BBC **WHERE WE'LL FIND THE SOLAR SYSTEM'S WATER**

#234 NOVEMBER 2024

Sky at Night

THE UK'S BEST-SELLING ASTRONOMY MAGAZINE

THE CATACLYSMIC UNIVERSE

Why astronomers are so fascinated by things that explode in space

DARK MATTER: HAVE WE GOT THE RULES OF GRAVITY WRONG?

STARS ON FILM: ASTROPHOTOS BEFORE THE DIGITAL AGE

WHICH METEOR SHOWERS POSE THE GREATEST THREAT?

THE MISSION THAT WILL SHOW US ALIEN WORLDS

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Christopher Ward

christopherward.com

SCAN ME

Welcome

Discover why cosmic carnage is good news for astronomers

As you would expect for a subject that studies nature on the grandest of scales, there are many branches of astronomy, from planetary science to stellar physics, galactic astronomy and cosmology. But there's one thing that unites scientists working across them all: their passion for things that go bang. We dig into some of the most cataclysmic explosions on **page 28**, with the UK Space Agency's Head of Space Science, Dr Caroline Harper, who explains what we get from events like supernovae and gamma-ray bursts (quite apart from them making great cover images).

We also take a look at something we cannot see at all – dark matter. On **page 35**, Colin Stuart puts the mysterious substance on the stand and asks: does it even exist? Since astronomers suspect that there's five times more of it in the Universe than there is ordinary, visible matter, it's a question of fundamental importance to our understanding of the cosmos.

Moving away from the invisible, there are plenty of exciting things to see in the night sky this month. At the time of writing, comet A3 Tsuchinshan–ATLAS has survived its close brush with the Sun and all indications are for a good show for Northern Hemisphere observers from mid-October into November. All the bright planets are reaching a decent altitude in evening skies too, and there's even the chance to see spellbinding interactions between Saturn and its moons. Catch up with the month's best observing in the Sky Guide from **page 43**.

Enjoy the issue!

Chris Bramley, Editor

PS Our next issue goes on sale on Thursday 14 November.

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Sky at Night – lots of ways to enjoy the night sky...

Television
Find out what *The Sky at Night* team have been exploring in recent and past episodes on page 18

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Visit our website for space news, astrophoto galleries, observing guides and more

Social media
Follow us on X (formerly Twitter), Facebook and Instagram for the latest astro news

Podcasts
Discover the best things to see in the night sky every week by listening to our Star Diary podcast

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Ⓒ = on the cover

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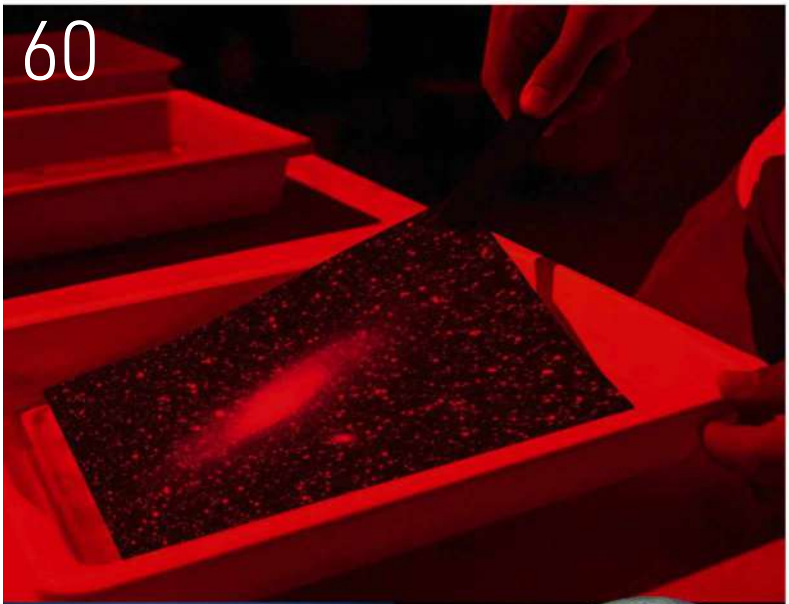
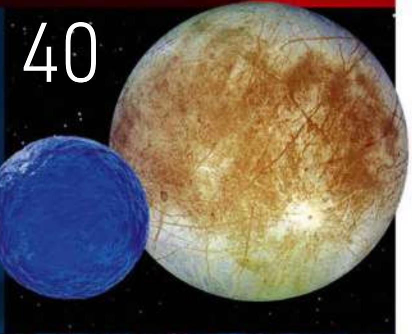
New to astronomy?

To get started, check out our guides and glossary at **www.skyatnightmagazine.com/astronomy-for-beginners**





This month's contributors

Caroline Harper

Space scientist

"Astronomers love looking at the cosmos's big bangs – they help reveal the most distant, most extreme and exotic physics." **Join Caroline for a look at what goes bump in the Universe on page 28**

Colin Stuart

Astronomy author

"Dark matter forms the underlying groundwork of modern cosmology. But how sure is that foundation?" **Colin puts the mysterious substance that may – or may not – be shaping the cosmos on trial, page 35**

Giles Sparrow

Astronomy writer

"The Roman Space Telescope is set to transform what we know about worlds beyond the Sun. I was amazed to find out how it will do this and what it means for exoplanet science." **Giles reports on the mission, page 67**

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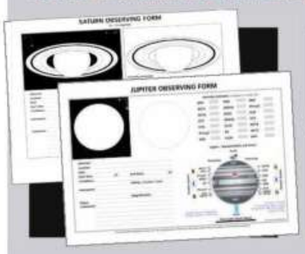
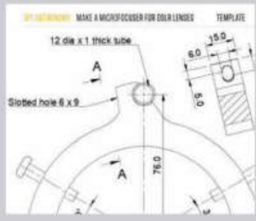
NOVEMBER HIGHLIGHTS

Interview: See the Northern Lights

Experienced aurora-chaser Tom Kerss reveals his top tips for catching one of nature's greatest spectacles.





Download and print observing forms

Keep track of your observations of the Sun and the planets through the eyepiece with our printable forms.

Get sharper stars with your DSLR camera

Download a template and extra images to help you build a microfocuser. See this month's DIY project on page 74.

The Virtual Planetarium

Pete Lawrence and Paul Abel guide us through the best sights to see in the night sky this month.

STAR INCUBATOR

Deep in its core, the bar in this galaxy is generating stars at breakneck speed

HUBBLE SPACE TELESCOPE, 9 SEPTEMBER 2024

Located 90 million lightyears from Earth in the constellation of Virgo, NGC 5668 is a barred spiral galaxy that's very similar to our own Milky Way in terms of its size, mass and shape. But there's one key difference: NGC 5668 forms new stars at a rate 60 per cent higher than the Milky Way.

This new Hubble image reveals one feature that astronomers think may be responsible for this remarkable fecundity: the galaxy's central bar, which is more oval and less bar-like than in most similar spirals. Fast-moving clouds of hot hydrogen speeding out from the galaxy itself to its outer halo – which isn't pictured here – may also play a part.

ESA/HUBBLE & NASA/C. KILPATRICK

FREE BONUS CONTENT

Explore a gallery of these and more stunning space images

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△ Back to the Arp

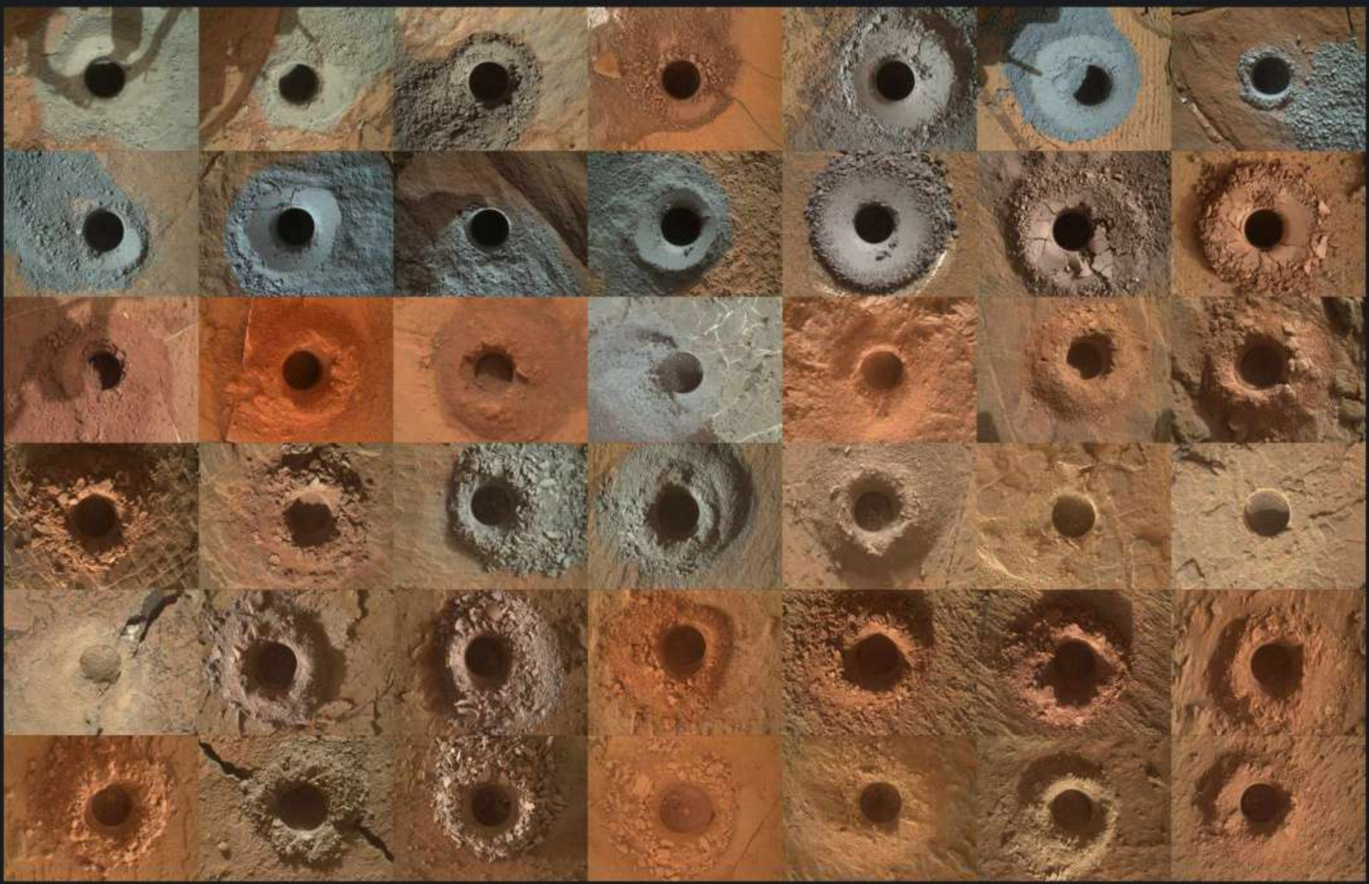
JAMES WEBB SPACE TELESCOPE, 18 SEPTEMBER 2024

We last featured Arp 107 – an interacting galaxy pair in Leo Minor, consisting of a small, elliptical galaxy (left) and a much larger Seyfert galaxy (right) – in November 2023. JWST's new near-infrared view, though, reveals far more clearly the bridge of gas linking the two, which has become a region of intense star formation.

▽ What a bore!

CURIOSITY MARS ROVER, 27 AUGUST 2024

These are the drill holes left behind by NASA's Curiosity rover after taking core samples from 42 different locations across the Red Planet between February 2013 and August 2024. Each of the holes is 16mm (0.63 inches) across in real life, with their varying hues revealing the diversity of the Martian regolith.



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Sylvia changed the story for us all. Now it's our turn to change the story for those who'll come after us.

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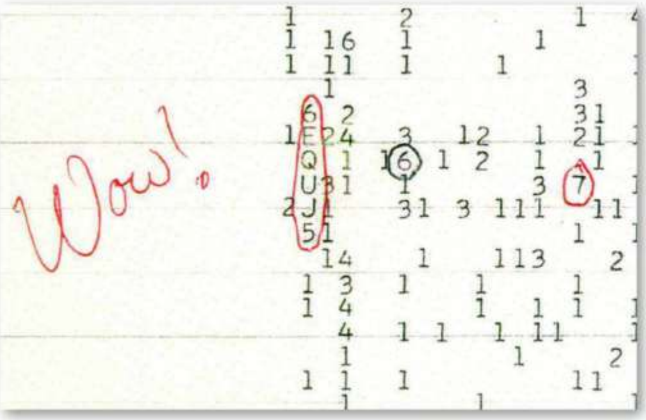
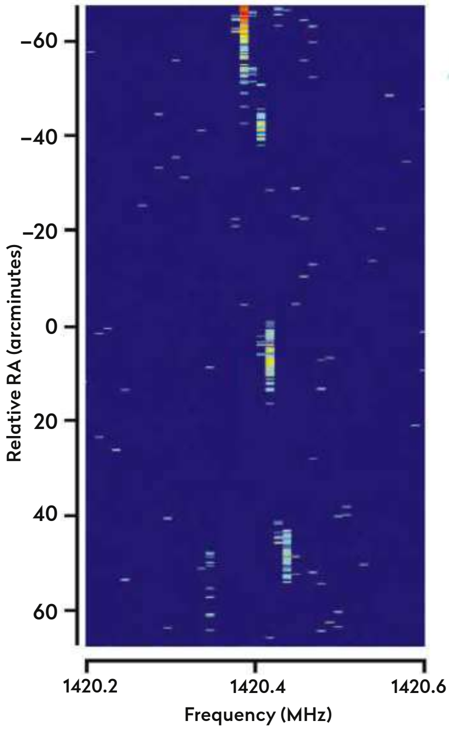
Stroke Association

At last: an explanation for the Wow! Signal

Rather than an alien communiqué, the signal was from a cosmic cloud



▲ **The unusual and very strong signal was picked up by Ohio State University's radio observatory in 1977**



▲ **By searching archive data, the team traced similar signals to interstellar clouds of cold hydrogen – putting ET theories to bed**

After almost half a century of wondering, astronomers may have found the cause of the mysterious Wow! Signal. And no, it's not aliens.

The signal was first spotted as part of a 22-year search for extraterrestrial intelligence, the longest ever carried out. Between 1973 and 1995, Ohio State University's 'Big Ear' radio telescope monitored the sky for signs of communications from distant civilisations. The Wow! Signal was picked up on 15 August 1977, when the observatory recorded an extremely strong pulse of radio waves lasting around 72 seconds, at the frequency of neutral hydrogen. The strength of the signal inspired astronomer Jerry R Ehman to write 'Wow!' next to it on the printout. Its origin – alien civilisation or natural event – has been debated ever since.

"The Wow! Signal remains an enigmatic outlier, representing a tantalising hint of potential extraterrestrial communication, while underscoring the challenges inherent in distinguishing genuine signals from cosmic noise and terrestrial interference," says Abel Méndez from the University of Puerto Rico, in a recent paper on the signal.

The paper is a result of the Arecibo Wow! project, which searched archived data from the Arecibo Radio Telescope for similar events. The team found several signals similar to the 1977 one, albeit much less intense. These similar signals all came from the radiation of a distant, transient background source, like a flaring neutron star, when it passed through a cloud of neutral hydrogen, the source's radiation exciting the hydrogen gas, making it glow intensely for several minutes.

Such events are rare and rely on the cloud, the background source and Earth being correctly aligned. And while most radio observations are broadband, these rare alignments are also only detectable in narrowband searches, meaning the similarities went unnoticed until now. The researchers suggest looking for more evidence to determine whether the Wow! Signal was an exceptionally bright occurrence.

"Since these neutral hydrogen clouds are easy to recognise, it may be possible to determine the exact location of the source of the Wow! Signal," the new study states. "Identifying the trigger source, however, would prove challenging. It may be close or behind the cloud location, or far in the background."

phl.upr.edu/wow

OSU/NAAPO, ARECIBO TELESCOPE/ARECIBO WOW

Comment

by Chris Lintott

Why did it take nearly 50 years to work out what the Wow! Signal was? While in Hollywood, alien signals set off alarms, in reality it took days for Jerry Ehman to notice the Wow! Signal in his data. Similarly, a signal detected by the Breakthrough Listen project in 2019, seemingly coming from Proxima Centauri, was only found after observations had finished. It took two more years to track down comparable signals – it, like Wow!, turned out not to be aliens.

Things would be easier if we could spot signals as they happen. Luckily, instruments such as MeerKAT in South Africa, along with machine learning, mean that a new generation of SETI projects will do just that. We might be saying 'Wow!' more often.

Chris Lintott co-presents *The Sky at Night*

▲ **Entrepreneur Isaacman was first out of his seat, spending minutes on the threshold of Dragon testing how the new EVA suit moves**

First private spacewalk makes history

The mission tested a new spacesuit and broke multiple records

The first-ever private spacewalk took place on 12 September, and it did so in style as the crew of the Polaris Dawn mission tested out the new extravehicular activity (EVA) suits made by SpaceX.

Polaris Dawn launched on 10 September onboard a SpaceX Crew Dragon capsule. The spacecraft initially entered a 1,400km-altitude (870 miles) orbit, breaking the record for the highest orbiting crewed spacecraft and the furthest a woman has ever been from Earth. It then settled into a lower orbit at 730km (450 miles) to get ready for the spacewalk on 12 September.

As Dragon isn't designed primarily for spacewalks, it has no airlock; instead, the entire capsule had to be depressurised before opening to the vacuum of space. Unlike the bulkier Extravehicular Mobility Units (EMUs) NASA uses, the new EVA suits were designed to be mobile and comfortable enough for wearing right through the mission, including while the capsule was pressurised.

Commander Jared Isaacman was the first to venture out of the spacecraft, poking his torso through the entry hatch.

"Looking at Earth was obviously very, very special," says Isaacman. "But when you look off to the side, you look out into the darkness of space, and you see your spaceship there and how gritty it looks, it gave you this sense of 'this isn't going to be easy'."

Isaacman conducted several tests to check his suit's manoeuvrability, before returning inside after almost eight minutes. Mission specialist Sarah Gillis then ventured outside to repeat the tests. During both walks, pilot Scott Poteet and medical officer Anna Menon remained inside the capsule, monitoring the spacecraft and their crewmates.

Before returning on 15 September, the mission helped set a new record for the most people in space at once. The ISS was at full capacity with 12 people onboard, including Butch Wilmore and Suni Williams. The pair have been unexpectedly living on the station after problems with their Boeing Starliner left it too unreliable to take them home. They will return onboard a SpaceX Crew Dragon in February 2025. They and the rest of the ISS residents, along with the four crew of Polaris Dawn and three taikonauts on the Chinese Tiangong space station, added up to a record 19 people in space.
www.polarisprogram.com/dawn

SPACEX X 4, EUROPEAN SOUTHERN OBSERVATORY/WIKIMEDIA COMMONS, HIRATA NAOYUKI/KOBE UNIVERSITY

Dark matter helps black holes grow

The mysterious substance could prevent gas clouds from collapsing too quickly


Decaying dark matter may keep hydrogen clouds hot enough to make black holes

For the last two years, the James Webb Space Telescope has imaged galaxies that are further away than any seen before, revealing the Universe as it was when it was only a billion years old. But it has also revealed a problem: the black holes at the centre of these galaxies are already far larger than they should be, given the time they've had to grow.

A new study suggests that the key could lie with dark matter. A team from the University of California, Los Angeles (UCLA) looked into the theory that supermassive black holes form directly from the collapse of giant gas clouds, rather than going through the intermediate step of forming stars first. For this to happen, the gas needs to stay together as one giant cloud. Under normal conditions, the clouds cool too quickly, causing them to fragment.

"How quickly the gas cools has a lot to do with the amount of molecular hydrogen," says Yifan Lu, who led the study. "Hydrogen clouds in the early Universe had too much molecular hydrogen, and the gas cooled quickly and formed small halos instead of large clouds."

To prevent this from happening, Lu suggests some form of radiation could break apart the molecular hydrogen, so the clouds are slower to cool. One potential source of radiation is from an unlikely candidate – dark matter. No one knows exactly what dark matter is, but theories predict it may have been unstable in the early Universe, releasing a photon when it decays. The study found that even if only a small fraction of dark matter decayed, the photons produced would disrupt enough of the hydrogen to allow the black holes to grow.

"If these supermassive black holes formed by the collapse of a gas cloud, maybe the additional radiation required would have to come from the unknown physics of the dark sector," says Zachary Picker, also from UCLA.

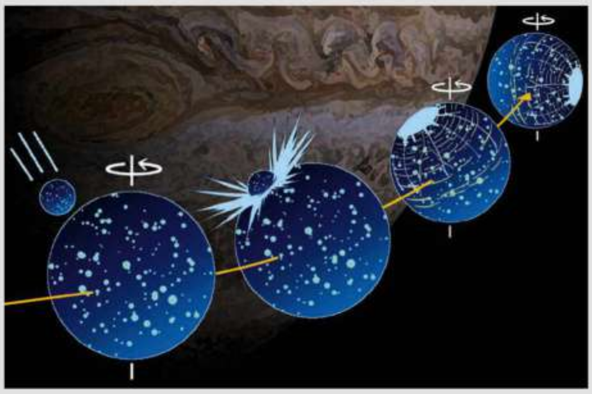
www.astro.ucla.edu

An asteroid's impact on Ganymede

Aftershocks from a colossal strike may have tilted the orbit of Jupiter's biggest moon

A colossal asteroid impact four billion years ago could have knocked Ganymede's axis askew, according to a new set of computer simulations.

Ganymede is the largest moon both in Jupiter's system and the entire Solar System. It has a subsurface ocean (see page 40) and is tidally locked, meaning it always shows the same face to its giant parent planet. One of its more intriguing features, however, is a series of concentric furrows which radiate from a point on the moon's far side.


▲ Hirata noticed that the location of the asteroid strike is almost precisely on the meridian furthest from Jupiter

"We know this feature was created by an asteroid impact about four billion years ago, but we were unsure how big this impact was and what effect it had on the moon," says Hirata Naoyuki from Kobe University in Japan.

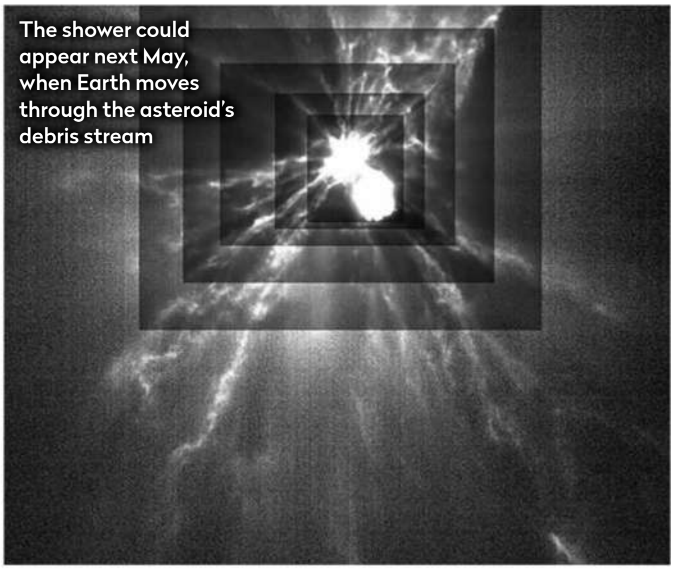
Hirata noticed the apparent impact site lay on the line of latitude directly opposite Jupiter, suggesting the collision reorientated Ganymede's axis into this precise alignment. Using simulations, Hirata estimated the asteroid would have been around 300km (190 miles) across, carving out a crater 1,400–1,600km (870–1,000 miles) wide. This would be large enough to change the distribution of Ganymede's mass, shifting its axis of spin and affecting many other aspects of the moon's geology too.

"The giant impact must have had a significant impact on the early evolution of Ganymede," says Hirata. "But the thermal and structural effects of the impact on the interior of Ganymede have not yet been investigated at all."

www.kobe-u.ac.jp/en

First human-made meteor shower predicted

Dust grains from the DART asteroid impact could reach Earth as meteors



The debris created during the DART mission, which tested humanity's ability to deflect dangerous asteroids, may unexpectedly create the first-ever artificial meteor shower.

On 26 September 2022, NASA's Double Asteroid Redirect Test (DART) collided with the 160-metre-wide (525ft) asteroid Dimorphos. The impact changed the asteroid's orbit around its larger companion, Didymos, by over 30 minutes, proving humanity had the ability to deflect an asteroid if it was found to be on a collision course with Earth.

As astronomers know the precise time and location of the impact, and this offered a rare opportunity to study how the large volume of debris it created spreads through the Solar System. By simulating over three million particles of different sizes and speeds, a team of researchers have predicted how they think the debris cloud will behave.

"We identified ejecta orbits compatible with the delivery of meteor-producing particles to both Mars and Earth," says Eloy Peña-Asensio from the Politecnico di Milano, who led the study.

The simulations reveal the smallest, fastest particles could reach Earth within seven years. They pose no threat, but could create a meteor shower, though it's uncertain how visible this would be. Smaller particles are more likely to be moving fast enough to reach Earth, while larger particles have a higher probability of reaching Mars.

"We were amazed to discover that it is possible for some centimetre-sized particles to reach the Earth–Moon system and produce a new meteor shower," says Josep M Trigo-Rodríguez from the Spanish Institute of Space Sciences.

The team will now monitor for signs of the meteor shower, which is expected to be slow-moving and most visible in the Southern Hemisphere during May.
dart.jhuapl.edu

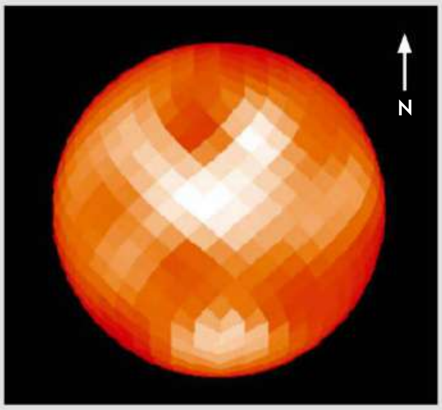
The North Star gives up its secrets

New observations of Polaris reveal more details than ever, including a mottled surface

The North Star, Polaris, may be a constant in the night sky, but the star is far from consistent. Now a new set of observations has revealed it has a spotted surface.

Located 448 lightyears away, Polaris is the closest known Cepheid variable to Earth. The rate at which a Cepheid varies is strongly linked to its luminosity, with fainter stars pulsing faster than bright ones. How bright a star appears in the sky depends on both its intrinsic brightness and how far away it is, meaning astronomers can use the variability to measure a Cephid's true brightness and work out its distance from us across space.

A team of astronomers used the CHARA Array at Mount Wilson, California, to take advantage of Polaris's



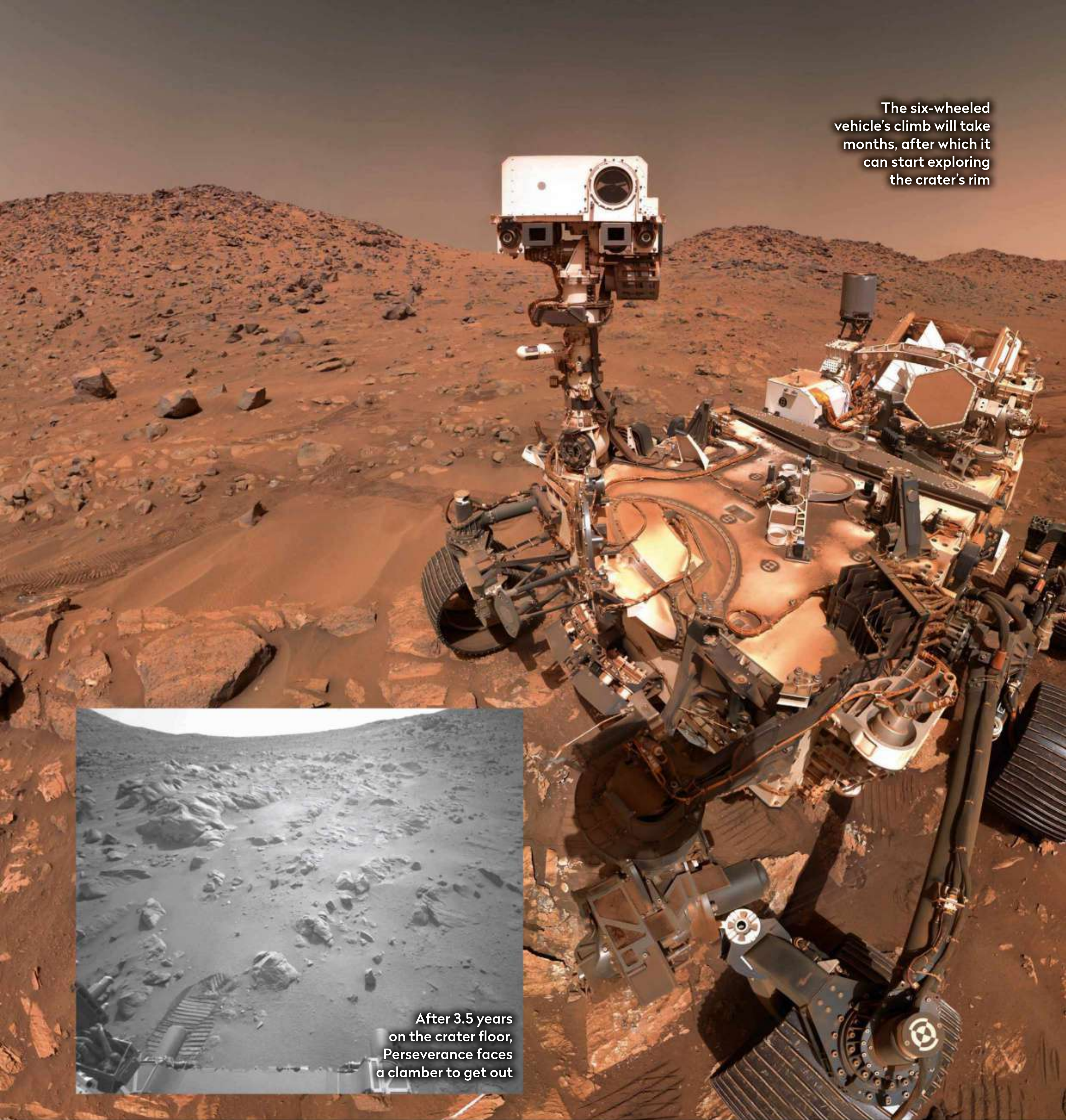
▲ **Researchers showed Polaris has large light and dark spots that vary over time – though how and why is not yet understood**

proximity and observe the fluctuating brightness of the star, finding it is 46 times brighter than the Sun. The team also tracked the orbit of a companion star which orbits once every 30 years, allowing them to measure the mass of Polaris at 5.1 solar masses (previous estimates have varied between 3.5 and 5 solar masses).

They also imaged the surface of the star, revealing something unexpected. "The CHARA images revealed large bright and dark spots on the surface of Polaris that changed over time," says Gail Schaefer, director of the CHARA Array.

"We plan to continue imaging Polaris in the future," says John Monnier, from University of Michigan, who took part in the study. "We hope to better understand the mechanism that generates the spots."
www.chara.gsu.edu

ASI/NASA/APL, NASA/JPL-CALTECH/MSSS, NASA/JPL-CALTECH



The six-wheeled vehicle's climb will take months, after which it can start exploring the crater's rim

After 3.5 years on the crater floor, Perseverance faces a clamber to get out

Mars rover begins its long climb

The Perseverance rover has a steep journey ahead out of Jezero Crater

Perseverance has begun the long climb up out of Jezero Crater, the former riverbed it's been exploring since landing there on 18 February 2021.

The journey marks the start of Perseverance's fifth science campaign. It will take many months to climb to the crater's rim, rising through 300 metres (1,000ft) of elevation. Though mission planners have picked out a route to avoid the steepest climbs, the rover will still have to navigate slopes of 23°. To put that into perspective, the UK's steepest street, Vale Street in Bristol, is just 22°.

"Perseverance has completed four science campaigns, collected 22 rock cores and travelled over 18 unpaved miles," says Art Thompson, Perseverance's project manager from NASA's Jet Propulsion Laboratory. "As we start the Crater Rim Campaign, our rover is in excellent condition and the team is raring to see what's on the roof of this place."
www.jpl.nasa.gov

Our experts examine the hottest new research

CUTTING EDGE

While good for stargazers, meteor showers can be a hazard for spacewalkers, satellites and spacecraft

When meteor showers attack

Forecasters are trying to pin down which comet debris poses a threat to us

Meteor showers are a delight to behold – nature's own fireworks displays. But their beauty hides a more dangerous side. Before they enter Earth's atmosphere, the fast-moving grains and pebbles of interplanetary rock – meteoroids – pose a risk to spacecraft. Larger meteoroids can penetrate the cabin of crewed space vehicles, and even small impacts can damage satellite components and short-circuit electronics. For example, ESA's Olympus 1 communications satellite started tumbling out of control and had to be subsequently deactivated during the 1993 Perseids shower.

There is an ever-present background threat of meteoroids, so spacecraft are built with shielding and redundant systems. But during a meteor shower, the risk can jump for a short period, forcing spacewalks to be postponed or satellites to be turned to present a less vulnerable side to the shower radiant.

Meteor showers are caused when Earth passes through the stream of debris left along the orbital track of a comet, and so they are broadly predictable. NASA's Meteoroid Environment Office, where Althea Moorhead works, issues annual meteor shower forecasts to help mission planners avoid the worst risks. The difficulty is that the intensity of different showers changes over the years or key parameters are unknown, such as the density of particles or their size range. Plus new showers are being reported all the time. Moorhead has been working on improving predictive models to make sure that warnings are only issued for the most genuinely hazardous events.

"Slow-moving showers dominated by smaller particles can act like a shotgun blast. The most hazardous include the Geminids and the Perseids"

Prof Lewis Dartnell is an astrobiologist at the University of Westminster

Gauging the risks

She started by defining the threshold of what constitutes a potentially hazardous meteor shower. It's a lengthy definition, but boils down to when the rate of energetic, potentially damaging, meteoroids is at least 5 per cent that of the background level. There are over 100 showers with relatively well measured parameters and Moorhead applied her criteria to pick out those that present the worst risks.

Perhaps surprisingly, the meteoroid showers that result in the most impressive displays of shooting stars can pose minimal risk to spacecraft. These are produced by unusually large, high-speed meteoroids, but if there's not a great number of them, the chance of any hitting a satellite is tiny. The Epsilon Geminids, for example, which occur in late October, are caused by exceptionally fast particles and can produce spectacular fireballs, but pose an utterly insignificant risk to spacecraft. On the other hand, slow-moving showers dominated by smaller particles can act more like a shotgun blast of particles hazardous to satellites.

The most hazardous showers identified by Moorhead include the Geminids, which peak in mid-December, and the Perseids in mid-August. She also keeps a close watch on variable showers, which are typically low-activity and don't exceed her danger threshold for most years, but can occasionally surge hundreds of times over during an outburst. The Leonids have frequently produced such outbursts in the past, when Earth passed through a particularly dense stream of meteoroids from the comet Tempel–Tuttle.

It's strange to imagine space mission planners checking the weather forecast for warnings of rocky rain, but hopefully now they should at least know when they need to take their proverbial umbrella.

Lewis Dartnell was reading... *The Threshold at which a Meteor Shower becomes Hazardous to Spacecraft* by Althea V Moorhead et al.
Read it online at: arxiv.org/abs/2408.04612

BURADAKI/ISTOCK/GETTY IMAGES, SDSS/HUAN YANG

Picking cosmic blueberries

Small 'Blueberry' galaxies close to home could help astronomers understand distant Green Peas

Prof Chris Lintott is an astrophysicist and co-presenter on *The Sky at Night*

First, there were the Green Pea galaxies. The compact, round, green systems were given their vegetal moniker by the volunteer participants on the Galaxy Zoo project who discovered them. Astronomers like amusing names, and so the Green Beans (stringier versions of the Peas) quickly followed, along with suggested Green Chillies (bendier versions of the beans).

These systems attract attention because of their distinctive green colour, caused by bright emission from oxygen that is associated with star formation. They are dwarf galaxies, but they are forming stars at a rate that would be unusual in systems 10 times their size. They are the most efficient factories of stars in the local Universe, though no one can agree why. Astronomers peering at the Green Peas with orbiting X-ray telescopes have found them much brighter than expected; signs, perhaps, that black holes more massive than we would have ever expected in such dwarf galaxies are present.

As if that wasn't intriguing enough, recent observations with the James Webb Space Telescope (JWST) of high-redshift galaxies in the early Universe look rather like our local Green Peas, suggesting that the latter might just be stragglers, the last systems to go through a spectacular stage that most galaxies got over billions of years ago. So studying the Peas is important, but there's a catch. Though nowhere near as distant as the galaxies studied by JWST, they aren't that local, existing between about 2.5 and 4 billion lightyears away.

Looking for local Peas

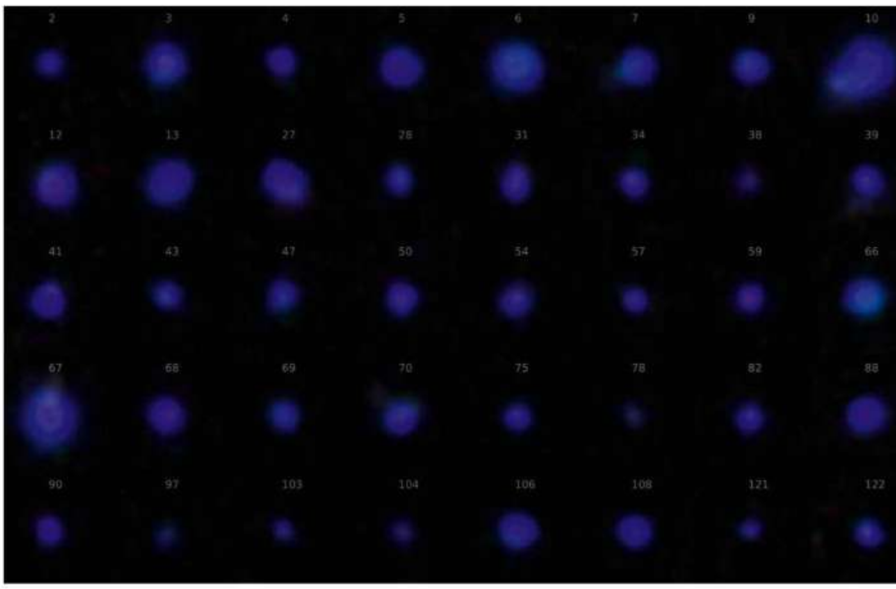
At those distances, the redshift caused by the expansion of the Universe shifts the oxygen emission towards the red, producing the distinctive green colour that allowed the Peas to be identified in the first place. Those hunting similar systems closer to home need to look for round, blue galaxies – which they've started calling Blueberries.

Several punnets-worth of these systems are now known, and this month's paper takes a first look at their X-ray emission using ESA's XMM-Newton orbiting observatory. This is the first time any Blueberry galaxies have been observed at X-ray wavelengths, and the results are surprising. While Green Peas seem bright at these wavelengths, most of the seven systems were less luminous in the X-ray than we'd expect for galaxies of their size; all but two weren't even detected!

"This is the first time any Blueberry galaxies have been observed at X-ray wavelengths, and the results are surprising"

So what's going on? One possibility is that the population of Blueberry galaxies may be very young, so much so that their stellar population hasn't yet evolved enough to produce binary systems with a normal star paired with a neutron star or black hole, which shine brightly in X-ray. If that's right, these small galaxies formed most of their stars in the last five million years, a blink of a cosmic eye.

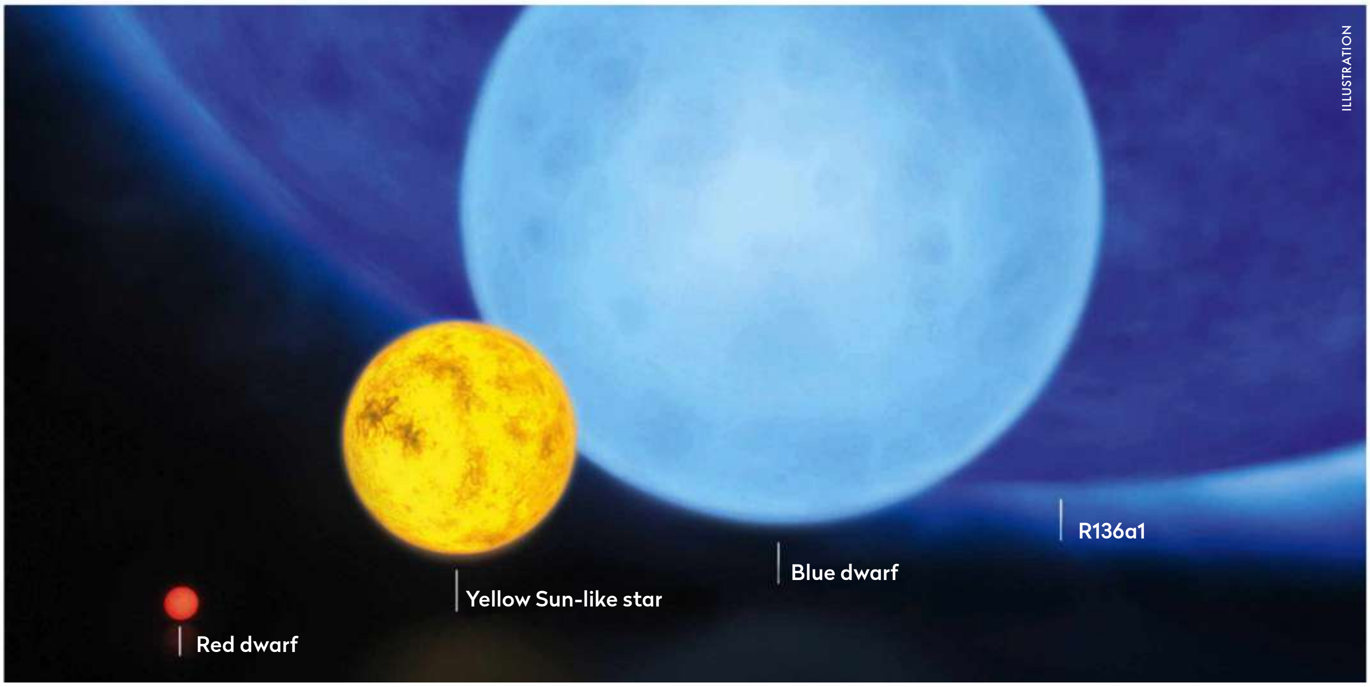
Confusingly, one of the systems (which *Star Wars* fans will be pleased to hear is called BB8) glows surprisingly brightly. The researchers suggest this might host a growing black hole, but then we need to explain why only one of the systems does. With more mysteries found by these observations than solved, telescopes will be picking Blueberries for a long while yet.



