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ASCA REDISCOVERY OF THE X-RAY SOURCE IN THE 1978 NOVEMBER 19 GAMMA-RAY BURST ERROR BOX

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ABSTRACT

We present an analysis of the X-ray content of the 1978 November 19 gamma-ray burst error box using *ASCA*. We confirm the presence of a source that was detected by *Einstein*, but not confirmed by *EXOSAT*, and measure its spectrum between 0.5 and 8 keV. Using a power-law fit with an index of 1.77, the source flux is 1.6×10^{-13} erg cm^{-2} s^{-1}. This source was also observed by *ROSAT*. Using both old and new optical and radio data, we examine a possible counterpart for the X-ray source. We find that the probability of a chance association between the X-ray source and the gamma-ray burst error box is small enough to warrant its consideration as a possible counterpart to the burst source.

Subject headings: gamma rays: bursts — stars: neutron

1. INTRODUCTION

The gamma-ray burst (GRB) of 1978 November 19 was one of the first to be precisely localized. Using the spacecraft of the first interplanetary network, Cline et al. (1981) derived an ~8 arcmin^2 error box for it, which was subsequently observed in the optical (Fishman, Duthie, & Dufour 1981), radio (VLA: Hjellming & Ewald 1981), and X-ray (*Einstein*: Grindlay et al. 1982; Pizzichini et al. 1986) ranges. Possible counterparts were found in all three observations, but the detection of an optical transient (OT) source within the error box by Schaefer (1981) defined a ~140 arcsec^2 region that was thought to contain the true counterpart. The 1978 November 19 GRB was noteworthy for yet another reason: analysis of its energy spectrum revealed two possible emission lines, at 420 and 740 keV, which could be interpreted as redshifted positron-electron annihilation and nuclear iron lines, respectively (Teegarden & Cline 1980), reinforcing the widely held idea that gamma-ray bursts originated on galactic neutron stars.

The *Einstein* detection, which was only in the high-energy band (0.5–3 keV), took place in 1980. Attempting to confirm this detection in 1983, Boer et al. (1988) observed the region with *EXOSAT*, but failed to detect the source. A detailed analysis of both the *Einstein* and the *EXOSAT* (0.02–2.5 keV) data, assuming a blackbody spectrum, showed that the *EXOSAT* upper limit could be consistent with the *Einstein* source if the distance were $\gtrsim$2 kpc and the temperature were in excess of several times 10^6 K. Alternatively, the rather weak (3.5 σ) *Einstein* detection could have been a statistical fluctuation. (We have reanalyzed the *Einstein* data with updated software and have confirmed that the properties of this source are essentially unchanged.) To settle this question, we observed the region again in 1994 with the *ASCA* satellite (Tanaka, Inoue, & Holt 1994). A subsequent *ROSAT* observation has also been carried out, as detailed elsewhere (Boer et al. 1996). These new X-ray observations (1) confirm the presence of the *Einstein* source, (2) indicate that the spectrum of the source is hard, extending to at least 8 keV, and (3) provide evidence for X-ray variability, which may explain the nondetection by *EXOSAT*. A previous analysis of a portion of the *ASCA* data yielded only an upper limit and not a source

TABLE 1

COMPARISON OF THE *EINSTEIN*, *EXOSAT*, *ASCA*, AND *ROSAT* OBSERVATIONS

Parameter	*Einstein*	*EXOSAT*	*ASCA* SIS	*ROSAT* HRI
Energy (keV)	0.5–3.0	0.02–2.5	0.5–8.0	0.1–2.0
Time since GRB (yr)....................	1.7	3.8	14.7	16.2 and 17.1
Total observing time (ks)................	9	81	26	2.5 and 41
Source detection?........................	Yes	No	Yes	Yes
Flux/3 σ upper limit (ergs cm^{-2} s^{-1})...	1.0×10^{-13}	4.6×10^{-13}	1.6×10^{-13}	N/A[a]

[a] As the *ROSAT* HRI has no spectral capability, a unique flux cannot be determined.

detection (Li et al. 1996); that limit is consistent with the present results.

