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The MAGIC Telescope and the observation of Gamma Ray Bursts(*)

D. Bastieri(1)(**), N. Galante(2), M. Gaug(3), M. Garczarczyk(4)
F. Longo(5), S. Mizobuchi(4)(6) and L. Peruzzo(1)
for the MAGIC Collaboration(***)

(1) *Università and INFN - Via Marzolo 8, 35131 Padova, Italy*
(2) *Università di Siena and INFN - Via Buonarroti 2, 56127 Pisa, Italy*
(3) *IFAE, Edifici Cn. Facultat Ciències UAB - 08193 Bellaterra (Barcelona), Spain*
(4) *Max Planck Institut für Physik - Föhringer Ring 6, 80805 München, Germany*
(5) *Università and INFN - Via Valerio 2, 34100 Trieste, Italy*
(6) *Ehime University 3 - Bunkyo-cho, Matsuyama 790-8577, Japan*

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Summary. — The MAGIC Telescope, now taking data with an energy threshold well below 100 GeV, will soon be able to take full advantage of the fast slewing capability of its altazimuthal mount. Exploiting the link with the GCN network, the MAGIC Telescope could be one of the first ground-based experiments able to see the prompt emission of Gamma Ray Bursts in the few tens of GeV region.

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1. – Introduction

The MAGIC Collaboration started to build the Telescope since the beginning of 2001. The MAGIC Telescope entered the commissioning phase in October 2003 and had, since then, observed few different sources at different redshifts.

The telescope is one of the so-called *last generation* Cherenkov telescopes and can explore the electromagnetic spectrum starting well below ~ 100 GeV.

Besides MAGIC [1], built at 2200 m a.s.l. in the island of La Palma, Canary Islands, there are three other Collaborations working with *last generation* Cherenkov telescopes: HESS [2] (Windhoek, Namibia), CANGAROO [3] (Woomera, Australia) and VERITAS [4] (Horseshoe Canyon, Arizona, USA). While these last three are actually an array

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(**) E-mail: bastieri@pd.infn.it (corresponding author)
(***) Updated collaborator list at `http://magic.mppmu.mpg.de/collaboration/index.html`

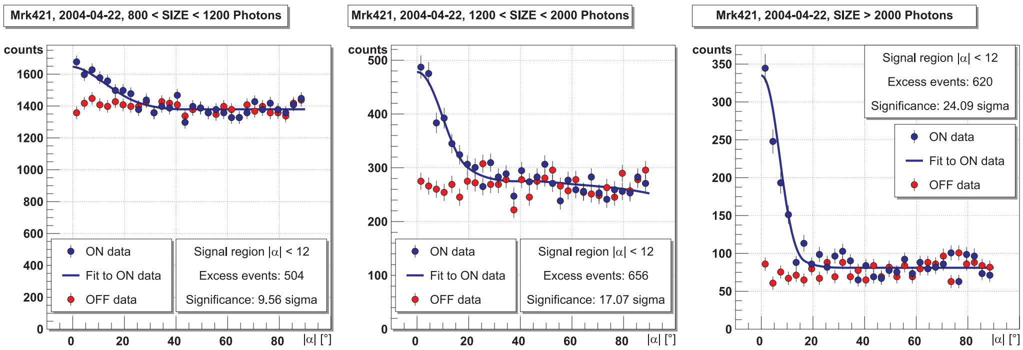

Fig. 1. – Data from 155-minutes of acquisition taken on April 22nd, 2004 with MAGIC pointing at MKN 421. The histogram of *alpha* for on- and off-source observations, are relative to different bin in *size*: 800–1200 (left), 1200–2000 (middle) and more than 2000 photons (right).

of telescopes (4 CANGAROO, 7 VERITAS and 4, at the beginning, also HESS), MAGIC favoured the construction of a single, although huge, telescope, featuring 241 m^2 of reflecting surface instead of $\sim 100\,\mathrm{m}^2$ as the other detectors do.

Nevertheless, a second telescope, clone of the first one, with the same dimensions and improven capabilities, is already foreseen for MAGIC and should be operating in 2007, by the time of the launch of the GLAST mission.

The keystones of the single MAGIC are the huge reflecting area, capable to collect even the few Cherenkov photons emitted by low energy gamma, and the trigger, able to cope with the high rate of the Night Sky Background, filtering it and let the data acquisition mostly deal with real atmospheric showers. In this way, MAGIC should reach the lowest energy threshold among the Cherenkov experiments.

Additionally, the overall mechanical design of the telescope, based upon a carbon-fiber *filigree*, allows the telescope to slew to a new position in less than 20 seconds, in order to follow up the GRB since its early onset.

For this reason, MAGIC is part of GCN, the *GRB Coordinates Network* [5].

In this work, after a brief description of MAGIC first observations, we provide some quantitative predictions on GRB observation for MAGIC, but most of all we show that MAGIC is working, and due to its low energy threshold and fast repositioning capabilities can be the ideal detector to follow the early development of GRB at high energies.

2. – The MAGIC Telescope

MAGIC has been in a commissioning phase since October 2003. Beyond technical runs, there was time also for some physics observations. Both kind of runs were necessary to tune or improve the hardware of the detectors, and the first physics signals were ready in February 2004.

