Recent Trends in the Study of Compact Objects: Theory and Observation
ASI Conference Series, 2013, Vol. 8, pp 135–138
Edited by Santabrata Das, Anuj Nandi and Indranil Chattopadhyay

The core collapse supernovae and compact stellar remnants

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Abstract. The core collapse supernovae are supposed to be the principal processes for the creation of compact objects like Neutron Stars, Magnetar or a stellar mass Black Hole. The nature of the explosions and the types of the compact objects are mainly dependent on the properties of the pre-SN stars. Multiwavelength observations of these events have revealed the diversity of these catastrophe. In this contribution, I shall summarize the diversity in core collapse explosions along with their energetic and progenitor properties. The nature of the compact remnants produced by these explosive events will also be discussed.

Keywords : supernovae: general – Supernovae: individual: SN 2007uy, SN 2008in

1. Introduction

Core-collapse supernovae (CCSNe) are the violent death of massive stars with zero age main-sequence (ZAMS) masses greater than $8M_\odot$ (where $M_\odot$ represents the mass of the Sun) (Eldridge & Tout 2004). During these processes the inner core forms a compact object − Neutron Star (NS), Magnetar or Black Hole (BH) due to gravitational collapse, while material at the outer shells expelled out in the form of a catastrophic explosion (energy $\sim 10^{50}-10^{52}$ erg) through intense flashes of γ-ray and X-ray or UV radiation depending on the initial mass of the exploding star, explosion energy and geometry of the explosion mechanism.

Due to an enormous development in automated sky survey programs, the detection rate of all kinds of supernovae (SNe) has increased significantly in the last few years (Lennarz et al. 2012). These initiatives have revealed several properties of different classes of such catastrophes, that further constrained the SN-physics. Photometry and spectroscopy of these transients have discovered a new class of events which are even more energetic and may have completely different mechanisms than our known nearby SNe. In a volumetric study with nearby events it was found that more than 75% of all SNe are CCSNe, out of which about 55−57% are hydrogen rich

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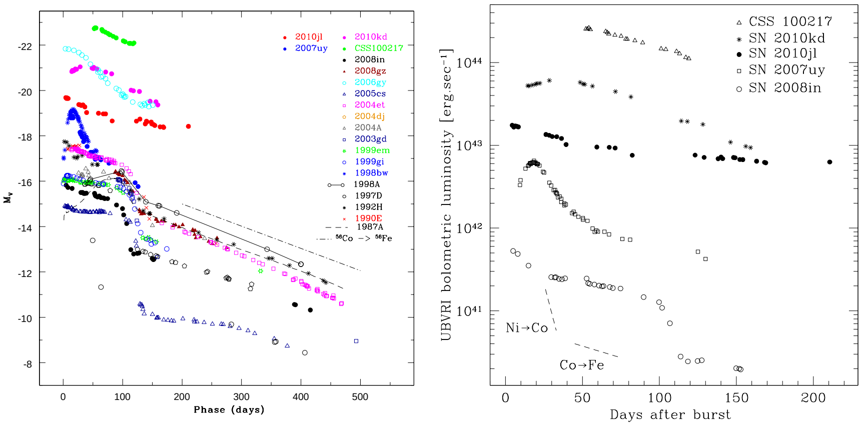

Figure 1. *Left panel:* Comparison of V-band lights of Type II events with Type Ibc and superluminous SNe. The 'Phase' represents The time elapsed after the burst. *Right panel:* $UBVRI$ bolometric lightcurves of CCSNe and superluminous events. The phase axis is with respect to the observer rest frame. The data for these two plots have been taken from Roy et al. (2011) and Roy et al. (2013) and the references therein.

(Type II) and rest are hydrogen deficit (Type Ibc) events (Li et al. 2011). Among all CCSNe, H-rich events show diversities in their light curves and spectra. There are distinct classes like normal and subluminous events, which show different properties along with several peculiar events like SN 1987A, which are resulted from explosion of a 'blue supergiant' stars (BSGs), which are more compact than 'red supergiants' (RSGs); the potential progenitors of Type IIP explosions.

2. Diversity in core-collapse supernovae

Comparison of visual (V-band) lights of all kinds of CCSNe with superluminous supernovae (SLSNe, $M_V \lesssim -21$ mag) demonstrates that these SNe emit over a wide range of optical luminosity (see left panel of Fig.1). The bolometric luminosity also varies within a range of several order (see right panel of Fig.1). This indicates toward different kinds of progenitors and explosion mechanisms. Few results in this regard are discussed here.

Recently a new class of catastrophe has been detected, that represent the upper-bound of the low-luminous category or lower-bound of normal Type IIP SNe – the events which simultaneously possess the signatures of normal and low-luminosity events. Extensive study of two such events have been done. They are SNe 2008in (Roy et al. 2011) and 2009js (Gandhi et al. 2013). The left panel of Fig.2 represent a comparison between bolometric light curves of normal and low luminous events. It is clearly seen that SN 2008in lies between these two categories. The peculiarities of these objects are reflected in their spectral resemblance with low luminosity events along with a higher ^{56}Ni production or vise-versa. A comparison of ejecta

