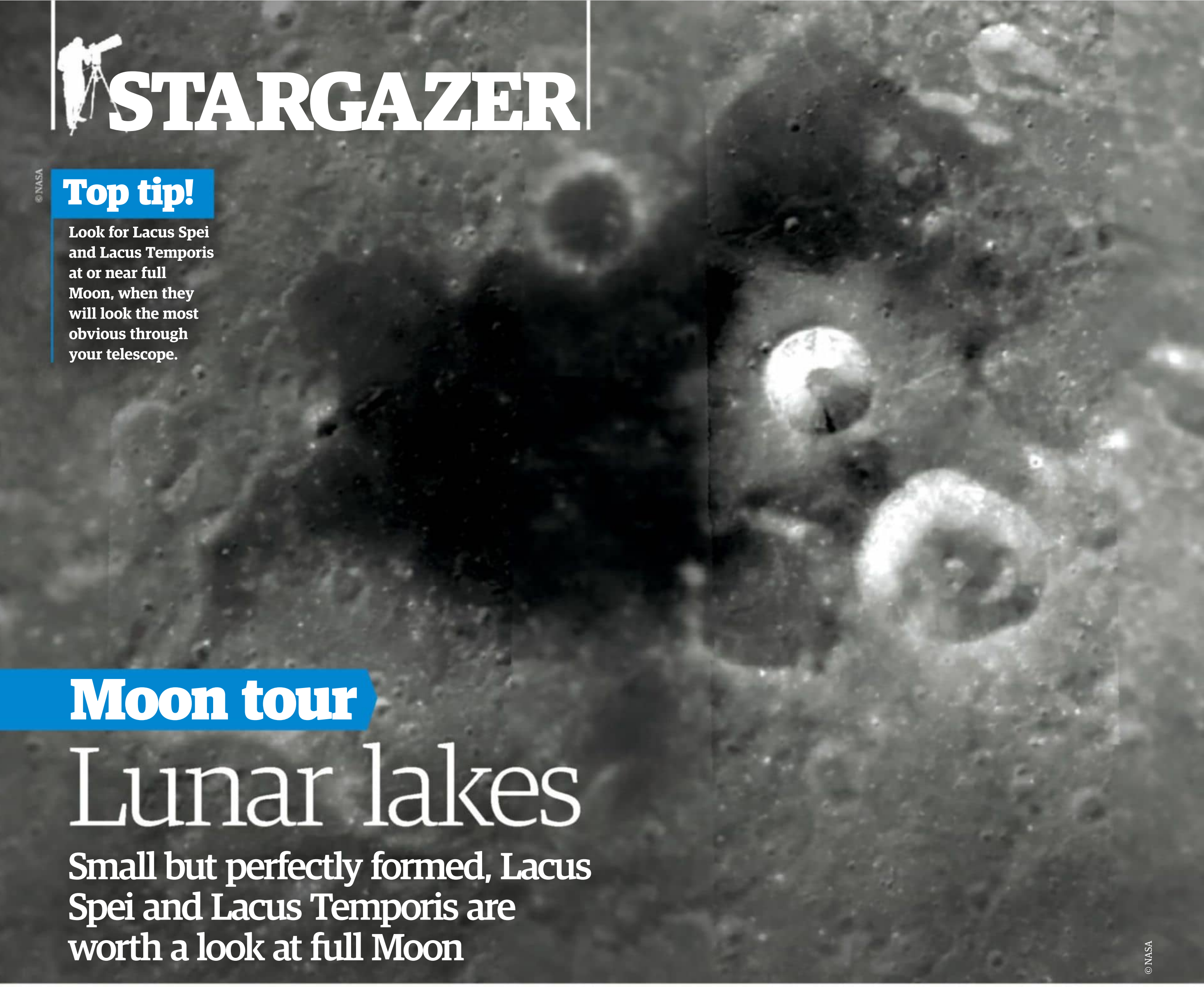


Constellation: Capricornus
Magnitude: +0.5
AM/PM: AM
Saturn is the middle of three planets, sandwiched between Mars to its lower left and much brighter Jupiter to its upper right. To the naked eye Saturn appears as a star with a slightly golden hue, in contrast to the more orange tone of Mars and the brighter yellow-white sheen of Jupiter.

Uranus 06:00 BST on 13 May



Constellation: Aries
Magnitude: +5.9
AM/PM: N/A
All through our observing period Uranus will be too close to the Sun to be visible. At the end of April it is close to the Sun in the evening. It will then pass behind the Sun and reappear in the morning sky, but will still be far too close to the Sun to be seen. Observing conditions will improve in the coming months.



Top tip!

Look for Lacus Spei and Lacus Temporis at or near full Moon, when they will look the most obvious through your telescope.

