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Letter to the Editor

Evidence for a late-time outburst of the X-ray afterglow of GB970508 from BeppoSAX

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Abstract. The $\gamma-$ray burst GB970508 was observed simultaneously by the Gamma Ray Burst Monitor (GRBM) and one of the X-ray Wide Field Cameras (WFC) aboard BeppoSAX. The latter provided a position within $1.9'$ radius. A series of follow-up observations with the Narrow Field Intruments (NFI) was then performed in a period from ~ 6 hours to 6 days after the main event. A previously unknown source, which we associate with the afterglow of the GRB, was discovered in the error box. We find that, after the initial burst, X-ray emission is still present and decays as $\sim t^{-1.1}$ up to $\sim 6 \times 10^4$ s. This is followed by a burst of activity with a duration $\sim 10^5$ s. The energy produced in this event is a substantial fraction of the total energy of the GRB, which means that the afterglow is not a remnant of the initial burst (the GRB) that fades away smoothly. Our results support the idea that the processes generating the GRB and its afterglow are the same.

Key words: Gamma rays: bursts $-$ X-rays: bursts

1. Introduction

The BeppoSAX[1] (Piro, Scarsi & Butler 1995, Boella et al. 1997a) observations of GB970228 (Costa et al. 1997a) opened a new era in the study of GRB's with the first discovery of an X-ray afterglow of GRB, followed by at least three well established similar detections in GB970402 (Piro et al. 1997a), GB970508 (Piro et al. 1997b) and then GB970828 by XTE/ASCA (Murakami et al. 1997). Other possible X-ray afterglow candidates include GB970111 (Feroci et al. 1997), GB970616 (Marshall et al. 1997), GB970815 (Greiner et al. 1997). In this paper, we present the BeppoSAX observations of GB970508. Its X-ray evolution is tracked from 1 to 10^6 s, i.e. from the initial burst to the afterglow. We compare it with that observed in other GRB's and discuss some of the implications on current models.

2. The observations

The GRBM (Costa et al. 1996) was triggered on May 8 1997 at 21:41:50 U.T. by a GRB, also observed by BATSE (Kouveliotou et al. 1997) and Ulysses. The event was simultaneously detected in one of the WFC (Jager et al., 1997). A first preliminary ($\sim 10'$) position was derived (Costa et al. 1997b) and used to program a follow-up observation with the NFI. Simultaneously this position (followed then by a refined $3'$ one (Heise et al., 1997) and the $50''$ derived from NFI (Piro et al. 1997b) were distributed to a network of observatories for follow-up observations in all wavelengths. This led to the identification of an optical transient just 4 hours after the burst (Bond,1997) and eventually to the spectroscopic observation that set the distance of the optical transient at $z > 0.83$ (Metzger et al. 1997).

The field was acquired by the NFI ~ 6 hours after the GRB. A previously unknown X-ray source, 1SAX J0653.8+7916 was detected in this observation (hereafter TOO1) by the MECS

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[1] BeppoSAX is a program of the Italian Space Agency (ASI) with participation of the Netherlands Agency for Aerospace Program (NIVR)

