Astron. Astrophys. 332, L29–L32 (1998)

ASTRONOMY AND ASTROPHYSICS

LETTER

Letter to the Editor

BeppoSAX follow-up search for the X-ray afterglow of GRB970111

M. Feroci[1], L.A. Antonelli[2], M. Guainazzi[2], J.M. Muller[2,3], E. Costa[1], L. Piro[1], J. Heise[3], J.J.M. in 't Zand[3], F. Frontera[4,5], D. Dal Fiume[4], L. Nicastro[4], M. Orlandini[4], E. Palazzi[4], G. Zavattini[5], P. Giommi[2], A.N. Parmar[6], A. Owens[6], A.J. Castro-Tirado[7], M.C. Maccarone[8], and R.C. Butler[9]

[1] Istituto di Astrofisica Spaziale, CNR, Via Fosso del Cavaliere, I-00133 Roma, Italy
[2] BeppoSAX Scientific Data Center, Via Corcolle 19, I-00131 Roma, Italy
[3] Space Research Organization in the Netherlands, Sorbonnelaan 2, 3584 CA, Utrecht, The Netherlands
[4] Istituto Tecnologie e Studio Radiazioni Extraterrestri, CNR, Via Gobetti 101, I-40129 Bologna, Italy
[5] Dipartimento di Fisica, Università di Ferrara, Via Paradiso 11, I-44100 Ferrara, Italy
[6] Astrophysics Division, Space Science Department of ESA, ESTEC, P.O. Box 299, 2200 AG, Noordwijk, The Netherlands
[7] Laboratorio de Astrofisica Espacial y Fisica Fundamental, INTA, Madrid, Spain
[8] Istituto Fisica Cosmica e Applicazioni Informatica, CNR, Via U. La Malfa 153, I-90146 Palermo, Italy
[9] Agenzia Spaziale Italiana, Viale Regina Margherita 202, I-00162 Roma, Italy

Received 6 January 1998 / Accepted 3 March 1998

Abstract. The BeppoSAX satellite has recently opened a new way towards the solution of the long standing gamma-ray bursts' (GRBs) enigma, providing accurate coordinates few hours after the event thus allowing for multiwavelength follow-up observational campaigns.

The BeppoSAX Narrow Field Instruments observed the region of sky containing GRB970111 16 hours after the burst. In contrast to other GRBs observed by BeppoSAX no bright afterglow was unambiguously observed. A faint source (1SAXJ1528.1+1937) is detected in a position consistent with the BeppoSAX Wide Field Camera position, but unconsistent with the IPN annulus. Whether 1SAXJ1528.1+1937 is associated with GRB970111 or not, the X-ray intensity of the afterglow is significantly lower than expected, based on the properties of the other BeppoSAX GRB afterglows. Given that GRB970111 is one of the brightest GRBs observed, this implies that there is no obvious relation between the GRB gamma-ray peak flux and the intensity of the X-ray afterglow.

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

1. Introduction

The comprehension of the nature of the Gamma-Ray Bursts (GRBs) is a long-standing problem of a world-wide scientific community since the announcement of their discovery (Klebesadel et al. 1973). Many observational (Fishman & Meegan 1995) and theoretical (Lamb 1995; Paczynski 1995) efforts did not succeed in understanding the origin of GRBs. The launch of the BeppoSAX satellite (Boella et al. 1997a) revolutionized the field, opening a new observational window soon after the GRB event. Due to its Gamma Ray Burst Monitor (GRBM, 40–700 keV, Frontera et al. 1997a; Feroci et al. 1997a) and its Wide Field Cameras (WFCs, 2–26 keV, Jager et al. 1997) this satellite is capable of detecting GRBs in the gamma-ray band and accurately localizing them in X-rays through a coded mask proportional counter.

Five GRBs, amongst those simultaneously detected by the GRBM and the WFCs, were promptly analyzed, allowing multiwavelength follow-up observational campaigns. The first result is the BeppoSAX discovery of the X-ray afterglow of GRB970228 (Costa et al. 1997, Costa et al. 1997a) and the discovery of a related optical transient by ground-based telescopes (van Paradijs et al. 1997). Further results have been achieved with the detection of the X-ray afterglows of GRB970402 (Feroci et al. 1997b, Piro et al. 1997a), GRB970508 (Costa et al. 1997c, Piro et al. 1997b) and GRB971214 (Heise et al. 1997a, Antonelli et al. 1997). From GRB970508 an indication of an extragalactic origin has been derived through the detection of an optical transient (Bond, 1997; Djorgovski et al. 1997) and the measurement of its optical spectrum (Metzger et al. 1997), providing a lower limit of 0.835 for the redshift of the possible GRB optical afterglow.