Moon tour

Lunar lakes

Small but perfectly formed, Lacus Spei and Lacus Temporis are worth a look at full Moon

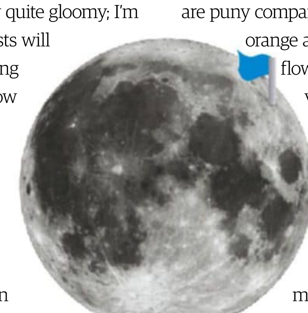
The Moon is famous for its dark seas, or mare, and even non-astronomers know the name of one: the Sea of Tranquillity is where Neil Armstrong and Buzz Aldrin landed in July 1969 on the Apollo 11 mission. Many of the seas have equally romantic names - the Sea of Crises, the Sea of Dreams, the Sea of Serenity - which is rather ironic considering they aren't beautiful seas at all, but huge plains of ancient, dark, frozen lava.

The largest lunar mare are clearly visible even to the naked eye, looking like dark blotches on the Moon's bright face, and are especially prominent at full Moon. Much smaller - and harder to see - than the seas are the lunar lakes, or lacus. These are essentially 'mini mare', visually more like ink splashes on a white shirt than vast spills of oil on the ocean, and are so small you generally need a telescope to see them.

This month's tour takes in not one, but two lakes. Lacus Spei, the Lake of Hope, lies up near the top right of the lunar disc, around the one o'clock position, to the upper left of the circular and much larger Mare Crisium. It's a small, flat splash of dark lava sandwiched between the two craters Mercurius and Messala. Just 77 kilometres (48 miles) across, it is so near the lunar limb that foreshortening makes it appear as a stubby, dark line, but overhead views taken by orbiting space probes have shown it is actually an hourglass shape.

Slightly to the lower left of Lacus Spei, a larger lake, Lacus Temporis, the Lake of Time, can also be seen. It is a solidified pool of lava some 205 kilometres (127 miles) across, and if it was closer to the centre of the Moon's disc it would appear quite obvious even in binoculars, but like neighbouring Spei its proximity to the Moon's limb vastly reduces its visibility and profile.

There are many other lakes on the Moon, and many have names that are frankly quite gloomy; I'm not sure many future lunar colonists will want to go for a romantic stroll along the shores of Lake Fear, Lake Sorrow or Lake Death. Our two lakes are not as large or as dark as some of those, but that makes them worth hunting down all the more!

