Observations of Gamma-ray Bursts with VERITAS and Whipple

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Abstract: Many authors have predicted very-high-energy (VHE; $E > 100$ GeV) emission from gamma-ray bursts (GRBs) both during the prompt phase and during the multi-component afterglow. To date, however, there has been no definitive detection of such emission. Recently, the Swift Satellite made the exciting discovery that almost 50% of GRBs are accompanied by one or more X-ray flares which are found to occur from several seconds to many hours after the prompt emission. The discovery of this phenomenon and the many predictions that VHE emission should accompany these flares increases the already strong motivation for making immediate follow-up VHE observations of GRBs. Observations of GRBs have high priority at VERITAS, preempting any observations which may be in progress. GRB alerts are received from the GCN via a socket connection. This is interfaced to the VERITAS Tracking Software to minimize the time between a notification arriving and the telescope being slewed to the GRB. We report here on GRB observations with VERITAS and with the Whipple Telescope from 2005 through 2007. The substantial sensitivity of VERITAS to GRB emission over many time-scales is also discussed.

Introduction

Gamma-ray bursts (GRBs) have been well studied at all wavelengths since their discovery in 1969 [44]. The very-high-energy (VHE; $E >$ 100 GeV) band is the only energy regime in which definitive evidence for GRB emission has yet to be detected. For the observation of photons of energies above 100 GeV, only ground-based telescopes are available at present. These fall into two broad categories, air-shower arrays and atmospheric Cherenkov telescopes (of which the majority are Imaging Atmospheric Cherenkov Telescopes). The air shower arrays, which have wide fields of view making them particularly suitable for GRB searches, are relatively insensitive. There are several reports from these instruments of possible TeV emission [47] & [4]. The Milagro Collaboration reported on the detection of an excess gamma-ray signal during the prompt phase of GRB 970417a with the Milagrito detector [5]. In all of these cases, the statistical significance of the detection is not high enough to be conclusive.

The Milagro Collaboration have performed a number of searches for VHE emission from GRBs [1], [7] & [6], but no evidence for VHE emission was found from any of these searches. Atmospheric Cherenkov telescopes, particularly those that utilize the imaging technique, are inherently more flux-sensitive than air-shower arrays and have better energy resolution but are limited by their small fields of view (3 - 5°) and low duty cycle ($\sim 7\%$). In the Burst And Transient Source Explorer, attempts at GRB monitoring were limited by slew times and uncertainty in the GRB source position [26]. Recently, upper limits on the VHE emission from the locations of seven GRBs observed with the Whipple 10m Telescope were reported [40]. With their fast-slewing telescope and low energy threshold, the MAGIC Group have placed the most stringent upper limits on VHE emission from GRBs to date [2] & [3].

The Gamma-Ray Bursts

Five different GRB locations were observed with VERITAS between March 2006 (when VERITAS was first operated as a 2-Telescope array) and May 2007. These observations are summarized in Ta-

	Discovery	GCN	Best Location (J2000)		T_{90}[a,b]	Fluence[a]	
GRB	Instrument	Number	R.A.	Dec.	(sec)	($x10^{-6}$)	z
060501	BAT	5040	21h 53m 30s	+43° 59' 53"	26	1.2 ± 0.1	N/A
061222a	BAT	5954	23h 53m 03s	+46° 31' 59"	72	8.3 ± 0.2	<3
070311	IBAS	6189	05h 50m 08s	+03° 22' 30"	50	2	low-z[b]
070419a	BAT	6302	12h 10m 59s	+39° 55' 34"	116	5.6 ± 0.8	0.97
070521	BAT	6431	16h 10m 39s	+30° 15' 22"	40	8.0 ± 0.2	0.553[c]

Table 1: The gamma-ray bursts.

[a] T_{90} is the time during which 90% of the prompt emission was detected. [b] The BAT T_{90} and fluence are measured between 15-350 keV. The IBAS T_{90} and fluence are measured between 20-200 keV. [c] [35] postulate that this GRB is at low redshift (see text). [d] A galaxy at z=0.0307 was also found in the XRT error circle.

ble 2. Four of these burst notifications were received from the Burst Alert Telescope (BAT) on the Swift satellite and one was from the INTErnational Gamma-Ray Astrophysics Laboratory (INTEGRAL) Burst Alert System (IBAS) using data from the Imagers IBIS and ISGRI. Some properties of each GRB are described in the following subsections with additional details in Table 1.

Many GRB locations were observed with the Whipple 10m Telescope between January 2005 and May 2007. The detailed description of these bursts and their analysis will be presented in [29] and these results will be summarized at the conference.

GRB 060501

This burst was detected by the BAT on Swift (trigger 208050) at 08:14:58 UT [8]. It had a time-averaged spectrum between T-1.3 and T+26.1 best fit by a simple power law with index 1.44 ± 0.15. The 1s peak photon flux measured from T+0.36s in the 15 - 150 keV band was 1.9 ± 0.3 photon cm^{-2} s^{-1} [9]. Several optical telescopes performed follow-up observations of this burst [41] but no optical counterpart was detected.

GRB 061222a

This burst was detected at 03:28:52 UT by the BAT on Swift (trigger 252588) [48]. The emission started at T-100 seconds with a small peak at T-zero followed by some flaring activity which was detected both by the BAT [10] and the XRT [31]. The burst had a time-averaged spectrum from T-2.5 to T+117.7 seconds which was best fit by a simple power law with index of 1.39 ± 0.04. The 1s peak photon flux measured from T+86.54 seconds in the 15 - 150 keV band was 9.2 ± 0.3 photon cm^{-2} s^{-1} [10]. Spectral fits to the XRT data showed that the absorption column density was significantly in excess of the Galactic value and, when the relation given in [32] was applied, a redshift of $z < 3.0$ was determined for this burst [31]. Optical emission with a Ks magnitude of 20.7 ± 0.3 was detected 2.1 hours after this GRB by the Gemini-North telescope. This emission faded by 1.2 magnitudes 25.4 hours after the burst with a shallow decay index of approximately 0.4 [14], [15]. Upper limits on the optical emission were reported from a number of other telescopes [42]. The position of this GRB was observed with the Very Large Array (VLA) at 8.46 GHz 1246 minutes after the burst and a emission with peak radio brightness of 285 $\pm$ 68 μJy was detected [22].

