TEACHER NOTES – ASTRONOMY IN THE NEWS #38

MILKY WAY'S SUPERMASSIVE BLACK HOLE

Slide 2 – Background Science: Black Holes at the centre of Galaxies

The presence of quasars from the centre of galaxies required an explanation, and the energy output required a mass of $10^5 - 10^9$ $M_\odot$. Further explanation was that matter accreting onto a massive compact object would explain the properties of a quasar. The quasars, a subset of active galactic nuclei, have luminosities thousands of times greater than a galaxy. They are caused by gas falling onto this compact object which heats up and releases energy.

These compact objects were then determined to be supermassive black holes (SMBH) due to the mass concentration required to explain numerous measurements. These observations were:

1) The relativistic jets of quasars and AGN require a mass too large to be a supermassive star.
2) The large velocity dispersions of stars found in the centre of elliptical galaxies required a mass concentration too high to be explained by ordinary stars, even an extremely dense stellar cluster.
3) A radio source, Sagittarius A* (Sgr A*) was discovered at the centre of the Milky Way. This object emitted synchrotron radiation; radiation produced by relativistic particles accelerated by a magnetic field. This object had to be a black hole as it was dense and not moving.
4) Finally, the HST telescope found ionised gas orbiting the central parts of external galaxies, which was followed by the proper motions of stars within the Galactic Centre of the Milky Way.

IMAGES:

1. (Top left) The SMBH at the centre of the galaxy, M87. This was the first SMBH directly imaged by the Event Horizon Telescope (EHT). This telescope will be described on the next slide.
2. (Bottom left) HST image of the jet emitted from the black hole in image 1. This jet is 4,400 light years long.
3. (Right) Part of the data that was used to determine the discovery of a SMBH in the centre of the Milky Way. The main panel shows the stars in the Galactic Centre, orbiting Sgr A* (the +). The arrows show the velocities of the stars and the direction they have moved, whilst the graphs show how far these stars have moved in units of milliarcseconds over the course of 4 years. The only explanation for these movements is a very dense, compact object that they are orbiting.

Slide 3: Milky Way's SMBH

The Event Horizon Telescope (EHT) is a collaboration of radio, millimetre, and sub-millimetre telescopes across the world, which when they observe the same object, produce a large baseline interferometer. This large baseline allows for very high-resolution images to be made at radio/millimetre wavelengths, specifically at a wavelength of 1.3mm.

The EHT has previously made the first ever observations of a black hole, the SMBH in the centre of the galaxy M87. However, the collaboration has now made the first direct observations of the SMBH in the centre of the Milky Way, Sagittarius A* (Sgr A*). These observations are shown on the slide.

The black hole is the dark circle in the centre, the shadow. The event horizon, or Schwarzschild radius, is the circle that can be drawn around this, on the inside of the emission ring. The emission ring is caused by the very hot, ionised gas orbiting the black hole. The physical properties of the SMBH are $4.0\ (^{+1.1}_{-0.6})\ \times10^{6}$ M. (The mass estimate used for the calculation below is the slightly different value determined from stellar orbits. It is within the uncertainties). The angular size of the shadow of 51.8 ± 2.3 as, that is 10^{-6} of a second, i.e., $1.42\ \times10^{-8}$ of a degree!

The articles that this bulletin is built on can be found here:

https://www.bbc.co.uk/news/science-environment-61412463

https://www.theguardian.com/science/2022/may/12/supermassive-black-hole-centre-milky-way-first-time-sagittarius-a-

A free version of the publication presenting this result can be found here:

https://iopscience.iop.org/article/10.3847/2041-8213/ac6674

And the full suite of EHT Sgr A* detection papers can be found here:

https://iopscience.iop.org/journal/2041-8205/page/Focus_on_First_Sgr_A_Results

There is also an article about this discovery from the Armagh Observatory and Planetarium:

https://armaghplanet.com/first-image-of-the-giant-black-hole-lurking-at-the-centre-of-the-milky-way-unveiled.html

IMAGES:

1. (Left) The main panel shows the image of the SMBH at the centre of the Milky Way. The shadow (dark circle) in the centre is the SMBH, with the bright emission on the edge is the material that is accreting giving off light as it is accelerated. The bottom four panels show the different morphologies that were detected of the emission. These four morphologies show the varying state of the accreting gas (and this variation is discussed in the activity).

2. (Right) Map of the facilities that make up the Event Horizon Telescope. The yellow lines and telescopes make up another network, with the EHT represented by those in blue. They span 9 facilities, 7 locations, 4 continents and 5 countries (along with Antarctica). These facilities are IRAM (Spain), NOEMA (France), SPT (Antarctica), ALMA and APEX (Chile), LMT (Mexico), SMT (USA), and SMA and JCMT (Hawaii, USA).

Slide 4 – Activity: Why is the Milky Way's SMBH so variable?

This week's activity is to compare the black holes at the centre of the Milky Way and M87.

One feature that was evident when looking at the multiple images of the SMBH was that, although very similar to the SMBH at the centre of M87, the Milky Way's seemed a lot more variable. Why would this be?

Using the gravitational force and centripetal force, and the masses of the two black holes to compare the two orbit times.

The two equations (gravitational and centripetal) should be put equal to each other:

$$\frac{GM_{BH}m}{r^2} = \frac{mv^2}{r}$$

$$\frac{GM_{BH}}{r} = v^2$$

At the Schwarzschild radius, $v = c$, and the distance travelled is $2\pi r_S$, therefore the minimum time taken to orbit the black hole is:

$$T = \frac{2\pi GM_{BH}}{c^3}$$

The black hole in M87 has a mass of 2.4 $\times 10^9$ $M_\odot$, and in the Milky Way it is 4.3 $\times 10^6$ $M_\odot$. This gives minimum orbit times of 20.6 hours and 2.2 minutes respectively. It is therefore obvious why the images were much more variable!

GCSE Specifications:

Specification	Knowledge Point
Pearson Edexcel Astronomy	13.10, 13.26, 13.27, 15.10, 15.11

A-Level Physics Specifications:

Specification	Knowledge Point
Pearson Edexcel Physics	107, 176
OCR Physics A	5.2.2(d), 5.4.2(a)
OCR Physics B	5.1.2(c)
AQA Physics	3.6.1.1, 3.7.2.1, 3.9.2.6