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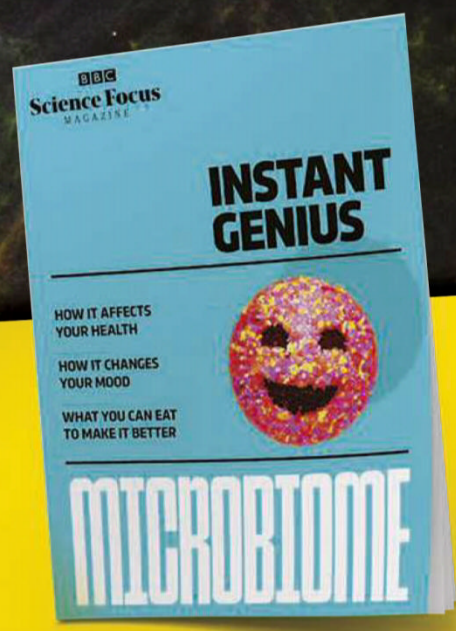

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HUBBLE'S HIDDEN GEMS

IN THE 30 YEARS SINCE HUBBLE'S LAUNCH, THIS ICONIC SPACE TELESCOPE HAS BEEN REVEALING THE WONDERS OF THE UNIVERSE WHILE BUILDING UP A LIBRARY OF SOME OF THE MOST SHINING SIGHTS IN THE COSMOS

WORDS: DR ELIZABETH PEARSON

IMAGES: NASA/HUBBLE SPACE TELESCOPE HERITAGE TEAM

LIFTING THE VEIL

←

VEIL NEBULA

Stars that reach a violent end and explode in a supernova will often leave behind a scar on the sky – a brightly coloured cloud of gas, known as a supernova remnant. The Veil Nebula is one such remnant, stretching out over 110 light-years.

Hubble took a look at the Veil Nebula back in 1997, only to return in 2015 when this image was taken. In the intervening years, astronauts had visited Hubble using the Space Shuttle and upgraded the main widefield and planetary camera for a second time. The improved resolution revealed the nebula's delicate gas filaments in a new level of detail.

The original supernova appears to have exploded just 8,000 years ago (practically yesterday in astronomy terms) and is still expanding. In the 18 years between the first and second images, the cloud has grown in size. Astronomers have been able to pick out these changes, helping to understand how such nebulae evolve. ▶

DUST BUSTER

←

PISMIS 24

Pismis 24 is just one cluster of stars in a large nebula, NGC 6357. The entire region is home to many young and growing stars, aka protostars. These grow up in thick dust clouds, which hide them from telescopes that can only view the Universe at visible wavelengths.

"Hubble can be used for UV, visible and some infrared observations. These panchromatic capabilities are incredibly useful for studying everything from Solar System activity to distant galaxies," explains Jennifer Wiseman, senior project scientist for the Hubble Space Telescope.

Here, Hubble has been able to pierce through the dust, creating a window into where infant stars are born. It was thought the mass of the cluster's brightest star, Pismis 24-1, was around 300 times that of the Sun, making it the heaviest in the Galaxy. However, Hubble puts it at a far more modest 100 solar masses.

STELLAR SHOCKWAVE

↓

BUBBLE NEBULA

Also known as NGC 7635, the Bubble Nebula was created by a petulant star, around 45 times the mass of our Sun, throwing out its gas, or stellar wind. The gas is travelling at around 6.5 million kilometres per hour, and as the resulting cloud expands out, it slams into the surrounding interstellar medium – this is the gas which fills the space between the stars – creating a shock wave. The advancing wave causes the regions it passes through to heat up and glow, producing the bright bubble that gives this nebula its name.

The bubble is lopsided, however, with the star located in the top left. The interstellar medium in this region is much cooler, and therefore denser, making it harder for the gas to expand in that direction.

JET PROPULSION

HERBIG-HARO JET

Here, we see a Herbig-Haro jet, which spurts out of some newborn stars. After a star forms, there is usually a disk of gas and dust left around it. Complex interactions between this disk and the star's magnetic field mean that some of the gas ends up being thrown out at incredibly high speeds. The shock wave of the gas ripping through the interstellar medium creates this brightly glowing jet, as seen here.

Not only has Hubble's high precision been able to reveal these jets in greater detail than ever before, we've been able to study them as they grow. As the jet moves further out, it hits new knots of gas, causing them to brightly flare up, then fade away over timescales of a few years. This has given astronomers a unique view of the usually invisible interstellar medium.

"Thirty years is not a lot of time in the astronomical realm," says Jennifer Lotz, director of the Gemini Observatory. "But we now have movies that show ejecta from massive stars. This opens up new ways to understand these phenomena, beyond just an instantaneous snapshot of time."

HOT STUFF

→

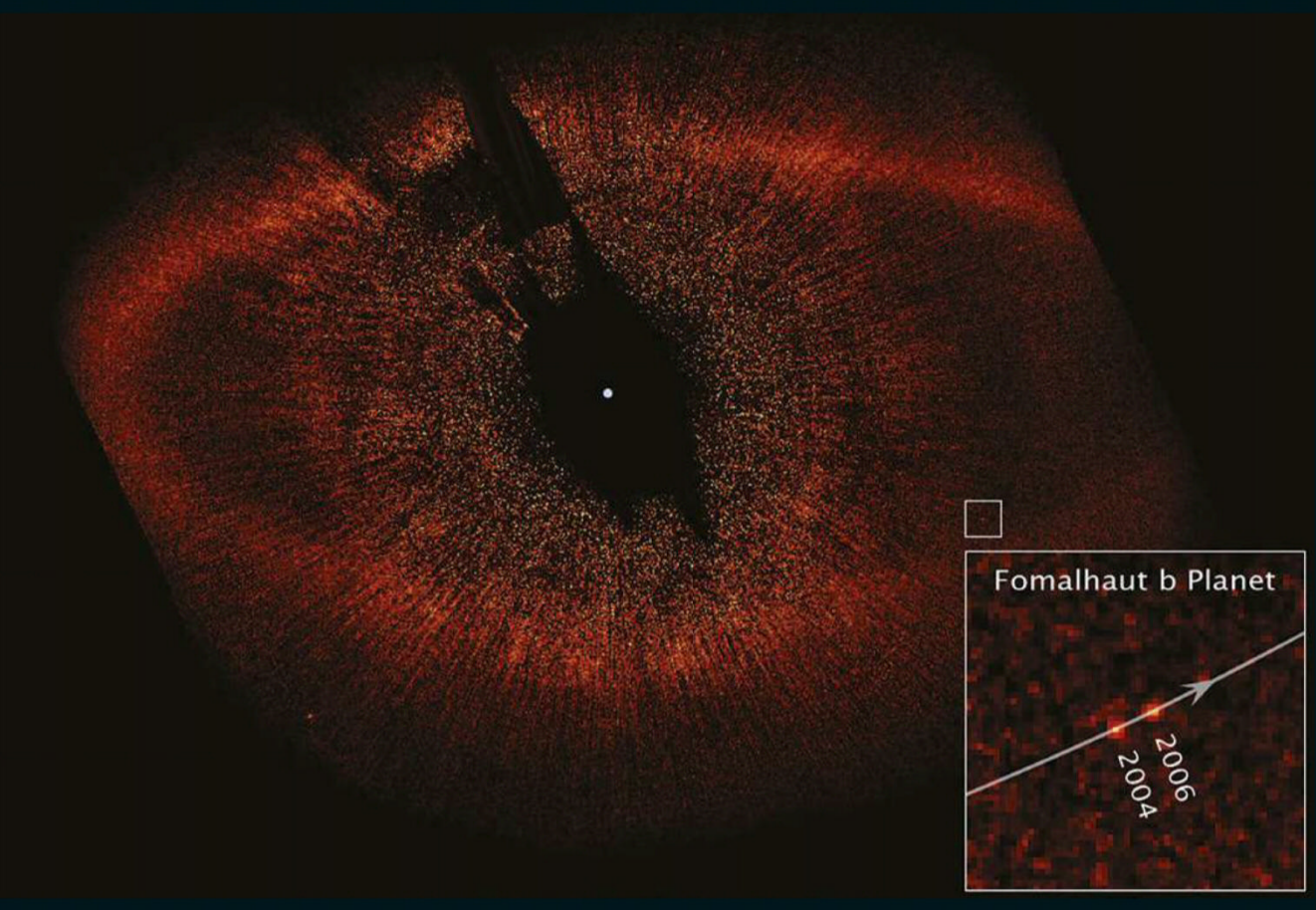
NGC 5033

Spiral galaxy NGC 5033 is much like our own. It's around the same size, about 100,000 light-years across, and at its core is a super-massive black hole, weighing anywhere between 10 million and a few billion solar masses.

