Gamma-ray burst observations with H.E.S.S.

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Abstract

The High Energy Stereoscopic System (H.E.S.S.) consists of four Imaging Atmospheric Cherenkov Telescopes (IACTs) in Namibia for the detection of cosmic very-high-energy (VHE) gamma-rays. Gamma-ray bursts (GRBs) are among the potential VHE gamma-ray sources. VHE $\gamma$-emission from GRBs is predicted by many GRB models. Because of its generally fast-fading nature in many wavebands, the time evolution of any VHE $\gamma$-radiation is still unknown. In order to probe the largely unexplored VHE $\gamma$-ray 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, VHE $\gamma$-ray flux levels predicted by GRB models are well within reach. We report the H.E.S.S. observations of and results from some of the reported GRB positions during March 2003 – May 2006.

Key words:
Gamma-ray bursts; Gamma-ray astronomy

1 H.E.S.S. telescopes

The H.E.S.S. array is a system of four 13m-diameter IACTs located in the Khomas Highland of Namibia \cite{Hinton2004}. 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
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\(\sigma\) detection. With this high sensitivity, we are capable to detect any signal comparable to that predicted in Zhang and Mészáros (2001) up to several days (see next section). A review of the system and observational highlights of H.E.S.S. can be found in Hofmann (2005).

## 2 Very-high-energy afterglow emission from GRBs

The highest energy radiation from GRBs ever detected unambiguously was a \(~ 18\) GeV photon coming from GRB 940217 using EGRET 1.5 hour after the GRB onset (Hurley et al., 1994). There is also no evidence of high-energy cut-off in the spectra of seven GRBs detected with EGRET at energies \( > 30\) MeV. There could be an energy flux from GRBs in the largely unexplored VHE \(\gamma\)-ray regime comparable to that radiated in keV-MeV or X-ray-to-radio energies.

In the context of standard models, photons with energies up to \(~ 10\) TeV from GRBs are expected. Possible radiation mechanisms for VHE \(\gamma\)-ray production include electron Inverse-Compton (IC) emission, proton synchrotron radiation, and \(\pi^0\) decay from \(p\gamma\) interactions. In one case considered by Zhang and Mészáros (2001) where electron IC emission dominates (Fig. 2b in the reference), an energy flux of about \(5 \times 10^{-11}\) erg cm\(^{-2}\)s\(^{-1}\) at 1 TeV one day after GRB onset is predicted, if one assumes a redshift of 0.15. This is well within H.E.S.S. detection limit. The detection of VHE \(\gamma\) photons (and its quantity) or upper limits could be used to constrain GRB properties, e.g. bulk Lorentz factor and ambient density (Pe’er and Waxman, 2005; Wang et al., 2005).

At cosmological distances, one has to take into account the absorption of VHE \(\gamma\) photons by extragalactic background light (EBL; their density in the range of infrared to optical is still uncertain). However for low-redshift GRBs and sub-TeV energies, the attenuation is less significant. There are also evidences from distant blazar spectra that the Universe is more transparent for VHE \(\gamma\) photons than previously thought (Aharonian et al., 2006a). Thus, current air Cherenkov systems are able to observe out to \(z \sim 1\) at \(\sim 100\) GeV.

## 3 H.E.S.S. GRB observing program

We currently follow on-board GRB triggers distributed by Swift, as well as triggers from HETE II and INTEGRAL confirmed by ground-based analysis. Upon the reception of a GRB Coordinates Network (GCN) notice from one of these satellites (with good indications of being a true GRB), we will observe...
the burst position as soon as possible, limited to $\theta_{ZA} < 45$ degrees (for reasonably low energy threshold) and HESS dark time\(^1\). We start observing the burst position up to 24 hours after the burst time.

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. By May 2006, 14 GRB positions had been observed using H.E.S.S. (see Table 1). The bursts are ranked according to the relative expected VHE $\gamma$-signal as estimated from the fluence in the 15-150 keV band multiplied by a factor of $t^{-1.3}$, where $t$ is the delay observation time. For simplicity, the effect of EBL absorption is neglected here.

4 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 Aharonian et al. (2006b). Except for the case of GRB 030329, where a different analysis cut was used because only two telescopes were operating, standard analysis cuts as described in Aharonian et al. (2006b) were applied to each GRB to search for any possible signal.

