Death of Massive Stars: Supernovae and Gamma-Ray Bursts
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GRB Prompt X-ray Emission

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Abstract. I present the observational properties of the prompt emission of supernova associated GRBs (SN-GRBs) focusing on temporal and spectral characteristics. I compare the properties of SN-GRBs with typical long GRBs to see whether there is a distinct difference or not. Furthermore, I present our attempt to search for hard X-ray emission prior to the discovery date from optically identified type Ibc supernovae using *Swift* BAT survey data.

Keywords. gamma rays: bursts

1. Introduction

After the first discovery of the supernova associated gamma-ray burst (SN-GRB) GRB 980425 detected by BATSE and *Beppo*SAX (Galama *et al.* 1998), the number of SN-GRBs has been increasing thanks to a rapid and accurate GRB position notice by *HETE-2* (Ricker *et al.* 2003), *INTEGRAL* (Winkler *et al.* 2003), and *Swift* (Gehrels *et al.* 2004). On the other hand, we have started to see a large diversity in the characteristics of the prompt emission of SN-GRBs (e.g., Kaneko *et al.* 2007). I will review the current observational status of the prompt emission properties of spectroscopically identified SN-GRBs by comparing them to typical long GRBs.

2. Sample of SN-GRBs

Table 1 shows the list of the spectroscopically identified SN-GRB samples in this work. Three GRBs – 030329, 060218, and 100316D (bold fonts in the table) – have secure associations with supernovae since a spectral evolution from a non-thermal power-law to a supernova-like thermal feature is clearly seen in the optical spectroscopic observations (e.g., Stanek *et al.* 2003, Hjorth *et al.* 2003 for GRB 030329; e.g., Pian *et al.* 2006 for GRB 060218; e.g., Chornock *et al.* 2011 for GRB 100316D).

Table 1. Spectroscopically identified SN-GRB sample.

GRB	SN	Mission	Redshift	SN-Type
980425	1998bw	BATSE/BSAX	0.0085	Ic
030329	2003dh	HETE-2	0.1685	Ic
031203	2003lw	INTEGRAL	0.1005	Ibc
060218	2006aj	Swift	0.0331	Ic
091127	2009nz	Swift	0.490	Ic
100316D	2010bh	Swift	0.059	Ic
101219B	2010ma	Swift	0.55	Ic

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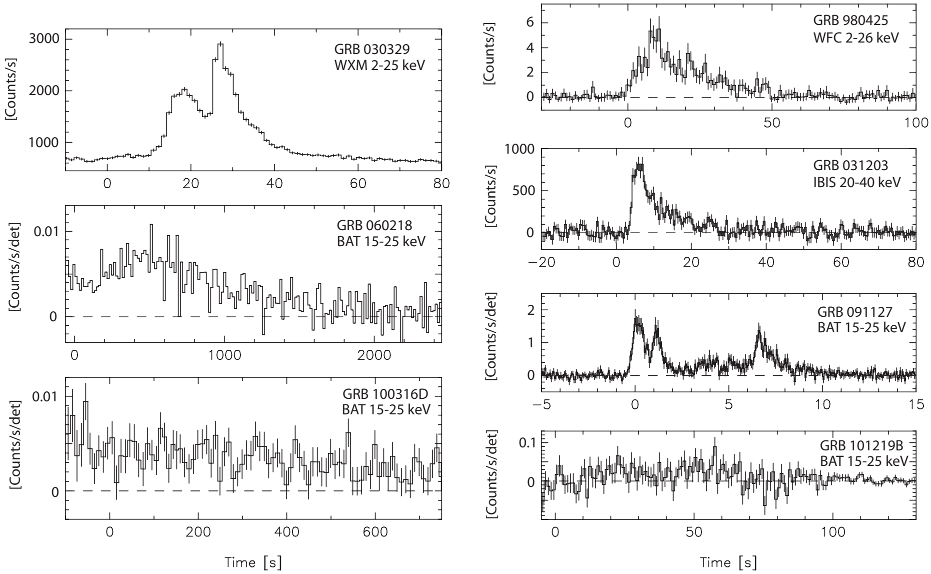

Figure 1. Prompt emission light curves of the SN-GRBs.