Unlike the Milky Way, however, NGC 5033's black hole isn't docile. Instead, it's surrounded by a swirling disk of gas and dust, moving so rapidly that it superheats. This makes it glow brightly, forming what's known as an active galactic nucleus.

Over the years, Hubble has found hundreds of supermassive black holes by looking at the motion of dust in the centres of galaxies. If the material is moving rapidly, there must be a black hole holding it in place or it would speed off into the rest of the galaxy.

"Hubble observations of the centres of massive galaxies showed that supermassive black holes lived in the centres of almost every galaxy," says Lotz. "We now believe that supermassive black holes play a critical role in shaping galaxies."



THE LONELY STAR

←

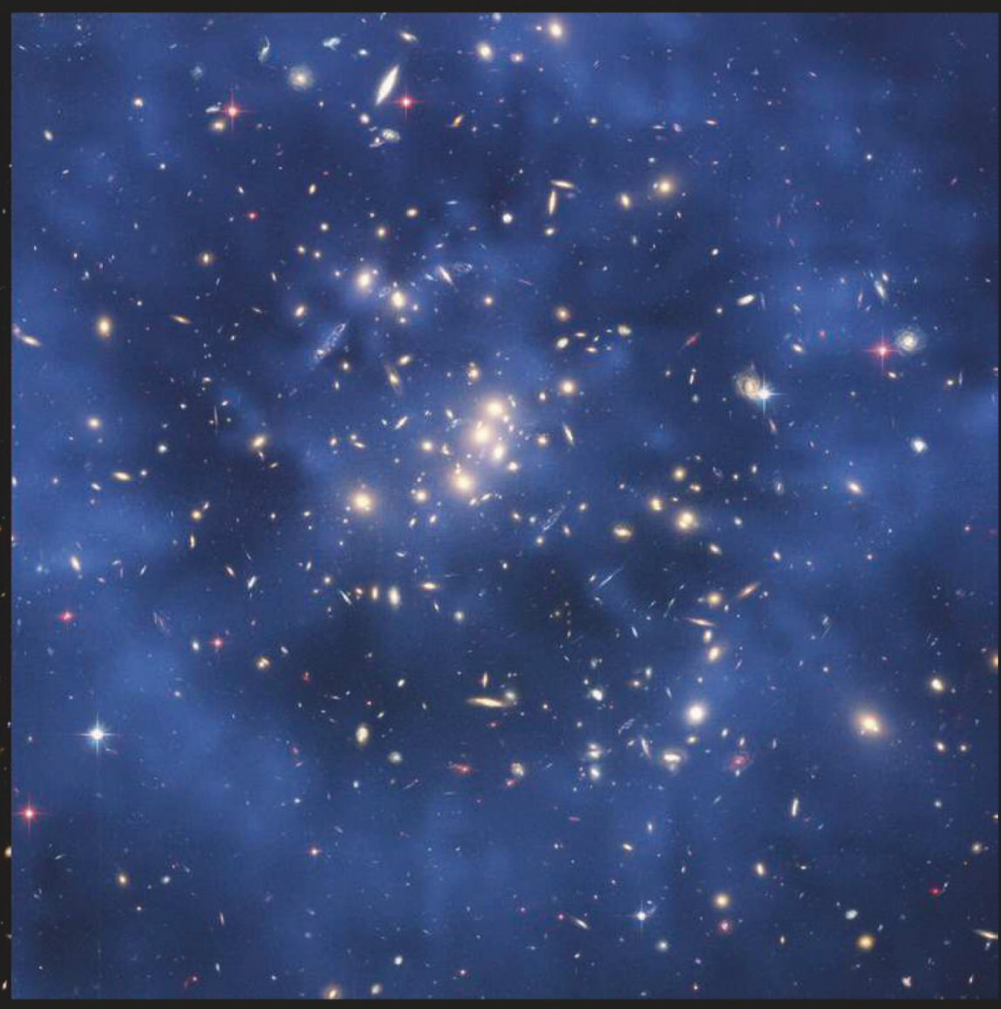
FOMALHAUT

Before Hubble launched, the only planets we knew about were those in our Solar System. Today, we know of thousands of exoplanets orbiting other stars.

"Hubble has been right at the forefront of studying exoplanets," says Wiseman. "It's not a great instrument for finding them – the field of view is too small and it only has a small window for searching the vast sky – but what it can be used to do, is carry out intimately detailed follow-up observations."

One rare case where Hubble did find a planet was around the star Fomalhaut. The star is surrounded by a ring of dust stretching out to around 20 billion kilometres – that's three times further out than Pluto.

Such rings are usually created by planets shepherding dust into a specific orbit. Hoping to track down this world, Hubble repeatedly took images of the system over a period of several years. Comparing the images, astronomers found a bright dot slowly moving around the disk. It was a planet, and the first one ever directly imaged in visible light.



COSMIC LENS

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GRAVITATIONAL LENSING

Galaxy clusters are one of the most massive objects in the Universe. They are so heavy that they warp the fabric of space-time, to the point that light gets bent as it passes by. Under the right conditions, this bending can act as a lens, magnifying galaxies located billions of light-years behind them, an effect known as gravitational lensing.

In the left-hand picture above, you can see several bright blue galaxies which have been lensed, though the process has distorted them into curved arc shapes. Such images are vital in tracking one of the most mysterious substances in the Universe, dark matter. "Most of the matter in a cluster is dark matter," explains Wiseman. "We don't know what dark matter is, but through Hubble's observations of lensing we can tell how it's distributed and the history of how dark matter evolved throughout the history of the Universe."

After studying the pattern of distorted galaxies, astronomers have created a map of dark matter within this cluster, shown in the right-hand image, in blue.

by **DR ELIZABETH PEARSON** *(@EzzyP)*
Elizabeth is a space journalist and news editor at BBC Sky At Night *magazine.*

WHEN GALAXIES COLLIDE

→

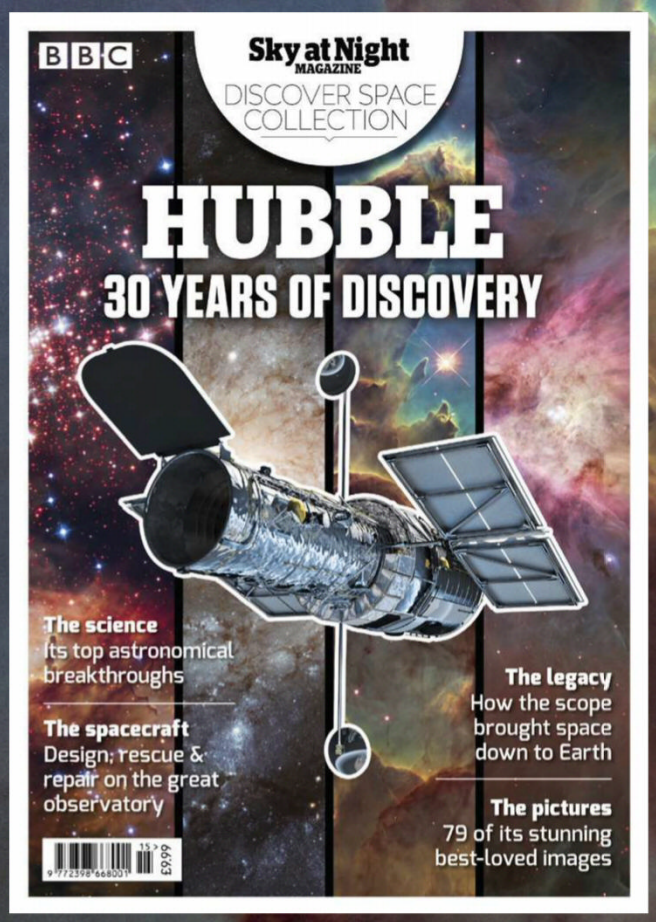
GALAXIES COLLIDING

Two galaxies colliding into each other sounds like it should be hazardous, if not fatal, to the objects involved. In reality, it is the main way these stellar collectives grow and evolve. When they crash together, or even just pass close by, the resulting chaos stirs up the gas within them, creating knots of material which go on to form stellar nurseries.