No evidence of excess events for any GRB observed using H.E.S.S. was seen. The 99.9% confidence level (c.l.) upper limits using the method of Feldman and Cousins (1998) for each GRB are included in Table 1. No EBL correction was applied to the upper limits shown here.

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References

Aharonian, F. et al. (HESS collaboration) 2006a, Nature, 440, 1018.
Aharonian, F. et al. (HESS collaboration) 2006b, A&A, 457, 899.

\(^1\) H.E.S.S. observations are taken in darkness and when the moon is below horizon; the dark time fraction is therefore about 0.2.
Table 1
GRBs observed with H.E.S.S. from March 2003 to May 2006, ranked according to the relative expected VHE γ-signal (see text). For each burst, start observation time, live time, mean zenith angle (ZA), energy threshold ($E_{th}$) and 99.9% c.l. upper limits (ULs) of the observation are shown.

| GRB     | Observation starts | live time | mean ZA | $E_{th}$ | ULs ($> E_{th}$) | redshift (z) |
|---------|--------------------|-----------|---------|----------|-----------------|--------------|
|         | after GRB onset    | (hrs)     | (deg)   | (GeV)    | (cm$^{-2}$ s$^{-1}$)    |              |
| 050922C | 52 min             | 0.7       | 23      | 200      | $1.22 \times 10^{-11}$ | 2.199$^a$    |
| 050801  | 16 min             | 0.5       | 43      | 370      | $3.40 \times 10^{-12}$ | 1.56$^b$     |
| 041211  | 9.5 h              | 2.0       | 46      | 420      | $4.00 \times 10^{-12}$ | –            |
| 041006  | 10.4 h             | 1.4       | 27      | 220      | $1.01 \times 10^{-11}$ | 0.716$^c$    |
| 040425  | 26 h               | 0.4       | 28      | 230      | $2.37 \times 10^{-11}$ | –            |
| 030821  | 18 h               | 1.0       | 28      | 290      | $1.52 \times 10^{-11}$ | –            |
| 060526  | 4.7 h              | 1.9       | 25      | 200      | $5.90 \times 10^{-12}$ | 3.21$^d$     |
| 030329  | 11.5 d             | 0.5       | 60      | 1400     | $2.58 \times 10^{-12}$ | 0.169$^e$    |
| 050209  | 20.2 h             | 2.5       | 48      | 520      | $3.32 \times 10^{-12}$ | –            |
| 050726  | 10.8 h             | 2.0       | 40      | 400      | $4.22 \times 10^{-12}$ | –            |
| 060403  | 13.6 h             | 0.9       | 39      | 310      | $9.37 \times 10^{-12}$ | –            |
| 050607  | 14.8 h             | 1.5       | 37      | 290      | $5.39 \times 10^{-12}$ | –            |
| 060505  | 19.4 h             | 2.0       | 42      | 450      | $6.29 \times 10^{-12}$ | 0.089$^f$    |
| 050509C | 21 h               | 1.0       | 22      | 220      | $1.08 \times 10^{-11}$ | –            |

$^a$D'Elia et al. (2005); $^b$Photometric z according to De Pasquale et al. (2007); $^c$Price et al. (2004); $^d$Berger and Gladders (2006); $^e$Stanek et al. (2003); $^f$Ofek et al. (2006)

Berger, E. and Gladders, M. 2006, GCN Circular, 5170.
D’Elia, V. et al. 2005, GCN Circular 4044.
De Pasquale, M. et al. 2007, M.N.R.A.S., in press
Feldman, G. J. and Cousins, R. D. 1998, Phys. Rev. D., 57, 3873.
Hinton, J. A. 2004, New Astronomy Review, 48, 331.
Hofmann, W. 2005, H.E.S.S. status in Proc. Conf. Towards a Network of Atmospheric Cherenkov Detectors VII, Palaiseau, France, 43.
Hurley, K. et al. 1994, Nature, 372, 652.
Ofek, E. O. et al. 2006, GCN Circular, 5123.
Pe’er, A. and Waxman, E. 2005, Ap. J., 633, 1018.
Price, P. A. et al. 2004, GCN Circular, 2791.
Stanek, K. Z. et al. 2003, Ap. J., 591, L17.
Wang X. Y. et al. 2005, A&A, 439, 957.
Zhang, B. and Mészáros, P. 2001, *Ap. J.*, **559**, 110.