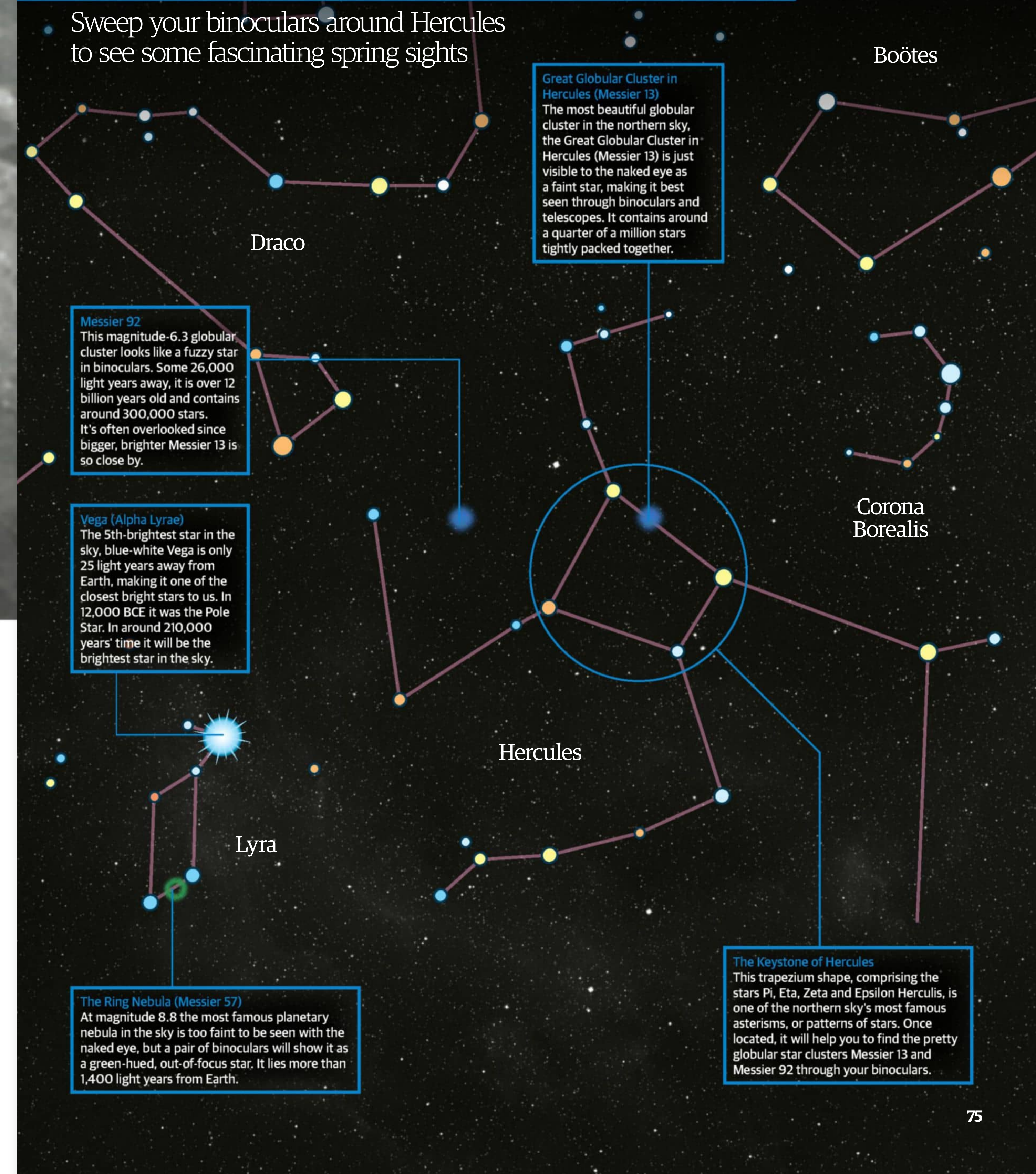


Unlike the Moon's deep craters, jagged mountain ranges or deep valleys, these are features best seen near or during a full Moon, when the Sun is shining straight down on them from overhead. Then the contrast between their darkness and the brightness of the surrounding terrain is most obvious. The best time to go out and look for these two lakes is between 5 and 8 May.

Lacus Spei and Temporis might not be the most dramatic features on the Moon, and they are pale imitations of the lakes found elsewhere in the Solar System. Unlike the terrestrial tourist traps of Lake Windermere, Grasmere and Ullswater they have no gift shops, no canoes for hire or flocks of geese. They are puny compared to the red-hot lakes of bubbling orange and purple sulphur that fester and flow around the violently beautiful volcanoes of Io, and are tiny compared to the deep, dark lakes of liquid methane that are spattered around the north polar regions of Saturn's largest moon, Titan, but they are still worth hunting down with your telescope on one of May's beautiful moonlit nights.

Naked eye & binocular targets

Sweep your binoculars around Hercules to see some fascinating spring sights



Sunflower Galaxy (Messier 63)

Deep sky challenge

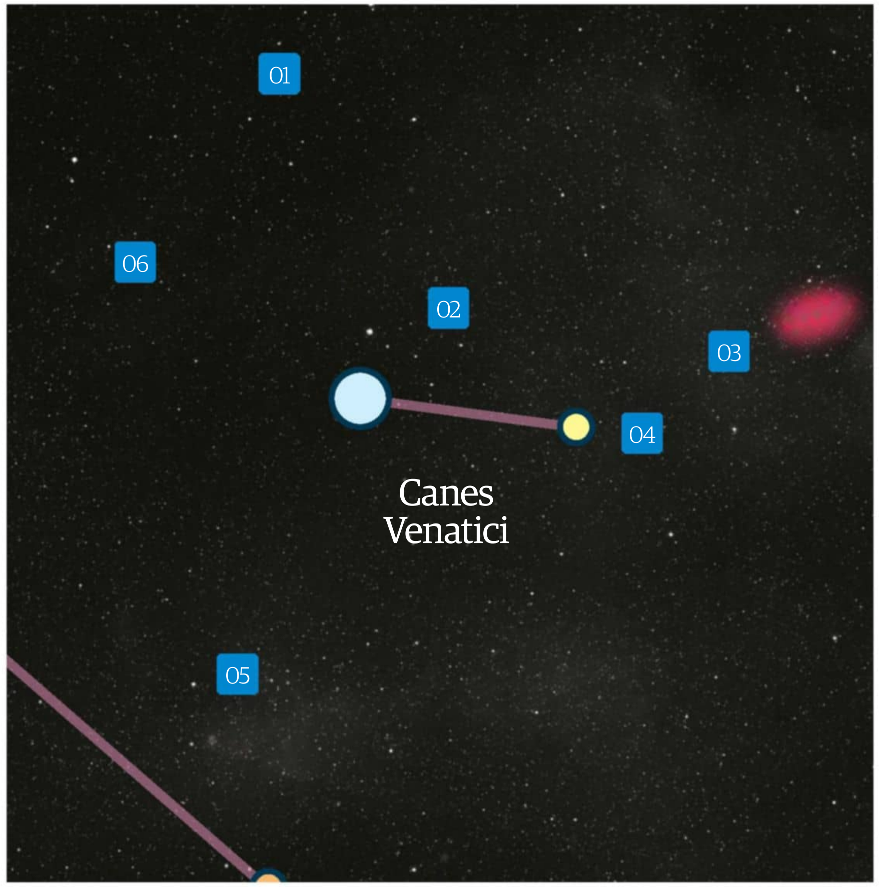
Go on a galaxy hunt

Sweep your telescope across Canes Venatici to see half a dozen distant galaxies

Spring is the season when deep-sky observers swing their telescopes away from the bright, glittering star clusters and colourful, wispy nebulae of winter and point them towards much fainter, hazier objects - galaxies far, far away. Their favourite hunting grounds are the constellations of Coma Berenices and Virgo, both of which are overflowing with galaxies big and small, bright and faint and of all different types.

