MAGIC follow-up of Gamma-Ray Bursts at very high energies

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Gamma-Ray Bursts (GRBs) are probably one of the most enigmatic sources in current astrophysics, especially when their high-energy (HE, 100 MeV $\lesssim E \lesssim$ 100 GeV) emission is considered. Fermi-LAT observations unveiled many properties of GRBs emission in the GeV band, but its physical origin is not clearly understood yet. In this context, observations of GRBs at very-high-energies (VHE, $E \gtrsim$ 100 GeV) could provide a crucial contribution in the understanding of the physical processes driving GRB emission at the highest energies. For this purpose, ground facilities performing fast-follow up of GRBs above $\sim$ 100 GeV with high sensitivity are needed. In particular the MAGIC telescopes were designed to have a low energy threshold ($\sim$ 50 GeV) and to perform fast follow-up of GRBs thanks to their fast slewing movement. Up to date, 101 GRBs were followed-up by MAGIC in different observational conditions, providing a large data sample to search for VHE emission. This contribution will focus on the MAGIC GRBs follow-up campaign and highlight the observation of the short and nearby (z = 0.16) GRB 160821B, an interesting event showing a hint of VHE gamma-ray emission.

Keywords: Gamma-Ray Bursts; MAGIC; VHE emission.

1. Introduction

Gamma-Ray Bursts (GRBs) are transient events occurring at cosmological distances, releasing a huge amount of energy in electromagnetic radiation in a small time period.[1] After more than 50 years from their discovery, many aspects of GRBs are still puzzling. Among them, the origin of their high-energy (HE) emission and the possible presence of a very-high-energy (VHE) component are still debated topics in GRB physics. In the HE range, Fermi-LAT provides most of the information, from which it is seen that the GeV emission is delayed with respect to the lower energy emission and with a long lasting duration. Generally the HE spectra are well fitted using a power-law model, even if in some cases an additional spectral component is needed.[2] The latter could be linked with a process producing photons at VHE, pointing out to the importance of performing GRB observations in the energy range above $\sim$ 100 GeV. In this context, ground-based instruments like Imaging Atmospheric Cherenkov Telescopes (IACTs) can provide a good photon statistics in the VHE range. Among IACTs, MAGIC has some important figures of merit which are crucial for the follow-up of GRBs, namely a low energy threshold, a high sensitivity and a lightweight structure to allow fast repositioning.

In the following contribution we describe the MAGIC GRB follow-up program, focusing on the observational challenges of such a project and on the results obtained in the last years.

2. The MAGIC experiment

MAGIC is an IACT experiment with two identical telescopes of 17 m diameter.[3] It is located in one of the Canary Islands, La Palma (28.8° N, 17.8° W), at an altitude of 2200 m a.s.l. The MAGIC telescopes were designed to observe astrophysical sources of gamma-rays in stereoscopic mode above an energy threshold of ~ 50 GeV at trigger level and at zenith. The sensitivity which can be achieved by MAGIC is as low as 0.7% of the Crab Nebula flux above 220 GeV in 50 h.[4] For short timescales, which are important in the case of the follow-up of transient sources like GRBs, the flux sensitivity is at the level of 10% of the Crab Nebula flux above 100 GeV in 1 hour.

2.1. *GRBs follow-up with MAGIC*

The detection of Gamma-Ray Bursts in the VHE band is one of the primary scientific goals of MAGIC and each year a considerable amount of hours are devoted to their follow-up. The transient nature of GRBs makes their follow-up challenging for facilities like MAGIC, characterized by a limited field of view. For this reason, MAGIC was designed to be able to repoint in short time[a] in response to GRB alerts coming from the GCN (*Gamma-ray Coordinates Network*[b]). These alerts are processed by the MAGIC Automatic Alert System, which checks the visibility of the targets from the MAGIC site. If a GRB is observable, an automatic procedure repoints the telescopes in fast mode towards its sky position, while the different subsystems are prepared for data taking. This procedure was revisited in 2013 in order to be more robust against possible hardware failures. Beside the automatic follow-up, MAGIC performs so called *late-time observations* of GRBs detected by *Fermi*-LAT: the source is observed even after 24 h or more with respect to the trigger time of the event. The goal of such strategy is to detect a possible long-lasting VHE emission from GRBs.

In 15 years of operation, up to June 2018, MAGIC followed-up 101 GRBs in good observational conditions and not affected by any major hardware problem. See Fig. 1 for a skymap of such events. Despite the huge effort, MAGIC could not detect any VHE gamma-ray signal from GRBs (status up to June 2018). In one case though, described below, MAGIC data shows a hint of signal in the VHE band.

2.2. *GRB 160821B*

Swift-BAT detected the short GRB 160821B ($T_{90} = 0.48$ s in the 15-350 keV energy range) at 22:29:13 UT[6] and MAGIC received the alert at 22:29:26 UT. Using

[a] 25 s for a 180° rotation.
[b] `https://gcn.gsfc.nasa.gov/`.

