ASTRONOMY & ASTROPHYSICS SUPPLEMENT SERIES

SEPTEMBER **1999**, PAGE 399

Astron. Astrophys. Suppl. Ser. **138**, 399–400 (1999)

Spectral evolution of gamma-ray bursts with BeppoSAX and correlation with X-ray afterglow properties

F. Frontera[1,2], L. Amati[1], A. Castro-Tirado[8], E. Costa[3], D. Dal Fiume[1], M. Feroci[3], J. Heise[4], N. Masetti[1], J.M. Muller[4,5], L. Nicastro[9], M. Orlandini[1], E. Palazzi[1], E. Pian[1], L. Piro[3], M. Tavani[6,7], and J. in't Zand

[1] Istituto Tecnologie e Studio Radiazioni Extraterrestri, CNR, Via Gobetti 101, 40129 Bologna, Italy
[2] Dipartimento di Fisica, Università di Ferrara, Via Paradiso 11, 44100 Ferrara, Italy
[3] Istituto Astrofisica Spaziale, CNR, Via Fosso del Cavaliere, 00133 Roma, Italy
[4] Space research Organization in the Netherlands, Utrecht, NL, The Netherlands
[5] BeppoSAX Scientific Data Center, Via Corcolle, 00100 Roma, Italy
[6] Istituto di Fisica Cosmica e Teconologie Relative, CNR, Via Bassini 15/A, 20133 Milano, Italy
[7] Columbia Astrophysics Laboratory, New York, U.S.A.
[8] LAEFF, Madrid, Spain
[9] Istituto Fisica Cosmica e Informatica, CNR, Palermo, Italy

Received January 21; accepted April 21, 1999

Abstract. We report some comparative results of an investigation devoted to study the spectral evolution of a sample of Gamma-Ray Bursts. They were simultaneously detected with both the Gamma-Ray Burst Monitor and the Wide Field Cameras aboard the BeppoSAX satellite and were reobserved with the Narrow Field Instruments aboard the same satellite.

Key words: gamma-rays: bursts — X-rays: general

1. Introduction

The BeppoSAX discovery of X-ray afterglows of Gamma-Ray Bursts (GRBs) has solved a great mystery about these events but many questions are still open about the origin of the GRB primary events and afterglows and their correlation. BeppoSAX offers the possibility to perform in a broad energy band ($2-700$ keV) spectral studies of the primary events and follow in the $0.1-10$ keV range the light curve and the spectrum of the GRB afterglow down to 10^{-13} erg/(cm^2 s).

We report here on some relevant results of an investigation, performed on a sample of GRBs observed with both the Wide Field Cameras (WFCs, $2-26$ keV, Jager et al. 1997) and the Gamma-ray Burst Monitor (GRBM, $40-700$ keV, Frontera et al. 1997; Feroci et al. 1997), devoted to study: (a) the evolution of the GRB spectral properties during the burst and their consistency with the synchrotron shock model (e.g., Katz 1994; Tavani 1996; Sari et al. 1998); (b) the correlation between energetics in GRBs and that in the associated X-ray afterglows; (c) the correlation between spectral properties of GRB events and fading law of the corresponding X-ray afterglows; (d) the hydrodynamical evolution of a fireball shock according to the model by Sari et al. (1998).

Send offprint requests to: frontera@tesre.bo.cnr.it

2. The GRB sample

Table 1 shows the GRBs in our sample with some basic information about the WFC and GRBM data. T_x and T_γ give the time duration of the primary event in the X-ray ($2-26$ keV) and γ–ray ($40-700$ keV) bands, respectively. Our sample includes almost all GRBs that triggered the GRBM until 25 April 1998, were detected with one of the two WFCs and were observed with the BeppoSAX NFIs. Peculiar GRBs are included in the sample, like GRB 970111, the afterglow emission of which was not firmly detected (Feroci et al. 1998).

The WFC and GRBM light curves of each GRB were divided into several temporal sections and, for each of them, the average spectrum in the $2-700$ keV range was fitted with a Band's model (Band et al. 1993) photoelectrically absorbed by the interstellar medium along the GRB direction.

3. Highlight results

Some relevant results of our study are given below. An exhaustive description of our investigation along with complete results will be published elsewhere (Frontera et al. 1999).

3.1. Test of the synchrotron shock model

The GRB spectra in our sample can be described by the Band's law (Band et al. 1993), that is a good approximation of the spectrum expected by a synchrotron shock model (Tavani 1996). We do not find low energy excesses that are not in agreement with the Band's law. The low energy photon index α, below the peak energy $E_{\rm p}$ of the $\nu F(\nu)$ spectrum, obtained from the spectra integrated over the rise time of the GRB in our sample, is below the limit photon index expected ($-2/3$) by the

