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The H.E.S.S. II GRB Observation Scheme

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Abstract. Gamma-ray bursts (GRBs) are some of the Universe's most enigmatic and exotic events. However, at energies above 10 GeV their behaviour remains largely unknown. Although space based telescopes such as the Fermi-LAT have been able to detect GRBs in this energy range, their photon statistics are limited by the small detector size. Such limitations are not present in ground based gamma-ray telescopes such as the H.E.S.S. experiment, which has now entered its second phase with the addition of a large 600 m² telescope to the centre of the array. Such a large telescope allows H.E.S.S. to access the sub 100-GeV energy range while still maintaining a large effective collection area, helping to potentially probe the short timescale emission of these events.

We present a description of the H.E.S.S. GRB observation programme, summarising the performance of the rapid GRB repointing system and the conditions under which GRB observations are initiated. Additionally we will report on the GRB follow-ups made during the 2014-15 observation campaigns.

Introduction

GRBs are some of the most energetic and distant astronomical objects yet discovered. Although their source it is not yet certain, their most likely progenitors are collapsing massive stars (long GRBs) and merger events (short GRBs). So far they have been detected in a number of different energy ranges of the electromagnetic spectrum, even up to GeV energies (e.g. [1]) which makes them a prime candidate for observation by very high energy telescopes such as H.E.S.S. (e.g. [2, 3, 4, 5]).

Due to their highly energetic nature, GRBs may also be a source of ultra-high-energy cosmic rays (UHECRs; [6]), as well as gravitational waves and neutrinos. By observing and attempting to understand the nature of GRBs it is therefore possible to attempt to answer many important scientific questions. Such as, understanding the physics of the jet likely launched from the GRB, the search for UHECR acceleration from the GRB jets, the attenuation of the highest energy gamma-rays by the extra-galactic background radiation fields and tests for Lorentz invariance violation (e.g. [7]) in these energetic distant sources.

The H.E.S.S. gamma-ray telescope array has recently entered its second phase by the addition of a fifth, almost 600 m² telescope to the centre of the array (CT5), greatly improves the energy threshold of the instrument (~50

FIGURE 1. GRB observation total response time (top), response time scaled by the angular distance of the repointing (middle) and the data acquisition system time overhead (bottom) for several real and fake GRB observations. Figure reproduced from [10].

GeV). This reduction in threshold, combined with the still large effective area ($> 10^4 \text{m}^2$) has substantially improved the changes of a GRB detection. The combination of H.E.S.S. II with facilities at other wavelengths would allow the study of GRBs in ways never before possible.

The H.E.S.S. II Rapid Repointing System

As the fall of in intensity of GRBs after the initial burst is quite rapid, in order to maximise the chance of a significant detection with the H.E.S.S. array, we must ensure the telescopes are able to slew to the target positions and begin observations as soon as possible after the GRB. This repointing time is minimised firstly by the significant upgrade in drive system performance of CT 5 over the original H.E.S.S. telescope (see [8] for details), allowing the instrument to perform a 180° rotation in only 110 seconds. In addition the CT 5 is also able to point in *reverse* mode, enabling the telescope to slew through zenith allowing it to arrive on target much faster for GRBs that would otherwise require a long slew in azimuth.

In order to ensure a response to GRB alerts as soon as possible a fully automatic array repointing system has been implemented when a GRB alert matching the observation criteria is received. This system begins observations immediately after an alert is received, initiating a special purpose run type, which minimises the hardware and software state transitions to ensure the fastest possible repointings (see [9]). This system is regularly checked by the injection of fake GRBs into the system. Figure 1 shows the response time of the repointing system to both real and fake bursts over time, demonstrating the optimisation of system response time.

GRB Observations with H.E.S.S. II

The GCN System

H.E.S.S. currently receives GRB alerts and localisations through the Gamma-ray Coordinates Network (GCN) [11], which automatically distributes the localisation of GRB detections from a number of instruments in different energy ranges typically in less than several minutes from burst detection. H.E.S.S. reacts to GRB alerts from two instruments, firstly the *Fermi* Gamma-ray Burst Monitor (GBM) [12] provides around 200 GRB localisations a year with an accuracy of 2-5 degrees [13]. In addition H.E.S.S. also reacts to alerts from the *Swift* Burst Alert Telescope (BAT) [14], which issues around 90 alerts per year with arc-minute level localisation accuracy.

