Proceedings of ICRC 2001: 2759 © Copernicus Gesellschaft 2001

ICRC 2001

Possible GRB observation with the MAGIC Telescope

D. Bastieri, C. Bigongiari, F. Dazzi, M. Mariotti, L. Peruzzo, A. Saggion, P. Sartori and N. Tonello

Dipartimento di Fisica & I.N.F.N. – Padova – Italy.

(for the MAGIC Collaboration)

Abstract. The MAGIC Telescope, with its reflecting parabolic dish of $17\,\mathrm{m}$ of diameter and its careful design of a robust, lightweight, alto-azimuthal mount, is an ideal detector for GRB phenomena. The telescope is an air Cherenkov telescope that, even in the first phase, equipped with standard PMTs, can reach an energy threshold below $30\,\mathrm{GeV}$. The threshold is going to drop well below $10\,\mathrm{GeV}$ in the envisaged second phase, when chamber PMTs will be substituted by high quantum efficiency APDs. The telescope can promptly respond to GRB alerts coming, for instance, from GCN, and can reposition itself in less than 30 seconds, 20 seconds being the time to turn half a round for the azimuth bearing. In this report, the effective area of the detector as a function of energy and zenith angle is taken into account, in order to evaluate the expected yearly occurrence and the response to different kinds of GRBs.

1 Introduction

The MAGIC Telescope is characterised by the lowest, envisaged, energy threshold for ground detectors and by the ability to revolve very fast on both alto-azimuthal axes. These two features may be exploited for GRB follow-ups in the gamma region.

First of all the energy threshold is somewhat below $30\,\mathrm{GeV}$ even in the first phase. This number is very important because, as can be seen, for instance, in figure 2 of Kneiske *et al.* (2000), cosmological GRBs should be affected, in their emission spectra, by the absorption of gamma-rays above this energy by diffuse background radiation. An accurate measure of the GRB energy spectrum and the extrapolation of a cutoff energy can lead, in principle, to infer the distance to the phenomenon, in the hypotheses of suffering mainly from external background absorption and following a proper model for GRBs (see, for example, Mannheim *et al.* (1996) and references therein).

Correspondence to: D. Bastieri (denis.bastieri@pd.infn.it)

In addition, the careful design of the supporting cradle of MAGIC allows rapid repointing of the telescope, as reported in Martinez (1999). In fact, in the hypothesis of handling simultaneously the procedure for the single panel realignment (active optics), in case of a significantly different zenithal position of the incoming GRB, and the procedure of downloading new trigger tables to deal with a higher rate (see Bastieri *et al.* (2001)), together with the azimuthal repointing ($20\,\mathrm{s}$ for a half-turn), we easily get that, on average, MAGIC can observe the GRB location after $10\,\mathrm{s}$ since its recognition by, for example, GCN (see Barthelmy (2000)). Given the short duration of GRB events, at least in the high-energy region, the rapid repositioning of MAGIC telescope may show to be of the utmost importance for the observation of gamma ray bursts.

In this work we intend to provide some quantitative predictions on GRB observation with the MAGIC telescope. As a first step we determine the sky *observability* of MAGIC, a quantity expressed as the product of steradians times the effective time (in hours) of possible observation. This quantity nicely fits into subsequent calculations of GRB occurrence probability, that need several hypotheses on GRB emission spectra and, above all, the MAGIC effective area for gamma induced showers as a function of energy and of zenith angle.

2 Object *observability* for MAGIC

Several constraints are set in order to check the object *observability*, *i. e.* if at a given time a given region of the sky is observable by MAGIC. The constraints used are:

– the Sun must be below the horizon of at least 10°;

– there should be no clouds;

– there should be no strong wind;

– the Moon should be away of at least 90°.