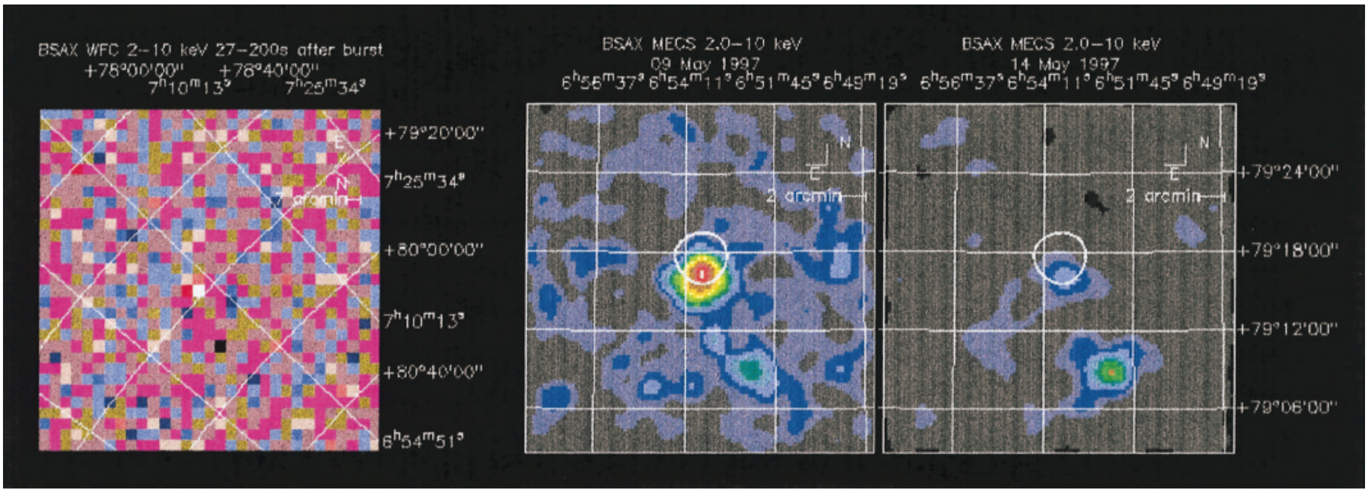

Fig. 1. Time sequence of images of the field of GB970508 observed by the WFC2 (left image, 27−200 s after the burst), MECS(2+3) on May 9 (TOO1, center image, 6 hours after the GRB), and MECS(2+3) on May 14 (TOO4, after 6 days). The WFC2 show the presence of the afterglow that was then detected by the LECS and MECS (1SAXJ0653.8+7916 visible in the 99% error circle of the WFC). Note the decrease in intensity between the two MECS observations, as compared to 1RXSJ0653.8+7916, the source in the lower right corner

(units 2 and 3) (Boella et al., 1997b) with F(2−10 keV)=$(0.7 \pm 0.07) \times 10^{-12}$erg cm^{-2} s^{-1} and the LECS (Parmar et al., 1997) with F(0.1−2 keV)=$(1.2 \pm 0.4) \times 10^{-12}$erg cm^{-2} s^{-1} at celestial coordinates (J2000) R.A.=6h53m46s.7, Decl.=$+79°16'02$" (estimated error radius of 50"), within the WFC error circle. This source was not detected in the ROSAT all sky survey (Voges, private communication). The image of the field is shown in Fig. 1 along with the refined WFC error region (radius $\sim 1.9'$, in 't Zand et al. 1997). The previously known ROSAT source 1RXSJ0653.8+7916, lying outside the WFC error box, was also detected.

Three other BeppoSAX observations (hereafter TOO2−4) were performed, the last took place $\sim$ 6 days after the burst. In all three observations we detected the source 1SAXJ0653.8+7916 at a position consistent with that of the first observation.

3. The association of 1SAXJ0653.8+7916 with GB970508

The probability of finding a serendipitous X-ray source in the WFC error box with a flux greater than that observed is $\sim 10^{-3}$ (e.g Cagnoni et al. 1997). However, this probability should be revised to consider the potential association of 1SAXJ0653.8+7916 to classes of sources which show similar properties. The very high value of X-ray emission compared to the optical ($\alpha_{ox} \sim 0.6$, where α_{ox} is the slope of the power law $F \sim E^{-\alpha_{ox}}$ connecting the optical to the 2 keV fluxes) is observed only in BL Lacs and emission line AGN (Maccacaro et al. 1980). The latter association is excluded by the absence of strong emission lines in the optical spectrum typical of AGN (Metzger et al. 1997). The observed values of $\alpha_{ox} \sim 0.6$ and $\alpha_{ro} \sim 0.3$ (radio from Frail et al. 1997) are the extreme of the range observed in X-ray selected BL Lacs (e.g. Padovani et al. 1997), so even this potential association is rather unlikely. Furthermore, on the basis of the logN−logS (Maccacaro et al. 1984), we find that the probability of a chance occurrence is $\sim 10^{-3}$(see also Castro-Tirado et al. 1997a). This number takes into account the number of searches in GRB error boxes - with an area comparable or less than that of the WFC - by BeppoSAX (5) and other X-ray satellites (9). Further support for the association of the transient with the GRB afterglow comes from the temporal behaviour observed in X-rays (next section) and other wavelenghts (e.g Djorgovski et al. 1997, Frail et al. 1997).

