Abstract. We report on prompt and afterglow observations of GRB 000615 detected by BeppoSAX. The study of the high-energy prompt event is presented along with the search for its X-ray and optical afterglow. Spectral fits seem to suggest a temporal evolution of the GRB prompt emission. We possibly find evidence for intrinsic $N_H$ (at 90% confidence level) and for a transient spectral emission feature around 8 keV (at 98% confidence level). The X-ray to $\gamma$-ray fluence ratio of 1.73 ± 0.22 is one of the largest among BeppoSAX GRBs. A weak X-ray source is also detected in the MECS, between 1.6 and 4.5 keV, and its position is compatible with the WFC error box. The behaviour of this source may be compatible with that of an afterglow. Low significance signal is detected in the 0.2–1.5 keV at a position consistent with the WFC and MECS error boxes. The S/N ratio is insufficient to speculate on the nature of this source. There is no evidence of an optical transient down to $R \sim 22$.

1. Introduction

GRB000615 was simultaneously detected, at 06:17:45 UT of 15 June 2000, by the BeppoSAX GRBM and WFC, with a localization uncertainty of 2′ (error circle radius), at coordinates (J2000) RA = 15$^h$32$^m$36$^s$.9, DEC = +73$^\circ$49′07′′ (Gandolfi et al. 2000). BeppoSAX NFI observations started $\sim$ 10 hours after the trigger time and lasted 1.44 days. Preliminary NFI data analysis by Nicastro et al. (2001) showed the presence of two sources, one in the LECS between 0.1 and 4 keV, and the other in the MECS between 1.6 and 4 keV. It is still not clear whether the MECS and the LECS sources are really distinct and which (if any) is related to GRB000615. Optical, IR and radio follow-up observations did not detect any transient in the WFC error box (Stanek et al. 2000; Pian et al. 2000; Di Paola et al. 2000; Frail et al. 2000). Here we present a refined analysis of the high energy BeppoSAX data along with that of optical data of the WFC error box.

2. Prompt event

Figure 1, left panel, shows the WFC (2–10 keV and 10–28 keV) and GRBM (40–700 keV) light curves of GRB000615. The $\gamma$-ray emission lasted about 13
s, while the X–ray emission was detected over a substantially longer interval of 120 s. Moreover, the bulk of the X–ray emission started \( \sim 40 \) s after the \( \gamma \)–ray peak. In order to perform time-resolved spectral analysis of the GRB emission in the 2–700 keV range, we divided the light curves into three time intervals (a, b and c; see Fig. 1, left panel) of duration 30 s, 30 s and 60 s, respectively. The spectra integrated over these time bins were analysed separately. In our fits the \( N_H \) was fixed at the Galactic value (2.7\( \times 10^{20} \) cm\(^{-2} \)) unless otherwise stated. The best-fit parameters for the three spectra are reported in Table 1.

In the first 30 s (slice a) the spectrum was first fitted with a single power-law (PL) with photon index 1.5 \( \pm 0.2 \). However, a 90% probability improvement was obtained using a single PL with free \( N_H \). In this case, we had a weak suggestion for a large \( N_H \) value (\( \sim 2 \times 10^{23} \) cm\(^{-2} \)), as shown in Table 1. We also fitted these data with the Band model (Band et al. 1993) or with a broken PL, but the spectral parameters were largely unconstrained.

The WFC data of the second temporal slice (b) were well fitted with a single PL with index 1.9 \( \pm 0.3 \); however, this model were inconsistent with the GRBM upper limits. When these were accounted for the fit, the PL index was steeper than 2.12, which was still within 1\( \sigma \) from the WFC data best-fit.

The spectrum of slice c was best fitted with a PL of index 2.2 \( \pm 0.3 \). However, an excess around 8 keV appeared in the residuals. When we added a narrow Gaussian line to the model, the fit improved at the 98% confidence level, but using instead a recombination edge model, the parameters were poorly constrained.
Study of the GRB000615 field

Table 1. Best-fit spectral parameters of the GRB000615 high-energy data. Errors are at 90% confidence level. $N_H$ in brackets are fixed at Galactic value.

| Slice | Model         | $N_H$ \((10^{22} \text{ cm}^{-2})\) | $\Gamma$    | $E_l$ \((\text{keV})\) | $\chi^2$/dof |
|-------|---------------|---------------------------------|-------------|-----------------|--------------|
| A     | PL            | [0.027]                         | 1.5 ± 0.2  | —               | 5.7/4        |
|       | PL+$N_H$      | \(21^{+66}_{-19}\)             | 1.9$^{+0.5}_{-0.3}$ | —      | 2.0/3        |
| B     | PL            | [0.027]                         | 1.9 ± 0.3  | —               | 2.9/8        |
| C     | PL            | [0.027]                         | 2.2$^{+0.4}_{-0.3}$ | —      | 7.9/8        |
|       | PL+GAUSS      | \(2.6^{+0.5}_{-0.4}\) \(8.2^{+0.8}_{-0.9}\) | —          | 2.1/6          |

Nevertheless, assuming that this excess was due to the Fe recombination edge at 9.27 keV, a redshift $z \sim 0.13$ was derived.