One of the most intriguing mysteries of GRB emitters is possibly solved, but the overall picture is far from clear. In fact, out of the five events for which BeppoSAX performed rapid follow up searches of a X-ray counterpart, one (GRB970111) has given a result that is significantly different from the other four. The celestial location of GRB970111 was observed by BeppoSAX just 16 hours after the GRB event, and no unambiguous evidence for an X-ray afterglow was found. A new faint source (1SAX J1528.1+1937) was detected at a flux level that is

Send offprint requests to: feroci@saturn.ias.rm.cnr.it

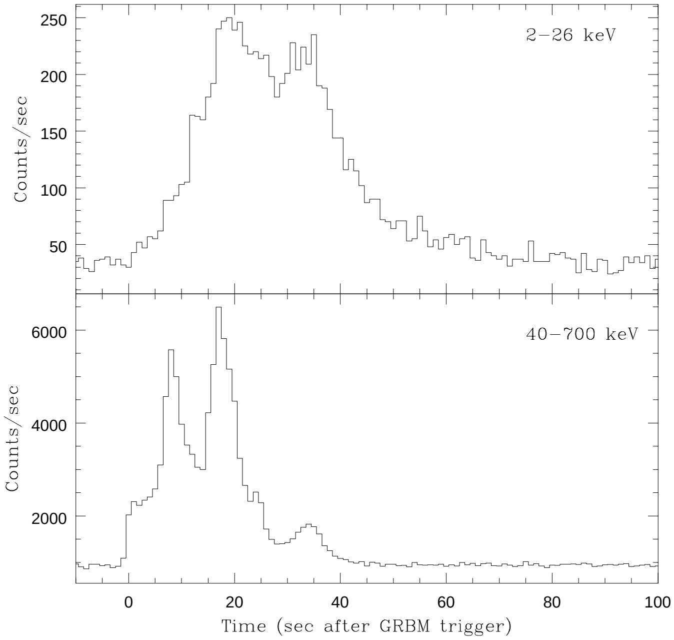

Fig. 1. BeppoSAX GRBM (40–700 keV) and WFC (2–26 keV) light curves of GRB970111

much lower than that expected on the basis of the properties of the other GRBs later observed by BeppoSAX. Here we present this detection, discuss its association with GRB970111 and the diversity from the other four BeppoSAX GRBs.

2. GRBM and WFC detection

On 1997 11 January, 09:43:59.99 UT the GRBM onboard BeppoSAX was triggered by an intense gamma-ray burst, showing a multipeak structure and lasting ~43 s (Costa et al. 1997b). The peak intensity was $(3.9 \pm 0.3) \times 10^{-6}$ erg cm^{-2} s^{-1} in the energy range 40–700 keV. This GRB was also detected by the WFC unit 2, with a similar time profile structure but a longer duration (see Fig. 1). The 2–10 keV peak flux was $(4.1 \pm 0.7) \times 10^{-8}$ erg cm^{-2} s^{-1}. The fluence of the event in 40–700 keV was $(4.14 \pm 0.31) \times 10^{-5}$ erg cm^{-2} while in 2–10 keV it was $(1.6 \pm 0.1) \times 10^{-6}$ erg cm^{-2}. In Fig. 1 the gamma-ray (GRBM) and X-ray (WFC) light curves of the event are shown. Given that GRB970111 was one of the earliest X-ray transients detected in the WFC at the Quick Look Analysis, the position of the event was promptly distributed with a $10'$ error radius (Costa et al. 1997b), somewhat worse than that obtainable from the instrinsic capabilities of the WFCs. After about 20 days a revised error box of the GRB970111 location with a $3'$ error radius was produced, centred at a position $4'.2$ apart from the centroid of the previous one (in 't Zand et al. 1997). The new position was R.A. = $15^{\rm h}28^{\rm m}15^{\rm s}$ and Decl.= +19°36$'$.3 (equinox 2000.0). Very recently the WFC hardware team again improved the instrument calibration, further reducing the error box area to an irregular circle of $1'.8$ radius (99% confidence) (Heise et al. 1997), centred at R.A. = $15^{\rm h}28^{\rm m}11^{\rm s}$ and Decl.=+19°35$'$.9. This new region is contained within the previous one, but is centred about $1'$ apart.

