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Tune in to *Stargazing Live* on BBC Two from Tuesday 28 March to Thursday 30 March to discover more about the supermassive black hole at the centre of our Milky Way.

There's a monster at the core of our Galaxy, and astronomers expect to see its silhouette later this year

THE HEART OF DARKNESS

At the core of the Milky Way lies an unseen monster. **Elizabeth Pearson** investigates how astronomers are trying to glimpse the supermassive black hole at the centre of our Galaxy

NASA/JPL-CALTECH

At the centre of the Milky Way lies a dark behemoth. One like it is thought to reside in the core of nearly every major galaxy, a hidden heart no one has ever seen – a supermassive black hole.

This body has the mass of over four million Suns but is crammed into a space that's only 20 times our star's diameter. Its gravitational pull is so strong that even light can't escape, meaning that while its influence is felt throughout the Galaxy, we'll never be able to look directly into the black hole.

We aren't completely blind to its mysteries, however. Though the black hole remains shrouded, it's surrounded by a swirling cloud of material known as an accretion disc. As this disc rotates, friction causes the gas and dust in it to heat and glow brightly. The visible part of this glow is shielded by dust, but enough emissions escape at radio wavelengths to create a bright spot 26,000 lightyears away in the constellation of Sagittarius. This radio source is called Sagittarius A* (Sgr A*).

Although enough radio emissions get through the dust for the black hole to be detected, what we can see still seems rather lacklustre compared to what might be expected from looking at the cores of other galaxies.

"The Milky Way's black hole is known to be very inactive. It's radiating several orders of magnitude less than the Eddington luminosity, the maximum luminosity the black hole could have," says Abhijeet Borkar, from the Czech Academy of Sciences in Prague, who was part of a team that spent four years monitoring SgrA* with the Australia Compact Telescope Array.

"Either most of the energy in the accretion disc isn't emitted as radiation, giving it a low luminosity, or there's no stable accretion disc around the black hole. Instead there's a clumpy, discontinuous disc so there is not enough material falling into the inner parts of the accretion disc to maintain its brightness," says Borkar.

ABOUT THE WRITER
Dr Elizabeth Pearson is *BBC Sky at Night Magazine*'s news editor. She gained her PhD in extragalactic astronomy at Cardiff University.

Disquiet in the calm

The does not mean the region is a calm and placid place, however. Despite its quiet background emissions, the material around the black hole regularly flares into brightness.

"We see about four instances of flaring each day, when we observe a six-fold increase in the luminosity of the black hole in infrared and X-rays. At radio and submillimetre wavelengths the luminosity increases by 30 per cent," says Borkar.

The flares typically last one or two hours, depending on the wavelength of light observed. They are also likely to originate from material that orbits around the black hole at speeds so fast that the effects of relativity become apparent.

"It's thought that either the light has been Doppler shifted as it goes around the black hole (creating ▸

TUNING IN TO A BLACK HOLE

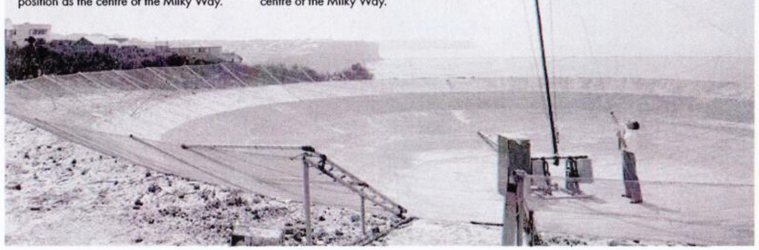
The centre of the Milky Way only became apparent in the age of radio astronomy

In the 1950s, radio astronomy was beginning to come into its own as huge telescopes were built across the world. As radio astronomers surveyed the sky at these newly available wavelengths, a bright new source was discovered in the night sky.

Located at a declination of –29°, the object was best viewed from the southern hemisphere. At the time, one of the largest radio telescopes in the world was the 21.9m 'Hole-in-the-Ground' scope at Dover Heights in Australia, perfectly located to observe this intriguing object. In 1951, the observations of the source, now called Sagittarius A, revealed that it was located at the middle of our Galaxy. In 1958 the International Astronomical Union decided to adopt its position as the centre of the Milky Way.