3. Temporal properties

3.1. *Light curves*

Figure 1 shows the prompt emission light curves of the SN-GRBs observed by various GRB instruments. As seen in the figure, there are large varieties in the light curves. For example, there are SN-GRBs which are composed of several bright overlapping pulses such as GRB 030329 and GRB 091127. On the other hand, GRB 060218, GRB 100316D and GRB 101219B show a very smooth and a long duration profile in their light curves.

3.2. *Durations*

The observed durations of SN-GRBs show diversity. While GRB 060218 and GRB 100316D show a duration of several thousands of seconds (Campana *et al.* 2006; Starling *et al.* 2011), SN-GRBs with a duration of a several tens to hundreds of seconds are also common. Although the durations of GRB 060218 and GRB 100316D are exceptionally long, the rest of the sample is well within the duration distribution of typical long GRBs (Figure 2).

3.3. *Lag-Luminosity relation*

Norris *et al.* (2000) found a correlation between the spectral lag and the peak luminosity (the so called lag-luminosity relation) of the prompt emission from the BATSE long GRBs. It is also known that short GRBs and several low luminous GRBs do not follow this relation (Norris & Bonnell 2006). The lag-luminosity relation is further confirmed by the *HETE-2* (Arimoto *et al.* 2010) and the *Swift* (Ukwatta *et al.* 2010) GRB samples. Figure 3 shows the BATSE, the *HETE-2* and the *Swift* long GRBs and the SN-GRBs in a peak luminosity versus lag plane. The lag and the peak luminosity values of GRB 980425, GRB 031203 and GRB 060218 are extracted from Norris *et al.* (2000), Sazonov, Lutovinov & Sunyaev (2004) and Liang *et al.* (2006), respectively. The values of the rest of the SN-GRBs are derived in this work. GRB 091127, GRB 030329 and possibly GRB 060218 are consistent with the lag-luminosity relations. According to Liang *et al.* (2006), the lag value of GRB 060218 has a large uncertainty since it requires an extrapolation

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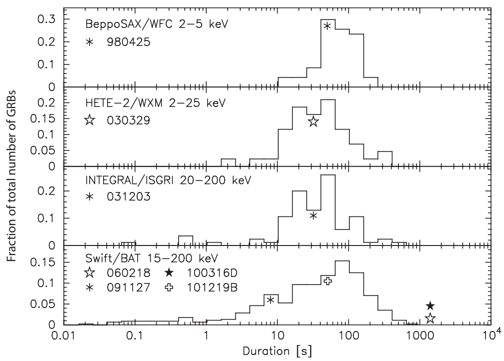

Figure 2. Observed duration distribution of *Beppo*SAX/WFC (2-5 keV), *HETE-2*/WXM (2-25 keV), *INTEGRAL*/ISGRI (20-200 keV) and *Swift*/BAT (15-200 keV) from top to bottom panel. The durations of the SN-GRBs are overlaid in the histograms.

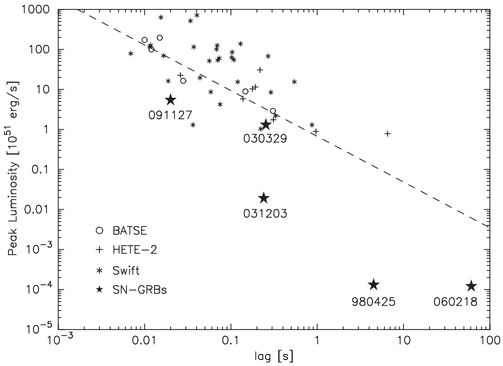

Figure 3. Lag-Luminosity relation of the BATSE (Norris *et al.* 2000), the *HETE-2* (Arimoto *et al.* 2010) and the *Swift* (Ukwatta *et al.* 2010) long GRBs. The dotted line is the lag-luminosity relation, $L_{\rm iso} \propto lag^{-1.14}$, originally proposed by Norris *et al.* (2000). The SN-GRBs are shown as stars.