The Interplanetary Network used the delay in the GRB arrival times between the interplanetary Ulysses mission and the ComptonGRO and BeppoSAX near-Earth satellites (Galama et al. 1997) to obtain a narrow strip of possible arrival directions in the sky. This allows the reduction of the GRB error box to a portion of the WFC error circle.

Table 1. 2–10 keV flux variation of 1SAX J1528.1+1937. The start of the elapsed time is the GRB970111 trigger time

Elapsed Time (s)	Count rate (10^{-3} c s^{-1})	Flux(2–10 keV) (10^{-13} erg cm^{-2} s^{-1})
59400–79700	(2.8 ± 1.2)	1.9 ± 0.8
79700–109940	(2.5 ± 0.9)	1.7 ± 0.6
109940–162530	(0.8 ± 0.6)	0.5 ± 0.4

3. BeppoSAX detection of 1SAX J1528.1+1937

The earliest ($10'$) error box of GRB970111 was imaged with the narrow field X-ray instruments (NFI) onboard BeppoSAX: the Low Energy Concentrator Spectrometer (LECS, 0.1–10 keV, Parmar et al. 1997) and the three Medium Energy Concentrator Spectrometers (MECS, 2–10 keV, Boella et al. 1997b). This Target of Opportunity observation was started 59,400 s after the GRBM trigger time, from 12 January 02:14 to 13 January 06:01 UT, for a total net exposure time of 52,139 s with the MECS and 11,594 s with the LECS (the latter being operated only during satellite night-time).

At the time when the NFI observation was performed the WFC improved error box was not available and therefore any source included in the error box region was a potential counterpart for the GRB970111. Two relatively bright X-ray sources were detected in the $10'$ error box by the BeppoSAX/NFI (Butler et al. 1997), resolved into three sources in the ROSAT All Sky Survey (Voges et al. 1997). One of them, RXJ152845+1944.5, was also inside the early intersection of the WFC error box and the IPN error strip (Hurley et al. 1997). A peculiar radio source was detected with the VLA (Frail et al. 1997) in a position coincident with this X-ray source. The final WFC error box, however, excludes this source as possible counterpart to GRB970111. The latest WFC error box only includes an unknown X-ray source, 1SAX J1528.1+1937. The false colour image obtained from the MECS is shown in Fig. 2. The image shows the WFC error box, intersected by the IPN annulus, together with the MECS source error box.

The data analysis of the MECS image, performed with *Ximage* (Giommi et al. 1991), gives the position of the new source at RA=$15^{\rm h}28^{\rm m}09^{\rm s}.2$ and Decl.=+19°37$'$02", with a 60" error radius (90% confidence level). The probability that this detection is due to a background fluctuation is of the order of 10^{-6}. The count rate of 1SAX J1528.1+1937 is $(1.8 \pm 0.5) \times 10^{-3}$ counts s^{-1} in the MECS (2–10 keV) and $(7 \pm 3) \times 10^{-4}$ counts s^{-1} in the LECS (0.1–2 keV). Taking into