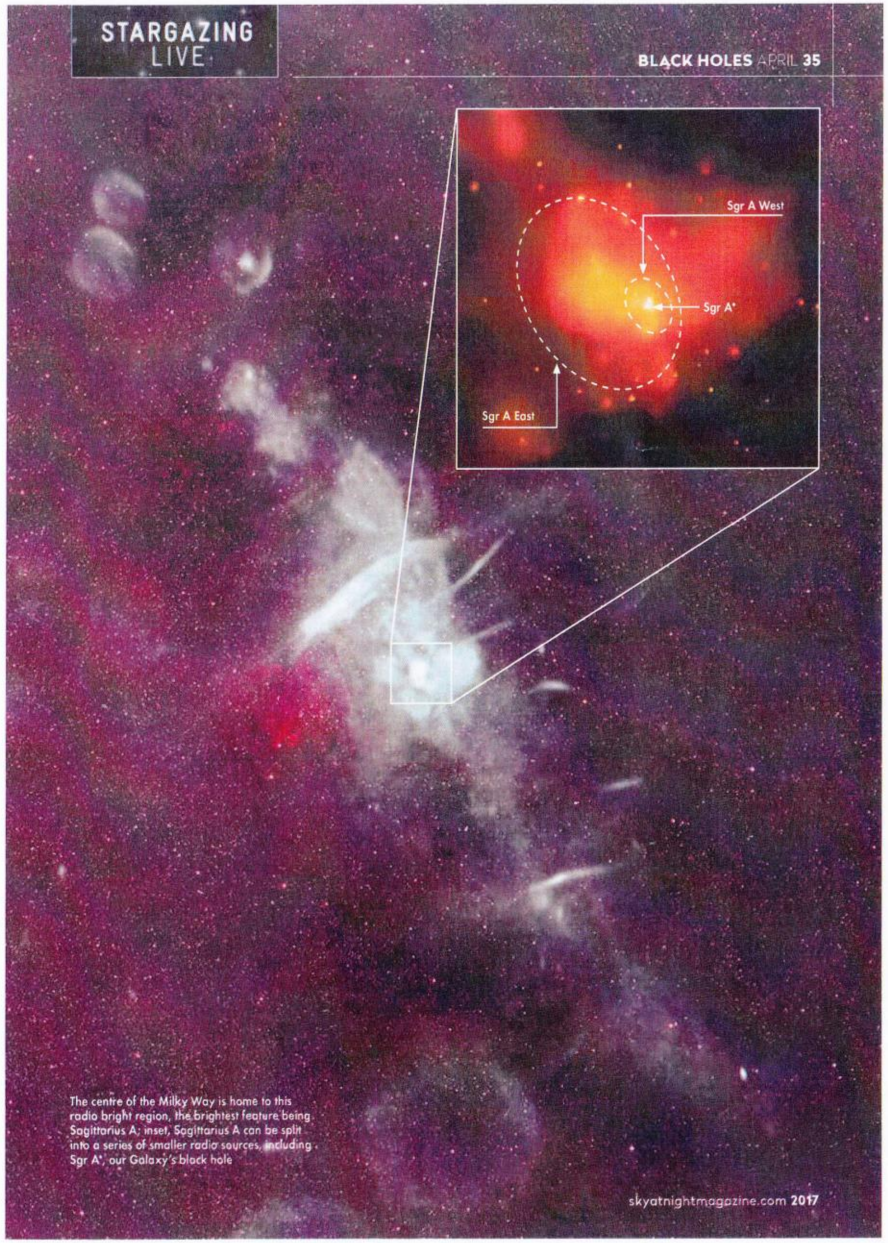
As radio telescopes increased in size and precision, it became apparent that Sagittarius A was not one single object but something made up of several regions. The eastern section appears to be the remnant of a supernova, while the western part seems to be a three-armed cloud of gas and dust.

In 1974 observations with the National Radio Astronomy Observatory in New Mexico revealed that there was a single bright source embedded within the region, Sagittarius A*. The stars in orbit around it showed the object must have a colossal mass in a tiny area, for which there was only one explanation. The astronomers had found the supermassive black hole at the centre of the Milky Way.



The Hole-in-the-Ground radio telescope in Australia was used to observe the mystery radio source in the 1950s

CSIRO, B. SAXTON/NRAO/AUI/NSF FROM DATA PROVIDED BY N.E. KASSIM/NAVAL RESEARCH LABORATORY, NASA/PENN STATE/G.GARMIRE ET AL.