from the original lag measurement between the BAT (Barthelmy *et al.* 2005) and the XRT (Burrows *et al.* 2005) band to that of the BATSE standard band to be able to plot on the lag-luminosity plane. Based on their analysis, GRB 060218 is within the 2σ confidence region of the relation. However, as noted by various previous works, GRB 980425 and GRB 031203 do not follow the relation. The relatively low peak luminosity for both GRB 980425 and GRB 031203 makes them outliers to this relationship. Note that since the low luminosity GRB 060218 seems consistent with the relation, not all low luminosity GRBs are outliers of the lag-luminosity relation.

4. Spectral properties

4.1. *Band function parameters*

The prompt emission spectra of SN-GRBs which have reported broad-band spectral parameters are well fitted with the Band function (Band *et al.* 1993). To compare the best fit parameters of the Band function between the SN-GRBs and typical long GRBs, the histograms of the low-energy photon index, α, the high-energy photon index, β, and the spectral peak energy, $E_{\rm peak}$, of the long GRBs are shown in Figure 4. α and β values are from the BATSE long GRBs (Goldstein *et al.* 2010). $E_{\rm peak}$ values are from Goldstein *et al.* (2010) for the BATSE, Sakamoto *et al.* (2005) and Pélangeon *et al.* (2008) for the *HETE-2*, and Sakamoto *et al.* (2011) for the *Swift* GRBs. The values of the best fit Band function parameters of the SN-GRBs are marked in the histograms. All the Band function parameters of the SN-GRBs are consistent with typical long GRBs.

4.2. *Additional blackbody component in X-ray spectrum*

The existence of an additional blackbody component in the prompt X-ray spectrum of GRB 060218 (Campana *et al.* 2006) and GRB 100316D (Starling *et al.* 2011) has been reported. The blackbody temperature is stable in the range of 0.1-0.2 keV up to several hundreds of seconds after the trigger, and then, decreases to < 0.01 keV. I also found an additional blackbody component for GRB 101219B. The *Swift* XRT spectrum extracted from 152 s to 300 s after the trigger shows a significant improvement in the fit with a blackbody plus a power-law model (χ^2/d.o.f. = 85.8/100) over a power-law model

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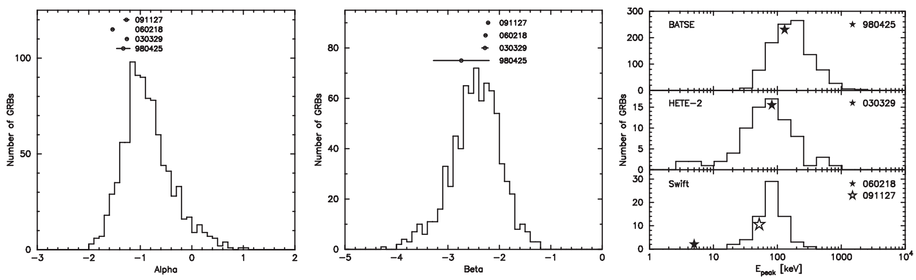

Figure 4. Distributions of the low-energy photon index α (left), the high-energy photon index β (middle) and E_{peak} (right). The E_{peak} histograms of the BATSE, the *HETE-2* and the *Swift* long GRBs are shown from top to bottom.

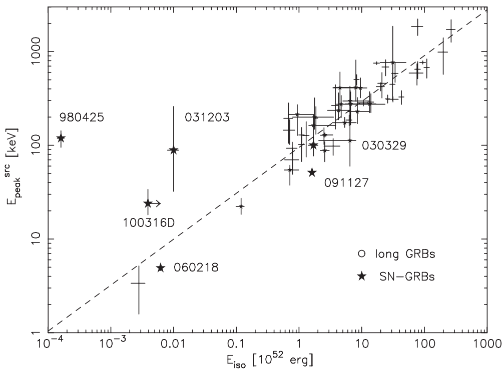

Figure 5. E_{peak}-E_{iso} relation. The long GRB samples are from Amati *et al.* 2006 and Sakamoto *et al.* 2011.

