FYI Type Ia Supernovae

A supernova is the violent death of a star. There are two types of supernovae: Type I, some of which are created by the deaths of white dwarf stars, and Type II, which are the deaths of isolated high-mass stars. Type II supernovae leave behind a neutron star or black hole in their core, while Type I supernovae often leave no remnant at all.

Figure 3-9: Drawing of a Type Ia supernova being created in a binary system with a red giant star and a white dwarf

Type Ia supernovae (a subset of Type I) occur when a white dwarf is in a binary system with a red giant star. A white dwarf star is a very hot, dense, small-radius star made mostly of carbon. The high-temperature, high-pressure conditions inside a white dwarf enable atoms to exist in a state called **degeneracy**, in which the atoms can support themselves under intense forces that would otherwise crush them. Without degeneracy, the star would collapse under the intense gravitational force of its outer layers. Degeneracy pressure can support stars up to a certain mass limit of 1.4 solar masses, or 1.4 times the mass of our sun.

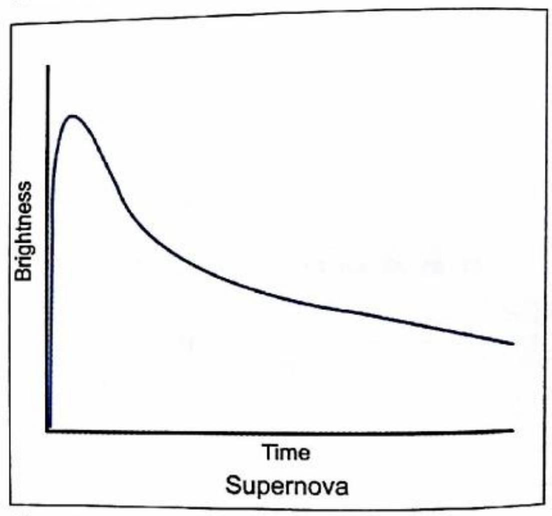

Figure 3-10: Light curve of a Type Ia supernova

As the red giant companion sheds its outer layers, mass is transferred and accumulates onto the white dwarf, making it more and more massive. Once the mass of the white dwarf reaches 1.4 solar masses, the degeneracy pressure is overtaken by the gravitational forces, and the star implodes. The implosion, which we observe as a Type Ia supernova, causes rapid burning of the carbon that made up the white dwarf star, much like a carbon bomb. The event is so energetic that the brightness of the one star can rival the brightness of the entire galaxy for several weeks.

Because all Type Ia supernovae occur when the star is exactly 1.4 solar masses, such supernovae will follow the same pattern of changes in brightness and have the same overall peak brightness. The peak brightness is the maximum brightness that the supernova reaches, and it occurs about 2 to 3 weeks after the initial explosion.

It is believed that Type Ia supernovae all have the same luminosity ($L_{SN} = 5.0 \times 10^9$ solar luminosities). This information is used to find the distances to these supernovae and the galaxies that host them.

Remember from FYI: *Inverse Square Law: Apparent Brightness and Luminosity* that when two objects have the same luminosity, the ratio of their apparent brightnesses is equal to the inverse ratio of the square of their distances from Earth. Therefore, if we know the distance to one galaxy containing a Type Ia supernova, we can find the distance to another galaxy containing a Type Ia supernova if we are able to measure the apparent brightness of the unknown Type Ia supernova at its peak brightness.

$$d_{unknown} = d_{known}\sqrt{(b_{known}/b_{unknown})}$$

We can also find the distance to a single Type Ia supernova by comparing its apparent brightness and distance to that of the sun.

Example: Find the distance to a Type Ia supernova with an apparent brightness of 5.0×10^{-20} times the apparent brightness of the sun.

Step By Step

Using the expression for apparent brightness in terms of luminosity and distance, find the ratio of the brightness of the unknown supernova to the brightness of the sun.

$$\frac{b_{SN}}{b_{sun}} = \frac{L_{SN} / 4\pi d_{SN}^2}{L_{sun} / 4\pi d_{sun}^2} = \frac{L_{SN}\, d_{sun}^2}{L_{sun}\, d_{SN}^2}$$

Substitute in the known luminosity ratio for Type Ia supernovae and the sun, $L_{SN}/L_{sun} = 5 \times 10^9$.

$$\frac{b_{SN}}{b_{sun}} = (5.0 \times 10^9)\frac{d_{sun}^2}{d_{SN}^2}$$

Rearrange the terms to solve for the distance ratio.

$$\frac{d_{SN}}{d_{sun}} = \sqrt{\frac{(5.0 \times 10^9)\, b_{sun}}{b_{SN}}}$$

Substitute in the given value for b_{SN}/b_{sun} and do the calculation.

$$\frac{d_{SN}}{d_{sun}} = \sqrt{\frac{5.0 \times 10^9}{5.0 \times 10^{-20}}} = 3 \times 10^{14}$$

Multiply your answer by the Earth-sun distance to find the distance to the supernova.

$$d_{SN} = 3 \times 10^{14}\text{AU} \times \frac{1.58 \times 10^{-5}\text{ ly}}{1\text{ AU}} = 8 \times 10^9\text{ ly}$$

Checking In

1. What is the luminosity of a Type Ia supernova that occurs in a nearby galaxy? How about in a distant galaxy?
2. If a Type Ia supernova occurs and is measured to be 6.0×10^{-19} times the apparent brightness of the sun, how far away is it?