TEACHER NOTES – ASTRONOMY IN THE NEWS #13

LIGHT BEHIND A BLACK HOLE

Slide 2 – Background Science: General Relativity and Black Holes

General Relativity is a theory postulated by Albert Einstein in which space and time are linked by something called spacetime. Spacetime is a mathematical model which describes the four-dimensions of space and time (x, y, z, t). A body in spacetime produces a well, or curvature, in the spacetime. The more massive an object is, the greater the curvature is.

The theory of General Relativity explains a number of astronomical results such as gravitational lensing, where a dense, massive object in the foreground is able to bend the light from behind it around it. These objects can be black holes. The presence of this gravitational lensing is strong evidence supporting this theory.

Black holes are formed when a massive star (greater than 20 times more massive than the Sun) explodes via a supernova. However, there are supermassive black holes in the centre of nearly all, if not actually all, galaxies, including the Milky Way. It is the presence of these black holes, and the accretion onto them, that is powering active galactic nuclei and quasars (a very bright galactic nucleus).

IMAGES:

1. (Left) A depiction of spacetime and how objects with different masses cause different curvatures in spacetime. The more massive the object, in this case the yellow sphere is the most massive, the greater the curvature caused.
2. (Centre) The first direct imaging of a black hole from the Event Horizon Telescope, a collection of radio telescopes across the globe. This shows the accretion disk on which matter accretes onto the black hole. This image is at a wavelength of 1.3mm and shows the polarisation around the supermassive black hole in the centre of the galaxy, M87. This polarisation is linked to the magnetic fields that surround the black hole. This image is also the
3. (Right) The Einstein cross, a gravitationally lensed quasar with four mirrors of the same object around a foreground a galaxy.

Slide 3: X-Rays around a Black Hole

As mentioned above when discussing active galactic nuclei, matter accretes onto a black hole. This occurs via a disk, which was shown in the image on the previous slide. As the matter, usually gas and dust in the centre of a galaxy, spirals into the accretion disk and eventually into the black hole, it heats up to a temperature of roughly 10 million degrees Celsius. At these temperatures, light is emitted as x-rays.

The galaxy I Zwicky 1 was observed to be emitting x-rays as flares. The spectrum of the x-rays indicated that these were coming from material accreting onto a spinning black hole, a black hole of mass 3.1 x10^7 solar masses.

However, the spectrum displayed some features which would not be expected from just a purely accreting spinning disk. These features were fit with models and they were found to be consistent with a reverberating model. A reverberating model is where photons reverberated, or reflect, from the accretion disk behind the black hole. These photons are then gravitationally lensed by the gravitational field around the supermassive black hole, and we then observe them. The signature of these reverberations are these features, or peaks, in the spectrum which is the re-emergence of emission. The existence of these reverberations confirms a key prediction of General Relativity.

The article that this resource is built on is:

https://www.theguardian.com/science/2021/jul/28/astronomers-detect-light-behind-black-hole-for-first-time

A free version of the research article can be found here:

https://arxiv.org/abs/2107.13555

IMAGES:

1. (Left) Image of a galaxy containing an x-ray emitting black hole. The red, green and blue are optical wavelengths from the Hubble Space Telescope, whilst the purple is x-ray emission from the Chandra X-Ray Observatory.
2. (Top right) The spectrum of the x-ray emission from I Zwicky 1 over a period of 10,000 seconds. The top panel shows the observed spectrum, of x-rays in the 3-5 keV band. These energies are known as "soft" x-rays. The blue line is a fitted model of Iron K line emission from a accreting black hole. An Iron K line is where an electron from the L shell (2nd shell) fills a gap in the K shell (1st shell). The bottom panel displays a model of emission of photons from a reverberating disk. The similarity of these two lines is further confirmation that there is x-ray emission coming from reflections from behind the black hole.
3. (Bottom right) A cartoon indicating the situation observed in I Zwicky 1. An x-ray source emits with some of the light reach the observer directly, however some are reflected off the accretion disk and some are reflected from the accretion disk behind the black hole. This is caused by the gravitational field bending the light towards the disk. However, the light from behind the black hole.

Slide 4 – Activity: Simulating Gravitational Lensing

The activity this week is an experiment to try to simulate gravitational lensing. This can be done by using a wine glass, or any other curved glass like a tumbler. Place the glass, filled with a dark liquid on the edge of a table or desk. The point a torch, preferably fixed, into the liquid. A dark liquid is preferable as there is a better contrast between the torch and the liquid. By moving around in front of the glass, you should be able to see mirror images of the torch, or background galaxy, around the edges. You may also see an arc of light. The glass acts as a lens, similar to how the spacetime around a black hole is deformed to act like a lens for background light.

GCSE Specifications:

Specification	Knowledge Point
Pearson Edexcel Astronomy	15.10, 15.11, 15.12
Pearson Edexcel Physics	5.6, 5.10, 6.7, 6.8
Pearson Edexcel Chemistry	1.2
Pearson Edexcel Combined Sciences	C1.2, P5.10, P6.7, P6.8
OCR Physics B	1.1.1, 1.1.6
OCR Combined Science B	P1.1.1, P1.1.6
AQA Physics	4.4.1.1, 4.4.1.3, 4.6.2.1, 4.6.2.3, 4.6.2.5
AQA Combined: Trilogy	6.4.1.1, 6.4.1.3, 6.6.2.1, 6.6.2.3

A-Level Physics Specifications:

Specification	Knowledge Point
Pearson Edexcel Physics	79
OCR Physics A	5.5.1(f)
OCR Physics B	6.1.2(b)
AQA Physics	3.2.2.2, 3.9.2.6, 3.9.3.3