A Comparative Study of Late-Time Light Curves of Type Ic Supernovae

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We present late-time Hubble Space Telescope (*HST*) observations of two broad lined type Ic supernovae, SN 2003dh and SN 2006aj associated with GRB 030329 and XRF 060218 respectively. Using multi-color observations covering ~70-350 days after the burst, we constrain the late-time decay of the supernovae. The late-time decay rates for SN 2003dh and SN 2006aj are steeper than the ^{56}Co->^{56}Fe decay rates indicating that there is some leakage of γ-rays. We also compare these supernovae with other broad lined type Ic with and without associated GRBs as well as normal type Ic's. For all the supernovae in our sample, ^{56}Ni masses have been estimated based on the early time (near peak) light curves of the supernovae. We find that when we scale the late-time (nebular phase) light curves of the supernovae by the estimate of ^{56}Ni mass, the light curves cluster together, with a particularly low dispersion in the *I* band. The excellent scaling between the late and peak light curves implies that inspite of their relativistic jets and high kinetic energies, the light curves of these supernovae are powered throughout by the radioactive decay of ^{56}Ni.

Introduction

- Broad lined type Ic SNe are a sub-class of stripped core collapse SNe without any trace of H and He in the spectrum with very high expansion velocities (~30,000 km/s).
- All spectroscopically confirmed SNe associated with long duration GRBs and XRFs known till date are broad lined type Ic and where measured have kinetic energy in excess of 10^{52} ergs which is about 10 times higher than the kinetic energy of normal core collapse SNe.
- GRBs are typically distant objects and hence lack detailed study at late-times due to unavailability of data. The *HST* data sets of two broad lined type Ic SNe - SN 2003dh associated to a bright, energetic GRB 030329 and SN 2006aj associated to an under-luminous event XRF 060218 offers a unique opportunity to study the late-time behavior of the light curves and to constrain their decay.

Data and Formalism

- GRB 030329 and XRF 060218 were observed with the Advanced Camera for Surveys (ACS) under the programs GO 9405 (P. I. Fruchter) and GO 10551 (P. I. Kulkarni) spanning ~70-350 days after the burst in multiple colors.
- We fit an exponential decline rate plus a constant to the *HST* fluxes. This allows us to fit the SN decay and the underlying host galaxy flux at the same time. The fits and the decay rates are shown in **Figure 1**.
- During the early phase most of the flux in a SN emerges in the optical, thus the integrated flux in the *UBVRI* bands gives a good estimate of the bolometric luminosity. For most of the SNe in our sample, ^{56}Ni masses have been estimated based on the peak bolometric luminosity.
- We scale the late-time (nebular phase) light curves of a sample of broad lined type Ic SNe with and without associated GRBs as well as normal type Ic's by the estimate of ^{56}Ni mass. A comparison of absolute magnitude light curves and scaled light curves in *B* and *I* bands is shown in **Figure 2.**

