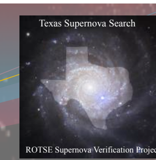
ULTRABRIGHT SNe AND PECULIAR TRANSIENTS: INSIGHTS FROM LIGHT CURVE FITTING



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Abstract

We present the results of our analysis of the light curve of the peculiar transient SCP06F6. We fit radioactive decay diffusion models to SCP06F6 for two redshift cases including the effects of H recombination as presented in Arnett & Fu (1989). We propose a new model of SCP06F6 in which the event is at a redshift of z~0.57 for which the blue absorption features are Ca H&K and iron-peak absorption features as qualitatively seen in the UV of some nearby supernovae.

We also revisit the physical properties of the brightest supernovae ever, most of them discovered by the ROTSE collaboration, by fitting the radioactive decay diffusion models of Arnett (1982) as generalized by Valenti et al. (2008) to their light curves using a Monte-Carlo chi-square minimization code. The best fitting parameters that we obtain lead to the conclusion that other energy generation mechanisms such as circumstellar collisions should be invoked for these events to account for their peak luminosities and the behavior of their light curves.

The peculiar transient SCP06F6

Barbary et al. (2008) reported the discovery of SCP06F6, a transient event with a nearly symmetric light curve with rise and decline of 100 d (Figure 1) and a very peculiar spectrum (see Figure 2). The spectrum showed only three broad absorption features in the wavelength range 4000-6000Å. Gaensicke et al. (2008) proposed that the broad absorption are molecular C_2 bands (Swan bands) at a redshift of z~0.143. Soker et al. (2008) proposed models to account for the light curve and spectrum of SCP06F6 including an extragalactic intermediate mass black hole (IMBH)-White Dwarf collision and a Galactic White-Dwarf asteroid merger.

In our work we consider the redshift of the event unknown and we investigate two special cases: z=0.143 as suggested by Gaensicke et al. (2008) and z=0.57 for which the blue absorption features are Ca H&K and iron-peak absorption elements as qualitatively seen in the UV of some nearby supernovae. We use our Monte-Carlo chi-square minimization fitting code to fit radioactive decay diffusion models (Valenti et al. 2008) to the light curve of the event. The implied best fit ejecta and nickel masses impose constraints on the redshift of the event (see Figure 3).

Our simple radioactive decay diffusion models have difficulty accounting for the low values of the points 100 days after the peak and hence reproducing the symmetric light curve. We consider two factors that may account for this discrepancy:

- Dust formation at late epochs: the formation of a total dust mass of about 0.0003 $M_\odot$ could account for the level of the last detection (180 days in the top panel of Fig. 1), an amount in agreement with other Type-II supernovae (Kotak et al. 2005; Kotak et al. 2009).
- H recombination effects: To incorporate the effects of H recombination we use the model developed by Arnett & Fu (1989) to fit the light curve of SN 1987A. After peak luminosity the recombination front recedes inwards and the optical opacity drops dramatically and the energy generated by the presumed shock diffuses out more quickly (dashed line, Figure 1). There is no evidence for hydrogen in the spectrum of SCP06F6, but if it falls at a redshift of 0.57, then the Hα line would be redshifted out of the range of the spectral coverage and Hβ would be contaminated by telluric lines (Figure 2). At a redshift of 0.57, if a SN, SCP would be “normally” ultrabright. The derived nickel mass and ejecta mass values that correspond to the solid and dashed line of Figure 1 are in the range of those assumed for confirmed supernovae.

Acknowledgements

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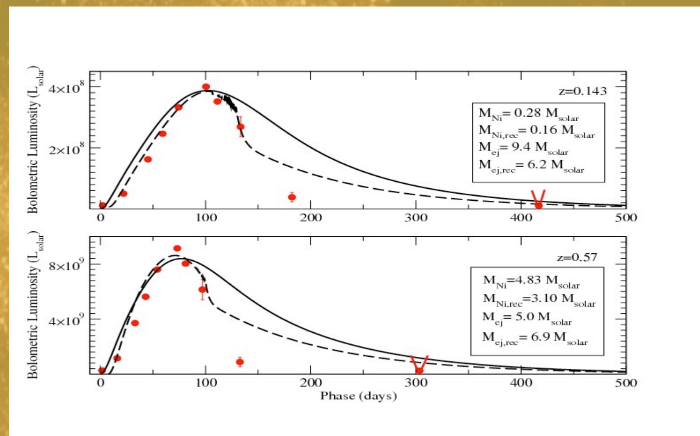

Figure 1: *Quasi-bolometric luminosity light curve of SCP 06F6 at redshifts of 0.143 (top panel) and 0.57 (bottom panel) (solid points). In each case, the solid line is a simple radioactive decay diffusion model and the dashed line is an illustration of the Arnett & Fu (1989) model that includes the effects of H recombination giving a decline in optical opacity and thus a steeper post maximum decline. The derived values of the original nickel mass and of the ejecta mass based on the simple radioactive decay diffusion and the H recombination model are given in the insets.*