The centre of the Milky Way is home to this radio bright region, the brightest feature being Sagittarius A; inset, Sagittarius A can be split into a series of smaller radio sources, including Sgr A*, our Galaxy's black hole

▸ an increase in luminosity when it's coming towards us) or a blob of material gets caught in the base of a jet and is pushed out. And as it's pushed out it expands," says Borkar.

Similar flares have been seen occurring around many other supermassive black holes, but what causes them remains largely unknown. Our proximity to SgrA* gives astronomers a fantastic view of these strange events: by studying the black hole in our Galaxy, astronomers can learn much about these beasts that lie at the centre of every galaxy.

"Black holes are highly significant astronomically," says Frank Eisenhauer from the Max Planck Institute for Extraterrestrial Physics.

▲ It's hoped the VLT's drum-like Gravity instrument will help us study stars even closer to the supermassive black hole

"They influence the full motion of a galaxy much more than stars do. There is a very strong correlation between the size of black holes and the inner parts of galaxies. They can blow the outer dust about and prevent further gas streaming in, so there's a very strong interplay between the formation and evolution of black holes and the centres of galaxies."

Eisenhauer is the principal investigator for the new Gravity instrument on the VLT, which has been specially made to take advantage of our excellent view of SgrA*. Gravity will image the region around the black hole, not only with an increased resolution compared to previous instruments, but also with a higher precision too. This will allow it to look at the stars that lie around the black hole, which are known as S stars.

THE EVENT HORIZON TELESCOPE

Capturing the heart of our Galaxy requires a telescope the size of the planet

The Event Horizon Telescope (EHT) is one of the biggest projects in the history of astronomy. It aims to combine up to a dozen of the world's premier radio telescopes – from the US, South America, Europe and the south pole – to observe SgrA* in greater detail than ever before.

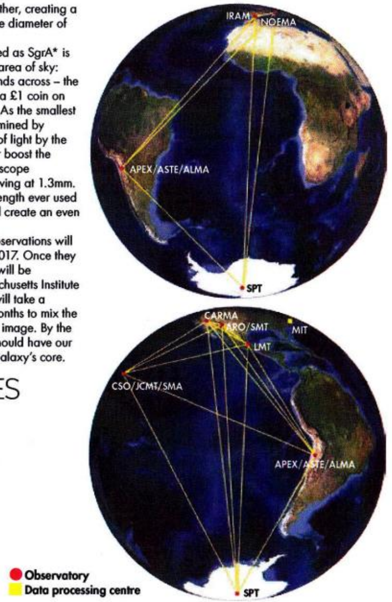
The telescope works using a technique called very-long baseline interferometry, in which a signal is collected at a number of telescopes. The size of the telescope is not based on the diameter of the dishes, but the distance between them. Each of the scopes has been updated with an atomic clock, the most precise timekeepers on Earth. As well as allowing researchers to make precise timing measurements of the black hole's changing brightness (effectively taking its pulse), the timepieces will make it possible to combine the signals. Using the slight differences in arrival time for the light at each of the scopes, it's possible to reach a much higher precision than can be attained by simply stacking the images together, creating a 'virtual telescope' with the diameter of the Earth.

This huge size is needed as SgrA* is expected to cover a tiny area of sky: around 10 microarcseconds across – the equivalent of looking for a £1 coin on the surface of the Moon. As the smallest angle resolvable is determined by dividing the wavelength of light by the size of the dish, to further boost the angular resolution of the scope researchers will be observing at 1.3mm. This is the shortest wavelength ever used for the technique and will create an even higher resolution scope.

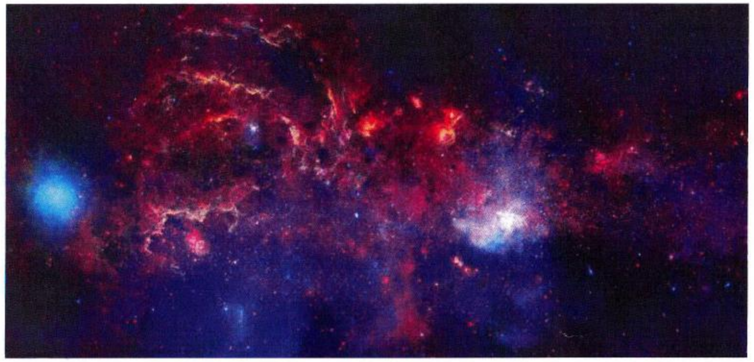
The EHT's first set of observations will be made on 5-14 April 2017. Once they are completed, the data will be transported to the Massachusetts Institute of Technology, where it will take a supercomputer several months to mix the separate signals into one image. By the beginning of 2018, we should have our first real glimpse of our Galaxy's core.

