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ROSAT DETECTION AND HIGH-PRECISION LOCALIZATION OF X-RAY SOURCES IN THE 1978 NOVEMBER 19 GAMMA-RAY BURST ERROR BOX

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ABSTRACT

We report on observations of the 1978 November 19 gamma-ray burst source, performed with the *ROSAT* X-ray HRI experiment. Two sources were detected, one of which is possibly variable. The latter source is identical to the source discovered in 1981 by the *Einstein* satellite and recently detected by *ASCA*. The precise localization of these sources is given, and our data are compared with optical, radio, and previous X-ray data.

Subject heading: gamma rays: bursts

1. INTRODUCTION

Gamma-ray bursts (GRBs) were discovered some 25 years ago, and their origin remains enigmatic. Current data and models involve objects at distances ranging from several hundred kiloparsecs to cosmological distances, an uncomfortable ignorance factor of at least 10^6 (see, e.g., Lamb 1995, Paczyński 1995, and following papers for a discussion of the GRB distance scale). Two approaches have been used to solve this problem, namely, (1) the use of the $\log N$ – $\log S$ relation combined with the angular distribution of GRBs and (2) the search for counterparts at other wavelengths, either quiescent or transient.

The first X-ray counterpart searches were performed with the *Einstein* satellite. Five GRB small error boxes were observed (Pizzichini et al. 1986). This resulted in only one marginal, 3.5σ detection (Grindlay et al. 1982) in the case of GRB 781119. Later, other observations were performed with the *EXOSAT* (Boër et al. 1988, 1991) and *ROSAT* satellites (Boër et al. 1993a, 1993b; Greiner et al. 1995), resulting in only one other possible candidate, that of the GRB 960501 source (Hurley et al. 1996b). In this last case, the source is seen at low Galactic latitude, is heavily absorbed, and is possibly extragalactic.

The error box of GRB 781119 is one of the smallest known, with a size of 8 arcmin² (Cline et al. 1981). It was observed at various wavelengths, and a possible counterpart was found in X-rays in 1981 as mentioned above. A radio source was found at this position (Hjellming & Ewald 1981). Using archival data, Schaefer (1981) found an optical transient object with a position marginally compatible with the X-ray object, but its reality was questioned (Zytkow 1990; Greiner, Wenzel, & Degel 1990; but see Schaefer 1990). In addition, two possible emission lines have been found in the spectrum of GRB 781119 at 420 and 470 keV (Teegarden & Cline 1980).

The error box of GRB 781119 was reobserved by Boër et al.

(1988) in 1983 in order to confirm the *Einstein* detection with the *EXOSAT* satellite. The source was not detected, and the 3σ upper limit on the flux was 1.2×10^{-12} ergs cm⁻² s⁻¹, for a $T = 10^6$ K blackbody spectrum. This limit was consistent with the *Einstein* detection for a 10^6 K blackbody source at a distance of ≥ 2 kpc. On the other hand, the *Einstein* source, detected at a 3.5σ level, might have been a variable source or, alternatively, a statistical fluctuation. In order to settle the question, we observed the region in 1995 with the *ROSAT* satellite. Because of a technical problem, the observation was interrupted and rescheduled in 1996. Independently, the same source was observed by Hurley et al. (1996a), using the *ASCA* satellite.

We report here on the observations carried out by *ROSAT*, which are compared with the *ASCA* observation and data acquired at other wavelengths. The observation resulted in the detection of two objects in the error box in 1996, one of them present in the 1995 observation, possibly variable, and probably associated with the *Einstein* source. The other is probably the X-ray counterpart of a quasar.

2. OBSERVATIONS AND RESULTS

The *ROSAT* X-ray telescope was used with the HRI detector. The total energy range is 0.2–2.5 keV, with 2" spatial resolution and no energy resolution. The data were processed using the EXSAS and MIDAS data analysis software packages. The first observation was carried out on 1995 January 10, for a total of 2481 s effective time, and the second period of observations lasted from 1995 December 21 until 1996 January 11, for a total of 40,776 s duration. The observations are summarized in Table 1. In the GRB error box, one object was detected during the 1995 observation, and two objects in 1996. A SIMBAD cross-identification of the HRI field of view showed that two cataloged sources are detected in X-rays: QSO 0116–288 and QSO 0117–2837.