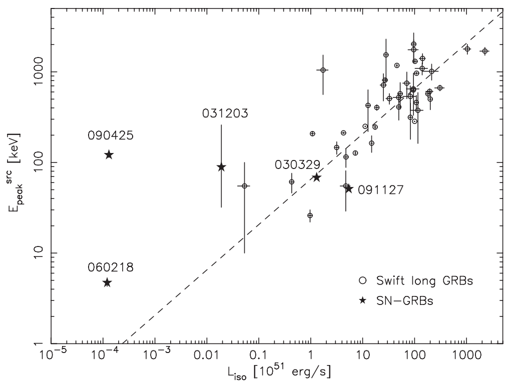

Figure 6. E_{peak}-L_{iso} relation. The long GRB samples are from Nava *et al.* 2012.

(χ^2/d.o.f. = 104.1/102). The F-test probability is 6.3×10^{-5} between these two fits. The best fit blackbody temperature is 0.12 ± 0.02 keV which is similar to the case of GRB 060218 and GRB 100316D. Since most of the XRT spectra of long GRBs can well be fit by a simple power-law model, this additional blackbody component could be a unique spectral feature of SN-GRBs.

4.3. *E_{peak}-E_{iso} and E_{peak}-L_{iso} relations*

The empirical spectral relations between E_{peak} and the isotropically radiated γ-ray energy E_{iso} (E_{peak}-E_{iso} relation; Amati *et al.* 2002) and between E_{peak} and the peak isotropic luminosity L_{iso} (E_{peak}-L_{iso} relation; Yonetoku *et al.* 2004) are well discussed relationships of the prompt emission. As shown in Figure 5 and 6, most of the long GRBs are consistent with the E_{peak}-E_{iso} and the E_{peak}-L_{iso} relations including the SN-GRBs except GRB 980425.

5. Searching for hard X-ray emission in supernova

We searched for hard X-ray emission using the *Swift* BAT survey data for 123 type Ibc and IIp supernovae (< 100 Mpc) discovered between 2005 and 2010. The BAT data starting from $\sim$ 28 days prior to the discovery up to the discovery date are processed. No significant hard X-ray emission was found for ordinary type Ibc and IIp supernovae. Our result is consistent with a radio survey of ordinary type Ibc supernovae (Soderberg *et al.* 2006), and might indicate that a fundamentally different mechanism is required to produce a GRB from a supernova.

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6. Summary

• Burst duration, spectral lag and spectral parameters of SN-GRBs are consistent with typical long GRBs.

• In addition to the Band function spectrum, GRB 060218 and GRB 100316D (and possibly GRB 101219B) show kT = 0.1-0.2 keV blackbody component in the prompt emission spectrum.

• Most of the SN-GRBs follow the empirical relations between lag and luminosity, E_{peak}-E_{iso} and E_{peak}-L_{iso}. However, GRB 980425 and possibly GRB 031203 are outliers of those relations.

• No hard X-ray emission is found from ordinary type Ibc and IIp supernovae.

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Discussion

Burrows: How does beaming affect your conclusions about the lack of hard X-ray emission from type Ibc SNe?

Sakamoto: We believe that beaming is playing a major role in generating a hard X-ray prompt emission between SN-GRBs and ordinary type Ibc SNe.

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Kulkarni: As yourself noted the SN-GRB sample has strong selection biases. The events have to be at low redshift. This selection effect may strongly affect the detection of very soft (BB) components.

Kulkarni: It was my impression that the volumetric rate of SN-GRBs is an order of magnitude larger than those of cosmological GRBs. If so, the selection biases are even more severe.

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