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VLBI Observations of GRB Afterglows

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Abstract. Once the afterglow from a GRB has been detected in the radio, Very Long Baseline Interferometry (VLBI) observations can provide a resolution of 1 milliarcsecond or better and absolute astrometry at a similar level. We will review the VLBI programs carried out to date which include observations of G970508, G980329, G980425, and G980703. All of these objects are found to be very compact (size < 1 mas) even months after the burst. This is consistent with the predictions of fireball models. Our ultimate goal is a direct measurement of the morphology and expansion of a GRB afterglow.

Key words: gamma-ray bursts – radio afterglows – VLBI

1. Introduction

Four out of five radio afterglows (see Table 1) have been observed with VLBI techniques. In this paper we review what has been learned so far, and discuss future applications.

2. VLBI observations of radio afterglows

G970508: A first epoch VLBA observation was obtained just 8 days after the gamma-ray burst, and within 48 hours of the VLA discovery of a radio counterpart (Frail et al. 1997a). An additional 8 epochs were obtained until ∼120 days after the burst when the radio afterglow faded below 0.3 mJy, the nominal sensitivity limit. From this data we derived a position accurate to better than 0.1 mas, placed a 3σ limit on the proper motion of less than 5 mas/y and placed a limit on the parallax of less than 0.3 mas corresponding to a distance limit of >3 kpc (Taylor et al. 1997; Taylor et al. 1998). The limit on the angular size was in all epochs less than 0.5 mas (<4 pc).

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Table 1. Radio afterglows as of 1998 November

GRB	8 GHz $S_{\rm peak}$ (mJy)	8 GHz $\tau_{\rm peak}$ (days)	VLBI detection
G970508	0.63	60	Yes
G980329	0.35	40	No
G980425	50.0	11	???
G980519[a]	0.20	30	–
G980703	1.0	10	Yes

[a] No VLBI observations were attempted for G980519.

G980329: We observed, but did not detect, G980329, because variability drove it below 0.2 mJy on the day we observed. The radio afterglow from this source peaked below 0.5 mJy so we did not attempt further observations.

G980425: Associated with SN1998bw in the galaxy ESO 184-G82 at z=0.0083, G980425 was studied with the ATCA during the first 60 days of its outburst (Kulkarni et al. 1998) and both scintillation and brightness temperature arguments predict a size of 0.1 mas on day 16. This time is near the peak in the radio light curve of 50 mJy at 8.4 GHz. Unfortunately, only limited VLBI observations were feasible for this far southern declination (−53°) source. On May 10 we observed G980425 at 22 GHz with the VLBA antenna at Mauna Kea and with the 70 meter antenna of the Deep Space Network at Tidbinbilla. The radio source was not detected above a 3σ limit of 30 mJy. On August 19 we observed with the same two telescopes but at 8.4 GHz and employing phase-referencing to increase the coherence time. No source was detected above a 3σ limit of 2.5 mJy. An 8.4 GHz observation by a southern hemisphere network of radio telescopes on May 9th is still being analyzed.

G980519: No VLBI observation was attempted of this very faint radio afterglow.

G980703: The radio afterglow from G980703 reached 1 mJy in the first two weeks after the burst. We detected

