Looking for the Source of ~Hour–long Soft X–ray Emission following GRB 780506

A. Connors and M. McConnell

ISEOS, Morse Hall, University of New Hampshire, Durham, NH 03824

GRB 780506, a gamma–ray burst discoverd in HEAO 1 A–4 data, was unusual in three respects. First, it was well–measured (by HEAO 1 A–2) in 2–60 keV X–rays. Second, two minutes after it ended, HEAO 1 A–2 detected a faint resurgence of 2–10 keV flux, lasting roughly an hour. From recently calculated position constraints, it appears the source of the extended flux is consistent with the source of the burst, and probably not from a serendipitous transient along the Galactic plane. Third, it now appears GRB 780506 belongs to a newly discovered softer subclass of gamma–ray bursts. This subclass is remarkable, as, in contrast to harder gamma–ray bursts, it is apparently homogeneous, with $\log(N > P)$ showing no turnover from $P^{-\frac{3}{2}}$ (1,2). Was GRB 780506 also unusual in having a detectable quiescent counterpart? A ROSAT Class C observation was scheduled which covered one side of the error box. The new HEAO 1 A–2 position constraints excluded all but four of the sixteen detected ROSAT sources. None of these four faint ($\leq 10^{-12}$ergs-cm^{-2}-s^{-1}) sources was a clear candidate for either a GRB counterpart, or for an X–ray transient, although this possibility is still being explored.

I. INTRODUCTION

During a 6 hour pointed observation along the Galactic plane near the Carina arm, the HEAO 1 A–4 scintillation detectors (0.1-3 MeV) and A–2 (2-60 keV) proportional counters observed GRB 780506, a $\sim 7 \times 10^{-7}$ erg-cm^{-2} γ–ray burst (3–5). The burst exhibited two peaks, roughly a minute apart, which were brightly visible in the A–2 X–ray proportional counters. Two minutes after this emission had faded to background, the A–2 detectors recorded a slow increase in count rate in the 2–10 keV band, lasting for at least 30 minutes, and possibly as long as several hours (4,5). Since the instrument was pointed along the Galactic plane, the question arose: could the afterglow have come from an X–ray transient that was by chance in the same field of view? To address this, we calculated the position constraints using a Bayesian approach (8). We found, for the afterglow, the 95.4% Bayesian credible region was $\sim 0.5° \times 6°$, centered around the error box for the burst (see Figure 1.a). From (7) one finds $10^4 - 3 \times 10^5$ 2–60 keV X–ray transient events per year

over the whole sky, implying a rate of $< 1.5\%$ of such events by chance within the error box over the six hour pointing (assuming an isotropic distribution). From this one finds a $> 98.5\%$ probability that the ∼hour long event did not come from a serendipitous second source, but indeed came from the same source as the burster. This leads to the question: did a γ–ray burster give off an ∼hour–long X–ray transient, or did a Galactic X–ray transient such as a Be–neutron star binary, give off a soft γ–ray burst? Intriguingly, GRB780506 was not only associated with extended X–ray emission, but its $E^{-2.4} > 45$ keV X–ray spectrum places it in the possibly nearby subclass of gamma–ray bursts delineated by 100–300 keV to 50–100 keV fluence hardness ratios < 1.5 (1,2).

These data suggested the question: was this source also unusual in having a potentially detectable quiescent X–ray counterpart?

We proposed two 6 ksec ROSAT exposures to look for X–ray sources with the ∼10–20 minute variability observed in the extended X–ray emission following GRB 780506. One was scheduled, covering one side of the combined GRB 780506 and X–ray afterglow emission error box. Four faint sources fell within the 99% confidence contours of both GRB 780506 and of the ∼ hours long X–ray emission. None of them is an outstanding candidate for a GRB counterpart.

In the following section we describe the ROSAT observation and list the observed point sources in more detail.

II. ROSAT OBSERVATION

On April 19–20, 1991, ROSAT pointed at (l^{II}, b^{II}) of $(257°, -7°)$, at one side of the A–2 error boxes (4). Two pointings totaling 3058 s were obtained during a 5.5 hour period. ROSAT observed with the PSPC, with no filter, for an energy range of ∼0.07-2.4 keV. We compared the revised HEAO 1 A–2 error–boxes with the results of the latest ROSAT (REV2) analysis for point sources.

Sixteen point sources were identified as significant in the ROSAT image. The light curves of two of the brighter sources (**A** and **P** in Table 1 below) showed weak evidence for time–variablity. All were considered too faint for spectral fitting, so instead we have listed two hardness ratios. The first uses bands A and B, where A $\sim 0.1 - 0.5$ keV and B $\sim 0.5 - 2$ keV, while the second uses bands C and D, with C $\sim 0.5 - 0.9$ keV and D $\sim 0.9 - 2$ keV.