GRB 070311

This GRB was detected at 11:52:50 UT by the IBAS in the IBIS/ISGRI data [46]. It had a peak flux of 0.9 photon cm^{-2} s^{-1}. The Swift XRT light curve followed a single power law with an index of 1.9 ± 0.4 from 7 to 14 ks after the burst [33]. The robotic 20-cm REM telescope at La Silla detected optical emission from the position of the GRB with an approximate magnitude of 14.3 about 3 minutes after the burst [27]. This detection was confirmed by the 1.3m PAIRITEL project [13] and at a number of other telescopes [16], [36] & [53]. When the optical afterglow was observed with the MDM 1.3m telescope on 070313, it was found to have brightened by 0.99 mag since the previous night [35]. The authors postulated that, given the level of Galactic extinction at this GRB location, it was possible that this burst was at low redshift and that the brightening was the result of the onset of a supernova. Further monitoring of the afterglow [37] found that the re-brightening peaked on day 2 after which it declined rapidly [30]. It was postulated that the optical re-brightening of this burst was due to late central engine activity [43]. The GRB was not detected with the VLA [23].

GRB 070419a

This burst was detected at 09:59:26 UT with the BAT on Swift (trigger 276205) [49]. The burst had a time-averaged spectrum from T-35 to T+93 seconds best fit by a simple power-law model with index of 2.35 ± 0.25. The 1-sec peak photon flux measured from T+86.54 seconds in the 15 - 150 keV band was 2.8 x 10^{-2} photon cm^{-2} s^{-1} [52]. A faint afterglow of magnitude $\sim$19 was detected with the Katzman Automatic Imaging Telescope [24] and subsequently confirmed by observations the Palomar 60-inch Telescope [17]. A spectrum was obtained with the Low-Resolution Imaging Spectrometer on the 10-m Keck I Telescope and, through the identification of a strong absorption signature, a redshift of z = 0.97 was derived for this burst [18].

GRB 070521

This burst was detected at 06:51:10 UT by the BAT on Swift (trigger 279935) [11]. The time-averaged spectrum from T-14.5 to T+49.7 seconds was best fit by a power law with an exponential cutoff and photon index of 1.10 ± 0.17 and peak energy of 195 ± 123 keV. The 1-sec peak photon flux measured from T+30.48 seconds in the 15 - 150 keV band was 6.7 ± 0.3 photon cm^{-2} s^{-1} [12]. The XRT light curve exhibits initial flaring behaviour superposed on the power-law decay up to $\sim$T + 600s [34]. [19] reported that the XRT error circle coincided with the outskirts of a nearby (z=0.0307) galaxy. Observations with the Subaru Telescope [39] revealed a faint source inside the XRT error circle at a redshift of z=0.553, and this source was also detected weakly with the Gemini North [21] and Keck Telescopes [51]. Two other sources consistent with the XRT error circle were also detected with Keck. Observations with Gemini North on 070522 detected marginal evidence for fading of the z=0.553 source [20] as well as a detection of the third source detected by the Keck. The strength of this third source was fainter than that reported the Keck, but the authors caution that the Gemini photometry at this location is quite uncertain due to the presence of a nearby bright galaxy.

GRB	ΔT[a] (min.)	Exp.[b] (min.)	Offset[c] (10^{-5} deg.)
060501	13	101	0.97[d]
061222a	11	120	3
070311	44	110	2
	5805	40	2
070419a	5	40	1
070521	18	80	29

Table 2: The VERITAS GRB Observations.

[a] The time in minutes between the start of the GRB and the beginning of observations. [b] The total VERITAS exposure time on the GRB. [c] The angular separation between the position at which these data were taken and the refined location of the GRB. [d] For this GRB, the angular separation is quoted in degrees.

The VHE GRB Data and Analysis

Burst notifications are received over a socket connection at both VERITAS and the Whipple 10m Telescope. GRB observations take priority over all other observations at both instruments so, whenever an observable burst is detected, the telescopes are immediately re-pointed and data are taken on the GRB location until the burst is more than three hours old. VERITAS and the Whipple Telescope can slew at 1°s^{-1} thus reaching any part of the observable sky within 6 minutes.

The VERITAS array is described in detail in [45]. The GRB data were taken in both *wobble* and *tracking* modes [28]. At all times during datataking, the point-spread function of VERITAS was <0.1° (the field of view of one PMT is 0.15°). For all but one of the GRBs reported on here (GRB 060501) the positional offsets were of order 10^{-5}degrees (Table 2) so a conventional “point source” analysis was performed. In the case of GRB 060501, the burst location was offset from the position tracked by VERITAS by $\sim$1 degree, so a two-dimensional analysis was performed.

The data have been analysed using independent analysis packages (see [25], [28] for details on the analyses). All of these analyses yield consistent results. The calibration techniques are described in [38]. The details and results of the VERITAS GRB analysis will be presented at the conference.

A detailed report of the Whipple 10m GRB observations and their analysis will be presented in [29]. These results will also be presented at the conference.

Discussion and Conclusions

The analysis for these GRB data is still ongoing and will be presented in full along with the sensitivity curves for GRB observations with VERITAS at the conference. Early results, however, do not show any evidence for a VHE signal in these data.

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