A REVIEW OF GRB COUNTERPART SEARCHES

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1. Introduction

Gamma-Ray Burst (GRB) research has been recently revitalized with exciting new results that have effectively started a new era in this thirty year old field, marked by the launch of the Italian–Dutch satellite BeppoSAX [1] on April 1996.

In the following, I will briefly (due to the limited space available) describe the searches and their results for each of the seven GRBs that have been rapidly followed-up in multiwavelength observations. As BeppoSAX, CGRO and RXTE are fully operational, we hope that the GRB counterpart sample will increase significantly within the next year, thus providing new insights to the properties of their parent population.

2. GRB Counterpart Searches

GRB970111: The event was detected with three satellites (BeppoSAX, BATSE, Ulysses). The original WFC error box (10′ in diameter) [5] was observed with the NFIs ∼21 hours after the burst trigger, and three X-ray sources were detected [3, 32]. A variable radio source was found within this error box [9] that coincided with one of the X-ray sources. A refined WFC error box [20] reduced the source location to a 3′ radius region, which although well within the original location, clearly excluded all X-ray and the radio source as the GRB counterparts. The radio non-detection may be used to set limits to GRB distances [12].

GRB970228: This is the first counterpart detection of a GRB after 30 years of searches [33]. The burst was detected and located with BeppoSAX [6], and it was observed with optical telescopes ∼21 hours after detection. Eight hours after the burst trigger, the NFIs detected an X-ray source associated with the WFC position, which decayed with an -1.1 power law index

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until the next NFI observation on 3 March 1997 [7]. Optical observations of the WFC error region made on 28 February and 8 March 1997 revealed a counterpart [16, 33] that was within the 0.75 arcmin^2 area defined by the WFC, NFI and the IPN annuli between Ulysses/SAX and Ulysses/WIND [19]. Subsequent optical observations on 13 March 1997 with ground-based telescopes revealed the existence of a 'fuzz' at the position of the transient [17]; the 'fuzz' was resolved with the Hubble Space Telescope (HST) Planetary Camera observations (on 26 March and 7 April 1997) into a point source and an extended source [29]. Claims of proper motion detection and intensity changes of the extended source [4] were not corroborated with a second HST observation on 4 September 1997, that detected the point source at the same position and the extended source at the same intensity [11].

GRB970402: This event was detected only with BeppoSAX; WFC located it to 3′ accuracy and the NFIs were repointed. A very weak X-ray source was detected that was not observed during a second pointing [28]. No optical/radio counterpart was found for this source.

GRB970508: H. Bond [2] discovered the optical counterpart associated with GRB970508 using the 36" telescope at Kitt Peak. It was subsequently observed with the Palomar [8] and with the Keck [23] telescopes; the latter observation led to the first limits for a GRB redshift, ie., $0.835 < z < 2.3$. The lower limit is associated with the detection of absorption lines in the optical spectrum of the counterpart; the upper limit is set from the absence of the Lyman-α absorption features in the spectrum [23]. HST observations of the source did not detect any nebulosity asssociated with the burst counterpart [27]. GRB970508 is the only event so far with an identification of a radio counterpart [10]. The VLA data show rapid fluctuations during the first two weeks, that decline thereafter. The simplest explanation of the fluctuations is that they are due to scintillation caused by the interstellar medium in our Galaxy [10]. The decline of their amplitude is a consequence of the increase of the angular size of the source; initial estimates of the source size are $\sim 3\mu$arcsec. Such a source size is consistent with the fireball expansion models that are prevalent in the field these days [22].

GRB970616: This is the first afterglow detected with the PCA scanning of a BATSE error box [21]. The RXTE/PCA source intensity was ~0.5 mCrab and was located with 1′ accuracy [21]; subsequent observations of the RXTE error box with ASCA revealed four X-ray sources within the PCA region [24]. ROSAT observations have shown that two of these are variable [13], which makes a choice for an X-ray counterpart uncertain. No optical/radio counterpart was detected for this event.

GRB970815: The burst was detected with the RXTE/All Sky Monitor(ASM) [30]; its error box was subsequently scanned with the PCA, but

no X-ray afterglow was discovered. The ASM error box was observed with ASCA and ROSAT but no counterparts were found [25, 14].

GRB970828: This is the second burst that was detected with the ASM [31]. The source region was observed with ASCA and ROSAT, which detected a declining X-ray afterglow within its error box [26, 15]. No optical/radio counterpart was found to coincide with the ASCA/ROSAT source [18].

TABLE 1. Summary of search results of GRB counterparts

GRB	Prompt X-rays (Crab)	γ-rays erg/cm^2	Secondary X-rays erg/cm^2 s	Optical	Radio mJy	Comments
970111	4.00[a]	6×10^{-5}[b]	—	—	—	Very intense GRB
970228	2.30[a]	10^{-6}[c]	3×10^{-12}[d]	V= 21.3 I= 20.6	—	First optical counterpart with nebulosity
970402	0.46[a]	?	2×10^{-13}[d]	V> 22.5 R> 21.0	—	Very weak NFI source
970508	1.00[a]	3×10^{-6}[b]	6×10^{-13}[d]	V= 20.5 R= 19.8	 0.43[e]	First redschift Radio source size: $< 10^{17}$ cm
970616	?	4×10^{-5}[b]	1×10^{-11}[f]	V> 25.5	—	Uncertain X-ray counterpart
970815	2.00[g]	10^{-5}[b]	$< 10^{-13}$[h]	V> 21.5 R> 23.0	—	
970828	~ 0.8[g]	7×10^{-5}[b]	1×10^{-11}[f]	R> 25.0	—	Very intense GRB

[a] Detected with the Wide Field Cameras (WFC) on BeppoSAX [b] Detected with the Burst And Transient Source Experiment (BATSE) on the Compton Gamma-Ray Observatory (CGRO) [c] Detected with TGRS on WIND [d] Detected with the Narrow Field Instruments (NFI) on BeppoSAX [e] Detected with VLA [f] Detected with the Proportional Counter Array (PCA) on the Rossi X-Ray Timing Explorer (RXTE) [g] Detected with the All Sky Monitor (ASM) on RXTE [h] Detected with ASCA

3. SUMMARY

Table 1 summarizes the GRB counterpart search results so far. The questions that are mostly asked today are: why some events do not have counterparts, what is the relation between detections in different wavelengths, what characteristics in GRB are correlated with the optical/X-ray afterglows. Although we have no definitive answers to any of these questions,

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simple explanations, such as large absorption from *circumstellar* dust in high to moderate redshifts could explain the lack of optical afterglows in several cases. Many more detections are needed, however, before we can establish a connection between GRB sources and their parent population.

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