GRB associated Supernovae at late-times

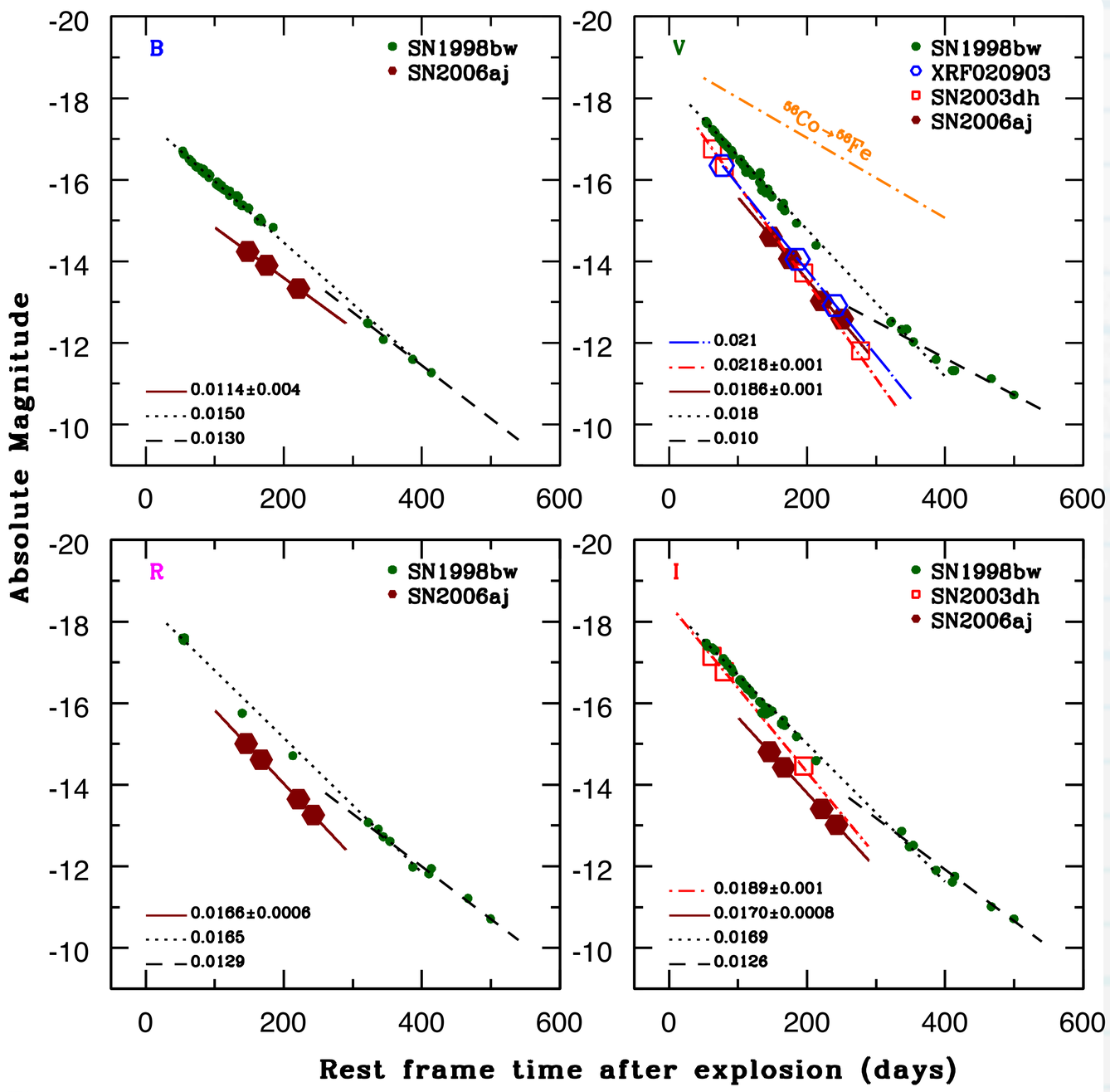

Figure 1: A comparison of multi-color absolute magnitudes of SN 1998bw (Galama et al. 1998; McKenzie & Schaefer 1999; Sollerman et al. 2000; Patat et al. 2001), the supernova associated with XRF 020903 (Bersier et al. 2006), SN 2003dh (This work) and SN 2006aj (This work). The light curves are corrected for extinction and host galaxy contribution. The decay rates (α) of SN 2003dh and SN 2006aj, as obtained from the fits, are indicated in the different panels. The decay rate of the supernova associated with XRF 020903 is adopted from Bersier et al. 2006. The dotted and dashed lines represent the decay rates of SN 1998bw in the ranges 54-312 and 321-500 days respectively. The dashed-dotted line corresponds to the ^{56}Co->^{56}Fe decay rate, expected that there is no leakage of γ-rays. We see that the decay rates of all the supernovae are steeper than the ^{56}Co->^{56}Fe decay rates indicating that there is some leakage of γ-rays.