▲ **Blueberry galaxies are thought to be faint, local relations of Green Peas, vigorously star-forming dwarf galaxies that dominated the early Universe**

Chris Lintott was reading... *X-ray Observations of Blueberry Galaxies* by B Adamcová et al. **Read it online at: arxiv.org/abs/2408.13572**

INSIDE THE SKY AT NIGHT



▲ **Raman studies gargantuan stars like R136a1 (back), over 200 times the mass of our Sun and one of the most massive and luminous stars ever discovered**

Following October's special *Sky at Night* Question Time episode, **Raman Prinja**, an expert in the biggest stars in the Universe, joins us to answer some of your top questions about massive stars

How do massive stars form?
Massive stars have between eight to over 100 times the mass of our Sun when they form. But astronomers aren't sure how these behemoths become so huge.

All stars are forged within vast, dense clouds of dust and gas located in interstellar space. The force of gravity causes the clouds to collapse in on themselves, making central clumps that get denser and hotter. The clumps are surrounded by plate-like, spinning discs of material, from which more matter is pulled in to grow the star.

The problem is that after the star reaches around 20 solar masses, very strong radiation from the forming massive star can create an outward force that prevents more matter being sucked up from the swirling disc. One possible solution could arise from the fact that massive stars always form in clusters or groups. It may be that a number of small clumps of gas (or protostars) are consumed by the main star to give birth to the most massive stars in the Universe.

What is the maximum mass a star can have?
Very massive stars, those over 100 solar masses, are very rare. A star called R136a1, which is located around 160,000 lightyears away in the centre of the Tarantula Nebula, in our neighbour galaxy, the Large Magellanic Cloud, is one of the most massive we know of – between 170 and 230 solar masses. Astronomers predict that stars of about 150 to 250 solar masses become very unstable, and huge amounts of energy and chemical elements are ejected when they go supernova.

How does the life of a massive star differ from that of the Sun?
The life cycle of a star depends on its mass – massive stars use their supply of nuclear fusion energy much quicker than lower-mass, Sun-like stars. Our Sun will live as a stable star for about five billion years, after which it will run out of fuel and bloat out into a red giant star, before puffing out its outer layers as a planetary nebula. The tombstone left behind will be a compact, Earth-sized, white dwarf.

A massive star born with 20 solar masses, however, will only have a five-million-year stable phase, after which it will rapidly expand into a supergiant star hundreds of times the radius of the Sun. When its nuclear fusion energy supply runs out, the star will explode as a supernova, blasting away all its outer layers in a hugely energetic event. What's left behind is either a neutron star or a black hole.

ESO/M. KORNMESSER, NASA/JPL, KAPOOK2981/ISTOCK/GETTY IMAGES

Stars change over millions or billions of years, so how can we know their life cycle?
We can't just observe a single star and watch it playing out its full life cycle, so astronomers act like detectives to figure out the phases stars go through. They take snapshots of clusters of many stars that were born with different masses, which means some have evolved faster and gone further in the cycles than others. In these snapshots, we can see a zoo of newly formed stars, stable stars, red giants, supergiants, supernova leftovers and so on. Using extra data, such as spectroscopy, astronomers then figure out these must be phases in stellar life cycles.

The author of many popular science books, **Raman Prinja** is professor of astrophysics at University College London

How are we connected to massive stars?
Our lives and the lives of massive stars are inextricably linked. This profound connection arises because life-giving chemical elements can only be forged in the interiors of massive stars or during their detonations. The elements oxygen, silicon, calcium, iron and phosphorus that are so important for our bodies were generated in the centres of massive stars. They were dispersed across space by exploding supernovae, spreading out to ultimately enrich our star-forming cloud of gas and dust, out of which the Solar System and Earth were forged. We are the stardust of massive stars!

Looking back: The Sky at Night

17 November 1971

On the 17 November 1971 episode of *The Sky at Night*, Patrick Moore looked at the first images of the Red Planet from NASA's Mariner 9. The spacecraft had arrived at Mars just four days earlier, becoming the first spacecraft to orbit the planet.

The mission's goal was to map 70 per cent of Mars's surface, but the plan was initially waylaid as Mariner arrived in the middle of a giant dust storm that obscured its view of the surface. The storm finally subsided in January 1972, allowing the spacecraft to begin charting the planet's surface. It eventually ran out of fuel on 27 October 1972, having taken 7,329 photos covering 85 per cent of the planet. These revealed many of Mars's major features, such as Olympus Mons.

▲ The summit crater of volcanic Olympus Mons, taken from orbit by Mariner 9

At the time of the November 1971 episode, however, Mariner wasn't the only spacecraft bound for Mars. Two Soviet probes were soon to arrive there, only rather than orbiting, they were bound for the surface.

Unfortunately, with the dust storm still raging, the pair were in for a rough ride. Mars 2 arrived on 27 November, but failed to deploy its parachute and crashed. Mars 3 then arrived on 2 December and was able to successfully soft-land on the surface of the Red Planet – the first spacecraft to do so. Shortly after touchdown, it began to transmit its first image, only for its signal to cut out after less than 20 seconds, never to be recovered.

The Sky at Night NOVEMBER

Ancestral Skies

From as far back as the ancient civilisations that used the stars as a guide, both literally and spiritually, humanity has always had a relationship with the night sky. This month's show looks at that relationship, as well as looking as what's being done to preserve historical sites and artefacts in space, and the impact of light pollution on society, health and wildlife.

BBC Four, **11 November,** 10pm (first repeat will be on BBC Four, **14 November**, 11:25pm)
Check www.bbc.co.uk/skyatnight for more up-to-date information

▲ Stones and stars: the *Sky at Night* explores our millennia-old connection to the cosmos

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MESSAGE OF THE MONTH

This month's top prize: two Philip's titles

The 'Message of the Month' writer will receive a bundle of two top titles courtesy of astronomy publisher Philip's: Nigel Henbest's *Stargazing 2025* and *Moon Map*, the essential map for all Moon watchers

Winner's details will be passed on to Octopus Publishing to fulfil the prize

A lifelong interest

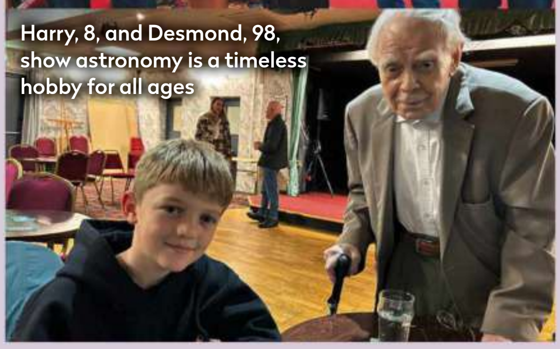
We had a very special evening at Preston and District Astronomy Society this month, with a presentation by Alexia Lopez about her exciting work 'The Big Ring and the Giant Arc'. Her fascinating research into the huge galactic structures she has uncovered had us all enthralled, including our special members seen here.

Young Harry Taylor, aged 8, is our youngest member and Desmond Hicks, aged 98, is our oldest member. Harry is very keen and attends all our events, and is in the process of decorating his room with old Palomar plates. There are 90 years between Desmond and Harry, but their enthusiasm is the same.

Nicky Robertson, via email

Thanks for getting in touch, Nicky! It's heartwarming to hear of Harry and Desmond's shared passion for astronomy, spanning the generations. *– Ed.*

Members of PADAS with Alexia (second from left)



Harry, 8, and Desmond, 98, show astronomy is a timeless hobby for all ages

Tweet

Greg Redfern
@SkyGuyinVA • 18 September

Partial lunar eclipse was beautiful at sea off the coast of Malaga, Spain, despite heavy clouds. iPhone Pro Max 15 with @NightCapApp. @skyatnightmag

Clive points out space tourism's impact on the climate

PATRICK T. FALLON/ISTOCK/GETTY IMAGES

Space travel toll

Your article on 'The new era of human spaceflight' (August 2024) did not mention the potential environmental impact of increased launches for space tourism. This must be a concern, particularly as such tourism will involve the richest on our planet who already contribute disproportionately to climate change.

Clive Butcher, Mansfield

Ceres theories

In response to Chris Lintott's Cutting Edge about a lunar telescope ('Building a telescope on the Moon', October 2024), I don't think an observatory on the Moon is the best option, but it is the only one for the immediate future. What we really need is to claim a larger asteroid or an entire dwarf planet (like Ceres) to build a radio telescope on. That way, you can reserve a landing base on one side while extending infrastructure around the body, so different organisations can mount their own instrumentation annexes.

Kerry L Baldwin, via email

A world away

I am a retired space engineer who has worked on the Space Shuttle, the ISS and space telescopes, and read your article on the JWST images ('Maggie's top 10 JWST images', October 2024). I thought the ▶

BBC Sky at Night Magazine

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▶ images were fantastic (the Pillars of Creation was my favourite), but I'm always interested in exoplanets. It's amazing that we are not just detecting exoplanets by transit or Doppler effects, but are now able to see them directly. The interesting part will be observing a rocky exoplanet, similar in size to Earth, in the Goldilocks zone. Maybe, just maybe, JWST could detect changes in a planet's atmosphere that might indicate a new civilisation.

The size of the Universe is mind-boggling, though. Especially so since there are young galaxies (less than 3–4 billion years old) that could be 5–10 billion lightyears away – so far that their light hasn't reached us yet. Since the Universe is around 13.7 billion years old, what about older galaxies 15–20 billion lightyears away and moving further away each year? Their light wouldn't have reached us either!

I believe we're not alone in the Milky Way, but these other civilisations could be so far away that we will never know they are there. We'd have to be able to travel faster than the speed of light, or be able to warp space and time, to reach them.

Kevin O'Hara, via email

Instagram

kates.universe • 19 September

Last night's partial lunar eclipse! Had to wait for the clouds to clear out, but am glad I managed to get a few images. #lunareclipse #partiallunareclipse #moon #luna @bbcskyatnightmag

Mystery rock

I think (hope) I've found a meteorite. It's dark brown in colour and heavy for its size, approximately 140–180 grams, and slightly magnetic. No colours to be seen with the naked eye except for specks of yellow and gold. Any replies and advice welcomed.

Gary Lee, via email

The possible meteorite that Gary found

SOCIETY IN FOCUS

Anglesey Astronomical Society, established in March 2023, is a growing community of astronomy enthusiasts in north Wales. Meeting monthly at Holyhead Breakwater Park, the society is led by four dedicated organisers – Gav, Dyl, Teresa and Chels – who have created a welcoming environment for stargazers of all ages. The society has hosted guests from as far as New Zealand and is open to visitors across the island.

Supported by Anglesey County Council and the Area of Outstanding Natural Beauty (AONB), we host well-attended meetings with talks from guest speakers on topics ranging from celestial events to deep-space mysteries. Recently, we launched a Young Astronomers Group, working with trainers from the European Space Agency to help young people and their parents learn how to use telescopes and engage in space-themed activities.

Gav giving a talk on constellations to the society's Young Astronomers Group

Looking ahead, we plan to expand our outreach across Anglesey, ensuring everyone on the island can experience and enjoy our dark skies. We aim to collaborate with local activity groups to promote dark skies initiatives and provide access to a mobile planetarium. The Anglesey Astronomical Society is committed to making astronomy accessible and engaging for all.

Gavin Malone, Anglesey Astronomical Society

▶ Follow Anglesey Astronomical Society on Facebook

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Up close with extraordinary

Michael Warner opens one of the UK's largest private collections of space artefacts

One of the most visited attractions in London right now is The Moonwalkers at Lightroom, King's Cross, a 360° immersive experience on the NASA Apollo missions, narrated by actor Tom Hanks. The show takes the public part-way along the historic journey to landing on the Moon.

The Space Vault Exhibition, however, on display at the River & Rowing Museum in Henley-on-Thames, goes deeper, bringing visitors to within inches of rare and historic artefacts that have put astronauts into space, flown in Earth orbit and landed on a celestial body other than Earth.

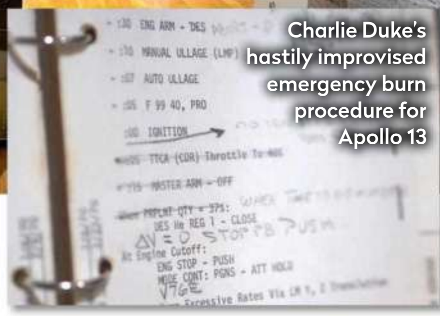
My interest in space began at age six. At school assembly, we joined millions across the world watching Neil Armstrong and Buzz Aldrin land on the Moon. The event lodged in my memory, largely I think because the school's black-and-white TV was housed in a wooden cabinet on spider-like legs, which looked a lot like the lunar lander. Jump forward 40 years to an article I read explaining how NASA had made an ownership claim against Apollo astronaut Jim Lovell, aiming to halt his sale of a page from the mission manual he used in the rescue of the aborted Apollo 13 mission. This single page had just sold at auction for $388,375 because Lovell had hand-written critical emergency procedures on it. NASA wanted it back.

I was staggered at the price and equally astonished to learn there was an auction market for Moon landing artefacts. NASA eventually lost its legal argument and in 2012, the full legal right of sale over artefacts owned by astronauts from the Mercury, Gemini and Apollo programmes was written into US law in Act HR 4158.

The passing of the Act coincided with my own sale of a small business, enabling me to participate in the short-lived wave of Apollo artefact auctions that were unleashed. Under the hammer came a suite of truly historic objects that had each played a part in placing humans on the Moon. These early auctions were a little like the unearthing of Egyptian treasures, but in this case coming onto the open market after a half-lifetime hanging on walls and sitting in the bank vaults of the Apollo astronauts.

Some of what is now on display at the Space Vault Exhibition includes Moon dust from the Hadley Rille landing site of Apollo 15; the complete, and heavily annotated, mission manuals from Apollo 13; and the astronaut evaluations of Buzz Aldrin conducted by Neil Armstrong, selecting Buzz as lunar module pilot for the first Moon landing. Visitors can view these and many more objects up-close. They can read the thrilling stories and watch archive material that takes you back to the heart of these wondrous missions. We've built a programme of expert talks too, as well as Behind-the-Vault sessions guided by myself and other experts.

The Space Vault showcases unique memorabilia from Apollo and other missions



Charlie Duke's hastily improvised emergency burn procedure for Apollo 13

Model of the lunar module descent engine and rare items from Apollo 13

THE SPACE VAULT EXHIBITION LTD X 3

▶ The Space Vault Exhibition is at the River & Rowing Museum, Henley-on-Thames, Oxfordshire, until 1 July 2025. **www.thespacevault.org/bookings**

Dr Michael Warner is the owner and curator of the Space Vault Exhibition

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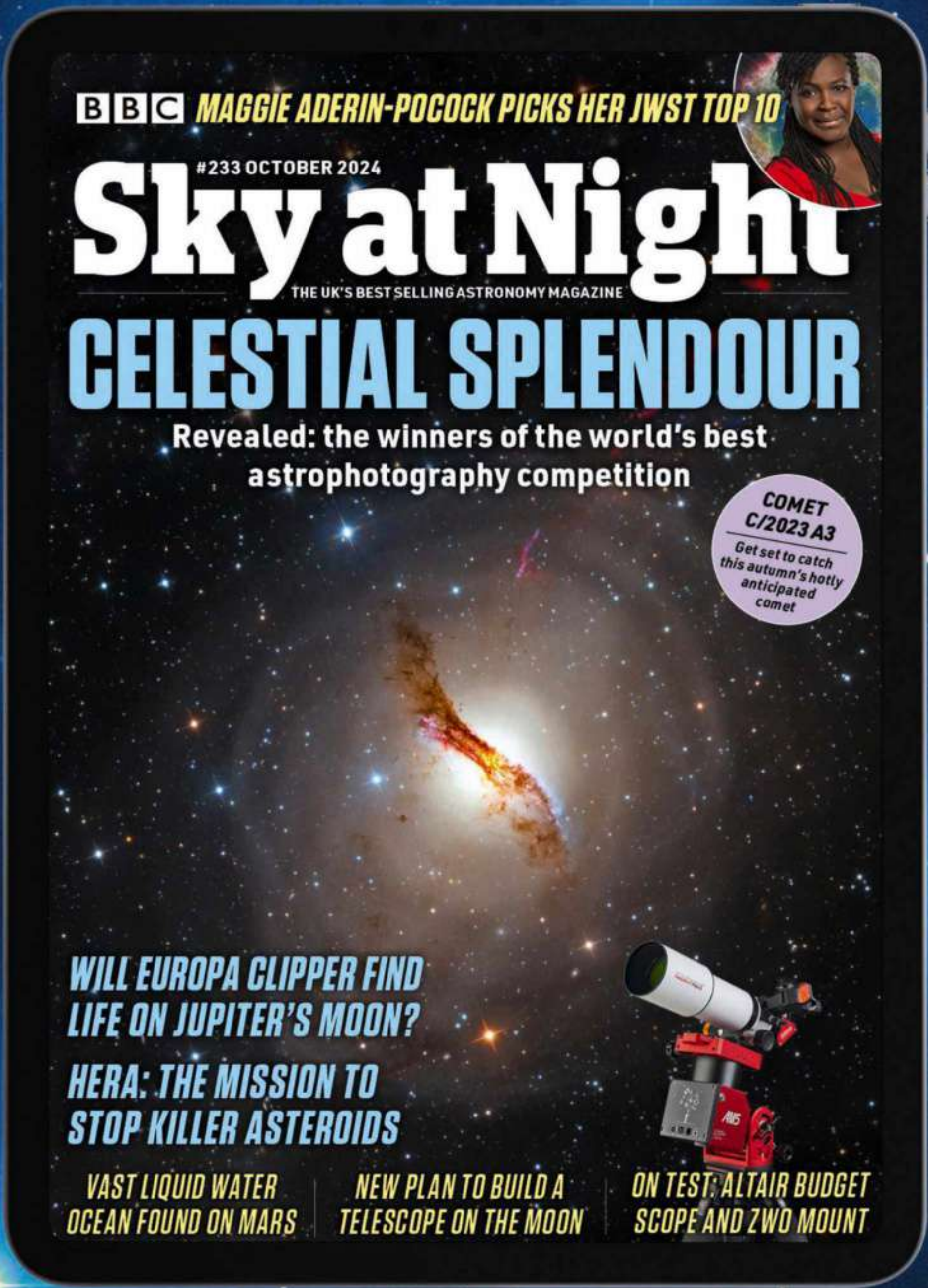

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News

THE CATACLYSMIC UNIVERSE

Cosmic carnage! A planet (left) bites the dust as a supernova detonates (right) – just one of the many cataclysmic explosions that astronomers love to study

From giant explosions to calamitous collisions, astronomers love to observe when things go bang. **Caroline Harper** explains the fascination

Around 13.8 billion years ago, a single, infinitely dense point suddenly expanded faster than the speed of light, producing a superheated fog of radiation and particles. This was the birth of the Universe in the Big Bang – the ultimate cataclysmic event.

The Big Bang is our best model to explain the Universe and the laws of physics as we understand them, including how space, time and matter came to exist. The more we study the Big Bang, the more we can learn about how the cosmos began and evolved into the Universe we see today. By studying it, we've learned the expansion of the Universe is accelerating. Meanwhile, fluctuations in the cosmic microwave background (the remnant light after the Big Bang) showed us dark matter and dark energy together account for an astonishing 95 per cent of the total content of the cosmos.

But this isn't the only cataclysmic scenario astronomers use to learn about the Universe. From exploding supernovae to the violent mergers of supermassive black holes, dramatic events are happening across the cosmos all the time, each releasing a huge amount of energy. Whenever one is spotted, scientists race to study them. But what is it that we love so much about big bangs?

Suicidal stars

Perhaps the best-known cosmic explosion is the supernova, when a massive star runs out of fuel and explodes in a sudden brilliant flash of light, billions of times brighter than our Sun. They are short-lived, and over a few weeks or months the light fades. What remains is a cloud of hot gas expanding around a neutron star, a stellar core so unimaginably dense even a teaspoon of it weighs around a billion tonnes (2.2 trillion pounds). In ▶

ILLUSTRATION: MARK GARLICK/SCIENCE PHOTO LIBRARY/ALAMY

FRBs are short-lived radio pulses, lasting a fraction of a second. One FRB can generate as much energy as our Sun does in a year

▲ Supernova 1987A, the explosion of a supergiant star, blazed with the power of 100 million Suns for several months in 1987

▶ some cases, if the star was extremely massive before it exploded, it forms a black hole.

Supernovae interest astronomers for several reasons. They happen fast, which is convenient. Most cosmic processes last for millions or even billions of years and we have to piece together what happens during most of a star's lifespan by observing similar stars at different stages of their lifecycle. A supernova, though, we can watch from start to finish.

They're also exceptionally bright, often outshining their entire galaxy, meaning they can be seen billions of lightyears away, so observing them helps us to see the large-scale structure of the Universe. Type Ia supernovae are particularly useful in this regard. These are caused when a white dwarf star in a binary system acquires so much material from its companion it reaches a critical mass – equivalent to 1.4 solar masses – at which point it collapses and then explodes. Because they all explode at about the same mass, the amount of light released is very consistent. Astronomers use them as 'standard candles' to measure cosmic distances accurately – if we observe two Type Ia supernovae and one appears dimmer, we know it must be further away.

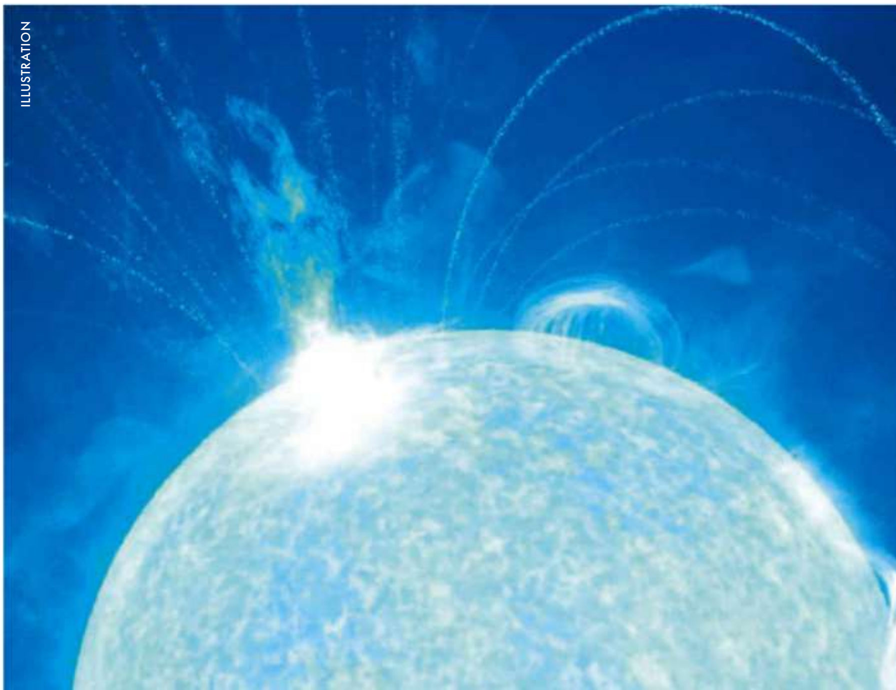
Short, sharp signals from space

While supernovae have been observed since ancient times, a recently discovered variety of high-energy event is Fast Radio Bursts (FRBs). Though we've only known about them since 2007, hundreds have been discovered. They are extremely short-lived radio pulses, normally lasting a fraction of a second, and are incredibly powerful – we estimate that one FRB can generate as much energy as our Sun does in a year. What causes them is still a mystery, but they are probably associated with dense objects like white dwarfs, neutron stars and black holes. Some have even been detected emanating from areas where we know the supermassive black holes of colliding galaxies are merging.

Most of these bursts are transient one-off events, making them challenging to study – by the time you realise you've seen one, it's already over. But some FRBs are repeating, opening up the possibility of observing them over time. What triggers these

▼ The most active, off-the-charts bright, repeating FRBs could be belted out by magnetars – neutron stars with incredibly powerful magnetic fields

ILLUSTRATION



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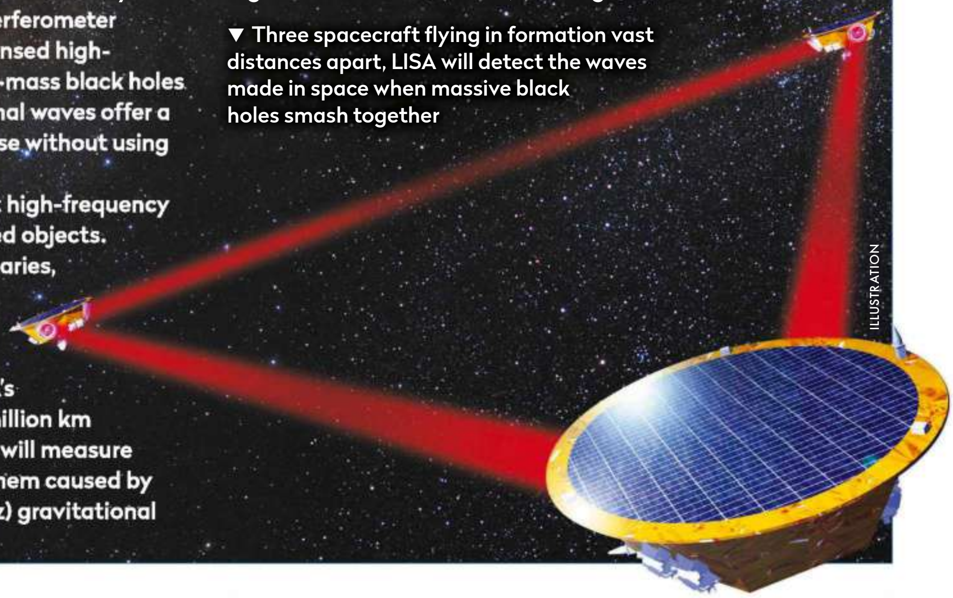
Tremors in the fabric of time

When things in space go bang, we can feel the ripples

Einstein postulated in his theory of general relativity that massive accelerating objects cause ripples in space-time travelling at the speed of light, known as gravitational waves. It would be another 100 years before we directly detected them, when in 2015 the Laser Interferometer Gravitational-wave Observatory (LIGO) sensed high-frequency waves from two colliding stellar-mass black holes 1.3 billion lightyears away. Now, gravitational waves offer a completely new way to observe the Universe without using electromagnetic radiation.

Ground-based systems like LIGO detect high-frequency (around 10Hz–10kHz) ripples from star-sized objects. Bigger objects, like massive black hole binaries, produce lower-frequency waves. To measure these, we need detectors like ESA's LISA (Laser Interferometer Space Antenna), due to launch in the 2030s. LISA's three spacecraft will fly in formation 2.5 million km (1.5 million miles) apart. Using lasers, they will measure the tiny differences in distance between them caused by the passage of low-frequency (0.1mHz–1Hz) gravitational waves. Researchers have begun detecting even lower frequencies by measuring minute changes in radio signals from pulsars – rotating neutron stars releasing regular beams of radiation, like a lighthouse.



▼ Three spacecraft flying in formation vast distances apart, LISA will detect the waves made in space when massive black holes smash together

ILLUSTRATION

ILLUSTRATION

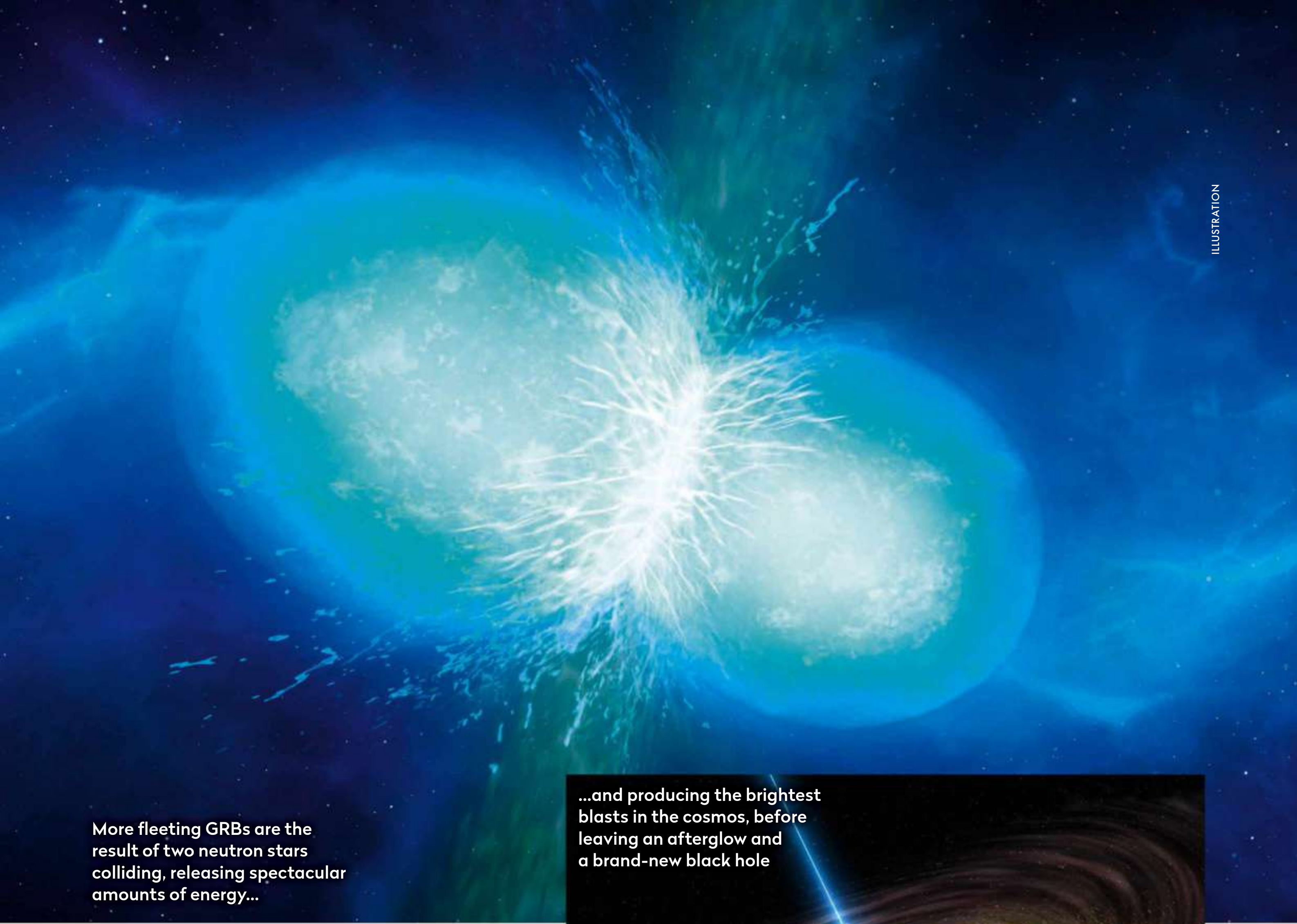
▲ **Long GRBs occur when especially heavy stars collapse, violently ejecting tremendously powerful jets of material – sometimes in the direction of Earth**

repetitive bursts? We aren't sure. One idea is that repeaters are produced by a specific type of neutron star called a magnetar, which has an astonishingly powerful magnetic field. The theory is this field stresses the magnetar's crust, causing starquakes and huge flares of radiation.

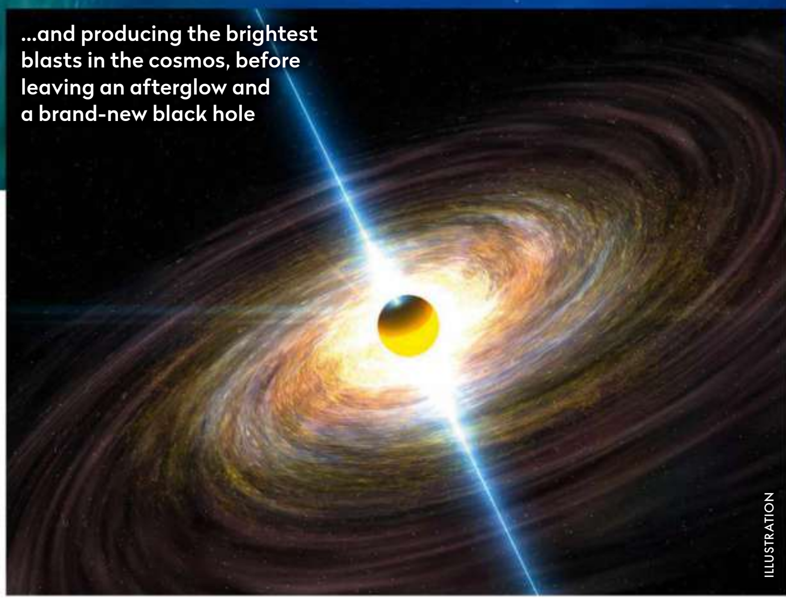
Repeating FRBs can act like a cosmic radar beacon, as their signals carry a signature of the material the burst travelled through. This makes them an exciting new tool to quantify the amount of matter between galaxies and to study the 3D clustering of matter. By allowing us to test and improve our cosmological models, they may even help us to resolve the Hubble tension and explain why the observed expansion of the Universe doesn't match theoretical predictions.

Mega-blasts from the past

In terms of high-energy events, however, both supernovae and FRBs pale in comparison to gamma-ray bursts (GRBs) – the most powerful explosions we know of in the Universe since the Big Bang, generated when spectacularly violent events take place. A typical GRB releases more energy in 10 seconds ▶



More fleeting GRBs are the result of two neutron stars colliding, releasing spectacular amounts of energy…



…and producing the brightest blasts in the cosmos, before leaving an afterglow and a brand-new black hole

▶ than our Sun will during its entire 10-billion-year lifespan. Some are short gamma-ray bursts, lasting milliseconds to two seconds, thought to be released when two neutron stars, or a neutron star and a black hole, merge to produce a new black hole.

By contrast, long gamma-ray bursts, lasting from two seconds to several minutes, are thought to be released when some giant stars go supernova, forming a black hole.

In 2022, an exceptionally bright GRB lasting 10 minutes was discovered emanating from a supernova 2.4 billion lightyears away, which was so powerful it affected Earth's atmosphere. A GRB this energetic and close to home is unusual, occurring perhaps once in 10,000 years. Certainly, it was the most energetic burst we've observed and it is now referred to as the BOAT (Biggest Of All Time). In both cases, the new baby black hole emits jets of energetic particles which produce bursts of gamma rays as they travel through the interstellar medium.

Echoes through time

Astronomers can observe these incredibly powerful GRBs over extreme distances. As light takes so long to travel the enormous distances of the Universe, astronomical distance is proportional to time, allowing us to study the Universe as it was many billions of years ago. This means studying GRBs gives us fresh insights into the early Universe, including the dramatic births and deaths of early massive stars, and the formation of some of the first black holes.

"It's just as well that black holes are involved in so many cataclysmic events, as they act as cosmic laboratories"

It's just as well that black holes are involved in so many of these cataclysmic events, as they act as cosmic laboratories. Black holes are so dense, their gravity so strong, that physics as we know it begins to break down inside them – they represent the very limits of our knowledge. Studying them takes us one step further to understanding fundamental physics on the largest and smallest scales, testing what we

ILLUSTRATION: MARK GARLICK/SCIENCE PHOTO LIBRARY/ALAMY, DRONANDY/ISTOCK/GETTY IMAGES, CERN, NASA'S GODDARD SPACE FLIGHT CENTER/SCOTT NOBLE/SIMULATION DATA: D'ASCOLI ET AL. 2018

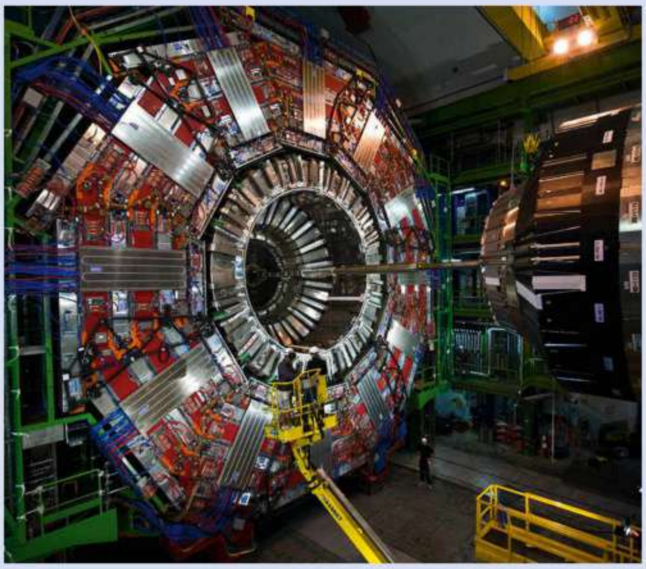
The Biggest Bang – this time on Earth

Particle accelerators allow us to replicate the greatest cataclysm of them all

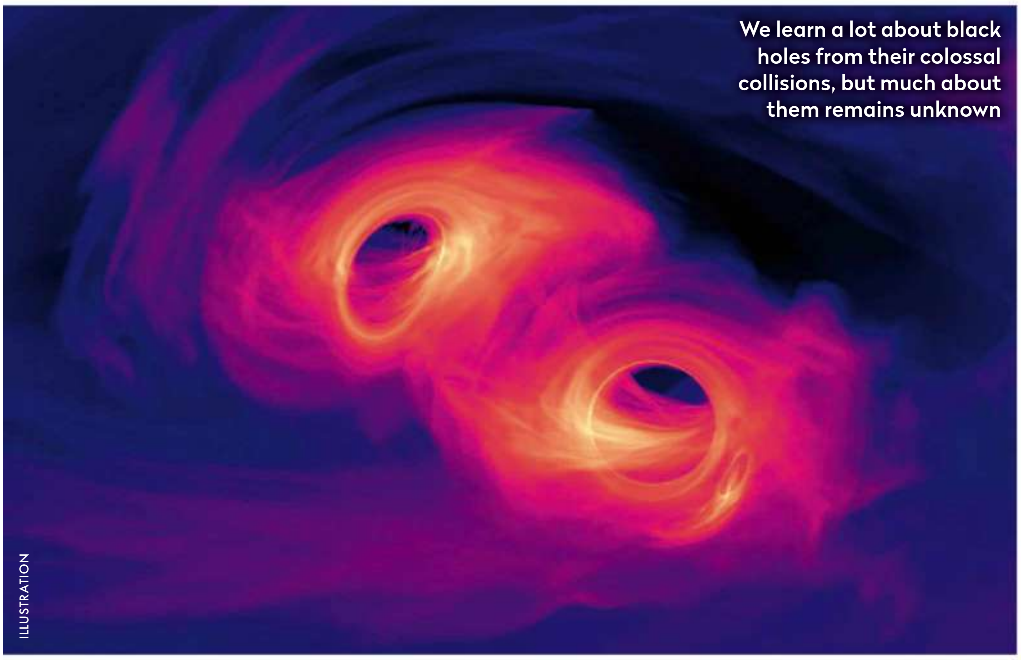
In most cases, astronomers are only able to watch their subjects from afar, learning from what they can see in the night sky. That's not so with high-energy events, thanks to particle accelerators, like the Large Hadron Collider at CERN.

Particle accelerators can recreate the conditions that existed just after the Big Bang, albeit on a much smaller scale, to reveal how things worked in the initial moments of the Universe – from the Big Bang itself to the formation of the first atoms. They can also create miniature supernovae, replicating the moments after core collapse and mimicking the reactions taking place. They can study neutrinos – ubiquitous, almost massless 'ghost' particles, generated at the core of a supernova. All this opens the door to new ways of testing our best fundamental theories of physics, such as the mysterious nature of dark matter (see page 35).

The drive to understand how the cosmos came to be, and how it is evolving, is fundamental for humankind. Now, astronomical observations of the biggest objects and events are being combined with experiments here on the ground to study the smallest particles, giving us an ever-clearer picture of our cataclysmic Universe.



▲ **All of the science, none of the explosions: the Large Hadron Collider mimics cosmic conditions at the birth of the Universe**



We learn a lot about black holes from their colossal collisions, but much about them remains unknown

know about both the general theory of relativity and quantum physics.

The challenge is that black holes themselves emit no light of any kind – we can only detect them indirectly by observing their effect on surrounding objects. But one of the best opportunities to study them occurs when two collide and merge. This truly cataclysmic event produces gravitational waves – ripples in space-time that race out across space, compressing and stretching anything they encounter. These gravitational waves can tell us about the black holes' size, how far away they were and how fast they were travelling when they collided. Combining these measurements with more traditional electromagnetic observations – a technique known as multi-messenger science – tells us even more.

Supernovae and the mergers of dense and compact objects like black holes and neutron stars are some of the most extreme phenomena in the Universe today. These dramatic and destructive events unfolding across the Universe on a colossal scale have much to tell us. We will continue to learn as increasingly sophisticated observatories advance our ability to detect electromagnetic radiation and gravitational waves, and to study the cataclysmic 'big bangs' that release them.

