Rapid ROSAT Observations of small Gamma-Ray Burst Error Boxes

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Abstract. I summarize the use of the ROSAT satellite over the last months for the investigation of well localized GRB error boxes. In particular, I report about the attempts for and results of quick follow-up observations (including the GRBs localized with BeppoSAX and RXTE) with ROSAT with its capability to achieve 10″ locations of X-ray afterglow sources.

INTRODUCTION

The discovery of X-ray afterglow emission with the narrow-field instruments of the BeppoSAX satellite (Costa et al. 1997) has given a dramatic boost to both, observations and theoretical investigations of gamma-ray bursts (GRBs) over the last few months. In particular, this finding has triggered a wealth of rapid follow-up observations in the X-ray, optical, infrared and radio bands. This has even lead to the development of a strategy of localizing the X-ray afterglow of strong GRBs with non-imaging X-ray instruments (scanning with the PCA onboard RXTE). Also, a procedure has been set up to recognize when individual dwells of the RXTE all-sky monitor cover BATSE burst locations and to derive arcmin size locations within a few hours (Smith et al. 1998).

X-ray follow up observations are primarily performed with the ASCA and ROSAT satellites. While ASCA's unique strengths are the very rapid response time (1–2 days) and the high spectral resolution of its X-ray CCD camera (Murakami et al. 1998), ROSAT can provide arcsec positioning and, due to its superb sensitivity, a rather long lever arm for studying the X-ray intensity decay up to 14 days after a GRB. Here I sumarize some results which have been obtained over the last months with rapid ROSAT follow-up observations of well localized GRB error boxes. Other areas of GRB research with ROSAT can be found elsewhere, such as the investigation of small IPN error boxes using the ROSAT all-sky survey data in Boër et al. (1994), a summary of all ROSAT pointings on GRB error boxes and a correlation of GRB locations with serendipituous ROSAT pointings in Greiner (1997).

TABLE 1. ROSAT target-of-opportunity observations (TOOs) towards GRB locations

GRB	Exposure (sec)	Detector[a)]	Date	Delay	$N_X^{b)}$	Ref.[c)]
920501	2784	P	May 19–20, 1992	18 days	1	1
920711	2432	H	Feb. 20–21, 1993	28 weeks	0	2, 7
930704/940301	3150/1385	P	Apr. 1, 1994	4 weeks	25	3
960720	6960	H	Aug. 30–31, 1996	6 weeks	1	4, 5
960720	2791	H	Jan. 14–17, 1997	24 weeks	1	7
961027-29	2065/2499	P	Feb. 24–28, 1997	13 weeks	54	7
970111	1198	H	Jan. 16, 1997	5 days	0	6
970111	777	P	Feb. 18, 1997	5 weeks	0	7
970228	34280	H	Mar. 10–13, 1997	11–14 days	1/A	8
970616	21950	H	Jun. 23–25, 1997	7–9 days	2	9
970815	17115	H	Aug. 20–22, 1997	5–7 days	1/A	10
970828	61270	H	Sep. 3–5, 1997	6–8 days	1/A	11
971024	≈15000	H	Oct. 30, 1997	6 days		12
SGR 1806–20	1416	P	Oct. 9–10, 1993	12 days (1hr)	0	7
SGR 1814–14	≈10000	H	Sep. 25–27, 1997	13–15 days		12

[a)] P and H denote PSPC and HRI, respectively.
[b)] Numbers of X-ray sources within the GRB error box; A marks afterglow detections.
[c)] (1) Hurley et al.(1996), (2) PI: Hurley, (3) Greiner et al. (1997a), (4) Greiner et al. (1996b), (5) Greiner & Heise (1997) (6) Frontera et al. (1997a), (7) Greiner (unpubl.), (8) Frontera et al. (1997b), (9) Greiner et al. (1997b), (10) Greiner (1997b), (11) Greiner et al. (1997c), (12) data not yet available during writing.

RAPID ROSAT FOLLOW-UP OBSERVATIONS

Motivated by the occurrence of a few very long lasting GRBs and by the detection of distinct spectral softening over the burst duration several attempts have been made in the past to observe well-localized GRBs with ROSAT as quick as possible after the GRB event in the hope to find the "smoking gun". To this end, the GRB had to be localized accurately (to fit the field of view) and quickly, and the GRB location had to be within the ROSAT observing window (≈30% of the sky at any moment). In retrospective, these ROSAT observations were done not quick enough and/or with too short exposure times.