Results

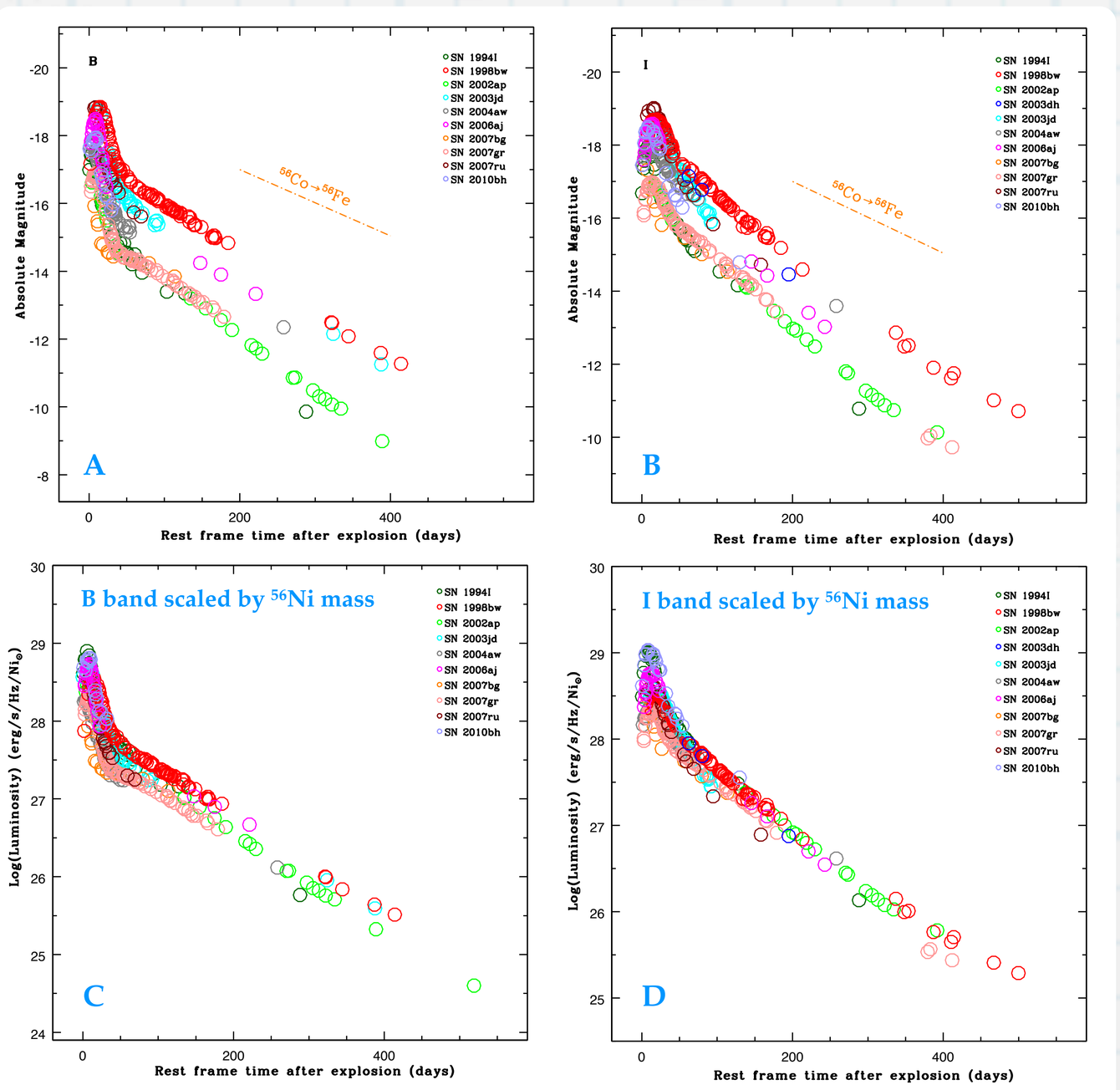

Figure 2 (A & B): A comparison of absolute magnitudes of type Ic SNe in our sample in *B* and *I* bands.

Figure 2 (C & D): The light curves of the supernovae when scaled by the estimated ^{56}Ni mass cluster together with a particularly low dispersion in the *I* band.

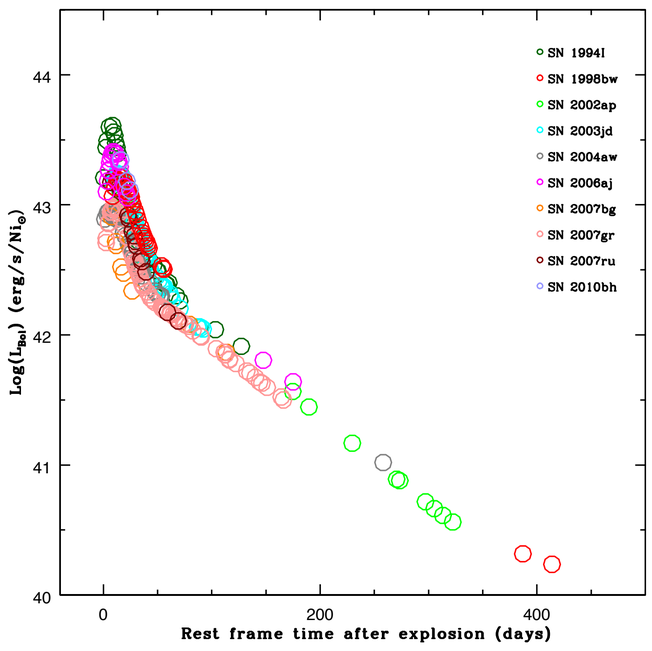

Figure 3: The clustering noticed in the scaled *I* band light curves of supernovae is also evident in the pseudo bolometric light curve when scaled by the estimated ^{56}Ni mass.

Conclusion

- We present the late-time *HST ACS* multi-color observations of SN 2003dh and SN 2006aj associated with GRB 030329 and XRF 060218 respectively.
- Using the late-time data we constrain the decay nature of SN 2003dh and SN 2006aj. We see that the decay rates are steeper than the ^{56}Co->^{56}Fe (0.0098 mag/day) decay rates indicating that there is some leakage of γ-rays. We notice that the decay rates are fairly similar in the *I* band.
- We find that the late-time light curves of the supernovae when scaled by the estimated ^{56}Ni mass, cluster together with a particularly low dispersion in the *I* band.
- The excellent scaling between the late and peak light curves implies that in spite of their relativistic jets, the light curves of these supernovae are powered throughout by the radioactive decay of ^{56}Ni.