Type Ia Supernovae

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1 Type I Supernovae

Supernovae type Ia are those with no hydrogen features in their spectra. This class is subdivided into types Ia and Ib depending on the presence or absence of a silicon absorption feature at in the supernova's spectrum. The type Ia has not only their spectra matched but also their *light curve*, *i.e.,* the plots of brightness in the weeks after the explosion.

These events are the result of thermonuclear explosion consuming 1.5 solar masses of degenerate stellar material composed mainly of C and O [2]. The peak of type Ia supernova is set by the synthesis in the explosion of radiactive ^{56}Ni, decaying into ^{56}Co and ^{56}Fe, and releasing the observed energy.

The majority of Ia have their peak brightness proportional to the timescale over which the lightcurve decays from its maximum, *the brighter is broader.* The supernovae that faded faster than the norm were fainter at their peak and the slower ones were brighter. This property allows Ia to be treated as *standard candles.*

2 K-Correction Problem

The *K-correction problem* states that the increasing redshifting of supernova spectra with distance means that the brightness of a very distant supernova measured through a given filter is hard to compare with the brightness of a closer one in the same filter [1]. This problem can be solved by measuring the supernova in a redshifted filter band.

Also, dust in the supernova's galaxy can dim the explosion's light. To detect this, one can use two redshifted filter bands to recognize dust absorption by its wavelength dependence.

3 Cosmology

The expansion history of the universe is determined by its mass density. The greater the density, the more the expansion is slowed by gravity. In the past, a high-mass-density universe would have been expanding much faster and we would not need to look too fair for faint supernovae. A low-mass-density universe would have to look farther back.

The observed high-redshifted supernovae are however fainter than it would be expected even for an empty cosmos. Including a cosmological constant allows the fit to data very well, where the vacuum energy density is large than the mass density, so that the cosmic expansion is accelerating. The cosmic microwave background indicates that the universe has no large-scale curvature, so that:

$$\Omega_\Lambda = \rho_\Lambda/\rho_c \sim 0.7,$$

and

$$\Omega_m = \rho_m/\rho_c \sim 0.3.$$

The standard model of particle physics predicts that the vacuum energy should be 10^{120} times greater, and this value would have not allowed the formation of stars and galaxies. A symmetry to cancel this energy would demand a tunneling that is not appealing.

The equation of states depend on the parameter $\omega = p/\rho$, *i.e.,* the ration of dark energy's pressure to its energy density. The acceleration of the universe depend on the general relativistic equation:

$$\ddot{R}/R = -3/4\pi G\rho(1 + 3\omega).$$

4 Ia as Standard Candles in Cosmology

As light travels in the expanding universe, the cosmic expansion stretches the wavelengths of photons, so that the spectral wavelength λ has been redshifted by $z = \Delta\lambda/\lambda$. Distant galactic candidates are too susceptible to evolutionary changes not being suitable for standard candles.

Type Ia supernovae are suitable candidates for measuring cosmic expansion: their peaks brightness are quite uniform and they are very bright to be seen at large distances.

However, recent observations are finding a range in the variation of the intrinsic brightness of these events, suggesting that more material could be burning from the single white dwarf [2]. The process of gaining mass from the binary companion, *accretion*, ignites the thermonuclear reactions for the explosion. In the beginning the reactions are slow, driving convection in the core. With the temperature rising, the thermonuclear reactions are faster and subsonic flame disrupt the star. One model for this subsonic deflagration to supersonic detonation is called *deflagration to detonation transition* (DDT).

5 Observations of a Ia SN

The observations are also interested on the properties of the host galaxy such as composition, age, and mass. Another correlation is between the brightness of an event and the isotopic composition and age, measured bu the proportion of material that have been processed in the stars (metals, *i.e.,* elements other than H and He), giving the galaxy's metallicity. These elements influence the amount of Ni synthesized, and the brightness of the lightcurve of an event.

Observations suggest dependence of brightness and metallicity with dimmer events in galaxies with more metals.

6 Numerical Studies of Ia

Numerical studies are made by considering the properties of the progenitor white dwarf such as structure and composition, following from properties of the host galaxy, such as age and metallicity. Another parameter s that the explosion depends on the initial conditions, still unknown.

Studies of the neutron excess of the progenitor white dwarf, *i.e.,* the weak interactions during burning such as electron capture, leads to the study of how neutron-rich is the star. The neutron excess drive to explosions toward stable group elements, less radiactive Ni, dimmer events.

Some models are:

- *Model Flame and Energetics Scheme*: compare the white dwarf radius to the *laminar nuclear flame width*. Thermonuclear flames are tracked with an *advection-diffusion-reaction scheme*, based on the evolution of a reaction progress variable ϕ, equals to 0 for unburned fuel and equals to 1 for burned ash [2]:

  $$\partial_t \phi + u \cdot \nabla \phi = \kappa \nabla^2 \phi + \frac{1}{\tau} R(\phi),$$

  where κ, τ are parameters tuned locally and $R(\phi)$ a chosen function.

- *Sub-grid-scale Models*: the previous model requires an input flame speed, but for the 1D laminar case, this is already available from simulations.

- *Statistical Framework*: developed to explore trends in the brightness on parameters such the composition of the progenitor, resulting on how much Ni is synthesized during the explosion.

References

[1] Perlmutter, S., *Supernovae, Dark Energy, Accelerating Universe*, Physics Today, 2003.

[2] Calder, A.C., et al, *On Simulating Type Ia Supernovae*, 2012.