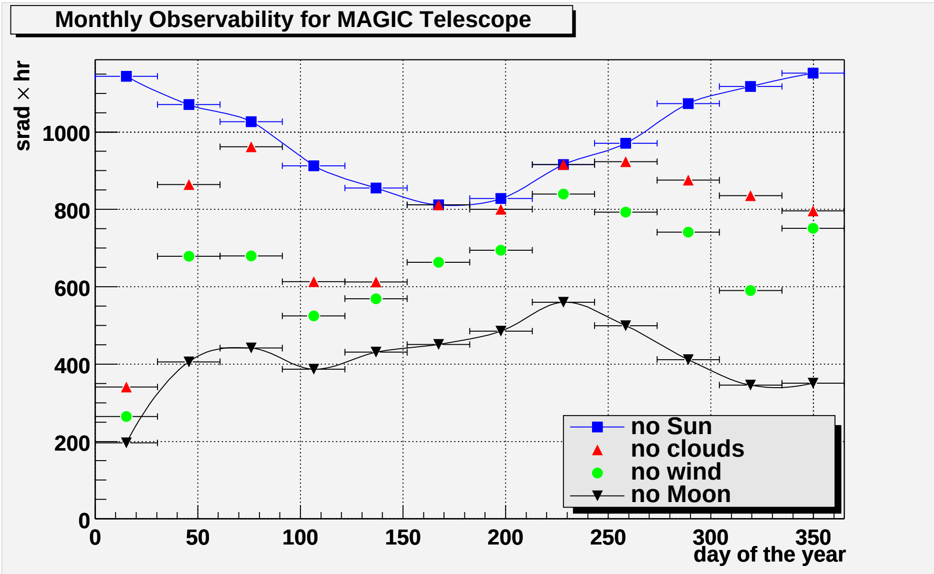

Fig. 1. In this plot four different data series appear. Each series is binned for an amount of time roughly equal to a month and its height is expressed in $\mathrm{srad} \times \mathrm{hr}$. It was obtained summing up all the *tens of minutes*, properly multiplied for the size of the relative area, in which MAGIC could observe. The four series are respectively, *observability* (*i. e.* the product $\mathrm{srad} \times \mathrm{hr}$) when the Sun is below $-10°$, when the humidity is below 100%, when the wind blows slower than $10\,\mathrm{m/s}$ and when the Moon, above the horizon, is at least $90°$ far away (see discussion in the text).

2.1 Sky binning

For the computation we need to divide the sky into different "bins". The sky seen by MAGIC, at least in the foreseen 2^{nd} phase, is roughly a spherical cap of $60°$ of opening centred on the zenith. This cap is sliced into 6 zones (a "zone" being the surface area of a spherical segment), each of which contains $10°$ of zenith angle. These zones are further subdivided along chosen meridians in order to make areas of roughly the same size.

So, for example, the zone comprised between $50°$ and $60°$ of zenith angle is cut into 6 areas, each covering $0.1549\,\mathrm{srad}$. The first area of each zone is chosen to have the local meridian of $0°$ of azimuth in its centre, and all the bins used for the calculation are listed in table 1.

zenith angle	nr. of bins	area (srad)
$[60, 50]$	6	0.1495
$[50, 40]$	5	0.1549
$[40, 30]$	4	0.1570
$[30, 20]$	3	0.1543
$[20, 10]$	2	0.1417
$[10, 0]$	1	0.0955

Table 1. Number and area of bins of a given zone.

Each bin contains the number of *tens of minutes* in a day during which observation in a given sky area was possible. Data were then summed up on a monthly or yearly base and results are plotted in figures 1 and 2 and are explained in the caption of the figures themselves.

2.2 Sun and Moon ephemerides

The first constraint was that there was enough darkness. We assumed, quite roughly, that this condition could be translated into the Sun being below the horizon of at least $10°$, or more than $100°$ of zenith angle. Sun ephemerides were calculated every ten minutes starting from midnight of January 1^{st}, 2000 until midnight of December 31^{st}, 2000 using NOVAS[1].