4. Time evolution from the GRB to the afterglow

GB970508 is a rather weak event, with a peak flux $f_\gamma \sim 3.4 \times 10^{-7}$erg cm^{-2} s^{-1} in the GRBM (40−700 keV) and $f(2-26\ \text{keV}) = (5.9 \pm 0.6) \times 10^{-8}$erg cm^{-2} s^{-1} in the WFC. In Fig. 2 we show the GRBM and WFC light curves of the event. The event lasted about 15 s in the GRBM and about 25 s in the WFC. The total fluence of the burst was $(1.8 \pm 0.3) \times 10^{-6}$erg cm^{-2} and $(0.7 \pm 0.1) \times 10^{-6}$erg cm^{-2} in the GRBM and WFC, respectively: about 40% of the burst energy emitted in the X-ray band. This fraction is substantially higher than that observed in other bursts: the value of $f_{X/\gamma} \sim 0.17$ of the peak fluxes is $\sim$ 5 times greater than that of GB970228 (Frontera et al. 1997), GB960720 (Piro et al. 1997c) and the average value of the GINGA sample (Yoshida et al.1989, Strohmayer et al. 1997).

Costa et al. (1997a) attributed the train of pulses observed in GB970228 40 s after the initial burst to the beginning of the afterglow (see also Frontera et al.1997). The light curves of GB970508 show a second prominent pulse in X-rays $\sim$ 10 s after the first one. This is substantially softer than the first pulse but it merges with the first pulse, so we cannot conclude whether it represents the beginning of the afterglow or not. However, at $t > 27$ s, faint residual activity emerges from a detailed analysis of the WFC image (Fig. 1). An analysis of the overall X-ray temporal behaviour supports the idea that this emission corre-

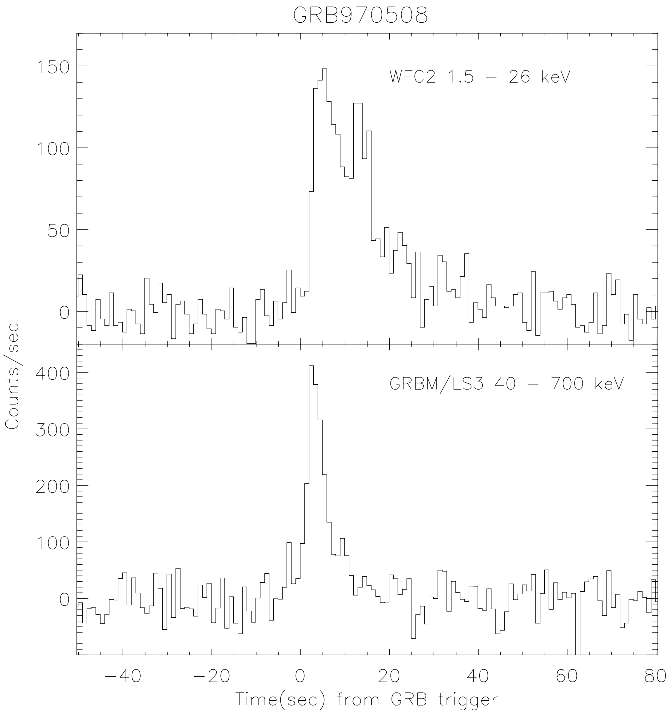

Fig. 2. Light curves of GB970508 in the GRBM (bottom) and WFC (top)

sponds to the afterglow (Fig. 3). The decreasing flux observed by the WFC in the 27−200 s period after the burst connects to the first data points of TOO1 with a power law $t^{-\delta}$ (where t is the time from the beginning of the GRB) with $\delta = 1.1 \pm 0.1$.

However, at $\sim 6 \times 10^4$ s, the flux increases in an outburst - on a time scale of $\sim 10^5$ s - with a time behaviour similar to that observed in the optical, followed by a sudden decrease observed in TOO4. The latter is caused by a spectral steepening, that we will describe in more detail in Piro et al. (1997d)