Beginning with GRB 970228 and the establishment of the approximate 1/t X-ray intensity decay law, ROSAT observations were sensitive enough to detect the X-ray afterglow of (some) GRBs. Since then, every GRB with a location inside the ROSAT viewing zone has been observed with ROSAT as quick as possible. We note, that GRBs 970402 and 970508 were not observable for ROSAT due to solar angle constraints. In several cases, even a second follow-up observation has been performed to allow a variability check of the detected X-ray sources. Tab. 1 lists the GRBs which have been observed as TOO together with the time delay of the ROSAT observation.

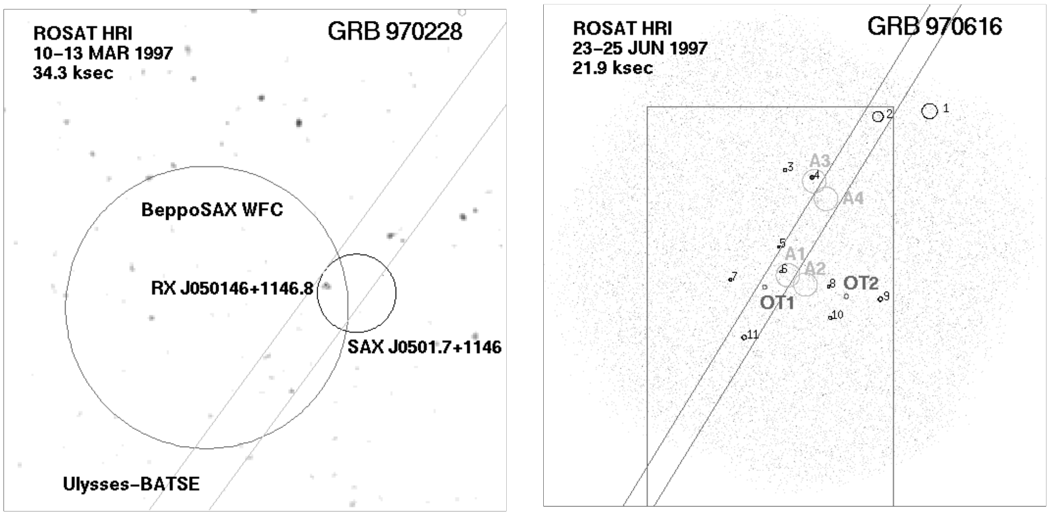

FIGURE 1. Left: Central 8′ part of the HRI FOV of the ROSAT observation of GRB 970228. The only source above 3σ is RX J050146+1146.8. The large circle shows the 3σ WFC error circle of GRB 970228, the small circle is the $\approx 1'$ position of the fading source SAX J0501.7+1146 (BSAX NFI pointings) and the two straight lines mark the triangulation arc derived from the BATSE/Ulysses timings (Hurley et al. 1997a, Cline et al 1997). (Adopted from Frontera et al. 1997c) **Right:** Image of the ROSAT HRI observation of GRB 970616: The large square denotes the RXTE error box, the straight lines are the Ulysses/BATSE triangulation arc (Hurley et al. 1997b), the enumerated circles denote the ROSAT X-ray sources (Greiner et al. 1997b), the circles marked with A1–A4 are the 4 ASCA X-ray sources detected 4 days after the GRB (Murakami et al.1997a) and OT1/OT2 denote the two variable optical objects reported (Galama et al. 1997, Udalski 1997). Colour versions of these images are available at http://www.aip.de:8080/~jcg/grbgen.html.