In fact, there are so many galaxies spattered across these two constellations that many galaxy observers rarely look anywhere else. It's a shame because not too far away, in the little-loved constellation of Canes Venatici, there are some rarely observed galaxies that are well worth a look - if only for a change of scenery.

This month we're going to guide you to a few of them, all of which need a large telescope to be enjoyed properly. Messier 63 is nicknamed the 'Sunflower Galaxy' because of its pretty, floral appearance, but you'll only see the subtle details within it under the most perfect viewing conditions. NGC 4490 and 4485 are a very close pair in a high-power eyepiece, but don't even try to look for them if the Moon is nearby. And although NGC 4631, dubbed the 'Whale Galaxy', looks more like a fat needle than a noble cetacean it is a good 'catch' on a clear, still night.



1 The Sunflower Galaxy (Messier 63)
This eighth-magnitude spiral galaxy is a visual treat in large telescopes. High-power eyepieces resolve its bright centre and hints of its curving spiral arms. It is 37 million light years away.

2 The Cat's Eye Galaxy (Messier 94)
Another eighth-magnitude spiral galaxy, M94 is a round smudge in a large telescope. Higher magnifications on Moon-free nights of perfect seeing will show the galaxy's faint outer ring.

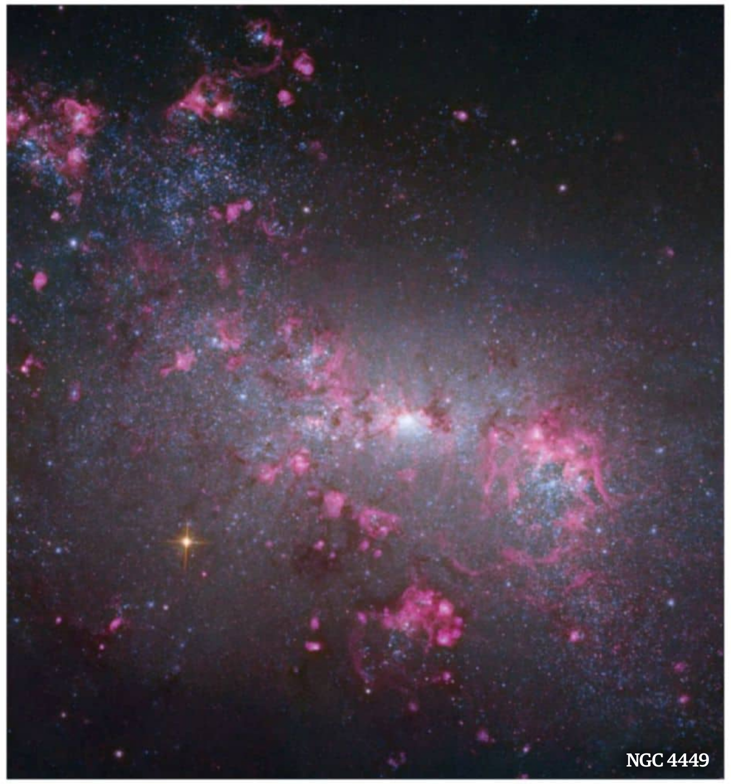
3 NGC 4449
This irregular galaxy resembles a small, hazy, faint patch with brighter knots through medium- and large-aperture telescopes, but it will fade into the background if light pollution is present.

4 NGC 4490 and NGC 4485
This pair of galaxies, lying just 24,000 light years apart, look like two tiny fuzzy patches through the high-power eyepieces of large telescopes. NGC 4490 is much larger and brighter.

5 The Whale Galaxy (NGC 4631)
Ninth-magnitude spiral galaxy NGC 4631 looks like a faint misty spike, or nail, through a large telescope. High magnifications might reveal mottling along it under perfect observing conditions.

6 NGC 5005
Through medium- and large-aperture telescopes this inclined spiral galaxy has a bright centre. On a Moon-free night without light pollution you'll also see hints of dark dust lanes.

NGC 5005



NGC 4449

The Northern Hemisphere

Summer is on its way with a selection of galaxies and star clusters to be enjoyed

With the summer sky bringing with it longer days and shorter nights, the constellations of May are reserved for those willing to stay up until the small hours to capture those stunning night-sky targets.

Observers in the Northern Hemisphere can look forward to gazing at the gems of Canes Venatici (the Hunting Dogs), Centaurus (the Centaur), Coma Berenices (Berenice's Hair) and Virgo (the Virgin), where a stunning selection of galaxies and star clusters are easy pickings with binoculars or a telescope. In particular, the Virgo Cluster is home to the Black Eye Galaxy (Messier 64) and spiral galaxy and brightest member of the Virgo Cluster Messier 100, which are a joy to behold on the increasingly warmer evenings.

Using the sky chart

This chart is for use at 22:00 (BST) mid-month and is set for 52° latitude.