In a similar way Moon ephemerides were calculated starting with the data provided by NASA JPL[2]. Given the large amount of CPU time involved in the calculation, Moon position was checked only after the Sun was found to be sufficiently set and weather conditions allow observations (see next paragraph: 2.3). For what concerns the Moon, we assumed that observation in a given bin were possible if the Moon, above the horizon, was at least $90°$ apart from the bin centre.

2.3 Weather conditions: humidity and wind speed

Weather conditions were checked exploiting Internet *NOT Weather Archive*, an online, browsable, archive that contains weather data logged at the Roque de Los Muchachos, and up-

[1] Naval Observatory Vector Astrometry Subroutines, is a *suite* of functions for the computation of astrometric quantities, distributed by the US Naval Observatory. To get NOVAS follow the links starting from `http://www.usno.navy.mil`.

[2] `ftp://navigator.jpl.nasa.gov/ephem/export`.

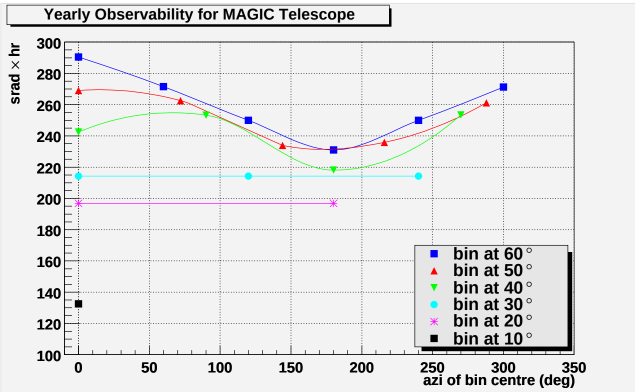

Fig. 2. Yearly *observability* expressed as $\mathrm{srad} \times \mathrm{hr}$. On the abscissa the azimuth ($0° = N \mapsto 90° = E$) of the bin centre. Data show that bins at South are less favourable for observation, an obvious effect due to the Moon. Data for each zenith angle are summed up in table 2. Lines joining data are meant only to be a visual aid to group together related markers.

dated every 5 minutes since February 3$^{\mathrm{rd}}$, 1997[3]. Two fields were interesting to us, namely, the humidity and the absolute wind speed. Humidity sets a cut to our observations if it is around 100%, and the wind speed should be below $10\,\mathrm{m/s}$ to avoid large oscillations of the MAGIC Telescope.

Weather cuts were applied just before the calculation of the Moon position.

2.4 Results

Data plotted in figure 2 may be summed up to give the total number of hours that a given zone is observable in a year.

zenith angle	yearly obs. $(\mathrm{srad} \times \mathrm{hr})$
$[60, 50]$	1564
$[50, 40]$	1262
$[40, 30]$	967
$[30, 20]$	642
$[20, 10]$	393
$[10, 0]$	132
Total	**4963**

Table 2. Total *observability* integrated over the year.

These results are reported in table 2, where the hours of observation are multiplied by the zone size. The total of roughly $5000\,\mathrm{srad} \times \mathrm{hr}$ gives an idea of the duty-cycle, in fact the whole sky spans an *observability* of $4\pi \times 365 \times 24 \approx 110000\,\mathrm{srad} \times \mathrm{hr}$, meaning that the observable GRBs are, for MAGIC, 4.5% of the total occurring bursts.

[3]Follow the links at `http://www.not.iac.es`, the NOT homepage.

3 Yearly rate of GRB detection

Given the *observability* for each area in which we have subdivided the sky, finding the yearly rate is a quite straightforward recipe, that needs only three main ingredients.

