TEACHER NOTES – ASTRONOMY IN THE NEWS #51

BLACK HOLE JETS

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: The Jet of M87

M87 is a supergiant elliptical galaxy with a relativistic jet emanating from the central regions. The SMBH was, as mentioned above, the first SMBH imaged by the EHT. Further observations from the Global Millimetre VLBI array, a collection of millimetre telescopes spread across the world, and was supplemented by ALMA (in Chile) and the GLT (Greenland). These observations, at a wavelength of 3.5mm, complement those made by the EHT at 1.3mm.

The 3.5-mm observations highlight two things. One is that the jet is connected to the material that is orbiting the central SMBH, although they are not resolved enough to securely pinpoint the location of the launching point. The second revelation is that the ring of material observed at 3.5mm is 50% larger than that shown at 1.3mm. This hints at some impact from gravitational lensing, along with absorption effects from the accretion flow. The mechanism launching this jet, which was also revealed to be triple-ridged, is unknown but the width of the jet towards the central SMBH suggests that there is a wind-driven element along with any accretion effects.

The article that this resource is built on can be found here:

https://www.theguardian.com/science/2023/apr/26/astronomers-capture-first-image-of-jet-being-launched-from-edge-of-black-hole

IMAGES:

1. 3.5-mm observations of the jet emanating from M87. The three-ridged structure of the jet is visible, along with the material from the jet connected to the central accretion ring.

Slide 4 – Activity: Calculating the Schwarzschild Radius

This week's activity is to calculate the Schwarzschild Radius for M87, the radius commonly known as the Event Horizon. Any object that is smaller than its Schwarzschild Radius is determined to be a black hole. Using the constants, quantities and equation on the slide, the students should obtain a value of 1.93×10^{13} m. The trickiest part is to ensure that the mass is converted into kg from solar masses, the conversion factor is shown on the slide.

GCSE Specifications:

Specification	Knowledge Point
GCSE Astronomy	13.26, 13.27, 15.10, 15.11, 15.12

A-Level Physics Specifications:

Specification	Knowledge Point
AQA	3.9.2.6
Scottish Advanced Higher	Rotational Motion & Astrophysics – General Relativity