01 Hold the chart above your head with the bottom of the page in front of you.

02 Face south and notice that north on the chart is behind you.

03 The constellations on the chart should now match what you see in the sky.

Magnitudes

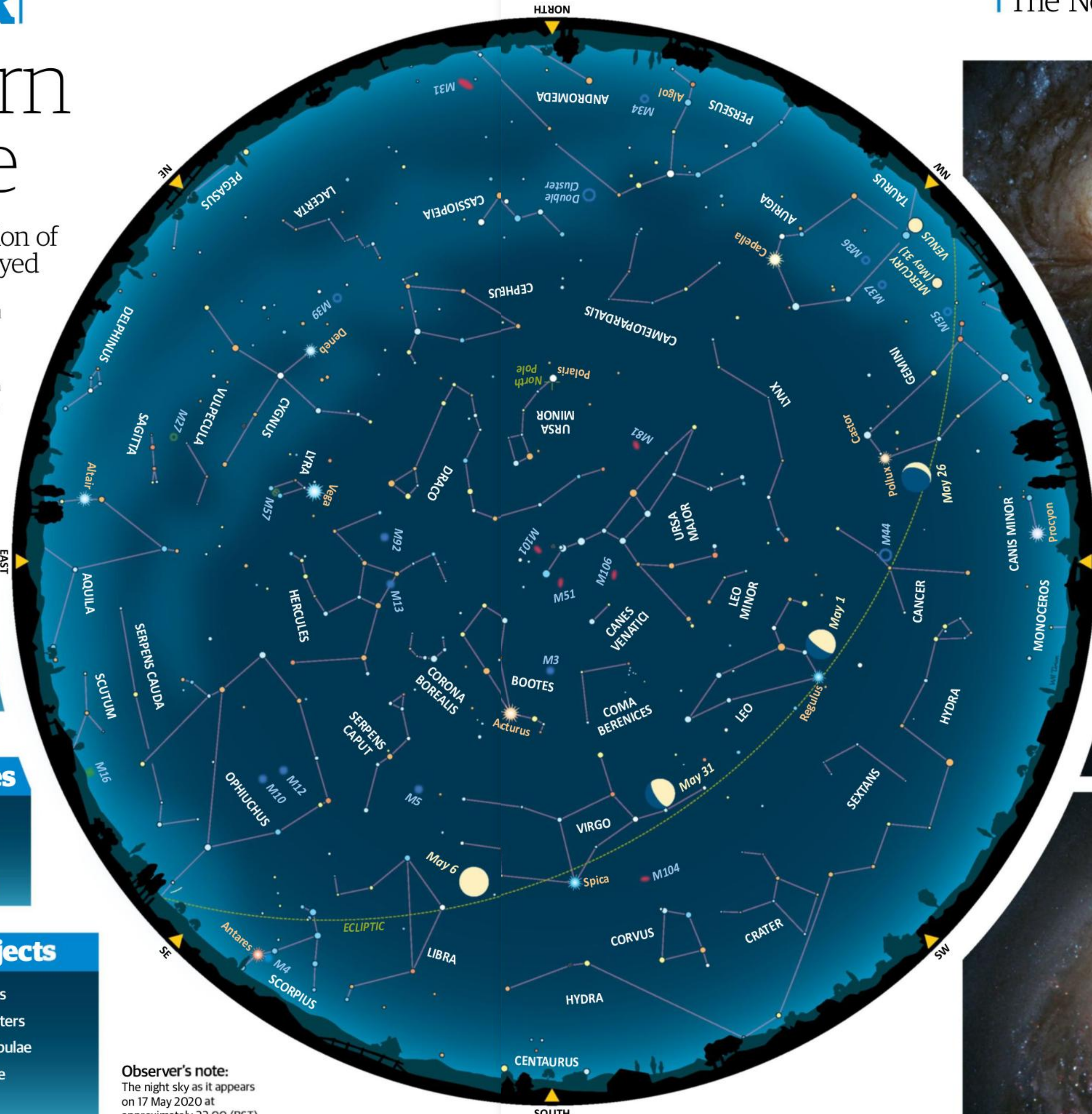
- Sirius (-1.4)
- -0.5 to 0.0
- 0.0 to 0.5
- 0.5 to 1.0
- 1.0 to 1.5
- 1.5 to 2.0
- 2.0 to 2.5
- 2.5 to 3.0
- 3.0 to 3.5
- 3.5 to 4.0
- 4.0 to 4.5
- Fainter
- Variable star

