GRBs with Extended Emission in the BATSE Archive

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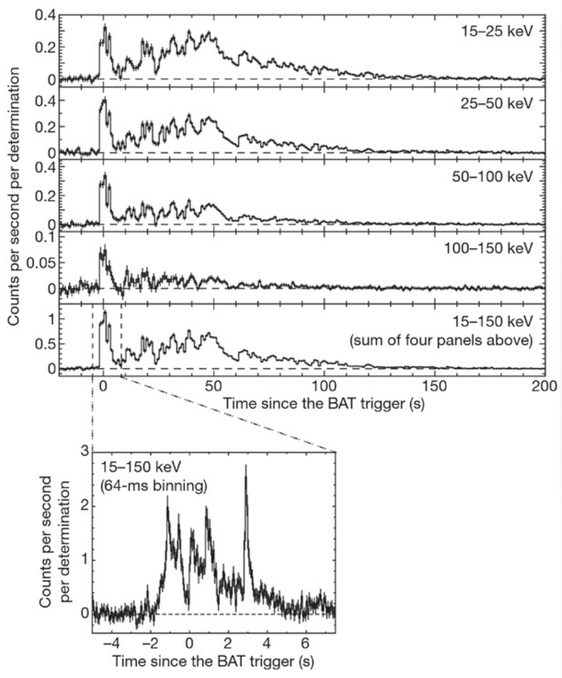
Introduction

Gamma ray bursts (GRBs) are traditionally divided into long soft and short hard classes, based on their duration and spectral hardness (Kouveliotou et al. 1993). Occasionally some GRBs exhibit a softer, low intensity extended emission component following an initial short-hard spike. Based on the study on GRB 060614 by Gehrels et al. (2006), these events are considered as a separate population between short and long GRBs (see below). Although the nature of the extended emission is still not clear, the possibilities for the extended emission include an early X-ray afterglow or a manifestation of the prolong activity of a central engine.

GRB 060614 as a reference for GRBs with extended emission :

- ✓It is a long GRB (102 s) as determined with the BAT, but BATSE would have classified it as short GRB.
- ✓It has a short hard spike + a soft extended emission (EE)
- ✓The EE is 5 times more energetic than the spike.
- ✓It's temporal lag & peak luminosity fall within the short-duration GRB subclass



During its 9 year long mission, BATSE (the Burst and Transient Source Experiment) recorded 2702 GRBs, of which ~25% are classified as "short". Taking advantage of the large BATSE archive, we performed a systematic search for GRBs with EE similar to GRB060614. Here we present the first results of our systematic search, and spectral & temporal properties of the identified bursts.

Search Procedure

- ✦We used BATSE Large Area Detectors (LADs) discriminator data (DISCLA) from two brightest detectors.
  - ✳four energy channels; 25-50, 50-100, 100-300 and >300 keV
  - ✳time resolution of 1.024 s
  - ✳recorded continuously
- ✦We subtracted orbital background rates
  - ✳the orbit of CGRO was at the same geographical coordinates every 15 orbits (~24 hrs) and also at the same position relative to the Sun.
  - ✳the background at the trigger time T_0 could be approximated by averaging the rates at times T_0±15 orbits, T_0±30 orbits, or T_0±45 orbits.
- ✦We binned the data to 4 s resolution, between T_0+5 and T_0+350 s from and calculated the Signal to Noise Ratio of each bin
- ✦We identified events with a SNR of 1.5 σ above background for at least 12 s in both detectors (Figure 2 and 4).
- ✦We scanned 648 short GRBs (T_{90} < 5 s) with these criteria, but for 2041 long GRBs (T_{90} > 5 s) we defined the following additional criteria:
  - ✳burst peak should occur before T_0+5 s
  - ✳the count rates should remain below 10% of the peak count rate for at least 60% after the peak time until T_0+5 s.

Results: Short GRBs with EE

We found 5 short GRBs with EE (GRBs 910725, 951211, 970918, 980112, 980904). The duration of the EE ranges from 14.3 s to 84 s. We present below the results of **GRB 980904** (BATSE Trig# 7063):