Caroline Harper is the head of space science at the UK Space Agency and the author of *Unseen Universe*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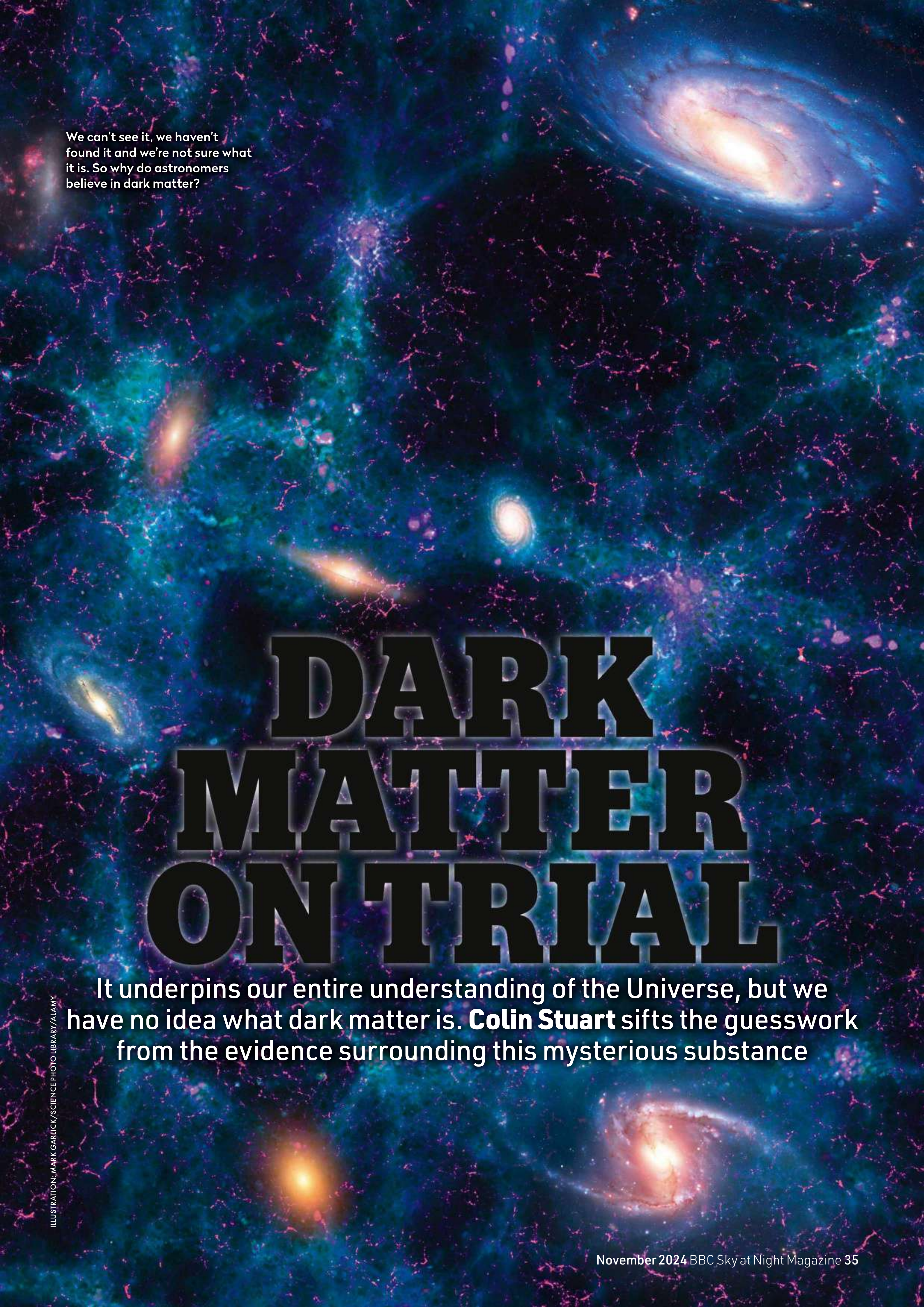

We can't see it, we haven't found it and we're not sure what it is. So why do astronomers believe in dark matter?

DARK MATTER ON TRIAL

It underpins our entire understanding of the Universe, but we have no idea what dark matter is. **Colin Stuart** sifts the guesswork from the evidence surrounding this mysterious substance

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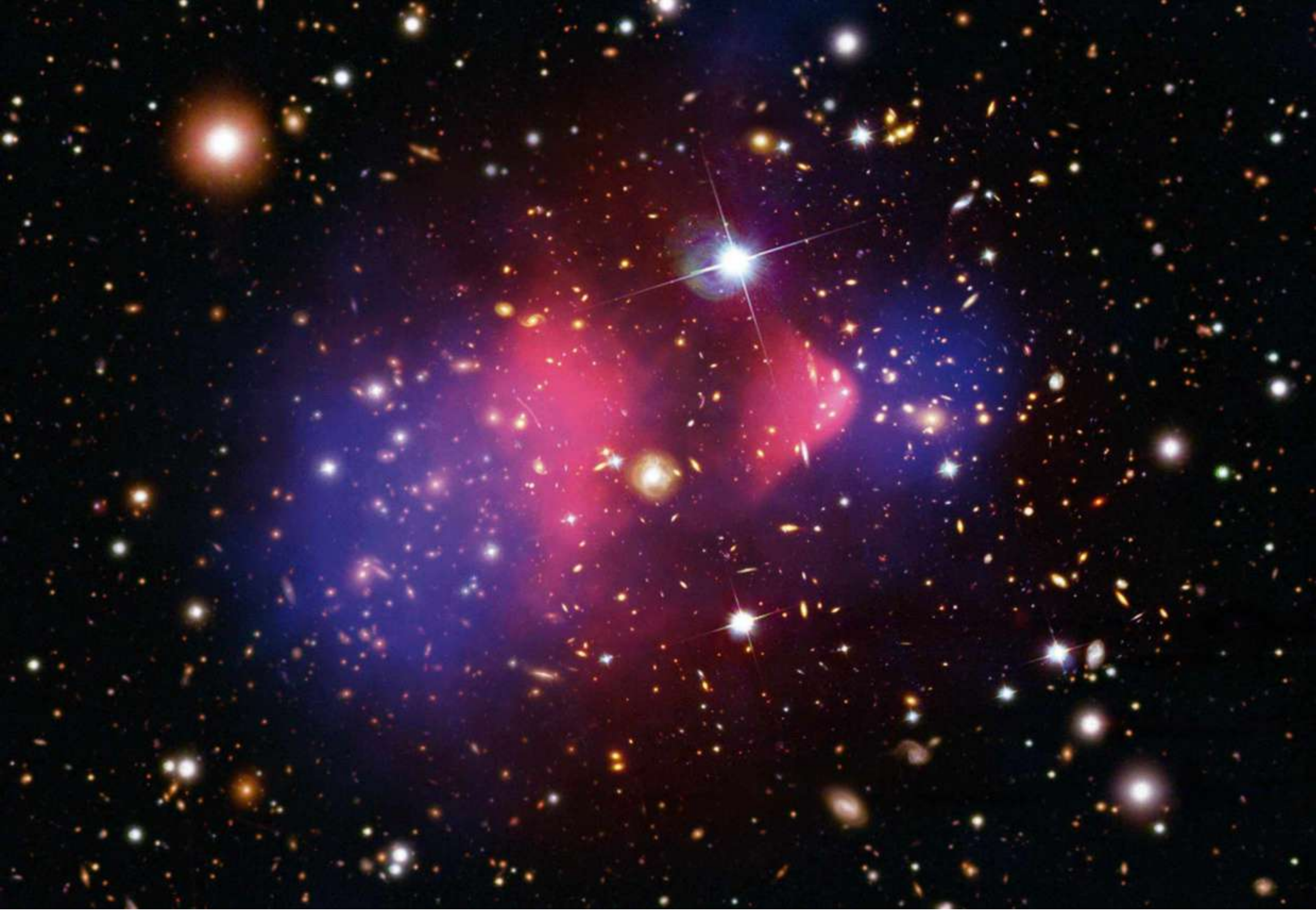

▲ **The Bullet Cluster, with blue showing where astronomers have identified the most mass. Nearly all of the matter in the cluster is invisible dark matter**

What is the Universe made of? It's a seemingly simple question, but one that turns out to have a rather more complicated answer.

When pressed, many of us would likely respond with galaxies, stars, or perhaps planets. Yet all the beautiful objects we see in photographs from our best telescopes appear to hide a deeper reality. The stuff that makes up stars and planets, even you and me, may be only a tiny minority of what's really out there. Astronomers have found signs of a celestial spectre, pulling the strings and invisibly shaping the cosmos – dark matter. Though it now forms the fundamental basis of our understanding of how the Universe works, astronomers aren't actually sure what dark matter is. So why do they have such trust in a substance they cannot find?

"The first evidence for dark matter appeared way back in the 1930s," says Justin Read, a dark matter expert at the University of Surrey. It was galaxies that provided some of the earliest clues.

At first, astronomers expected galaxies to behave just like bigger versions of the Solar System. As you move out from the Sun, the speed of the planets drops off as the Sun's gravitational pull wanes. The innermost planet, Mercury, moves at 47km (29 miles) per second and takes just 88 days to complete one orbit. Meanwhile, the furthest planet, Neptune, moves at 5.4km (3.4 miles) per second and takes nearly 165 years to go around.

But galaxies do not behave in the same way. Stars near their edges are rotating at similar speeds to those much closer to the centre. These outer stars are moving so fast that they should be able to escape from the galaxy and fly off on their own. Except they don't. So astronomers suspect there is some hidden gravitational glue that binds galaxies together and helps keep hold of these fast-moving stars. It's this astronomical adhesive that's known as dark matter.

Rethinking gravity

The majority of astronomers suspect that dark matter is a physical substance, one that outnumbers ordinary matter by about 5:1. Most often it's considered a type of particle, one that doesn't interact with light and so we can't see it. Instead, we can only sense it by the gravitational influence it exerts on its surroundings, including its ability to help galaxies keep hold of fast-moving stars.

However, there is another school of thought that says that dark matter is a mirage, a misunderstanding of the rules of gravity. This theory goes by the name of Modified Newtonian Dynamics (MOND). At its heart, MOND argues that gravity works differently on the small scale of a Solar System compared with the much bigger scale of a galaxy. Specifically, it suggests that the strength of gravity doesn't drop off as quickly in galaxies as it does in planetary systems. That would make the gravity on the edge of galaxies stronger than we've been accounting for, which is why the fast-moving stars there don't go rogue and escape into intergalactic space.

Not everyone is convinced, however. "[MOND] is all but dead in my view," says Read. "We have evidence

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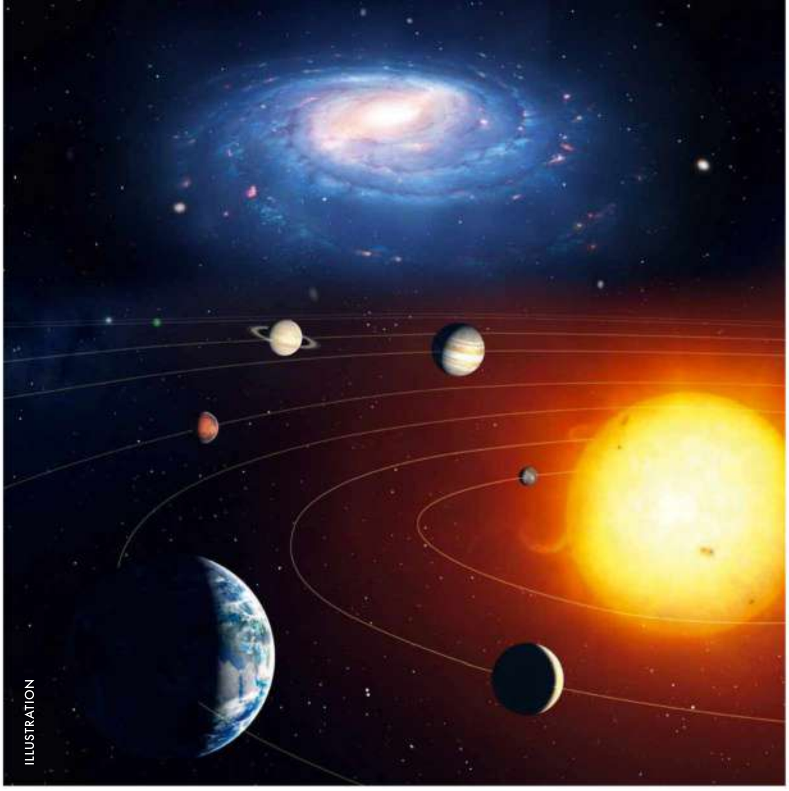


◀ **Unlike in planetary systems, outer objects in galaxies move fast. MOND theory says an unknown form of gravity is what stops them spinning off into space**

that dark matter can be physically moved around."

Read points to the Bullet Cluster as a particularly important piece of evidence. This structure was formed when two separate groups of galaxies collided. The merger heated up the galaxies' gas, producing copious amounts of X-rays. However, when astronomers mapped the Bullet Cluster's mass, they found that most of it is separated from the hot gas (see Mapping the invisible Universe, below). During the collision, the gases of both galaxies interacted with each other, and the ensuing friction slowed all the gas down. The dark matter, however, did not. "It passed through itself like a ghost," Read says. This led to a clear separation between ordinary matter and its shadowy counterpart.

Unfindable particles

MOND isn't the only alternative astronomers have looked into. As well as dark matter, astronomers also suspect another mysterious quantity, dark energy, is causing the expansion of the Universe to accelerate. Could they be the same thing?

One idea was that both effects were caused by a 'dark fluid' made of particles with negative mass. It had the added benefit of being able to explain the formation of galaxies and the large-scale structure of the Universe. However, the theory was discarded once astronomers realised that galaxies would be the wrong shape and would have to be moving at close to light speed. ▶

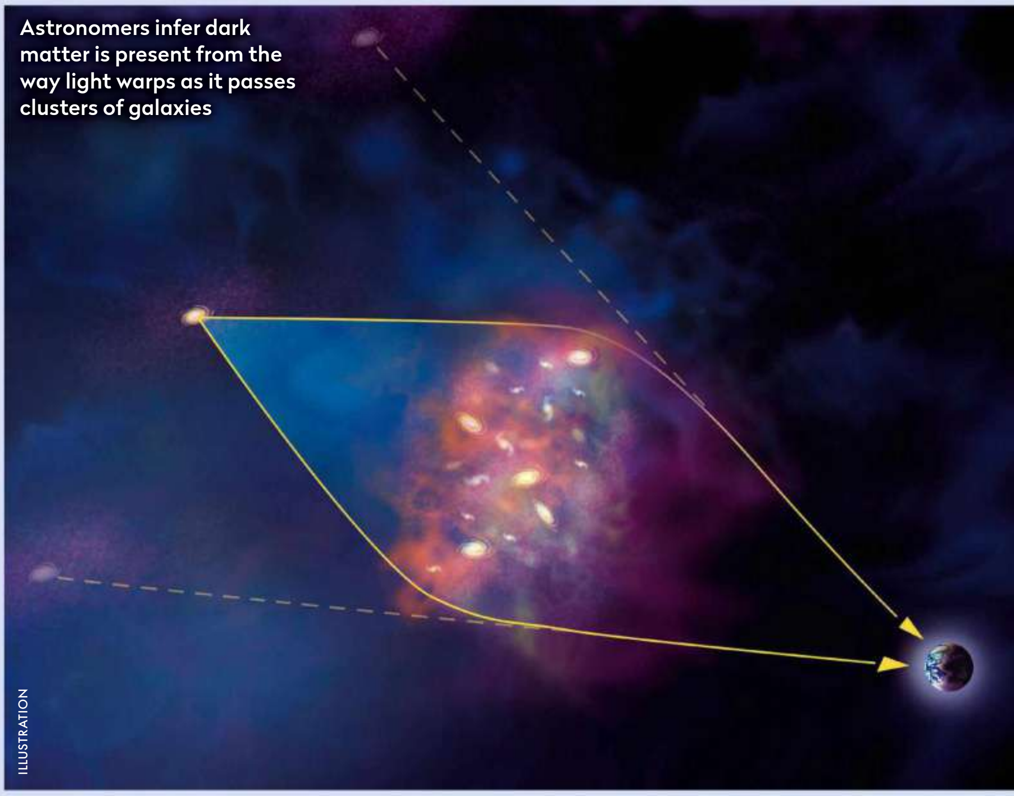
Mapping the invisible Universe

How can we pin down where dark matter is when we can't even see it?

As its name suggests, dark matter doesn't seem to absorb or emit light, so it cannot be seen directly. However, it does exert a gravitational pull. After all, that's why we needed it in the first place – to provide the gravitational glue that keeps galaxies and clusters of galaxies stuck together. So dark matter can be mapped using its gravitational influence instead.

This is usually achieved using a technique called gravitational lensing. Imagine that there's a cluster of galaxies that we want to put on the celestial scales (such as the well-studied cluster collision called the Bullet Cluster). As light from a more distant object approaches the cluster, it is bent around the cluster by its gravity, just as a lens bends light in a pair of glasses or a telescope.

The higher the mass of the cluster, the more bending we see. Wherever astronomers look in the Universe, galaxies and galaxy clusters appear roughly five times more massive than can be accounted for by adding up all the visible material. So that visible material must be merely a light dusting of ordinary matter on a much more significant scaffold of invisible dark matter. Without it, there would be no structure to the Universe.



Astronomers infer dark matter is present from the way light warps as it passes clusters of galaxies

Tracking down dark matter

Hidden deep underground, experiments are scouring the cosmos for the missing matter

IceCube hunts neutrinos – potential dark matter particles – deep in the South Pole ice

Most of the experiments that have tried to find dark matter assume it's made of some kind of as-yet-undiscovered particle. For decades, the leading contender was so-called Weakly Interacting Massive Particles (or WIMPs). One of the biggest WIMP searches took place at the Large Underground Xenon (LUX) experiment, a tank of liquid xenon buried deep underground in an abandoned gold mine, where it would be hidden from background noise. If WIMPs are passing through Earth, they should whack into one of the xenon atoms every now and then, causing it to recoil. LUX ran for three years without picking up a single WIMP.

The IceCube detector in Antarctica takes a slightly different approach. As the Sun orbits around the Galaxy, it should pass through and absorb dark matter. Dark matter particles could interact with one another inside the Sun and produce particles called neutrinos. IceCube has been looking for solar neutrinos with the right energy, but it too has come up empty.

Dark matter collisions should be even more frequent in the heart of our Milky Way galaxy. The Alpha Magnetic Spectrometer (AMS-02) experiment was attached to the International Space Station to look for the by-products of such events, but again has found nothing conclusive.

▶ Even the idea of dark matter particles with ordinary mass has been beset with problems. For one, we haven't been able to detect any. It's not like we haven't tried. Physicists have built underground detectors in abandoned mines and beneath the Antarctic ice. They've even strapped an experiment to the International Space Station to look for signs of dark matter interactions deep in the heart of our Milky Way Galaxy (see Tracking down dark matter, above). Yet so far, nothing.

Computer simulations of how galaxies form throw up more problems. Dark matter is supposed to be the scaffold upon which galaxies are constructed, creating a clump – or halo – that draws ordinary matter in, then collapses to form stars. Our working model of the Universe and its evolution assumes that dark matter is 'cold'. This means the particles of dark matter are heavy and slow. Yet when astronomers simulate the formation of galaxies with cold dark matter, the simulations predict significantly more smaller galaxies than we see in the real Universe. This has become known as the 'dwarf galaxy problem'.

Hot- or cold-running matter

One possible solution is that dark matter is warm, not cold – its particles are light and fast, making them harder to slow down to form galaxies. "The warmer we make dark matter, the later galaxies will form and the fewer small ones there'll be," Read says.

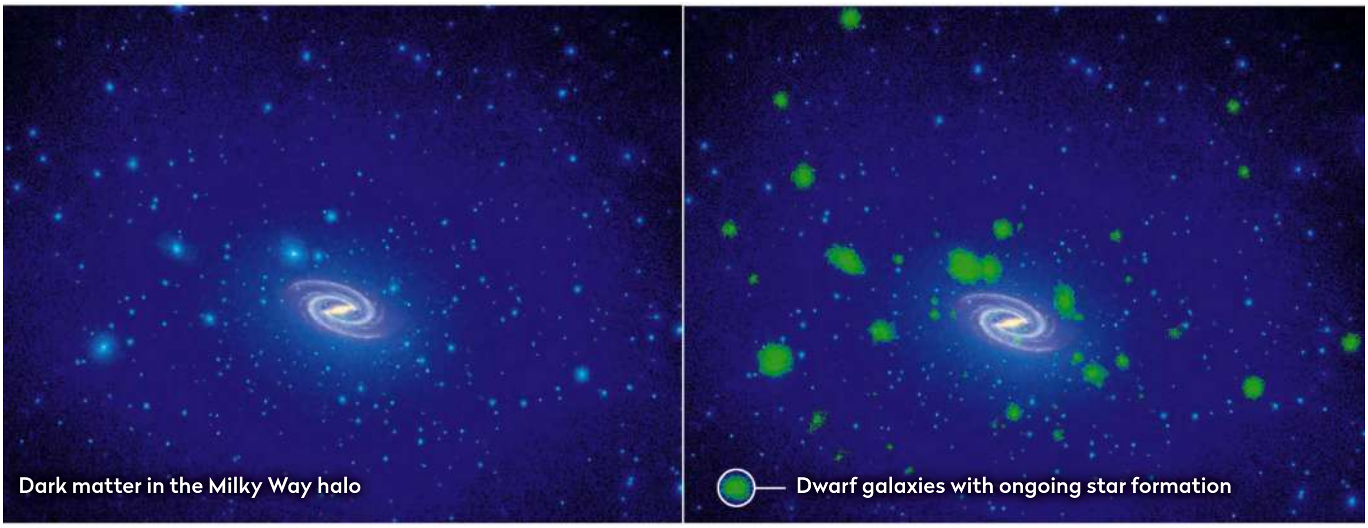
But there is another option. In the original simulations, every dark matter halo went on to form a visible galaxy. Yet the more we learn about galaxy formation, the more this looks like an unrealistic assumption. "As the mass of the dark matter halo goes down, it gets increasingly difficult to form galaxies," Read says.

That could solve the dwarf galaxy problem, but it does lead to an unavoidable consequence: there should be empty dark matter haloes out there that didn't form galaxies. If these empty haloes don't exist, then dark matter cannot be cold. Thankfully, astronomers have found such empty haloes. "All the evidence so far points towards dark matter being cold," Read says.

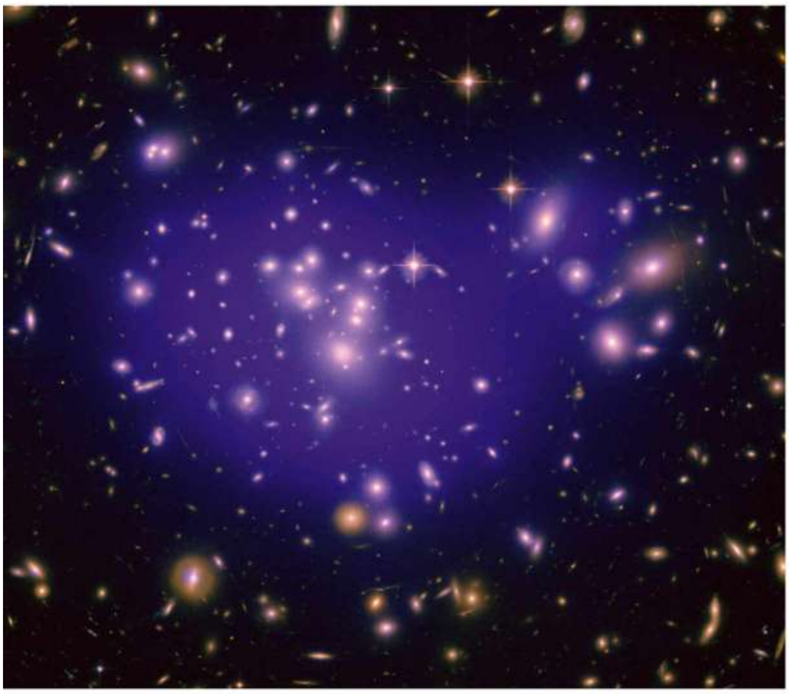
So why haven't we been able to detect any cold dark matter particles so far? "We've only looked for

▲ The AMS-02 Alpha Magnetic Spectrometer attached to the ISS hunts for signs of dark matter collisions – so far in vain

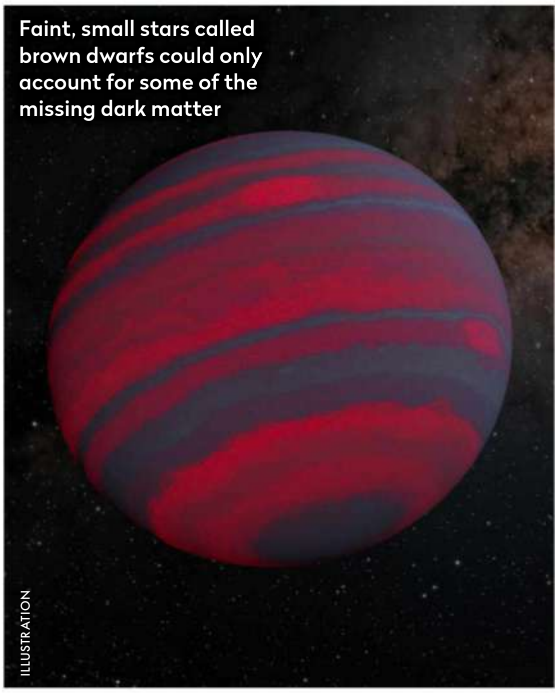
ERIK BEISER/ICECUBE/NSF, NASA, NASA/ESA AND T. BROWN AND J. TUMLINSON (STSCI), NASA/ESA/E. JULLO (JPL/LAM) P. NATARAJAN (YALE) AND J-P. KNEIB (LAM), NASA/JPL-CALTECH



▲ Computer simulations showing how dark may behave: (left) swarms of dark matter form in clumps around our Milky Way and (right) clumps that are massive enough to gather gas from the intergalactic medium trigger the formation of stars and eventually dwarf galaxies



▲ Distorted, arcing galaxies show the effect of dark matter (blue) in Abell 1689



Faint, small stars called brown dwarfs could only account for some of the missing dark matter

an incredibly small fraction of the possible particles," says Jocelyn Monroe, a dark matter researcher at the University of Oxford. "I think we have our work cut out for us."

That's if dark matter really is made of an as-yet-undiscovered particle. There are other options, which Monroe whimsically refers to as "dim stuff".

Dim mini black holes

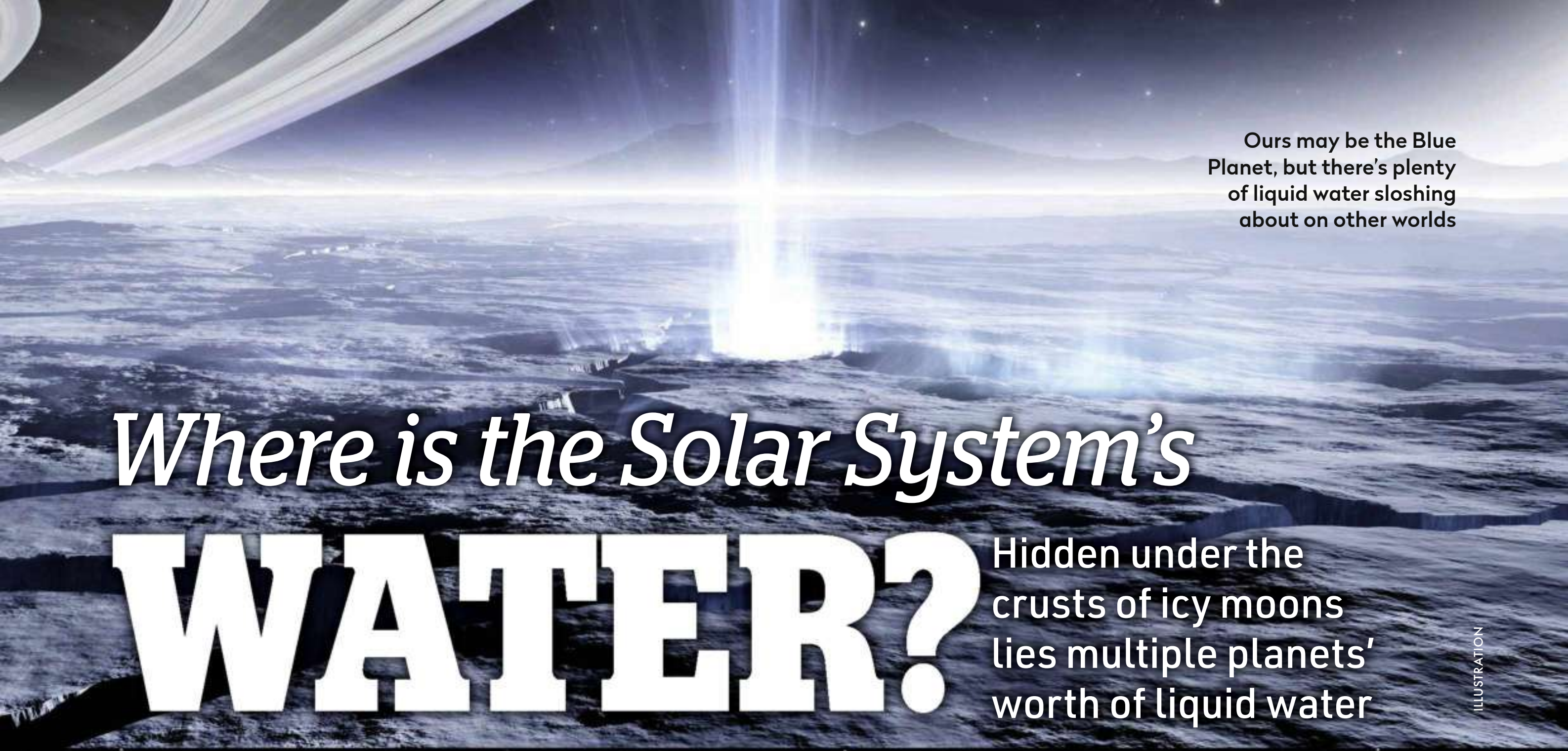
Originally, astronomers wondered whether small, dim objects such as failed stars called brown dwarfs could be the bulk of dark matter. Yet numerous studies have shown that there just aren't enough of them to provide the amount of missing gravity we need to hold the Universe together. "They make up less than 15 per cent of dark matter," Monroe says.

A slightly more exotic option is black holes, objects whose very name implies that they can't easily be seen. Usually, black holes form when the biggest stars die, but again there just aren't enough black holes of that size. "They make up less than one per cent of the dark matter," Monroe says.

While black holes with masses equal to stars have been ruled out, much smaller black holes still remain a possibility. Astronomers speculate that tiny black holes formed in the early Universe just after the Big Bang. They are known as primordial black holes and could each have the mass of an asteroid. As black holes are almost unimaginably dense, these primordial black holes would be tiny – smaller than an atom. According to Monroe, there aren't many direct observational constraints on how many of these miniscule black holes could exist. So at least in principle there could be enough to account for the majority of dark matter.

Indeed, dark matter could well turn out to be more than one thing. "I certainly think it's likely that dark matter is a mixture of particles and dim stuff," Monroe says. If so, then perhaps one of the greatest astronomical questions of our age has more than just one answer, even if we aren't any closer to finding them. One thing is clear though: dark matter still reigns as our current best explanation of what's holding the Universe together.

Colin Stuart (@skyponderer) is an astronomy author and speaker. Get a free e-book at colinstuart.net/ebook



ILLUSTRATION

Ours may be the Blue Planet, but there's plenty of liquid water sloshing about on other worlds

Where is the Solar System's WATER?

Hidden under the crusts of icy moons lies multiple planets' worth of liquid water

Our Solar System is filled with water. Most of it is solid ice, locked away in the frozen bodies of comets, planets, moons and asteroids. But there are several places you can find water in its liquid form. Most obviously, it covers the surface of our own Blue Planet, but it's estimated there is enough liquid water in the Solar System to fill Earth's oceans 25 to 50 times over. But these oceans lie beneath kilometres of ice on the frozen moons of the outer planets.

Liquid water is one of the most important factors in how worlds grow. It transports minerals and erodes rock formations, but perhaps its most important role is in allowing life to flourish. Could the liquid water oceans on other worlds provide havens where alien microbes have been able to evolve? We take a look at some of these worlds and the surprising volume of liquid water that lies beneath their surfaces.

At planetary scales, volume is measured in zettalitres. 1 ZL = 1,000 billion billion litres (694 billion billion US gallons)

Enceladus

Moon of Saturn

Water volume: 0.01 ZL • 20 per cent of moon's volume

Unlike most icy moons, Enceladus's water isn't completely locked away beneath its icy crust, as plumes of water have been spotted erupting from cracks near the moon's southern pole. The moon's surface is covered with the chemical ingredients of life and these fissures could allow them access to the ocean below.

Triton

Moon of Neptune

Water volume: 0.03 ZL • 0.3 per cent of moon's volume

Triton is one of the most active moons in the outer Solar System, but rather than spewing molten rock, it's cryolava that flows from the moon's volcanoes. This mixture of liquid water, ammonia and other hydrocarbons shapes the moon's surface much like hot lava does on terrestrial planets.

Dione

Moon of Saturn

Water volume: 0.14 ZL • 19 per cent of moon's volume

It was the Cassini orbiter that discovered several of Saturn's moons had subsurface oceans, including the fourth-largest, Dione. Cassini was able to map out Dione's gravitational profile, which suggests the moon has a 160km-deep (100-mile) layer of water around its rocky core.

Pluto

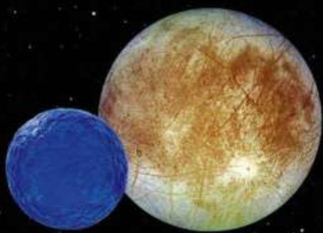
Dwarf planet

Water volume: 1.0 ZL • 15 per cent of dwarf planet's volume

When the New Horizons probe arrived at Pluto in 2015, astronomers were surprised to find the dwarf planet free of craters. This suggested there was an underground ocean – most likely kept warm by radioactive elements and ammonia acting like antifreeze – which occasionally floods the surface, smoothing out Pluto's rough features.

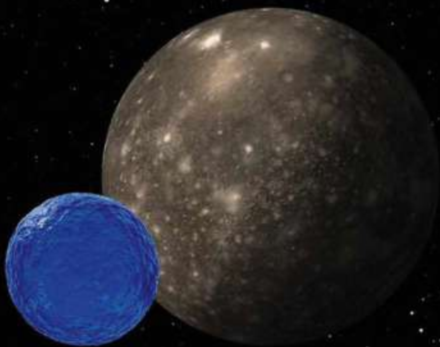
Earth

Home
Water volume: 1.3 ZL
0.12 per cent of planet's volume
Water covers 71 per cent of Earth's surface – the only world we know of where liquid water can pool above ground. Despite this, our planet's body is almost entirely rock, meaning water makes up only 1/1,000th of its volume. As such, several moons actually have more water on them than our Blue Planet.



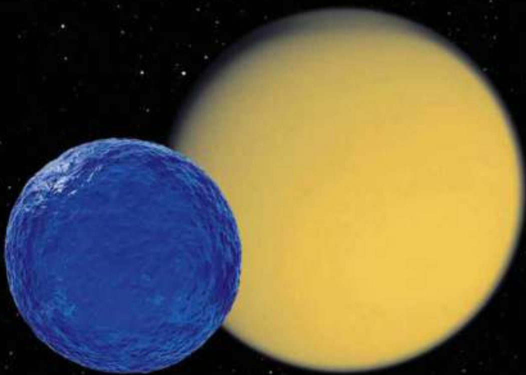
Europa

Moon of Jupiter
Water volume: 2.6 ZL • 16 per cent of moon's volume
Beneath its 25km-deep (15-mile) icy crust, Europa is thought to have a layer of liquid water around 100km (60 miles) deep. Like Jupiter's other icy moons, it's believed Europa's ocean is kept liquid via tidal heating, where Jupiter's huge gravitational pull flexes and pushes the moon's interior, causing it to heat up and stay molten.



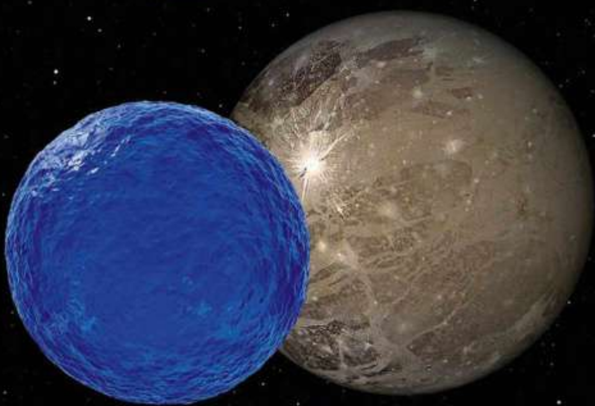
Callisto

Moon of Jupiter
Water volume: 5.3 ZL • 9 per cent of moon's volume
When the Galileo spacecraft passed Callisto in the 1990s, it measured small fluctuations in the moon's magnetic field as it circled Jupiter. These suggested Callisto had a conductive liquid layer – such as salt water – which was conducting electric currents and interfering with the magnetic field. Similar fluctuations were also found around Europa.



Titan

Moon of Saturn
Water volume: 18.6 ZL • 26 per cent of moon's volume
Titan is famously known for its surface lakes of liquid methane, but what's less well known is that it also has a salty ocean located around 50km (30 miles) below the surface. Given the rich abundance of hydrocarbons – the building blocks of life – on the surface, Titan is considered the best place to look for extraterrestrial life.



Ganymede

Moon of Jupiter
Water volume: 35.4 ZL • 46 per cent of moon's volume
Surface features, gravity and magnetic measurements all point towards Ganymede having a liquid water ocean, but what's not certain is what that ocean might look like. Rather than one huge body of water, it's possible the moon has multiple oceans layered one on top of the other, sandwiched between slabs of ice.

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BBC Sky at Night MAGAZINE

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16-PAGE CENTRE PULLOUT

BBC Sky at Night MAGAZINE

The Sky Guide

NOVEMBER 2024

TITAN SHADOW TRANSITS

As Saturn approaches a ring-plane crossing in March 2025, see Titan's shadow move across the planet's disc

PETE LAWRENCE

PLEIADES CHALLENGE

Can you observe the nebula hiding in the Seven Sisters?

BORDER PATROL

Hunt beautiful targets on the fringes of Lacerta

About the writers

Astronomy expert **Pete Lawrence** is a skilled astro imager and a presenter on *The Sky at Night* monthly on BBC Four

Steve Tonkin is a binocular observer. Find his tour of the best sights for both eyes on page 54

Also on view this month...

- ✦ Jovian moon events
- ✦ Mars near the Beehive Cluster
- ✦ The Eyes of Clavius
- ✦ Perigee full Moon near Uranus

Red light friendly

To preserve your night vision, this Sky Guide can be read using a red light under dark skies

Get the Sky Guide weekly

For weekly updates on what to look out for in the night sky and more, sign up to our newsletter at **www.skyatnightmagazine.com**

NOVEMBER HIGHLIGHTS

Your guide to the night sky this month

Friday 1

At 02:00 UT, Jupiter's outer Galilean moon Callisto sits 4 arcseconds south of the planet's southern limb.

Sunday 3

There's an excellent opportunity to observe a Ganymede shadow transit between 02:30 and 04:50 UT this morning. Ganymede transits from 06:05 UT (deep twilight) until 08:05 UT (daylight).

Monday 4 ▶

Just after sunset, look out for a tricky 9%-lit waxing crescent Moon separated from brilliant Venus by 5.2°, both very low above the southwest horizon.

A rare Titan shadow transit on Saturn can be seen at 21:08–22:51 UT.

◀ Saturday 9

The Eyes of Clavius lunar clair-obscur effect can be seen at 19:10 UT.

Jupiter's southern limb scrapes in front of a background mag. +11.0 star between 19:50 and 21:30 UT.

Tuesday 12

Look for Neptune 1.2° east-northeast of the 79%-lit Moon just before moonset. Sitting 7 arcminutes south of the planet is a similar-magnitude star (HIP 117614); the pair appear like an easy double through binoculars.

Friday 15

This evening's full Moon (full at 21:29 UT) occurs a day and a half after lunar perigee (11:18 UT on 14 November), making it a perigee full Moon, or supermoon. Near midnight on 15 November, the Moon sits 3.7° north of Uranus.

Saturday 16

As dawn breaks, the full Moon sits 2.2° southwest of the Pleiades open cluster.

Mercury reaches greatest eastern elongation, separated from the Sun by 22.5° in the evening sky.

Sunday 17 ▶

Distant Uranus reaches opposition. Shining at mag. +5.6, Uranus is currently 6.7° southwest of the Pleiades.

The 97%-lit waning Moon and Jupiter are 7.5° apart this morning.

Family stargazing

The Andromeda Galaxy, M31, is the furthest object visible to the naked eye from your back garden. This assumes okay skies, although it does withstand a bit of light pollution. If your skies aren't great, try with binoculars. One simple way to locate it is to first identify the 'W' of Cassiopeia. Imagine the right-half of the 'W' as an arrow and follow where it points for a fraction over the width of the 'W'. M31 sits slightly right of this position. If you spot it, don't forget to mention that the light your eyes are now seeing left M31 2.5 million years ago!
www.bbc.co.uk/cbeebies/shows/stargazing

◀ Tuesday 26

This evening, moon Io and its shadow are quite close together as they both transit Jupiter. Both are in the middle of the planet's disc at 19:50 UT.

PETE LAWRENCE X 8

Tuesday

5 Rhea's shadow can be seen transiting Saturn's disc from 23:30 UT up until Saturn sets.

Thursday

7 Dione's shadow can be seen transiting Saturn's disc from 18:54 until 22:05 UT.

Friday

8 The lunar clair-obscur effect known as the Face in Albategnius reaches its peak at 21:25 UT, when the profile of a face is formed by the shadow cast by crater Albategnius's rim on its floor.

Sunday

10 The 68%-lit waxing Moon sits 2.7° southwest of Saturn at 22:30 UT, gradually approaching the planet as they both move towards setting. At 00:40 UT on 11 November, the separation reduces to 1.5°.

Monday ▶

11 The Northern Taurid meteor shower is expected to peak this evening and into tomorrow morning. The shower has a broad peak with a low ZHR of just five meteors per hour.

◀ Wednesday

13 In the early hours, around 01:40 UT, look for Mons Herodotus near the lunar crater Aristarchus. Shining brightly, the mountain's peak creates the clair-obscur effect known as the Star-Tip Mountain.

Wednesday ▶

20 Another Titan shadow transit at 19:44–22:54 UT today; this one is very well-placed for UK viewing.

Around 21:00 UT, the 70%-lit Moon sits 1.7° north of Mars as they rise.