THE EVENT HORIZON SCOPES

APEX: Atacama Pathfinder Experiment
ASTE: Atacama Submillimeter Telescope Experiment
ALMA: Atacama Large Millimeter/Submillimeter Array
CARMA: Combined Array for Research in Millimeter-wave Astronomy
CSO: Caltech Submillimeter Observatory
IRAM: Institut de Radioastronomie Millimétrique
JCMT: James Clerk Maxwell Telescope
LMT: Large Millimeter Telescope
MIT: Massachusetts Institute of Technology
NOEMA: Northern Extended Millimeter Array
SMA: Submillimeter Array
SMT: Submillimeter Telescope
SPT: South Pole Telescope



MPE/GRAVITY TEAM, EVENT HORIZON ILLUSTRATION BY PAUL WOOTTON, X-RAY: NASA/CXC/UMASS/D. WANG ET AL/ OPTICAL: NASA/ESA/STSCI/D.WANG ET AL/IR: NASA/JPL-CALTECH/SSC/S.STOLOVY, C-K CHAN/D PSALTIS/F OZEL X 4



▲ This spectacular image combines infrared and X-ray light to see past obscuring dust through to our Galaxy's core; Sgr A is the bright white region

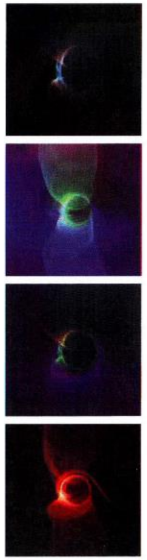
"These are stars in the centre of our Galaxy that are a few million years old, with masses around 20 times that of our Sun. They trace the gravitational field and are very good test particles because they are frictionless through the vacuum of space," says Eisenhauer.

The motions of the stars are governed by the black hole they surround. It is by monitoring the motions of these stars that scientists have been able to determine the mass and size of SgrA*. The closer the star, the more accurate the estimation, and the VLT's Gravity instrument will help to refine those measurements.

"Gravity will see fainter stars further in, which are on shorter orbits. We hope to find stars that orbit on the order of a few months or years," says Eisenhauer. Currently the closest known star is S2, which takes 15.5 years to complete one lap around SgrA*. In 2018, it will pass through the point of closest approach – a 'mere' 120 AU from the black hole. During this time, it will be accelerated to 30 million km/h, or 2.5 per cent the speed of light. Travelling this fast means S2 will experience the effects of relativity on its motion, giving the Gravity team a fantastic opportunity to put Einstein's equations through one of their most extreme tests yet.

Little kicks

"Most of the time the star follows Newton's laws, but when it comes very close in 2018 it gets a little kick, and the orientation of its orbital ellipse rotates a bit due to the effects of general relativity," says Eisenhauer. "We know so little about black holes, but they are such a fundamental cornerstone for the understanding of relativity and gravity."



▲ The team behind the Event Horizon Telescope have run many simulations to show how matter and light behave near to an event horizon

These observations will test Einstein's theories in the one place where they might falter – at the edge of a black hole. "Relativity has passed every test so far, but it hasn't been tested in a scenario where gravity becomes dominant," says Sheperd Doeleman, an astrophysicist from the Smithsonian Astrophysical Observatory. "Gravity is really the weakest force, so it's only near a black hole that it can play with the big boys."

Doeleman is the director of one of the most ambitious astronomical collaborations ever undertaken, the Event Horizon Telescope, which aims to take the first ever image of the shadow cast by the Milky Way's black hole.

"We can't see the black hole directly because it is surrounded by this event horizon that does not permit information to leave the black hole. Because the gravity around the black hole warps light around it, we expect to see the silhouette of the black hole against the backdrop of superheated gas," says Doeleman. "We expect to see a very characteristic strong lensing feature, a ring of light that indicates the last orbit that photons can move through around the black hole before they themselves are sucked in. You end up with an annulus with a relatively dim interior – the silhouette of a black hole."

The size and shape of this silhouette was predicted by Einstein's theories of relativity, which were laid down over 100 years ago. Comparing the shadow that has been forecast with reality could help to solidify our understanding of them. On the other hand, if the observations do not show what is expected, they could throw Einstein's theories into doubt. Within the next year, humankind should have its best look at the dark heart of a galaxy, and with it may even find the key to unlocking the rules that govern our Universe.