New Frontiers in Black Hole Astrophysics
Proceedings IAU Symposium No. 324, 2016
Andreja Gomboc, ed.

doi:10.1017/S1743921317001442

Search for High Energy emission from GRBs with MAGIC

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Abstract. Gamma-Ray Bursts (GRBs) are the most violent explosions in the Universe, releasing a huge amount of energy in few seconds. While our understanding of the prompt and the afterglow phases has increased with *Swift* and *Fermi*, we have very few information about their High Energy (HE, $E \lesssim 100\,\mathrm{GeV}$) emission components. This requires a ground-based experiment able to perform fast follow-up with enough sensitivity above $\sim 50\,\mathrm{GeV}$. The MAGIC (Major Atmospheric Gamma-ray Imaging Cherenkov) telescopes have been designed to perform fast follow-up on GRBs thanks to fast slewing movement and low energy threshold ($\sim 50\,\mathrm{GeV}$). Since the beginning of the operations, MAGIC followed-up 89 GRBs in good observational conditions. In this contribution the MAGIC GRBs follow-up campaign and the results which could be obtained by detecting HE and Very High Energy (VHE, $E \gtrsim 100\,\mathrm{GeV}$) γ-rays from GRBs will be reviewed.

Keywords. Gamma-Ray Bursts, MAGIC, high-energy emission

1. Introduction

Gamma-Ray Bursts are transient sources caused by explosive events with a relevant release of energy in the form of HE radiation. Even after almost 50 years since their discovery, there are still open questions about them (see Kumar and Zhang (2015) for a review). One of these concerns the possible emission by GRBs of VHE photons. Observations at lower energies by the *Large Area Telescope* (LAT) instrument onboard the *Fermi* satellite prove that is relatively common for GRBs to emit photons with GeV energies, with the highest energy photon (94 GeV) detected from GRB130427A (Ackermann *et al.* (2014)). Two peculiar features of the GeV emission are the delay with respect to the lower energies and the long lasting duration (see for example Abdo *et al.* (2009)), even up to one day again in the case of GRB130427A. Usually the GeV spectrum can be fitted by an extension of the power law describing the low energy emission, but in some GRBs a second component is clearly present in the LAT data. The physical processes underlying this kind of emission could be better understood with the detection of a possible VHE signal from GRBs with ground-based instruments, like Cherenkov telescopes.

Among the current Imaging Atmospheric Cherenkov Telescopes (IACTs), MAGIC has a low energy threshold and a fast repositioning speed which allow it to follow-up GRBs in an efficient way. In this contribution we describe the possible models of VHE emission and the MAGIC follow-up program for GRBs, focusing on its performance after the new automatic GRB observation procedure was implemented. No VHE signal has yet been detected from GRBs by IACTs experiments.

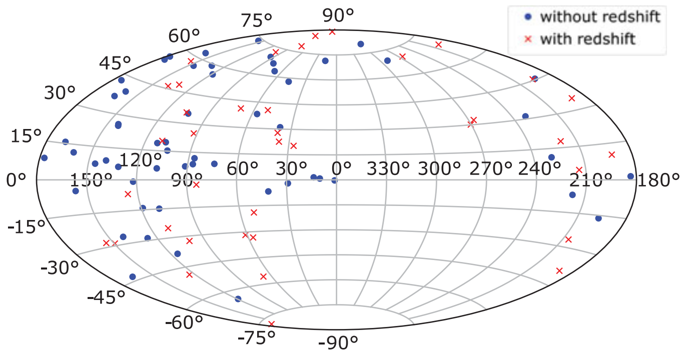

Figure 1. Galactic Aitoff projection of the positions of the GRBs followed up by MAGIC.

2. VHE emission models for GRBs

Possible VHE emission from GRBs could be explained in first approximation as an extension of the low-energy processes. The most simple case is the synchrotron emission by relativistic electrons in the forward shock of the afterglow. As shown by Kumar and Duran (2010), in this case the HE synchrotron emission can be used to predict very well the flux of low energy emission (e.g. optical and X-ray band). Synchrotron models can have a leptonic (see Zhang and Meszaros (2001)) or hadronic origin (see Böttcher and Dermer (1998) and Pe'er and Waxman (2004)). A second model is the Self-Synchrotron Compton (SSC) emission in the afterglow (Sari and Esin (2001)), which however fails in explaining the MeV-GeV delayed emission. More exotic processes include the upscattering of prompt γ-rays by electrons (Meszaros and Rees(1994); Belobodorov (2005); Fan And Wei (2005)), upscattering of CMB photons (Plaga (1995)) or Compton scattering by electrons of photospheric thermal emission (Toma *et al.* (2011)).

Moreover, the detection of the VHE emission of GRBs could answer some pending questions like their possible role in the production of UHECRs or neutrinos (see Waxman (1995) and Paczynsky and Xu (1994)).

3. GRBs follow-up by MAGIC

MAGIC is a system of two Cherenkov telescopes, each with a diameter of 17 m. They are located in the Canary island of La Palma (28.8° N, 17.8° W), almost at the top of the Roque de Los Muchachos mountain at an altitude of 2200 m a.s.l. (Aleksic *et al.* (2016a)). MAGIC observes gamma-ray sources in stereoscopic mode, reaching a sensitivity of less than 0.7% of the Crab Nebula flux for energies above 220 GeV in 50 h and an energy threshold at trigger level of ∼50 GeV at zenith (Aleksic *et al.* (2016b)), or even less using the so called *sum trigger*. GRBs are one of the primary targets for MAGIC, being one of its Key Observation Programs (KOP). MAGIC was designed from the beginning to be able to react very fast to external alerts coming from the Gamma-Ray Burst Coordinate Network (GCN†).