We have plotted the positions of these 16 sources in Figure 1. On these we have superposed HEAO 1 A–2 position constraints for GRB 780506 (shaded) and the ∼hour long afterglow (unshaded). These are contours of constant log Bayesian likelihood, enclosing 95.4% and 99.7% (2 and 3σ) of the probability (8). There was some indication from comparing the HEAO 1 A–4 and A–2 spectra that the source of GRB 780506 was located $\sim 1°$ on one side or the other of the center of the error box, along the long axis (5), so the ROSAT pointing covered one of the two combined A–2/A–4 best–fit positions. Only

TABLE 1. Summary of X–ray properties of 16 ROSAT sources

Source	R.A, Dec 2000 h m s , o ′ ″	Cts/Sec ±1σ 0.07 − 2.4keV	Ratio±1σ $\frac{B-A}{A+B}$	Ratio±1σ $\frac{D-C}{D+C}$
A	7 52 14.5 , -42 19 16	0.024 0.003	0.37 0.13	0.11 0.15
B	7 52 43.3 , -42 21 10	0.002 0.0009	1.75 0.72	−0.93 1.70
C	7 52 58.3 , -42 22 04	0.003 0.001	0.68 0.37	0.19 0.39
D	7 53 44.3 , -42 22 54	0.003 0.001	0.72 0.36	−0.58 0.32
E	7 53 10.9 , -42 23 53	0.008 0.002	0.57 0.23	−0.16 0.24
F	7 52 28.2 , -42 25 49	0.004 0.001	−0.14 0.35	−0.75 1.91
G	7 54 40.7 , -42 26 49	0.022 0.003	—	—
H	7 54 2.2 , -42 27 20	0.005 0.002	0.97 0.42	0.47 0.28
I	7 53 4.5 , -42 28 07	0.004 0.001	0.13 0.36	−0.47 0.38
J	7 53 5.3 , -42 30 15	0.005 0.001	0.33 0.33	0.53 0.30
K	7 53 14.4 , -42 31 33	0.003 0.001	0.08 0.41	—
L	7 53 17.8 , -42 35 10	0.004 0.001	0.01 0.35	—
M	7 51 28.5 , -42 37 26	0.014 0.003	0.87 0.15	0.31 0.18
N	7 52 17.0 , -42 39 24	0.006 0.002	0.49 0.44	0.16 0.46
O	7 52 23.6 , -42 40 00	0.006 0.002	−0.12 0.38	2.10 1.77
P	7 51 33.7 , -42 45 28	0.047 0.006	0.26 0.13	−0.02 0.15

TABLE 2. Summary of potential optical IDs for 16 ROSAT sources

Source	10^{-14}erg/cm^2-s±1σ 0.07–2.4 keV	OpticalID SIMBAD	Type	m_V m_B	f_{bol} erg/cm^2-s
A	24. 3.0	HD64458	B7IV	7.7 7.2	1.5 10^{-6}
”	” ”	HD64441	B9III	8.4 7.7	4.3 10^{-7}
B	2.3 0.9	—	—	—	—
C	3.0 1.0	—	—	—	—
D	3.0 1.0	—	—	—	—
E	8.0 2.0	—	—	—	—
F	4.0 1.0	—	—	—	—
G	2.2 3.0	HD64954	M1III	7.5 8.6	3.3 10^{-7}
H	5.0 2.0	—	—	—	—
I	4.0 1.0	—	—	—	—
J	5.0 1.0	HD64623	F5IV	9.4 9.0	1.5 10^{-8}
K	3.0 1.0	—	—	—	—
L	4.0 1.0	—	—	—	—
M	14. 3.0	—	—	—	—
N	6.0 2.0	HD64505	A0V	9.4 8.8	3.7 10^{-8}
O	6.0 2.0	HD64505	A0V	9.4 8.8	3.7 10^{-8}
P	47. 6.0	CD-42 3600	A0	— 10.0	1.2 10^{-8}