3.1 GRB signal: detected photons

First of all we have to evaluate the possible *signal* in each bin, that is we select a GRB model, or better, its spectral flux $F_{\mathrm{GRB}}(E, t)$: the number of gammas of energy E that reach the ground at time t per unit time per unit area; then, if the GRB occurred in a sky area at a zenith angle Θ, the number of detected gammas in the bin obeys the formula:

$$S(\Theta) = \int_{10\,\mathrm{s}}^{\hat{T}\approx 20\,\mathrm{s}} dt \int_{E_{\mathrm{th}}\approx 10\,\mathrm{GeV}}^{E_{\mathrm{cut}}\approx 300\,\mathrm{GeV}} dE\, A_\gamma(E, \Theta)\, F_{\mathrm{GRB}}(E, t) \qquad (1)$$

where $A_\gamma(E, \Theta)$ is the effective area for gamma detection, as explained in Blanch *et al.* (2001).

The integration limits are $10\,\mathrm{s}$, that is the average time lag between GRB identification on satellite and MAGIC pointing (see section 1); $\hat{T}$, a characteristic time of the GRB (in according with the BATSE catalog, Paciesas *et al.* (1999), we can set this value around $20\,\mathrm{s}$ and still retain a discrete number of GRB events of roughly 50 per year); E_{th}, the MAGIC energy threshold and E_{cut}, the cutoff energy of the GRB, due to background absorption. Unluckily, effective area studies are still on-going and it thus makes no sense, now, such a fine treatment.

As a first guess, we can use for the spectral flux a power law with spectral index $\alpha = -2.5$, in agreement with data published in the BATSE Catalog (Preece *et al.* (2000)). For what concerns the time evolution, we assume that the flux remains constant until $\hat{T}$, and zero afterwards. In these hypotheses, the data in figure 3 can be promply integrated in E to give a factor of 6, once scaled to a typical EGRET energy of $300\,\mathrm{MeV}$. This "6" must be multiplied by a typical EGRET-detected flux (expressed in $\mathrm{Hz} \times \mathrm{m}^{-2}$) to give the rate of MAGIC-detected photons in the interval $[10\,\mathrm{s}, \hat{T}]$. Typical reported fluxes are of the order of $1 \div 100\,\mathrm{Hz}\,\mathrm{m}^{-2}$, so that the expected signal is roughly $6 \div 600\,\mathrm{Hz}$.

3.2 Observable GRBs

In addition, we have to calculate the number of observable GRBs. This number can be found looking up into the BATSE catalog for GRBs with durations longer than $20\,\mathrm{s}$. Figure 8 in Paciesas *et al.* (1999) shows that roughly 250 obey this requirement, or a total of 50 bursts per year. Assuming that they are equally distributed in the sky, the actual number of "long"-GRBs on sight by MAGIC in a year may be obtained multypling this number by the ratio of MAGIC *observability* and the *total observability* (≈ 110000) as stated in paragraph 2.4. The result is that only 2 to 3 "long"-GRBs happen in the MAGIC field of view.

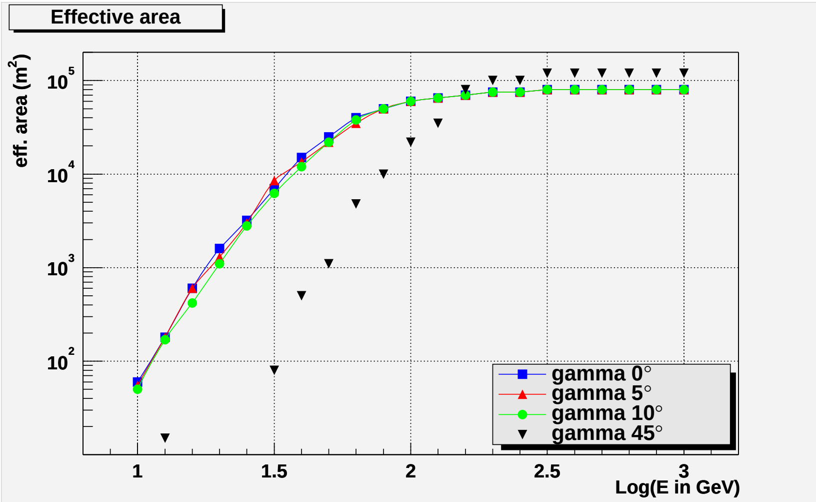

Fig. 3. This plot contains data on the effective area obtained by means of Montecarlo techniques, as detailed better in Blanch *et al.* (2001). On-going studies will cover the range between 0° and 60° of zenith angle. The simulation, based on CORSIKA, handles correctly showers roughly below 30°, while needs further checks for a desirable extension dealing with showers further beyond this point. Data obtained at 45° are merely indicative, but are a real *spur* to investigate the behaviour at large zenith angle, given the big differences among the plotted curves.

