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THIRD INTERPLANETARY NETWORK LOCALIZATION, TIME HISTORY, FLUENCE, PEAK FLUX, AND DISTANCE LOWER LIMIT OF THE 1997 FEBRUARY 28 GAMMA-RAY BURST

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ABSTRACT

The gamma-ray burst of 1997 February 28 was localized using the arrival time analysis method with the *Ulysses*, *BeppoSAX*, and *WIND* spacecraft. The result is a $\pm 31\farcs5$ (3 σ) wide annulus of possible arrival directions that intersects both the position of the burst determined independently by the *BeppoSAX* Wide Field Camera and the position of a fading X-ray source detected by the *BeppoSAX* focusing X-ray telescopes and reduces these source location areas by factors of 7 and 1.5, respectively. The combination of the annulus and the *BeppoSAX* locations, a 0.76 arcmin square error box, is consistent with that of an optical transient source and an extended object, possibly a galaxy. We also present the time history, peak flux, and fluence of this event, and we derive a model-independent lower limit to the source distance of $\approx$11,000 AU.

Subject heading: gamma rays: bursts

1. INTRODUCTION

The gamma-ray burst (GRB) of 1997 February 28 is the first for which a fading X-ray source (Costa et al. 1997a, 1997b; Yoshida et al. 1997) and an optical transient (Groot et al. 1997a; van Paradijs et al. 1997) have been reported. The position of the optical transient is consistent with that of an extended object that may be a galaxy (Groot et al. 1997b; Sahu et al. 1997), leading to the possibility that this may be the first observation of a counterpart to a classical GRB. The probability that the GRB, the fading X-ray source, the optical transient, and the extended source/galaxy are related is in part a function of the position and size of the GRB error box. In this Letter, we present the annulus of possible arrival directions derived by triangulation between the *Ulysses*, *BeppoSAX*, and *WIND* spacecraft, as well as the error box formed by the intersection of the annulus with the independently determined *BeppoSAX* burst positions. We also present the time history, peak flux, and fluence of this burst, and we derive a lower limit to its distance based only on the curvature of the wave front.

2. OBSERVATIONS

GRB 970228 was observed by the *Ulysses* GRB (Hurley et al. 1992), *WIND* KONUS (Aptekar et al. 1995), and *BeppoSAX* Wide Field Camera (WFC; see Jager et al. 1997) and Gamma-Ray Burst Monitor (GRBM; this is part of the Phoswich Detection System; see Frontera et al. 1997a; Costa et al. 1997c; Pamini et al. 1990) experiments. The *Ulysses* and GRBM light curves are shown in Figure 1. *Ulysses*, in heliocentric orbit, was 1988 lt-s from Earth; *WIND*, at the first Lagrange point, was 4.6 lt-s from Earth; and *BeppoSAX* is in low Earth orbit. For the purposes of GRB triangulation, this means that the *Ulysses*/*BeppoSAX* and *Ulysses*/*WIND* baselines are practically identical; the two independent annuli of burst positions are consistent with one another, but redundant.

3. POSITION

Figure 2 shows the *Ulysses*/*BeppoSAX* GRBM triangulation annulus, the *BeppoSAX* WFC position (Costa et al. 1997d; Frontera et al. 1997b), and the position of the fading X-ray source determined by the *BeppoSAX* Low and Medium Energy Concentrator/ Spectrometers (LECS/MECS; see Boella et al. 1997; Parmar et al. 1997). The position of the extended source/fading optical source is also indicated. This annulus is consistent with, but smaller than, those previously determined (Hurley et al. 1997a, 1997b; Cline et al. 1997). Table 1 gives the details of the *Ulysses*/*BeppoSAX* GRBM and *Ulysses*/*WIND* KONUS annuli, and Table 2 gives the intersection points between the *Ulysses*/*BeppoSAX* GRBM annulus and the *BeppoSAX* WFC and LECS/MECS error circles.