Here, we see two separate galaxies that have recently passed close enough that they've pulled each other's spiral arms out of shape. Hubble's ultraviolet cameras have been able to pick out regions where hot, young stars are busily forming. These are the bright blue clumps clustered around the galaxies' distorted arms, where the interaction would create the most turbulence.

Hubble's unparalleled sharpness and ability to see in the ultraviolet is one of the key ways in which it differs from its Earth-bound counterparts. Our atmosphere soaks up most of the ultraviolet radiation that arrives at our planet, and so Hubble's view above the atmosphere gives us a unique view of the Universe at these wavelengths of light. SF

SPECIAL EDITION



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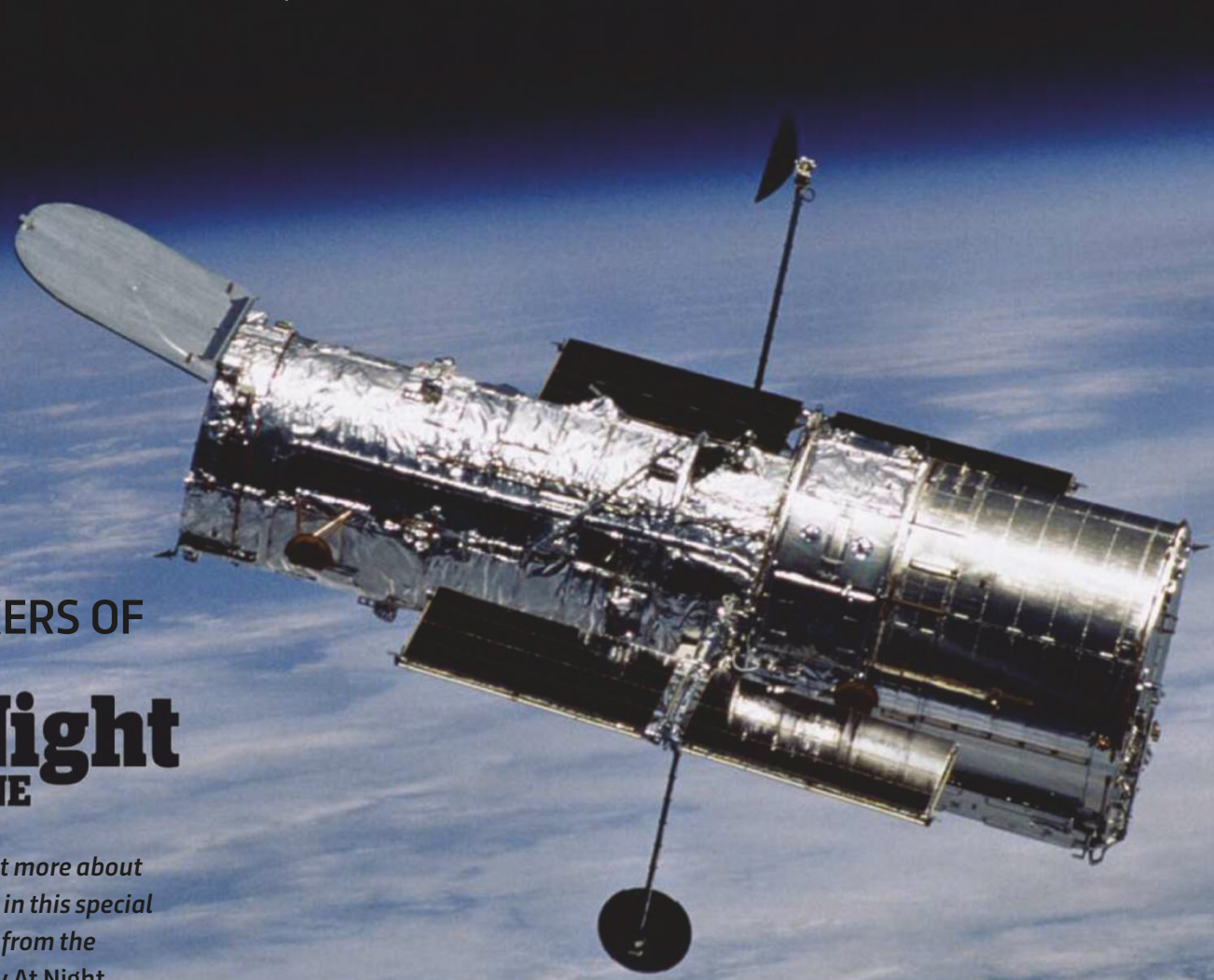
WHAT **HUBBLE** TAUGHT US

Hubble launched in 1990 and over the last 30 years it has given us a new perspective on our Solar System, the worlds beyond our cosmic neighbourhood, and even the fabric that holds it all together

by **DR ELIZABETH PEARSON**

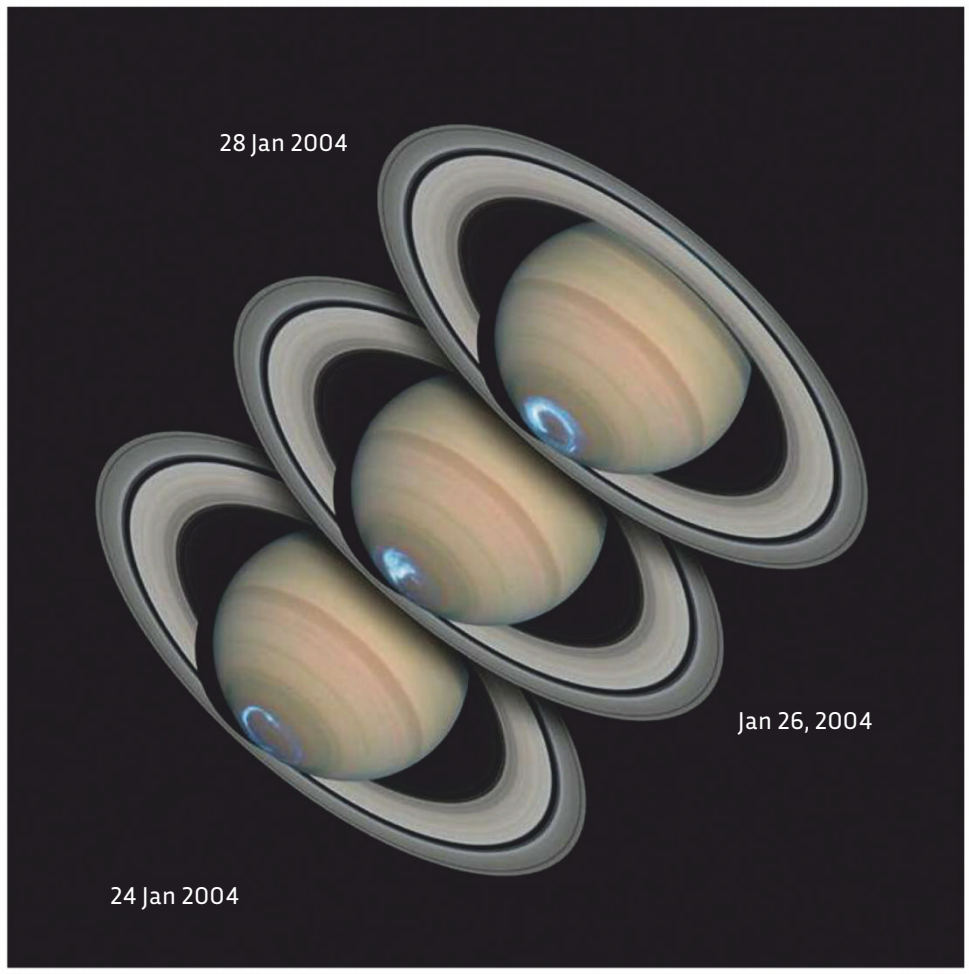


NASA

PART ONE

A NEW PERSPECTIVE ON THE PLANETS

Hubble has changed the way we see our cosmic neighbours, as it works with other probes to bring our Solar System into focus