Thursday

21 The 68%-lit waning gibbous Moon sits 2.4° north of M44 and 3.1° from Mars this morning.

Saturday ▶

30 Mars sits 2° from the centre of the Beehive Cluster, M44, today.

NEED TO KNOW

The terms and symbols used in The Sky Guide

Universal Time (UT) and British Summer Time (BST)
Universal Time (UT) is the standard time used by astronomers around the world. British Summer Time (BST) is one hour ahead of UT

RA (Right ascension) and dec. (declination)
These coordinates are the night sky's equivalent of longitude and latitude, describing where an object is on the celestial 'globe'

Family friendly
Objects marked with this icon are perfect for showing to children

Naked eye
Allow 20 minutes for your eyes to become dark-adapted

Photo opp
Use a CCD, planetary camera or standard DSLR

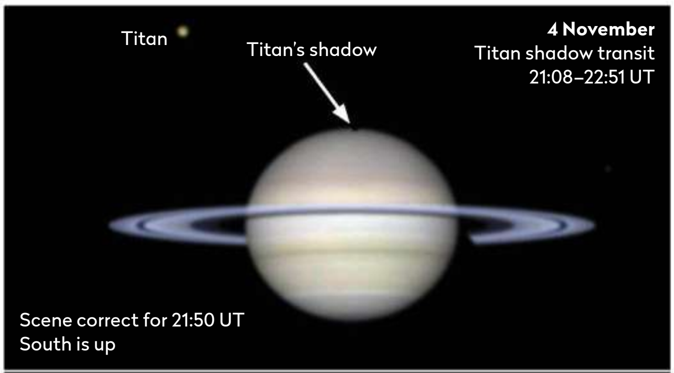
Binoculars
10x50 recommended

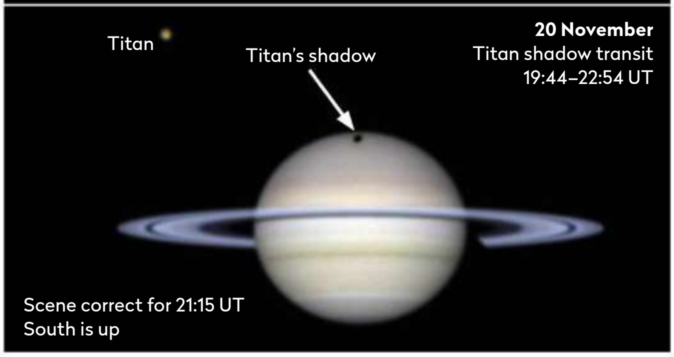
Small/ medium scope
Reflector/SCT under 6 inches, refractor under 4 inches

Large scope
Reflector/SCT over 6 inches, refractor over 4 inches

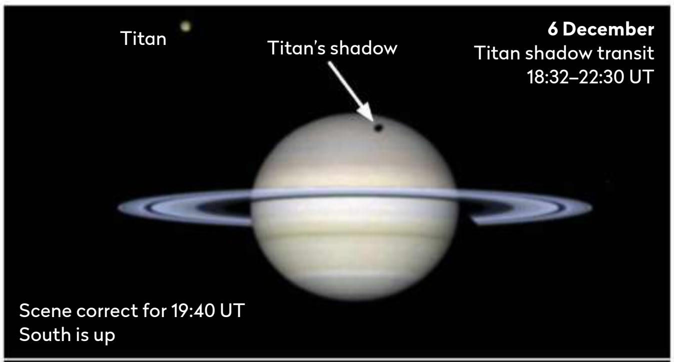
GETTING STARTED IN ASTRONOMY

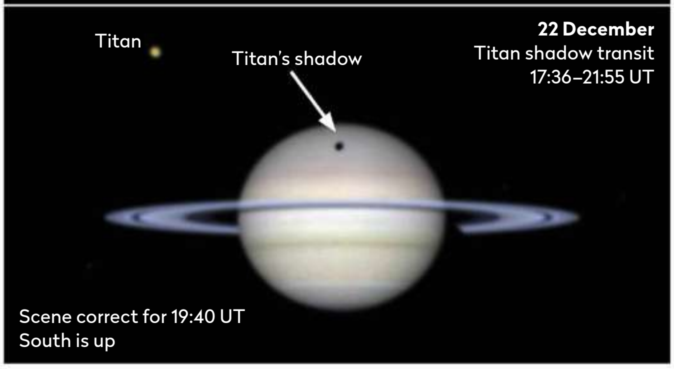
If you're new to astronomy, you'll find two essential reads on our website. Visit **bit.ly/stargazing-top-tips** to learn how to stargaze in 12 easy steps and **bit.ly/choose-first-telescope** for advice on choosing your first scope





▲ **There are two rare opportunities to see the shadow of Saturn's moon Titan cross the planet this month, on 4 and 20 November**





▲ **If skies aren't clear for November's transits, you'll get two further chances next month, on 6 and 22 December**

DON'T MISS

Titan shadow transits begin

BEST TIME TO SEE: 4 and 20 November, 6 and 22 December at the times stated

After spending several years very low in the UK's sky, Saturn is now gaining altitude and becoming a more viable target. Always a favourite to observe through a telescope because of its beautiful ring system, Saturn currently has other attractions in store. The planet has an axial tilt of 26.7° and takes 29.4 years to orbit the Sun. Twice during this orbit, at roughly 13- to 15-year intervals, Saturn experiences an equinox and presents itself sideways-on to Earth.

As this happens, the rings appear edge-on to us and effectively disappear from view. Actually, this doesn't only occur just once – the relative positions of Saturn and Earth make it look as if Saturn undergoes either a single or a triple ring plane crossing. Single crossing events occur with Saturn positioned near to the Sun as seen from Earth, triples are more favourably placed. The next ring plane crossing occurs on 23 March 2025 and is unfortunately a single event not well placed for viewing.

However, as the ring plane crossing approaches, the almost equatorially aligned orbits of the majority of the major moons of Saturn also appear sideways-on to us. This means that these moons and their shadows will eventually appear to transit across Saturn's disc.

The most impressive of Saturn's moons is Titan and this month its shadow starts to clip the planet. The first Titan shadow transit occurs on 4 November, when just a small part of the shadow appears to scrape across the southern polar region of Saturn's globe. The next occurs 16 days later on 20 November, a more tangible event, with the moon's shadow fully visible on Saturn.

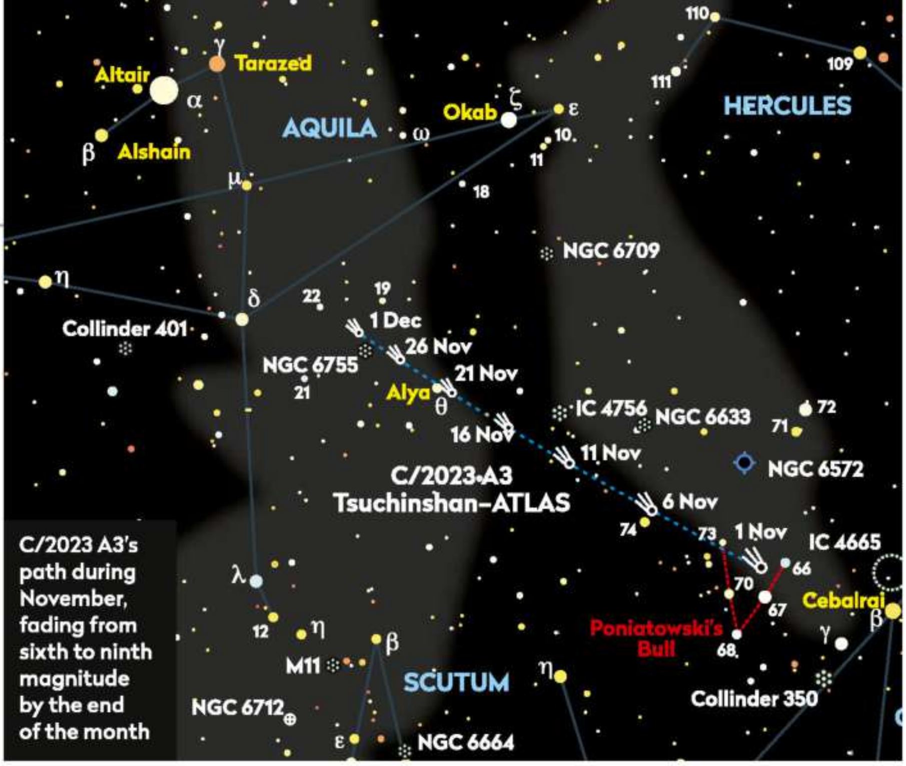
These events can be seen through a small telescope, the 20 November one being a better option for such instruments. We'd recommend at least 100mm of aperture and, of course, the larger the scope, the better the view. Seeing will make a difference here too, and despite Saturn being able to achieve a peak altitude of 30° from the UK when it's due south, the timing of the Titan shadow transits may not sync with this optimal altitude, leading to a lower-altitude, more unsteady view. Imaging setups using high-frame-rate cameras and an atmospheric dispersion corrector (ADC) should work well for this. An ADC is highly recommended for colour camera imaging, but can also provide benefits for mono cameras using imaging filters.

Fingers will be well and truly crossed for clear skies as these rare transits take place, but if the weather doesn't cooperate, two more transits occur next month, on 6 and 22 December.

ALL PICTURES: PETE LAWRENCE

Comet C/2023 A3 Tsuchinshan–ATLAS

BEST TIME TO SEE: All month, but the Moon interferes 7–19 November



C/2023 A3's path during November, fading from sixth to ninth magnitude by the end of the month

Last month was the big one for C/2023 A3 Tsuchinshan–ATLAS, with the comet appearing in the post-sunset sky after its closest encounter with the Sun. If everything went to plan, it should have been a naked-eye object from mid-October, but at the time of writing, we don't know how this panned out. Assuming it didn't evaporate into a cloud of dust, as was the case for the much-hyped C/2012 S1 ISON back in 2013, comet C/2023 A3 should now be in a really good position for regular observing as it appears to track eastwards above the west-southwest horizon.

During November, the comet moves from a location off the eastern shoulder of Ophiuchus, beginning near the V-shaped asterism known as Poniatowski's Bull and heading towards Aquila the Eagle. It ends the month tucked under the eagle's western wing. You might associate Aquila more with summer and you'd be right, but the increased length of darkness at this time of year keeps the constellation conveniently visible throughout the whole of November. The comet will be fading throughout November and is expected to appear with an integrated magnitude of +6.0 on 1 November, fading to a predicted magnitude of +9.3 by the month's end.

At this level of brightness, it remains viable for binoculars until mid-month; small telescopes will keep it in view all month long. As it heads east during November, the comet passes into the band of the Milky Way, being near to open clusters IC 4665 in late October and IC 4756, together with NGC 6633, in the first half of November. At the end of the month, it's near cluster NGC 6755.

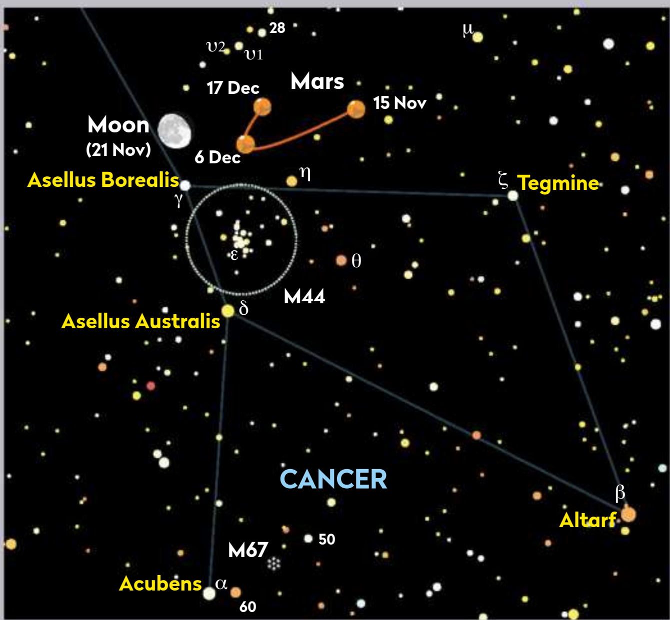
Mars hits reverse near the Beehive

BEST TIME TO SEE: Early hours, mid-November through to mid-December

The planet Mars is no stranger to buzzing the Beehive Cluster, M44, but the visits are infrequent enough to make them special to look out for. For the next visit, Mars approaches the Beehive Cluster in early December, with a minimum separation of 2° on 6 December. On this date, the planet appears to change direction from moving east to moving west. The reversing direction occurs at what's known as a stationary point, the apparent movement changing from prograde (eastward) to retrograde (westward).

This encounter doesn't see Mars cross the face of the Beehive, but make its closest approach northwest of the cluster's centre. The start of Mars's retrograde motion is the first bend in what's known as a retrograde loop. The second bend occurs in Gemini on 24 February 2025, when the planet reverses direction and heads east again. This brings it on an apparent collision course with the Beehive, passing across the cluster in early May 2025.

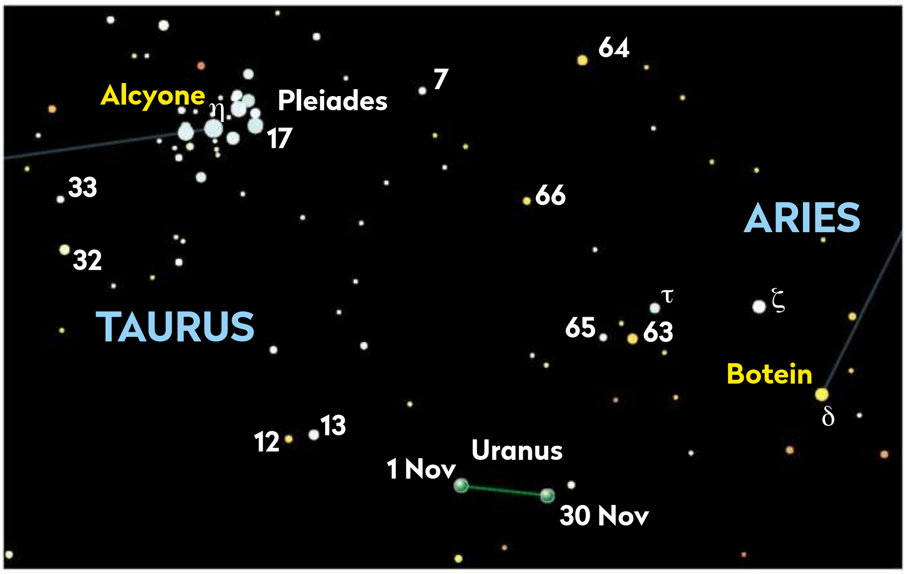
Although there's no real scientific significance to the encounter, it's an interesting visual target which is also relatively easy to photograph. A good clear run at the end of November into early December will allow images taken on sequential nights to be combined to show Mars passing its stationary point near this iconic cluster.



▲ See Mars loop in towards the Beehive Cluster, M44, this month before appearing to stop and reverse direction on 6 December

PICK OF THE MONTH

Uranus



▲ Currently at its brightest and reaching 56° altitude, now's the time to view and image Uranus

Best time to see: 17 November, 00:00 UT
Altitude: 56°
Location: Taurus
Direction: South
Features: Colour, subtle banding through larger instruments, main moons
Recommended equipment: 150mm scope or larger

The planet Uranus reaches opposition on 17 November, when it appears to shine at mag. +5.6 among the stars of Taurus. At present, the planet is extremely well placed from the UK. Listed as being theoretically visible to the naked eye, now – while it's at its opposition brightness – is the time to put that theory to the test, if you have access to a dark-sky location. In practice, although it can be seen unaided, any stars of a similar brightness nearby tend to confuse the sighting.

Approaching midnight on 15 November, the full Moon (the Moon also being at opposition) appears to sit 3.7° to the north of the planet. This is a sighting best suited to binocular or small telescope viewing.

Uranus is able to reach its highest position in the sky, 56° up when due south, all month long under truly dark skies.

Although some of the major planets can be seen under lighter twilight skies, true darkness delivers the best contrast and makes seeing Uranus's green hue a more dramatic experience. At least a small scope is required to achieve this.

Larger instruments, especially ones equipped for lucky imaging with high-frame-rate cameras, may reveal detail on the planet, typically in the form of subtle banding. Good seeing and well-collimated optics are required for this. A dark red filter also helps.

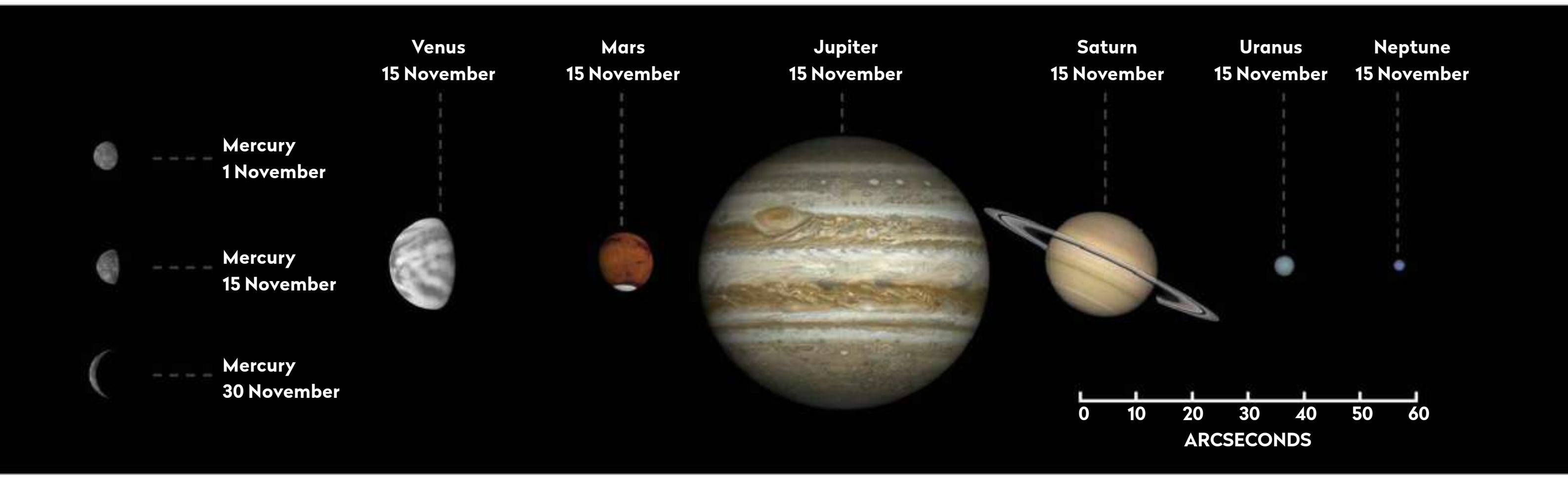

▲ Uranus's major moons close to the planet (SeeStar S50 smart scope)

Another popular Uranian imaging challenge is to try to grab a shot of the planet's major moons. For this you'll definitely need to be able to show the planet as a disc and to use an exposure that over-exposes the planet to reveal the moons as tiny star-like points. If you own a smart telescope, give it a try as many can show the moons, albeit at a small scale.

PETE LAWRENCE X 2

The planets in November

The phase and relative sizes of the planets this month. Each planet is shown with south at the top, to show its orientation through a telescope



Mercury

Best time to see: 15 November, 25 minutes after sunset
Altitude: 1° (extremely low)
Location: Ophiuchus
Direction: Southwest

Mercury is an evening object poorly positioned for the first half of November and not visible from the UK. Greatest eastern elongation occurs on the 15th, when mag. –0.2 Mercury sets just 40 minutes after the Sun. By the 30th, having dimmed to mag. +1.9, it sets 35 minutes after sunset.

Venus

Best time to see: 30 November, 50 minutes after sunset
Altitude: 10°
Location: Sagittarius
Direction: South-southwest

Evening planet Venus shines at mag. –3.9 on 1 November, setting 90 minutes after the Sun. By the end of the month, mag. –4.0 Venus sets nearly 3 hours after sunset and is better presented. A very low-altitude waxing crescent Moon passes south of Venus on the evenings of 4 and 5 November.

Mars

Best time to see: 30 November, 04:10 UT
Altitude: 58°
Location: Cancer
Direction: South

Mars reaches its highest position 60° above the southern horizon under true darkness. Telescopically, mag. +0.1 Mars appears 9 arcseconds across on 1 November, brightening to mag. –0.5 and appearing 11 arcseconds across by the 30th. Rising early evening, on the 20th, Mars is located 1.7° below the centre of the 70%-lit waning gibbous Moon, both objects rising around 21:00 UT. On the 30th, Mars sits 2° from the centre of the Beehive Cluster, M44.

Jupiter

Best time to see: 30 November, 00:40 UT
Altitude: 59°
Location: Taurus
Direction: South

Jupiter reaches opposition next month. At the start of November, after rising around 18:30 UT, it climbs to a peak of 60° at 02:43 UT, appearing as a mag. –2.5 object among the stars of Taurus. Catch it rising with the 94%-lit waning Moon early evening on the 17th. On the 30th, just a week before opposition, it appears very bright at mag. –2.7, reaching peak altitude around 00:30 UT.

Saturn

Best time to see: 1 November, 20:20 UT
Altitude: 28°
Location: Aquarius
Direction: South

Mag. +0.5 Saturn is visible as soon as darkness falls, reaching a peak of 30° on 1 November around 20:30 UT. A 68%-lit waxing gibbous Moon sits 2.7° southwest at 22:30 UT on the 10th, slowly approaching the planet as setting approaches in the early hours of 11 November.

Neptune

Best time to see: 1 November, 21:15 UT
Altitude: 35°
Location: Pisces
Direction: South

Neptune reaches its peak altitude of 35° under dark-sky conditions all month. At mag. +7.8, a small scope shows its tiny disc and blue hue. On 12 November, it sits 1.2° east-northeast of a 79%-lit Moon just before moonset.

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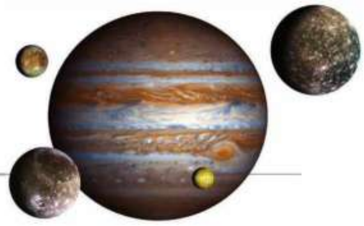
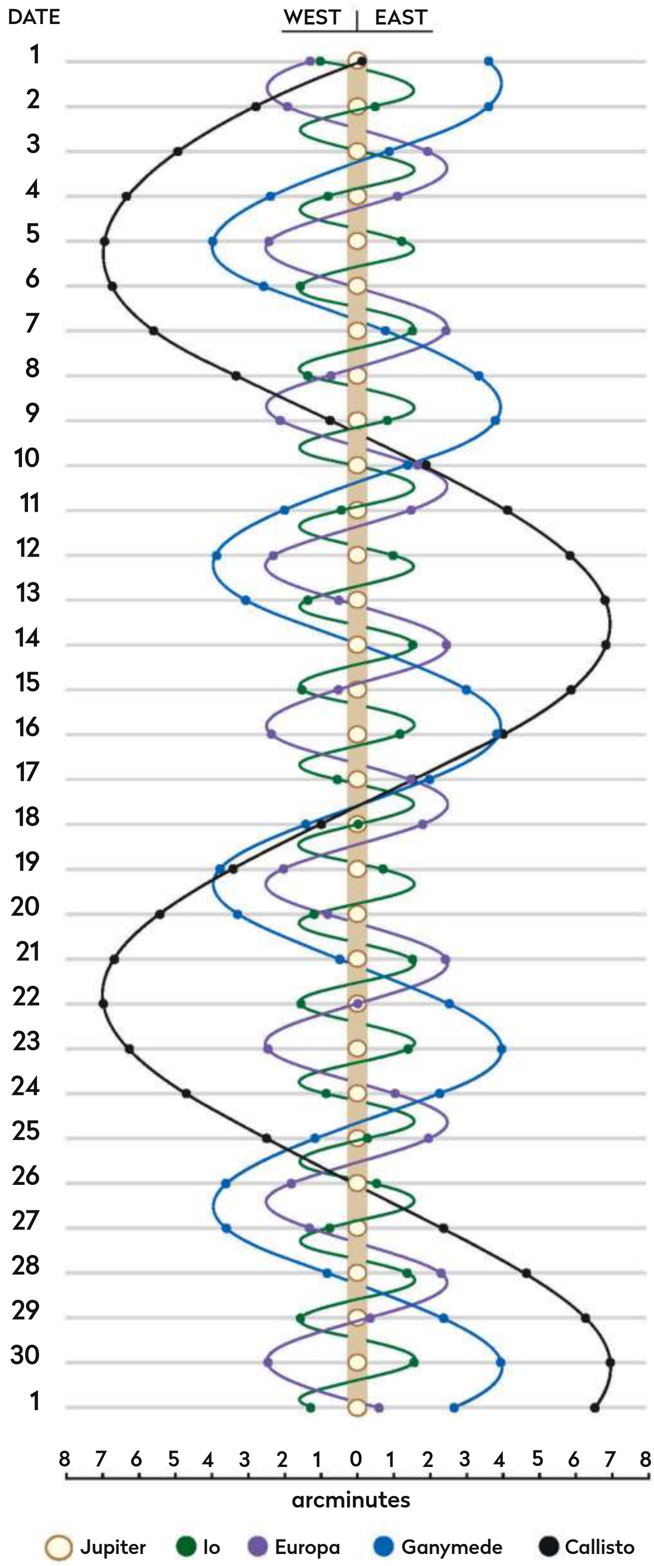
Print planet observing forms
www.skyatnightmagazine.com/bonus-content



JUPITER'S MOONS: NOVEMBER

Using a small scope you can spot Jupiter's biggest moons. Their positions change dramatically over the month, as shown on the diagram. The line by each date represents 00:00 UT.



THE NIGHT SKY – NOVEMBER

Explore the celestial sphere with our Northern Hemisphere all-sky chart

KEY TO STAR CHARTS

- Arcturus — STAR NAME
- PERSEUS — CONSTELLATION NAME
- GALAXY
- OPEN CLUSTER
- GLOBULAR CLUSTER
- PLANETARY NEBULA
- DIFFUSE NEBULOSITY
- DOUBLE STAR
- VARIABLE STAR
- THE MOON, SHOWING PHASE
- COMET TRACK
- ASTEROID TRACK
- STAR-HOPPING PATH
- METEOR RADIANT
- Circlet — ASTERISM
- PLANET
- QUASAR

STAR BRIGHTNESS:

- MAG. 0 & BRIGHTER
- MAG. +1
- MAG. +2
- MAG. +3
- MAG. +4 & FAINTER

- N, E, S, W, 5° — COMPASS AND FIELD OF VIEW
- MILKY WAY

CHART: PETE LAWRENCE

When to use this chart

1 November at 00:00 UT
15 November at 23:00 UT
30 November at 22:00 UT

On other dates, stars will be in slightly different positions because of Earth's orbital motion. Stars that cross the sky will set in the west four minutes earlier each night.

How to use this chart

1. Hold the chart so the direction you're facing is at the bottom.
2. The lower half of the chart shows the sky ahead of you.
3. The centre of the chart is the point directly over your head.

Sunrise/sunset in November*

Date	Sunrise	Sunset
1 Nov 2024	07:09 UT	16:36 UT
11 Nov 2024	07:29 UT	16:19 UT
21 Nov 2024	07:47 UT	16:04 UT
1 Dec 2024	08:03 UT	15:54 UT

Moonrise in November*

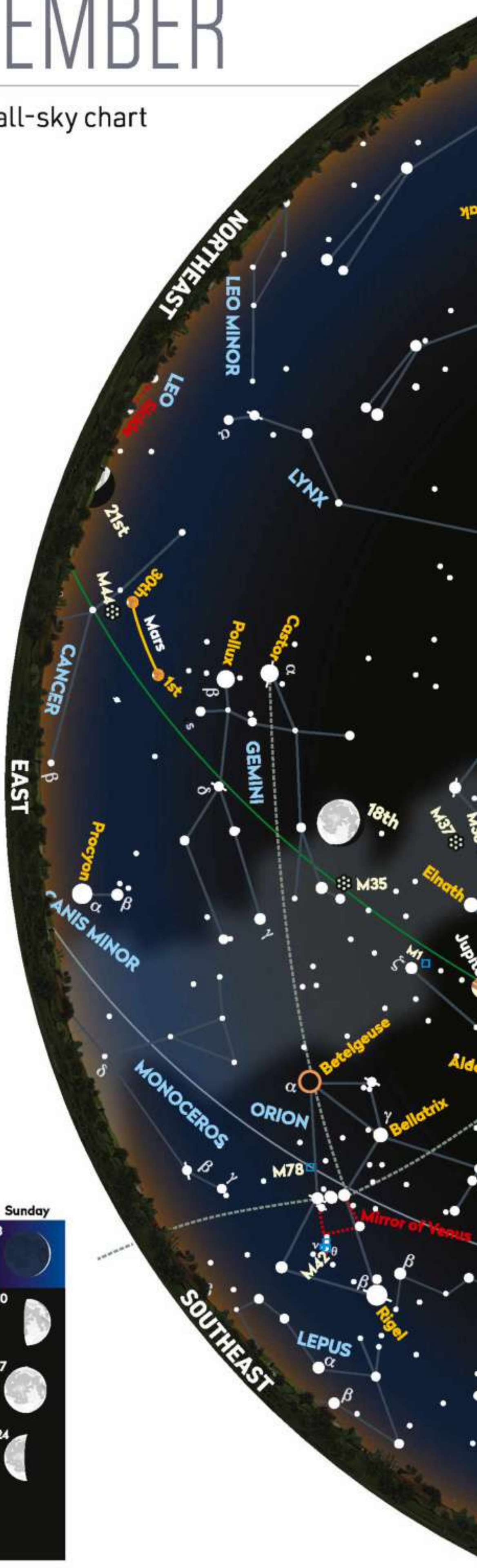
Moonrise times

1 Nov 2024, 07:13 UT	17 Nov 2024, 16:35 UT
5 Nov 2024, 12:11 UT	21 Nov 2024, 21:34 UT
9 Nov 2024, 14:17 UT	25 Nov 2024, 01:21 UT
13 Nov 2024, 15:01 UT	29 Nov 2024, 06:15 UT

*Times correct for the centre of the UK

Lunar phases in November

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
				1 NEW MOON	2	3
4	5	6	7	8	9	10
11	12	13	14	15 FULL MOON	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	



FREE BONUS CONTENT

Paul and Pete's night-sky highlights

Southern Hemisphere guide

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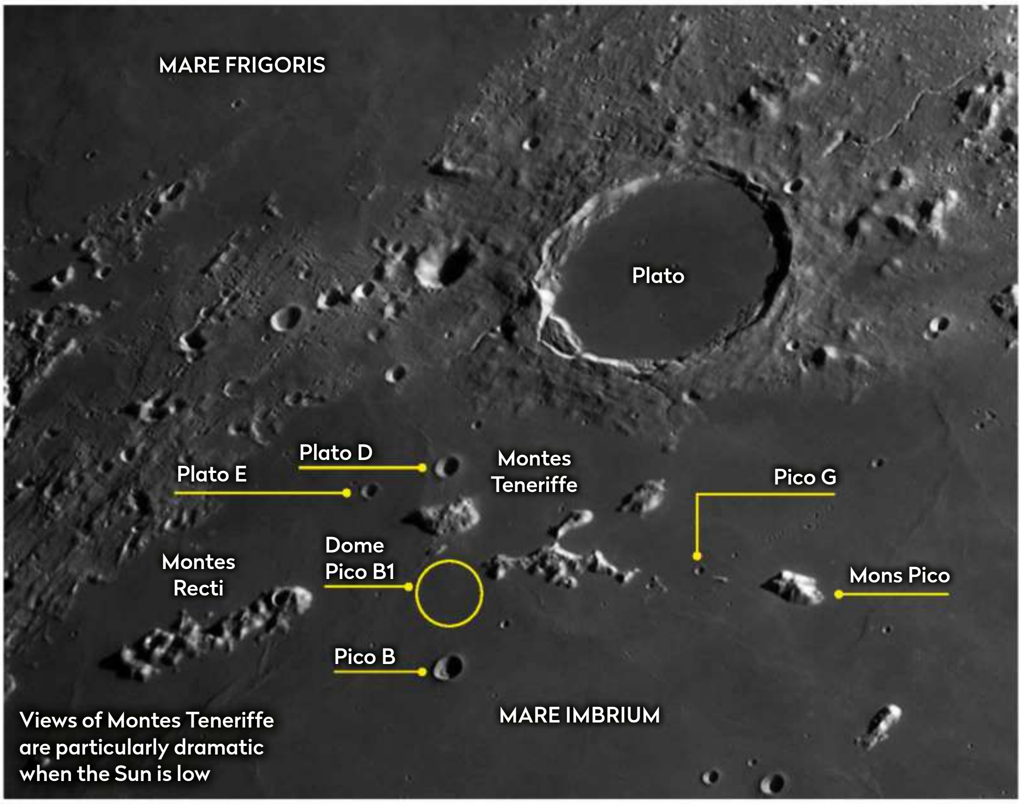
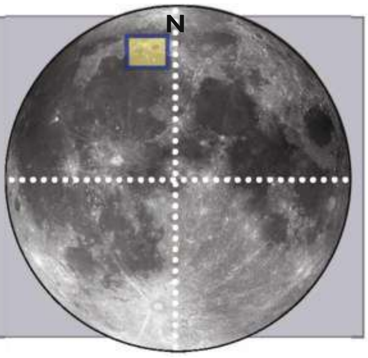


Views of Montes Teneriffe are particularly dramatic when the Sun is low

Montes Teneriffe

Type: Mountain range
Size: 120km x 40km
Longitude/latitude: 13.2° W, 47.9° N
Age: 3.2–3.9 billion years
Best time to see: One day after first quarter (9 and 10 November) or last quarter (23 and 24 November)
Minimum equipment: 100mm telescope



Montes Teneriffe is an easy-to-identify mountain range located in the northern part of 1,250km-diameter **Mare Imbrium**, immediately southwest of the distinctive 101km dark lava-filled crater **Plato**. The range stands out because it's located on the flat, dark lava of the mare.

Named after the island of Tenerife in the Canary Islands, the range consists of a few isolated mountains and one three-armed branch. The linear mountain range further to the west isn't part of Montes Teneriffe, but rather 90km x 20km **Montes Recti**. From Montes Recti, head east for 50km and you'll arrive at the first massif of Montes Teneriffe, a rough elevation measuring 26km east to west and 18km north to south. Its main peak rises to 2km above the surrounding surface of Mare Imbrium. A wrinkle ridge runs up through this feature, heading south to north, passing up through 9.4km **Plato D**. Look 70km south of the main massif and you'll arrive at 11.6km **Pico B**.

The range stands out because it's on the flat, dark lava of the mare

Further east lies the three-armed structure that actually turns out to be a linear structure 63km in length and 20km wide, with a second detached mountain to the north, the division between the two being very narrow. The highest peak on the main section sits around 1.4km above Mare Imbrium's surface, while that on the smaller section to the north rises to a maximum height of around 900m. The region immediately to the west of the main east–west structure is occupied by a subtle bulge in the surface of Mare Imbrium, known as **dome Pico B1**. Measuring 11km x 16km, this is a shield volcano rising to an approximate height of around 150 metres. An additional massif is located 27km further to the west of the northern arm of the three-armed main section of Montes Teneriffe. This is 20km x 14km in size and rises to a peak height of around 1.2km.

Following the line of the main linear structure within the range points east to a few smaller bumps and craterlets, the largest of which is 4km **Pico G**. Follow the line further east and you'll arrive at the impressive **Mons Pico**, a 25km x 15km mountain that rises 2.2km above the flat surface of Mare Imbrium.

It's the relatively flat surrounding lava that gives these mountains their visual impact. During elevated illumination, when the Sun is high in their sky, the mountains appear bright against the darker lava which surrounds them. But it's when the Sun gets low in their sky that things really start to get interesting. Under such circumstances, elevated structures cast extensive shadows across the Moon's surface, but it's often the case that other structures or rough terrain get in the way and dilute the shadow's impact. Here, the flat surrounding lava of Mare Imbrium acts as a screen on which these impressive shadows can be displayed. Consequently, at the times when the Sun is at a low angle, the mountain peaks cast sharp, jagged and elongated shadows across the surrounding surface. This often gives the impression that the mountains are much taller than they actually are.

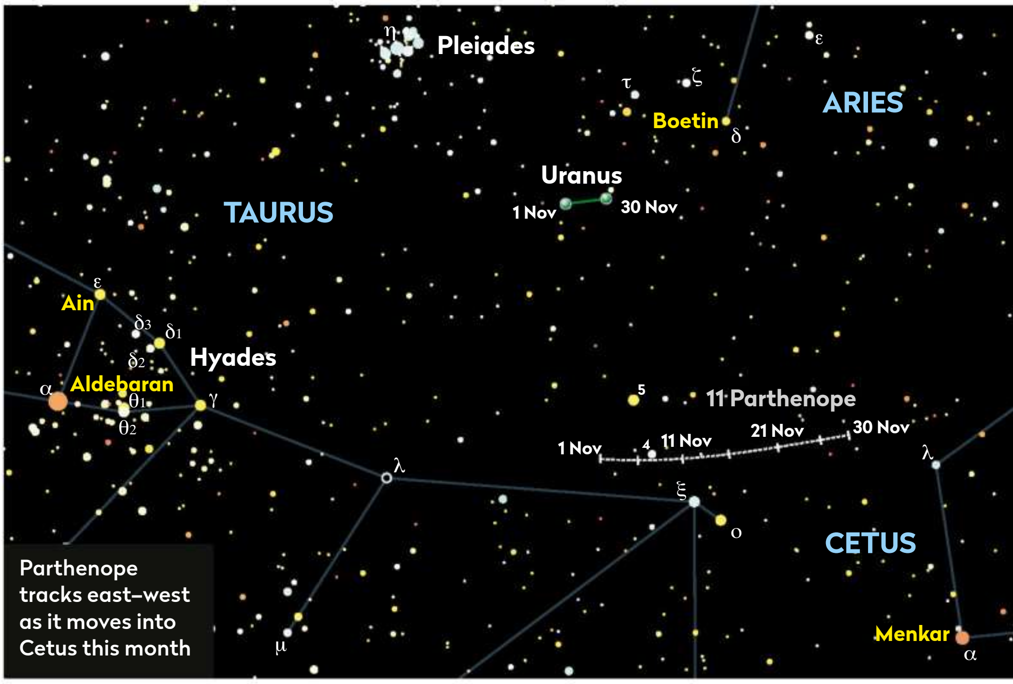
COMETS AND ASTEROIDS

Follow 11 Parthenope as it reaches opposition

Minor planet 11 Parthenope will reach opposition on 13 November when it can be found shining at mag. +9.8 on the border between Taurus, Aries and Cetus. At this brightness, it'll be most comfortably seen using a small telescope, but binoculars of at least 50mm aperture from a dark-sky site should be able to see it too. Although opposition delivers us the brightest version of Parthenope, the variation through November isn't great, the minor planet starting the month at mag. +10.0 and ending it at the same value.

The best way to locate Parthenope is to first locate the pair of stars at the extreme western side of Taurus: Xi (ξ) and Omicron (ο) Tauri. Start from the V-shaped Hyades and follow the direction pointed at by the 'V' to reach the variable star Lambda (λ) Tauri. Return to Aldebaran (Alpha (α) Tauri) and extend a line from it through Lambda for the same distance again to reach Xi and Omicron. Parthenope will be located approximately 1.3° north of Xi Tauri on the night of 11/12 November. Throughout the month, the roughly east–west track of Parthenope is less than 7° in length, which makes it a fairly easy target to track.

Parthenope's orbit takes it out as far as 2.7 AU from the Sun and in as close as 2.2 AU, and takes 3.84 years to complete.



Parthenope tracks east–west as it moves into Cetus this month

STAR OF THE MONTH

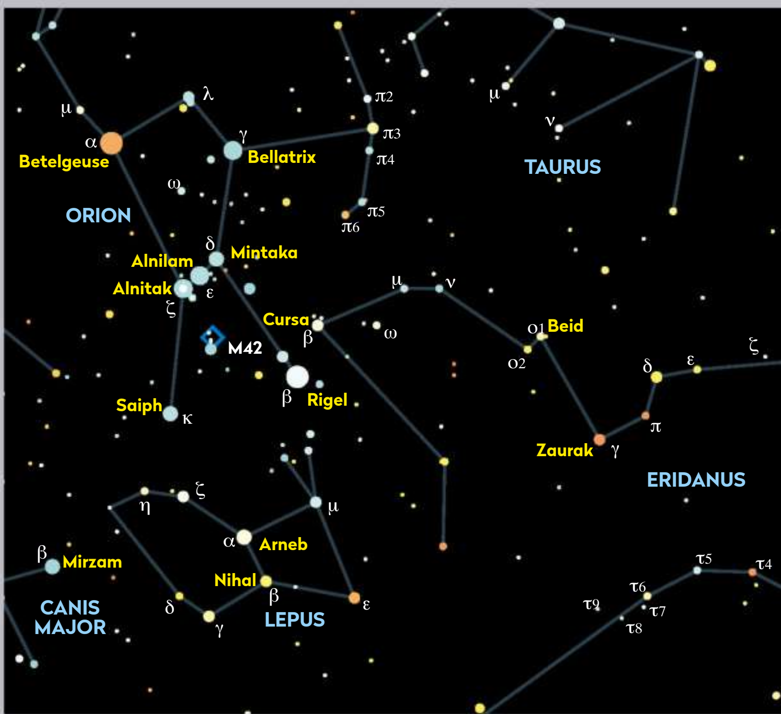
Zaurak, a red giant boat on the river

Sounding more like the protagonist from a sci-fi movie, Zaurak is the name attributed to mag. +2.9 Gamma (γ) Eridani. The literal translation is 'boat', which makes sense as Eridanus is a long, winding constellation representing a river. A rough but practical way to locate Zaurak is to imagine the line between Rigel (Beta (β) Orionis) and Betelgeuse (Alpha (α) Orionis), then rotate it 120° clockwise around Rigel. The end roughly points to Zaurak.

Located 203 lightyears from the Sun, Zaurak is a red giant star of spectral classification M0III-IIIb. In this dying phase of stellar evolution, its interior has separate shells fusing hydrogen and helium outside of its main core. Although it exhibits slight variation between mag. +2.88 and +2.96, Zaurak is used as a base reference for comparing to less normal stars of similar type.

