Broad Band X-ray Spectral Properties of Gamma-Ray Bursts with BeppoSAX

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Abstract. In about one year, five gamma–ray bursts were simultaneously observed with the Wide Field Cameras and Gamma Ray Burst Monitor aboard the BeppoSAX satellite. From some of them X–ray afterglow emission has been clearly detected with the same satellite. In order to understand how GRB emission is related to the X–ray afterglow, we are performing a systematic study of the spectral properties of these events. We report here preliminary results of this study.

INTRODUCTION

The discovery by BeppoSAX [1] of the first afterglow sources of celestial Gamma-Ray Bursts (GRB) has strongly increased the astrophysical interest for the GRB phenomenon. BeppoSAX offers the possibility not only to discover the presence of very faint X-ray afterglow emission ($\geq 5 \times 10^{-14} \text{erg}/(\text{cm}^2\text{s})$) following a GRB event, but also to study in a broad energy band (1.5–700 keV) the specific bursts from which afterglow emission can be searched for. This is possible thanks to the presence aboard the same satellite of a Gamma-Ray Burst Monitor (GRBM) [2] and two Wide Field Cameras (WFC) [3]. These instruments have a field of view partially superposed. When an event is simultaneously detected by both instruments, the position of the burst can be precisely determined (within a few arcmin error radius) and thus a follow-on observation of the GRB error box can be started.
TABLE 1. GRBs simultaneously detected from BeppoSAX GRBM and WFCs

| GRB      | γ-ray Fluence (10^{-5}erg/cm^2) | γ-ray Duration (sec) | TOO time delay | X-ray afterglow (yes/no) |
|----------|---------------------------------|----------------------|----------------|-------------------------|
| GRB960720 | 0.34 ± 0.40                     | 8                    | 43^d           | ? [4]                   |
| GRB970111 | 4.14 ± 0.30                     | 43                   | 16^h           | ? [5]                   |
| GRB970228 | 1.17 ± 0.20                     | 55                   | 8^h            | yes [6]                 |
| GRB970402 | 0.91 ± 0.09                     | 150                  | 8^h            | yes [7]                 |
| GRB970508 | 0.18 ± 0.03                     | 15                   | 5.7^h          | yes [8]                 |

FIGURE 1. WFC/GRBM Time averaged spectrum of GRB970111. The best fit in the 1.5 to 700 keV energy band is obtained with a broken power law (see continuous line) with the following parameters: \( \alpha_1 = 0.50 \pm 0.04 \), \( \alpha_2 = 2.13 \pm 0.03 \), \( E_{\text{break}} = 101 \pm 1 \) keV, \( (\chi^2/195 = 1.24) \). In the fit the instrument relative normalization was a free parameter.

...in other bands of the electromagnetic spectrum (X-rays, optical, IR, radio).

So far 5 GRBs were simultaneously detected with GRBM and WFC (see Table 1). Of them GRB970111 was the strongest event, in terms of peak flux and fluence, and GRB970402 was the weakest. While search for afterglow X-ray emission from GRB960720 started after a long time (43 days) from the initial
FIGURE 2. WFC/GRBM Time averaged spectrum of GRB970228. The best fit in the 1.5 to 700 keV energy band is obtained with a broken power law (see continuous line) with the following parameters: \( \alpha_1 = 1.35 \pm 0.07, \alpha_2 = 1.95 \pm 0.05, E_{\text{break}} = 13 \pm 3 \) keV, \( \chi^2/195 = 1.05 \)

event [4], this search for the other bursts started after about 6–16 hrs (see Table 1). The result is known: three clear X-ray afterglow sources, associated with GRB970228 [9,6], GRB970402 [10,7], GRB970508 [11,8], respectively, were discovered. For the first and the last of these events also an optical afterglow was observed [12,13]. In addition, for the last event (GRB970508) also a radio counterpart was detected [14].

For the strongest event, GRB970111, there is some evidence of X-ray afterglow [5] and no detection of optical or radio counterpart. It is of primary importance to understand the reason for that.

A possible signature of the peculiarity of GRB970111 with respect to the other bursts is its energy spectrum. Thus a comparison of time averaged energy spectra of these bursts can help to solve the problem.

Here we report preliminary results of this spectral analysis.
RESULTS

Spectra averaged on time profiles of GRB970111, GRB970228 and GRB970402 in the broad energy band from 1.5 to 700 keV were obtained by using both WFC and GRBM spectral data. A response matrix was obtained for each of these instruments for on-axis incident photons. This can introduce some systematic errors in the flux estimate, but not in the spectral shape, as confirmed by the Crab Nebula spectrum determination [15]. XSPEC software package (v. 9.0) was used to derive spectral parameters and their uncertainties (1σ). Figures 1, 2 and 3 show preliminary results.

DISCUSSION

From the fit results, both GRB970111 and GRB970228 spectra are fit with a broken power law, while the spectrum of GRB970402 is fit with a single power law. By comparing the break energy of the GRB970111 spectrum with that of the GRB970228 spectrum, we see that it is much higher for GRB970111 than
for GRB970228: 101 keV vs. 13 keV. This fact could be a hint that the peak energy of the $\nu F_\nu$ spectrum evolved much more rapidly toward lower energies in the case of GRB970228. A fast evolution of $\nu F_\nu$ was actually observed in GRB970228 [16]. How this different evolution can influence the presence or not of an afterglow emission is not clear.

Work is in progress to complete the comparative spectral analysis by including the spectral evolution of the bursts.

REFERENCES

1. Boella, G. et al. 1997a, A&A Suppl. Ser., 122, 299.
2. Frontera, F., Costa, E., Dal Fiume, D., Feroci, M., Nicastro, L., Orlandini, M., Palazzi, E., and Zavattini, G. 1997a, A&A Suppl. Ser., 122, 357.
3. Jager, R., et al. 1997, A&A Suppl. Ser., in press.
4. Piro, L. et al. 1996, IAU Circ. 6480.
5. Feroci, M. et al. 1997, in preparation
6. Costa, E. et al. 1997, Nature, 387, 783
7. Nicastro, L. et al. 1997, in preparation
8. Piro, L. et al. 1997c, A&AL, submitted.
9. Costa, E. et al. 1997, IAU Circ. 6576.
10. Piro, L. et al. 1997a, IAU Circ. 6617.
11. Piro, L. et al. 1997b, IAU Circ. 6656.
12. Groot, P.J. et al. 1997, IAU Circ. 6584.
13. Bond, H. E. 1997, IAU Circ. 6654.
14. Frail, D. A. et al. 1997, IAU Circ. 6662.
15. Feroci, M. et al. 1997, this proceedings
16. Frontera, F. et al. 1997, ApJ Lett., accepted.