four sources (**L**, **M**, **N**, and **O**) fall within the 99.7% (3 σ) Bayesian credible region.
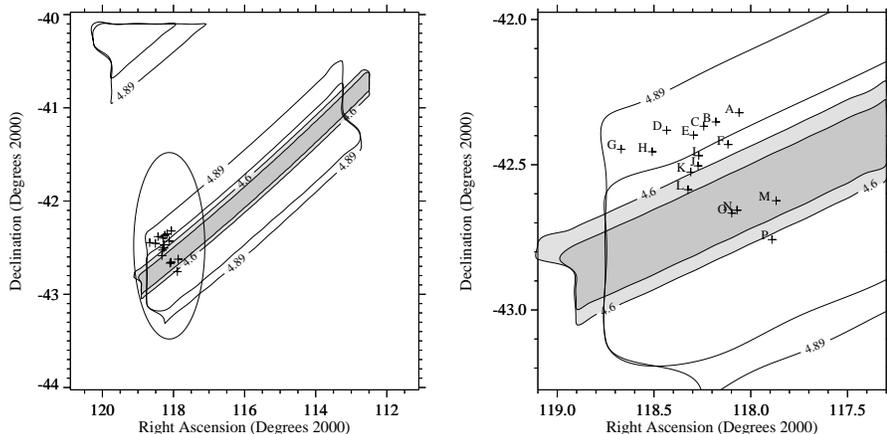
Figure 1.a (left): The ROSAT 1° circular field of view, superposed on the 95.4 and 99.7% (2 and 3 σ) Bayesian credible regions for GRB 780506 (filled contours) and extended emission (line contours). The sixteen significant ROSAT sources are each marked with '+'. **Figure 1.b (right):** The same, but just for the region containing the ROSAT field of view. The sources are marked with a '+' and labelled by letter.

To check optical identifications, the ROSAT source positions were compared with those of sources in the SIMBAD database. We list properties of the potential optical counterparts to the ROSAT sources in Table 2. For the X−ray flux, we estimated roughly 10^{-11} ergs/cm^2 per 0.07–2.4 keV count. This is consistent with convolving a range of spectra, such as the spectrum one expects from the active corona of a normal star (roughly a 10^7K thermal spectrum) through the telescope + PSPC response. Along with the statistical uncertainty, which is listed in in Table 2, we expect an overall systematic uncertainty of roughly a factor of three, due to the uncertainty in the true shape of each spectrum. The bolometric luminosty was estimated from the optical magnitudes (9).

Two of the four ROSAT sources which fell within the error box (**N** and **O**) had positions consistent with that of an A0 V star (HD 64505). Notice that **A**, the second−brightest source, is positionally coincident with two B stars, both of which could have contributed to its flux. For stars of type O and B, one expects $\log[L_x/L_{bol}] \sim -7$ (10). One sees the flux from **A** is consistent with coronal emission from both stars. For stars of types M−F, one expects to find active coronae with $\log[L_x/L_{bol}] \sim -3$ (10). This is consistent with the remaining suggested optical IDs in Table 2, except for source **P**.

This sample is consistent with what was found by (6) in ROSAT Galactic plane survey observations. About 40% of the survey sources could be associ-

ated with normal stars; compared with 38% in this sample. Roughly 10% of their sources not identified through SIMBAD should be faint red dwarfs with active coronae. This suggests ~ 1 of our 10 remaining unidentified sources is a red dwarf. Possibilities for the remaining sources include clusters of Galaxies, AGNs, and unidentified cataclysmic variables.

III. CONCLUSION

ROSAT observed one side of a γ–ray burst error box that was also apparently observed to have an $\sim$hour long 2–10 keV afterglow. No compelling quiescent candidate was detected. The preliminary optical identifications of the sixteen ROSAT sources that were detected are consistent with the sample seen in other, larger, surveys of the Galactic plane. Of the four sources in the GRB 780506 error box, source **M** is the most promising, as it is not only the brightest but shows the hardest, most absorbed spectrum. All four will be targeted for optical identification in the near future.

ACKNOWLEDGMENTS

REFERENCES

1. Pizzichini, G., 1995, in *Proc. of the 24th ICRC*, Vol 2, p 81
2. Kouveliotou, C., et al. 1996, these proceedings
3. Hueter, G., *HEAO-1 Observations of γ–ray Bursts*, Ph.D. Thesis, University of California at San Diego (1987).
4. Connors, A., *An All Sky Survey of Fast X–ray Transients*, Ph.D. Thesis, University of Maryland (1988)
5. Connors, A. and Hueter, G., in preparation (1996).
6. Motch, C., *et al.*, *A&A*, **246** (1991), L24.
7. Connors, A., Serlemitsos, P. J., and Swank, J. H. it Ap. J., **303**, (1986), 769.
8. Connors, A., in preparation (1996).
9. Lang, K., *Astrophysical Formulae* – Springer–Verlag New York (1974).
10. Linsky, J.L., in *Imaging X–ray Astronomy*, ed. M. Elvis, Cambridge University Press New York (1990) 39.