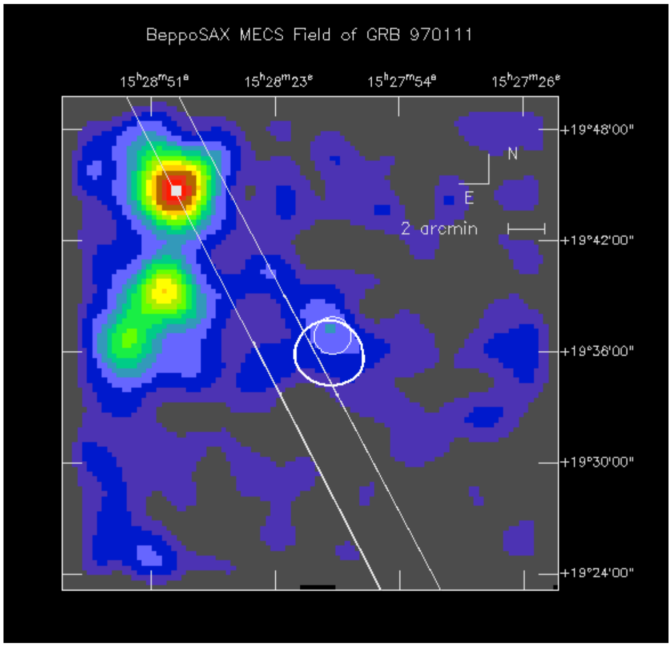

Fig. 2. False colour image of the MECS observation of the GRB970111. The WFC error box is shown as an irregular circle containing the MECS error circle of the X-ray source 1SAX J1528.1+1937. The latter lies outside the region of the WFC error box intersected by the IPN annulus. On the top left the source RXJ152845+1944.5 is clearly detected

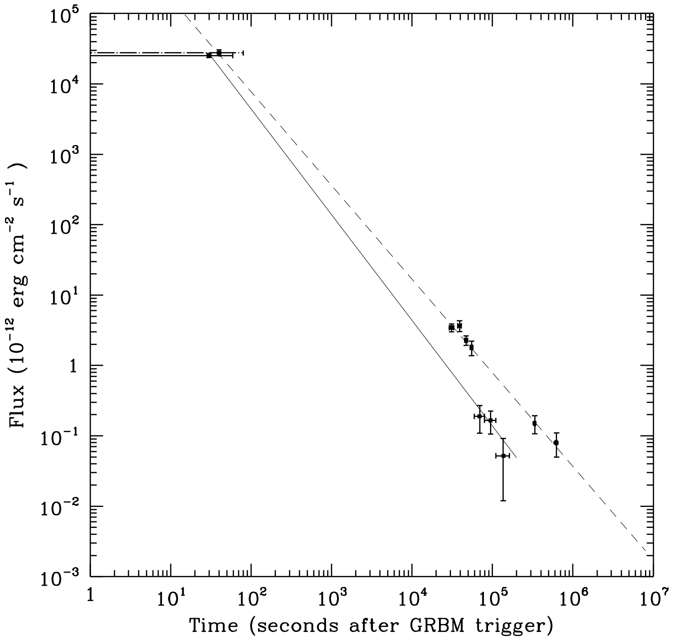

Fig. 3. X-ray (2–10 keV) decay law of the candidate counterpart of GRB970111, compared to GRB970228. The dot-dashed and the solid horizontal lines are the mean X-ray flux for GRB970228 and GRB970111, respectively. The inclined dashed line is the decay law suggested by Costa et al. (1997a) for GRB970228. The inclined solid line shows the power-law index, 1.5, needed for connecting the WFC GRB970111 mean flux and the 1SAXJ 1528.1+1937 flux

account the vignetting correction for the off-axis position, and assuming a Crab-like energy spectrum, the above count rates correspond to fluxes of $(1.2 \pm 0.3) \times 10^{-13}$ erg cm^{-2} s^{-1} in the 2–10 keV energy range and $(8 \pm 4) \times 10^{-14}$ erg cm^{-2} s^{-1} in the 0.1–2 keV energy range.

The MECS error box of the new source 1SAX J1528.1+1937 is almost entirely contained within the WFC error box of GRB970111. Considering the 99% confidence IPN annulus the source 1SAX J1528.1+1937 is at a position only marginally consistent with GRB970111. Therefore, if we use the reduced WFC-IPN error box, the upper limit to the 2–10 keV flux of 1.6×10^{-13} erg cm^{-2} s^{-1} (3 σ).

In the context of the possible association of 1SAX J1528.1+1937 with GRB970111 it is interesting to note that dividing the NFI observation into three time intervals consisting of the first 10 ks, the following 15 ks, and the last 26 ks of exposure time, gives the count rates listed in Table 1. Even if the count rate is rather low, considering the combination of the temporal and positional coincidences and the indication of a decaying behavior, then the possibility of a random occurrence of 1SAX J1528.1+1937 in the error box of GRB970111 is lower than the $\sim$3% derived from the source statistics of the ASCA GIS (Cagnoni et al. 1997).