ABOVE These images reveal how much Saturn's aurorae change in the space of just a few days

NASA/ESA/A SIMON/GODDARD SPACE FLIGHT CENTER, NASA X4

The Solar System is our cosmic back garden. It should be one of the best-known parts of our corner of the Universe. Yet when Hubble launched in 1990 our planetary neighbourhood was still deeply shrouded in mystery. Looking up from Earth, the ever-shifting atmosphere blurred our view of the planets, making it difficult to see their features. Above the turbulent air, Hubble could watch these worlds in peace and has been doing so for the last three decades.

This long life has been one of Hubble's greatest assets, making it possible to reveal the weather and climate patterns of changing seasons on our sister worlds as they make their journeys around the Sun. The Hubble science team has taken advantage of this unique long view by undertaking a project called the Outer Planet Atmospheres Legacy (OPAL).

"OPAL employs Hubble to look every few months at Jupiter, Saturn, Uranus and Neptune to see if they've changed," says Jennifer Wiseman, Hubble's senior project scientist. "Through OPAL we've learned how the Great Red Spot on Jupiter, a giant storm, is actually shrinking and changing colour over time. We see new storms cropping up, and we see them coming and going on some of the other outer planets too. Studying the changing nature of the planets in our Solar System is something that Hubble is enabling us to do through both its clarity of imagery and its longevity."

MISSION SUPPORT

Of course, Hubble hasn't been the only one watching the planets over the years. Since its launch, dozens of missions have been sent across our Solar System and Hubble is often called upon to supply much needed context. When Cassini arrived at Saturn in 2004, it could only see small parts of the planet at a time. Hubble, however, was able to take in the entire planet. While this was at a much lower resolution, the telescope was able to track storms and auroral activity to help planetary scientists understand the data Cassini was sending back.

"This profoundly improves the science return from any of these particular missions, compared to them operating on their own," says Wiseman.

Mars has been another target of Hubble's attentions as it works in concert with the armada of spacecraft on and around the Red Planet. The telescope has helped to track the huge dust storms which blow across the planet every Martian year. Once again, this gives a global appraisal of the storm's progress while the in-situ probes note localised changes such as temperature and pressure.

It's not just during missions that Hubble offers support, however. For almost every planetary mission of the last 30 years, Hubble has been used to scout the way before the spacecraft even reached its target.

"Hubble was used to help in planning the New Horizons mission which passed by the Pluto system in 2015," says Wiseman. "The space telescope's observations helped inform the planning of that probe's trajectory and get it safely to Pluto."

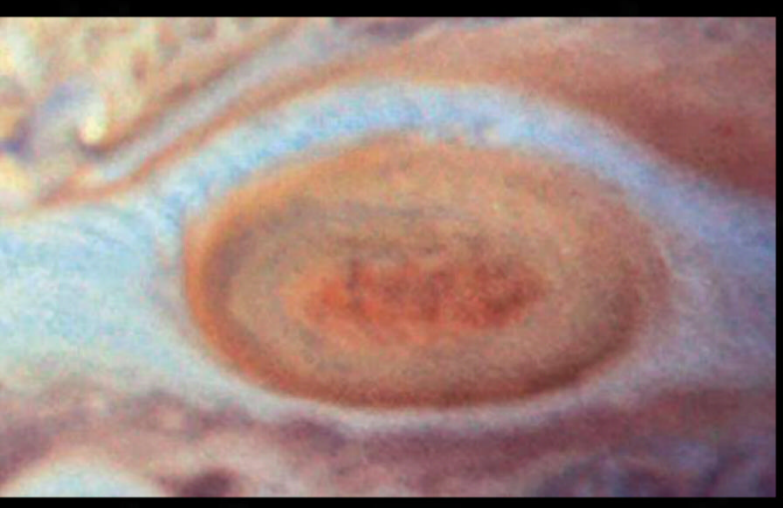
EYE IN THE SKY

Before New Horizons' approach, the operations team feared flying into an unseen moon or other obstacle around the dwarf planet, and so used Hubble to search for potential hazards. It was during this campaign that Hubble revealed the presence of a pair of moons, Nix and Styx, allowing New Horizons to plot a trajectory which avoided them.

Hubble offers another perspective that many of these planetary spacecraft lack – the ability to observe in the infrared and ultraviolet. For the Juno mission at Jupiter this capability

21 April 2014

The dramatic shrinking of Jupiter's Great Red Spot is captured in 1995, 2009 and 2014



1995

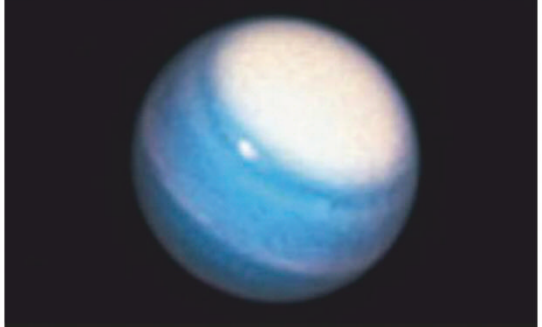
2009

2014

HUBBLE'S TOP 3

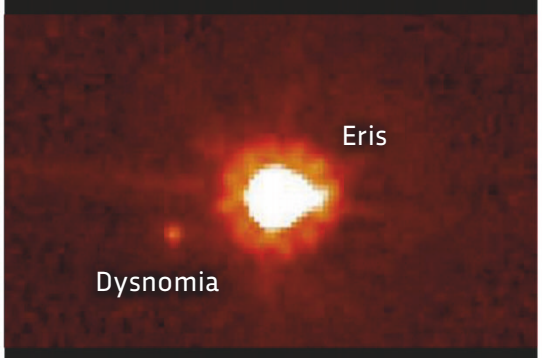
SOLAR SYSTEM MOMENTS

Hubble has made some of the most definitive planetary discoveries in recent times



SEASONS ON URANUS

When Voyager 2 flew past Uranus in 1986, the ice giant appeared to be a placid marble with little weather. But Hubble has revealed the planet is now more active, suggesting that seasons have changed. It's found several dark patches, which are believed to be storms blowing up on the planet.



DEMOTING PLUTO

In 2005, Mike Brown uncovered a large body in the outer Kuiper Belt, now known as Eris. It was over 2,300km wide, around the same size as Pluto. The discovery triggered a debate, and ultimately led to Pluto being demoted to dwarf planet.

JUPITER'S AURORAE

In 1997, Hubble was upgraded with a more sensitive Space Telescope Imaging Spectrograph, which revealed Jupiter's ultraviolet aurorae. Astronomers found it formed curtains just like Earth's, extending several hundred kilometres over the surface.

LEFT Comet Shoemaker-Levy 9 colliding with Jupiter

provides extra resolution to its observations of the gas giant's magnetic field. Juno's instrument payload cannot register the high-energy, ultraviolet aurorae these fields create but Hubble can. By combining the two, astronomers are given a far more complete view of the planet, allowing them to work out even more detail about the magnetic fields of this giant world.