The region defined by the *BeppoSAX* WFC error circle and

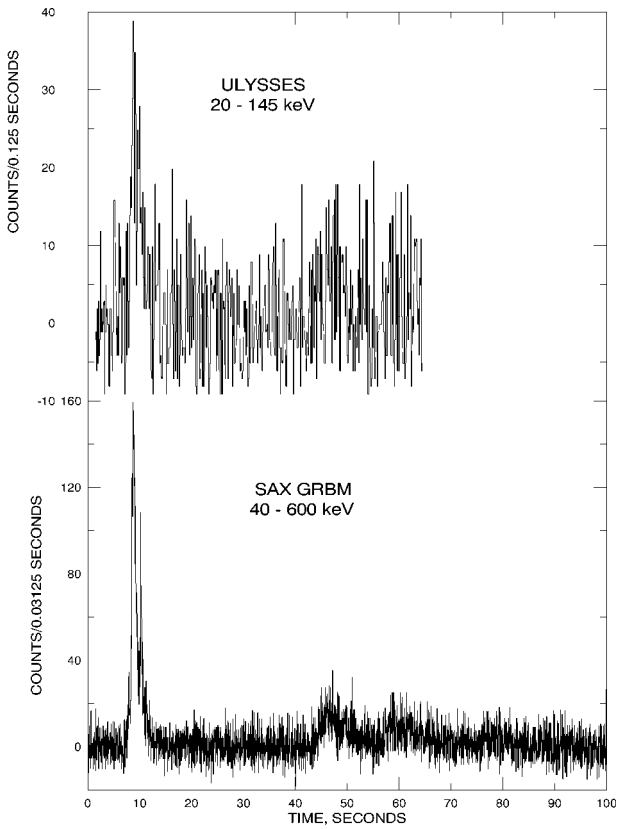

FIG. 1.—Background-subtracted time histories of GRB 970228 as observed by *Ulysses* GRB and *BeppoSAX* GRBM.

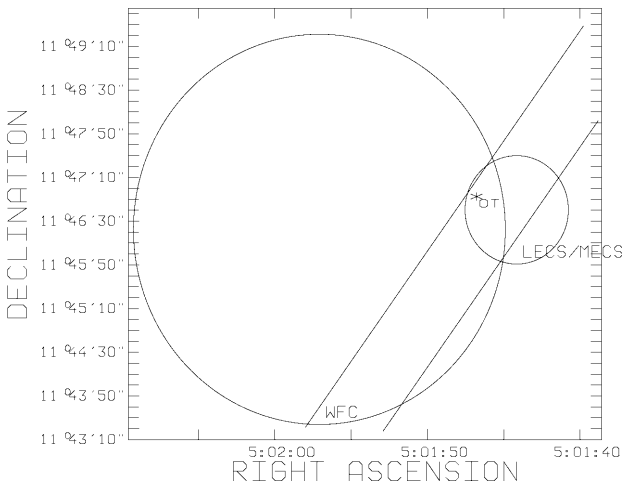

FIG. 2.—*BeppoSAX* WFC, *BeppoSAX* LECS/MECS, and IPN annulus for GRB 970228. For clarity, only the *Ulysses*/*BeppoSAX* annulus is indicated; the *Ulysses*/KONUS annulus is virtually identical. The position of the optical transient (OT) is also indicated.

the *Ulysses*/*BeppoSAX* annulus has an area of approximately 4 arcmin square, or 0.14 times the area of the *BeppoSAX* WFC error circle; the region defined by the *BeppoSAX* LECS/MECS error circle and the *Ulysses*/*BeppoSAX* annulus has an area of approximately 1.5 arcmin square, or 0.67 times the area of the *BeppoSAX* LECS/MECS error circle. The combination of the two error circles and the annulus defines a region with an area of approximately 0.76 arcmin square. Finally, the extended source possibly associated with the optical transient lies approximately 22″.5 from the center line of the *Ulysses*/*BeppoSAX* annulus.

4. FLUENCE AND PEAK FLUXES

When the distance of the extended source is eventually determined, the total energy and peak luminosity of this burst will be important parameters for any models. Although the *Ulysses* spectral memory triggered late in the burst and resulted in too few counts for an accurate determination of the energy spectrum, we can calculate the fluence and peak flux of this burst under the assumption of a power law spectrum with index -1.07, which is consistent with the spectral data that we have. For convenience, we have extrapolated these numbers to an energy range and have used time intervals that allow a comparison with cataloged BATSE bursts (Meegan et al. 1996). The 25–100 keV fluence was approximately 4.3×10^{-6} ergs cm^{-2}. The 25–100 keV peak fluxes were approximately 1.4×10^{-6} ergs cm^{-2} s^{-1} over 0.0625 s and 1.2×10^{-6} ergs cm^{-2} s^{-1} over 0.25 s.