The 2–10 keV to 40–700 keV fluence ratio of this GRB is 1.73 ± 0.22, one of the highest to date found for a BeppoSAX GRB (marginally higher than that of GRB990704, which was 1.52 ± 0.15; Feroci et al. 2001).

3. The search for the afterglow

3.1. X–rays

Confirming the preliminary results of Nicastro et al. (2001), the analysis of the MECS data revealed the presence of an uncatalogued steady X-ray source in the 1.6–4.5 keV interval. Its position was consistent with the WFC error box of the GRB. The spectrum of this object was fitted with either a PL with index $\sim$2.3 or with a blackbody having $kT \sim 0.6$ keV. The average flux in this band was $(8.0 \pm 1.6) \times 10^{-14}$ erg cm$^{-2}$ s$^{-1}$.

In the LECS image we detected some signal at the center of the WFC error box with a significance of 2.5 $\sigma$ between 0.2 and 1.5 keV during the first 60 ks (corresponding to 15 ks of actual on-source time) of the observation. Its position was 2$'$ away from the center of the MECS source error box, and therefore marginally consistent with it, considering the low S/N. The non-detection of substantial emission in the LECS at the position of the MECS source suggested that additional absorption ($N_H \sim 4\times10^{21}$ cm$^{-2}$) could be present if the PL model was chosen. No additional $N_H$ was required if, instead, a blackbody model was assumed.

Figure 1, right panel, shows the 2–4 keV flux of the GRB and of the MECS source. The plotted line corresponds to a power-law decay with index $\alpha \simeq 1.7$ which is typical for X–ray afterglows. The steadiness of the flux from the source detected in the MECS is intriguing and could suggest that this was not the GRB afterglow; nevertheless this unusual behaviour occurred at least in another case, GRB970508 (Piro et al. 1998), in which a rebursting laid on a powerlaw decay was observed.
3.2. Optical

We performed an accurate analysis of $R$-band data (Stanek et al. 2000) acquired at FLWO on June 15 and 16, 2000; the results confirmed that 4 hours after the GRB trigger no optical afterglow was present in the WFC error box down to $R \sim 22$, i.e. slightly deeper than the previous limit ($R \sim 21.5$) determined from these data.

4. Summary

GRB000615 is probably the X–ray richest GRB observed by BeppoSAX, with a fluence ratio $S_X/S_\gamma = 1.73 \pm 0.22$. We found marginal evidence of spectral evolution in the prompt event: during the first 30 s, the spectrum shows very marginal evidence of absorption in addition to the Galactic one, which may be due to a high density circumburst medium. Between 60 and 120 s after the trigger, an emission feature is present at 98% confidence level, which can be interpreted as a Fe recombination edge at $z \sim 0.13$.

An uncatalogued and non-significantly variable source is detected with the MECS in the 1.6–4.5 keV energy range. The 2–4 keV fluxes measured by the WFC during the prompt event and by the MECS during the NFI pointing can be connected assuming a power-law decay of index 1.7, which is typical for X-ray afterglows. While the steadiness of the MECS source flux is uncommon in afterglows, we note, as remarked before, that this behavior is reminiscent of the short-term variability exhibited by the X–ray afterglow of GRB970508.

A transient 2.5\sigma signal is present below 1.5 keV in the LECS image, at a position marginally consistent with the MECS source, but fully consistent with WFC error box. Although this latter circumstance may suggest its association with the GRB, the low significance of the detection prevents us to establish its reality and its relationship with the afterglow.

No optical afterglow down to $R \sim 22$ is present and this might suggest that GRB000615 is a “dark” burst which likely occurred in a high density environment.

References

Band, D., Matteson, J., Ford, L., et al. 1993, ApJ, 413, 281
Di Paola, A., Antonelli, L. A., Licausi, G., et al. 2000, GCN circ. 708
Feroci, M., Antonelli, L. A., Soffitta, P., et al. 2001, A&A, 378, 441
Frail, D. A., Becker, K. M., Berger, E., et al. 2000, GCN circ. 721
Gandolfi, G. 2000, GCN circ. 705
Henden, A. A. 2001, ftp://ftp.nofs.navy.mil/pub/outgoing/aah/grb/grb000615.dat
Nicastro, L., Cusumano, G., Antonelli, L. A., et al. 2001, in ESO Astroph. Symp., Gamma Ray Bursts in the afterglow era, ed Costa, E., Frontera, F., & Hjorth (Berlin: Springer-Verlag), 198
Pian, E., Masetti, N., Palazzi, E., et al. 2000, GCN circ. 727
Piro, L., Amati, L., Antonelli, L. A., et al. 1998, A&A, 331, L41
Stanek, K. Z., Garnavich, P. M., Berlind, P., & Jha, S. 2000, GCN circ. 709