"We've also used Hubble to study the nature of some of the moons of these planets, and we've revealed some quite unexpected results," says Wiseman. "For example, when Hubble observed some of the moons of Jupiter, we found that both Ganymede and Europa showed signs of liquid water oceans under an ice-crusted outer layer."

In 2016, Hubble helped to confirm the presence of water outside the moons as well, when it discovered there was a plume of water ice fountaining high over Europa, forced up from an underwater ocean through the cracks in the moon's crust.

But some of Hubble's greatest triumphs have come from those times when the Solar System threw out something unexpected.

INTERSTELLAR VISITORS

"One of Hubble's most famous detections happened early on in its career, when comet Shoemaker-Levy 9 unexpectedly collided with Jupiter in 1994," says Wiseman. As soon as astronomers realised the comet would collide, they called on the Hubble team to make sure the telescope was watching.

"That incredible set of images completely transformed our understanding of how dynamic the Solar System is," says Wiseman. "We realised how vulnerable planets actually are to being impacted by objects and debris whizzing around."

Hubble has observed many comets and asteroids since then, but in the last few years a new category of transient space rock has been added to the line-up – interstellar visitors. In 2017, asteroid 'Oumuamua was seen speeding through our Solar System, having been thrown out of another star system. Then in late 2019, comet 2I/Borisov followed suit. In both cases, Hubble was on hand to capture the objects on camera as they flew by.

Since Hubble launched in 1990 it has revolutionised our knowledge of the worlds in our back garden. The telescope has been a key tool in helping to unravel their mysteries, but there are still plenty of secrets hidden in the shadows of these distant worlds. As long as it's still running, astronomers will be calling on Hubble to help drag them into the light.

NASA/KSC, NASA/HUBBLE SPACE TELESCOPE X3, NASA/ESA/HUBBLE AND THE HUBBLE HERITAGE TEAM

PART TWO

THE MILKY WAY

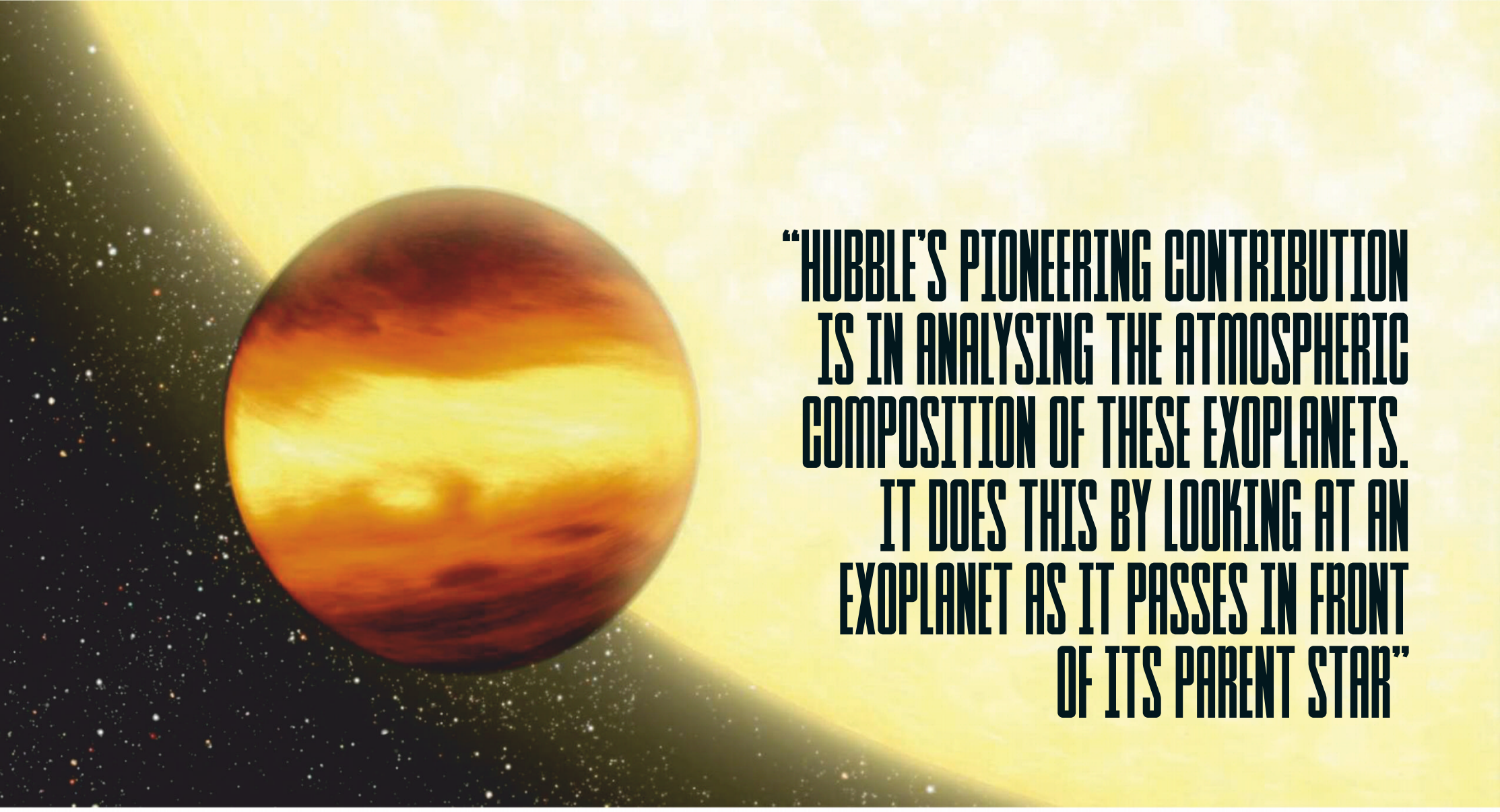
The story of the stars is written across our Galaxy, and Hubble has helped us read it

The Milky Way is home to some incredible sights. From the dusty beauty of stellar nurseries to the colourful detritus left after a star explodes, Hubble has helped to reveal the beauty of our Galaxy. Yet these images are not only stunning to look at. To an astronomer's eye, these photographs tell the story of a star's life.

The tale begins soon after Hubble launched 30 years ago, when it first turned its eye towards some of the clouds of dust dotted throughout our Galaxy. Astronomers believed that these were stellar nurseries, the places where every star in our night sky began its life. The most famous image of one of these birthing grounds (and perhaps Hubble's most famous shot ever) is of the Eagle Nebula, M16 (pictured here). The image, taken in 1995, is better known as the Pillars of Creation, inside which new stars are starting to form.

"We see these pillar-like structures in many Hubble observations of these nebulae," says Jennifer Wiseman, Hubble's senior project scientist. "The wind from massive newly formed stars carves out these structures around the bigger clumps in the gas that is left behind."

This image of the Pillars of Creation in the Eagle Nebula was taken by Hubble's newer Wide Field Camera 3 in 2014. To give an idea of scale, the towering pillars are about five light-years tall



"HUBBLE'S PIONEERING CONTRIBUTION IS IN ANALYSING THE ATMOSPHERIC COMPOSITION OF THESE EXOPLANETS. IT DOES THIS BY LOOKING AT AN EXOPLANET AS IT PASSES IN FRONT OF ITS PARENT STAR"

By studying the shapes of these cloud formations, astronomers were able to unpick these critical early stages in a star's life. Partly, they've done this by watching how the clouds have changed over the last 20 years. In 2015, a new version of the same image revealed that one of the jets within the cloud had grown by almost 100 billion kilometres, demonstrating just how dynamic these regions truly are.

Even more excitingly, when Hubble took a closer look at some of the Orion Nebula's infant stars, it found several of them had disks of swirling dust – a sign they were entering the next chapter of their lives and forming planets. As a star grows, it often forms a protoplanetary disk of dust around it. Over time this debris clumps together, gradually growing in size to eventually become a planetary system.