4. Discussion and conclusions

The BeppoSAX follow-up observation of the error box of GRB970111 was the first prompt follow-up observation of a GRB ever performed by an X-ray satellite. Before BeppoSAX the time-scale of a possible X-ray emission from GRB remnants was completely unknown. This first basically non-detection, therefore, could only be interpreted as an upper limit to the time-scale of the decline of an X-ray afterglow or to its flux. Now, with the detection of the X-ray afterglows of GRB970228, GRB970402, GRB970508 and GRB971214, BeppoSAX has set up a new scenario in which GRB970111 seems misplaced. Also the detection of the X-ray afterglow of a GRB (GRB970828, Remillard et al. 1997; Murakami et al. 1997) by the RossiXTE and the ASCA satellites supports the general framework for the GRBs' afterglow built by BeppoSAX.

GRB970228, GRB970402 and GRB970828 showed a similar behavior, with a fading X-ray counterpart continuously decaying from the GRB main emission into the afterglow following an approximate $t^{-1.3}$ law. In the case of GRB970228, the spectral analysis (Frontera et al. 1997b) confirms the continuity between the latest GRB emission and the X-ray counterpart detected after few hours. This temporal behaviour could be explained in the framework of the fireball model (Cavallo & Rees 1978; Rees & Meszaros 1992) as a highly radiative expansion of a relativistic shell. GRB970508 has shown a X-ray counterpart whose decay is more complicated than the above three. The above model could still account for this different behavior, but it needs to invoke a non-uniform surrounding medium, with a density scaling as r^{-2} (Vietri 1997).

Whether 1SAX J1528.1+1937 is related to GRB970111 or not, this gamma-ray burst had a much faster decay than observed for any of the others. In order to make this clear, we compare a hypothetic power-law decay of GRB970111 with the "typical" power-law decay of GRB970228 reported in Costa et al. (1997a). Therefore, in Fig. 3 we assume that the new X-ray source is associated with the GRB and impose a power-law decay of the afterglow starting from the WFC mean flux at a time centred on the GRB X-rays duration. The needed power-law index is -1.5. Alternatively, assuming that 1SAX J1528.1+1937 is not related to GRB970111 we can derive a lower limit to the power-law index by using the upper limit of the MECS flux in the region of sky defined by the error box, to obtain a value very similar to the 1.5 value given above.

Trying to extract GRB970111 from the group as an intrinsically different event, we note that its gamma-ray fluence is about more than three times larger than the largest of the other three. On the other hand, even if this GRB is of the "No High Eenergy" type (that is, it shows only weak emission above 300 keV, Pendleton et al. 1997), the ratio between the X-ray (2–10 keV) and gamma-ray (40–700 keV) fluences is about 4%, to be compared to 20% (2–10 keV) for GRB970228 (Frontera et al. 1997b), 5% (2–10 keV) for GRB970402 (Nicastro et al. 1997) and 40% (2–26 keV) for GRB970508 (Piro et al. 1997b). GRB970111 appears therefore as the one (together with the April event) with the less efficient low X-rays mechanism for energy release. Furthermore, no optical source was found in the WFC error box changing its intensity more than 0.5 magnitudes at a level of B=23 and R=22.6 from about 19 hours to about one month later (Castro-Tirado et al. 1997; Gorosabel et al. 1998). A radio search at 1.4 GHz (Frail et al. 1997) and at millimetric wavelength (Smith et al. 1997) did not find a counterpart to 1SAXJ1528.1+1937. These results support the idea that the optical, radio and millimetric channels are unefficient as well. Since GRB970111 was one of the brightest events ever detected in gamma-rays, one may conclude that its gamma-ray channel was efficient enough to dissipate most of the energy generated in the burst.

Alternative interpretations of the lack of X/optical/radio afterglow of the GRB970111 may be either a very rapidly evolving afterglow, with a decay law faster than observed in the other BeppoSAX GRB afterglows, or the absence of an afterglow source. The former hypothesis would be in agreement with the model by Tavani (1997) of a decay behavior represented by a power law with index $-21/8$ due to the observation in a fixed energy band (2–10 keV) of a synchrotron emission spectrum with a rapidly evolving critical frequency. Alternatively, the latter situation could be due, as an example, to the scenario in which the event that caused the GRB occurred in a region in which the interstellar medium density is low enough (perhaps the external regions of a host galaxy) to justify the absence of an external shock, possibly responsible for the afterglow emission in the other cases (Katz & Piran 1997).