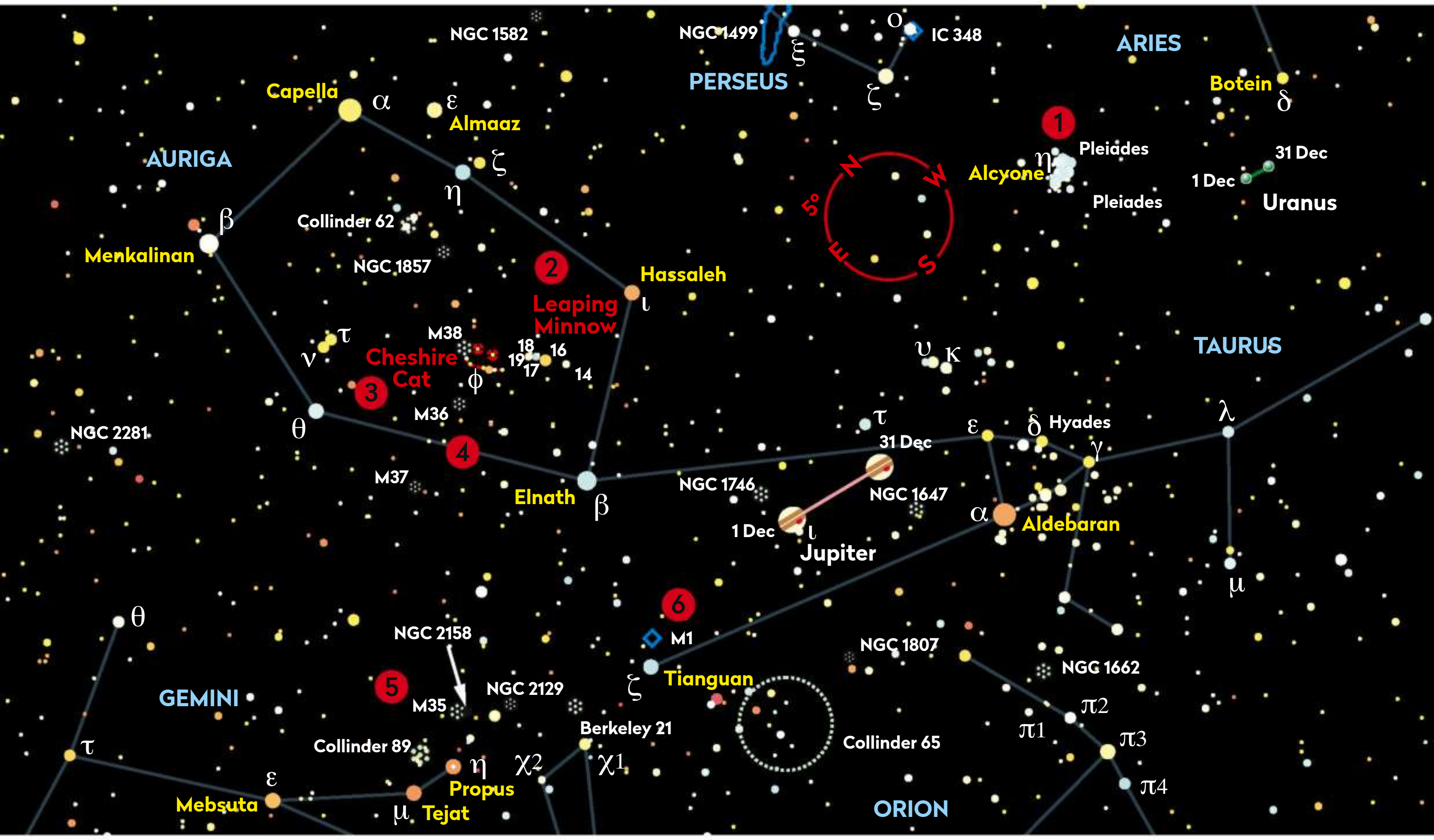
Recent observations made by the Gaia spacecraft have identified a small companion to Zaurak. Estimated to have a mass just one-tenth that of our Sun, this companion moves through space with Zaurak at a projected separation of 1,000 AU. Another, even closer red dwarf companion is also suspected, possibly within 50 AU. If true, it would be too close to the primary to be seen.

▼ Zaurak – not a supervillain, but the third-brightest star in Eridanus



BINOCULAR TOUR With Steve Tonkin

Catch an airborne fish, find a feline grin and explore a guaranteed "Wow!" generator



1. The Pleiades

10x 50 You can easily see the blue-white stars of the Pleiades (the Seven Sisters, M45) with your naked eye, but you need binoculars to really experience their true splendour. These diamonds scattered on black velvet are one of the sights that evoke lots of "Wow!"s at star parties. It's hardly surprising that they inspired the poet Tennyson to declare that they "Glitter like a swarm of fire-flies tangled in a silver braid". ☐ **SEEN IT**

2. Leaping Minnow

10x 50 Slightly more than 4° east of mag. +2.7 Hassaleh (Iota (ι) Aurigae), there is a little group of fifth-magnitude stars that includes 16, 17 and 19 Aurigae. Your 10x50 binoculars reveal that this group's arrangement is reminiscent of the bright stars in the constellation Delphinus (the Dolphin), hence its common name. To the northeast of the Minnow in the direction of mag. +5.0 Phi (φ) Aurigae, you will see the 'splash' of stars it made. ☐ **SEEN IT**

3. The Cheshire Cat

10x 50 Phi Aurigae is the brightest star in our next asterism, a broad smile in the sky that includes some of the 'splash' from our previous target. This grin of mostly sixth- and seventh-magnitude stars extends northwards for nearly 2° to a little fuzzy patch, with two yellow stars – the cat's eyes – 0.5° to the west. Apart from a small group of fainter stars representing its nose, that's all that remains of the Cheshire Cat. ☐ **SEEN IT**

4. The Auriga trio of clusters

10x 50 The fuzzy patch at the northern end of the Cheshire Cat's smile is the Starfish Cluster, M38. A couple of degrees southeast you'll find another one, M36, sometimes called the Pinwheel Cluster. Now put M36 at the northwest of the field of view and yet another fuzzy patch, larger and brighter than either of the previous two, is visible to the left of centre of the field of view. This is the Salt and Pepper Cluster, M37. ☐ **SEEN IT**

5. The Queen of Clusters, M35

10x 50 Use the chart to locate mag. +2.9 Tejat (Mu (μ) Geminorum). Put it at the southeast edge of your field of view and find a large misty patch near the opposite side. Under suburban skies, you may resolve about a dozen stars in this aptly named 'Queen of Clusters'. Darker skies and averted vision may reveal glimpses of a smaller cluster, NGC 2158, 0.5° to the southwest. ☐ **SEEN IT**

6. M1

15x 70 We'll finish this month with a bit of a challenge. You'll need very dark, very transparent skies and eyes adapted to the dark for at least 20 minutes to see supernova remnant M1, the Crab Nebula. Navigate to mag. +3.0 Tianguan (Zeta (ζ) Tauri) and look for a tiny 5-arcminute misty patch 1.1° northwest. To be successful, you'll most likely need averted vision. ☐ **SEEN IT**

☑ Tick the box when you've seen each one

PETE LAWRENCE X 2

THE SKY GUIDE CHALLENGE

Can you pick out the Merope Nebula inside the glorious Pleiades?

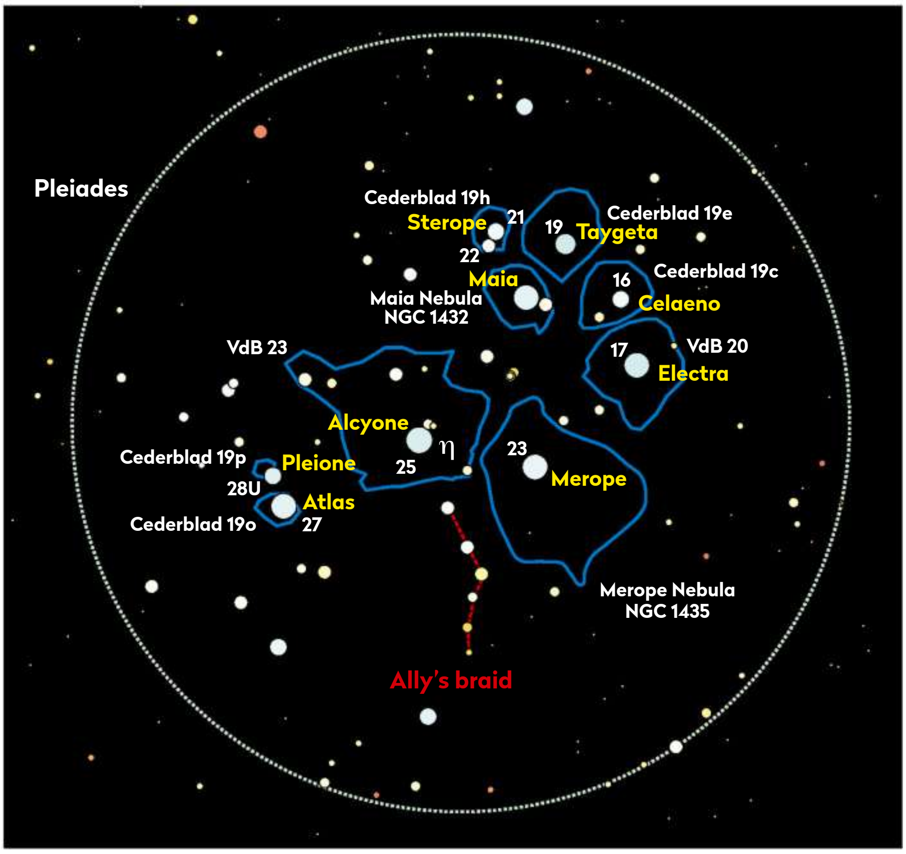
The Pleiades open cluster is an iconic showpiece of the autumn night sky. Located in Taurus, it's easily visible to the naked eye and looks resplendent through binoculars. Sparkling like diamonds scattered on velvet, the stars of the Pleiades contain this month's deep-sky challenge, the faint Merope Nebula.

This reflection nebula results from the cluster stars passing through dust clouds as they move within our Galaxy. The nebula is relatively straightforward to record using long-exposure photography, but is challenging to see visually. The brightest part is that just to the south of the star Merope (23 Tauri). Known as the Merope Nebula, NGC 1435, it occupies the area west of a bent line of stars known informally as Ally's braid, Ally being a reference to the brightest Pleiad, Alcyone (Eta (η) Tauri).

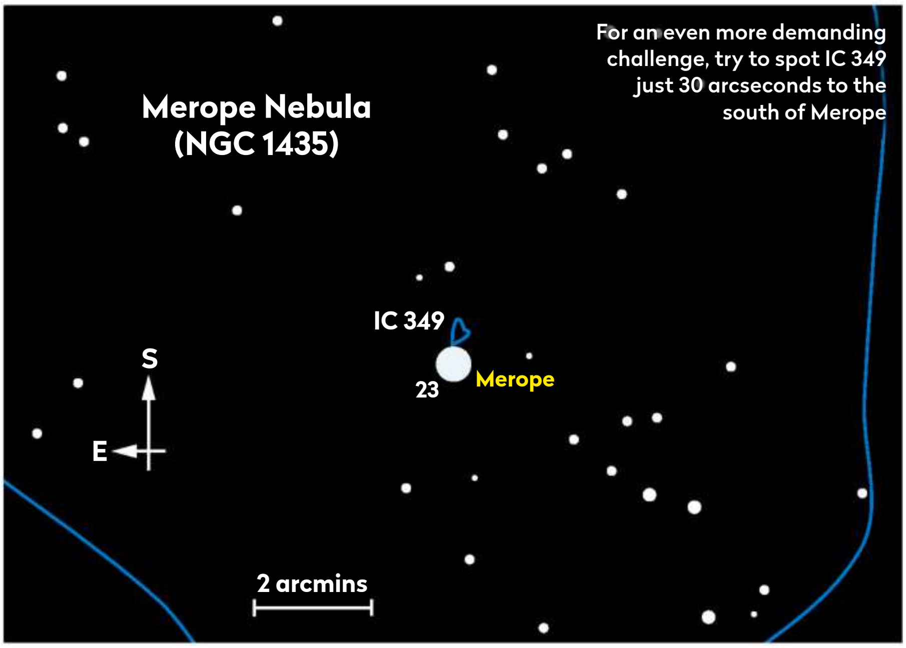
The Merope Nebula was first identified using a 100mm refractor by the German astronomer Wilhelm Tempel in 1859 and was originally known as Tempel's Nebula. Although this may give hope for a view through smaller apertures, it's important to realise that you need very dark skies if using anything under 200mm and even then, the darker the better. It goes without saying that in order to maximise your chances of spotting the nebula, you need to make sure your eyes are properly dark-adapted, keeping them in darkness for at least 20 minutes.

A mid- to low-power eyepiece works best. The sky needs to be clear and mist-free, as do your optics. If it's a cold night, make sure your eyepiece isn't misted up, as this can hide it too. Ally's braid is a useful guide to identifying the position of the Merope Nebula and it can also help confirm its existence too. If you suspect you've seen nebulosity, switch your view to the other side of the braid (east side) which is dark without nebulosity. Alternating your view between each side really helps to confirm you have seen something. Use averted vision here, the technique of looking slightly to the side of a faint object to place its light onto a more sensitive part of your retina.

If you catch the misty nebula and get a taste for investigating the region, and have access to a 300mm or larger scope, try for IC 349. Also known as Barnard's Merope Nebula, this is a 30-arcsecond knot of nebulosity that sits just 30 arcseconds south of Merope. It shines at 13th magnitude, which makes this a really tough challenge. An occulting bar to hide Merope's light is one method that can help reveal its triangular shape.



▲ The Pleiades and the main areas of nebulosity that can be revealed photographically. You'll find dark skies are essential for our challenge, to see the Merope Nebula visually



DEEP-SKY TOUR

Join our expedition around the star-packed border between Lacerta, Cepheus and Cygnus

1 M39

Despite its large area and being extremely rich in 'local' (Milky Way-based) deep-sky objects, Cygnus only has two Messier objects: M29, just south of Sadr (Gamma (γ) Cygni) and M39, 9.2° east and a fraction north of Deneb (Alpha (α) Cygni). M39 is a bright cluster at mag. +4.6, but it's positioned within a star-packed part of the Milky Way, which makes it hard to see. It has a similar apparent diameter to the full Moon, at 32 arcminutes, a low-power view revealing about 30 stars, the brightest of which form a vaguely triangular shape. Located 825 lightyears from the Sun, the cluster is estimated to be 230–300 million years old and has a physical diameter of around 7 lightyears. ☐ **SEEN IT**

2 Sharpless 2-125

The busy star fields in this region make identification quite challenging, and that's certainly the case for the Cocoon Nebula, Sharpless 2-125. It's located 3.7° east and slightly south of M39. Often photographed as a beautiful, deep red-purple circular nebula, the Cocoon is tricky to see visually, appearing more as a faint 11-arcminute circular glow. The designation IC 5146, often tied to the nebula, refers to an associated open cluster. The misty stars of the Milky Way help to pick out a finger of dark nebulosity, B168, that appears to extend towards and surround the Cocoon. A UHC or H-beta filter should help you see the Cocoon's glow. ☐ **SEEN IT**

3 NGC 7243

Our next target, the open cluster NGC 7243, requires you to move 4.5° northeast of the Cocoon, hopping from Cygnus into Lacerta. This is a great cluster for small telescopes, sitting immediately west of the Mini W asterism formed from the stars Beta (β), Alpha (α), 4, 5 and 2 Lacertae. While Lacerta isn't the easiest of constellations to navigate, the Mini W is remarkably distinctive and easy to see without optical aid. NGC 7243 sits 1.5° west and 0.3° north of the middle star in the asterism, 4 Lacertae. It's a large cluster 21 arcminutes across and shining at mag. +6.4. It's a sprawling affair, with a distinctive parabola of stars in the southwest quadrant. A 150mm scope shows around 40 stars. ☐ **SEEN IT**

▲ **Beautiful Sharpless 2-125, known as the Cocoon Nebula, may be tricky to pick out from the busy background star field**

GÜNTER KERSCHHUBER/CCDGUIDE.COM, CHART BY PETE LAWRENCE

4 IC 1434

Head 3° north and 0.7° west of our previous target and you'll arrive at our next stop-off, another open cluster. Catalogued as IC 1434, this is distinctly smaller and fainter than NGC 7243, with an apparent diameter of 8 arcminutes and a magnitude of +9.0. A 150mm scope shows about 40 stars. With a 250mm or larger scope, try to spot the impressive curved star string that heads from the northern part of the cluster off towards the northeast. There are around 20 stars in this string, ranging in magnitudes between +11.5 and +13.5 and stretching in a curve measuring over 10 arcminutes long. A 300mm scope shows a cluster with over 60 members. ☐ **SEEN IT**

5 NGC 7245

Next is the mag. +9.2 open cluster NGC 7245. This is a rich but small object best viewed through a 250mm or larger scope, as the brightest stars are all below 13th magnitude. A mid to high magnification with a 250mm scope will show around 40 stars against a background haze. You're looking square into the Milky Way here, and this really shows in the dense background star field and numerous other clusters nearby. One of the brightest is the sprawling group of around three-dozen stars 0.3° to the south-southeast which form the open cluster IC 1442. The small haze of stars 10 arcminutes northeast of NGC 7245 is the open cluster King 9. ☐ **SEEN IT**

6 NGC 7235

Our final target takes us north into Cepheus. Another open cluster, NGC 7235 is located just within the main figure of Cepheus and this allows us to use one of the major constellation stars to find it. Head 2.7° due north from NGC 7245 to mag. +4.2 Epsilon (ε) Cephei. NGC 7235 is 0.4° northwest of Epsilon. It's just 4 arcminutes across, shining at mag. +7.7 and visible through small scopes. A 150mm scope shows a few brighter members sitting over a gentle background haze. Just over a dozen stars can be seen through a 250mm scope, organised in an elongated shape reminiscent of the much brighter M35 cluster in Gemini. ☐ **SEEN IT**

This Deep-Sky Tour has been automated

ASCOM-enabled Go-To mounts can take you to this month's targets at the touch of a button. Find the Deep-Sky Tour file in our free Bonus Content online.

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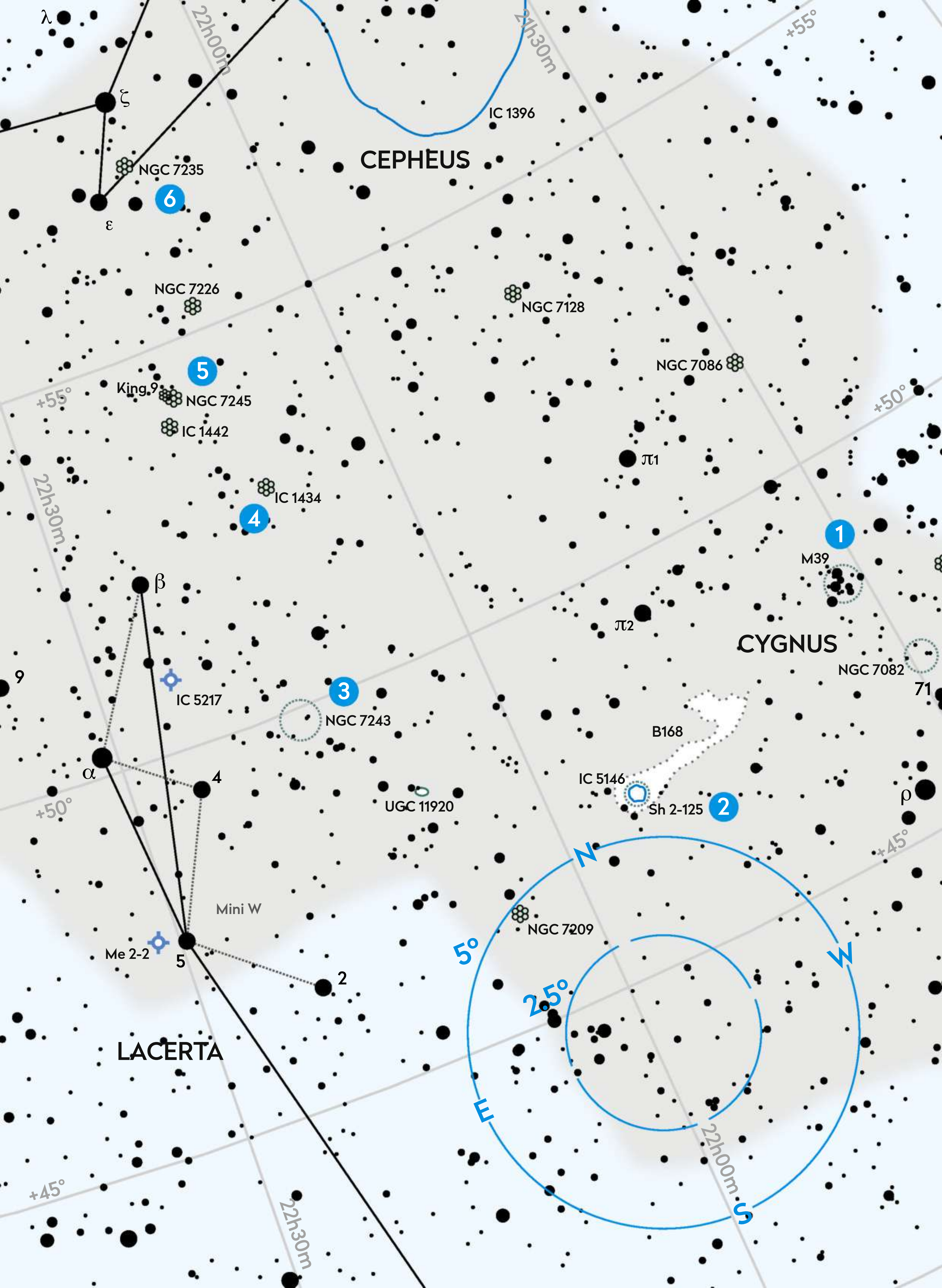

CEPHEUS
IC 1396
NGC 7235
NGC 7226
NGC 7128
NGC 7086
King 9
NGC 7245
IC 1442
IC 1434
π1
M39
π2
CYGNUS
NGC 7082
71
IC 5217
NGC 7243
B168
IC 5146
Sh 2-125
UGC 11920
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Mini W
NGC 7209
Me 2-2
LACERTA
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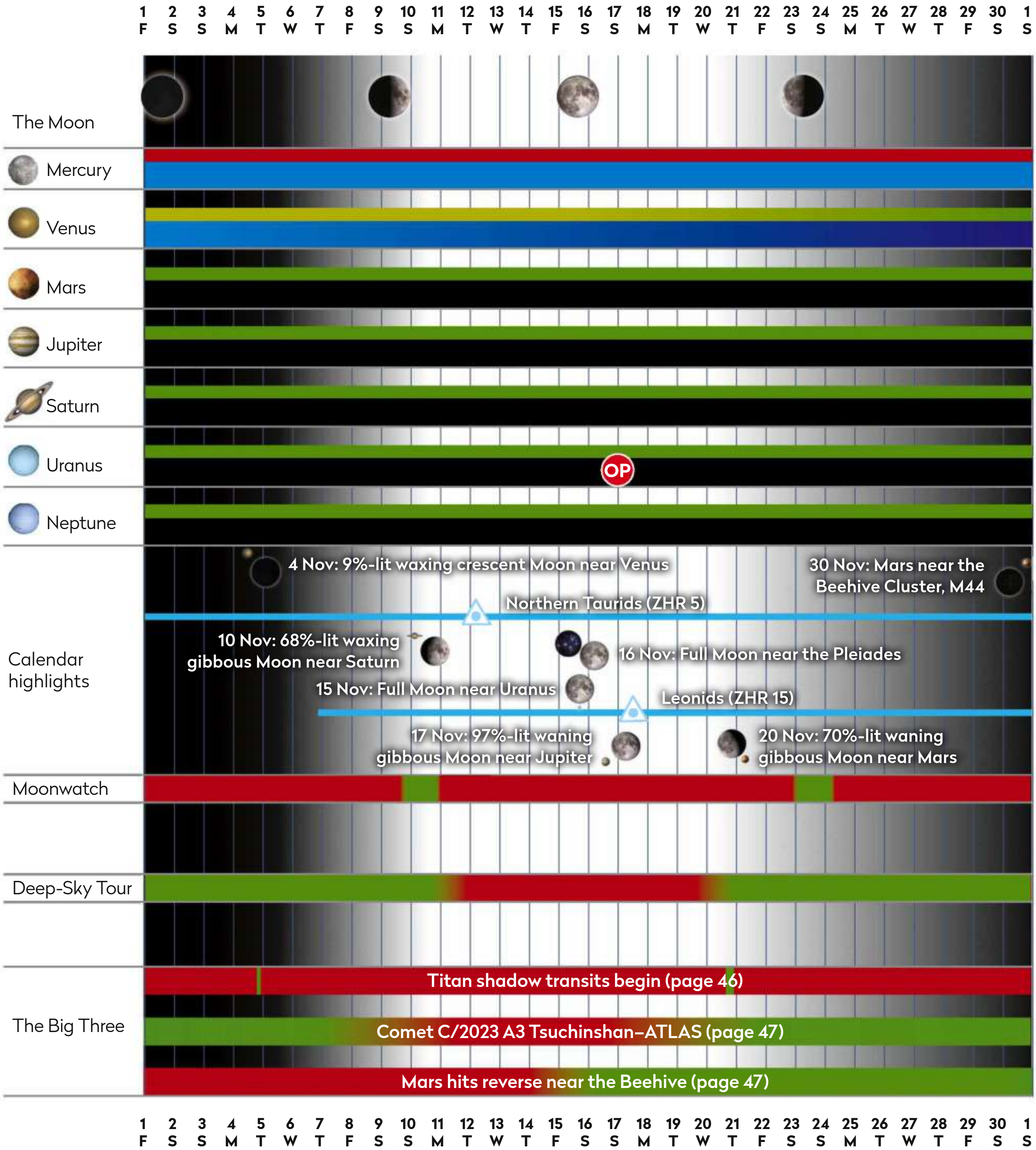
AT A GLANCE How the Sky Guide events will appear in November



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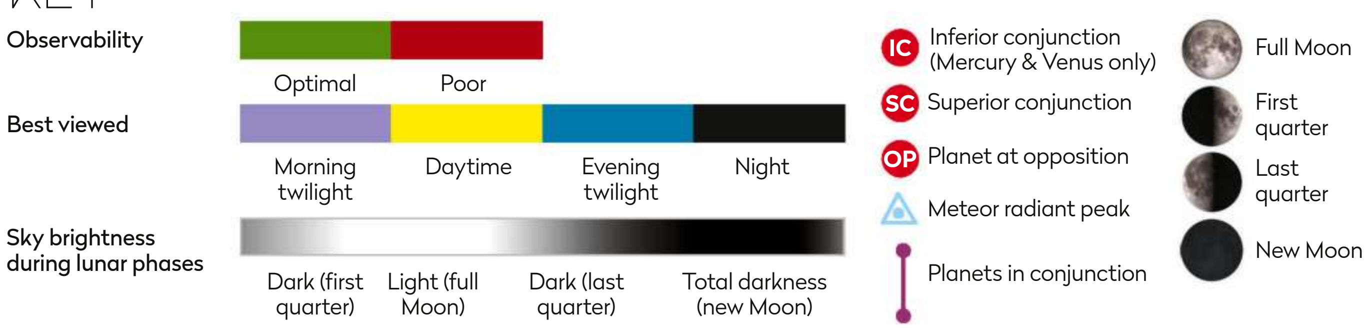

CHART BY PETE LAWRENCE

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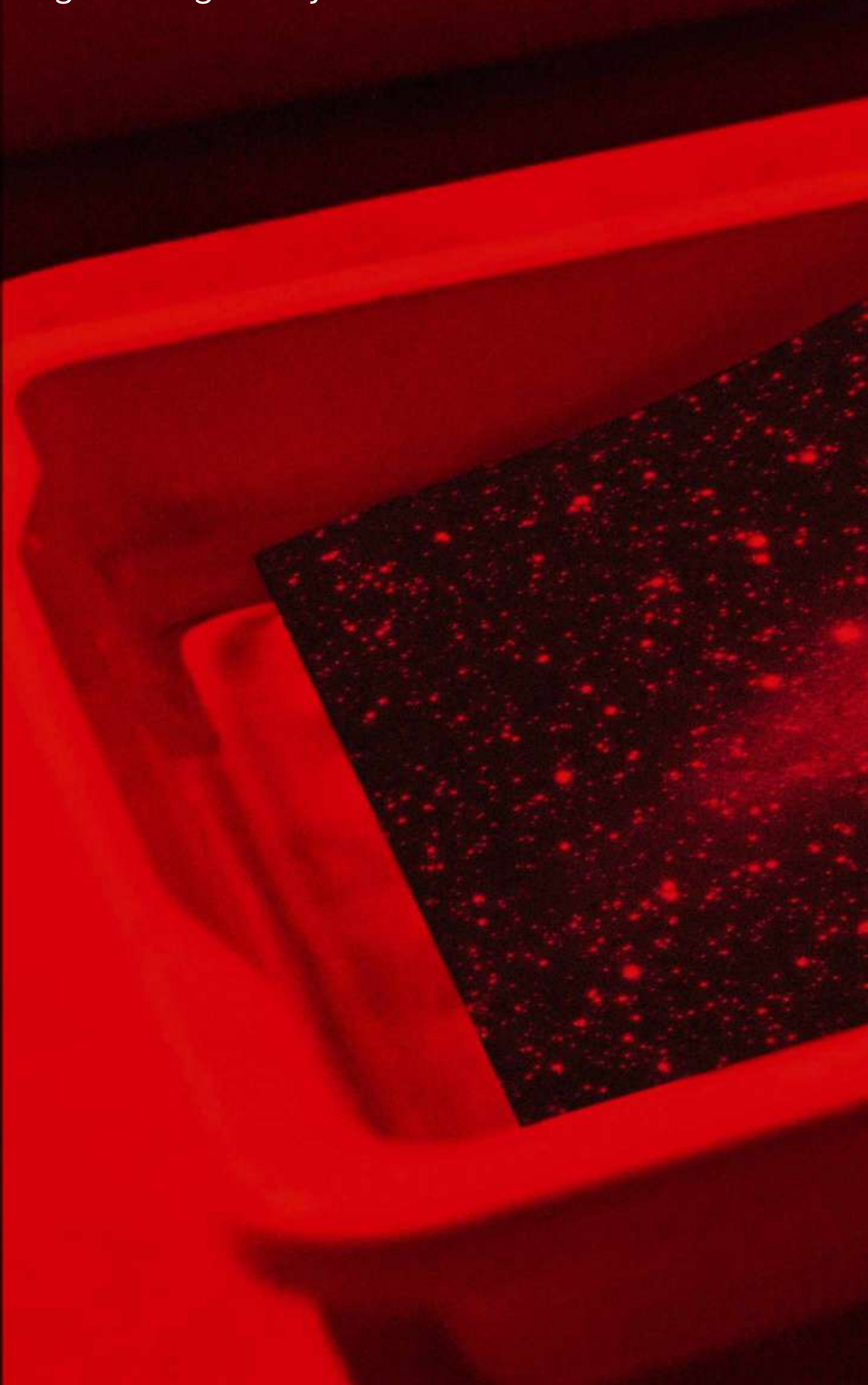
Coming out of the DARKROOM

Thirty years on from the digital photography revolution, **Pete Lawrence** looks back to times past, revisiting the many challenges of capturing the night sky on film



EAKYALDIZ/ISTOCK/GETTY IMAGES

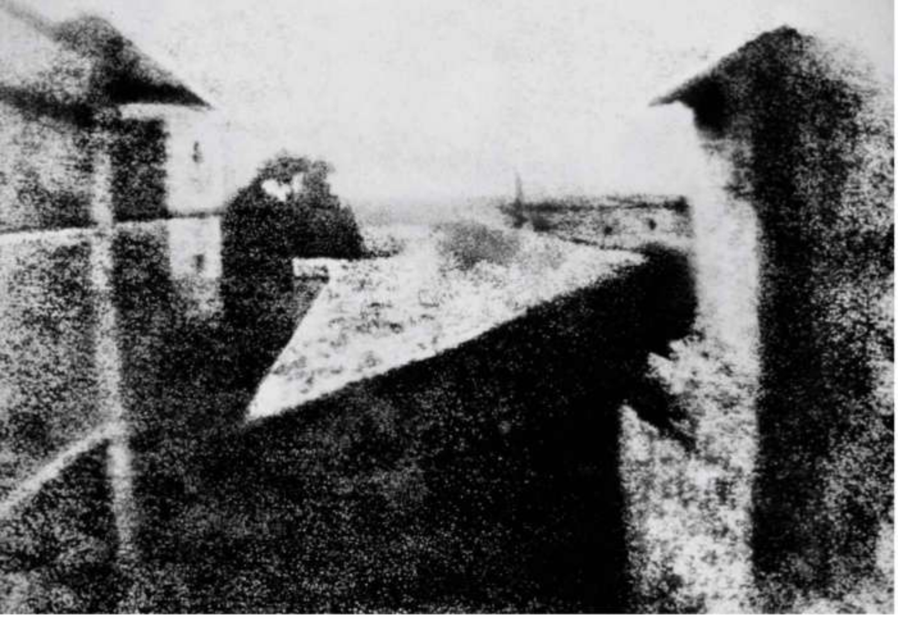
As another bright aurora display appears, the internet becomes awash with vibrant images capturing the scene. Nowadays, we take for granted our ability to instantly record and share pictures of low-light phenomena. But if you're over a certain age, you'll remember a time when film photography was king. Photographing the night sky using film, or analogue photography as it was also called, took considerable skill and was fraught with pitfalls. Compared to digital astrophotography, it was expensive and cumbersome, but for those who put the work in, the results were pioneering and stunning.

The first permanent photographic image was made by Joseph Niépce in 1826, an eight-hour exposure of his window view, recorded on pewter coated with bitumen. Naming the process 'heliography', Niépce set about improving the technique in collaboration with Louis-Jacques-Mandé Daguerre. After Niépce's death in 1833, Daguerre managed to create high-contrast, sharp images by exposing onto silver iodide-coated plates developed by exposure to mercury vapour, using a common salt solution to 'fix' the image and stop further light sensitivity. Daguerre's method came to be known as the 'daguerreotype'.

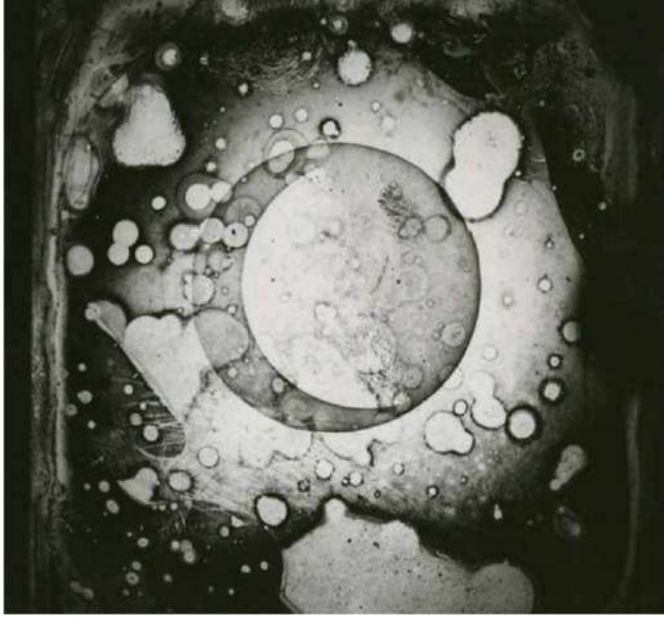
First fuzzy frames

It's believed Daguerre made the first astrophotographic image in 1839. It was a long, untracked exposure of the Moon, which came out fuzzy and indistinct. The first successful astro image, again of the Moon, was taken by John Draper on 26 March 1840, a 20-minute daguerreotype through a 5-inch refractor. The first nighttime star image was made on 16/17 July 1850, when John Whipple and William Bond took a daguerreotype of Vega through the 15-inch refractor at Harvard College Observatory. ▶

Andromeda strain: difficult, slow, frustrating and expensive, astrophotography in the film age was not for the easily discouraged!

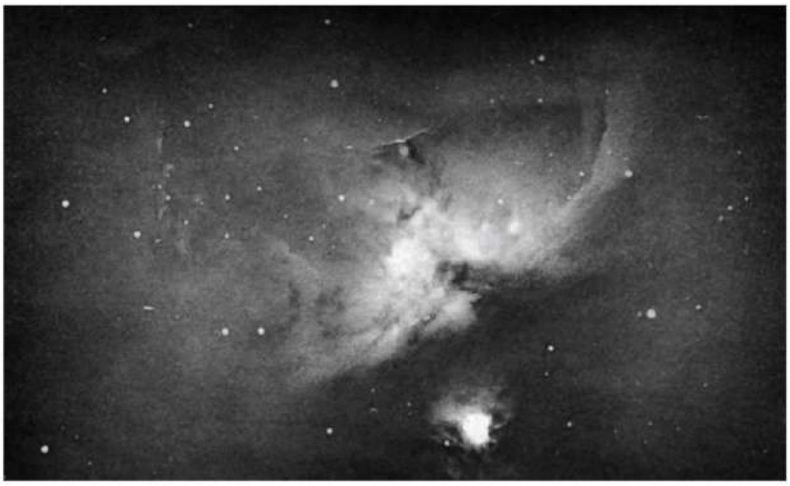


▲ **Photo first: a 'sundrawing' of the view from Joseph Niépce's workroom window, taken circa 1826, is the earliest known surviving photograph**



▲ **First astro image: John Draper's image of the Moon, taken in March 1840 using the daguerreotype process**

Henry Draper's Orion Nebula from a 51-minute exposure in 1880



▲ **Common's 1883 version proved the benefits of the dry-plate method**

▶ Astrophotography advanced with the shift from a wet-plate to a dry-plate process. Dry plate used silver salts held in gelatine and coated onto a glass or paper substrate. In 1880, Henry Draper used a dry plate to take a 51-minute exposure of the Orion Nebula, M42, using an 11-inch refractor. Although not the sharpest image, it was a first and clearly showed the nebula's bright central region. In 1883, amateur astronomer Andrew Ainslie Common used the dry-plate process to take several 60-minute exposures through his homemade 36-inch reflector in Ealing, then outside London. M42 was again the subject, and the result was far more recognisable by modern standards, clearly showing stars to 13th magnitude.

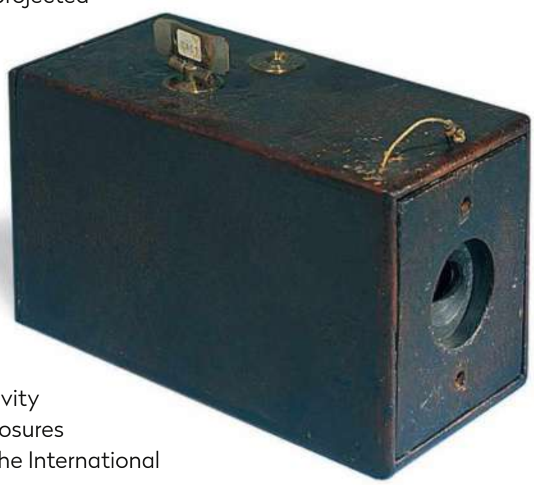
True photographic film was first introduced by George Eastman in 1885. Initially with a paper backing, things switched to celluloid in 1889, which is also when the familiar 35mm format was introduced. The first film camera, the 'Kodak', became available for sale in 1888, the first 35mm single-lens reflex (SLR) camera coming to mass market in 1935. Digital SLR cameras came into development in the 1980s and 90s, and by the start of the 21st century, film SLRs were largely replaced by their digital successors, DSLRs.

So how did film astro imaging work? Exposed to light, film recorded a 'latent image' which was revealed by developing, and fixed to stop further light sensitivity. The silver halide crystals in film are roughly analogous to the photosites on a modern digital sensor and for astrophotography, maximising the light sensitivity in both cases was paramount.

A developing story

Positive 'prints' were created via a darkroom enlarger, basically a vertically mounted projector. The negative film image was projected onto photographic paper, which was subsequently developed and fixed; essentially it was a photograph of a photograph. Film stock was initially monochrome, colour rolls first appearing in the early 1930s. Introduced by Eastman Kodak in 1935, Kodachrome colour film was positive: developing it produced slides which could be viewed using portable viewers or projected through slide projectors. If you've ever given a presentation using a slide projector, you may recall the feeling of angst if the cartridge holding the slides was dropped, spilling the contents onto the floor!

Different film sensitivities were available, with high sensitivity being used for shorter exposures but with grainier results. The International



▼ **On a roll: one of the first Kodak cameras from 1888, sold preloaded with a 100-shot film roll that was wound on with the key on top**

V&A IMAGES/GETTY, MICHAEL COVINGTON, ALEKSANDR KONDRATOV/ALAMY STOCK PHOTO, PETE LAWRENCE

How the stars were captured on film

Michael Covington explains the kit that astrophotographers typically used to capture the night sky in the days of film – and its many limitations

There were two main kinds of film astrophotography: lunar and planetary work through the telescope (with or without added magnification from a Barlow lens or eyepiece projection); and 'piggybacking', which was widefield deep-sky imaging through a telephoto lens with the camera riding piggyback on the telescope to benefit from its mount and guiding. Deep-sky work through the telescope was possible, but very challenging.

Either way, the camera was almost always a 35mm SLR, preferably one with mirror lock to reduce vibration, which was still severe due to the focal-plane shutter. The shutter would be operated with a cable release. The Olympus OM-1 and Nikon F3 SLR cameras were considered especially suitable. Unitron marketed a sheet-film planetary camera with a low-vibration shutter, but I never saw one.

Lunar and planetary work was usually disappointing. A picture showing any detail at all on Jupiter or Mars was a triumph. There was no way to stack multiple images or enhance them digitally. Wider-field views of the Moon often impressed our non-astronomer friends, though we knew they showed much less than the view through a telescope did.

▲ A popular deep-sky setup in the 1980s: an Olympus OM-1 camera, telephoto lens and shutter release cable piggybacking a Celestron C5 telescope

Piggybacking was more satisfying. Typically you'd make a single 10- or 20-minute exposure, which had to be good throughout (no aeroplanes!), because there was no way to reject subframes. To make guiding corrections, you had to watch a star on crosshairs through the main scope and adjust the mount. Many used 100mm or shorter lenses so we wouldn't have to do this.

The bane of film was reciprocity failure. That means that at low light levels, the film was forgetting photons and it made long exposures a losing game. Kodak Technical Pan Film worked almost magically if baked in hydrogen gas, losing most of its reciprocity failure and gaining lots of speed, and was the standard for deep-sky work.

Michael Covington wrote the handbook on film astro imaging, *Astrophotography for the Amateur*, in 1985

▲ The Zenit-E Pete used for astrophotography in the 70s, along with some of his old slides and film stock

Standard Organisation (ISO) introduced a sensitivity or speed rating for film: ISO 100 film being less sensitive or 'slower' than, say, ISO 400 film, which was a higher sensitivity or 'faster'. Off-the-shelf film was available in speeds between ISO 100 and 3200.

Today, we take for granted how easy it is to mimic ISO values in-camera, but with film you were stuck with the one ISO of the film you'd chosen. Film of a certain ISO rating was supposed to be developed a certain way, but a sensitivity boost could be introduced by developing for a higher rating, a process known as 'pushing'. The quest for higher ISO sensitivity was a driving force in astrophotography, since the restricted range of film ISOs limited what could be achieved by amateurs.

In use, film was cumbersome. It typically came in rolls of up to 36-shot capacity, though advanced astrophotographers could purchase longer rolls that could be cut to size. Today's equivalent would be inexpensive, reusable storage cards, each with the capacity for thousands of high-resolution images. Loading camera film was straightforward, but removing mid-roll wasn't recommended unless under darkroom conditions. Storage cards can, of course, be ejected and replaced wherever you are.