2. *ASCA* OBSERVATION

Table 1 gives some general information about the *ASCA* observation and compares it to the *Einstein*, *EXOSAT*, and *ROSAT* observations. In the combined SIS0 and SIS1 data, two sources were detected, and one was in the GRB error box. This source, at $\alpha(2000) = 01^h18^m50^s$, $\delta(2000) = -28°35'32''$ (90% confidence error radius $1'$), probably corresponds to the *Einstein* source (Fig. 1 [Pl. L5]). The net number of counts for it in a $2'.2$ error radius is 149 ± 19, and it is detected with 7 σ confidence. Spectral fitting was done after subtracting the background within a $2'.2$ radius. Power-law and thermal bremsstrahlung fits both give acceptable reduced χ^2-values (0.60 and 0.54, respectively); the power-law fit is shown in Figure 2. The power-law index is $1.77^{+0.98}_{-0.43}$ (90% confidence), and the hydrogen column density is $3.2^{+45}_{-3.2} \times 10^{20}$ cm^{-2}. The latter is consistent with the total column density in this general direction, 1.7×10^{20} cm^{-2} (HEASARC on line nh program). The bremsstrahlung fit gave $kT = 5.1^{+19}_{-3.3}$ keV. The combined GIS2 + GIS3 data for this source are consistent with the SIS data.

Using the SIS count rate ($\sim 3 \times 10^{-3}$ counts s^{-1}) and the power-law spectral index, we can predict the count rates that should have been observed by *Einstein* and *EXOSAT* using the HEASARC PIMMS program. This is only approximate, because the spectral index is not well constrained and its assumed value changes the predicted rates considerably. For an index of 1.77, the results are 4×10^{-3} counts s^{-1} for the *Einstein* low- plus high-energy bands (vs. an observed rate of 5.1×10^{-3} counts s^{-1} for the two bands) and 9.5×10^{-4} counts s^{-1} for the *EXOSAT* low-energy detector with the 3000 Å Lexan filter (vs. an observed upper limit of 4.5×10^{-4} counts s^{-1}). Thus, our *ASCA* observation appears to be consistent with the *Einstein* observation, but variability is required to explain the nondetection by *EXOSAT*. Boer et al. (1996) show that such variability may indeed be present.

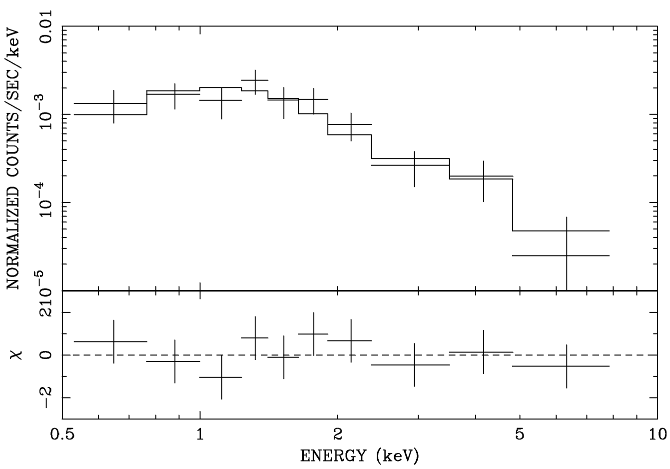

FIG. 2.—SIS spectrum of the X-ray source in the 1978 November 19 GRB error box. A power-law fit with index 1.77 is shown.