Acknowledgements. This research is supported by the Italian Space Agency (ASI). All authors warmly thank the extraordinary teams of the BeppoSAX Scientific Operation Center and Operation Control Center for their enthusiastic support to the GRB program.

References

Antonelli, A., Butler, C., et al. 1997, IAU Circ. n.6792
Boella, G., Butler, C., et al. 1997a, A&ASS, 122, 299
Boella, G., Chiappetti, L., et al. 1997b, A&ASS, 122, 327
Bond, H. 1997, IAU Circ. n.6654
Butler, C., Piro, L., et al. 1997, IAU Circ. n.6539
Cagnoni, I., Della Ceca, R., Maccacaro, T., 1998, ApJ, 493, 54
Castro-Tirado, A., Gorosabel, J., et al. 1997, IAU Circ. n.6598
Cavallo, G. & Rees, M.J., 1978, MNRAS, 183, 359
Costa, E., Feroci, M., et al. 1997, IAU Circ. n.6572
Costa, E., Frontera, F., et al. 1997a, Nat, 387, 783
Costa, E., Feroci, M., et al. 1997b, IAU Circ. n.6533
Costa, E., Feroci, M., et al. 1997c, IAU Circ. n.6649
Djorgovski, G., Metzger, M., et al. 1997, Nat, 387, 876
Feroci, M., Frontera, F., et al. 1997a, Proc. SPIE 3114, 186
Feroci, M., Costa, E., et al. 1997b, IAU Circ. n.6610
Fishman, G.J. & Meegan, C.A., 1997, ARA&A, 33, 415
Frail, D., Kulkarni, S., et al. 1997, IAU Circ. n.6545
Frail, D., Kulkarni, S., et al. 1997b, ApJ, 483, L91
Frontera, F., Costa, E., et al. 1997a, A&AS, 122, 357
Frontera, F., Costa, E., et al. 1997b, ApJ, 493, L67
Galama, T., Groot, P., et al. 1997, ApJ, 486, L5
Giommi, P., Angelini, L., et al. 1991, ASP Conf.Ser., 25, 100
Gorosabel, J., Castro-Tirado, A., et al. 1997, A&A, submitted
Heise, J., in 't Zand, J., et al. 1997a, IAU Circ. n.6787
Heise J., in 't Zand J., et al. 1997b, Proc. 4^{th} Huntsville Symp. on GRBs.
Hurley, K., Kouveliotou, C., Fishman, G., et al. 1997, IAU Circ. n.6545
in 't Zand, J., Heise, J., et al. 1997, IAU Circ. n.6569
Jager, R., Mels, W., et al. 1997, A&ASS, 125, 557
Katz, J.I. & Piran, T., 1997, ApJ, 490, 772
Klebesadel, R., Strong, I., Olson, R., 1973, ApJ, 182, L85
Lamb, D.Q. 1995, Publ. Astron. Soc. Pac., 107, 1152
Metzger, M., Djorgovski, G., et al. 1997, Nat, 387, 878
Murakami, T., Ueda, Y., et al. 1997, IAU Circ. n.6732
Nicastro, L. et al. 1997, in preparation
Paczynski, B. 1995, Publ. Astron. Soc. Pac., 107, 1167
Parmar, A., Martin, D., et al. 1997, A&ASS, 122, 309
Pendleton, G., Paciesas, W., et al. 1997, ApJ, 489, 175
Piro, L., Feroci, M., et al. 1997a, IAU Circ. n.6617
Piro, L., Amati, L., et al. 1997b, A&A, 331, L41
Rees, M.J., & Meszaros, P., 1992, MNRAS, 258, 41P
Remillard, R., Wood, A., Smith, D., Levine, A., IAU Circ. n.6726
Smith, I., Gruendl, R., Liang, E., Lo, K.Y., 1997, ApJ, 487, L5
Tavani, M., 1997, ApJ, 483, L87
van Paradijs, J., Groot, P., et al. 1997, Nat, 386, 686
Vietri, M., 1997, ApJ, 488, L105
Voges, W., Boller, T., 1997, IAU Circ. n.6539