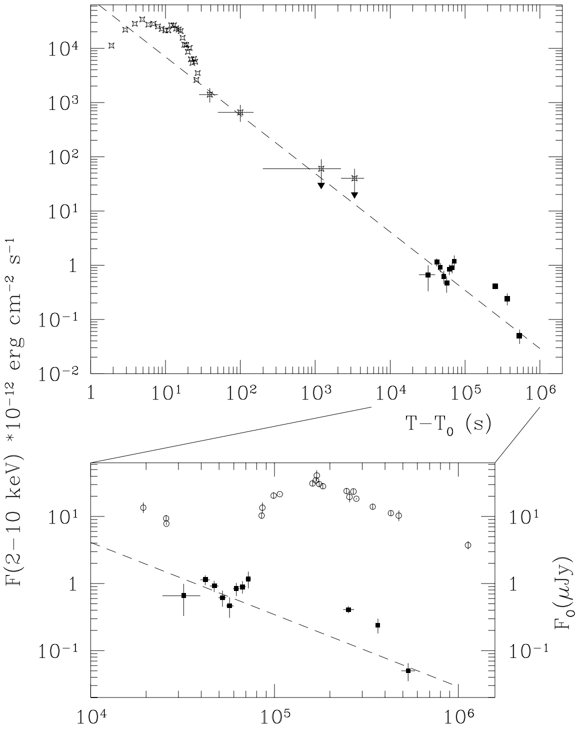

Fig. 3. Upper panel: X-ray light curve (2−10 keV) from the GRB to the afterglow (upper panel, starred=WFC, filled squares=NFI). The dashed line is the best fit power law to the WFC data (excluding the GRB) and the first part of TOO1 data stream, before the increase at 6×10^4 s. The lower panel is a blown-up that includes the optical behaviour of the source in the R band (open circles) from Galama et al. (1997), Castro-Tirado et al. (1997b), Chevalier & Ilovaisky (1997), Mignoli et al. (1997), Schaefer et al. (1997), Groot et al. (1997), Garcia et al. (1997), Kopylov et al. (1997a,b). The vertical right hand scale refers to the optical data.

5. Discussion and conclusions

The combination of the WFC sensitivity and fast follow-up with the NFI allowed to follow the evolution of the X-ray emission of the GRB from 1 to 10^6 s. We find that after the initial burst the X-ray emission detected with the WFC between 27 and 200 s, the two WFC upperllimits between 200 and 4×10^3 s and the NFI measurements between 2.5×10^4 and 6×10^4 s are well fitted by a $t^{-1.1}$ power law decay. The data are therefore consistent with a continuing afterglow emission, although a deviation from the power-law decay, during the $200 - 4 \times 10^3$ s time interval cannot be excluded. While this temporal behaviour is similar to that observed in GB970228 (Costa et al. 1997a), GB970402 (Piro et al. 1997a) and GB970828 (Murakami et al.1997), it is the first time that the afterglow was detected immediately after the primary event. However, the evolution after $6 \times 10^4 s$ deviates from this power law, being dominated by an outburst with a duration $\sim 10^5$ s. The energy released in the 2−10 keV range in the power law component of the afterglow integrated from 27s to 5.8×10^5 s corresponds to about 20% of the total X- and γ-ray energy of the GRB. This is comparable to the case of gb970228 (Costa et al. 1997a). The energy excess with respect to the power law during the burst event (from 6×10^4 s to 5.8×10^5 s), is $\sim 5\%$ of that of the GRB.

Therefore, not only the afterglow carries an energy comparable to that of the main event, but a significant fraction of this energy is released in an outburst taking place on a time scale $\sim 10^4$ times larger than that of the GRB. The overall evolution of the afterglow *and* the GRB could be then described by a power law on the top of which bursts of different time scales occur, in particular on $1 - 10$ s (the GRB proper) and on $\sim 10^5$ s. These results suggests that the same process is responsible for both the GRB *and* the afterglow. In the fireball shock scenario (e.g Mészáros & Rees 1997, Vietri 1997, Katz & Piran 1997), models in which both the GRB and the afterglow are produced by the same mechanism are therefore preferred. The increase of the bursting duration with time agrees with the general fireball scenario, where the timescales are primarily determined by the superluminal motion of a shell, whose Lorentz factor decreases very rapidly as the shell expands.

The optical turn up (Fig. 3, lower panel) appears to follow the X-ray burst with no substantial delay (lag $< 2 \times 10^4$ s), suggesting a same origin for the optical and X-ray events. It then appears unlikely that the optical turn up is produced by an energy dependent effect, as a shift of the break energy (Vietri 1997, Katz & Piran 1997).

The reason of the different evolution of GB970508 compared to GB970228 after the initial phase is not clear. It could be associated with the very soft primary event of GB970508 or with a different environment in which the fireball expands. This may also be the case of GB970111, for which there are indications of very faint afterglow activity (Feroci et al. 1997). It is however possible that similar bursts happened in the other GRB's but have been missed due to the sparse sampling of the light curves.

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