Spectral types

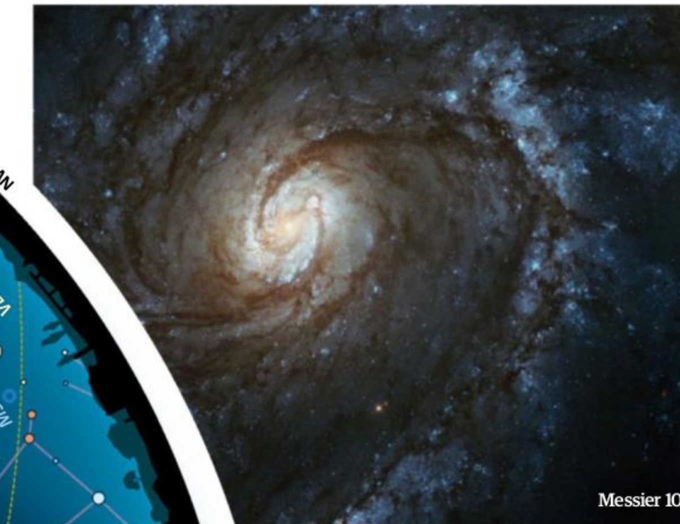
- O-B
- A
- F
- G
- K
- M

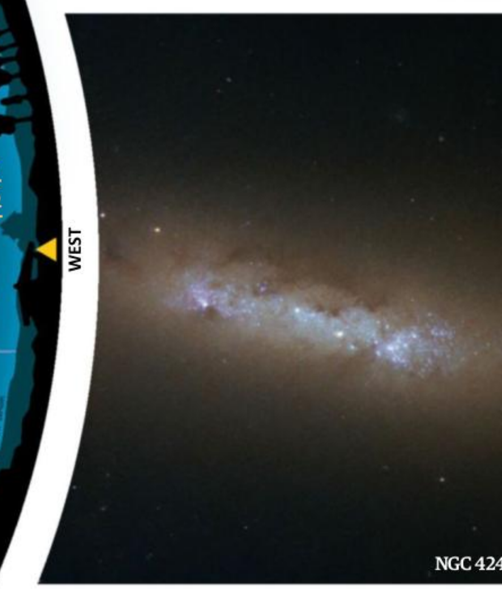
Deep-sky objects

- Open star clusters
- Globular star clusters
- Bright diffuse nebulae
- Planetary nebulae
- Galaxies



Observer's note:
The night sky as it appears on 17 May 2020 at approximately 22:00 (BST)


Messier 100


NGC 4248


Black Eye Galaxy (Messier 64)

Meade 20-60x80 Wilderness

An instrument that's built to last, this spotting scope is ideal for the casual astronomer and serious wildlife watcher

Telescope advice

Cost: £250
From: Hama UK Ltd
Type: Spotting scope
Aperture: 3.15" (80mm)
Focal length: 35.43"

Best for...

- Intermediate
- Medium budget
- Planetary viewing
- Lunar viewing
- Digiscoping

If you can't quite commit to a full-blown hobby in astronomy but enjoy watching nature at play, then a spotting scope in the Meade Wilderness range could be the instrument for you. The 20-60x80 is an excellent specimen, featuring rugged, rubber armour to protect the optics from moisture, and it is finished to a high standard. The spotting scope is supplied with a high-quality 20-60x zoom eyepiece, a soft case and camera adapter, but unfortunately it doesn't come with a tripod - something that this spotting scope requires for stable observations. For this reason we think that the Meade Wilderness is suitable for those interested in casual astronomy and with a medium budget. If your budget is low, then we recommend taking the plunge and buying a telescope that's much more geared towards observing the night sky and comes equipped with accessories and a tripod. We can certainly recommend any spotting scope tripods from the Meade range, however.

Combined with its waterproof design, which allows nature lovers to watch wildlife in a variety of weather conditions with its added protection, the Meade Wilderness also features a nitrogen fog proofing inside the armour - something that observers of the night sky will appreciate. Astronomers know all too well about the condensation that a change in temperature can bring - from moving an observing instrument from the warm indoors to the much colder outdoors - which ultimately can cause damage to the objective lens' coating and the optical system in general. The Meade Wilderness ensures that condensation isn't a problem, allowing the sky-watcher to enjoy a selection of targets with little fuss. While the Meade Wilderness is coated in a generous amount of protective armour, this doesn't hinder the exquisite lightness of the instrument that makes it ideal as a 'grab-and-go' scope for travel.

Spotting scopes are often overlooked - even for the most basic of astronomical observations - but the Meade Wilderness certainly got our attention since it was particularly useful when it came to observing the Moon, star clusters and the brighter naked-eye planets. The skies of March offered a good selection of targets to test the Wilderness' mettle. Mars and Saturn in the east got our immediate attention. The spotting scope was easy to use, with no need for a finderscope to guide us to specific targets. Mars was an easy target to locate, a red-orange star that appeared as a salmon-pink disc through the Meade Wilderness. Small views of the Red Planet were achieved through this spotting scope, even using the 20-60x zoom eyepiece. We couldn't see any detail on Mars' surface, but the Meade Wilderness did provide clear and crisp views - particularly of Saturn in the constellation of Capricornus. Despite the small views of the gas giant we were able to make out the planet's rings, and while not as spectacular a sight as you'd get through a telescope with a medium-sized aperture, views of Saturn were still satisfactory.

We waited until the following evening to catch the Moon at its first quarter, which provided excellent views of its cratered surface along the terminator. Operation of the zoom eyepiece was smooth, similar to the twist eyecup, which we noted to have very good eye relief that makes it suitable for those with or without spectacles. The angled orientation of the Meade Wilderness' eyepiece holder at 45 degrees made for very comfortable viewing. A multi-coated lens, along with the BaK4 prisms, ensured clear and crisp views across a very good proportion of the field of view when using the high-quality zoom eyepiece.

