High Energy Astronomy

Stellar Death and Novae

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History

- In the early 1900s, astronomers studied a unique object, thought of to be a star, which would suddenly flare up in brightness by a factor of over 10^5, only to dim back to normalcy after a month or so. In particular, astronomers Fritz Zwicky and Walter Baade at Caltech studied these peculiar objects with keen interest.

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- Based on observational data, they hypothesised that these superluminal events were the result of an explosion of a massive star. Coining the name **supernovae** for these events, they estimated massive energy outputs across the electromagnetic spectrum - a supernova can generate a greater light output than its entire host galaxy.

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- Within each type there are further sub-types based on minor differences in spectral features. Some of these sub-types are Type-Ia,Ib,Ic,IIb etc.
- However, it more convenient to study Type-Ia supernovae separately from the others. This is because the latter constitute **Core Collapse Supernovae**, while the former are a very special case, and do not arise from the deaths of massive stars.

Core Collapse Supernova

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- The death knell for a massive star is when iron starts accumulating in the core. Fusion of iron does not produce energy, but consumes it. So there is no energy generated to support the star, and the weight of the star is supported by the degeneracy pressure alone.
- Once the mass of the core exceeds $1.4 M_\odot$, the degeneracy pressure gives away, and the collapse begins.

Remark

The critical mass $1.4 M_\odot$ comes from the **Chandrashekhar Limit** for white dwarfs.

Core Collapse Supernova

- During the collapse, high energy gamma rays are produced in the core, which causes **photodisintegration** of the iron atoms.

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{}^{56}_{26}\mathrm{Fe} + \gamma &\longrightarrow 13\,{}^{4}_{2}\mathrm{He} + 4\,\mathrm{n} \\
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- If the star is of intermediate mass, then the neutron-rich core resists further collapse through neutron degeneracy pressure, forming a *neutron star*. But in case of higher masses, even neutron degeneracy cannot resist collapse, forming a *black hole*.

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- The outer layers are blown away, leaving behind the supernova remnant, as brightness begins to decline exponentially.
- Looking at the enrgy output of these kinds of supernovae, only a small amount of energy actually goes into the explosion (typically $\sim 1\%$). Most of the energy is carried by the neutrinos released, providing a way of detecting these supernovae.

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- In these systems, the white dwarf usually accretes matter from its companion star, due to its greater gravitational influence. As it adds more mass, it is pushed closer to the Chandrashekhar limit, crossing which it would collapse into a neutron star.
- However, just before achieving this mass, the temperature of the white dwarf reaches that required to initiate nuclear fusion. Furthermore, the degenerate nature of a white dwarf ensures the entire matter is more or less at the same temperature.

Type-Ia Supernova

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- This causes widespread thermonuclear ignition leading to a nuclear runaway reaction, causing the entire white dwarf to explode in a supernova.
- Due to the fact that the mass at which the supernova explosion occurs, the light curves for these supernovae are extremely similar after taking into account the distance of the system and the color and magnitude of the companion.

Remark

The homogeneous nature of the light curves of Type-Ia supernovae is exploited by treating them as **standard candles**. These are events whose energy output is known (constant), and based on the apparent brightness we can infer the distance of the system.

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- While both these novae involve an exponential decay in luminosity after the event, a common feature in light curves of core collapse supernovae is a “bump” in the curve, where the decay slows or comes to a halt for a short period.
- This plateau in the graph is attributed to the synthesised radioactive isotopes of Ni and Co in the surrounding gas, which begins to decay at this time, heating up the surrounding gas and stalling the decay in energy output.

Comparing Light Curves

- The light curves of Type-Ia supernovae do not possess this characteristic "bump" as they occur due to a completely different set of pre-conditions.

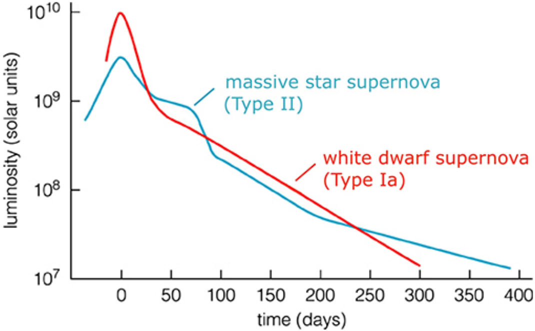

Figure: Light curves of Type-Ia and Type-II (core collapse) supernovae.