Used film then needed developing, which cost money. Most astrophotographers sent exposed film rolls to a commercial company for developing, prints and negatives being returned by post. More advanced astrophotographers had home darkrooms and developed the film themselves under carefully controlled light and temperature conditions.

As a young boy starting out in astrophotography, I had a home darkroom setup. I had a portable developing kit – basically a small black bag and a frame onto which the used film could be wound, and ▶

▲ The Teapot region, taken by Pete on film (left) and digital (right). While film meant battling inadequately light-sensitive film stock, a 36-shot limit and the tyranny of the processing lab, digital capture and processing makes taking superb images possible for everyone

▶ I installed a large water container in my bedroom to wash the film between the various development processes. I then made my room as dark as possible, even taping up door gaps to stop stray light entering.

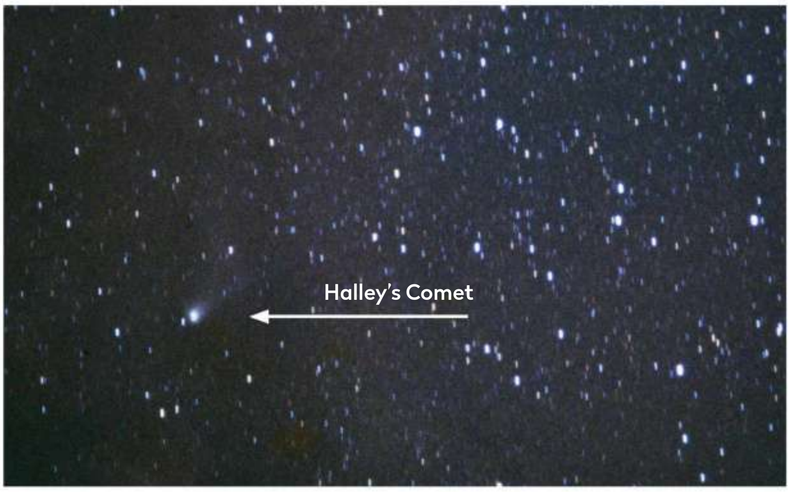
During one early darkroom session, I attempted to wash an extracted film by placing it under the water container and turning the tap, only for it to completely pop out of the container. A large jet of water poured out onto the carpet under the cloak of complete darkness – something that proved highly unpopular with my parents.

For a while I contended with the cost of commercial developing and took more care when capturing photos. Nowadays, we'll happily photograph anything, of course, even taking test shots on the fly, something simply not possible with film. The delay between taking a film astrophoto and getting the result meant that a lot could go wrong: imagine getting photos back from the developer to find the focus was off. Without instant image review, it was also easy to commit the cardinal sin of leaving the lens cap on!

Print lab frustrations

Another common complaint concerned automatic developing machines. Unable to determine where the frame edge was on dark night-sky images, the machines would often guess where to start chopping film rolls into more manageable strips. Film-based meteor photographers found this particularly galling if a chopped frame contained a bright fireball. Additional insults would come in the form of advice stickers on the returned prints that said "Your exposure was too dark". The workaround was to take a regular daytime shot as the first image, but it was easy to forget to do this. DSLR meteor imaging typically uses repeating, high-ISO, 30–60 second exposures, where eight hours of 30-second exposures produces almost 1,000 images, often repeated over several nights. On film, you'd need 27 36-exposure rolls to replicate one eight-hour session of 30-second exposures – an expensive process back in the day.

PETE LAWRENCE X 4, MICHAEL COVINGTON



▲ Halley's Comet captured on film on 8 April 1986 from The Gambia, using an Olympus OM-10 film camera on a home-made equatorial drive

▲ North America Nebula on film, 2003, Nikon F3 SLR with 180mm f/2.8 lens piggybacking a Meade 8-inch LX200, 15' exposure

When it came to longer exposures and deep-sky photography, film suffered from becoming less sensitive over time. Though exposures of 20–30 minutes were common, they were plagued by this 'reciprocity failure'. Different methods were used to reduce the effect of reciprocity failure, such as

Astrophotography for science

In the days of film, scientifically significant photos were largely the preserve of professional observatories. Today it's entirely different

The advent of digital imaging opened up the opportunity to do scientific imaging that wasn't feasible with film. All-sky cameras now regularly record the night sky from dusk through to dawn, giving rise to collaborative imaging where meteor images can be recorded and triangulated. High-speed photometry now lets us measure the micro-changes in a star's brightness due to a transiting exoplanet. Lucky imaging of Solar System objects resulted in a digital process that greatly improved our images of the planets, Moon and Sun, as well as allowing us to look for transient phenomena such as impacts on these worlds.

▲ **Even amateur kit can monitor the whole sky all night – something film could never do**

Long-exposure imaging now benefits from autoguiding, where the position of a guide star is read off an image and fed back through a computer interface to adjust the position of a mount. This allows deep imaging often with speciality filters to reveal faint chemical traces or even the spectra of dim targets – which although it would have been possible with film, would have been very challenging to do successfully.

But in many respects, it's the immediacy of digital which is its greatest strength. Now we can simply have an idea for an imaging project and use test images to refine and get it right.

▲ **Now, every photographer can instantly share their images with the world and discover hints and tips online**

photographic hypersensitisation. This required soaking the film in a forming gas such as nitrogen, hydrogen or a nitrogen–hydrogen mix, often with added heat to help things along. Hypersensitisation was a specialist technique applied to film stock shortly before it was needed; it reduced the film's shelf life, making it impractical at the manufacturing stage. By comparison, digital sensors have almost linear responses.

Digital images typically end up getting downloaded to a computer, embedded with lots of information from the point of capture as Exif data, such as date and time, camera settings and even the location. This makes reviewing shot analysis and working out what settings were used so easy today, but when you forgot to log the contents of a film roll, especially if it spanned several sessions, when you eventually finished and sent it off, the returned images could be something of a mystery!

As digital sensors slowly took over from film, there were occasional cries of how it wasn't worthy, but the benefits were soon clear. The ability to manipulate and store large collections of digital images is a massive bonus. Imagine carrying thousands of physical prints around! Digital images are easily backed up, something that can't be said for film, and we can now share images instantly. Sharing images on social media also provides a rapid means to teach or learn how to improve our imaging techniques.

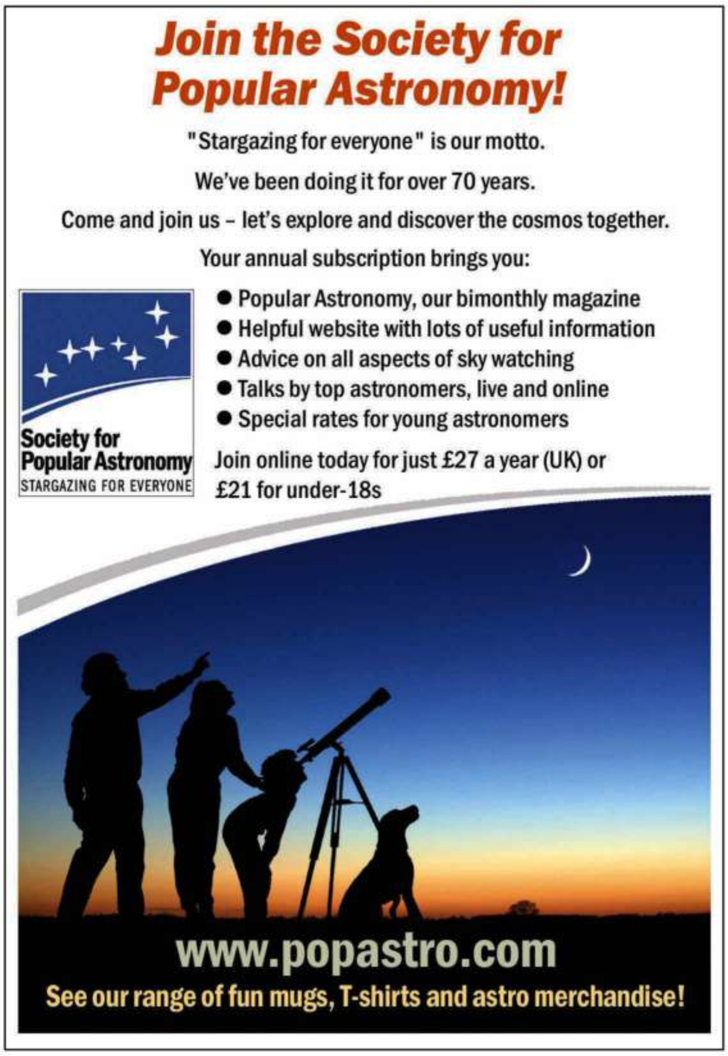
Sharper and smarter

One major advance has been lucky imaging, something that was beyond film. Here, thousands of images of a planet, the Moon or the Sun, are quality-assessed, registered and stacked by software to produce a final result much better than any of the original frames. Many free applications have been created to do this laborious task automatically.

Digital images are also commonly manipulated to reveal details not otherwise obvious. Specialist routines can now do things that would have seemed like magic in the days of film. One dramatic example is creating amazingly smooth, long-exposure shots of comets against razor-sharp starry backgrounds. Another is the way we can now separate a nebula from stars in an image, processing each independently, before recombining them for the final result. With digital image-editing software, we can deal with noise intelligently, remove satellite trails or other unwanted blemishes, and even animate sequenced images with ease. Clever as this is, we shouldn't forget that many of these processes have roots in film photography. Ever used unsharp masking to sharpen your shots? That technique was developed in the darkroom back in the days of film.

We live in a different imaging world now, one which benefits from massive advances in technology. It's interesting to consider whether astrophotography will go through another step change, whether people will claim it's being deskilled as they did when digital started to usurp film. Only time will tell.

An award-winning astrophotographer, **Pete Lawrence** is a presenter on *The Sky at Night* on BBC Four and your guide to the night sky in our monthly Sky Guide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Close up on exoplanets

As the Nancy Grace Roman Space Telescope reaches a key milestone before its launch in 2027, **Giles Sparrow** looks at how it will provide direct views of planets around other stars

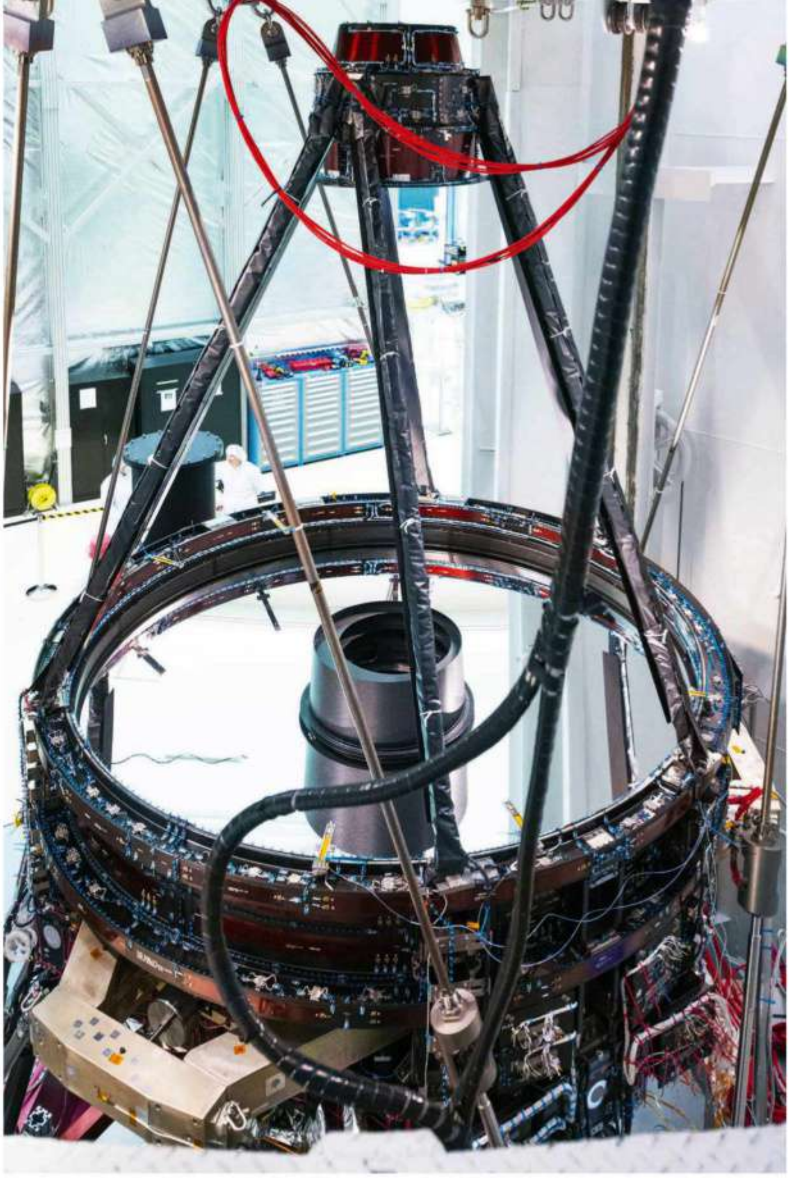
By detecting telltale changes in starlight, Roman will find and photograph thousands of gas giant worlds

ILLUSTRATION: NASA/GETTY/NASA'S GODDARD SPACE FLIGHT CENTER

In a giant clean room at NASA's Goddard Space Flight Center, engineers have just put the finishing touches to the 'bus' that will deliver its next observatory into space. The launch of the Nancy Grace Roman Space Telescope is still some 2.5 years away, but excitement is building as astronomers anticipate the next step in astronomical imaging.

With similar dimensions to the Hubble Space Telescope, Roman won't rival the James Webb Space Telescope for light-collecting power, but its unique optics and advanced instruments will help it accomplish two different objectives. Its primary goal, using a camera called the Wide-Field Instrument (WFI), is to image broad areas of the sky in a single frame, providing insights into the large-scale Universe at visible and near-infrared wavelengths. Alongside this sits a device designed to capture some of the faintest light sources ever detected. It's hoped this pioneering detector, the Roman Coronagraphic Instrument (CGI), will transform one of the most challenging fields in modern astronomy – the direct imaging of planets around other stars.

Although more than 5,600 exoplanets have now been confirmed, most of what we know has been gleaned second hand by analysing the light of



▲ All 10 of the telescope's mirrors, including the 2.4-metre (7.9ft) primary, are now assembled. They will direct light onto Roman's unique precision instruments

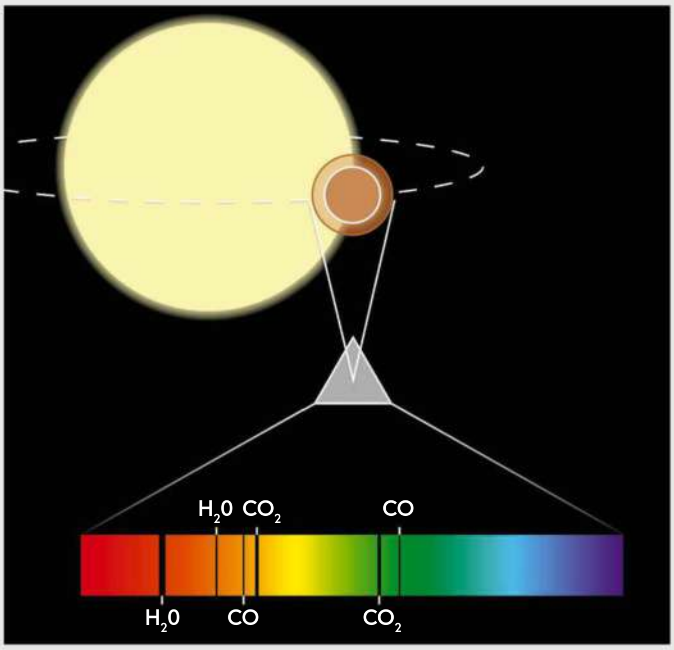
Exoplanets: the story so far

How do astronomers gather information on planets beyond our Solar System?

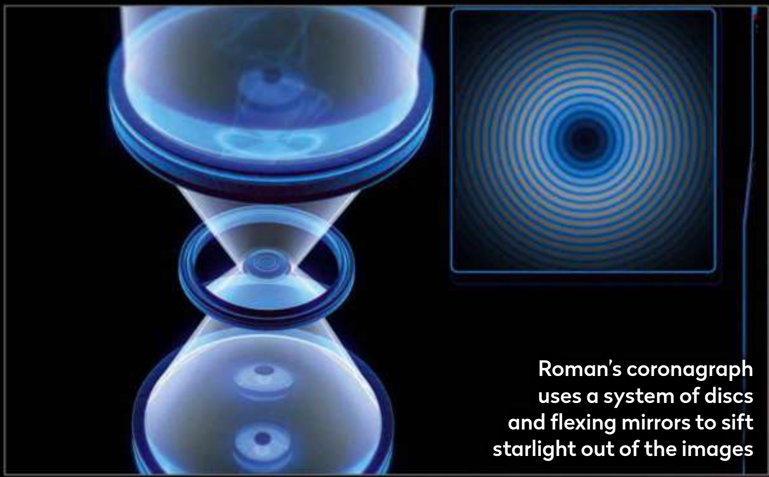
Since the first discoveries in the 1990s, astronomers have faced limits to the information they can gather about most exoplanets. Many are known only through Doppler shifts in the light of their parent stars (caused as the planet's gravity tugs the star in different directions) or from dips in brightness when a planet transits the face of its parent star, blocking part of its light. These techniques are biased towards finding certain types of planets – such as those with higher masses and those in shorter orbits – so the range of known exoplanets is unlikely to be representative of the entire population.

Measurements of Doppler shifts and transits can reveal exoplanet properties such as orbital period, mass and diameter, allowing astronomers to deduce characteristics like probable surface temperature, density and likely broad composition.

Yet direct insights into individual planets are rare because their light is so faint. Direct imaging can be used on a few young, hot gas giants, some so bright their radiation can be split into spectra for chemical analysis. Insights into the chemistry of a broader range of exoplanets can be obtained from transit spectroscopy – measurements of changes to a parent star's light as it passes through gases in a planetary atmosphere during a transit.



▲ Both of Roman's main instruments will use spectroscopy to analyse the starlight that passes through planetary atmospheres



Roman's coronagraph uses a system of discs and flexing mirrors to sift starlight out of the images

ILLUSTRATION

Only by suppressing the light from stars can Roman directly image their orbiting planets

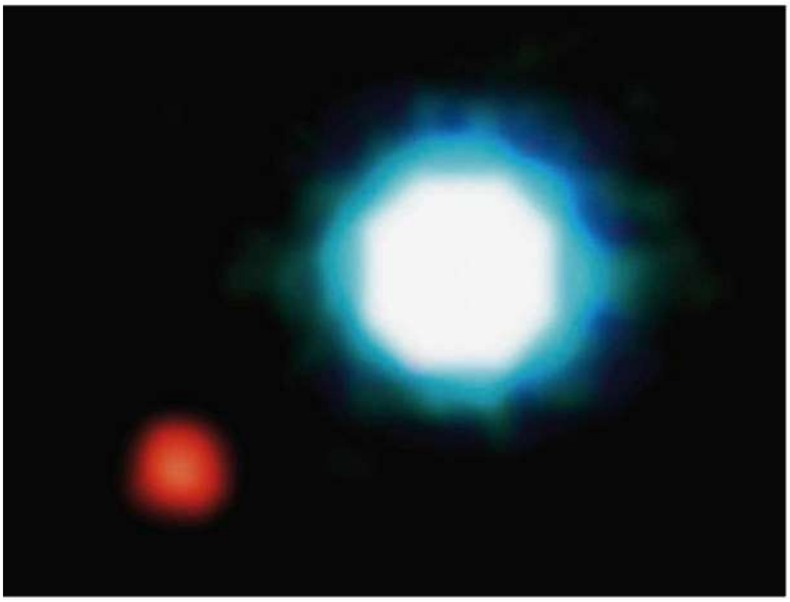
The Coronagraphic Instrument (CGI) under construction at NASA's JPL Lab

their parent stars. Only in a few dozen cases have astronomers revealed exoplanets directly, blocking out the parent star's dazzling light to capture fainter radiation from nearby objects. So far, direct imaging has been possible for the brightest exoplanets: young gas giants bigger than Jupiter, pumping out large amounts of heat, light and other forms of radiation as they contract under their own gravity.

"Young super-Jupiters still glowing red-hot from the heat of their formation may be a mere 10,000 times fainter than their stars in the near-infrared, although they become cooler and dimmer as they age," explains Dr Vanessa Bailey of NASA's Jet Propulsion Laboratory in Pasadena, California. "An old, cold Jupiter twin – a Jupiter-sized planet, at Jupiter's orbital distance, around a Sun-like star – would be about a billion times fainter than its star. Because it's cold, it emits little visible or near-infrared light and would be detectable in reflected visible light. An Earth-twin would be 10 billion times fainter than its star, again in reflected visible light."

Bailey, an instrument technologist on the coronagraph, raises a second challenge: "These planetary systems are tens or even hundreds of lightyears away, and planet and star appear close to each other in the sky – often less than an arcsecond, 1/3,600th of a degree. Detecting one of those 'easy' young super-Jupiters is like seeing a firefly 20ft from a lighthouse halfway across the country."

▼ The first directly imaged planet (red), captured in 2004 orbiting the brown dwarf 2M1207



Blocking lighthouses

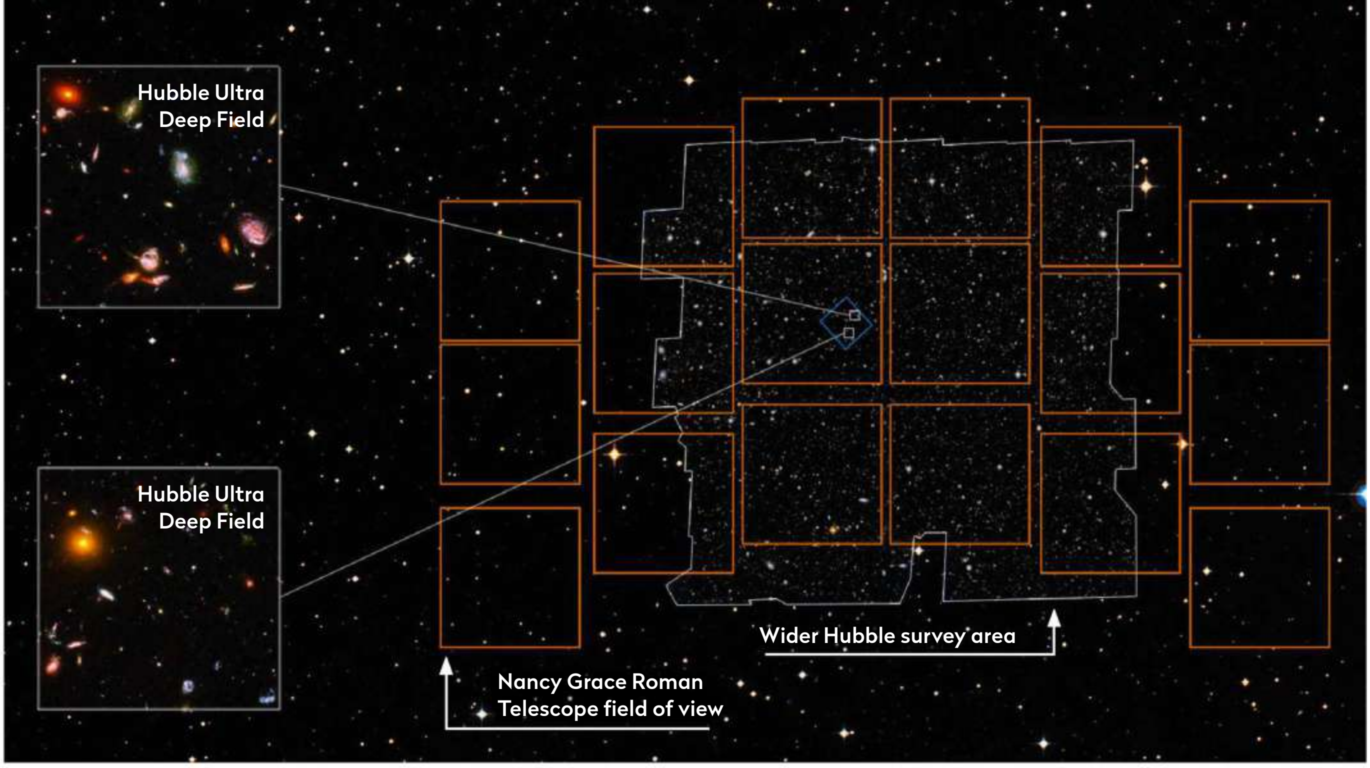
The aim of any coronagraph is to block out direct starlight while allowing light from nearby objects to pass uninterrupted.

"At its most basic, a coronagraph is an opaque spot inside the instrument that covers the star but not the planet," explains Bailey. "Due to the wave nature of light, the starlight diffracts each time it encounters an optic in the telescope and the light spreads out across the image. It's more than enough to swamp a planet that's much fainter."

"Modern coronagraphs still use an 'occulting spot' to cover the star, but they use additional optics upstream and downstream, fine-tuned to reduce the effects of diffraction and, therefore, glare."

However good optical solutions to the diffraction problem may be in theory, the behaviour of starlight before it even reaches the coronagraph can make their practical application hit-and-miss. "Coronagraph performance is limited by the quality of the images landing on them," says Bailey. "[On Earth] it wasn't until 'adaptive optics' technology – the addition of deformable mirrors that can bend and flex at high speeds to counteract the blurring of the atmosphere – that high-performance coronagraphy became possible on the ground." ▶

NASA/CHRIS GUNNX 2, ESA, NASA'S GODDARD SPACE FLIGHT CENTER, NASA'S GODDARD SPACE FLIGHT CENTER CONCEPTUAL IMAGE LAB, ESO



▲ While it will match Hubble's sensitivity and infrared resolution, Roman will capture roughly 100 times more sky and will scan the cosmos 1,000 times faster

▶ Operating in space frees telescopes from the need to compensate for atmospheric fluctuation, but adaptive optics can play a similar role in improving performance, as Bailey points out. "The Roman Coronagraph will be the first to utilise deformable mirrors to compensate for minute aberrations. It will be able to suppress starlight hundreds of times more effectively than Hubble, Webb or current ground-based telescope coronagraph instruments."

Catching fireflies

Once its optics have removed excess starlight, the Roman Coronagraph still needs to capture the weak signals that remain. "Even with a 2.4-metre [7.9ft] aperture telescope, we may receive as little as one star or exoplanet photon per pixel, per minute," explains Bailey.

Like almost all modern telescope cameras, the instrument captures images using electronic CCDs (charged-coupled devices). CCDs are semiconductor chips covered in a grid of tiny, charge-storing electronic capacitors. When photons strike the grid, they generate negatively charged photoelectron particles that build up in proportion to radiation intensity. The charge of the grid squares can then be 'read', their values converted to pixels in a digital image, but this introduces 'read-out noise': random variations that swamp weaker signals.

So, the Roman Coronagraph uses an advanced detector called an Electron-Multiplying CCD (EMCCD). This adds a 'gain register' component that causes a single photoelectron to produce several thousand more electrons before the charge is stored and read out. Noise is reduced and the faintest images can be captured.

"During vacuum chamber testing, we illuminated the instrument with an artificial star and showed that we can suppress that artificial starlight by a factor of at least 10 million," Bailey says. "We're confident it will be able to detect exoplanets at least 10 million times fainter than their stars, and we think it may be able to detect planets 100 million times fainter or more."

While the Roman Coronagraph is intended as an imaging instrument, it has other capabilities that could reveal more details of exoplanets and other material orbiting around nearby stars.

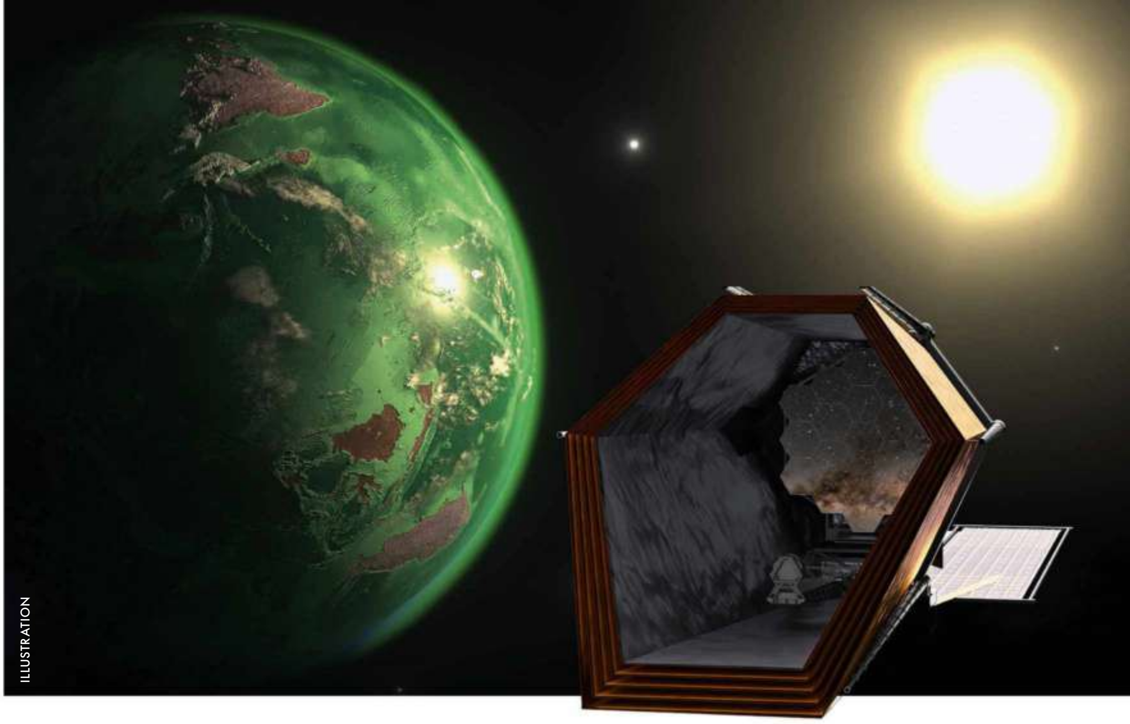
In polarimetry mode, it can measure the polarisation or orientation of incoming light waves. While starlight is typically emitted with random polarisation, reflections from certain materials can cause waves to align in specific ways, potentially revealing secrets of dust clouds around stars or particles suspended in the atmospheres of exoplanets. In spectroscopy mode, light from exoplanets can be split into a spectrum, revealing dark 'absorption lines' at specific wavelengths created by elements such as methane, potassium and sodium, to uncover the chemical makeup of their atmospheres.

▲ Technicians assemble the focal plane system, the heart of Roman's main Wide-Field Instrument (WFI)

Observing plans

While Roman's WFI will make observing time available to the global scientific community, the coronagraph is intended as a technology demonstrator, a pathfinder for instruments that could fly on NASA's Habitable Worlds Observatory

NASA/ESA/A. KOEKEMOER (STSCI) AND A. PAGAN (STSCI), NASA/CHRIS GUNN, BAKONYI SZABOLCS/ ISTOCK/GETTY IMAGES, NASA'S GODDARD SPACE FLIGHT CENTER CONCEPTUAL IMAGE LAB, ESA



▶ **Roman will be a test run for the tech that NASA's Habitable Worlds Observatory will use to find Earth-like planets**

(a large telescope intended to investigate Earth-sized planets around stars' habitable zones) during the 2040s. "We expect to have roughly 2,200 hours of observing time, split across multiple campaigns during the first 18 months," explains Bailey.

Plans are already advanced for the planets and systems the coronagraph might target. Based on orbital parameters and other properties of known exoplanets, astronomers can estimate their likely brightness and separation from their stars, helping them infer which objects lie within its reach.

"It's likely we'll observe a few young, glowing super-Jupiters," says Bailey, "as well as circumstellar dust discs in polarised light, since those objects are brighter. Using reflected visible light, we may be able to take an image of another cold, Jupiter-like planet, like 47 Ursae Majoris c [an exoplanet in a 6.5-year orbit around a Sun-like star, 45 lightyears from Earth]. That would be at the limit of our performance, so it'll be a nail-biter!"

If Roman can capture spectra from planets like 47 Ursae Majoris c or the broadly similar Upsilon Andromedae d (another potential observing target), it could lead to major advances. Using computer simulations, NASA astronomers have investigated the kinds of information the coronagraph might glean from the spectra of such planets, showing how it could be used to measure atmospheric composition, identify seasonal atmospheric changes such as the formation of clouds and hazes, and even probe the planet's internal temperature.

Truly Earthlike planets will remain beyond the Roman Coronagraph's capabilities – too faint or too close to their star to resolve. Yet this exciting instrument should be a significant step forward, allowing exoplanet imaging to move beyond massive newborn stars and begin to reveal the secrets of mature systems more like our own.

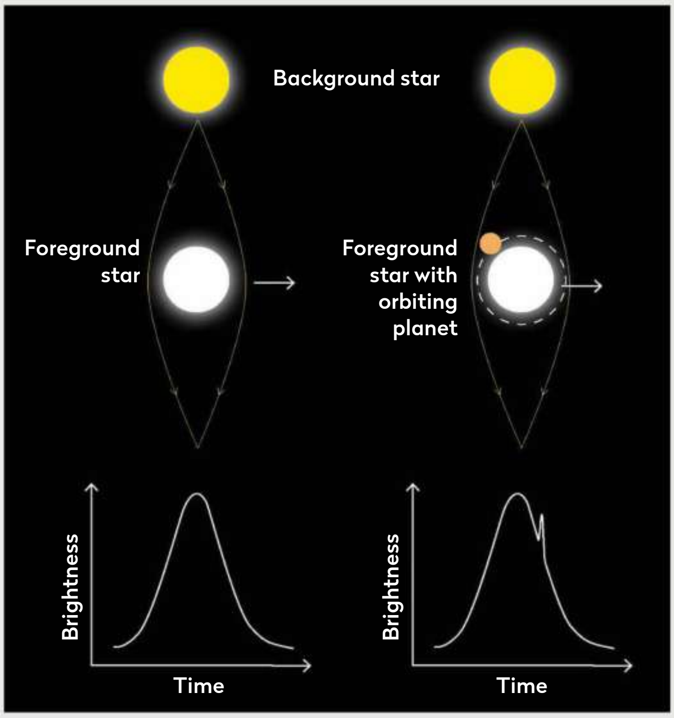
Giles Sparrow is a science writer and fellow of the Royal Astronomical Society

Roman revolution

Exoplanet imaging is just one string to Roman's bow. Here's what else the observatory will do

Named after NASA's first female executive and former chief of astronomy, the Nancy Grace Roman Space Telescope has a primary mirror with the same 2.4-metre (7.9ft) diameter as the Hubble Space Telescope, but a shorter focal length. Using its primary Wide-Field Instrument (a 300.8MP camera capable of detecting wavelengths from blue to the near-infrared), it can capture widefield views of the sky roughly 100 times greater than Hubble. Its main mission is to survey a billion galaxies across the sky, using images, spectra and other data to map the large-scale structure of the Universe and reveal the properties of dark energy, the mysterious force that appears to be increasing the rate of expansion of the Universe.

A companion survey will monitor hundreds of millions of stars towards the centre of our Galaxy. This should reveal new transiting exoplanets, but also the elusive effects of microlensing – a temporary spike in brightness caused when gravity around a foreground star (or another object such as a lone black hole) intensifies the light from another star directly behind it. Because microlensing is highly sensitive to the shape of the gravitational field, it can betray the presence of relatively low-mass planets in quite large orbits, filling in a major gap in the current exoplanet census.



▲ **Roman will watch for microlensing, spikes in the brightness of background starlight which can reveal new low-mass exoplanets**

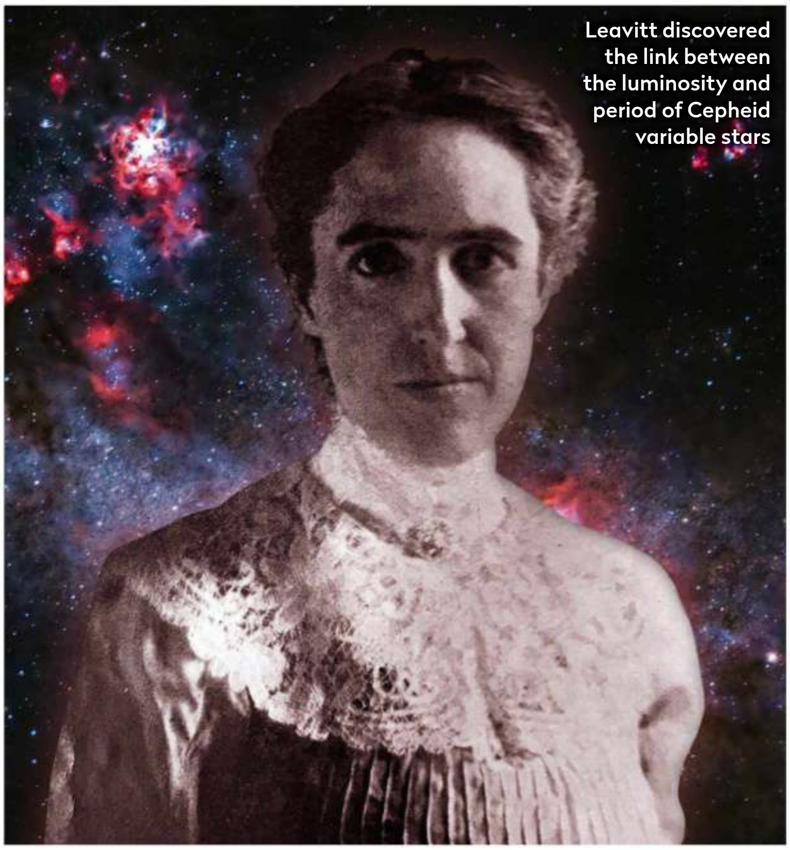
ASTRONOMERS YOU SHOULD KNOW

The fundamentals of astronomy for beginners

EXPLAINER

Henrietta Swan Leavitt

An astronomer who laid the foundations for establishing the vastness of the cosmos


Leavitt discovered the link between the luminosity and period of Cepheid variable stars

Henrietta Swan Leavitt (1868–1921) nearly won a Nobel Prize. Up to that point, only one Nobel Prize in physics and one in chemistry had ever been awarded to a woman, and both had gone to Marie Curie. Nonetheless, Leavitt was put forward and would have been a nominee had she not died in 1921 at the age of 53. Her work on Cepheid variables left a huge legacy. Using it, astronomers were able to work out the size of the Milky Way and show that it was not the only galaxy in the cosmos. Thanks to Leavitt's work, our known Universe is now much larger. Without her, we might still think we were at its centre.

Leavitt was born in 1868 in Massachusetts, USA. Her father was a church minister and her mother came from a family of church ministers. Education for women was growing at this time, with the first colleges for women opening in the US in the 1860s. Leavitt first attended Oberlin College in Ohio and then Radcliffe College at Harvard, graduating in 1892. From there she became a 'computer' at Harvard, working unpaid at first before being hired in 1902. She remained there until her death, working on analysing glass plate negatives.

Observatory director Edward Charles Pickering employed Leavitt to identify variable stars in the Small and Large Magellanic Clouds on the glass plates from Harvard's telescope in Arequipa, Peru. In 1908 and 1912, she and Pickering published her discoveries. Leavitt took a particular interest in Cepheid variables, stars whose variability followed a repeated pattern or period. As Leavitt studied these stars, she noticed a new pattern. The brightness of the stars and their period of variability were *related*. Not only that, but if you took a group of Cepheid variables known to be all roughly the same distance from Earth (for example, stars in the Small Magellanic Cloud), it was possible to find a relationship between their absolute magnitude (actual brightness, not just how it appears from Earth) and their period.

The relationship she found, now referred to as Leavitt's Law, not only told astronomers more information about Cepheid variables, it also gave


Harvard's women astronomical computers with observatory director Edward Pickering in 1913

THOMAS ROELL/ISTOCK/GETTY IMAGES, SCIENCE HISTORY IMAGES/ALAMY STOCK PHOTO, MXW PHOTO/ISTOCK/GETTY IMAGES, HARVARD UNIVERSITY

Harvard Observatory's women computers

In a profession dominated by men, this team of female astronomers was unique in the field

There were very few astronomy posts open to women in the early 20th century, many societies didn't have female members and it was rare for women to have papers published in scientific journals. There was also a belief that women should not be appointed as observers (due to the cold and the dark). However, what was permitted was paying a woman half the salary of a man.

The application of photography to astronomy in the late 19th century meant observatories were creating large collections of glass plates that needed analysing. Greenwich, Paris and Potsdam all experimented with using female graduates for this role. Only at Harvard, however, was a dedicated team of women astronomical computers sustained for several decades.

Leavitt (right) with star classification pioneer Annie Jump Cannon

Besides Leavitt, other Harvard computers included Annie Jump Cannon, who created a stellar classification system still used today; Cecilia Payne-Gaposchkin, who first concluded that stars were composed primarily of helium and hydrogen; and Williamina Fleming. Fleming was not university educated, but hired by Pickering as a housekeeper; her aptitude for astronomy was soon identified and put to good use. She is best known for her discovery of the Horsehead Nebula. All were able to publish their work, thanks to the journal *Annals of the Astronomical Observatory of Harvard College.*

Leavitt's study of the Small Magellanic Cloud set down benchmarks for measuring the Universe

them a tool for measuring distance that was better and more accurate than parallax, the only method previously available. Unusually for the time, Leavitt was able to publish under her own name rather than have her work subsumed, uncredited, within that of a male colleague.

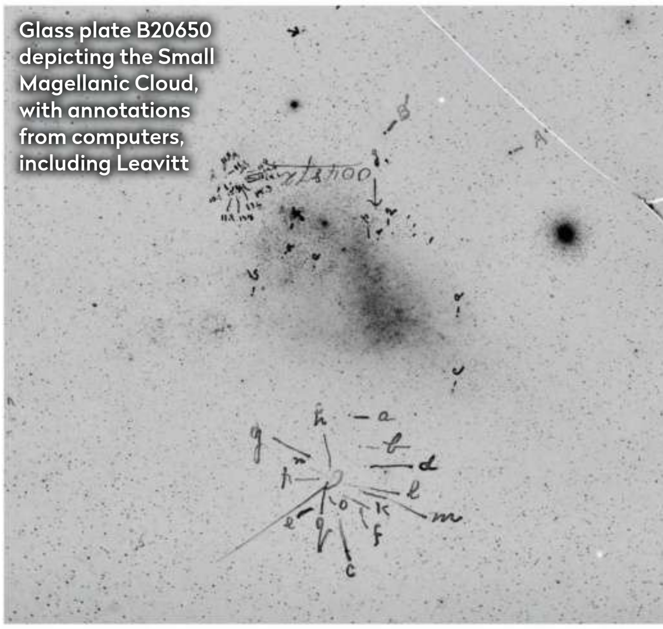
Legacy as big as the Universe

Leavitt's Law has come to hold a pivotal place in the history of cosmology. With this new tool for measuring distance, the US astronomer Harlow Shapley was able to find the edges of our Milky Way and so give us an accurate map of our Galaxy. Edwin Hubble brought an end to the Great Debate of 1920 (were our Galaxy and the Universe the same thing, or were there more galaxies?) by using Leavitt's Law to show the Andromeda Galaxy, and later other galaxies too, were beyond Shapley's edges for the Milky Way.