3.3 *Signal to Noise* ratio

The third and last ingredient is the noise. For MAGIC and GRB observations, "noise" are hadronic showers, that are believed to occur with a rate of $150\,\mathrm{Hz}$. Even with a moderate gamma/hadron separation, MAGIC believes to reach a Q factor of improvement on the S/N ratio of ≈ 5 at low energies. In these hypotheses, the calculation of the significance σ leads to:

$$\sigma = Q\frac{S}{\sqrt{N}}\sqrt{\hat{T} - 10\,\mathrm{s}} \tag{2}$$

putting everything inside we obtain the final value of $\sigma \approx 7.5 \times (1 \div 100)$ well above the characteristic value of 5 requested for a detection.

Summarising the content of this section, we found that in the MAGIC field of view should happen from 2 to 3 detectable GRBs per year.

4 Conclusions

The studies here presented are neither conclusive nor exhaustive, but nevertheless show clearly the potential for GRB observation with the MAGIC Telescope. Further data on gammas from higher zenith angles and data on hadron background are still needed. The Montecarlo production is, however, running and updated results will be shown during the conference.

Acknowledgements. The authors, for this contribution, have extensively made use of *NASA's Astrophysics Data System Abstract Service*. They also wish to thank the web team of the **N**ordic **O**ptical **T**elescope — La Palma, for providing the detailed *NOT Weather Archive*, the US Navy for providing NOVAS, the *suite* of C-functions for the computation of astrometric quantities and the NASA JPL people for providing Sun and Moon ephemerides. The development and construction of the MAGIC Telescope has been mainly supported by the BMBF (Germany), CYCIT (Spain), INFN and MURST (Italy).

References

Barthelmy, S. D., "GCN: Recent Developments", to appear in the Proc. of Gamma-Ray Burst in the Afterglow Era: 2$^{\mathrm{nd}}$ Workshop, Roma, October 17–20, 2000.

Bastieri, D. *et al.*, "A two-level pattern-trigger for the MAGIC telescope", Nucl. Instr. & Meth. A 461 (1–3), 521–623, 2001.

Blanch, O., González, J. C., Kornmayer, H. for the MAGIC Coll. "Detailed Montecarlo studies for the MAGIC Telescopes", these proceedings.

Kneiske, T. M., Mannheim, K. and Hartmann, D., "Evolving stellar background radiation and gamma-ray optical depth", to appear in the Proc. of the Heidelberg International Symposium on High Energy Gamma-Ray Astronomy, Heidelberg, June 26–30, 2000, astro-ph/0011013.

Mannheim, K., Hartmann, D. and Burkhardt F., "The Gamma-Ray Burst rate at high photon energies", Astroph. Jour., 467, 532–536, 1996.

Martinez, M. for the MAGIC Collaboration, "The MAGIC telescope project", Proc. of 26$^{\mathrm{th}}$ ICRC, Salt Lake City, August 17–25, 1999, D. Kieda *et al.* eds., vol. 5, 219–221, 1999, OG 4.3.08.

"The Fourth BATSE Gamma-Ray Burst Catalog (Revised)" Paciesas, W. S. *et al.*, Astroph. Jour. Suppl. Ser., 122, 465–495, 1999.

Preece, R. D. *et al.*, "The BATSE Gamma-Ray Burst spectral catalog. I. High time resolution spectroscopy of bright bursts using high energy resolution data", Astroph. Jour. Suppl. Ser., 126, 19–36, 2000.