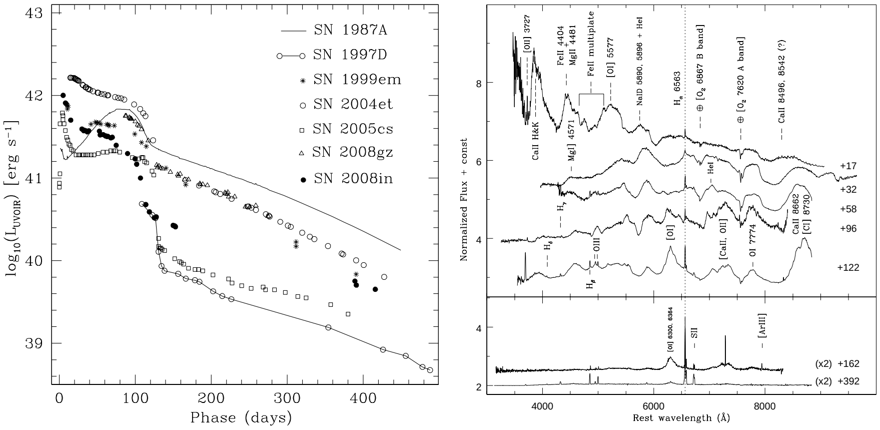

Figure 2. *Left panel:* Comparison of the quasi-bolometric light curve of SN 2008in with the low-luminosity SNe 1997D, 2005cs; the normal SNe 1999em, 2004et, 2008gz; and the peculiar Type II SN 1987A. The data for this plot have been taken from Roy et al. (2011) and the references therein. *Right panel:* Spectroscopic evolution of SN 2007uy. All the spectra have been normalized with respect to the peak flux of the underling H_α feature and a constant offset has been applied to present them clearly. The +162d and +392d spectra have been multiplied by a factor of 2 to enlarge several tiny features. The dotted vertical line represents the position of H_α and confirms the wavelength calibration within the limits of the spectral resolution. The figure has been taken from Roy et al. (2013).

kinematics of SN 2008in with the hydrodynamical simulations of Type IIP SNe indicates that it is a less energetic event ($\sim 5 \times 10^{50}$ erg). However, the light curve indicates that the production of radioactive ^{56}Ni is about one order higher than that in the low-luminosity SNe. Using semi-analytical formulae, the calculated value of pre-SN radius is $\sim 126 R_\odot$. Interestingly these progenitors are relatively compact than RSGs, but more massive than BSGs. The detail hydrodynamic simulation (Utrobin & Chugai 2013) has also pointed out these unusual photometric and spectroscopic behaviors of this event. The estimated mass of the progenitor and ^{56}Ni produced during this process are comparable with previous calculations. However, it has been proposed that the size of the progenitor is comparable with RSGs. These all proximate events are not luminous in radio or X-ray, indicating very less interaction with their surroundings. Certainly a rigorous spectroscopic and photometric analysis of such Type IIP events are necessary to understand the underlying physics of these catastrophic explosions in a better way.

It is also important to study the asymmetric nature of CCSNe explosions. This gives a clue about explosion geometry. Spectropolarimetry is the best way to understand the asymmetric evolution. Type Ibc events are supposed to be more aspheric than Type II explosions. The right panel of Fig.2 presents the spectral evolution of Type Ib SN 2007uy. Starting from the early epochs, highly blended features can be noticed. The highly blueshifted emission lines in early epochs can not be explained by means of dust formation or by contamination due to other emission lines. In late epochs the emission features of all spectral lines attain their rest positions. It probably marks the initial asymmetric evolution of different line forming regions, which in due course of time attain a spherical symmetry (Roy et al. 2013). The photospheric velocity measured from He I line at around the peak is roughly around 15200 $\mathrm{km\,s^{-1}}$, which is consistent with other Type Ib events. We found that the temporal evolution of line profiles for different species are not similar to each other. This probably implies that there is no major effect of radioactive Ni on the evolution of different lines, at least for SN 2007uy. From optical light curve modeling it is determined that about $0.3 M_{\odot}$ radioactive ^{56}Ni is produced and roughly $4.4 M_{\odot}$ material is ejected during this explosion with liberated energy $\sim 15{\times}10^{51}$ erg, indicating the event to be an energetic one.

3. Fate of the progenitors: natures of compact remnants

The fate of a massive star is governed chiefly by its mass and composition during its birth and by the history of its mass loss. For single stars, mass loss occurs as a result of stellar winds, for which semiempirical estimates are present. Heger et al. (2003); Eldridge & Tout (2004) have used the pre-existing stellar evolution models and evolved the stars up to the point at which they become SNe. According to their formalism, most of the stars having $9M_{\odot} \lesssim$ M $\lesssim 25M_{\odot}$ and hosted in solar/subsolar metallic environment, ends-up with Type II SNe along with NS as a compact remnant. Stars with $25M_{\odot} \lesssim$ M $\lesssim 40M_{\odot}$ may form BH through “fall-back” process, whereas stars with M $\gtrsim 40M_{\odot}$ would form a BH through “direct-collapse”, probably through even violent explosions like GRBs. These stars, having solar/supersolar metallicity may also form NS or magnetar through Type Ibc explosions.

References

Eldridge J. J., Tout C. A., 2004, MNRAS, 353, 87
Gandhi P., et al., 2013, ApJ, 767, 166
Heger A., et al., 2003, ApJ, 591, 288
Lennarz D., Altmann D., Wiebusch C., 2012, A&A, 538, A120
Li W., et al., 2011, MNRAS, 412, 1441
Utrobin V. P., Chugai N. N., 2013, A&A, 555A, 145
Roy R., et al., 2011, ApJ, 736, 76
Roy R., et al., 2013, MNRAS, 434, 2032