3. DISCUSSION

Figure 1 shows the radio and optical content of the region around the *ASCA*, *Einstein*, and *ROSAT* (Boer et al. 1996) error circles. The region shown in this figure is fully contained within the GRB error box. The radio source "Q" first noted by Hjellming & Ewald (1981) is the only obvious candidate for the counterpart to the X-ray source. As is evident from Figure 1, this possible identification comes from the *ROSAT* observation of Boer et al. (1996), since the *ASCA* error circle has a radius approximately 10 times larger. We reobserved this region in 1993 January with the VLA[1] at 3.6 and 20 cm, and confirm the characteristics of this source noted by Hjellming & Ewald (1981), namely, that it is pointlike ($\lesssim 0.6'' \times 0.3''$ in extent at 3.6 cm), and that its 20 cm flux is $1.6 \pm 0.4 \times 10^{-3}$ Jy, consistent with Hjellming & Ewald's (1981) flux of 0.9×10^{-3} Jy. Pedersen et al. (1983) noted a possible optical counterpart to this radio source. Several observations of it have since been carried out using the 1.54 m Danish, 2.2 m, and 3.6 m telescopes at ESO. They indicate that this object is starlike on exposure sums, having resolution of $1''.6$ FWHM, with $m_V = 22.64 \pm 0.15$, and $B - V = 0.46 \pm 0.30$. (Fig. 1 is from the ESO 3.6 m telescope; better seeing was obtained at the other two telescopes). If this is the optical counterpart to the X-ray source, it would have a very high X-ray to optical luminosity ratio, $L_X/L_{opt} \sim 60$, found only in X-ray binaries and in some active galaxies (White, Giommi, & Angelini 1996). Further optical observations will be required to confirm this association, however. The images taken between 1983 and 1988 give no indication of variability of source Q, to a limit of several tenths of a magnitude.

The relation between the X-ray source and the source of the GRB is more difficult to judge. Grindlay et al. (1982) estimated the probability of a chance association between the *Einstein* source and the error box at $\sim 1.7 \times 10^{-3}$. Using the statistics of the WGA (White et al. 1996) catalog of X-ray sources at Galactic latitudes $\geq 20°$ (the *ASCA* source is at $b = -84°$), we find the probability of a chance association between an X-ray source of any intensity and an 8 arcmin^2 error box to be $\sim 2.3 \times 10^{-3}$. Other hypotheses may be tested. For example, the probability that one of the two sources detected in the $22' \times 22'$ SIS field of view falls in the GRB error box is $\sim 3.3 \times 10^{-2}$. The latter probability is about the same as that

[1] The Very Large Array of the National Radio Astronomy Observatory is operated by Associated Universities, Inc., under a cooperative agreement with the National Science Foundation.

