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Gamma-ray burst observations with the H.E.S.S. Air Cherenkov array

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Abstract: Gamma-ray bursts (GRBs) are among the potential very-high-energy (VHE) gamma-ray and cosmic-ray sources. Particles are accelerated to highly-relativistic speeds. This might give rise to emission of VHE gamma-ray and/or cosmic-ray particles with ultra-high energy $> 10^{19}$ eV. Despite its generally fast-fading behavior seen in many longer wavebands, the time evolution of any VHE radiation is still not clear. In order to probe the largely unexplored VHE spectra of GRBs, a GRB observing program has been set up by the H.E.S.S. collaboration. With the high sensitivity of the H.E.S.S. array and given favorable observational conditions, VHE flux levels predicted by GRB models are within reach. Extra-galactic background light (EBL) absorption is considered in cases where redshifts of the GRBs are reported. We present the H.E.S.S. VHE gamma-ray observations of and results from some of the reported GRB positions during the past few years, including recent observations in early 2007.

Introduction

Gamma-ray bursts (GRBs), being established as originating from highly-relativistic ejecta, are among potential VHE gamma-ray and cosmic-ray sources. First detected in late 1960s [1], the origin of GRBs is still not well understood, especially compared with other objects such as pulsars and quasars which were also detected in the same era but the origins of which are much more understood nowadays than GRBs. The main reason is that to obtain multi-wavelength information other than gamma-rays proves to be operationally very difficult. Two breakthroughs in understanding GRBs include the establishment of the isotropic spatial distribution by the BATSE experiment on board CGRO in the 1990s [2] and the discovery of longer-wavelength counterparts after the launch of BeppoSAX in Feb 1997 [3]. Since then not only GRBs are confirmed to be of cosmological origin, but the theories of GRBs and their modeling have drawn a lot of attentions from the astrophysical community.

After the highly variable radiation seen in keV-MeV gamma-ray energies (known as the prompt GRB phase), fast-fading behavior is generally seen in counterparts in longer wavebands (known as the afterglow phase). It is believed that during the GRBs, particles are accelerated to highly-relativistic speeds. Highly-relativistic particles might give rise to emission of VHE gamma-ray and/or cosmic-ray particles with ultra-high energy $> 10^{19}$eV (see e.g. [4]). Although VHE emission from GRBs during the prompt GRB phase or the afterglow phase is predicted, its flux level and temporal behavior is not clear, given that no emission in this energy range has ever been detected unambiguously by now. With the high sensitivity of the H.E.S.S. array and given favorable observational conditions, VHE flux levels predicted by GRB models are within reach.

VHE emission from GRBs

The highest energy radiation from GRBs ever detected firmly by any instrument was a ~ 18 GeV photon coming from GRB 940217, detected using EGRET about 1.5 hour after the onset of the GRB [5]. From the theoretical point of view, photons with energies up to ~ 10 TeV from GRBs are expected (for review, see e.g. [6] and references therein). In one case considered by [7] where electron IC emission dominates, an energy flux of about $5 \times 10^{-12}\mathrm{erg\,cm^{-2}s^{-1}}$ at 1 TeV one day after GRB onset is predicted[1], if one assumes a redshift of 0.15. This is within H.E.S.S. detection limit. The detection of VHE photons (and its quantity) or upper limits (in cases of null detections) could be used to constrain GRB properties, eg. bulk Lorentz factor and ambient density [8, 9].

Currently, the most sensitive detectors in the VHE gamma-ray regime are air Cherenkov systems, including H.E.S.S., MAGIC, VERITAS, and Whipple. While still no detection using any of the instruments is established, results on upper limits have been reported by the MAGIC collaboration [10] and the Whipple collaboration [11]. In general, their results are consistent with power-law extrapolation of the keV spectra obtained with satellite data.

At cosmological distances, one has to take into account the absorption of VHE gamma-ray by extragalactic background light (EBL). For low-redshift GRBs and sub-TeV energies, the attenuation is less significant. Moreover, there is evidence from distant blazar spectra that the Universe is more transparent for VHE gamma-ray than previously thought [12]. Thus, current air Cherenkov systems are able to observe out to $z \sim 1$ at ~ 100 GeV.

H.E.S.S. GRB observing program

The H.E.S.S. array is a system of four 13m-diameter Imaging Atmospheric Cherenkov Telescopes (IACTs) located in the Khomas Highland of Namibia [13]. Since the completion of the whole array in late 2003, H.E.S.S. has proven to be very successful in VHE gamma-ray astronomy, thus opening a new era in astronomy in this observational window. The array is one of the most sensitive VHE gamma-ray detectors. For a point source with integral flux $\sim 1.4 \times 10^{-11}$ ph cm^{-2}s^{-1} above 1 TeV and spectral index 2.6, only a 2-hour H.E.S.S. observation is required for a 5-σ detection.