TABLE 1
SUMMARY OF THE *ROSAT* HRI OBSERVATIONS

| Observation Date | Name | Exposure Time (s) | Count Rate (counts ks ⁻¹) | Signal-to-Noise Ratio | Flux ^a (10 ⁻¹³ ergs cm ⁻² s ⁻¹) |
|------------------------------|-----------------|----------------------|--|--------------------------|---|
| Object 1: | | | | | |
| 1995 Jan 10..... | RX J0118.7-2835 | 2481 | 6.6 ± 1.8 | 3.6 | 4.3 |
| 1995 Dec 21-1996 Jan 11..... | | 40776 | 2.8 ± 0.3 | 10 | 2.2 |
| Object 2: | | | | | |
| 1995 Dec 21-1996 Jan 11..... | RX J0118.8-2835 | 40776 | 1.2 ± 0.3 | 5.5 | 0.8 |

^a Assuming a power-law spectrum of index 1.77 and a hydrogen column density of 1.76×10^{20} cm⁻² (Hurley et al. 1996a; Dickey & Lockman 1990).

The best position for object 1 (detected in both the 1995 and 1996 observations) is $\alpha = 1^{\text{h}}18^{\text{m}}49^{\text{s}}.6$, $\delta = -28^{\circ}35'53''$ (equinox 2000.0), and for object 2, $\alpha = 1^{\text{h}}18^{\text{m}}47^{\text{s}}.4$, $\delta = -28^{\circ}35'45''$, with an error radius of $10''$ (Briel et al. 1994). These positions were computed using the 1996 observation only. As indicated in Table 1, there are some marginal indications that the flux of object 1 varied by a factor of ≈ 2 between 1995 and 1996, while no evidence of variability was found during the 1996 observation. However, if we look at the flux over an extended period, assuming a constant spectrum for the source, long-term variability is clearly implied from the nondetection by *EXOSAT* (Boër et al. 1988). The nondetection of object 2 in 1995 is consistent with its flux in 1996. The 3σ upper limit to the count rate for object 2 in 1995 January is 4.6×10^{-3} counts s⁻¹. No variability has been found in the 1996 data for this object.

3. DISCUSSION

Figure 1 displays the *ROSAT* HRI image from the observation of 1996. We show the *Einstein* (Grindlay et al. 1982), *ASCA* (Hurley et al. 1996a), and *ROSAT* error boxes, as well as the radio sources present in the GRB 781119 error box (Hjellming & Ewald 1981). There are two HRI sources in the

GRB 781119 error box. Object 2 may be identified with the quasar QSO 0116-288, whose catalog position is only $4''$ from the *ROSAT* position. Object 1 is the closest to the *Einstein* error box and may be identified with radio source Q of Hjellming & Ewald (1981). This source is however slightly outside the 90% confidence *Einstein* error box, but the low level of confidence (3.5σ) of the *Einstein* detection may introduce some additional uncertainties in its confidence region. In addition, the proximity of the HRI $10''$ error box and the *Einstein* error box is probably compatible with the possibility that the *ROSAT* source is in the 99% *Einstein* error box.

