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MAGIC upper limits on the high energy emission from GRBs

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Abstract: During its cycle-1 observation period, between April 2005 and March 2006, the MAGIC telescope was able to observe nine Gamma Ray Burst (GRB) events since their early beginning. Other observations were performed during the following months in the cycle-2 observation period. The observations, with an energy threshold spanning from 80 to 200 GeV, did not reveal any γ-ray emission. The computed upper limits are compatible with a power law extrapolation, where intrinsic fluxes are evaluated taking into account the attenuation due to the scattering in the metagalactic radiation field.

Introduction

The Major Atmospheric Gamma Imaging Cherenkov (MAGIC) telescope [1], located on the Canary Island of La Palma, is currently the largest Imaging Air Cherenkov Telescope (IACT). MAGIC has a $17\,\mathrm{m}$ diameter tessellated reflector dish consisting of 964 ($0.5 \times 0.5\mathrm{m}^2$) diamond-milled aluminium mirrors. In its current configuration, the MAGIC photo-multiplier camera has a trigger region of 2.0° diameter [2], and a trigger collection area for γ-rays of the order of $10^5\,\mathrm{m}^2$, which increases further with the zenith angle of observation. Presently, the accessible trigger energy ranges from $50 - 60\,\mathrm{GeV}$ (at small zenith angles) up to the TeV region close to the horizon. The MAGIC telescope is focused to $10\,\mathrm{km}$ distance – the most likely height at which a $50\,\mathrm{GeV}$ γ-ray shower has its shower maximum. The accuracy in reconstructing the direction of incoming γ-rays, the point spread function (PSF), is about 0.1°, slightly depending on the analysis.

In this contribution we report the results of observation of GRBs by the MAGIC telescope during cycle-1. Preliminary results from a selected sample of GRBs of cycle-2 are also included. The technical details of the MAGIC observations are reported in a separate contribution [3].

The Observations

During the fourteen months of observation cycle-1 nine GRB events suitable for analysis were selected. Approximately the same amount of events was also collected during cycle-2, spanning from May 2006 up to May 2007, out of which four were analyzed in a preliminary way. Table 1 summarizes the thirteen GRBs observed by MAGIC up to now with their principal features obtained from the GCN circulars.

The majority of the events were triggered by the *Swift* satellite. GRB050502a and GRB060121 were triggered by Integral and HETE-2 respectively. Apart from GRB060121 and GRB061217, all GRBs observed by MAGIC are long bursts. In two cases, for GRB050713a and GRB050904, the fast repositioning of the telescope allowed the observation of their prompt emission phase [4, 3], while the burst was still emitting low-energy γ-rays.

	GRB	Satellite	Trigger #	Energy Range	T_{90}	Fluence	z
1.	050421	*Swift*	115135	15-350 keV	10 s	1.8×10^{-7}	-
2.	050502a	Integral	2484	20-200 keV	20 s	1.4×10^{-6}	3.79
3.	050505	*Swift*	117504	15-350 keV	60 s	4.1×10^{-6}	4.27
4.	050509a	*Swift*	118707	15-350 keV	13 s	4.6×10^{-7}	-
5.	050713a	*Swift*	145675	15-350 keV	70 s	9.1×10^{-6}	-
6.	050904	*Swift*	153514	15-350 keV	225 s	5.4×10^{-6}	6.29
7.	060121	HETE-2	4010	0.02-1 MeV	2 s	4.7×10^{-6}	-
8.	060203	*Swift*	180151	15-350 keV	60 s	8.5×10^{-7}	-
9.	060206	*Swift*	180455	15-350 keV	11 s	8.4×10^{-7}	4.05
10.	060825	*Swift*	226382	15-350 keV	15 s	9.8×10^{-7}	-
11.	061028	*Swift*	235715	15-350 keV	106 s	9.7×10^{-7}	-
12.	061217	*Swift*	251634	15-350 keV	0.4 s	4.6×10^{-8}	0.83
13.	070412	*Swift*	275119	15-350 keV	40 s	4.8×10^{-7}	-

Table 1: Main properties of GRBs observed by MAGIC. The fourth column shows the typical energy range of the detector on board of the GRB triggering satellite, while the fifth, sixth and seventh columns give the corresponding measured duration T_{90}, fluence in [erg cm^{-2}] and redshift.