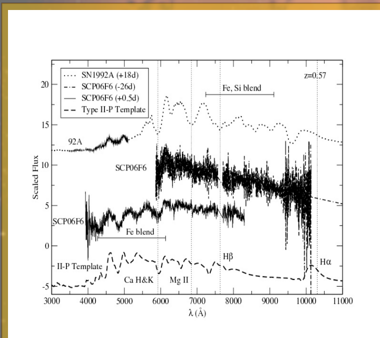

Figure 2: *Comparison of the VLT and the Subaru observer's frame spectra of SCP 06F6 obtained on 05-18-2006 (near maximum) and 05-22-2006 respectively (Barbary et al. 2008) with the IUE+CTIO spectrum of the Type Ia SN 1992A obtained on 01-24-1992 (+18d after maximum) (Kirshner et al. 1993) and with a template Type-IIP spectrum at +6d after the explosion (Gilliland et al. 1999) both boosted to a redshift of 0.57. The dashed vertical lines indicate the positions of the Ca H&K absorption component and the Mg II triplet. The ranges of Fe and Si blends are also indicated. Line identification is based on Kirshner et al. (1993).*

The redshifted positions of the Hα and Hβ lines are also indicated for illustration. Note that Hα and Hβ could be present, but unobserved, at this redshift due to the large redshift and telluric contamination.

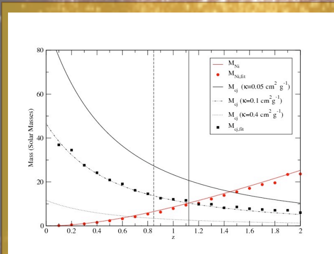

Figure 3: *The dependence of the initial nickel mass and the ejecta mass on redshift for SCP06F6. The ejecta mass depends linearly with the photospheric velocity assumed to be 10,000 km/s and inversely on the mean opacity, for which three choices are shown. At redshifts to the right of the solid vertical line the mass of the radioactive nickel becomes larger than the total ejecta mass for opacity of 0.1 cm^2/g. This line thus defines the lower redshift boundary of a forbidden region in redshift space for this class of model. The forbidden region extends to lower redshifts for higher opacity and lower photospheric velocity.*

Ultrabright SNe

Over the past five years, the Texas Supernova Search and the ROTSE Supernova Verification Project discovered the brightest supernovae ever recorded: SN 2005ap, SN2006gy (II-L), SN2006tf (II-L), SN2008es and SN2008am (II-L). The extraordinary peak luminosities and, in some cases, large diffusion time scales of these events triggered a variety of discussions concerning the properties of their progenitors and their environments and the possibility of the first Pair-Instability event observed, associated with SN 2006gy.

The light curves of these events are an important tool that can help us probe the underlying physics. The light curve peak is determined by the initial mass of nickel-56 and by the degree of interaction between the supernova ejecta and the Circumstellar Matter (CSM) that was shed by the progenitor in the years prior to the explosion. The width of the light curve depends on the total mass of the supernova ejecta through which the radiation diffuses out. Arnett (1982) developed analytic models that fit a variety of supernova light curves providing us with estimates of the nickel and the ejecta masses of some events. Valenti et al. (2008) generalized these models to include the contribution of the radioactive decay of cobalt-56.

We developed a Monte-Carlo chi-square minimization code that takes as input the quasi-bolometric light curve of a SN and finds the best light curve fit based on the Valenti et al. (2008) model. We also generalized the Valenti et al. (2008) model to include the effects of gamma-ray leakage. This provides us with best fitting parameters for a given event: nickel mass, diffusion time, explosion date, gamma-ray opacity. The estimated values of the nickel mass for these events are, in most of the cases, unrealistic (larger or very close to the ejecta mass) and thus other energy sources should be invoked to account for the high peak luminosity. The best fitting nickel and ejecta masses for four ultraluminous SNe are given in the insets of Figure 4 for illustration.

The difficulty that the radioactive decay diffusion models have accounting for the light curves of the ultraluminous SNe implies that for this class of objects that are also identified as Type-IIL, the interaction of the ejecta with the CSM is essential. For the other ultraluminous events that do not show signs of CSM interaction (e.g.. SN 2008es) in their spectra, other mechanisms should be considered to explain the behavior of their light curve. One possibility for SN2005ap and SN 2008es is that, at late epochs there is dust formation similar to that which we propose for SCP06F6, providing a steeper decline than that predicted by the radioactive decay diffusion models. However that does not solve the fundamental problem that the radioactive models require more nickel than ejecta mass.

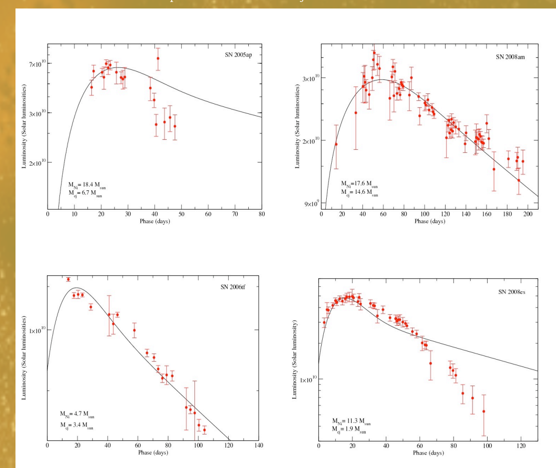

Figure 4: *Light curve fits of four ROTSE discovered ultraluminous SNe using the radioactive decay diffusion model introduced by Arnett (1982) and generalized by Valenti et al. (2008).*