This spotting scope is limited to the brighter targets of the night sky. If nature-watching is of no interest to you or you are just learning your way around the night sky, then we strongly recommend buying a pair of binoculars or a telescope that comes as a more complete package. On the other hand, if you're looking for an instrument that's easy to carry and compliments your existing kit, then this rugged spotting scope, which is ideal in low light and for basic astrophotography, is certainly worth a look.

Above: The objective lens is multi-coated, and combined with the BaK4 prisms provides bright and clear views

"The 20-60x80 is an excellent specimen, featuring rugged, rubber armour"

Below: The eyepiece is angled at 45 degrees for a comfortable viewing experience

Right: The spotting scope features rugged, waterproof armour

Remembering Katherine Johnson

A true pioneer at NASA whose incredible contributions to America's space program are grossly understated

Katherine Johnson recently passed away on 24 February 2020 at the age of 101. Her story went untold for many years, but her work was crucial in sending the first Americans into orbit around Earth and the first humans to the Moon back in the 1960s.

Born on 26 August 1918 in White Sulphur Springs, West Virginia, Johnson's adolescent years took place at a time when racial segregation was still commonplace in the country's southern states. In 1939 Johnson was handpicked along with two other male students to be the first people of colour integrated into a graduate school. It was at this point she left her teaching job and enrolled in a graduate math program at West Virginia University.

In 1953 she landed a job as part of an all-black computing section at the National Advisory Committee for Aeronautics' (NACA's) Langley laboratory. The role here essentially used female workers as 'computers' to solve maths problems. Here she spent her initial four years analysing the data taken from flight tests for the Flight Research Division.

The Soviet Union's surprise launch of the Sputnik satellite in 1957 completely changed her life trajectory, as the US began rushing to step up its space program in an attempt to catch up. NACA transformed into NASA, and engineers from the Flight Research Division formed the Space Task Group, which had the aim of putting humans into orbit around Earth. This began a period in which Johnson would prove pivotal for the American space program.

The first major milestone in space for the US came in May 1961, when Alan Shepard became the first of his country to journey into space, but what isn't usually mentioned is that Johnson performed the trajectory analysis for the spaceflight. The year before she had also co-authored an important paper, detailing the equations of orbital spaceflight in which the landing position of the spacecraft is specified.

Johnson worked for NASA for over 30 years

©NASA

> "Her work was crucial in sending the first Americans into orbit"

In February 1962, John Glenn prepared to become the first American to orbit the Earth inside his Mercury capsule, Friendship 7. Glenn didn't trust the new technology at the time due to its unreliability, and he asked Johnson to manually run the same flight calculations. "If she says they're good, then I'm ready to go," Glenn famously said. The mission was a success, and many consider this the moment when the scales of space power shifted towards the US, as it eventually went onward to become the first nation to step on the Moon.

Johnson retired from NASA in 1986 after the success of the Apollo era, to which she contributed much of her mathematical expertise. In 2015 she was awarded the Presidential Medal of Freedom by Barack Obama, which is the highest honour an American civilian can receive. The year after her story was told in Margot Lee Shetterly's book *Hidden Figures*, along with those of her friends and colleagues Dorothy Vaughan and Mary Jackson. This book was subsequently made into a biographical drama blockbuster film of the same name, impressively nominated for three Oscars and two Golden Globe awards.

All About Space

Future PLC Richmond House, 33 Richmond Hill, Bournemouth, Dorset, BH2 6EZ

Editorial
Editor-in-Chief **Gemma Lavender**
gemma.lavender@futurenet.com
Art Editor **Jonathan Wells**
Staff Writer **Lee Cavendish**
Production Editor **Nikole Robinson**
Research Editor **Baljeet Panesar**
Senior Art Editor **Duncan Crook**
Photography **Olly Curtis**

Contributors
Stuart Atkinson, Meghan Bartels, Charles Q. Choi, David Crookes, Chelsea Gohd, Andrew Jones, Dominic Reseigh-Lincoln, Laura Mears, Libby Plummer, Nola Taylor Redd, Brendon Specktor, Colin Stuart, Michael Wall

Cover images
Tobias Roetsch; Getty

Photography
Alamy; ESA; ESO; NASA; Science Photo Library; Shutterstock; SpaceX; University of Arizona; Wikipedia Commons;
All copyrights and trademarks are recognised and respected

Advertising
Media packs are available on request
UK Commercial Director **Clare Dove**
clare.dove@futurenet.com
Senior Advertising Manager **Amanda Burns**
amanda.burns@futurenet.com
0330 390 6036
Account Manager **Garry Brookes**
garry.brookes@futurenet.com
0330 390 6637

International Licensing
All About Space is available for licensing. Contact the Licensing team to discuss partnership opportunities.
Head of Print Licensing
Rachel Shaw licensing@futurenet.com