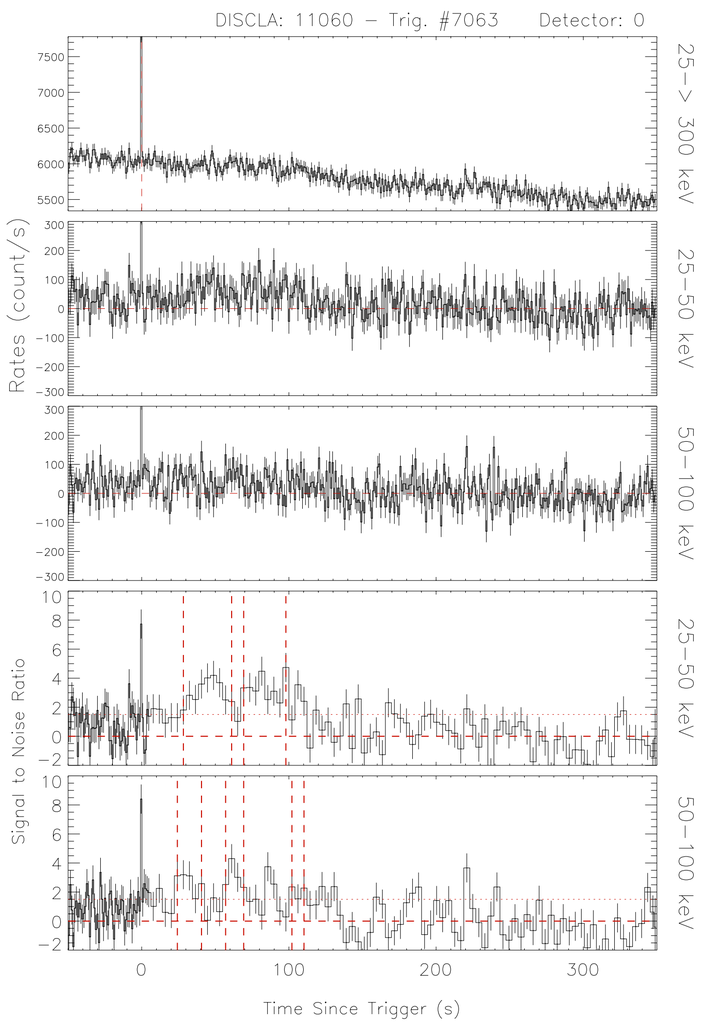


Figure 2: Light curve of GRB 980904. *Top panel*: sum of four energy channels. *The second and third panels*: background subtracted light curves in two lowest energy channels. Horizontal red dashed line indicates the level of the background. *Last two panels*: signal to noise ratio as a function of time. Vertical lines show the time ranges where the SNR is at least 1.5 σ for at least 12 s. The horizontal dashed and dotted lines show the background level and the 1.5 σ level, respectively.

Results: Long GRBs with EE

We found 3 long GRBs with EE (GRBs 921022, 980525, 990605). The duration of the EE ranges from 22.5 s to 118.3 s. We present below the results of **GRB 980525** (BATSE Trig# 6782):

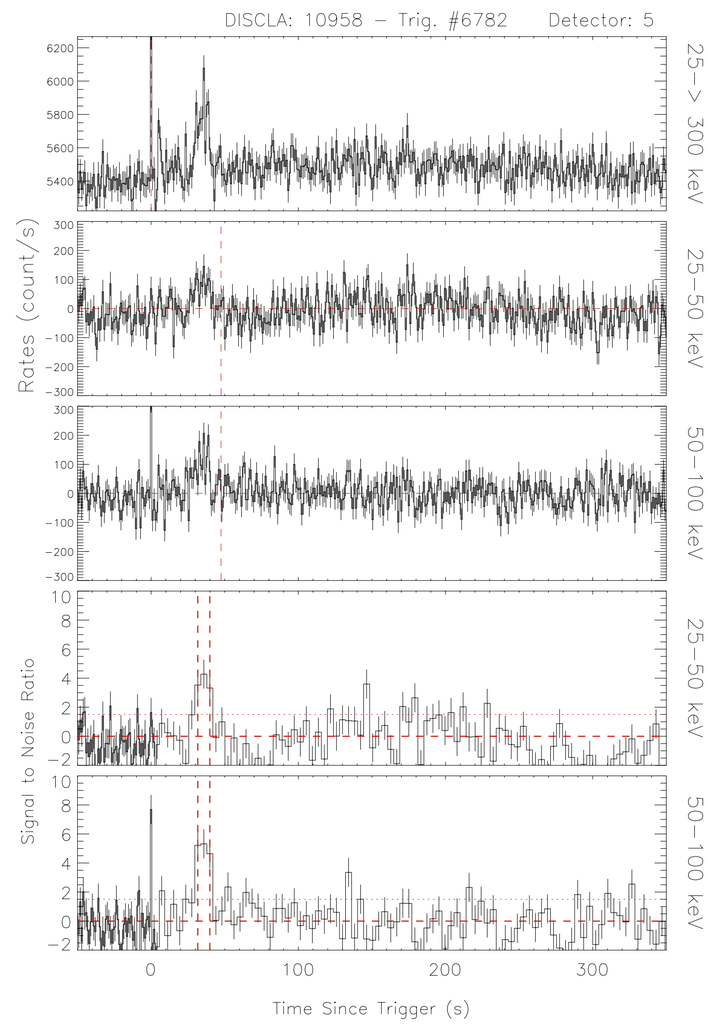


Figure 4: Light curve of GRB 980525. *Top panel*: sum of four energy channels. *The second and third panels*: background subtracted light curves in two lowest energy channels. Horizontal red dashed line indicates the level of the background. *Last two panels*: signal to noise ratio as a function of time. Vertical lines show the time ranges where the SNR is at least 1.5 σ for at least 12 s. The horizontal dashed and dotted lines show the background level and the 1.5 σ level, respectively.

Spectral Analysis

We performed spectral analysis using MER data (64 ms resolution). In case there is no MER data, we used CONT data (2 s resolution). We analyzed the initial spike and EE for each GRB separately (see results in Table 1).