OBSERVING ALIEN WORLDS

Studying these disks is a vital step in one of the fastest growing study areas of astronomy: exoplanets, the planets that exist in other solar systems.

"When Hubble was designed there was no concept that it would be used to study planets outside our Solar System. We didn't know of exoplanets at that time," says Wiseman.

Since the first exoplanets were discovered back in the 1990s, over 4,000 worlds have been confirmed; a number which grows every day. Tracking these planets down requires looking at large areas of sky for a long time. With its narrow field of view and the high-demand for its time, Hubble is ill-equipped for this task. But it can take a deeper look at planets other observatories have already discovered.

"Hubble's pioneering contribution is in analysing the atmospheric composition of these exoplanets," says Wiseman. "It does this by looking at an exoplanet as it passes in front of its parent star. During that transit, light from the star passes through the outer regions of the atmosphere. Some of that light is absorbed by the atmosphere of that planet and that signature is still in the light received by Hubble."

By pulling this signature apart, astronomers are able to detect several key elements and molecules within a planet's atmosphere. One important molecule that Hubble is especially suited to look for is water. On Earth, wherever you find water you find life. So astronomers are keen to pin down how many other planets are as wet as ours in the hope of predicting where else in our Galaxy we might find life.

Hubble's resolution is so great that it can even create a basic outline of the weather patterns on a planet's surface. When the telescope

ABOVE To date, more than 4,000 exoplanets have been discovered

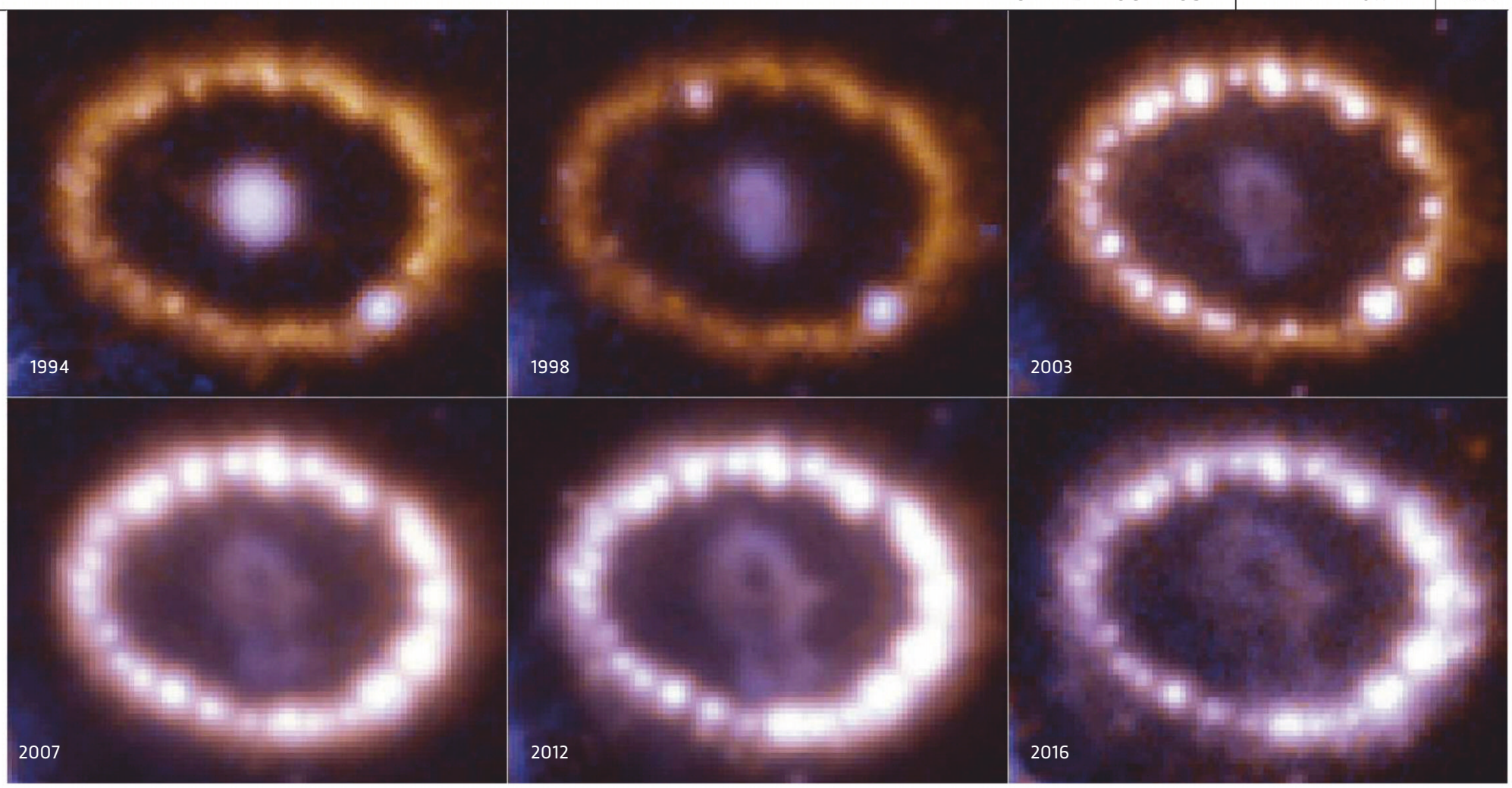
HUBBLE'S TOP 3

DISCOVERIES IN THE MILKY WAY

Hubble has peered into the heart of the spiral galaxy we call home to reveal some amazing discoveries

V838 MONOCEROTIS

In 2002, the red star V838 Monocerotis flared up, temporarily shining 600,000 times brighter than the Sun. No one is sure why, but over the last 20 years the light from this flash has advanced outwards, illuminating the surrounding gas. Hubble has allowed astronomers to map this expanding 'light echo'.



NASA/THE HUBBLE HERITAGE TEAM, ESA/HUBBLE/M. KORNMESSER, NASA/ESA/P KALAS, NASA/JPL-CALTECH, NASA/ESA/R KIRSHNER,P CHALLIS /HARVARD-SMITHSONIAN CENTER FOR ASTROPHYSICS

ABOVE The evolution of the supernova 1987A between 1994 and 2016, as captured by Hubble telescope

looked at tidally locked WASP-43b, where one side of the planet always faces its sun, it was able to pick out the hot patches on its eternally sunlit side. Using this, astronomers were able to predict how the winds of the planet blow between the day and night sides.

But just as Hubble reveals the origins of stars and planets, it has also turned to the pages of their final act. When a star's nuclear fuel is expended, they die. If the star is large enough, this death is an explosive affair known as a supernova. Once again, Hubble's power lies not in first detecting these cosmic flashes but in taking a look at them afterwards.

SUPERNOVA STUDIES

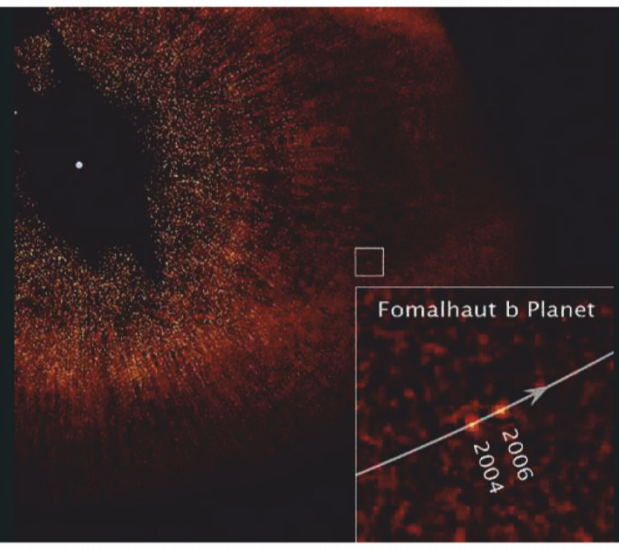
Throughout their lifetimes, stars transform the hydrogen created in the Big Bang into helium and other heavier elements. When the star goes supernova, it throws these elements outward. As the hot cloud of gas crashes into the surrounding medium it creates an advancing shock wave, lit from within by a white dwarf – a small hot star, all that remains of the exploded stellar body. As these gas bubbles look fuzzy and spherical from Earth, they were initially mistaken for planets, leading them to be called 'planetary nebula', despite having nothing to do with planets.

