TEACHER NOTES – ASTRONOMY IN THE NEWS #12

WHOLE SUPERNOVA LIGHT CURVE

Slide 2 – Background Science: Core-collapse supernovae

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.

These events are some of the most violent in the Universe and are observed when a “new” star appears in the night sky. However, an important aspect of supernova research is determining the type of star, the progenitor, that exploded to leave behind the supernova remnant we observe. Determining this usually requires one of two things, either observations prior to the supernova or modelling of the light curve (the brightness over time of the supernova). However, as all observed supernovae occur in external galaxies (the last to be observed in the Milky Way was 1604, and resolving individual stars at those distances isn’t possible, detailed modelling is the way to determine the progenitor properties.

IMAGES:

1. (Top) Cartoon demonstrating the different life cycles of stars depending on their initial mass. The top row is for stars less massive than 8 solar masses, whilst the bottom row is for stars with an initial mass of 8 solar masses or greater. A further differentiation is made with the most massive stars at 40 solar masses, where below that the supernova leaves a neutron star, whilst greater than that, a black hole remains.
2. (Bottom left) Light curves for different types of supernovae, Type Ia and Type II. Type II are core-collapse supernovae, whilst Type Ia are formed in a different manner. They occur in binary systems, where the more massive star exhausts its fuel and leaves behind a white dwarf. This white dwarf then accretes matter from the outer limits of the smaller star. Once a mass limit is reached, 1.4 solar masses, the white dwarf cannot be sustained and it explodes as a supernova. Type II occur as described above. Determining between the two occurs as Type I supernovae have no hydrogen in their spectra, whilst Type II supernovae exhibit hydrogen emission lines. The shape of the light curve is also different, as described in Image 3.
3. (Bottom right) A theoretical light curve for a Type II supernova. When the star explodes as a supernova, the brightness immediately increases and rapidly (shock breakout). This occurs as the shock wave of the supernova expands through the outer layers of the star and breaks out of the star. The brightness starts to decrease as the temperature of the outer layers starts to decrease. At this point, we are observing the outer layers, which is ionised hydrogen as the shock wave stripped the hydrogen of its electrons. Ionised hydrogen is opaque. However, as the layers cool,

they begin to recombine and become neutral again. Neutral hydrogen is transparent and we begin to see deeper into the star and the photosphere. This causes a plateau in the light curve, with the more nickel that is in the system, the brighter this plateau is. Once this begins to cool, the decline in the light curve begins again.

Slide 3: Light curve of SN 2017jgh

Supernova SN 2017jgh occurred in December 2017. It was initially observed by the ground-based telescope PAN-STARRS1 in the near-infrared and at visible wavelengths. More precisely at wavelengths of 481, 617, and 752 nm. These observations appeared to detect the initial decline from the shock breakout, but did not securely detect the rise.

However, the Kepler mission was a space-based telescope which observed different fields throughout different campaigns in a broad optical/infrared filter. Each campaign observed the same field every 30 minutes for 80 days, and the 16th campaign observed the field which would go on to contain supernova SN 2017jgh. By processing these data, a total light curve could be constructed. The host galaxy was observed for approximately 8-9 days before explosion, at which point the shock breakout rise occurs, and the entire light curve is observed until the decline to almost pre-supernova levels.

By observing the full light curve, model fits have the benefit of having accurate measurements of the shock breakout rise, allowing for more accurate estimates of the velocity of the shock wave that burst through the exploding star. These models gave an estimate of 9100 ± 470 km/s. The authors of this paper were also able to compare the results of the model fit to those that are produced just using the ground-based data. Visual inspection of these fits show they do not do a good job of recreating the shape of the shock breakout rise, which is reflected in the resulting shock wave velocity estimate of 11500 ± 3200 km/s. Although they are consistent within the error bars, this is not a good fit to the data.

The fits to the ground-based data do give a good estimate of the mass and radius of the progenitor which indicates the decline of a light curve gives you this information, whilst the initial rise is important for determining the shock velocity.

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

https://www.theguardian.com/science/2021/aug/06/champagne-moment-as-supernova-captured-in-detail-for-the-first-time

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

https://arxiv.org/abs/2108.06654

IMAGES:

1. (Left) Light curves for SN 2017jgh. The yellow, purple and green points reflect the ground-based telescope observations at 752, 617, and 481 nm, respectively. The

black points are the Kepler observations taken every 30 minutes, whilst the red points overlaid are averages for each 6-hour period. This light curve clearly indicates all features of the theoretical light curve. The solid vertical line is the end of the "shock cooling light curve" where the outer layers have cooled sufficiently so that the star can be observed. The dashed vertical line is the point at which a spectrum of the supernova was taken to determine the supernova type.

2. (Right) Models of the progenitor star fit to the ground-based data. The yellow, purple and green points are the ground-based data which are fit, whilst the shading/lines of those colours are the model fits. The black lines are the medians of these fits. The red points are the Kepler data, with the lines reflecting the fits just using the observations covering the time range of the ground-based data. It is obvious that these fits do not reflect the data well.

Slide 4 – Activity: What is left behind?

The supernova SN 2017jgh was determined to be a yellow supergiant. This means that it has an initial mass of between approximately 1 solar mass to 20 solar masses. Can the students determine what is left behind from the supernova, either a neutron star or a black hole, knowing this range of masses. Since the star went supernova, the initial mass must be above 8 solar masses. To become a black hole, a star must have an initial mass above 20 solar masses, therefore this rules out a black hole.

GCSE Specifications:

Specification	Knowledge Point
Pearson Edexcel Astronomy	6.1, 13.14, 13.21, 13.32, 14.8, 14.10
Pearson Edexcel Physics	7.18
AQA Physics	4.8.1.2

A-Level Physics Specifications:

Specification	Knowledge Point
OCR Physics A	5.5.1(e)
AQA Physics	3.9.2.6