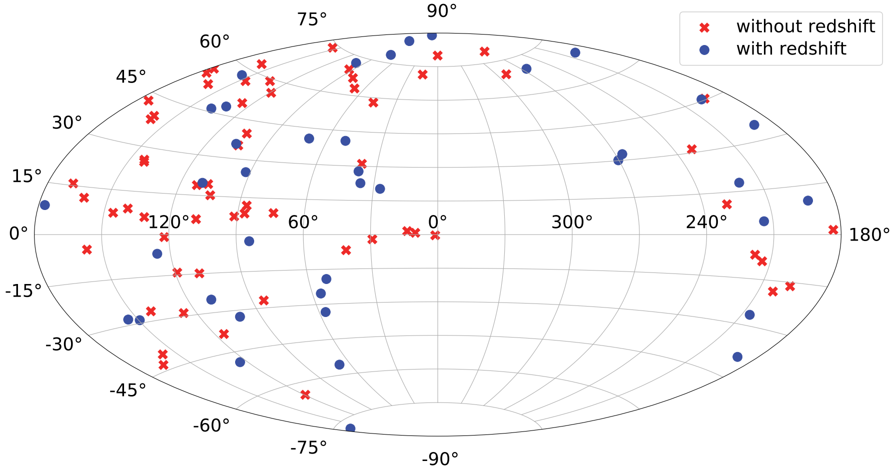

Fig. 1. Sky locations of the 101 GRBs followed-up by MAGIC up to June 2018. Filled blue dots are GRBs with redshift estimation, while red crosses are GRBs without redshift.

the automatic GRB procedure, MAGIC was on target just 24 s after the onset of the GRB. Thanks to optical observations by the William Herschel Telescope, the redshift of the GRB was estimated to be $z = 0.16$.[7]

MAGIC observation started under moderate moonlight conditions at a zenith of ∼34 degrees, with a night sky background (NSB) level between three and five times the one under dark moonless conditions. The first 1.5 hours of data were affected by a non optimal atmospheric transmission, due to the presence of clouds. For the rest of the observation the weather conditions were good and the NSB increased at a level between five and nine times with respect to dark conditions. The observation stopped after 4 hours from the trigger time, with the GRB reaching a zenith of ∼55 degrees.

A dedicated analysis was performed on GRB 160821B, for two reasons in particular: the presence of the Moon during observations and the low atmospheric transmission in the first part of data taking. The former issue is handled as as described in Ref. 5. In the latter case, the data are corrected for the low atmospheric transmission using the data collected by the LIDAR instrument installed on top of the MAGIC counting house building.[8] The dedicated analysis resulted in a hint of gamma-ray signal detection with a significance of 3.1σ, as shown in Fig. 2.

If we make the assumption that this signal is real, this GRB would be the first to be detected at VHE energies and it would open a new window in the understanding of (short) GRBs emission. A detailed modeling and interpretation of such event will be the main topic of an upcoming paper, currently in preparation.

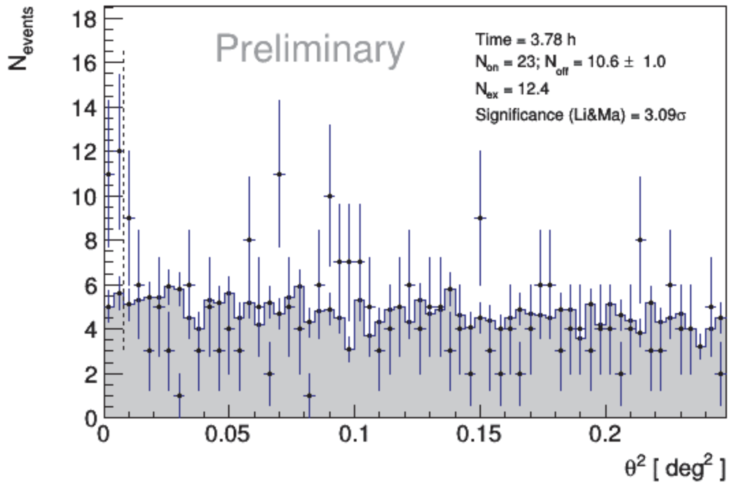

Fig. 2. θ^2 distribution for data taken on GRB 160821B (points) and for the background events (grey shaded area). θ^2 is defined as the squared angular distance between the nominal position of the source and the reconstructed arrival direction of the events.

3. Future prospects for GRB follow-up with MAGIC

MAGIC is currently one of the main actors in the follow-up of GRBs in the VHE band. The automatic procedure ensures to observe GRBs as fast as possible, without causing hardware failures. The efforts in pushing the capabilities of the telescopes under moonlight or non optimal weather conditions provide MAGIC with a higher chance to detect a GRB at very high energies, as indicated by the case of GRB 160821B. Even in this case, there is room for improvement. A change in the automatic procedure is foreseen in the nearby future, namely the inclusion of the Sum Trigger.[9] This novel trigger system, used successfully when MAGIC operated as a single telescope, is now in an advanced and stable state, providing an energy threshold as low as 30 GeV for low zenith angles. This feature is crucial for the observation of distant sources like GRBs.

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