In six cases the early GRB afterglow observation with MAGIC overlapped with the X-ray observation from space, namely for GRB050421, GRB050713a, GRB050904, GRB060206, GRB060825 and GRB061028. During cycle-1, in the case of GRB050421 the X-Ray Telescope (XRT) on board *Swift* detected two flaring events in the afterglow at $T_0 + 110\,\mathrm{s}$ and $T_0 + 154\,\mathrm{s}$, as well as in GRB050904, where a clear flare was detected at $T_0 + 466\,\mathrm{s}$. In these two cases data taking with the MAGIC telescope started at $T_0 + 108\,\mathrm{s}$ and $T_0 + 145\,\mathrm{s}$ respectively, the flaring activity in X-rays was therefore covered by the MAGIC observation window. During cycle-2 only in the case of GRB060825 flaring X-ray emission was also covered by the MAGIC observation window.

Analysis and Results

For the reconstruction of γ-events the standard MAGIC analysis software [5] based on the Hillas analysis [6] was used. The reconstructed signal was calibrated and cleaned from spurious backgrounds using an image cleaning algorithm which requires a signal exceeding fixed reference levels, improved with the reconstructed information of the arrival time [7]. Some additional quality cuts based on combinations of Hillas parameters were applied to remove non-physical images from the data. The separation between γ and hadron showers was performed by means of the Random Forest (RF) method, a classification method that combines several parameters describing the shape of the image into a new parameter called *hadronness* [8]. The energy of the γ-ray was also estimated using the RF approach, yielding a resolution of $\sim\ 30\%$ at $200\,\mathrm{GeV}$.

Dedicated OFF-data samples were selected for each GRB according to the same observation conditions (zenith angle, discriminator threshold, trigger rate, Moon phase). The cut on *hadronness*, ensuring at least 90% of efficiency on γ-like events, was optimized using a dedicated Monte Carlo simulation. In the final analysis step a cut on the *alpha* parameter was chosen. This parameter is related to the direction of the incoming shower, thus it is expected to peak at $alpha = 0°$ if the telescope points directly at the source, while it is uniformly distributed for background events. The *alpha* parameter is used to evaluate the significance of the signal.

No significant excess of VHE γ-rays could be extracted with the standard analysis approach. In parallel to the analysis of the complete data set a search for short emission periods in different time bins was performed. Also with this approach no significant deviation of the number of excess

	Energy bin [GeV]	Energy [GeV]	Fluence Upper Limit [cm^{-2} keV^{-1}]	[erg cm^{-2}]	C.U.
GRB050421	175-225	212.5	5.26×10^{-16}	3.80×10^{-8}	0.20
	225-300	275.8	3.64×10^{-16}	4.43×10^{-8}	0.27
	300-400	366.4	5.21×10^{-17}	1.12×10^{-8}	0.08
	400-1000	658.7	2.07×10^{-17}	1.41×10^{-8}	0.14
GRB050502a	120-175	152.3	1.67×10^{-15}	6.21×10^{-8}	0.27
	175-225	219.3	2.83×10^{-15}	2.18×10^{-7}	1.15
	225-300	275.8	1.13×10^{-15}	1.37×10^{-7}	0.83
	300-400	360.8	7.57×10^{-17}	1.58×10^{-8}	0.11
	400-1000	629.1	5.62×10^{-17}	3.56×10^{-8}	0.35
GRB050505	175-225	212.9	2.03×10^{-15}	1.48×10^{-7}	0.76
	225-300	275.1	2.66×10^{-15}	3.22×10^{-7}	1.94
	300-400	363.6	5.28×10^{-16}	1.11×10^{-7}	0.79
	400-1000	704.1	1.85×10^{-17}	1.46×10^{-8}	0.15
GRB050509a	175-225	215.1	1.04×10^{-15}	7.69×10^{-8}	0.40
	225-300	273.4	1.39×10^{-15}	1.67×10^{-7}	1.00
	300-400	362.8	7.74×10^{-16}	1.63×10^{-7}	1.15
	400-1000	668.5	1.69×10^{-16}	1.21×10^{-7}	1.22
GRB050713a	120-175	169.9	3.63×10^{-15}	1.68×10^{-7}	0.76
	175-225	212.5	1.12×10^{-15}	8.08×10^{-8}	0.42
	225-300	275.8	2.07×10^{-15}	2.52×10^{-7}	1.52
	300-400	366.4	3.33×10^{-16}	7.16×10^{-8}	0.51
	400-1000	658.7	2.24×10^{-17}	1.55×10^{-8}	0.15
GRB050904	80-120	85.5	9.06×10^{-15}	1.06×10^{-7}	0.32
	120-175	140.1	3.00×10^{-15}	9.42×10^{-8}	0.38
	175-225	209.9	2.18×10^{-15}	1.53×10^{-7}	0.79
	225-300	268.9	5.82×10^{-16}	6.74×10^{-8}	0.40
	300-400	355.2	5.01×10^{-16}	1.11×10^{-7}	0.71
	400-1000	614.9	1.26×10^{-16}	7.63×10^{-8}	0.73
GRB060121	120-175	151.3	2.64×10^{-15}	9.67×10^{-8}	0.41
	175-225	212.8	6.57×10^{-16}	4.76×10^{-8}	0.25
	225-300	273.7	2.13×10^{-16}	2.56×10^{-8}	0.15
	300-400	367.7	4.47×10^{-16}	9.66×10^{-8}	0.69
	400-1000	636.4	4.84×10^{-17}	3.14×10^{-8}	0.31
GRB060203	120-175	151.5	1.10×10^{-14}	4.03×10^{-7}	1.71
	175-225	219.5	5.07×10^{-16}	3.91×10^{-8}	0.21
	225-300	274.0	1.57×10^{-16}	1.88×10^{-8}	0.11
	300-400	365.3	3.54×10^{-16}	7.56×10^{-8}	0.54
	400-1000	639.5	4.45×10^{-17}	2.91×10^{-8}	0.29
GRB060206	80-120	85.5	1.23×10^{-14}	1.44×10^{-7}	0.44
	120-175	139.9	9.83×10^{-16}	3.08×10^{-8}	0.13
	175-225	210.3	5.50×10^{-16}	3.89×10^{-8}	0.20
	225-300	269.2	3.65×10^{-16}	4.23×10^{-8}	0.25
	300-400	355.4	6.47×10^{-16}	1.31×10^{-7}	0.91
	400-1000	614.0	2.88×10^{-17}	1.74×10^{-8}	0.17