In 1987, just before Hubble launched, a supernova detonated in the Milky Way's companion galaxy, the Large Magellanic Cloud. Over the years, Hubble has watched as the ring of gas from this explosion has moved out and expanded into the interstellar medium – the gas which fills the space between the stars.

The turbulence caused by these shock waves can, in time, cause the interstellar medium to gather together. This new cloud, enriched with all the elements the dying star threw out into the Universe, then goes on to form stellar nurseries, bringing the cosmic tale of stellar life back around to its beginning again.

The Milky Way is a dynamic place, filled with stars being born, forming planets and then dying, only for their remains to provide the fuel to repeat the cycle again. And Hubble has been critical to observing every step of this incredible process.

WATER IN THE HABITABLE ZONE
Astronomers have found many exoplanets in the so-called 'habitable zone' – the region around a star where temperatures allow liquid water to pool on the surface, potentially allowing life to evolve. In 2019, Hubble was able to discover water vapour in the atmosphere above exoplanet K2-18b for the first time.



FIRST DIRECT IMAGE OF A PLANET
In 2004, Hubble imaged the disk of dust, measuring 34.5 billion kilometres in diameter, surrounding the star Formalhaut. The disk has a sharp inner edge, suggesting it is being shepherded by a planet. Over the years, Hubble watched a bright point of light move around the star. It was an orbiting alien world – the first ever to have been imaged directly.

PART THREE

A VIEW ACROSS TIME

Hubble has helped to peer back across the aeons of time and shown that the Universe is growing at an ever faster rate

Hubble's high resolution, large aperture and extreme precision means that it can pull photons out of the darkest reaches of the Universe, looking further back than any visual telescope that came before it. As the light from these distant galaxies and stars has taken billions of years to cross the void, we see them as they were millennia ago, all the way back to the earliest days of the Universe.

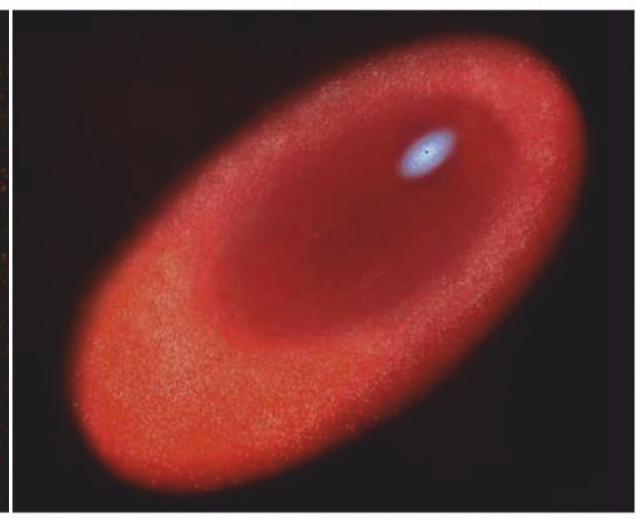
"We can compare the nature of the most distant galaxies to those we see closer to us in space and time, to see if they are different. And, in fact, they are," says Jennifer Wiseman, Hubble's senior project scientist. "I think Hubble's most profound contribution has been revealing to us how the Universe has changed over time."

Nowhere is this capability better showcased than in the Hubble Deep Field images. The first of these was taken in 1995, when the telescope took a 100-hour long exposure – many times longer than normal – of an apparently blank stretch of sky. At the time, some astronomers argued the image was a waste of precious Hubble time, but when the image was put together, they were swiftly proved wrong.

This first image contained almost 3,000 galaxies, some dating back to when the first stars were forming. These appeared to be smaller and more irregular than those in the present day, demonstrating that galaxies do change over time.

RIGHT In 1996, Hubble captured this Deep Field image, which shows a view stretching to the Universe's visible horizon

BELOW The core of the Andromeda Galaxy (left) photographed by Hubble, and an artist's impression of it (right). Both images show a disk of stars (in blue) that were used as evidence for a huge black hole

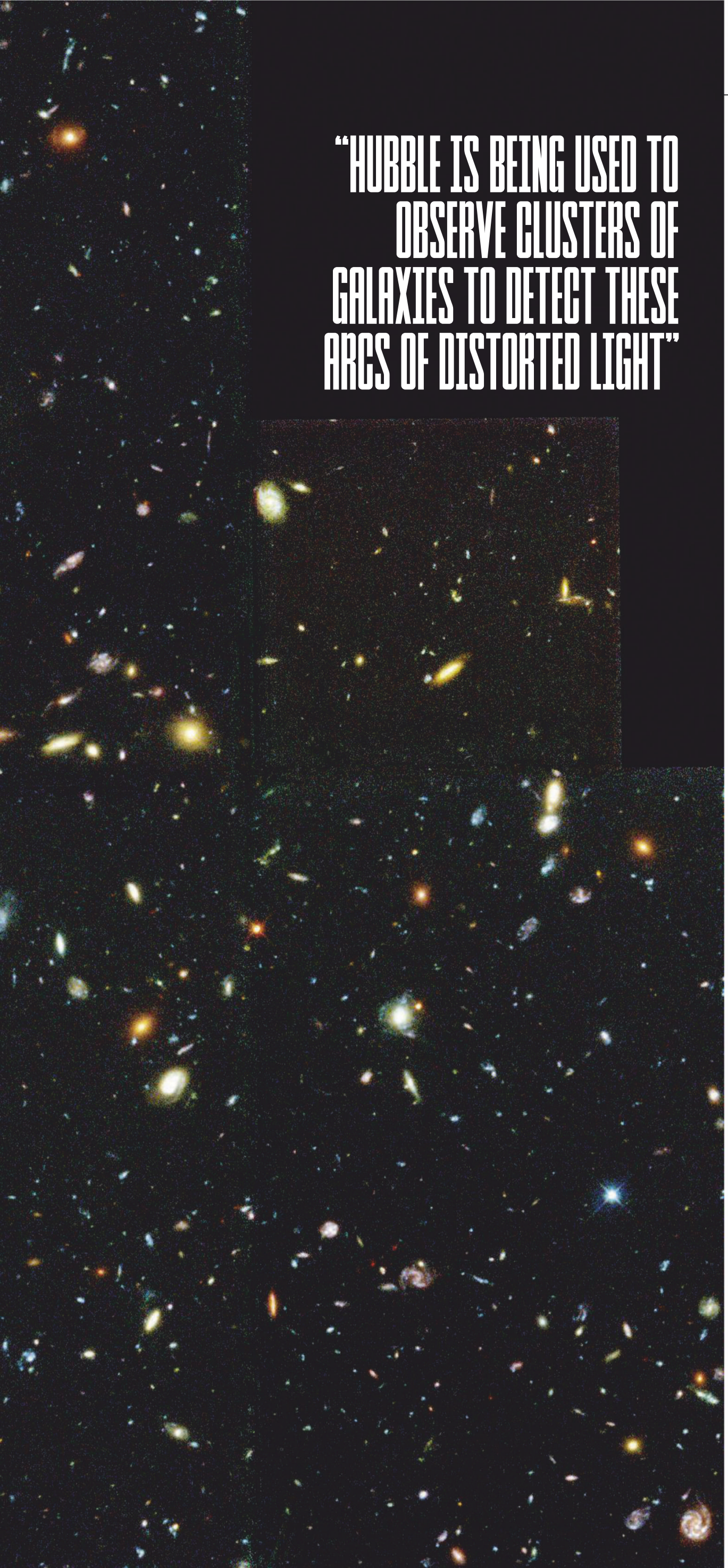


SUPERNOVAE CLUES

While Hubble's keen eye has been able to make out these distant galaxies, it has also been key in working out exactly how far away these remote stellar collectives are.

