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MAGIC upper limits on the high energy emission from GRBs

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Abstract: During its first observation cycle, between April 2005 and March 2006, the MAGIC telescope was able to observe nine different GRB events since their early beginning. Other observations have been performed during the following months in its second observation cycle. The observations, with an energy threshold spanning from 80 to 200 GeV, did not reveal any gamma-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 (MRF).

Introduction

The Major Atmospheric Gamma Imaging Cherenkov (MAGIC) telescope [9], located on the Canary Island of La Palma, is currently the largest Imaging Air Cherenkov Telescope (IACT), with a 17 m diameter tessellated reflector dish consisting of 964 0.5×0.5 m^2 diamond-milled aluminium mirrors. In its current configuration, the MAGIC photo-multiplier camera has a trigger region of 2.0° diameter [5], and a trigger collection area for γ-rays of the order of 10^5 m^2, which increases further with the zenith angle of observation. Presently, the accessible trigger energy ranges from 50-60 GeV (at small zenith angles) to tens of TeV. The MAGIC telescope is focused to 10 km distance – the most likely height at which a 50 GeV γ-ray shower has its 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.

Because of its technological design, MAGIC is the most suited IACT for the observation of Gamma-Ray Bursts [3].

In this contribution we report the results of observation of GRBs by the MAGIC Telescope during its first observation cycle, and the preliminary results from its second observation cycle.

The Observations

An automatic alert system has been operational from July 15$^{\text{th}}$, 2004. During Cycle 1 of observations[1] the Telescope could operate according the strategy described in [3] and collect a statistics of nine GRBs suitable for analysis. Other GRB events were triggered during Cycle 2 of observation[2], out of them four were analyzed in a preliminary way. Table 1 summarizes the thirteen GRBs observed by MAGIC during Cycle 1 and Cycle 2 of observation with their principal features according to the GCN Circular service.

Most of the events were triggered by Swift, while GRB 050502a and GRB 060121 were triggered by Integral and HETE-II respectively. Moreover, all GRBs observed by MAGIC are long bursts, apart from GRB 060121 and GRB 061217. In two cases, for GRB 050713a and GRB 050904, the fast reaction of the Telescope permitted the observation of the burst still during its prompt phase [3, 1].

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1. from April 2005 to May 2006
2. from May 2006 to May 2007

	Burst	Satellite	Trigger #	Energy Range	T_{90}	Fluence	z
1.	GRB 050421	Swift	115135	15-350 keV	10 s	1.8×10^{-7}	-
2.	GRB 050502a	Integral	2484	20-200 keV	20 s	1.4×10^{-6}	3.79
3.	GRB 050505	Swift	117504	15-350 keV	60 s	4.1×10^{-6}	4.27
4.	GRB 050509a	Swift	118707	15-350 keV	13 s	4.6×10^{-7}	-
5.	GRB 050713a	Swift	145675	15-350 keV	70 s	9.1×10^{-6}	-
6.	GRB 050904	Swift	153514	15-350 keV	225 s	5.4×10^{-6}	6.29
7.	GRB 060121	HETE-II	4010	0.02-1 MeV	2 s	4.7×10^{-6}	-
8.	GRB 060203	Swift	180151	15-350 keV	60 s	8.5×10^{-7}	-
9.	GRB 060206	Swift	180455	15-350 keV	11 s	8.4×10^{-7}	4.05
10.	GRB 060825	Swift	226382	15-350 keV	15 s	9.8×10^{-7}	-
11.	GRB 061028	Swift	235715	15-350 keV	106 s	9.7×10^{-7}	-
12.	GRB 061217	Swift	251634	15-350 keV	0.4 s	4.6×10^{-8}	0.83
13.	GRB 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 detector on board of the satellite, while in the fifth, sixth and seventh columns there are the corresponding measured duration T_{90}, fluence in [erg cm^{-2}] and redshift.

In six cases the MAGIC observation of the afterglow overlapped with the X-ray observation from space, namely GRB 050421, GRB 050713a, GRB 050904, GRB 060206, GRB 060825 and GRB 061028. During Cycle 1, in the case of GRB 050421 the X-Ray Telescope (XRT) on board Swift could detect two flaring events in the afterglow at $T_0 + 110$ s and $T_0 + 154$ s, as well as in GRB 050904, where a clear flare was detected at $T_0 + 466$ s. On these two last bursts, the MAGIC Telescope data taking started at $T_0 + 108$ s and $T_0 + 145$ s respectively, so the flaring activity of the X-ray afterglow happened inside the MAGIC observation window. Another flaring event of the X-ray afterglow was observed by MAGIC during Cycle 2 on GRB 060825, where a flaring activity was observed at $T_0 + 220$ s by XRT, already inside the MAGIC observation window.