Table 2: Fluence upper limits on the VHE γ-ray emission from GRBs observed with the MAGIC telescope. The limits were extracted from the first $30\,\mathrm{min}$ of observation. The first column show the reconstructed energy range. The second column shows the energy at which the upper limit was calculated. The last column shows the upper limit value in Crab Units ($\mathrm{C.U.} = 1.5 \cdot 10^{-3} \left(\frac{E}{\mathrm{GeV}}\right)^{-2.59} \frac{\mathrm{ph}}{\mathrm{cm^2\,s\,TeV}}$).

	Energy bin [GeV]	Flux U.L. [erg cm^{-2} s^{-1}]
GRB060825	80-125	1.8×10^{-10}
	125-175	1.9×10^{-10}
	175-300	1.2×10^{-10}
	300-1000	0.6×10^{-10}
GRB061028	100-125	1.6×10^{-10}
	125-175	0.8×10^{-10}
	175-300	0.7×10^{-10}
	300-1000	0.3×10^{-10}
GRB061217	300-500	0.53×10^{-10}
	500-1000	0.35×10^{-10}
GRB070412	80-125	1.03×10^{-11}
	125-175	0.31×10^{-11}
	175-300	0.75×10^{-11}
	300-1000	0.77×10^{-11}

Table 3: Preliminary flux upper limits on four GRBs observed by MAGIC during cycle-2. The first column shows the reconstructed energy bin. For the bursts GRB060825, GRB061028 and GRB061217 the upper limits correspond to the first $30\,\mathrm{min}$, while in the case of GRB070412 the whole data set of $2\,\mathrm{h}$ was used.

events in comparison to the background was found. The upper limits presented in table 2 cover the cycle-1 observations [9]. The results were obtained for the first $30\,\mathrm{min}$ of MAGIC observation using the Rolke approach [10], including an estimated systematic uncertainty of 30% on the absolute flux level. Table 3 contains the preliminary upper limits on four GRBs observed during cycle-2, as published in the GCN circulars.

Conclusions

We presented the results of thirteen GRB observations performed by MAGIC during the last two years of operation. As a response to the GCN alerts provided by dedicated satellites, MAGIC was able to start the observation during the early afterglow emission phases, while the X-ray emission was still visible. In three cases the MAGIC observation covered flaring activity in X-rays. In two cases the observation started even when the prompt emission in γ-rays was still active. No significant γ-ray emission above $\sim 100\,\mathrm{GeV}$ was detected. We derived upper limits for the γ-ray flux between 85 and $1000\,\mathrm{GeV}$. These limits are compatible with a naive extension of the power law spectrum, when the redshift is known, up to hundreds of GeV. For the first time a IACT is able to perform direct rapid observations of the prompt emission phase of GRBs. This is particularly of interest to extend the observational energy range in the so called "*Swift* era" and for the future experiments as AGILE and GLAST.

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