Table 1. GRBs included in our sample with WFC and GRBM data

GRB	R.A. (2000)	DEC (2000)	Position WFC error radius	X–ray [(a)] peak flux	T_x (s)	γ–ray [(a)] peak flux	T_γ (s)	Counterparts
GRB 960720	$17^h30^m36^s$	$+49°05'48''$	$3'$	0.25	17	10	8	X?
GRB 970111	$15^h28^m15^s$	$+19°36'18''$	$3'$	1.4	60	56	43	X?
GRB 970228	$05^h01^m57^s$	$+11°46'24''$	$3'$	1.4	55	37	55	X, opt.
GRB 970402	$14^h50^m16^s$	$-69°19'54''$	$3'$	0.16	150	3.2	150	X
GRB 970508	$06^h53^m28^s$	$+69°17'24''$	$1.9'$	0.35	25	5.6	15	X, opt., radio
GRB 971214	$11^h56^m30^s$	$+65°12'00''$	$3.3'$	0.2	35	6.8	35	X, opt.
GRB 980329	$07^h02^m41^s$	$+38°50'42''$	$3'$	1.3	53	51	35	X, opt., radio
GRB 980425	$19^h34^m54^s$	$-52°49'54''$	$8'$	0.61	45	2.4	25	X, opt, radio?

[(a)] Peak fluxes in units of 10^{-7} erg cm^{-2} s^{-1}.

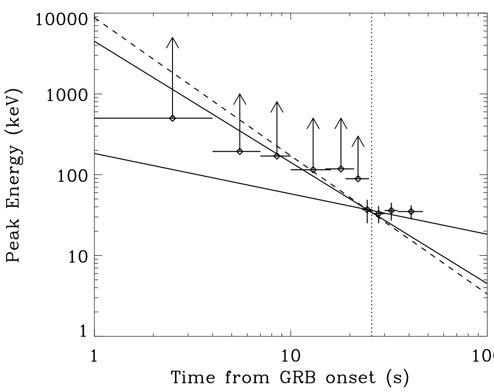

Fig. 1. Behaviour of the measured peak energy of the $\nu F(\nu)$ spectrum as a function of the time from the onset of GRB 970111. Also shown is the expected behaviour of E_p, normalized to the first value firmly established, in the case of an adiabatic (continuous line) and a radiative (dashed line) cooling of the shock, according to the model by Sari et al. (1998). The dashed verical line corresponds to the time at which the afterglow is expected to start (see text)

optically thin synchrotron shock model for 50% of the GRBs. For the other GRBs, this limit index is exceeded in the first few seconds from the GRB onset. In the case of GRB 970111, a higher low energy photon index is found for the entire GRB duration. From the high energy photon indices measured, we derive a spectral indices p of the energy distribution of the electrons accelerated in the shock ($N(E_e) \propto E_e^{-p}$) that generally increase with time. The greatest increase is observed in the case of GRB 970111.

3.2. Correlation between GRB emission and X-ray afterglow

By extrapolating the X-ray afterglow fading law ($F(t) \propto t^{-\delta}$) back to the time of the burst, we have already demonstrated that at least in two cases, GRB 970228 (Costa et al. 1997) and GRB 970508 (Piro et al. 1998), the expected $2-10$ keV flux is consistent with that measured in the same energy band during the GRB tail. For all GRBs in our sample with well detected X-ray afterglow emission, we find that the $2-10$ keV fluence of the GRB tail is consistent with that expected in the same energy band if the fluence is due to afterglow emission. The early afterglow appears to start at about 60% of the GRB duration.

3.3. Hydrodynamical evolution of a fireball shock

We find a continuous decrease with time of the peak energy E_p of the $\nu F(\nu)$ spectrum. At very early times from the GRB onset the decrease is faster than that expected in the case of a radiative or adiabatic cooling of an external shock (Sari et al. 1998). This fact could imply that the process that gives rise to the GRB or, at least, to the early phase of the GRB, is different from that that gives rise to the afterglow emission, as discussed by Sari (1997). For GRB 970111, at about 60% of the GRB duration (see dashed vertical line), when the afterglow is expected to start, a very slow decrease of E_p with time is observed (see Fig. 1). We find (see continuous line with lower slope) that the latter data points are consistent with a slow adiabatic cooling of an external shock of a fireball with the interstellar medium (Sari et al. 1998). For GRB 970508, combining the E_p values measured during the GRB event with that obtained by Galama et al. (1998) 12.1 days after the primary event, a transition from fast cooling to slow cooling is inferred. Assuming an adiabatic cooling, this transition is expected to occur at about 1000 s from the GRB onset. This time value is consistent with that (700 s) estimated by Galama et al. (1998).

Acknowledgements. This research is supported by the Italian Space Agency ASI.

References

Band D., Matteson J., Ford L., et al., 1993, ApJ 413, 281
Costa E., Frontera F., Heise J., et al., 1997, Nat 387, 783
Feroci M., Frontera F., Costa E., et al., 1997, Proc. SPIE 3114, 186
Feroci M., Antonelli L.A., Guainazzi M., et al., 1998, A&A 332, L29
Frontera F., Costa E., Dal Fiume D., et al., 1997, A&AS 122, 357
Frontera F., Amati L., Costa, et al., 1999 (in preparation)
Galama T., Wijers R.A.M., Bremer M., et al., 1998, ApJ 500, L97
Jager R., Mels W.A., Brinkman A., et al., 1997, A&AS 125, 557
Piro L., Amati L., Antonelli L.A., et al., A&A 331, L41
Sari R., 1997, ApJ 489, L37
Sari R., Piran T., Narayan R., 1998, ApJ 497, L17
Tavani M., 1996, ApJ 466, 768