An Introduction to Supernovae

What causes these spectacular stellar explosions?

If you have read through the **Stellar Lifecycles** worksheet, you will have seen that stars of similar mass to our Sun will evolve into **white dwarfs** at the end of their lifecycles. However, **massive stars** (those that exceed around 8 solar masses), will end their lives in powerful **supernova explosion**s.

In our galaxy, the Milky Way, evidence suggests that supernova explosions occur approximately **once every 50 years** and we're in fact overdue one! The last supernova to be seen was observed by Johannes Kepler in 1604. Although there is some evidence for more recent supernovae having occurred in the Milky Way, there are no historical records of them. This is probably because they were obscured from our view by large amounts of dust in the disc of our galaxy. However, even if supernovae are not visible to us by eye, it is possible to spot them with infrared telescopes since galactic dust does not block infrared light as much as it does visible light.

Supernovae are a type of **transient object,** these are objects that **change in brightness** very suddenly and often unexpectedly over a particular timescale. When a supernova occurs, the star displays an extreme increase in brightness by up to 100 million times. However, this marks the end of the star's life and so supernovae are "**one-off**" events.

Upon exploding, supernovae release up to **10^{44} J of energy**. This instantaneous explosion releases around the same amount of energy released by the Sun over its entire lifetime. Such events are so bright that they outshine the entire galaxy in which they are located, their host galaxy.

Supernovae can be categorised into two broad classifications according to the type of **progenitors** (the star that exploded) that are involved. Massive stars that explode at the end of their lives are called **Type II** or **core-collapse** supernovae. However, sometimes there are two stars of around the same mass as the Sun involved, and these can lead to **Type Ia** supernovae.

Let's take a look at them in more detail.

Supernova Type Ia

Type Ia supernovae, also known as **thermonuclear** supernovae, involve a **white dwarf star and a companion star** in what is called a **binary system**. This is where the two stars are both in orbit around a common centre of mass.

White dwarfs are very dense stars. Although they have masses comparable to the Sun, they are squeezed into a volume similar to that of the Earth. This means they exert a strong gravitational force which can pull material away from the companion star onto its own surface (as illustrated in Figure 1). The companion star is usually a star like our Sun or a massive red giant star, but it can also be another white dwarf. The mass of the white dwarf gradually increases as it draws more and more material from its companion, this process is known as **accretion**.

Figure 1 – An artist's impression of a white dwarf (right) accreting mass from its companion star (left).

Image source: ESA/ATG medialab/C. Carreau.

As the mass of a white dwarf increases it becomes more and more **unstable**. Once the white dwarf reaches a mass of **1.44 solar masses** (2.87 x 10^{30} kg), it is unable to accrete any more material, we call this the **Chandrasekhar limit.** Before this point, gravitational collapse of the white dwarf is prevented by "**electron degeneracy pressure**" which is exerted by electrons within the white dwarf. However, once the Chandrasekhar limit is exceeded, this pressure can no longer balance the gravity and the star explodes.

A more recent discovery has also shown evidence for the possibility of Type Ia supernovae resulting from the collision of two white dwarf stars. These objects are seen to be in a shrinking orbit around one another, eventually leading to their collision.

Note: For more information on white dwarf stars, see the "Stellar Lifecycles" worksheet.

Supernova Type II

Type II supernovae mark the end of a **massive star's life** (stars over approximately 8 solar masses). Massive stars use up their nuclear fuel much quicker than lower mass stars and are therefore shorter lived. At the point where the star has exhausted all its resources and can no longer produce any more energy, the inner regions of the star **collapse**, and the outer regions are **expelled** outwards in a supernova explosion.

In terms of timescales in the Universe, this is a relatively quick process (of the order of a few million years), and so the stars that result in Type II supernovae are said to "**live fast and die young**".

How can we tell the difference?

So if both processes end in a supernova, how can we tell what type it was and identify the progenitors that the explosion resulted from?

There are several ways of classifying these two types of supernovae, one of which is by using **photometry** to produce **light curves**. Photometry is the measurement of light output and light curves show how this output varies over time.

Note: For further information on light curves see the "Variable Stars and Light Curves" worksheet.

After the initial explosion, the **brightness decreases**. The rate of this decline is different depending on the type of supernova that occurred. This means different types of supernova produce different shaped light curves, Figure 2 illustrates these differences.

Figure 2 – Typical light curves of Type Ia and Type II supernovae.

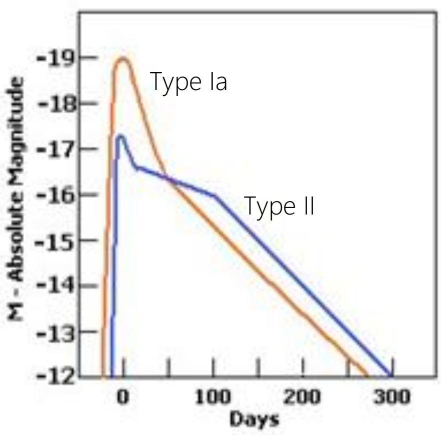

Image source: http://www.uni.edu/morgans/astro/course/Notes/section2/new9.html

Figure 2 displays absolute magnitude against number of days. **Absolute magnitude** describes the brightness of an object where **lower numbers** represent a **greater brightness**. In this example, all the values of absolute magnitude are negative and range from -12 to -19. This means that -19 is the lowest value and therefore the brightest and -12 is the highest value and therefore the faintest.

Note: See the "Calculating Magnitudes" worksheet for further information on magnitudes.

You can see from Figure 2 that the light curves **peak** very rapidly in the **first few days to weeks** for both types of supernovae but Type I are approximately 2 magnitudes (40 times) brighter than Type II. This peak is the initial explosion that releases vast amounts of radiation, and the brightness then gradually **declines over several months**. The shape of the light curve is different for the two types because of the different **chemical elements** that are expelled from the progenitors in the explosion. The **radioactive decay** of these different elements influences the shape of the light curve.

Now you've been introduced to supernova explosions, you can use some data from the Faulkes Telescopes to produce your own light curves and classify these objects. To do this, refer to the photometry worksheets.