Arguably it is the successes of these men using and crediting Leavitt's discoveries that have allowed us to see and appreciate Leavitt herself. Women are so often written out of the history of science, if they are not it is often because the men around them used their voices to prevent that from happening.

There are no great love stories that we know of in Leavitt's life. She was, however, a loyal friend and a supportive colleague. She was often unwell and spent a considerable amount of her adult life away from Harvard convalescing or taking care of her relatives. However, when she was well enough to work, her scientific contribution was exceptional, perhaps even on a par with Marie Curie.

Emily Winterburn is an astronomy historian and author of *The Quiet Revolution of Caroline Herschel*



Glass plate B20650 depicting the Small Magellanic Cloud, with annotations from computers, including Leavitt

Make a microfocuser for DSLR lenses

A DIY gadget to achieve the fine focus you need for really sharp stars

Fitted to your lens body, the microfocuser lets you make minute adjustments to get pin-sharp results

Perfect lens focus is vital if you want to achieve pin-sharp stars in astrophotos. While there are plenty of factors to consider – accurate polar alignment, tracking and processing skills – mastering these won't overcome an out-of-focus image.

This DIY microfocuser can be attached to a DSLR lens to help your focusing efforts. The design fits a range of Canon lenses with outside diameters of 67–95mm, but should also be suitable for other makes and models.

DSLRs are a popular option for deep-sky imaging for beginners. Not only are there many low-budget models, but they're also versatile for other types of photography, and we can swap lenses around for different focal lengths. DSLRs commonly have an autofocus system, which works great in daylight but is not reliable for astrophotography, when the lack of available light reduce its effectiveness. Precise manual focus is therefore an essential skill.

Aids can assist in identifying the optimum focus point on stars, such as zooming in using the DSLR's 'live view' or adding a Bahtinov mask to the front of your lens. Even with these aids, however, the manual focusing rings on DSLR lenses can be clumsy to use when homing in on the perfect point of focus.

Our microfocuser overcomes this by allowing very fine movements of a lens's manual focus ring. It also retains the focus position once achieved, so you can't accidentally knock it when removing a Bahtinov mask or moving between targets.

Our design consists of two plywood rings. One is clamped to a fixed part of the lens body using three nylon bolts – these are soft, so they won't scratch the lens body. The second ring is similarly attached to the rotatable focus ring. There are 'lugs' on each ring which hold the adjustment mechanism.

By turning the adjustment knob (switch to Manual focus first!), the focus ring is rotated towards or away from the fixed ring and focus is adjusted. The M6 thread moves the ring 1mm after a whole turn, which means you would have to fully turn the knob about 475 times for one complete rotation of the focus ring!

This microfocuser can only move about 5° either way, so it's important to first rough-focus your lens before tightening the nylon bolts. This means it only requires a small amount of final adjustment.

The build is quite straightforward, but the threaded inserts need generous holes in the plywood so they're very lightly screwed in or even glued without splitting the plywood. The slots on each metal tube may need to be enlarged too to allow the threaded adjuster to work freely – a bit of fine-tuning may be required.

Mark Parrish is a bespoke designer based in West Sussex

FREE BONUS CONTENT

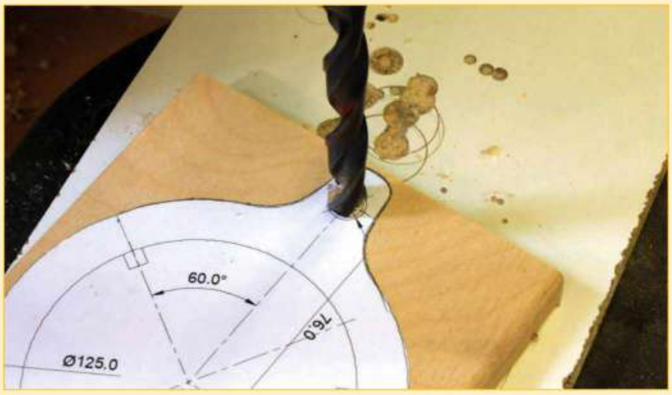
Find a template and more photos to help with your build at www.skyatnightmagazine.com/bonus-content

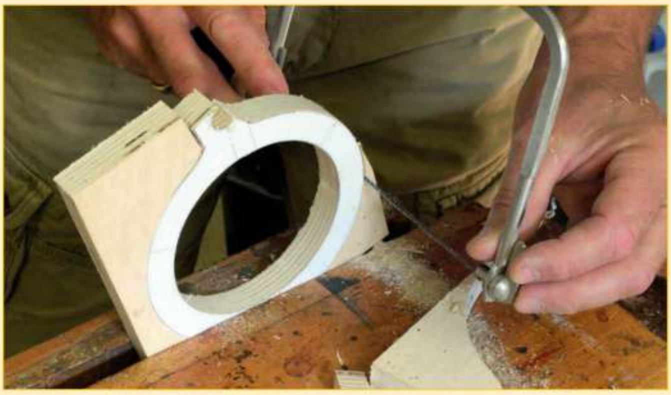
What you'll need

- Drill, drill bits (12.5mm for tubes, 10.5mm for inserts, 6mm for slots in tubes)
- Coping saw, hacksaw, files
- A4 piece of 15mm good-quality plywood or similar
- 80mm length of M6 threaded rod
- M6-sized knob, nut, barrel nut and two washers
- Short length of metal tube with 10mm inside diameter (to suit barrel nut)
- Spring, 9mm diameter x 40mm length
- Six M6 threaded inserts, six M6 x 50mm nylon bolts
- Sandpaper, epoxy two-part glue, paint or varnish

ALL PICTURES: MARK PARRISH

Step by step



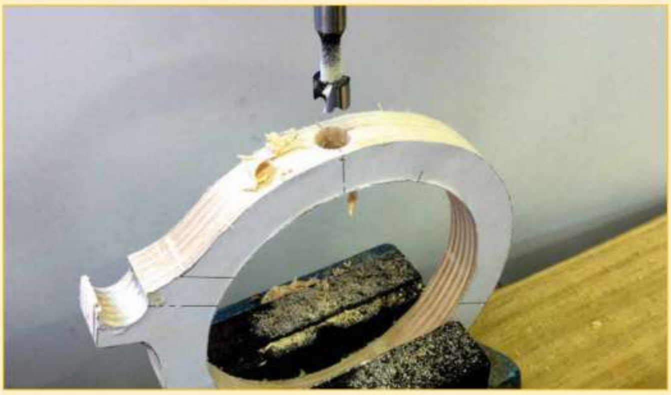


Step 1

Using the template found in the Bonus Content on our website, mark out the design on the plywood. Drill the holes for each metal tube. Cut the inside of each ring with a coping saw or by 'chain drilling' (to produce a continuous row of holes) and filing.

Step 2

Use a coping saw to cut the outside of each ring. Take care cutting around the two lugs for the metal tubes. Before removing the template, make sure to mark the three insert positions on each outer circumference for the nylon bolts. Sand everything smooth.

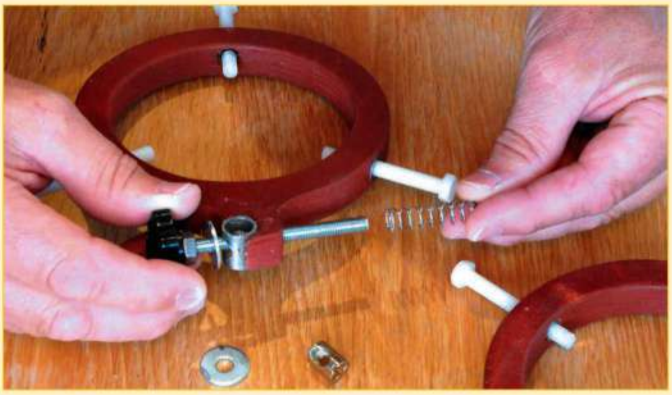


Step 3

Before using a hacksaw to cut two lengths of metal tube – one short (15mm) and one long (35mm) – drill 6mm holes about 7.5mm from one end of each tube length. Gently wiggle the drill while running, to turn the holes into slots. Remove any burrs with a file.

Step 4

Use a drill to make generous holes for the inserts. Normally these would be tight, but to avoid splitting the plywood make them at least 10.5mm diameter. Once completed, the plywood can be finished and smartened with a coat of paint or varnish.



Step 5

Drill a slotted hole through the side of the lug to align with the hole in the short metal tube. Add the threaded inserts and nylon bolts to each ring before gluing. We used epoxy glue to stick the metal tubes and inserts into their holes.

Step 6

Screw in the nylon clamping bolts and assemble the adjustment mechanism. Give it one last check; we had to do a little filing to get everything to align and move freely. Carefully fit to the camera lens, keeping the rings concentric and parallel.

Take the perfect astrophoto with our step-by-step guide

ASTROPHOTOGRAPHY CAPTURE

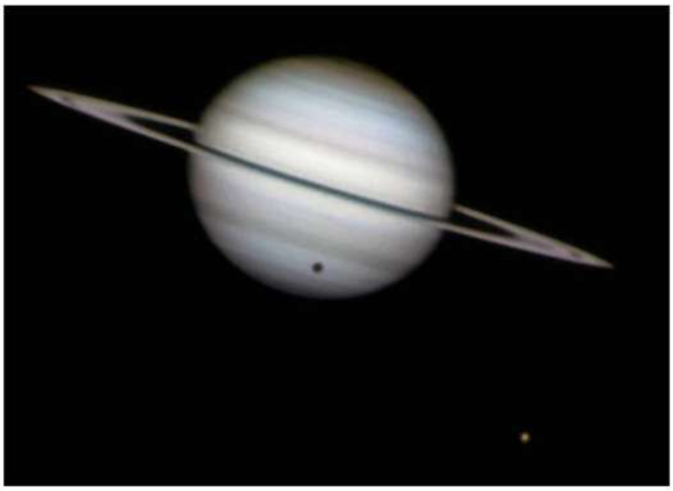
Record a Titan shadow transit

How to capture the upcoming rare crossings by the shadow of Saturn's largest moon

Saturn's apparent tilt from Earth reduces in November to such an extent that its largest moon, Titan, can start interacting with the planet's disc. This month, the interactions will involve the moon's shadow passing across Saturn's atmosphere in what's known as a shadow transit.

Saturn is approaching an equinox, when it is effectively sideways-on to the Sun relative to its axis of rotation. In this orientation, from Earth it also looks sideways-on, but the relative geometries of both planets' orbits make Saturn wobble a bit over time. In March of 2025, we'll see Saturn's rings edge-on, an event known as a ring plane crossing. The Earth–Saturn-induced wobbles can give us either a single ring plane crossing event as we'll have next year, or a triple event where Saturn's rings appear to go edge-on three times in relatively short succession.

Single ring plane crossings have Saturn placed in a bad location for observation, putting the planet too near to the Sun to be seen; triples are better placed. After the single ring plane crossing on 23 March 2025, the good news is that the next one will be a triple. The bad news is that you'll have to wait until 15 October 2038 to see the first of them, with subsequent crossings occurring on 1 April 2039 and 9 July 2039.



▲ Titan's shadow will start to transit Saturn's globe this month, the start of a 16-month window to capture these unusual events

Grab your chance

Saturn is a slow mover compared to Mars and Jupiter, taking 29.4 years to complete each orbit. As a result, events that occur near a ring plane crossing, such as Titan interactions, are all the more important to observe and record. To put it bluntly, you don't get too many opportunities to do this over a lifetime.

The situation is made frustratingly worse by Titan's orbital period, which is 15.94 days (sidereal, that is measured against the stars as seen from Saturn). Being so close to 16 days, if a Titan interaction is poorly positioned from a set location on Earth – for example, occurring during daylight hours – the next one will occur under similar conditions, the situation only slowly changing over the course of many events. Fortunately, from the UK during November and December, we get a total of four shadow transits, the shadow moving further onto Saturn's disc with each one, and they are all well timed. Upcoming Titan transits at the start of 2025 won't be so well timed, but as Saturn remains in a fairly edge-on position throughout 2025, there will be some excellent Titan and shadow transits to look forward to later in 2025 too, finally ending in February 2026.

In this month's Capture section, we'll walk you through ways to record the events for posterity. Obviously, in order to see a Titan shadow transit, you'll need a setup capable of showing Saturn's disc, but many different camera types can be used to do the recording. If you have a high-resolution planetary imaging setup, this will give the best results of course, but the relative movement of the moon and its shadow needs to be taken into account. Take too long over a capture and both the moon and its shadow will blur. Whatever method you use to make the recording, these are exciting times and we wish you good luck and clear skies!

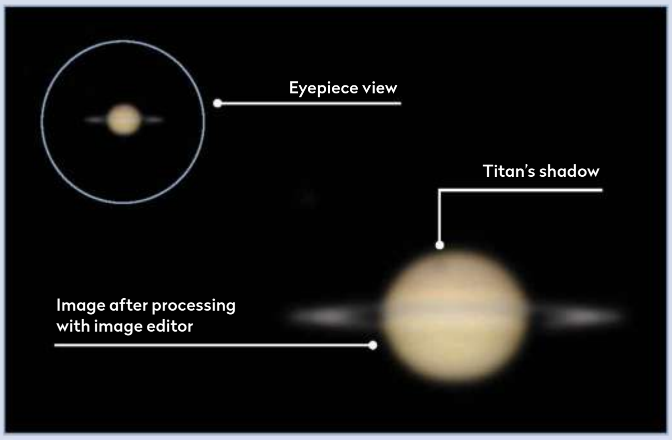
Pete Lawrence is an expert astro-imager and a presenter on *The Sky at Night*

Equipment: A telescope capable of showing Saturn as a tangible disc, and a camera

Send your images to:
gallery@skyatnightmagazine.com

ALL PICTURES: PETE LAWRENCE

Step by step



STEP 1

Not all captures need high-end cameras. If you have a telescope that shows Saturn's disc, get the planet in view, focus (if you wear glasses, keep them on), then try pointing a smartphone camera down the eyepiece during a shadow transit. The shadow will be very subtle and may need a little coaxing via an image editor.

STEP 2

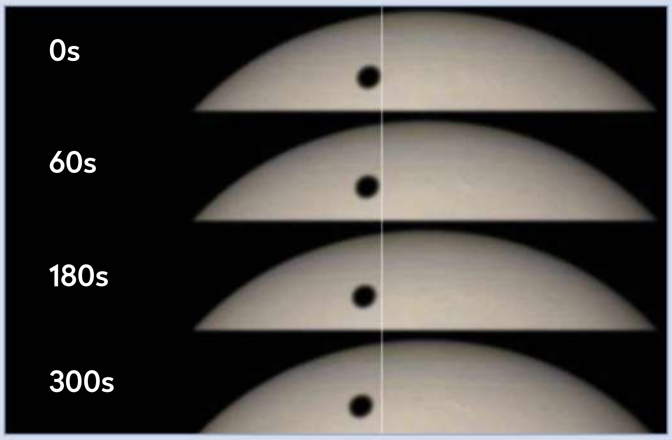
Holding a smartphone in place by hand, known as afocal photography, can be tricky, especially when the time comes to press the shutter button. An adaptor can remove any alignment issues and a Bluetooth shutter control can trigger the shutter without wobbling the camera/telescope.

STEP 3

A DSLR (or equivalent) coupled to a telescope will also work, but upping magnification – via a Barlow or Powermate, for example – will amplify any seeing and atmospheric dispersion problems, and your photo may not be that sharp. Despite this, the additional control such a camera affords will make the capture a lot easier.

STEP 4

For best results, use a high-frame-rate setup. Saturn currently reaches a maximum altitude approaching 30° when due south, low enough for atmospheric dispersion to be an issue. With no guarantee that Titan events occur at peak altitude, using an atmospheric dispersion corrector (shown) can help.



STEP 5

Keep capture sequences below 180 seconds, during which Titan's shadow moves by around 14 per cent its diameter. Above that, it moves 18 per cent. Registration-stacking such captures should produce a reasonably sharp shadow or moon. A higher-than-usual gain may be required. A lower focal length will help too.

STEP 6

If you do manage to make captures, consider repeating them, say every 5 minutes, for the duration of the event. This will give you enough results to animate into a movie sequence. Be consistent with settings and take care to avoid Saturn becoming hidden by a foreground object before the event concludes.

Expert processing tips to enhance your astrophotos

ASTROPHOTOGRAPHY

PROCESSING

Combining comets with deep-sky objects

Part 2: How to blend both elements to create one sharp image

▲ **Martina's original blurry image of C/2017 K2 Pan-STARRS meeting globular cluster M10 in July 2022 (left) and the final, sharp composite (right) after using DeepSkyStacker, PixInsight and Photoshop to stack, process and blend her 27x 120-second light frames**

This month, I continue with part two of creating a composite image featuring comet C/2017 K2 Pan-STARRS and the globular cluster M10.

In part one, we stacked our subframes, creating two files – one aligned on the stars (the Stars file), the other aligned on C/2017 (the Comet file) – then began processing them in PixInsight. Now we'll finish processing and then combine our files. First, we'll perform a histogram stretch on both, before extracting the stars from our Stars file to create a 'Stars Only' file minus the blurry comet. We'll then combine the two files.

Let's start by stretching the Stars file – which currently includes a blurred comet (see Before, above). We previously performed a temporary automatic stretch with the Screen Transfer Function in PixInsight, but now we click Process › All Processes › HistogramTransformation (see Screenshot 1).

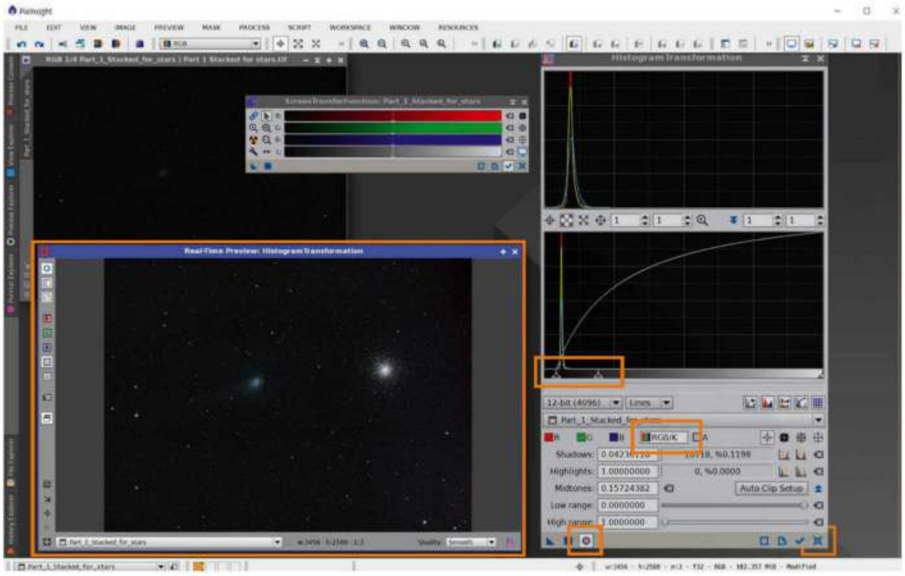
Open the Stars image, then select it in the dropdown menu of the HistogramTransformation window. Select RGB/K to adjust the red, green and blue colour channels simultaneously before clicking the orange circle to open a Real-Time Preview window (highlighted). Click and drag the right anchor point under the histogram leftwards to start stretching the data. Once you're happy, click the blue square 'Apply' button, followed by the 'X' icon on the bottom right.

Next, drag the left anchor point to the right, closer to the histogram but without clipping the curve. Click Apply, then 'X'. You can make further stretches, but don't go too far as we'll adjust again later. Once satisfied, close the preview window. Repeat these HistogramTransformation steps for the Comet image.

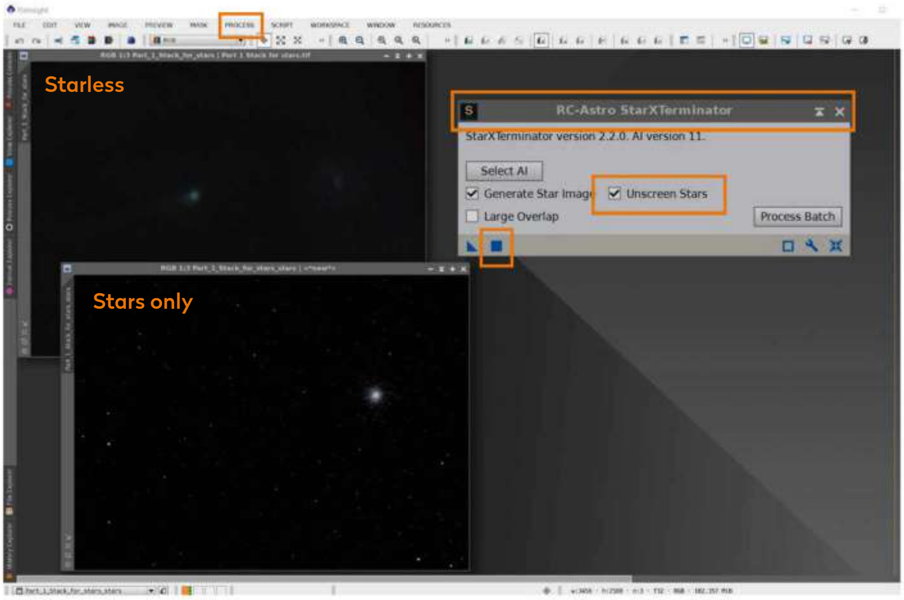
Remove the stars

Now we can extract the stars from the Stars image. I use Russ Croman's StarXTerminator plugin for PixInsight. Once installed, click Process › All Processes › StarXTerminator (see Screenshot 2). Tick 'Unscreen Stars' and then the blue square icon to run the star removal script. This

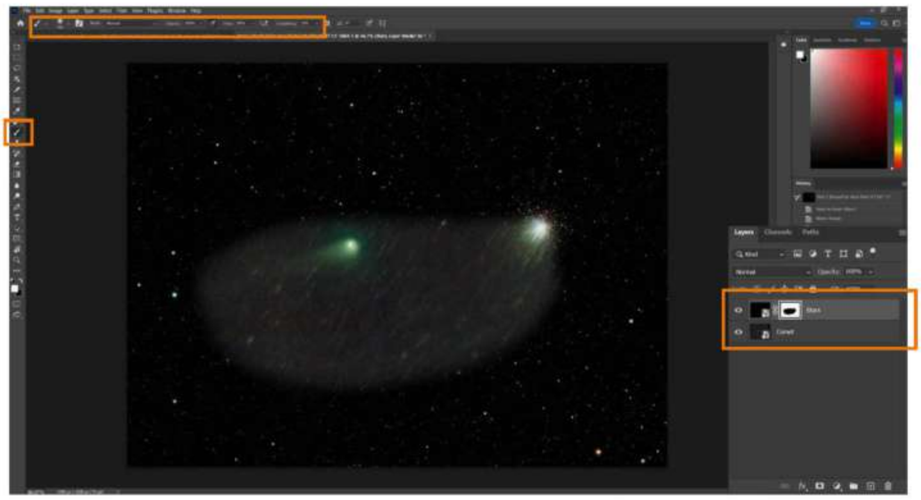
ALL PICTURES: MARTINA MCGOVERN



▲ **Screenshot 1: open your Stars image in PixInsight. Use HistogramTransformation to stretch your data before adjusting the colour channels. Repeat for your Comet image**



▲ **Screenshot 2: the StarXTerminator PixInsight plugin will create a starless image and a stars-only image. Use HistogramTransformation again to stretch the stars-only image**



▲ **Screenshot 3: using Layers in Photoshop, rename each file's layers then move the Stars layer on top of the Comet layer. With a mask and the brush tool (try size 400, hardness 0, Normal mode, opacity at 100 per cent), blend the two before flattening and saving**

3 QUICK TIPS

1. Starnet2 is a standalone program that can be used to extract stars, instead of the StarXTerminator plugin.

2. PixInsight's CurvesTransformation tool can be used to further improve the colours of your Stars and Comet.

3. Check the progress of your layer mask by highlighting the Stars layer, holding the Alt key and clicking the 'Layer mask' icon.

creates a starless image and a 'Stars Only' image (highlighted). Close the unneeded starless image and continue stretching the Stars Only one using the HistogramTransformation tool.

You now have Stars Only and Comet files, ready to merge in Photoshop. Save them as 16-bit TIFs. Click File › Open as Smart Object › file location, so they appear side by side. In the Layers section of each file (highlighted, Screenshot 3), rename the layer. Name the Stars Only layer 'Stars' and the Comet's layer 'Comet'.

Select the Comet image and the Move tool. Drag the Comet layer onto the header bar of the Stars Only image. Still holding the mouse button, bring the cursor to the centre of the image and release the mouse button. Now, re-click and hold to move the Comet image so that it covers the Stars Only image.

You now have two layers in Stars Only: a Stars layer and a Comet layer. Make sure Stars is above Comet. Now blend your comet into the Stars using a layer mask. To add this to the Stars layer, select it and click 'Layer mask' (highlighted, Screenshot 3). Click the thumbnail that's appeared next to the Stars layer and invert the mask by pressing Ctrl + i. Your Comet image is now visible and the Stars Only image is 'hiding' behind it.

Using the Brush tool (highlighted), wipe over the Comet image background to allow the stars to 'pop' through. Adjust the brush size and opacity the closer you get to the comet. Once happy with your results, flatten the image and save the file.

Martina McGovern is an amateur astronomer, astrophotographer and retired engineer

Your best photos submitted to the magazine this month

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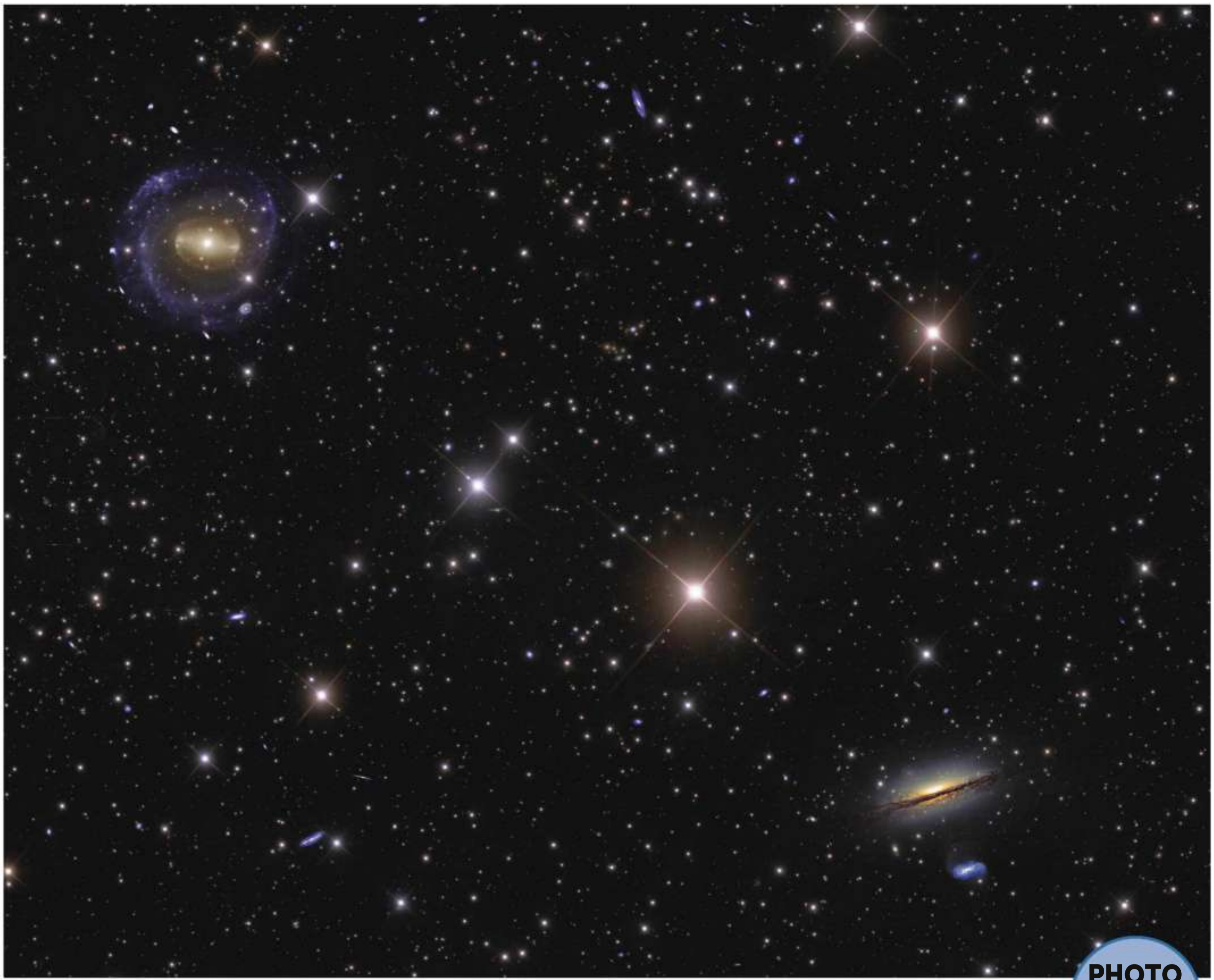


PHOTO OF THE MONTH

△ NGC 5101 and NGC 5078

Daniel Stern, Rio Hurtado, Chile, March–July 2024

Daniel says: "The two most prominent galaxies in this picture – NGC 5101 in the upper left and NGC 5078 in the lower right – are similar in size to our own Milky Way and are about 90 million lightyears away. To put that into perspective, the light captured in this image left its source 25 million years before dinosaurs went extinct."

Equipment: Moravian C4-16000 camera, PlaneWave CDK-17 astrograph, PlaneWave L-500 mount
Exposure: L 96x 300", R 109x 300", B 117x 300"
Software: PixInsight

Daniel's top tips: "The more experience I get, the less processing I do. I've found that less is more. Even as my toolset expands, I try to let the data speak for itself. In the past, I always tended to over-process images, but now I use a lighter hand. It's more challenging, but I think the quality of my images has improved."

◁ Perseid meteors

Constantine Themelis, Pelion, Greece, 12 and 13 August 2024

Constantine says: "I waited until the Jupiter–Mars conjunction was above the horizon and captured more than 180 meteors, with the brightest making it into the final image."

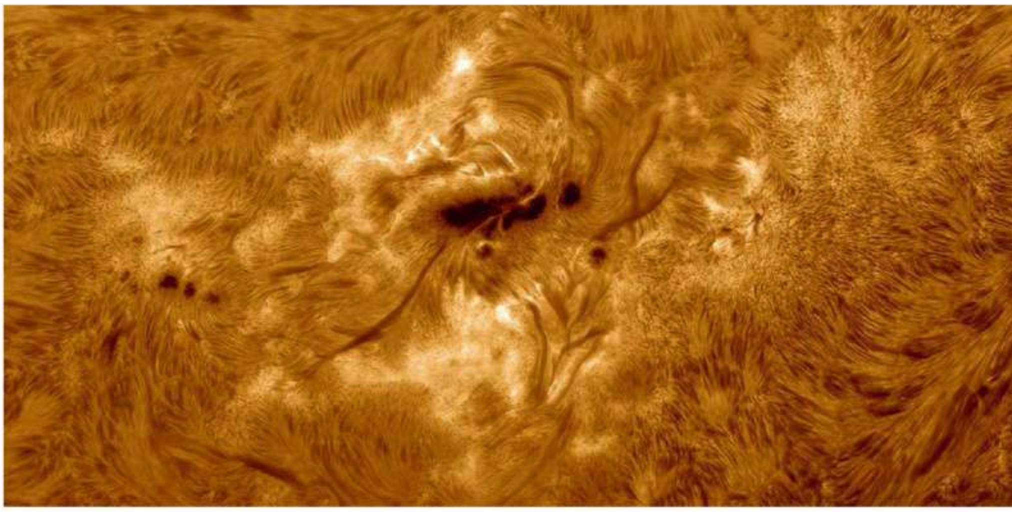
Equipment: Sony α7 III and Canon EOS 6D cameras, both with Sigma 14mm lens, Benro Tortoise 24C and Leofoto Summit LM-364C tripods
Exposure: Best of 3,000 exposures, ISO 3200 f/1.4 and f/1.8, 13"
Software: Photoshop, PixInsight

Sunspot AR3780 ▷

Ewan Hobbs, Hastings, East Sussex, 11 August 2024

Ewan says: "I wanted to capture AR3780 as it's one of the biggest sunspots this cycle. Once I'd processed the image, I just said 'wow' – a rare reaction to one of my own pictures!"

Equipment: Point Grey IMX174 camera, Tecnosky 152/900 refractor, Sky-Watcher AZ-EQ6 GT mount
Exposure: Best 2,500 of 5,000 30fps frames
Software: ImPPG, AutoStakkert!, Photoshop



◁ Star scribbles

Paolo Palma, Naples, Italy, August 2023–July 2024

Paolo says: "This mosaic of 26 images of stars in the constellations of Delphinus, Aquila and Lacerta was created by tapping the body of my 18-inch Dob while holding a smartphone up to the eyepiece."

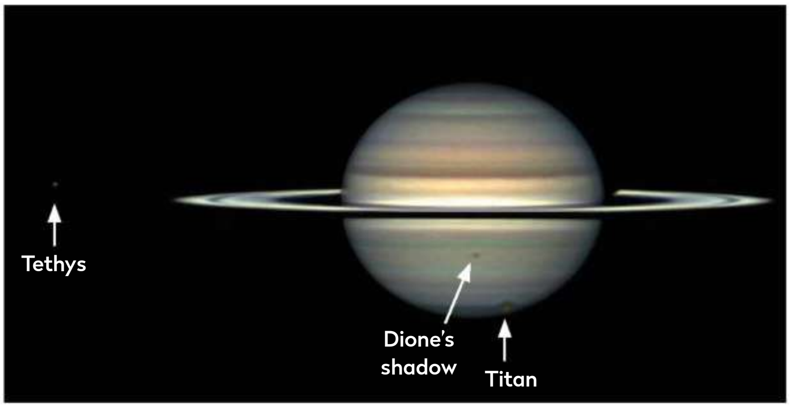
Equipment: Huawei P30 Pro smartphone, Sky-Watcher N458/1900 Stargate Dobsonian
Exposure: Various, 0.33"–1"

The Crescent Nebula, NGC 6888 ▷

Arpad Rektor, Westcliff-on-Sea, Essex, 20–21 June 2024

Arpad says: "It was a challenge to image this on the shortest nights of the year! But five hours was enough to bring out the soap bubble around the main gas cloud."

Equipment: Altair Hypercam 26C camera, Celeston C8 Schmidt–Cassegrain, Sky-Watcher AZ-EQ6 Pro mount **Exposure:** 105x 180" **Software:** DeepSkyStacker, Siril, GIMP



◁ Titan transit

Eric Sussenbach, Willemstad, Curaçao, 1 August 2024

Eric says: "I was excited to capture a rare Titan transit. You can also see the shadow of Dione, and the moon Tethys on the left."

Equipment: Player One Neptune 664C camera, Celestron EdgeHD 14-inch Schmidt–Cassegrain, iOptron CEM120 mount
Exposure: Best 2,500 of 5,000 frames at 30fps
Software: WinJUPOS, RegiStax, Pixelmator Pro

Perseid meteors and the aurora ▷

Meena Singele, Belalp, Switzerland, 11 August 2024

Meena says: "The curve of the Aletsch glacier flanked by the Alps is one of my favourite landscapes to photograph the Perseids from. The Northern Lights were a bonus!"

Equipment: Sony a7 IV camera, Sony 24mm lens, K&F Concept tripod
Exposure: ISO 3200 f/1.6, 13"
Software: Lightroom

△ Milky Way over Derwentwater

Toby Sinkinson, Derwentwater, Cumbria, 27 July 2024

Toby says: "I was shocked by how dark the skies were over Derwentwater. This symmetrical island made for a great photo and I thank the clouds for parting!"

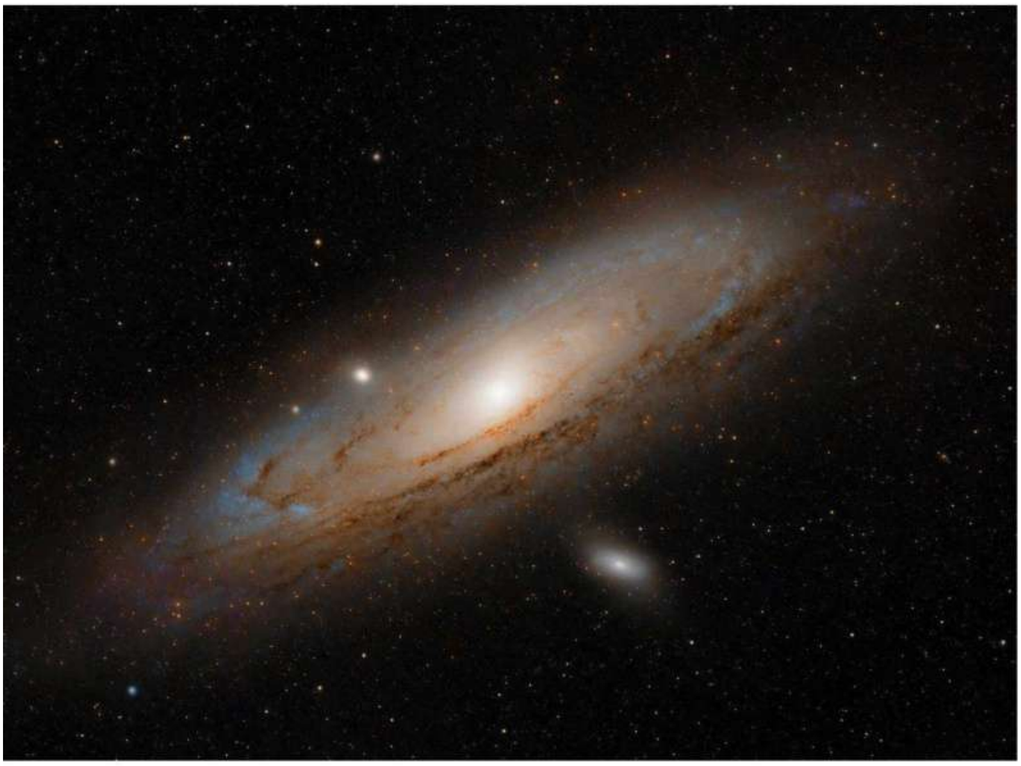
Equipment: Canon EOS 6D camera, 17–40mm f/4L lens **Exposure:** sky ISO 1600 f/4.0, 8x 30"; foreground ISO 1600 f/4.0, 120" **Software:** Starry Landscape Stacker, Photoshop

△ Globular cluster M92

Ron Brecher, Guelph, Ontario, Canada, 31 July–1 August 2024

Ron says: "M92 is one of my favourite telescope targets. I was pleased with how nicely this shows all the tiny stars in the outer halo."

Equipment: QHY600M camera, Celestron EdgeHD 14-inch Schmidt–Cassegrain, Paramount MX mount **Exposure:** R 1h 30', G 1h 34', B 1h 29' **Software:** PixInsight



◁ The Andromeda Galaxy, M31

Jim Owen, Swadlincote, Derbyshire, 27 and 28 August 2024

Jim says: "Andromeda was the first galaxy I imaged when I took up the hobby four years ago. I decided to revisit it and was really pleased with the results."

