Death of Massive Stars: Supernovae and Gamma-Ray Bursts
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The Type II supernovae 2006V and 2006au: two SN 1987A-like events

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Abstract. We studied optical and near-infrared (NIR) light curves, and optical spectra of Supernovae (SNe) 2006V and 2006au, two objects monitored by the Carnegie Supernova Project (CSP) and displaying remarkable similarity to SN 1987A, although they were brighter, bluer and with higher expansion velocities. SN 2006au also shows an initial dip in the light curve, which we have interpreted as the cooling tail of the shock break-out. By fitting semi-analytic models to the UVOIR light curve of each object, we derive the physical properties of the progenitors and we conclude that SNe 2006V and 2006au were most likely Blue Supergiant (BSG) stars that exploded with larger energies as compared to that of SN 1987A. We are currently investigating the host galaxies of a few BSG SNe, in order to understand the role played by the metallicity in the production of these rare exploding BSG stars.

Keywords. supernovae: general, supernovae: individual (SN 2006V, SN 2006au, SN 1987A)

Supernova (SN) 1987A, a milestone in the history of supernova observations, was the explosion of a compact blue supergiant (BSG) star. Due to the small progenitor radius, the explosion energy was mainly spent to adiabatically expand the SN and therefore its light curve exhibited a long rise to maximum and a low luminosity at early times. Objects similar to SN 1987A (87A-like or BSG SNe) are particularly rare. Pastorello *et al.* (2005) presented SN 1998A, the first BSG SN after SN 1987A. SN 2000cb was recently presented by Kleiser *et al.* (2011) and modelled by Utrobin & Chugai (2011). In Pastorello *et al.* (2012) we have recently drawn up a list of 12 87A-like events. Among them, only 6 have an exhaustive dataset, including the aforementioned SNe and our objects from Taddia *et al.* (2012) that we present here. SN 2006V and SN 2006au were respectively located in the spiral galaxies UGC 6510 and UGC 11057, at 72.7±5.0 and 46.2±3.2 Mpc. They were observed by the CSP, which obtained optical+NIR photometry and optical spectroscopy, thanks to the Swope and the Du Pont telescopes at Las Campanas Observatory (Chile). The objects were observed for ∼130 and ∼90 days, so that the light curve tail powered by the ^{56}Co decay was detected for SN 2006V but not for SN 2006au. As we can see in Fig. 1, both SNe follow the light-curve shape of SN 1987A. Additionally, SN 2006au also presents an initial slowly declining phase, which we have interpreted as the cooling tail after the shock break-out. This feature has been observed for a small sample of SNe, including SNe 1987A, 1993J, 1999ex, and 2008D. From the comparison of their absolute magnitudes, both SNe 2006V and 2006au turn out to be brighter than SN 1987A. We notice that for SN 2006V we assumed negligible host galaxy extinction whereas for SN 2006au we assumed $E(B-V)_{host} = 0.312$ mag (from the equivalent width of the Na I D absorption line). The colors computed from the photometry show that both SNe are bluer than SN 1987A, suggesting higher photospheric temperature. This is obviously confirmed by the spectral comparison, since our objects suffer low suppression in the blue part of the spectrum if compared to SN 1987A. The P-Cygni profiles which characterize

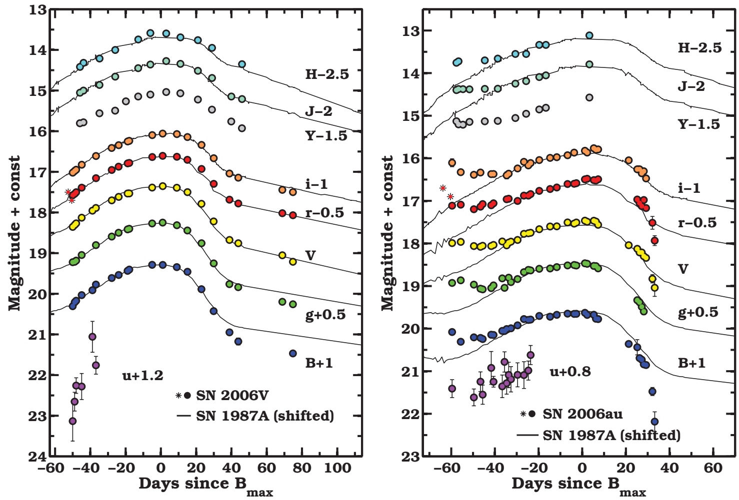

Figure 1. Light curves of SNe 2006V and 2006au compared to those of SN 1987A.

the spectral lines of our SNe reveal high expansion velocity, in particular for SN 2006au. Overall the spectra exhibit typical Type II features. The complete photometric datasets enabled us to build bolometric light curves (BLCs) for both SNe, by converting the magnitudes into fluxes at the proper effective wavelength and then integrating the resulting spectral energy distributions. We also estimated the explosion day of our objects by applying the expanding photospheric method, e.g. Dessart & Hillier (2005). This allowed us to properly model the BLCs, using the semi-analytic model of Imshennik & Popov (1992). We also modelled the early BLC of SN 2006au with the analytic model of Chevalier (1992). The best model fit gave us estimates for the ejecta mass (M_{ej}), the explosion energy (E), the progenitor radius (R) and the ^{56}Ni mass of both events. We obtained $M_{ej} \approx 20\ M_{\odot}$, $E \approx 2-3 \times 10^{51}$ erg and $R \approx 75-100\ R_{\odot}$. The ^{56}Ni mass was estimated to be 0.127 $M_{\odot}$ for SN 2006V and $\leqslant$0.073 $M_{\odot}$ for SN 2006au. The physical parameters we derived for the progenitors, in particular the small radii, are consistent with a scenario where both SNe 2006V and 2006au were BSGs which exploded with larger energies as compared to that of SN 1987A. In order to understand why these rare 87A-like SNe have BSG progenitors, we are measuring the metallicity at the explosion site of each event in the sample by Pastorello *et al.* (2012). We will be able to test if the sub-solar metallicity is a necessary ingredient to produce exploding BSG stars, as it has been thought for SN 1987A (see Podsiadlowski 1992). Preliminary results suggest some of these SNe were produced at solar metallicity, opening interesting questions on their origin.

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