Death of Massive Stars: Supernovae and Gamma-Ray Bursts
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The Fast Evolution of SN 2010bh associated with GRB 100316D

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Abstract. We report on the type-Ic SN 2010bh associated with XRF 100316D at $z = 0.059$, which is among the latest spectroscopically confirmed GRB-SNe (Bufano *et al.* 2012). This supernova proves to be the most rapidly evolving GRB-SN to date.

Keywords. supernovae: individual (SN 2010bh), gamma-rays: burts

1. Introduction

So far only a handful of supernovae (SNe) associated with gamma-ray bursts (GRBs) have been spectroscopically confirmed; see Woosley & Bloom (2006) and Hjorth & Bloom (2011) for reviews. Out of those only SN 2006aj associated with XRF 060218 has shown signatures of the cooling of the shock breakout (Campana *et al.* 2006).

For the case of the association SN 2010bh/XRF 100316D, GROND provided data from 0.5 to 80 days after the burst covering a wavelength range from 350 to 1800 nm, significantly expanding the pre-existing data set for this event (e.g., Cano *et al.* 2011).

2. Results

Broad Band Spectral Energy Distribution: Detections at 50 ks in $g'r'i'z'J$ are combined with a UVOT $uvw1$-band detection at 33 ks and an interpolated XRT spectrum. We model the SED (left panel of Fig. 1) with a blackbody associated with the cooling of the shock breakout and a power-law representing the afterglow. We obtain a host-galaxy extinction of $A_{V,\rm host} = 1.2 \pm 0.1$ mag and a metal absorption equivalent to a hydrogen column density of $N_{H,\rm host} = (4.4 \pm 0.4) \times 10^{22}$ cm^{-2}.

Evolution of the Thermal Component: Early X-ray measurements from Starling *et al.* (2011) complement our results for the temperature and radius of the blackbody component (Fig. 1, right panel). Assuming a linear growth, we obtain $v = 8000$ km/s. The best model is a power law, which yields an initial apparent radius of $R_0 = (7.0 \pm 0.9) \times 10^{11}$ cm. As seen in the upper right panel of Fig. 1, adiabatic expansion fails to reproduce $T_{BB}(t)$.

Pseudo Bolometric Light Curve: The flux integrated from the g' to the H bands was fitted using the two component model from Maeda *et al.* (2003), which consists of a dense inner core and an outer core with lower opacity (e.g., Valenti *et al.* 2008). The transition from optically thick to thin occurs at ≈ 33 days after the burst for SN 2010bh. The physical parameters of the explosion are $M_{\rm Ni} = (0.21 \pm 0.03) M_\odot$, $M_{\rm ej} = (2.60 \pm 0.23) M_\odot$, and $E_{\rm k} = (2.4 \pm 0.7) \times 10^{52}$ erg.

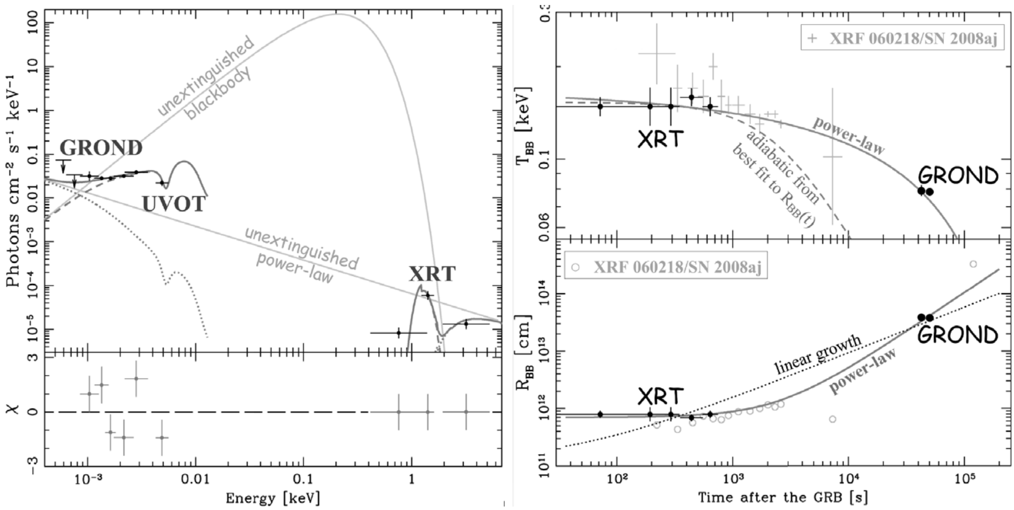

Figure 1. ***Left:*** Broad-band spectral energy distribution. The afterglow spectral slope is $\Gamma = 1.8 \pm 0.1$. ***Right:*** Temporal evolution of the blackbody component. Temperature is shown in the upper panel and blackbody radius in the lower panel.

3. Conclusions

Combining GROND and *Swift* data, the early broad-band SED is modeled with a blackbody and power-law component attenuated by ISM absorption in the host galaxy. The evolution of the thermal component reveals a cooling envelope at an apparent initial radius, which is compatible with a dense wind surrounding a WR star. Moreover, the early-time expansion velocities are compatible with the SN nature. Multicolor templates of SN 1998bw show that SN 2010bh is on average 70% as bright as SN 1998bw (see Olivares E. *et al.* 2012). Reaching maximum brightness at 8 − 9 days after the burst in the blue bands, SN 2010bh is the most rapidly evolving GRB-SNe to date. A two-component parametrized model fitted to the pseudo bolometric light curve delivered physical parameters of the explosion. The kinetic energy makes this SN the second most energetic GRB-SN after SN 1998bw. SN 2010bh also shows one of the earliest peaks ever recorded and it fades more rapidly than any other GRB-SN or type-Ic SN. Further analysis can be found in Olivares E. *et al.* (2012).

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