The first sources observed were the Crab Nebula and MKN 421. Both of these sources are a sort of *standard* sources: the Crab has a steady flux that can be used to calibrate detectors, and MKN 421, while not being steady, stays from time to time in a high state with fluxes few times bigger than the Crab one.

These two sources were observed in Winter 2003/2004 (the Crab Nebula) and during Spring 2004 (MKN 421) and both revealed signals well above the 5σ level.

Special attention must be given to fig. 1. It represents the data collected on April

22nd, 2004 pointing at MKN 421 that was in a high state. The so-called IACT (Imaging Atmospheric Cherenkov Technique) used by MAGIC, records for each event the directions of the Cherenkov photons emitted during the shower development. The image is then analysed using a well-established technique that exploits the so-called *Hillas parameters* [6].

Two Hillas parameters have a particular importance in the figure: *alpha* and *size*. *Alpha* is related to the actual direction of the primary particle that initiated the shower, thus an excess in *alpha* must be seen in the direction of a source. *Size* is the number of photons making up the image and is related to the energy of the primary particles (the more energetic is the particle, more photons appear in the image).

The three figures show that the MKN 421 flare was well detected by MAGIC at different energies, and the excess seen in the first figure with *size* ranging from 800 to 1200 photons is consistent with an energy well below 100 GeV.

3. – GRB observability

Having shown that MAGIC is effectively working, let us see what we expect from GRBs. The main parameter influencing the GRB observability is the telescope *duty-cycle* [7]. The duty-cycle of the telescope was calculated as the fraction of sky area accessible to MAGIC per year, where, to be accessible, the following conditions must be met:

- the Sun must be below astronomical horizon or have a zenith angle $> 108°$;
- the minimum angular distance from the Moon must be 30°;
- the relative humidity of the air must be lower than 80%;
- the wind speed must be lower than 10 m/s.

The calculation, using the weather data and ephemerides for year 2001, gives a value slightly below 10%. This means that roughly 1/10 of all GRB alerts can be immediately pursued.

Once determined the fraction of GRB observable, it is possible to estimate how many GRB can be actually observed, that is, if their significance is above 5σ. The number of σ can be calculated using the Li-Ma formula:

$$N_\sigma = Q\frac{(R_{\rm on}-R_{\rm off})T}{\sqrt{(R_{\rm on}+R_{\rm off})T}} = Q\frac{R_\gamma\sqrt{T}}{\sqrt{R_{\rm on}+R_{\rm off}}}\,, \tag{1}$$

where Q, the so-called *quality factor*, represents the efficiency of the analysis and is of order unity at low energies, T is the actual acquisition time and the R's represent the rates. Each R takes into account the particle flux, Φ, and the detector sensitivity to the flux itself, expressed as the *effective area* of the telescope, $A_{\rm eff}(E,\vartheta)$. For instance, we have that the expected signal from the GRB is: $R_\gamma = \int \Phi_{\rm GRB}(E)A^\gamma_{\rm eff}(E,\vartheta){\rm d}E$ and the cosmic-ray background is: $R_{\rm off} = \int \Phi_{\rm CR}(E,\vartheta)A^{\rm CR}_{\rm eff}(E,\vartheta){\rm d}E$.

The effective area of a Cherenkov telescope is quite huge, reaching $10^5\,{\rm m}^2$ around 100 GeV and dropping to $10^4\,{\rm m}^2$ around 50 GeV.

The GRB flux is obtained extrapolating the power law spectrum found inside the BATSE catalogues, taking also into account the cosmological cutoff due to the absorption of high-energy γ by the Metagalactic Radiation Field via $\gamma_{\rm HE}\gamma_{\rm MRF} \to {\rm e}^+{\rm e}^-$.

Of paramount importance for a good observation of GRBs is the delay between the GRB onset and the time when MAGIC can actually observe the GRB. This delay sums up three different times:

1. the time needed by the satellite to recognise that a GRB event may be going on;
2. the time elapsing between the sending of the alert by the satellite, the broadcast via GCN and the final acknowledgment by MAGIC (~ 2 seconds);
3. the slewing time needed by MAGIC to point to the GRB position (< 20 seconds).

It can be calculated that reducing this total delay from 1 minute to 15 seconds increases of a factor 5 the number of observable GRBs.

It should be noted also that the zenith angle, ϑ, enters the formulae for the rates. The number of observable GRBs thus it is not obtained with a straightforward multiplication of the duty-cycle ($\approx 10\%$) times the number of GRBs expected to have a significance $N_\sigma > 5$, but it is better expressed with $N_{\mathrm{GRB}} = \sum_\vartheta D(\vartheta)\eta(\vartheta)$ where $D(\vartheta)$ is the duty-cycle in a given bin of zenith angle, $\eta(\vartheta)$ is the number of GRBs (extrapolated from BATSE catalogues) actually observable in a given bin of zenith angle and the sum is performed over all zenith angle bins.

Values of $\eta(\vartheta)$ range between 5 and 24, strongly depending upon the delays from the GRB onset to the actual observation of the GRB by MAGIC, and the final result is that MAGIC should observe 0.5–2 GRBs per year.

4. – Conclusions

The results exposed in this work show that MAGIC is now operating and can be used to follow the GRB events since its early onset. Observations with Cherenkov detectors below 100 GeV seem now attainable, even if the analysis of low-energy events is still a challenge and may require more work.

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