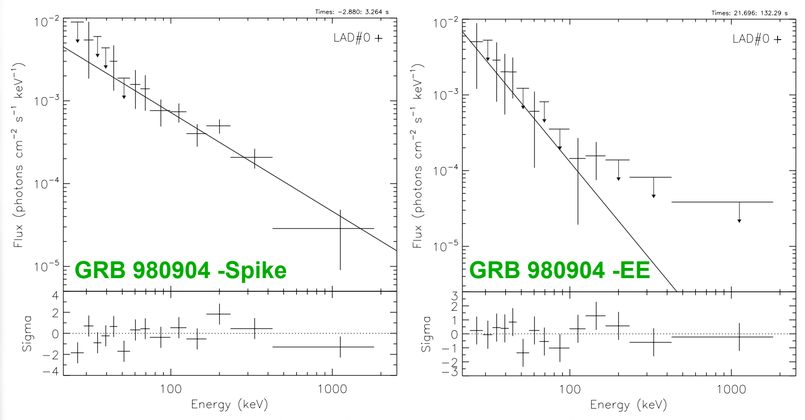


Figure 3: Photon spectra for the spike (*left*) and extended emission (*right*) fitted by a power law.

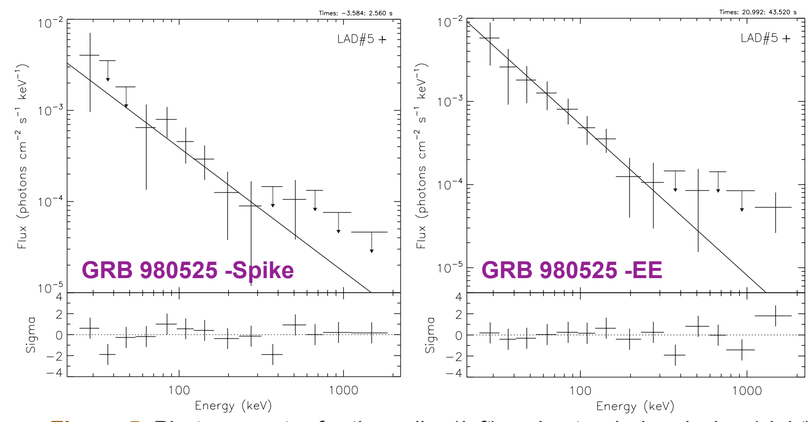


Figure 5: Photon spectra for the spike (*left*) and extended emission (*right*) fitted by a power law.

Table 1: Summary of spectral fit results of two GRBs with 1σ uncertainties.

GRB	Component	Time Interval (s)	A (10^{-5} ph s^{-1} cm^{-2} keV^{-1})	Γ	χ^2/dof	Energy Flux * (10^{-7} erg s^{-1} cm^{-2})	Energy Fluence * (10^{-7}erg cm^{-2})
980904	Spike	-3.58 : 2.56	39.08 ± 9.80	-1.36 ± 0.27	10.16 / 12	0.50 ± 0.17	3.07 ± 1.04
	EE	20.99 : 43.52	52.44 ± 8.21	-1.79 ± 0.26	10.59 / 11	0.39 ± 0.12	8.79 ± 2.70
980525	Spike	-2.88 : 3.26	72.14 ± 10.7	-1.19 ± 0.13	14.37 / 12	1.12 ± 0.17	6.88 ± 1.04
	EE	21.70 : 132.29	13 ± 6.73	-2.59 ± 0.68	6.88 / 12	0.06 ± 0.04	6.64 ± 4.42

* Energy flux/fluence is calculated in the 30 - 1500 keV range.

Summary & Discussion

- ✓ Based on a systematic search of 2689 GRBs from the BATSE archive, we identified 8 GRBs with EE that comply with our criteria. 5 of these events were short and 3 were long GRBs.
- ✓ The fraction of BATSE GRBs with EE is 0.3% of total bursts, while the fraction of the BAT GRBs with EE corresponds to 2% of the second Swift Burst Alert Telescope catalog which contains 476 GRBs (Sakamoto et al. 2011). This is expected due to the differences in the instrumental responses, since the EE components are much softer in general.
- ✓ We present here spectral fit results of two GRBs. The spike and EE components are both well described with a single power law. Results indicate clearly that EE is softer than the initial spike. The energy fluence ratio (E_{EE}/E_{spike}) is ~1 for the short GRB (980904) and ~3 for the long GRB (980525).
- ✓ Norris et al. (2006) also searched by eye GRBs with EE within the BATSE archive and identified 8 GRBs with EE, of which only one was identified in our systematic search (GRB 921022). They reported that EE component is always softer than the initial spike. Our analysis results of the 2 example GRBs presented here are consistent with their conclusion.
- ✓ Detailed temporal and spectral analysis of all of the 8 GRBs identified in our search is on-going.

References

Kouveliotou et al. 1993, ApJ, 413, L101
Norris et al. 2006, ApJ, 643, 266
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Sakamoto et al. 2011, ApJS, 195, 2

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