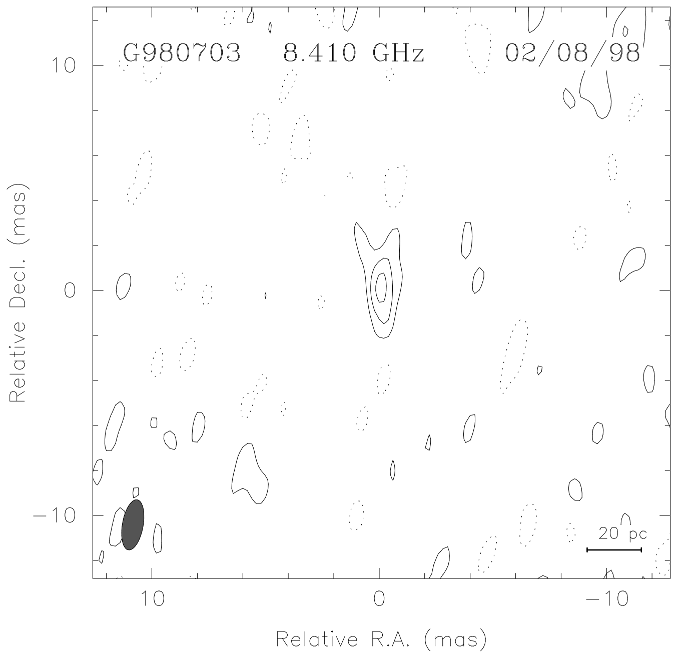

Fig. 1. VLBA observation of G980703 at 8.4 GHz for 5 hours. The synthesized beam is drawn in the lower left-hand corner of the plot and has dimensions: 2.2 × 0.92 mas in position angle −10°. Contours are drawn at −0.1, 0.1, 0.2, and 0.3 mJy/beam.

G980703 at a level of 0.5 mJy 30 days after the burst, when it was already in decline (Fig. 1). We place a limit on the angular size of G980703 of <0.3 mas, and derive a position of α(J2000) = $23^{\rm h}59^{\rm m}06\overset{\rm s}{.}6661$, δ(J2000) = $8^\circ35'07\overset{''}{.}0939$ with an uncertainty of 0.0007 arcsec in each coordinate.

3. What we can learn from VLBI

Two weeks after the explosion a size for G970508 was estimated from the observed scintillation (Frail et al. 1997b) to be 0.003 mas. G970508 reached a peak of 0.7 mJy (with considerable variability) 60 days after the gamma-ray burst. At this time we can estimate a size of ∼0.02 mas from equipartition arguments, unresolvable by VLBI observations (see Table 2). A similar GRB at a redshift of 0.2 would be ∼40 mJy, and have a size of 0.07 mas 60 days after the burst. With an easily achievable dynamic range image of 300:1, such a burst would be resolved by the VLBA. Unfortunately, if GRBs are homogeneously distributed out to z=4, or trace the star formation in the universe, then our chances of observing a GRB at $z < 0.2$ are less than 1 in 10^4 (assuming Ω_0=0). Belying that simple picture one GRB, G980425, has already been found at z=0.0083. This has been explained as either a separate class of GRBs (Bloom et al. 1998), or the result of beaming such that only a small fraction of distant GRBs are detected (Wang & Wheeler 1998). By day 60 the predicted size of G980425 was 0.4 mas. Such an object in the northern sky would be easy to study with the VLBA.

Table 2. VLBI limits on expansion

GRB	z	$t_{\rm VLBI}$ (days)	$S_{\rm t}$ (mJy)	$\theta_{\rm eq}$ (mas)	$\theta_{\rm VLBI}$ (mas)
G970508	0.835	60	0.63	0.02	< 0.3
G980425	0.008	14	35.0	0.08	<??
G980703	0.965	32	0.58	0.01	< 0.3

Granot, Piran & Sari (1998) have recently computed images of what the relativistically expanding fireball showing a disk-like, limb brightened geometry. If GRBs are substantially beamed (as is often invoked to reduce the energy requirements), then we expect substantial deviations from these predictions. Estimates of the rate of expansion also differ greatly (Waxman 1997 vs. Sari, Piran & Narayan 1998). By resolving the explosion the VLBA could play a crucial role in understanding the physics of these energetic events.

Combined VLA and VLBA observations can rule out significant gravitational lensing on scales of 10 mas - 300 arcsec in G970508 and G980703. This covers the range of lenses discussed in the literature, and rules out any substantial flux magnification of the gamma-ray burst by gravitational lensing.

The location of the GRB within the host galaxy is also a subject of interest. VLBA observations can pinpoint the location to within 1 mas (or a few parsecs at z∼1). Future optical or IR instruments capable of high resolution and absolute astrometry could use the VLBA position to shed light on the environment of the progenitor object.

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