More accurate spectral measurements were made by the KONUS experiments aboard both the *WIND* and *Kosmos 2326* spacecraft over the 13 keV–10 MeV range. An optically thin thermal bremsstrahlung fit ($kT = 150$ keV) gives 25–100 keV fluences and peak fluxes 3.0×10^{-6} ergs cm^{-2} and 1.0×10^{-6} ergs cm^{-2} s^{-1}, respectively. The latter was derived by scaling the average spectrum over approximately 4 s to the 16 ms resolution time history.

The *BeppoSAX* GRBM recorded 2×10^{-6} ergs cm^{-2}, 40–100 keV, 8×10^{-6} ergs cm^{-2}, 100–700 keV, and a peak flux 4×10^{-6} ergs cm^{-2} s^{-1} (over 1 s, 40–600 keV).

5. DISTANCE LOWER LIMIT

Virtually all distance estimates for GRBs involve models of matter distribution (e.g., in the Oort cloud, the Galactic halo, or at cosmological distances). It is therefore interesting to consider model-independent distance limits. If we assume that some source within the annulus (say the optical transient) is

TABLE 1

INTERPLANETARY NETWORK ANNULI

Spacecraft	Annulus R.A. (2000)	Annulus Decl. (2000)	Annulus Radius (deg)	Annulus Half-Width[a] (arcsec)
Ulysses/*BeppoSAX*	11 03 47	36 31 31	83.4228	31.5
Ulysses/*WIND*	11 03 47	36 27 46	83.4326	35.7

NOTE.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.

[a] 3 σ confidence.

TABLE 2

ULYSSES/*BEPPOSAX* ANNULUS INTERSECTIONS WITH *BEPPOSAX* WFC AND LECS/MECS ERROR CIRCLES

Error Circle	R.A. (2000)	Decl. (2000)
BeppoSAX WFC.....	5 01 51	11 43 46
BeppoSAX WFC.....	5 01 45	11 46 02
BeppoSAX WFC.....	5 01 58	11 43 28
BeppoSAX WFC.....	5 01 45	11 47 34
BeppoSAX LECS/MECS.....	5 01 45	11 45 58
BeppoSAX LECS/MECS.....	5 01 41	11 47 15
BeppoSAX LECS/MECS.....	5 01 47	11 47 01
BeppoSAX LECS/MECS.....	5 01 46	11 47 26

NOTE.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.

associated with this GRB, we can derive a distance lower limit from the wave front curvature. To do this, we imagine that the source is at a very large distance from Earth, along the Earth-source vector, and allow the distance to decrease. For each value of the assumed distance, we calculate the difference in arrival times at the *Ulysses* and *BeppoSAX* satellites and compare this with the arrival time difference for a source at infinity (i.e., a plane wave). When these two times differ by an amount that corresponds to the measured timing uncertainty in the comparison of the two time histories in Figure 1 (300 ms), we have a source distance lower limit. In this case, that limit is $\approx$11,000 AU, or about 0.05 pc; a refined analysis, currently in progress, may raise this limit.

6. CONCLUSION

The Interplanetary Network (IPN) localization for GRB 970228 is consistent with the *BeppoSAX* error circles and the position of the optical transient and extended source. *BeppoSAX* WFC localizations of GRBs provide a strong confirmation of IPN accuracies. Consistency between IPN annuli and *BeppoSAX* error circles is in effect a rigorous "end-to-end" test of the spacecraft timing and the software used to derive burst positions by triangulation. In the case of GRB 970228, this consistency demonstrates that IPN uncertainties cannot exceed approximately $\pm 3'$, the radius of the WFC error circle. A similar result was obtained for GRB 970111 (Hurley et al. 1997c). Assuming that the fading X-ray source is associated with the GRB, the uncertainty becomes approximately $\pm 1'$, and further assuming that the optical transient is associated with the GRB leads to a maximum uncertainty of approximately $\pm 30''$.

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