Alerts from satellite-based experiments like *Swift* and *Fermi* are sent to MAGIC through TCP/IP socket and a specific program receives and processes them in order to decide if they comply with predefined observation criteria. When this happens, the sky coordinates of the event are sent to the central control of the MAGIC telescopes, which are promptly repointed to the GRB position for data taking. Given their transient nature and their short duration, in particular as far as the prompt emission is concerned,

† `http://gcn.gsfc.nasa.gov/`

https://doi.org/10.1017/S1743921317001442 Published online by Cambridge University Press

the follow-up of GRBs should be done as fast as possible after the onset. The MAGIC telescopes were built with a lightweight carbon-fiber structure which allows them to repoint within few tens of seconds after the alerts.

Since 2013, a new automatic procedure was adopted in order to reduce the number of failures (most of them hardware related), namely without stopping the Data Acquisition (DAQ) system during the slewing. The observation of the GRB is then carried on up to 4 h after the onset taking into account the observational conditions. In the last year, the MAGIC GRB group considered to change the GRB observation strategy, extending the standard four hours of observation in the case of particularly bright events. We refer to this new approach as "late time observations". The primary targets that could be the aim of the new strategy are LAT detected GRBs, since they are likely to present GeV emission extended in time in the afterglow phase. Although the alert system was not yet updated for this kind of targets, there were few events (GRB160310A, GRB160509A, GRB160623A, GRB160625B) which were followed at late times and whose analysis is ongoing. Even if only flux upper limits could be calculated, they can give important informations about the possible VHE emission, in particular in the case of brighter events:

(*a*) constrain the phase space of the several parameters describing the emission in the VHE band;

(*b*) discard or validate emission models proposed to be at the origin of the possible VHE emission;

(*c*) put limits on SSC emission if it dominates over the synchrotron component (see Beniamini *et al.* (2015));

(*d*) obtain lower limits on the intergalactic magnetic field if VHE emission comes from pair echoes (Takahashi *et al.* (2008)).

An example of the use of flux upper limits is the observation of the afterglow of GRB090102 by MAGIC (Aleksic *et al.* (2014)). Flux upper limits for this burst were derived for the GeV-TeV emission both from MAGIC and Fermi-LAT observations (see Figure 2). The use of the sum trigger allowed for MAGIC an analysis energy threshold of ~ 30 GeV. The results were compared with the simulated afterglow emission by different processes, e.g. synchrotron by electrons or protons and SSC by electrons. Although low-energy observations, especially in the optical, constrained well the parameters characterizing the burst, it was not possible to discriminate between a leptonic or hadronic emission process.

4. Conclusions and prospects

The scientific reward which could be obtained by detecting a VHE signal from a GRB is considerable. Beside understanding the physical processes behind this kind of emission, the detection could improve our understanding of other science cases related to GRBs.

First of all, given the cosmological origin of GRBs, their spectrum at very high energies is attenuated by the Extragalactic Background Light (EBL). The characterization of the attenuated spectrum, with a reasonable assumption on the unabsorbed one, can be used to constrain the intensity of the EBL in the infrared region. It is crucial to have a low energy threshold and enough sensitivity in that energy band, since also for moderate redshift GRBs the attenuation is significant.

A second possibility is the discrimination between leptonic and hadronic emission models for the afterglow phase of GRBs. As shown in Aleksic *et al.* (2014), hadronic models can dominate over leptonic ones in some regions of the phase space of the GRBs parameters. However, a good knowledge of the GRBs parameters could be obtained by lower energies observations, which points out to the strong necessity of multi-wavelength observations of GRBs.

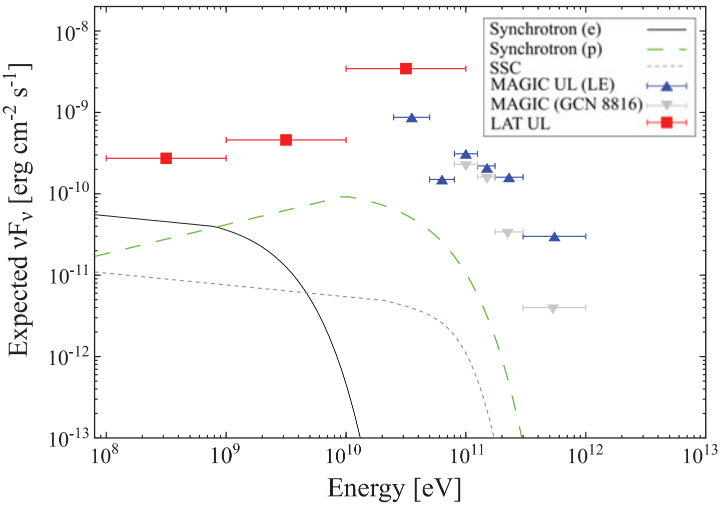

Figure 2. Modelled emission for the afterglow of GRB090102. Up-pointing triangles are MAGIC flux upper limits (95% CL) with optimized low-energy analysis (regular ones are down-pointing triangles). Squares represent LAT 95% CL ULs. The solid and short-dashed lines show the energy flux expected by electron synchrotron and SSC processes, while the long-dashed curve corresponds to the synchrotron emission from protons. From Aleksic *et al.* (2014)

The MAGIC GRB group is now investigating ways to improve the analysis at low energies and the observation strategy. Another improvement could be achieved by using in stereoscopic mode the sum trigger, which is being developed and is supposed to lower routinely the MAGIC energy threshold down to $\sim 30\,\mathrm{GeV}$.

Finally, a forthcoming publication comprising the analysis of all the GRBs observed in good conditions with the new automatic procedure by MAGIC is in preparation.

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