# TEACHER NOTES – ASTRONOMY IN THE NEWS #27

## HOW STARS BECOME BLACK HOLES

## Slide 2 – Background Science: Core-Collapse Supernova

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.

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.

IMAGES:

1. (Left) 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 30-40 solar masses, where below that the supernova leaves a neutron star, whilst greater than that, a black hole remains.
2. (Right) Hubble Space Telescope of a Wolf-Rayet star. This star is massive, spanning approximately 6 light years across. The mass ejections have occurred for approximately 20,000 years.

## Slide 3: From a star to a black hole

The usual light curve of a supernova shows a rapid rise in the brightness of the star due to the explosive, violent nature of the event, followed by a rather gradual decline in brightness over time until it eventually reaches the original level. For supernova that likely occurred from stars who had lost their envelope and atmosphere, either from processes such as those described above or where there is material stripped from the star by a binary, a drop of 2-3 magnitudes is expected over a period of 60 days.

Supernova SN2021csp was first discovered on February 11th, 2021 as part of large-scale surveying of the night sky looking for transient events like these. Observations in multiple wavelengths confirmed that this object was a supernova, and modelling of the light curve determined it was a stripped-envelope event. However, the drop in magnitude of SN2021csp is quite prodigious compared to similar events. A 60-day decline of 5 magnitudes is found.

The light curve shows a rise much quicker than usual supernovae of this type, whilst the flux after 60 days is too faint for a supernova explosion that produces significant ejecta. The proposed explanation of this is that the Wolf-Rayet star that was there previously has directly collapsed to a black hole. This process launches a jet that interacts with the material that was previously ejected by the Wolf-Rayet star. The fact that there was so much material around the star is the only reason that this process was detected!

This bulletin is slightly different to the usual bulletins in that it is not built upon a news article that was in the national media. Instead, it is built upon a press release from my host department at Liverpool John Moores University and I wanted to highlight some of the work done here. The article that this resource is built on can be found here:

https://www.ljmu.ac.uk/about-us/news/articles/2022/1/12/cosmic-explosions-offer-new-clue-to-how-stars-become-black-holes

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

https://arxiv.org/abs/2111.12110

IMAGES:

1. (Left) Images of SN2021csp at optical wavelengths from the Nordic Optical Telescope. These occurred at 48, 65 and 80 days after the explosion, respectively. The top row includes the host galaxy, whilst the bottom row shows this subtracted away. There is no supernova detected in the final image.
2. (Right) Light curves of similar events to SN2021csp, with SN2021csp shown for comparison. There are 6 objects shown. The black line shows this object, the orange, red and purple dot-dot-dot dash line are supernovae of this nature, the green line is a “hybrid” supernova, and the purple dashed line is an undefined transient. It is either a supernova, or more likely, a black hole-star disruption event.

# Slide 4 – Activity: How fast is the stellar wind of a Wolf-Rayet star?

The activity here is to calculate the speed of the stellar winds of a Wolf-Rayet star. We have an approximate size for this nebula (6 light years) and the central star has expelled material for 20,000 years. Using these two facts, and the information on the slide to calculate the speed. The only “trick” is to realise that the material has travelled 3 light years, and not 6 since the diameter is 6 light years. This gives a speed of approximately 45 km/s. This is about a seventh of the speed of light, so very fast!

# 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 |