GRBs 920501 and 960720: One X-ray source was found in each of the two GRBs 920501 and 960720. In both cases there is no strong evidence that these X-ray sources are related to the GRB. For GRB 960720 the X-ray intensity during a second observation in Jan. 1997 is about a factor 2 higher than 6 weeks after the GRB. This supports the identification with the (presumably unrelated) variable radio source QSO 1729+491 (Greiner & Heise 1997).
GRB 970228: The last glimpse of the X-ray afterglow of GRB 970228 was captured with ROSAT (Fig. 1, left) at 11–14 days after the burst. Its position with an error radius of 10″ is well within the combined WFC/IPN error box and coincides within 2″ with the optical transient (Paradijs et al. 1997). The measured X-ray count rate during the ROSAT observation is consistent with an X-ray intensity decay law of $t^{-1.25\pm0.15}$ (Frontera et al. 1997c).
GRB 970616: For GRB 970616 (Fig. 1, right) three X-ray sources have been found with ROSAT in the RXTE/IPN box, one of which (R.A. = $01^{h}18^{m}50\overset{s}{.}3$, Decl. = $-05°25'58''$) coincides with one of the 4 X-ray sources found with ASCA (Murakami et al. 1997a). The unabsorbed ROSAT flux (using a power law model with photon index 2 and the galactic absorbing column N_{H} =

4×10^{20} cm^{-2}) is 1.4×10^{-14} erg/cm^2/s in the 0.5–2 keV range, i.e. a factor 5 lower than the flux measured by ASCA on June 20/21 (using the same model assumptions and energy range). The 3σ upper limit of the flux at the position of the ASCA source A4 is a factor 7 lower than that of the ASCA detection. With two fading X-ray sources within the RXTE/IPN error box an association to the GRB remains open.

GRB 970815: One faint X-ray source is detected with ROSAT at R.A. = $16^{\rm h}08^{\rm m}47\overset{\rm s}{.}7$, Decl. = $+81°31'53''$ (equinox 2000.0), which just falls on the border of the RXTE error box (Greiner 1997b). Using a power-law model with photon index 2 and the galactic absorbing column $N_{\rm H}=4.7\times10^{20}$ cm^{-2}, the observed count rate of 0.00073±0.00025 cts/s corresponds to an unabsorbed ROSAT flux (0.1–2.4 keV) of 5×10^{-14} erg/cm^2/s. This flux level is consistent with a t^{-1} flux decay, suggesting that it may be the afterglow of GRB 970815.

GRB 970828: One X-ray source, located at R.A. = $18^{\rm h}08^{\rm m}31\overset{\rm s}{.}7$, Decl. = $+59°18'50''$ (equinox 2000.0; uncertainty $\pm10''$; RX J1808.5+5918), is detected in the longest ever ROSAT TOO pointing within the RXTE/IPN error box and coincides with the X-ray source detected with ASCA 5 days earlier (Murakami et al. 1997b). Using a power-law model with photon index 2 and the galactic column $N_{\rm H} = 3.7\times10^{20}$ cm^{-2}, the observed countrate of $(4\pm1)\times10^{-4}$ cts/s corresponds to an unabsorbed ROSAT flux (0.1–2.4 keV) of 2.5×10^{-14} erg/cm^2/s, consistent with a power-law decay.

Density of background (foreground?) X-ray sources: At the low sensitivity limits reached during the rather long pointings, the number density of X-ray sources is already remarkably high. From the results of many deep pointed observations and combined with the particularly deep Lockman hole observations of ROSAT an improved log N–log S distribution of X-ray sources has been derived (Hasinger 1997) which gives 100–700 X-ray sources per 1 □° at the level of 10^{-14}...10^{-15} erg/cm^2/s. Thus, the probability for a chance coincidence of a quiescent, soft X-ray source with a GRB location is 25%–100% for a 10 arcmin^2 size error box.

CONCLUSION

The search for X-ray counterparts (afterglows) in small error boxes remained inconclusive in the past as long as the observation was performed more than 2 weeks after the GRB. Only the $10''$ localization with ROSAT (Frontera et al. 1997c) of the fading X-ray source within the GRB 970228 error box (Costa et al.1997) has allowed to unequivocally associate it with the optical transient (Paradijs et al. 1997), the properties of which (location within extended fuzz) have been used to conclude the cosmological distance scale of GRBs.

The X-ray afterglows of two further GRBs have been localized with ROSAT, but despite the $10''$ accuracy no optical transients could be identified even several magnitudes fainter than the GRB 970228 OT brightness. While this

has been interpreted as a consequence of absorption inside the GRB host site (discussion between B. Paczynski and J. van Paradijs), it emphasizes the need for further GRB/afterglow positions at the arcsec level in order to avoid ambiguities due to background sources (in the X-ray as well as optical bands).
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