TEACHER NOTES – ASTRONOMY IN THE NEWS #52

LARGEST COSMIC EXPLOSION

Slide 2 – Background Science: Central Black Holes and Cosmic Explosions

As we've discussed at many times in these bulletins, the centres of galaxies house a supermassive black hole (SMBH). SMBHs, those black holes with a mass above 100,000 solar masses, are found in all large galaxies, such as the Milky Way. Active galactic nuclei, AGN, and quasars are powered by the accretion of interstellar gas onto these SMBHs. These objects are some of the brightest objects in the Universe, such is the power that is released.

However, there are other cosmic events which give off a significant amount of energy, such as supernovae and gamma-ray bursts (GRBs). Massive stars end their lives in violent core-collapse supernovae. These events impact stars which have an initial mass of greater than 8 solar masses. A core -collapse supernova occurs when all the fuel is exhausted and the core of the star collapses. This collapse continues until it is unable to collapse any further, at which point an explosion occurs, catapulting all of the stellar envelope and material into the interstellar medium. Within the stars that go supernova, there are two evolutionary routes, again separated by mass. Those stars between 8 and approximately 30-40 solar masses leave behind a neutron star, whilst in those more massive than that, a supernova remains.

The cause of GRBs is not entirely known but one such formation mechanism is also related to stellar evolution. One stage prior to a core-collapse supernova in the most massive stars is the Wolf-Rayet stage. Once a massive star has finished burning its hydrogen it enters the helium-burning phase, and is in the red supergiant (or blue supergiant) phase. Lower mass massive-stars will explode at this point, whereas more massive stars start to expel their atmospheres and get hotter, becoming Wolf-Rayet stars. These stars burn hydrogen very quickly, which causes mixing of heavy elements, resulting in very fast stellar winds, giving off large amounts of material from the outer layers of the star. As a result, Wolf-Rayet stars are surrounded by a nebula, whilst ending their lives in a supernova. If these stars were to explode, they may go straight to a black hole, with an accretion disk and relativistic jets, which are observed as a GRB.

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).
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. (Top right) Artist's impression of the most energetic supernova ever observed, SN2016aps.
4. (Bottom right) Time-lapse of the most energetic GRB ever observed. These are gamma-ray observations (approximately 20 degrees across). The image only shows the most energetic gamma rays (the diagonal streak across the image is the Milky

Way). GRB 221009A is the bright explosion that is revealed during the time lapse, with these observations spanning approximately 10 hours.

Slide 3: Largest Cosmic Explosion

The Zwicky Transient Facility (ZTF) is an astronomical observatory that observes a large fraction of the night sky (47 square degrees) in the optical and infrared wavelengths. The goal of the ZTF is to detect changes in the sky, i.e. transient astronomical events such as supernovae and GRBs. On April 13th, 2021 an event was observed, which was independently verified by other facilities attempting to detect transient events.

By looking at the spectroscopic properties, it was determined that this event was at high redshift (z=0.9945). They fit a spectral energy distribution (the brightness at multiple wavelengths), along with tracking the brightness over a long period of time (over three years), and the amount of energy released, the only explanation was continuous accretion onto a SMBH.

Before these observations, the largest cosmic explosion observed was GRB 221009A, the time lapse of which is on the previous slide. The peak of that explosion was much higher than this, however, the amount of time that this accretion has occurred over makes this the most energetic event ever observed, ten times more than the brightest true transient!

The articles from which this resource is built on can be found here:

https://www.bbc.co.uk/news/science-environment-65571309

https://www.theguardian.com/science/2023/may/12/astronomers-capture-largest-cosmic-explosion-ever-witnessed

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

https://arxiv.org/abs/2303.04412

IMAGES:

1. (Top left) NEOWISE mid-infrared observations of AT2021lwx. The unspectacular nature of this observation hides such an amazing explosion!
2. (Top right) Artist's impression of a supermassive black hole accreting material, in this case a molecular cloud.
3. (Bottom) Light curve (brightness over time) of AT2021lwx. The teal and cyan squares are from the ZTF, the facility that made the initial discover, whilst the red and yellow diamonds are from WISE (Image 1). The other points are from the observatories that made the independent verifications of this event. What is obvious from these observations is the length of time that the increase in brightness occurred over is significant.

Slide 4 – Activity: How much brighter is AT2021lwx than the Sun?

This week's activity is to work out how bright AT2021lwx is compared to the Sun. It introduces the idea of magnitudes. Magnitudes are the unit in which the brightness of objects in the sky are measured in, with the smaller the number, the brighter it is. There are also two types of magnitude. The first, apparent, is how bright they appear in the night sky, whereas absolute magnitude considers distance, so thus is relative to each other if they were at the same distance.

Each magnitude is 2.5 times brighter than its previous one. Therefore, a magnitude 1 star is 100 times brighter than a magnitude 6 star. The formula is thus $2.5^{\text{difference}}$. Given the values on the slide, can the students work out how much brighter AT2021lwx is. Considering an absolute magnitude difference of 27.42, it is 81 billion times brighter!

GCSE Specifications:

Specification	Knowledge Point
Pearson Edexcel Astronomy	13.1, 13.2, 14.10, 15.10
Pearson Edexcel Physics	7.18
OCR Physics B	6.5.6
AQA Physics	4.8.1.2
CCEA Physics	2.5.10, 2.5.11
CCEA Double Award	P2.5.10, P2.5.11
WJEC Physics	2.5 (c)
WJEC Science Double Award	6.4 (c)

A-Level Physics Specifications:

Specification	Knowledge Point
OCR Physics A	5.5.1(e)
OCR Physics B	5.1.3(b)
AQA Physics	3.9.2.2, 3.9.2.6, 3.9.3.3