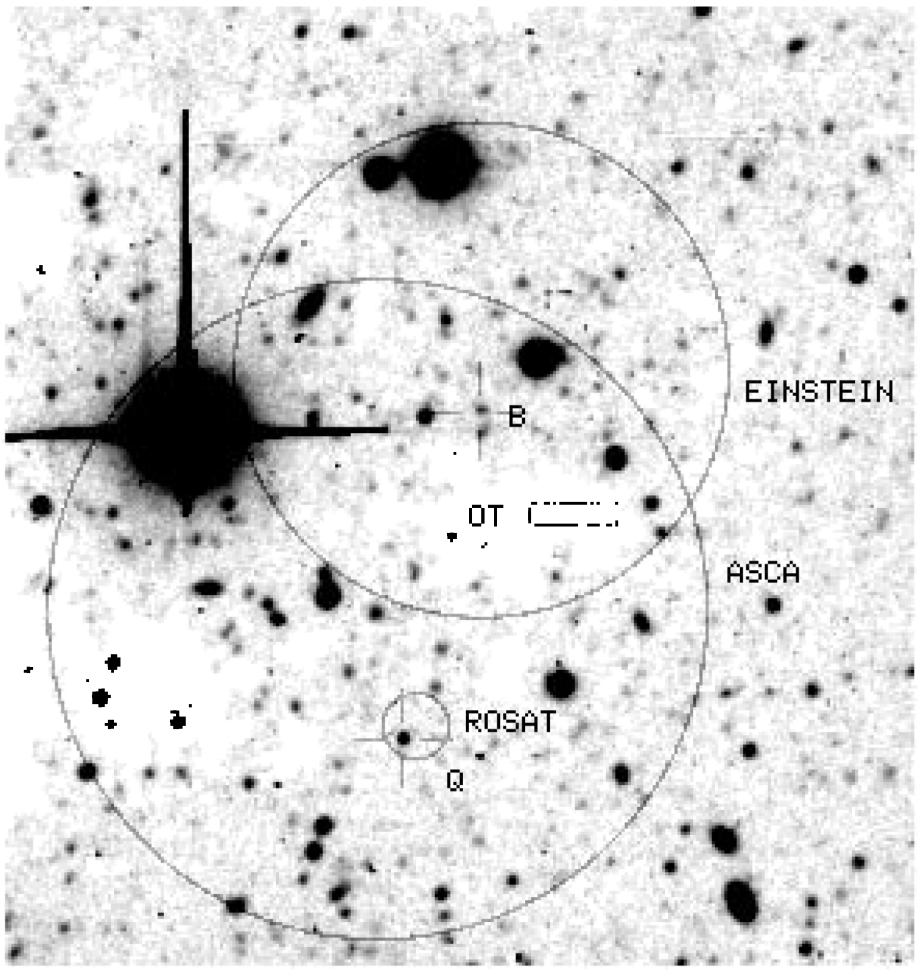

FIG. 1.—Sum of two 40 m *B* exposures and one 30 m *V* exposure obtained at the ESO 3.6 m telescope during 1984–1985. The boxes labeled B and Q indicate the positions of the radio sources observed by Hjellming & Ewald (1981) and reobserved by us in 1993. At the position of B, two galaxies are seen. Circles indicate the X-ray detections by *Einstein* (45″ radius, 90% confidence), *ASCA* (60″ radius), and *ROSAT* (6″ radius, Boer et al. 1996). OT is the error region of the optical transient reported by Schaefer (1981). The object seen within the *ROSAT* and radio source Q region is starlike, and has $m_V = 22.64$, $B - V = 0.46$. Other, much fainter objects are present. The GRB error box is off scale, and fully contains the region shown.

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which would be predicted using the *ASCA* X-ray source log *N*-log *S* relation, which gives a probability $\sim 2.7 \times 10^{-2}$ that a source with an intensity equal to or greater than the one observed here would fall into an 8 $arcmin^2$ error box anywhere on the sky. These probabilities are about 100 times less if a *variable* X-ray source is specified a priori (P. Giommi 1995, private communication). Approximately four searches for X-ray sources in GRB error boxes have been conducted in the past that would have detected a source with intensity equal to the one we observed with *ASCA*. However, the facts that (1) this source is variable and (2) it is the highest fluence GRB whose error box has been searched make it difficult to include this in a probability calculation. Even taking into account the increase in probability due to the number of past searches (Hurley et al. 1996), though, does not alter the conclusion that this one should be retained as a possible counterpart to the GRB source. In view of the relatively low probability of a chance coincidence that was also found for the 1992 May 1 GRB (Hurley et al. 1996; Murakami et al. 1996), it is beginning to seem possible that deep X-ray counterpart searches of other interplanetary network error boxes, both old and new, may be a fruitful avenue to explore. The 1992 May 1 and 1978 November 19 GRBs had in common the facts that they were bright (fluences 1.3×10^{-5} erg cm^{-2} s^{-1} and 3.4×10^{-4}, respectively), relatively long (32 and 15 s), and had complex time histories. Their possible X-ray counterparts have in common the fact that both have relatively hard spectra extending to ~8 keV. However, it is difficult to find any other unifying properties. For example, the ratios of burst fluences or peak fluxes to quiescent X-ray fluxes differ by well over an order of magnitude.

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REFERENCES

Boer, M., et al. 1988, A&A, 202, 117
———. 1996, in preparation
Cline, T., et al. 1981, ApJ, 246, L133
Fishman, J., Duthie, J., & Dufour, R. 1981, Ap&SS, 75(1), 135
Grindlay, J., et al. 1982, Nature, 300, 730
Hjellming, R., & Ewald, S. 1981, ApJ, 246, L137
Hurley, K., et al. 1996, ApJ, 464, 342
Li, P., et al. 1996, in High Velocity Neutron Stars and Gamma-Ray Bursts, ed. R. Rothschild & R. Lingenfelter (New York: AIP), 176
Murakami, T., et al. 1996, PASJ, 48-2, L9
Pedersen, H., et al. 1983, ApJ, 270, L43
Pizzichini, G., et al. 1986, ApJ, 301, 641
Schaefer, B. 1981, Nature, 294, 722
Tanaka, Y., Inoue, H., & Holt, S. 1994, PASJ, 46, L37
Teegarden, B., & Cline, T. 1980, ApJ, 236, L67
White, N., Giommi, P., & Angelini, L. 1996, The WGA Catalog of *ROSAT* Point Sources (available on-line from the HEASARC)