More interesting is the fact that the *ROSAT* source may be variable. Its flux varied by a factor greater than 2 within roughly 1 yr, though the uncertainty in the first (1995 January) observation is large. In addition, there is some evidence of variability between the *ASCA* observation (Hurley et al. 1996a) and the present data, and a clear discrepancy with the *EXOSAT* observation, which can only be explained by variability. On the other hand, there is no evidence of variability in the data taken by *ROSAT* during the period 1995 December 21-1996 January 11. Hence we deduce that object 1 is variable

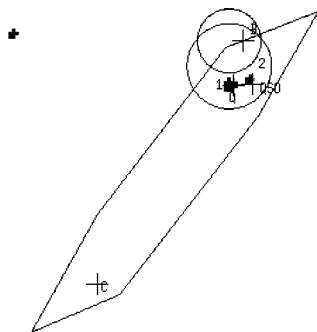


FIG. 1.—A $15' \times 15'$ close-up of the *ROSAT* HRI image centered on the GRB 781119 error box, taken during the period 1995 December 21-1996 January 11. The error box of the GRB source is displayed (polygon), as well as the *Einstein* (small circle) and *ASCA* (large circle) error regions, HRI sources 1 and 2, the radio objects B, C, and Q detected by Hjellming & Ewald (1981), and the position of the quasar source QSO 0116-288 (crosses).

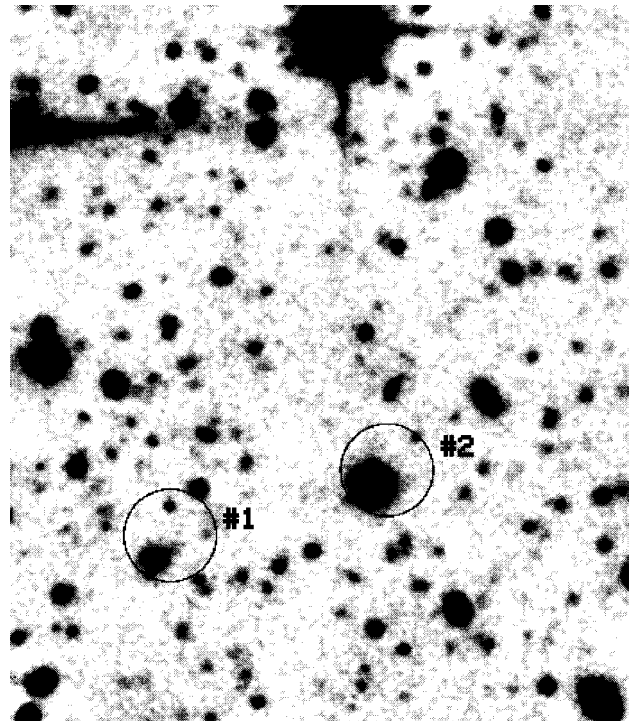


FIG. 2.—Optical content of the region of the *ROSAT* HRI sources 1 and 2. The image is the sum of several unfiltered CCD exposures from ESO.

over the long term (i.e., ≥ 1 yr). Because of the lack of spectral resolution of the *ROSAT* HRI instrument, we were unable to investigate whether this variability is also present in the source spectra.

Thanks to the high precision of the localization given by the *ROSAT* HRI, we can reanalyze data taken in 1981–1982 at ESO (Pedersen et al. 1983), as well as more recent, unpublished observations. The sum of several unfiltered exposures is displayed in Figure 2. The uncertainty circles for objects 1 and 2 are also displayed. A detailed study of the optical data and of the optical variability of the objects near the *ROSAT* sources is reported by Pedersen (1996). From archival data taken by Pedersen et al. (1983), we estimate the R , V , and B magnitudes of object 2 to be respectively ≈ 22 , 22.9, and 23.8.

The probability of having one X-ray source in the GRB error box is 0.16. This probability has been computed by using the local number of sources detected above a 5σ level within the *ROSAT* HRI $30' \times 30'$ field of view. This probability is consistent with the *ROSAT* $\log N$ – $\log S$ relation derived by Hasinger et al. (1993) for a 5σ detection level of 5×10^{-14} ergs $\text{cm}^{-2} \text{s}^{-1}$ in our observation. Given the presence of two

sources in the error box, it is even more difficult to associate any of them with the GRB source. However, we note that object 1 is variable, at least on a 1 yr timescale, reinforcing the probability of a possible association with the GRB source. Optical observations are planned at ESO to determine the precise photometry of the sources, to derive their redshifts, and a possible association, as they could both belong to the same cluster of galaxies.

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