"Hubble observes the Type Ia supernovae that astronomers use to gauge the distance to far away galaxies," says Wiseman.

These Type Ia supernovae always explode with the same brightness, so by measuring their apparent brightness from Earth, astronomers can work out how far away they – and the galaxy they occurred in – must be.



"HUBBLE IS BEING USED TO OBSERVE CLUSTERS OF GALAXIES TO DETECT THESE ARCS OF DISTORTED LIGHT"

R WILLIAMS/THE HUBBLE DEEP FIELD TEAM /NASA/ESA, NASA/ESA X2

Calculating these distances is a key part of one of Hubble's main science goals – measuring the rate at which the Universe is expanding.

"Ever since Edwin Hubble took observations showing galaxies were receding a century ago, we've known that the Universe appears to be expanding, and that space seems to be stretching," says Wiseman. "But measuring the actual rate of that expansion has been challenging because it requires precise distance measurements. Hubble has helped to make these observations with higher and higher precision, leading to one of its most impactful contributions – realising the Universe's expansion is actually accelerating."

Astronomers were surprised when two independent teams discovered this acceleration in 1998. Everyone had assumed that after the Big Bang the expansion would either slow to a stop or plateau to a steady rate. If the expansion is accelerating, then the question arises: what's speeding it up?

"We still don't fully understand," says Wiseman. "It's a very hot topic in astrophysics. We call it dark energy and Hubble has really played a key role in its study."

Today, astronomers believe dark energy makes up around 75 per cent of the Universe. A small portion of the rest is made up of luminous matter, such as the gas and dust that glows in clouds or burns in stars. The remaining 24 per cent is dark matter, another mysterious substance which threads through our Universe, extending out between galaxies and stars.

DARK ENIGMA

This dark matter doesn't interact with light the way normal matter does, making it completely invisible to normal telescopes. But it does interact with the visible Universe through gravity, meaning that Hubble is able to bring this 'unseeable' substance into the light.

"Any type of mass will distort space-time," says Wiseman. "If you have a very large collection of mass, that distortion might actually create a phenomenon significant enough to be observed."

This effect is known as gravitational lensing, where light from a distant galaxy is bent by the gravity of a huge object, such as a cluster of galaxies. However, the process isn't perfect and by the time the light from the distant galaxy reaches Earth it's usually been badly distorted.

"Hubble is being used to observe clusters of galaxies to detect these arcs of distorted

HUBBLE'S TOP 3

UNIVERSE MOMENTS

Hubble has fundamentally altered our view on the largest of scales

EXTREME DEEP FIELD
In 2012, the Hubble team released the eXtreme Deep Field. The image covered just 2x2.3 arcminutes, around 1/32,000,000ths of the sky, yet had an exposure time of around 23 days. It looks back through 13.2 billion years, showing one galaxy when it was just 450 million years old.

CONFIRMING PRIMORDIAL HELIUM
In 1995, Hubble finally confirmed the presence of primordial helium. Theory had predicted that after the Big Bang, the cooling Universe formed both helium and hydrogen, but the former had never been seen before.

GAMMA RAY BURSTS
GRBs are the most powerful explosions in the known Universe, but their origins are a mystery. In 2019, Hubble found a GRB that had come from the dense environment of a bright galaxy around five billion light-years away – a clue to the conditions that might cause a GRB.

ABOVE This image, taken by Hubble, is a good example of gravitational lensing. The massive galaxy cluster in the centre of the image is about 4.6 billion light-years away. It is surrounded by four arcs (three in the top right, one in the bottom left). Within these narrow arcs are at least 12 copies of a galaxy nicknamed the Sunburst Arc, located nearly 11 billion light-years away. Its light is being distorted into multiple images by gravitational lensing

light," says Wiseman. "By examining the gravitational lensing of the galaxy clusters we can tell something about how mass is distributed in these clusters."

Most of this mass is dark matter. By looking at how much galaxies are distorted, astronomers are able to map out how the mysterious substance is distributed throughout the Universe.

SPOTTING BLACK HOLES

Another seemingly invisible object that Hubble has helped illuminate are supermassive black holes. These dense bodies are several billion times more massive than our Sun and are thought to lie at the heart of most galaxies. Before Hubble, these black holes were entirely theoretical. The only evidence of their existence were radio observations of distant galaxies known as quasars, which contained objects around the size of the Solar System but which shone brighter than any other known thing in the Universe. Hubble was able to determine that the radio emissions were coming from the centres of the galaxies that held them, most likely from extremely hot gas that was being intensely heated as it swirled around a giant black hole.

In 1997, the Space Telescope Imaging Spectrograph was installed on Hubble. This instrument was much better at looking at the region close to a galaxy's centre, and it could make out the rapid movement of stars caught in orbit close to a black hole. The instrument soon found them, definitively proving the existence of supermassive black holes.

For the last 30 years, Hubble has helped astronomers to pull out photons from the deepest depths of space, and even illuminated places in our cosmos where no light shines, helping to reveal the Universe's darkest secrets. **SF**

by **DR ELIZABETH PEARSON** *(@EzzyP)*
Elizabeth is a space journalist and news editor at BBC Sky At Night *magazine.*

INTERVIEW

KEVIN HARTNETT

Hubble's science operations manager joined the team in 1997, and is responsible for overseeing scientific aspects of the space telescope's operations. With a bachelor's degree in physics and astronomy, his career began in the private industry before he started working at NASA

HOW IS HUBBLE DOING?
It's performing at the peak of its capabilities and functioning marvellously. There aren't as many available backups as there were some years ago. For instance, Hubble has six gyros to keep itself orientated, but only three are active and we need three to do our best science.

Our engineers are coming up with clever ways to combat ageing. Things dim, they fade, one side of the detector has a greater sensitivity than the other. But they've kept the observations really at the forefront of what anyone can do on the ground or in space, and that's pretty remarkable.

"WE HAVE VERY FINE GUIDANCE SENSORS. IT'S LIKE KEEPING A LASER POINTER ON A DIME 330KM AWAY FOR 24 HOURS"

WHAT SETS HUBBLE APART?
It's a one-stop shop for very stable, high contrast imaging and spectroscopy from the near infrared wavelengths right through to the ultraviolet, with a 2.4m mirror above the atmosphere. We have very fine guidance sensors too. In layman's terms, it's like being on top of the Washington Monument in Washington, DC and keeping a laser pointer on a dime on the top of the Empire State Building in New York City 330 kilometres away for 24 hours. So once we lock on, we really lock on target.

WHAT TYPE OF RESEARCH DOES HUBBLE DO?
Solar System astronomy, galaxies, large-scale structure of the Universe, and everything in between – Hubble has made major contributions to every astronomical field. There are also legacy programmes. For instance, there's a large project right now to observe every Milky Way globular cluster. Not because someone wants to write a paper on all 150 clusters, but the data is there if someone ever does.

DOES THE OLD DATA STILL GET USED?
Oh my, yes. There's a lot of interesting science you can do with a 25-year baseline. If you've got good observations from 25 years ago, you can compare them to similar observations today. You can see jets actually moving out of the big quasar in M87. You can calculate velocities. Scientists can get a lot out of data like that.

HOW LONG DOES HUBBLE HAVE LEFT?
Hubble doesn't have a propulsion system and it is slowly falling to Earth. A report from September 2018 predicts Hubble re-entry no earlier than 2027, and the mean date is around 2038. We're very in-tune with the performance of the telescope and we're trying to pamper all of its systems, to keep it running as long as possible.

ABOVE Kevin Hartnett working in the Space Telescope Operations Control Center during Hubble's final servicing mission in 2009

DISCOVER MORE

READ
Hubble: 30 Years Of Discovery *is out now.*