Subscriptions
Email enquiries **contact@myfavouritemagazines.co.uk**
UK orderline & enquiries **0344 848 2852**
Overseas order line and enquiries **+44 (0)344 848 2852**
Online orders & enquiries **www.myfavouritemagazines.co.uk**
Head of subscriptions **Sharon Todd**

Circulation
Head of Newstrade **Tim Mathers**

Production
Head of Production **Mark Constance**
Production Project Manager **Clare Scott**
Advertising Production Manager **Joanne Crosby**
Digital Editions Controller **Jason Hudson**
Production Manager **Frances Twentyman**

Management
Chief Content Officer **Aaron Asadi**
Commercial Finance Director **Dan Jotcham**
Brand Director **Evan Kypreos**
Head of Art & Design **Greg Whitaker**

Printed by William Gibbons & Sons Limited, 26 Planetary Road, Willenhall, Wolverhampton, West Midlands, WV13 3XB

Distributed by Marketforce, 5 Churchill Place, Canary Wharf, London, E14 5HU www.marketforce.co.uk Tel: 0203 787 9060

ISSN 2050-0548

FUTURE Connectors. Creators. Experience Makers.

Future PLC is a public company quoted on the London Stock Exchange (symbol: FUTR)
www.futureplc.com

Chief executive **Zillah Byng-Thorne**
Non-executive chairman **Richard Huntingford**
Chief financial officer **Penny Ladkin-Brand**

Tel +44 (0)1225 442 244

ipso. Regulated


Sky-Watcher®
Be amazed.
SKYMAX
MAKSUTOV-CASSEGRAINS
SKYMAX Maksutov-Cassegrains are Conveniently Compact, High-Contrast optical instruments that excel for the High-Power observation of Double-Stars and the surface detail of the Moon and Planets.
SKYMAX-102 (AZ-EQ AVANT)
102mm f/12.7
Code 10269
Dual-function Equatorial/Alt-Azimuth Mount
SRP £329
SKYMAX-127 (AZ5)
127mm f/11.8
Code 10262
SRP £499
SKYMAX-102 AZ-GTi
102mm f/12.7
Code 10264
SRP £435
Wi-Fi
GO-TO
FREEDOM FIND
"I really liked using this kit...Zipping around the sky and visiting all manner of objects presented it with no challenges."
ASTRONOMY NOW MAGAZINE
SKYMAX-127 AZ-GTi
127mm f/11.8
Code 10265
SRP £549
Sky at Night MAGAZINE
REVIEWED IN Issue 152 January 2018
"This is a fun system to use...feels like the future of telescope control, certainly for anyone that likes technology"
BBC SKY AT NIGHT MAGAZINE
Please note: AZ-GTi Wi-Fi telescopes are controlled by the users own smartphone or tablet and the free Synscan™ App for iOS or Android
SRP £399
SKYMAX-102 AZ GO-TO
102mm f/12.7
Code 10210
SYNSCAN™ GO-TO
"Delivers high-contrast, pin-sharp views one has become accustomed to with Sky-Watcher Maksutovs"
BBC SKY AT NIGHT MAGAZINE
SRP £499
SKYMAX-127 AZ GO-TO
127mm f/11.8
Code 10211
SYNSCAN™ GO-TO
SKYMAX-90 (EQ1)
90mm f/13.8
Code 10673
SRP £209
"The optics of the review instrument were staggeringly good, giving superb views of the Moon"
BBC SKY AT NIGHT MAGAZINE
SKYMAX-102 (EQ2)
102mm f/12.7
Code 10674
SRP £315
SKYMAX-127 (EQ3 PRO)
127mm f/11.8
Code 10672/20230
OTA ONLY: SRP £315
(Code 10672)
SRP £814
SYNSCAN™ GO-TO
"The rings of Saturn appeared sharply defined... Turning to the Moon it was a revelation...In the deep sky, the Skymax performed well on everything from galaxies to nebulae"
BBC SKY AT NIGHT MAGAZINE (OTA reviewed)
SKYMAX-150 (EQ5 PRO)
150mm f/12
Code 10885/20981
OTA ONLY: SRP £599
(Code 10885)
SRP £1298
Sky at Night MAGAZINE HIGHLY COMMENDED 93%
applies to OTA
SYNSCAN™ GO-TO
"Jupiter was a mesmerising sight... High contrast optics indeed"
BBC SKY AT NIGHT MAGAZINE
SKYMAX-180 (EQ6-R PRO)
180mm f/15 Code 10217/20855
OTA ONLY: SRP £975 (Code 10217)
SYNSCAN™ GO-TO
SRP £2404
"This instrument is not just good for visual observing, but also capable of deep-sky astro imaging"
BBC SKY AT NIGHT MAGAZINE (OTA reviewed)
THE ESSENTIAL Optical Product Guide
DISCOVER NEW IMAGING HORIZONS
OVL
Available from dealers throughout the UK
OPTICAL VISION LIMITED
Full product details at:
www.opticalvision.co.uk
info@opticalvision.co.uk
Email for 88 Page FREE Catalogue