We have been observing GRBs since early 2003. At the beginning of 2005, a GRB coordination team was set up and since then our GRB observation program has been fully established. An automated program is running on site to keep the shift crew alerted of any new detected GRBs in real-time.

We have followed on-board GRB triggers distributed by the *Swift* satellite, as well as triggers from INTEGRAL and HETE II confirmed by ground-based analysis. Upon the reception of a GRB Coordinates Network (GCN [14]) notice from one of these satellites (with good indications that the source is a genuine GRB), we will observe the burst position as soon as possible, limited to $\mathrm{ZA} < 45°$ (to ensure a reasonably low energy threshold) and HESS dark time[2]. We start observing the burst position up to 24 hours after the burst time. The nominal observation time is 2 hours (within the above observational constraints). If there are tentative positive signals indicated by a quick analysis, further observations will be carried out accordingly.

In Table 1, we show 17 GRBs which we have observed using H.E.S.S. during the period from March 2003 to April 2007. For each burst, the start observation time, live-time of the observation and the mean zenith angle (ZA) are presented.

Data Analysis and Results

Calibration of data, the event reconstruction and rejection of the cosmic-ray background (i.e. gamma-ray event selection criteria) were performed as described in [15]. Except for the case of GRB 030329, where a different analysis cut was used because only two telescopes were operating, standard analysis procedures as described in [16]

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[1] The attenuation factor due to EBL absorption is about 0.1 at 1 TeV for a GRB with $z = 0.15$ [12].

[2] H.E.S.S. observations are taken in darkness and when the moon is below the horizon. The fraction of H.E.S.S. dark time is about 0.2.

were applied to each GRB to search for any possible signal. The background was then estimated using the reflected-region model as described in [17]. The energy threshold ($E_{\rm th}$) after analysis cuts of each GRB observation (mainly depending on the zenith angle) is shown in Table 1.

No evidence of excess events for any GRB observed using H.E.S.S. was seen. The 99.9% confidence level (c.l.) integral photon flux upper limits above $E_{\rm th}$ using the method of [18] for each GRB are included in Table 1. For GRBs with reported redshifts < 1, the EBL-corrected values using the P0.45 model as in [12] are also shown. For GRBs with redshifts > 1, the attenuation of VHE gamma-ray by EBL is large, thus the EBL-corrected values are much higher (which are not shown here).

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Table 1: GRBs observed with H.E.S.S. from March 2003 to April 2007. For each burst, start observation time after GRB onset ($t_{\rm start}$), live-time, mean zenith angle (ZA), energy threshold ($E_{\rm th}$) and 99.9% c.l. upper limit (UL) of the observation are presented.

GRB	$t_{\rm start}$	live time	mean ZA	$E_{\rm th}$	Flux ULs*	redshift
		(hrs)	(deg)	(GeV)	(photon cm^{-2} s^{-1})	
070429A	64 min	0.4	23	290	1.06×10^{-12}	–
070419B	15.1 h	0.9	47	700	3.89×10^{-12}	–
070209	15.4 h	1.0	41	480	7.48×10^{-12}	–
060526	4.7 h	1.9	25	200	5.90×10^{-12}	3.21 [19]
060505	19.4 h	2.0	42	450	$6.29 \times 10^{-12}(1.55 \times 10^{-11})$	0.089 [20]
060403	13.6 h	0.9	39	310	9.37×10^{-12}	–
050922C	52 min	0.7	23	200	1.22×10^{-11}	2.199 [21]
050801	16 min	0.5	43	370	3.40×10^{-12}	1.56†
050726	10.8 h	2.0	40	400	4.22×10^{-12}	–
050607	14.8 h	1.5	37	290	5.39×10^{-12}	–
050509C	21 h	1.0	22	220	1.08×10^{-11}	–
050209	20.2 h	2.5	48	520	3.32×10^{-12}	–
041211	9.5 h	2.0	46	420	4.00×10^{-12}	–
041006	10.4 h	1.4	27	220	$1.01 \times 10^{-11}(2.69 \times 10^{-8})$	0.716 [22]
040425	26 h	0.4	28	230	2.37×10^{-11}	–
030821	18 h	1.0	28	290	1.52×10^{-11}	–
030329	11.5 d	0.5	60	1360	$2.58 \times 10^{-12}(5.59 \times 10^{-11})$	0.169 [23]

* Flux upper limits ($> E_{\rm th}$) are at the 99.9% c.l. using the method given in [18]. For GRBs with redshifts < 0.2, the EBL-corrected values in the energy range [$E_{\rm th}$,10 TeV] are also given in the brackets. For GRB041006, the EBL-corrected value in the energy range [$E_{\rm th}$,0.7 TeV] is given.

† Photometric redshift according to [24].