Selection Criteria

GRB follow-ups are selected by H.E.S.S. using cuts based on the observability of the GRB position from the H.E.S.S. site and the likely presence of high energy emission. H.E.S.S. GRB observations are split into two categories, *prompt* and *afterglow* observations.

Prompt GRBs are classified as those where the burst occurs during H.E.S.S. observation time and an array repointing can begin immediately. For prompt GRBs only observability criteria are applied, only requiring the GRB position to be visible for 30 minutes or more above 60 degrees zenith angle. Observations then proceed for 2 hours or until the source falls below 60 degrees zenith angle. If further (more accurate) GRB positions are issued by any instrument the H.E.S.S. observation position can then be updated to observe this point.

Afterglow observations are defined as those where the GRB position is not immediately observable from the H.E.S.S. site. These bursts are subject to cuts on both the observability as well as the likelihood of high energy emission. Stronger observability cuts are applied to such bursts, requiring the GRB to be observable for at least 30 minutes above 45 degrees zenith angle. Additionally cuts are placed on the redshift of the GRB where available. Most often no redshift is available, for such bursts a maximum of 4 hours observation delay is accepted, increasing to 6 hours for redshift below 1, 12 hours for redshift below 0.3 and 24 hours for redshifts below 0.1. For such afterglow observations a human is included in the decision making process, allowing exceptions to be made for bursts of particular interests, for example if a confirmed high energy Fermi-LAT detection has been made.

GRB 140818B

GRB 140818B was a long GRB detected by a number of dedicated GRB instruments (Fermi-GBM, Swift-BAT & XRT) at 18:44:16 UTC. This event took place within the Fermi-LAT field of view, however no detection was made by this instrument. A GRB alert was issued through the GCN system and the alert reached the H.E.S.S. observatory at 18:45, immediately triggering an automated array repointing. Observations began at 18:46, with a delay of 117 seconds after burst detection and only 78 seconds after the alert was received. In total H.E.S.S. took 4 consecutive data taking runs with CTs 1-5, with a total of almost 2 hours observation time.

Analysis of this source position was then made using low energy optimised mono event analysis (CT5 only) [15]. Figure 2 shows a significance map of the region surrounding the Swift-BAT reconstructed GRB position, with no significant emission being found. Integral (table 1) and differential (figure 3) upper limits were therefore extracted from the GRB position.

TABLE 1. Integral flux upper limits (99% confidence level above 100 GeV) at the Swift-BAT reconstructed position for the 4 H.E.S.S. data taking runs (assuming a photon index of 2)

Run	Time after burst (s)	Integral Flux Limit ($\text{cm}^{-2}\text{s}^{-1}$)
1	117-1758	3.9×10^{-11}
2	1865-3544	2.6×10^{-11}
3	3613-5298	5.1×10^{-11}
4	5365-7023	1.8×10^{-11}

FIGURE 2. Significance map of the region surrounding GRB 140818B for the first observation run made by H.E.S.S. and the sum of all 4 runs (white cross marks Swift-BAT reconstructed position). Data was analysed using mono event analysis.

FIGURE 3. Differential flux upper limits (99% confidence) for the first observation run made by H.E.S.S..

Conclusions

Taking into account the delay of the GCN system, the hardware and software overheads, and the repointing time of the array we expect to arrive at the GRB target position within 2-3 minutes for many possible observation positions. Analysis of simulated data shows that we expect to be sensitive down to around 50 GeV, greatly overlapping with the observed range of energies already seen by Fermi-LAT, with a greatly increased effective area. The first mono analysis of H.E.S.S. II data taken on GRB 140818B reveals no significant emission. However, this shows a stable and sensitive low energy analysis and providing upper limits on emission down to 100 GeV.

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