Equipment: Altair Hypercam 26C camera, Altair Starwave 60ED refractor, iOptron CEM40 mount
Exposure: 120x 30", 120x 1'
Software: Astro Pixel Processor, PixInsight

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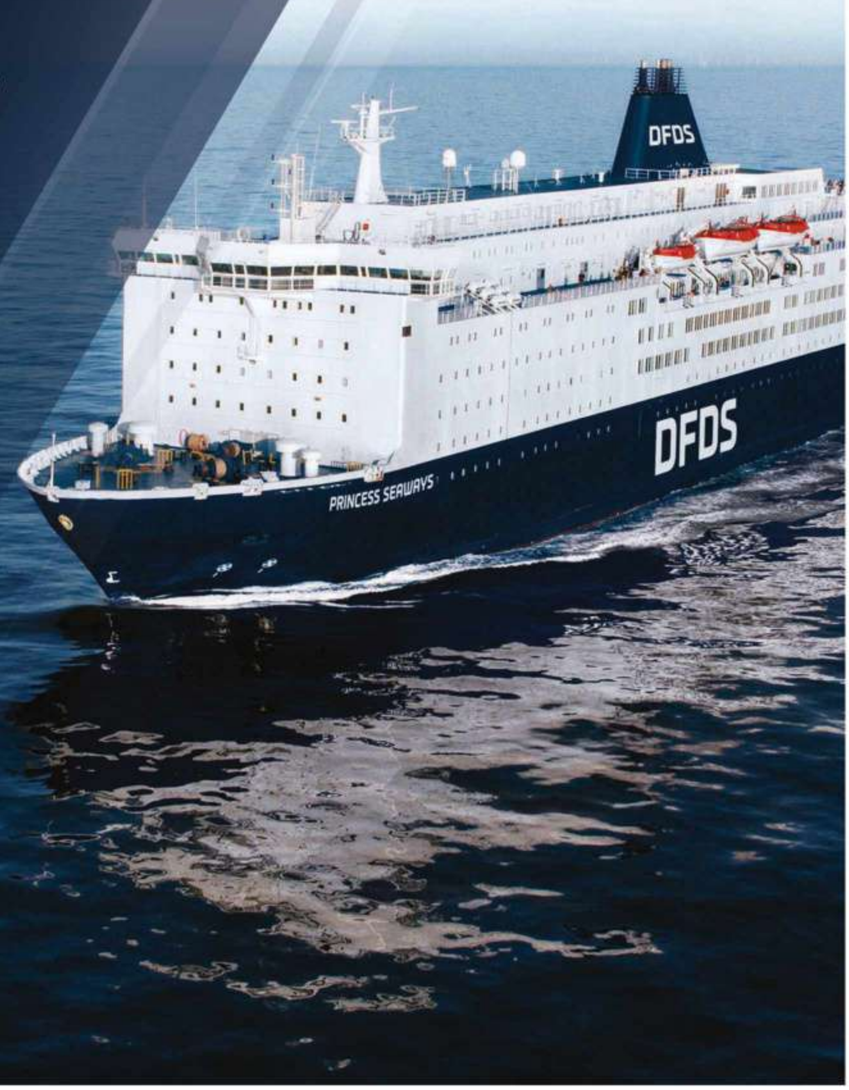

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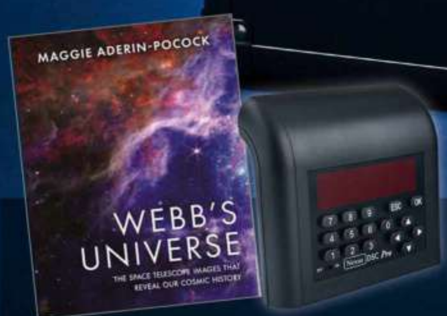
86

Packing a punch
Heavy payloads, silent motion, zero backlash... and all without counterweights? We put WarpAstron's new mount to the test



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HOW WE RATE

Each product we review is rated for performance in five categories. Here's what the ratings mean:

★★★★★ Outstanding ★★★★★ Very good
★★★★★ Good ★★★★★ Average ★★★★★ Poor/avoid

WarpAstron WD-20 harmonic drive mount

This compact setup handles hefty payloads a treat – with no bulky counterweights

WORDS: CHARLOTTE DANIELS

VITAL STATS

- **Price** £3,199
- **Mount type** Servo direct drive, harmonic, GEM/altaz
- **Load capacity** 22kg
- **Slew speed** Up to 10° per second
- **Power input** 2.1mm/2.5mm, 12V 5A DC
- **Autoguider port** ST4 (USB-C)
- **Protocols** ASCOM, INDI, LX200
- **Weight** 5.4kg
- **Supplier** Widescreen Centre
- **Tel** 01353 776199
- **www.** widescreen-centre.co.uk

Harmonic drive mounts are on the rise, and plenty of the most well-known astronomy equipment manufacturers have put their own models on the market. WarpAstron is a new name, however, not just to the mount sector, but astro equipment in general. Its second harmonic offering, the WD-20, promises a load capacity of 22kg within an astonishingly portable 5.4kg mount – most impressively, doing it without a counterweight. Featuring high-precision encoders, built-in GPS and claiming zero backlash, our interest was piqued!

Arriving in a smart, solid carry case, the WD-20 comes with three connection cables (for PC, power and controller), Allen keys and a controller. At the time of review, WarpAstron doesn't manufacture an accompanying tripod, and we mostly tested the WD-20 using our handmade pier via a Sky-Watcher EQ6 adaptor. However, the Widescreen Centre also loaned us an Avalon 110 tripod as a portable option. The WD-20 doesn't come with a power supply, so we used our own 12V 5A supply with 2.1mm jack. Setting up, we noted a pier extension would be handy, especially if filter wheels, off-axis guiders and electronic focusers are in your imaging train.

We alternated between an 81mm refractor and 8-inch Newtonian reflector on board the WD-20, using a laptop to coordinate image sequences and guiding via SGPro and PHD2. Locating and downloading ASCOM drivers from the WarpAstron website was simple, while connecting to either software was consistently easy.

Silent running

Ready to test, we found ourselves appreciating little design details. The WD-20's altitude and azimuth clamps were easy to lock/unlock during drift alignment, while we particularly liked the mount's built-in Home button – a great back-up option that ensures it parks correctly if needed.

It's difficult to describe just how quiet the WD-20 is, not only when idle or tracking, but also slewing. The ▶

Servo drive, no backlash

The WD-20 incorporates servo direct-drive technology with encoders for low to zero backlash, precise tracking and Go-To.

Direct drive means the servo motors are directly connected to and driving the strain wave gear (harmonic drive), without stepper motors or timing belts. Common in traditional equatorial mounts, these can affect guiding corrections and mount performance, either through degradation or by introducing torque loss into the system. Not having them removes the requirement for a counterweight with higher payload weights.

As a result, this mount's load capacity exceeds many others in this weight category before a counterweight is needed. The RA axis is fitted with an electromagnetic auto brake in the event of power failure.

The RA and dec. axes servo motors are each equipped with encoders to increase pointing accuracy and guiding precision, and to ensure faster response times for corrections. In our opinion this delivered superior Go-To capability. The PHD2 Guiding Assistant also confirmed WarpAstron's backlash claim, returning a figure of 0 +/-29ms.

TRIPOD NOT INCLUDED

ALL PICTURES: @THESHED/PHOTOSTUDIO

Altitude/azimuth adjusters

The same style of adjusters used on the mount saddle is used for the azimuth adjustments during polar alignment. These provided the grip for minute nudges, ensuring a swift and precise drift alignment process. The altitude bar offers a similar level of movement precision, while the side clamps locked everything securely.

Ports

Each port is annotated to ensure correct mount connection. Two USB-C ports are located at the front of the WD-20: one to connect to a PC and the other to connect the provided controller. A power port completes the set. Two LED lights confirm power, slewing and tracking activities.

Dual-fit saddle

The beautifully machined saddle comfortably accommodates Vixen and Losmandy mounting plates. We particularly liked the design of the adjustment knobs; rather than the common rounded style, their star-like shape fitted the curve of our fingers, allowing us to effortlessly tighten everything while remaining easy to locate in the dark.

Controller

The hand controller connects to the WD-20 via an included USB-C to USB-C cable. This can be used for operational functions in the event that a laptop with astronomy command software isn't available. For example, we easily performed a three-star alignment, slewed to astronomy targets and parked the mount via the controller.

FIRST LIGHT

▲ **The proof is in the stars, which were gratifyingly pin-sharp in the Elephant's Trunk Nebula, using a William Optics GT81 refractor and Starlight Xpress H694 camera**

Hard case

The aluminium case accompanying the WD-20 is an excellent addition, providing compact and secure transportation. Featuring twin handles and robust locking clamps, we felt confident that the case could easily take the weight of its contents. The mount, controller and cables fit snugly inside the foam compartments.

▶ first time we asked it to locate a target, we assumed the mount hadn't responded to our command; it wasn't until we shone our torch that we saw it silently moving to the object. Go-To accuracy was impressive, both via the hand controller and SGPro automation software. Each night, the WD-20 successfully centred our chosen target within minutes.

While astrophotographers tend to use laptops and/or astronomy controllers, the supplied WD-20 hand controller is a solid backup option. It contains an LED display, although in the dark we wish the buttons had been backlit. It would be remiss of us not to note some of the controller's confusing terminology: 'guide rate' in the controller actually means the WD-20's 'slew rate', while the 'pulse guide rate' is the guide rate. Nevertheless, in no time we had overcome these minor quirks, which allowed us time to focus on PHD2's guide settings.

We quickly discovered that to get the best from this rapidly responsive mount, we had to discard everything we thought we knew about PHD2 guiding. After a couple of nights adjusting guide exposure times, 'MinMo' (minimum move) and RA/dec. aggression settings, we felt we'd discovered the best combination for our equipment.

We were undeniably curious about guiding performance, especially using an off-axis guider and therefore guiding with the focal length of our telescope. WarpAstron has claimed an average total guiding accuracy of 0.5 arcseconds RMS can be expected – in average seeing conditions across several nights, we easily achieved this, regularly reaching 0.35 arcseconds.

Of course, we weren't utilising the full payload capacity of the WD-20, and guide numbers come second to star shape; our findings were further confirmed by the tight stars in our image of the Elephant's Trunk Nebula, IC 1396.

One thing that we noticed was lacking from the mount was a smartphone control app. WarpAstron has advised that one is in development, yet we didn't feel its absence – seeing it rather as a 'nice to have'.

The WarpAstron WD-20 is a mount for dedicated astrophotographers, yielding impressive results once you've got to grips with it, yet with a little potential left to fulfil. It might not be 'plug and play', but that doesn't undo the rewarding returns of this high-performance harmonic mount. It's a strong sign of things to come for WarpAstron.

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VERDICT

Assembly	★★★★★
Build & design	★★★★★
Ease of use	★★★★☆
Go-To/tracking accuracy	★★★★☆
Stability	★★★★☆
OVERALL	★★★★☆

KIT TO ADD

1. Avalon T-Pod 110 tripod

2. Avalon 3/8-inch adaptor for T-Pod 110 tripod

3. ZWO PE200 pier extension

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CRUISE COLLECTIVE

Acuter Solarus 80 solar telescope and mount

An enjoyable entry-level all-in-one for observing sunspots and eclipses

WORDS: SONIA TURKINGTON

VITAL STATS

- **Price** £549
- **Optics** Multi-coated, built-in glass white-light solar filter
- **Aperture** 80mm
- **Focal length** 400mm, f/5
- **Mount** Go-To solar tracking, 16x and 1,200x slewing speeds, 0.625 arcsecond resolution
- **Extras** Solar finder, filter wheel, filters, 90° diagonal, accessory tray, Vixen-style dovetail, smartphone holder
- **Weight** 1.75kg; 4.05kg with mount and tripod
- **Supplier** Optical Vision Ltd
- **Email** info@opticalvision.co.uk
- **www.** opticalvision.co.uk

Solar astronomers require specialist equipment to safely view the Sun. In a market of solar telescopes, high-end filters and Herschel wedges, it's fairly unusual to see budget equipment. However, Acuter has come up trumps with its Solarus 80 refractor.

This solar telescope comes complete with built-in white-light filter, solar finder, diagonal, zoom eyepiece, smartphone adaptor and a filter wheel pre-loaded with colour filters. While the telescope bundle is available to purchase on its own, Acuter also offers a complete telescope and mount outfit, including GPS solar tracking mount and tripod, which is what we're reviewing here.

Receiving the full kit, we were keen to take advantage of some late summer sun. Assembling the Solarus 80 setup was easy; we attached the pier extension to the locking bolt on top of the tripod, followed by the mounting head, before adding the mount and telescope. We noted two options to power the mount: there's an input port for an external power supply or you can use eight AA batteries. Neither option comes supplied with the kit, so we opted to use batteries.

In less than 15 minutes, we were ready to look for sunspots. Heading outside, we found the full setup easy to carry. Ensuring we placed it on even, flat ground was also simple, thanks to bubble levels on the tripod and mount. Powering up, we waited for the mount to complete its initial search for the Sun before using the solar guider provided; it took a couple of attempts, but we soon located it in our eyepiece with a slight adjustment of the mount's slewing button – you need to press this button and the power button simultaneously to slew.

Trying out the filters

Glimpsing the Sun, we got that familiar wow factor, particularly due to the numerous sunspots present as it nears solar maximum. While we struggled to see surface granularity, we were still impressed as we moved through the different coloured filters. ▶

One-stop solar setup

The Solarus 80 telescope and mount package includes everything a beginner solar astronomer could want. Thanks to the pre-installed white-light filter, the photosphere of the Sun can be safely observed almost straight from the box. Sunspots, partial and total solar eclipses, and planetary transits can be enjoyed with this budget setup.

We particularly liked the mount's built-in GPS. A few minutes is all it took for the mount to establish our time and location, before calculating the Sun's azimuth and altitude via Acuter's patented solar-alignment technology and commencing its search.

Slewing was smooth and quiet. While the Sun wasn't quite in the eyepiece, a slight adjustment was all that was needed to centre it in our field of view. Using the mount across several sessions, we found the location accuracy was consistently impressive for such a budget setup. Tracking was also effective; we left the setup for over 30 minutes and returned to discover the Sun was still central in the eyepiece.

ALL PICTURES: @THESHED/PHOTOSTUDIO

Safe solar finder

The handy included solar finder allows you a second, manual method to safely locate the Sun, in the event of GPS location issues. By viewing the Sun's shadow as a dot in the finder's crosshairs, we could slew the mount until it appeared in the built-in eyepiece's field of view.

Built-in zoom eyepiece

Zoom eyepieces are relatively unusual in beginner kits, but the Solarus 80 is fitted with a 5–16mm version. This allowed us to view the Sun across three different focal lengths and magnifications, providing options to adapt our field of view to suit the conditions of the day and individual eyesight.

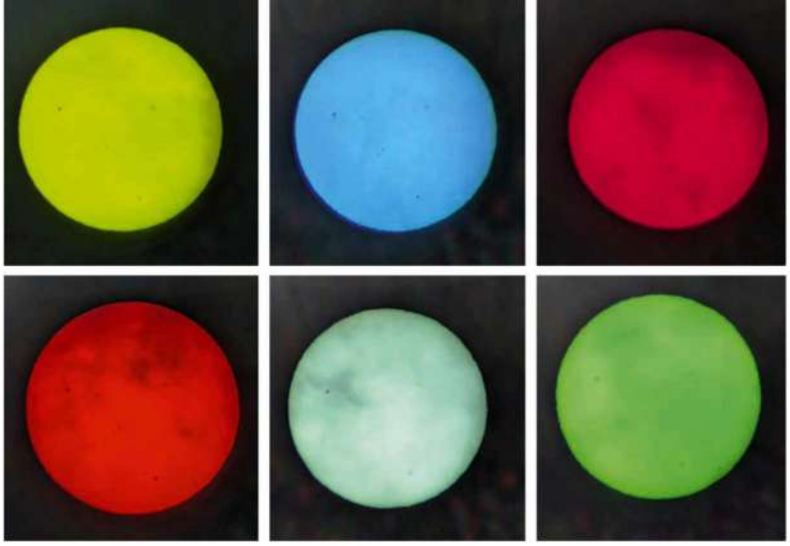
Diagonal

The 90°-angled diagonal comes fitted to the Acuter Solarus 80, sandwiched between the built-in filter wheel and eyepiece, and provided a comfortable viewing experience. The internal mirror provided an upright, back-to-front image. Note that the diagonal is not rotatable.

SCALE

Filter wheel and filters

The filter wheel comes preloaded with red, yellow, blue, green, orange and neutral-density filters to help boost sunspot contrasts and details according to user preference. An empty slot is also included, should you wish to do solar observing with only the built-in white-light filter. A simple switch allows easy movement between the options.



▶ Personally, we preferred the lighter options. Changing filters required a bit of force, but we found holding onto the diagonal helped.

Visually, we didn't note any internal glare, enjoying clear views of the Sun's surface. The built-in zoom eyepiece offers three set focal lengths and magnifications: 5mm (80x), 10mm (40x) or 16mm (25x). During our time with the Solarus 80, we found this handy as we didn't have to keep swapping eyepieces. The downside is not being able to interchange accessories, which limits your options longer-term.

While the 16mm length presented the Sun at a relatively wide field of view, we found it to be clear, sharp and in focus, thanks to the Solarus 80's Crayford focuser. We thought the 10mm view was optimal for this setup, as the solar disc perfectly fitted the field of view while the sunspots remained clear, sharp and perfectly focused. At 5mm, the sunspots lacked the same clarity.

Of course, we couldn't resist using the smartphone adaptor provided for a few snaps. We discovered that if the phone had more than one lens, it was a struggle to find and focus the Sun in the right one, but once we did and clamped the phone in place, we were able to take some satisfying images, albeit noting some internal reflections.

We thoroughly enjoyed our time with the Acuter Solarus 80 solar telescope and mount outfit. It is well suited to beginner and intermediate astronomers looking to enjoy daylight sessions, and Acuter has clearly considered the suite of accessories included. We found the mount's solar auto-tracking and built-in GPS nice to use, easily navigating to our nearest star.

This isn't a telescope for observing prominences or the Sun's delicate surface details, but for sunspots it performed brilliantly. While it would be unfair to directly compare this to higher-end solar scopes, the price point and viewing experience prove this is an excellent starter set. With or without the mount option, the Acuter Solarus 80 shouldn't gather dust: it's rewarding and convenient enough to return to time and time again.

▲ **All shots taken with a Google Pixel 8 Pro mounted on the Solarus 80's smartphone holder and using the various pre-installed filters**

VERDICT

Build & design	★★★★☆
Ease of use	★★★★☆
Features	★★★★☆
Go-To/tracking accuracy	★★★★☆
Optics	★★★★☆
OVERALL	★★★★☆

KIT TO ADD

1. DC 7.5–12V 500mA power supply

2. AA batteries

3. Bluetooth shutter release for smartphone

Universal smartphone holder

Acuter has considered the needs of budding solar photographers with this universal holder. When correctly positioned across the eyepiece, it allowed a steady shot of the Sun to be safely taken. We were pleased to note that the holder had a secure grip of our phone throughout each photography session.

@THESHED/PHOTOSTUDIO X 2, SONIA TURKINGTON

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ASTRONOMY Back to Basics

DATE: Saturday 30th November 2024
TIME: 9:30 am – 6 pm
with registration and refreshments from 9 am
VENUE: University of Greenwich / Royal Observatory Greenwich

The British Astronomical Association (BAA), Flamsteed Astronomy Society (FAS) and the Society for Popular Astronomy (SPA) have come together to bring you a fantastic opportunity to explore the basics of astronomy

Join us for this all-day event including a planetarium show at the Royal Observatory – one of the most iconic venues in London

Topics to be covered include:

Observing the night sky

Introduction to astrophotography

Choosing binoculars and telescopes

Understanding the solar system, comets and deep sky objects

Connecting with other enthusiasts

★ Free raffle ★ Astronomy stands ★ Goodie bags ★

TICKETS:

Members of BAA, FAS and SPA	£8
Non-member adults	£10
Under 18s accompanied by an adult	£5

Prices include refreshments but not lunch

BOOKINGS:
Online: britastro.org/events
Phone: 0207 734 4145 (BAA Office)

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Charlotte Daniels rounds up the latest astronomical accessories

GEAR

1 Astro Devices Nexus DSC Pro with Wi-Fi

Price £398 • **Supplier** First Light Optics
www.firstlightoptics.com

ADVANCED These digital setting circles turn a non-Go-To mount into one that helps you locate objects in the night sky. It features built-in GPS and internal memory with over 73,000 objects, while Wi-Fi capability means you can access planetarium software from a tablet or smartphone.

2 Pushing astronauts bookends

Price £19.99 • **Supplier** Maison Des Cadeaux
www.mdcgifts.com

Show your love for space with these unique astronaut bookends. Made from high-quality resin, this pair of hand-painted holders will keep your books, DVDs and video games organised and in check.

3 Bresser Clearview 7-in-1 Wi-Fi weather station

Price £219.95 • **Supplier** Weather Shop
www.weathershop.co.uk

Stay one step ahead of temperamental skies with this mobile weather station. The 7-in-1 outdoor sensor measures wind speed, direction, temperature, humidity, rainfall, UV levels and light intensity, calculating local weather trends for up to 24 hours.

4 QHY spacer set

Price £49 • **Supplier** Modern Astronomy
www.modernastronomy.com

Spacer rings are essential to any astrophotographer's toolkit, allowing you to achieve the correct backfocus for a range of cameras and field flatteners. This set features five adjustment rings between 0.5mm and 7mm thick, plus a 4mm M54 female camera adaptor.

5 Map of the Universe jigsaw

Price £19.99 • **Supplier** The Yorkshire Jigsaw Store
www.theyorkshirejigsawstore.co.uk

Tackle rainy days head-on with this challenging 1,500-piece 80cm x 60cm jigsaw. Learn about galaxies, our Solar System and even stellar magnitudes as, piece by piece, the detailed map of the Universe emerges.

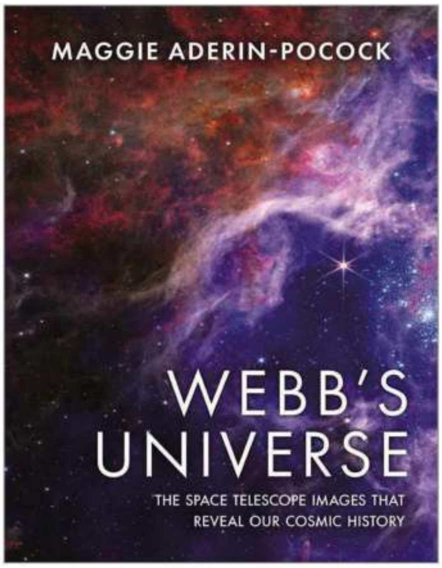
6 Cashmere fingerless gloves

Price £27.75 • **Supplier** Turtle Doves
www.turtle-doves.co.uk

Temperatures may be dropping, but your astronomy sessions don't have to suffer. Prevent frozen hands with these soft fingerless gloves made from 100 per cent recycled cashmere. Available in several colours.

New astronomy and space titles reviewed

BOOKS



Webb's Universe

Maggie Aderin-Pocock
Michael O'Mara
£25 ● HB

The James Webb Space Telescope represents the work of around 10,000 scientists and engineers from around the world. The author of this book was one of them and her voice, boundless enthusiasm, deep knowledge and good humour shine out as brilliantly in the text as the images that she's describing shine out from the page. This is not just a book of pretty pictures; it is so much more.

The book is divided into three sections. The first details the telescope itself, its history and the history of space telescopes in general, and goes on to describe how Webb was designed and built, and how it works. The second part explains Webb's science goals, the instruments it carries and how the data is processed, taking wavelengths we are unable to see with our eyes and mapping them onto wavelengths of corresponding visible light to produce images that are scientifically accurate as well as good to look at. The author worked on the Integrated Field Unit (IFU), which forms parts of Webb's NIRSpec (Near-Infrared Spectrograph) instrument, but all four of JWST's instruments are described clearly and in satisfying detail.

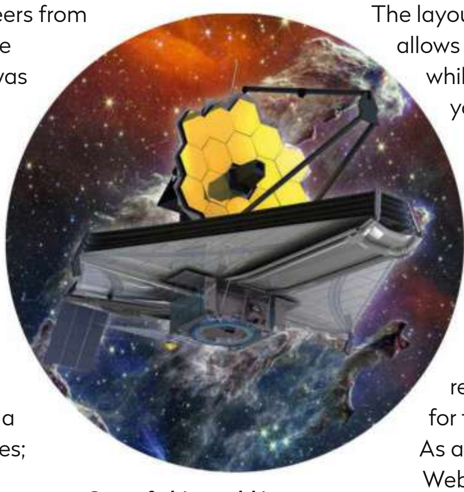
It is the third part of *Webb's Universe* that takes your breath away, since its images are simply spectacular. From planets within our own Solar System to nebulae, stars, galaxies and exoplanets, each image is beautifully presented, while the science behind each is drilled into and explained in depth. Often this is with side-by-side comparisons and combined images with data from other telescopes as well. Throughout the book, scientific processes are detailed with useful diagrams, and peppered throughout are the names and faces of astronomers from the past who have contributed to our knowledge of the cosmos.

The layout is crisp and really allows the images to shine, while the text draws your attention to fascinating details in the images and adds scientific background to the processes on display, including how Webb's infrared sensitivity is able to reveal these processes for the first time.

As a self-confessed Webb obsessive, I found this book a joy to read, with plenty of technical detail and scientific insight alongside the stunning images. A feast for the mind as well as the eyes.

★★★★★

***Jenny Winder** is a science writer and broadcaster*



Out-of-this world images meet in-depth scientific explanation in Aderin-Pocock's book

SCIENCE: NASA/ESA/CSA/STSCI/IMAGE PROCESSING: JOSEPH DEPASQUALE (STSCI) ALYSSA PAGAN (STSCI) ANTON M. KOEKEMOER (STSCI)

Interview with the author
Maggie Aderin-Pocock

What are your favourite images from Webb?

Too many to mention! The image of Uranus with the north polar cap and glowing outer rings is pretty special. The Pillars of Creation are incredible. They were first brought to the public's attention when they were photographed by the Hubble Space Telescope in 1995, but while Hubble's view was blocked by the nebula's dust, JWST's infrared vision enables us to see through the dust.

What should Webb investigate next?

One of the things on Webb's dance card is investigating more exoplanets. We know that the stars in the night sky are suns like ours, some bigger, some smaller. We've also found out that most of them have planets in orbit around them. Planets don't generate light, but Webb can spot more of these exoplanets and in some cases, if they have them, can analyse their atmospheres. This gives us a better understanding of planet formation and the variety of planets out there.

How big an achievement is Webb?

The moment it left Earth, there were over 300 steps at which the multibillion-dollar observatory could fail, and as it sits about a million miles from Earth (1.5 million kilometres), we've no way of fixing any problems, which made for a very tense launch. It took scientists and engineers over two decades to design and build. It involved the work of over 10,000 of us, years of development and problem-solving. I'm immensely proud to be one of those scientists who made a small contribution.

***Maggie Aderin-Pocock** is a space scientist and co-presenter of* The Sky at Night

Mars

FOR MARS FANS

Brendan Owens
Collins
£8.99 ● PB

I've been fascinated by Mars ("More like obsessed with!", shouts a voice from the other room) since I was knee-high to R2D2, so as you can imagine I've read a lot of books about it, probably almost as many books as there are craters on the Red Planet. It takes a lot for a new book about that faraway rusted world to impress me, but this one did.

Reading this slim volume (112 pages) is like listening to an outreach talk given by a very knowledgeable speaker who has chosen their slides carefully and wisely. It's concise and clear, with no hyperbole or breathless gushing: just facts, all linked together smoothly to tell the story of our relationship with Mars over the centuries.

Broken up into very logical sections, it covers everything, and I do mean everything. Mars mythology, early naked-eye and telescopic observations, modern space probe missions – everything is in there, covered in just enough detail to educate the reader without drowning them in information.

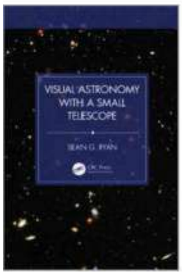
It's lavishly presented too. In fact, it was a little unnerving to find that almost every photo in the book is one of my own personal favourite Mars images. But every image is there for a good reason – there are no fillers in this book.

If you're already fascinated by Mars and think you know everything about it, you'll still find new information and new insights in this book, as I did. If you're just getting to know the Red Planet, this book is an excellent introduction to its history and geology, and to its special place in our imaginations and hearts. ★★★★★

***Stuart Atkinson** is an astronomy writer and author*

Visual Astronomy with a Small Telescope

Sean G Ryan
CRC Press
£22.99 ● PB



If you've recently bought your first small telescope or are thinking about buying one, *Visual Astronomy with a Small Telescope* is just the book to help get you started in your new observing journey. Written by Sean G Ryan, professor of astrophysics at the University of Hertfordshire, who has almost 50 years of experience as an amateur astronomer, this practical guide will assist anyone using or thinking about buying a telescope with an aperture 3–6 inches (75mm–150mm) in diameter.

Over five chapters, Ryan covers a range of topics, from understanding the telescope and how to plan an observing session, to what you'll be able to see in the night sky. Included in the book are 43 detailed star charts for both hemispheres and details of a whopping 380 objects that can be seen through a small telescope (that don't require computer control), including planets, galaxies, variable stars and planetary nebulae. It's a list capable of inspiring anyone to put their telescope into action.

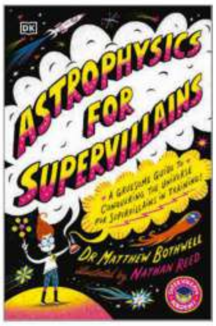
The book can be technical at times, which may put some people off, but such detail is necessary to understand the capabilities of your telescope, how the optics work and what eyepieces to use and when. More experienced observers may want to skip the technical chapters altogether and simply use the charts to help locate objects in the night sky.

This small, invaluable paperback is not for complete beginners, but rather for those who have a sufficient interest and some experience observing the night sky, who want to progress their observing skills and look further afield through a small telescope. ★★★★☆

***Katrin Raynor** is an astronomy communicator and fellow of the Royal Astronomical Society*

Astrophysics for Supervillains

Matthew Bothwell
DK
£7.99 ● PB



Astrophysics for Supervillains is far more whimsical, light-hearted and child-friendly than many astronomy books (even if it is a little evil).

With the subtitle *A Gruesome Guide to Conquering the Universe for Supervillains in Training*, it's aimed at a very general level, neither getting bogged down in details nor over-simplifying. The text is written very much in spoken voice, so one can imagine shouting the large, bold all-caps bits and whispering the lighter text. The well-aimed humour also makes it easy to forget at times that you're learning.

The many bold (albeit black and white) images, while not figures that convey scientific information, serve to break up the dynamic text in a fun way and overall make this look less like a textbook.

We start off learning how the various planets in our Solar System could kill you, then move on to nuclear fusion in the heart of the Sun, supernova explosions and black holes, finishing with the end of the Universe.

It's slightly odd that most of the book is 'background reading' to equip the budding evil genius with information about the Universe and how it works (albeit with a fair dose of morbidity); it's only in the final brief 10 pages that we really get to any supervillainy based on what we've learned so far. But at least those dastardly plans are based on sound science!

I'm not sure that a middle school child completely uninterested in astronomy would necessarily pick up *Astrophysics for Supervillains*, but if you know a kid who keeps asking about black holes yet doesn't want a lecture on astrophysics or to be given a textbook, this might just be the answer. Though maybe keep them away from rockets for a while... ★★★★☆

***Chris North** is head of public engagement at Cardiff University School of Physics and Astronomy*

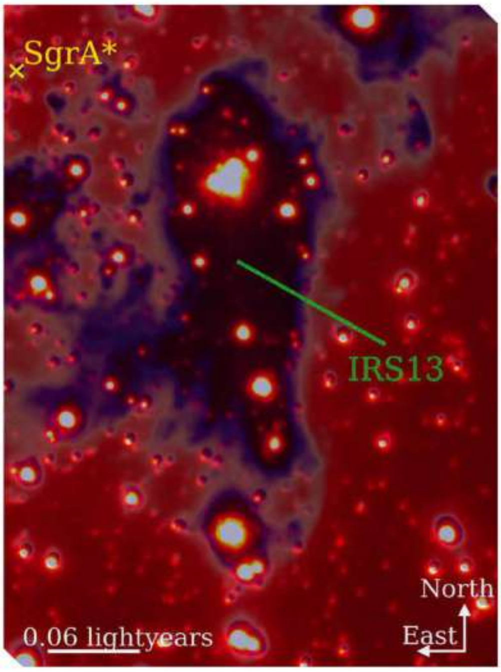
Anita Chandran interviews Dr Florian Peissker

Q&A WITH A BLACK HOLE INVESTIGATOR

A dense cluster of strangely young stars found at the centre of our Galaxy may prove that a rare middling-sized black hole is sitting nearby

What is about this cluster, IRS 13, that makes it so interesting?
In early observations of our galactic centre, astronomers found what they thought were stars around Sagittarius A*, the supermassive black hole at the Milky Way's heart. One of these stars was IRS 13. As observations improved, IRS 13 was found not to be a single star, but instead a group of several sources, which were later found to be clusters of stars. We have found that there are at least 70 objects in IRS 13. In fact, IRS 13 contains the highest density of stars of any region in the Milky Way.

How did you discover that IRS 13 was also hiding a black hole?
IRS 13 used to be treated as a tight group of bright objects. We found that it also contains a long, elongated, evaporating tail which moves together with the densely packed group of bright objects. That implies the existence of an object at the centre of IRS 13 that holds the whole structure together. By looking at evidence from different observations, we can infer that this object is an intermediate-mass black hole.



▲ **Researchers found super-young stars and a black-hole-shaped object in IRS 13, very near black hole Sgr A***

What is an intermediate-mass black hole (IMBH)?
Around 50 years ago, astronomers proposed every traditional galaxy hosts a supermassive black hole at its centre. These black holes are extremely large and heavy, over 100,000 times the mass of our Sun. There are also stellar black holes, which are not as heavy, with masses up to 10 or maybe hundreds of times the Sun's mass. But there is a big gap in the middle, and this is where we expect to find IMBHs. As of a few months ago, there are only 10 confirmed intermediate-mass black holes in our entire Universe, which is an amazingly low number.

What makes them so hard to detect?
If we look at the Milky Way to determine the presence of an IMBH, we can investigate single stars and their motion. Where there's a black hole, stellar orbits will be curved by the presence of an unseen object and you can calculate the mass of the unseen object based on the orbit of these stars. That's what we did for IRS 13. We gathered all the available data at all available wavelengths, from X-ray observations right the way across the electromagnetic spectrum. When we compared this data to theoretical predictions, we found they matched very well.

What were you investigating when you discovered IRS 13 had an IMBH?
We showed that IRS 13 is an evaporating cluster, which is itself an important discovery. The Nobel Prize winner Andrea Ghez once proposed the 'paradox of youth', an amazing finding which showed that the stars around Sagittarius A* are surprisingly young. Paradoxically so. But that raises a question of how and where these stars formed. Most astronomers agree they can't have formed around Sagittarius A* because of the extreme environment near the black hole.

But if a cluster with some younger stars approaches within 1–2 parsecs of Sagittarius A*, then this cluster might violently interact with another cluster or the material near the black hole. This violent interaction could cause the cluster to begin spiralling inwards towards Sagittarius A*, constantly interacting with the black hole but in a partially stable state. In this situation, young stars could start to form. This is exactly what we found in IRS 13: a cluster core containing evolved stars, but with an elongated tip containing candidates for very young stars. This is a mechanism that could potentially exist in other galaxies and could tell us about how a supermassive black hole could influence the formation of new stars.

What's next for your team?
The galactic centre is packed with so much amazing stuff, and there are many interesting objects floating around. In a few years, we will have access to the Extremely Large Telescope, which will give us the chance to observe the galactic centre in a previously impossible way. From all this data, I hope to draw lines of connection using the evidence we already have.

For example, we could start to explain how supermassive black holes get so large so quickly – something we don't yet know. This could arise from intermediate-mass black holes acting as seeds, which might also explain why we don't detect them as often as we might expect.

Florian Peissker is a researcher at the University of Cologne

FLORIAN PEISSKER/UNIVERSITY OF COLOGNE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SRP £299
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THE SOUTHERN HEMISPHERE

With Glenn Dawes

Enjoy views of five naked-eye planets and test your sea legs with four water-themed asterisms

When to use this chart

1 Nov 00:00 AEDT (31 Oct, 13:00 UT)
15 Nov 23:00 AEDT (12:00 UT)
30 Nov 22:00 AEDT (11:00 UT)

The chart accurately matches the sky on the dates and times shown for Sydney, Australia. The sky is different at other times as the stars crossing it set four minutes earlier each night.

NOVEMBER HIGHLIGHTS

See all five naked-eye planets in the evening sky this month – let the Moon be your guide. In late twilight, low in the west, Mercury is 2° from the thin crescent Moon on the 3rd. Two days later, spectacular Venus is 5° from the Moon. As twilight closes on 11th, Saturn and the Moon are together due north. Look north at midnight on 17th to find the full Moon close to Jupiter. Finally, at midnight on 20th, Mars and a near third-quarter Moon have just risen in the northeast.

STARS AND CONSTELLATIONS

Several lesser-known asterisms and constellations take centre stage, many with a water theme. Being mostly composed of fourth-magnitude stars, they can be surprisingly easy to find. Look north to find the Circlet of Pisces (the western fish), followed by another circle to the east, the head of Cetus the Whale. High above Pisces' circlet is the fish-shaped Piscis Austrinus (southern fish), with Fomalhaut forming its mouth. Next door (west) is the smiley-shaped Capricornus the Sea Goat.

THE PLANETS

November sees a brief evening return by Mercury, remaining low in the western twilight and lost in the Sun's glare by month's end, to return to dawn skies in late December. The early evening sees Venus ruling the western sky, with Saturn and Neptune having already transited in the northwest. Jupiter arrives around 21:00, presenting excellent opportunities to observe this gas giant high in the northern morning sky. As Mars rises around midnight, its best views will be before dawn.

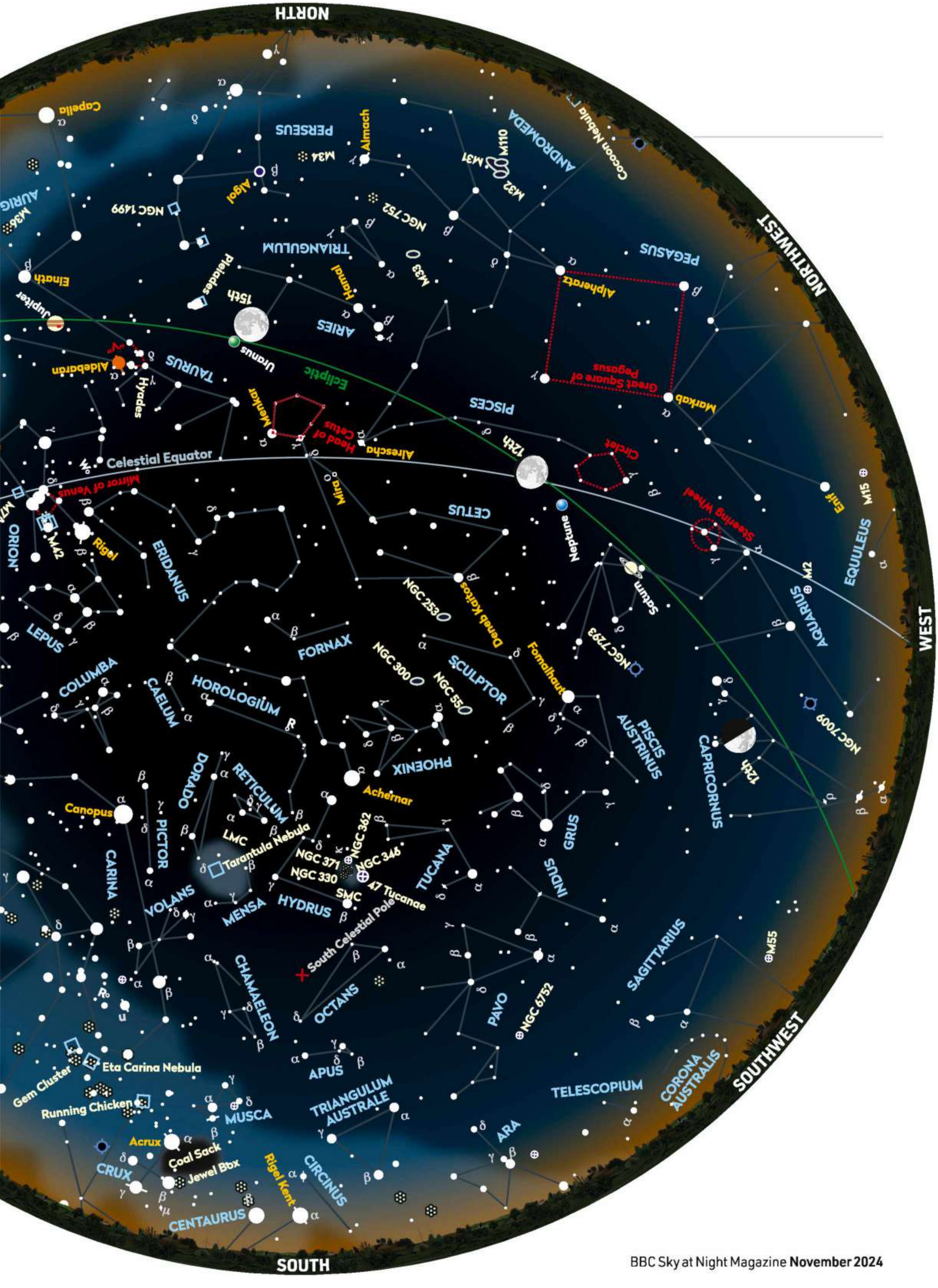
DEEP-SKY OBJECTS

The Small Magellanic Cloud appears as a 4° fuzzy blob high in the southern evening sky at this time of year. Binoculars display some tantalisingly scattered bright knots. The brightest example is located near the northern edge of the cloud: NGC 346 (RA 00h 59.1m, dec. –72° 11'). This is the most active star-forming region in the SMC, like the Tarantula is to the Large Magellanic Cloud. Telescopes show NGC 346 as a compact open star cluster, embedded in an oval-shaped nebula, roughly 5 arcminutes across. Also, in the same (wide) field of view, lies the open cluster NGC 371 (0.4° to the east). Compared to NGC 346, it's larger (10 arcminutes), more diffuse and made up of fainter stars. Lying 0.3° southwest of NGC 346 is the open cluster NGC 330. It is bright and compact, around 1 arcminute across, in a rich but faint star field.

Chart key

GALAXY
OPEN CLUSTER
GLOBULAR CLUSTER
PLANETARY NEBULA
DIFFUSE NEBULOSITY
DOUBLE STAR
VARIABLE STAR
COMET TRACK
ASTEROID TRACK
METEOR RADIANT
QUASAR
PLANET
STAR BRIGHTNESS:
MAG. 0 & BRIGHTER
MAG. +1
MAG. +2
MAG. +3
MAG. +4 & FAINTER

CHART: PETE LAWRENCE


NORTH
SOUTH
WEST
NORTHWEST
SOUTHWEST
PERSEUS
ANDROMEDA
PEGASUS
TRIANGULUM
ARIES
TAURUS
PISCES
CETUS
ERIDANUS
ORION
LEPUS
FORNAX
SCULPTOR
COLUMBA
CAELUM
HOROLOGIUM
PHOENIX
PISCIS AUSTRINUS
CAPRICORNUS
AQUARIUS
EQUULEUS
GRUS
DORADO
RETICULUM
PICTOR
CARINA
VOLANS
MENSA
HYDRUS
TUCANA
INDUS
CHAMAELEON
OCTANS
PAVO
SAGITTARIUS
APUS
TRIANGULUM AUSTRALE
TELESCOPIUM
CORONA AUSTRALIS
ARA
MUSCA
CIRCINUS
CRUX
CENTAURUS
Capella
Almach
Algol
Elnath
Jupiter
Aldebaran
Hyades
Pleiades
Uranus
Hamal
Menkar
Head of Cetus
Alrescha
Mira
Mirror of Venus
Rigel
Celestial Equator
Ecliptic
Alpheratz
Markab
Great Square of Pegasus
Circlet
Steering Wheel
Enif
Neptune
Saturn
Deneb Kaitos
Fomalhaut
Achernar
Canopus
LMC
Tarantula Nebula
SMC
47 Tucanae
South Celestial Pole
Eta Carina Nebula
Gem Cluster
Running Chicken
Acrux
Coal Sack
Jewel Box
Rigel Kent
Cocoon Nebula
M31
M32
M110
M34
M33
M36
M42
M15
M2
M55
NGC 1499
NGC 752
NGC 253
NGC 300
NGC 55
NGC 7293
NGC 7009
NGC 362
NGC 346
NGC 371
NGC 330
NGC 6752
15th
12th
12th
12th

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