Analysis and Results

The reconstruction of the events and the image analysis used the MAGIC standard analysis software [4] by means of the standard Hillas analysis [8]. The reconstructed signals were calibrated and then cleaned of spurious backgrounds from the light of the night sky, using an image cleaning algorithm which requires a signal exceeding fixed reference levels, improved with the reconstructed information of the arrival time [6]. Some pre-cuts and quality cuts on the Hillas parameters remove non-physical images from the data set as well as events unsuited for a low enwergy analysis, while Gamma/hadron separation is 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* [7]. The energy of the γ-ray is also estimated using a RF approach, yielding a resolution of $\sim 30\%$ at $200\ \mathrm{GeV}$. The final γ/hadron separation has been done by cutting in the *hadronness* and *alpha* parameters. Dedicated OFF-data samples were selected for each GRB according to some observation conditions (zenith angle, discriminator thresholds, trigger rate, Moon phase), and a cut in *hadronness* ensuring at least 90% of efficiency on γ-like events was optimized using a dedicated Monte Carlo simulation. The *alpha* parameter, instead, is related to the direction of the incoming shower, thus is expected to peak at $0°$ if the Telescope points to a point-like source, while it is uniformly distributed for background events. The *alpha* parameter is thus used to evaluate the significance of a signal.

The analysis showed no hint of signal over the entire data set of each burst. The same analysis has been performed also in different time bins for each burst, showing no significant deviation of the num-

	Energy bin [GeV]	Energy [GeV]	Fluence Upper Limit [cm^{-2} keV^{-1}]	Fluence Upper Limit [erg cm^{-2}]	C.U.
GRB 050421	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
GRB 050502	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
GRB 050505	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
GRB 050509a	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
GRB 050713a	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
GRB 050904	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
GRB 060121	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
GRB 060203	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
GRB 060206	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: Derived fluence upper limits for the first 30 minutes of data of nine Gamma-Ray Bursts. The first column shows the reconstructed energy bins in which the analysis has been done. The second column shows the true energy at which the upper limits have been calculated, and is the energy giving the average flux upper limit in the reconstructed energy bin. The last column shows the upper limit value in Crab Unit.

	Energy bin [GeV]	**Flux U.L. [erg cm^{-2} s^{-1}]**
GRB 060825	80-125	1.8×10^{-10}
	125-175	1.9×10^{-10}
	175-300	1.2×10^{-10}
	300-1000	0.6×10^{-10}
GRB 061028	100-125	1.6×10^{-10}
	125-175	0.8×10^{-10}
	175-300	0.7×10^{-10}
	300-1000	0.3×10^{-10}
GRB 061217	300-500	0.53×10^{-10}
	500-1000	0.35×10^{-10}
GRB 070412	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 derived flux upper limits on four GRBs observed during MAGIC second cycle of observation. The first column shows the reconstructed energy bins in which the analysis has been done. Upper limits have been derived for the first 30 minutes of data on GRB 060825, GRB 061028 and GRB 061217, while for the whole data set of 2 hours on GRB 070412.

ber of excess events from 0. Therefore, upper limits were derived for the first 30 minutes of data of each GRB, using the Rolke approach [10] in different energy bins. Using an unfolding procedure, all statistical upper limits were converted into flux upper limit. In table 2 we report the upper limit values obtained for each GRB observed during the first observation cycle. For the details see [2]. In table 3 are reported the preliminary upper limits on four GRBs observed during the second observation cycle.

Conclusions

MAGIC was able to observe part of the prompt and the early afterglow emission phase of thirteen GRBs as a response to the alert system provided by several satellites. In three cases, the flaring activity of the X-ray afterglow was observed. No significant excess events above $\sim$ 100 GeV were detected, neither during the prompt emission phase nor during the early afterglow. We have derived upper limits for the γ-ray flux between 85 and 1000 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 was able to perform direct rapid observations of the prompt emission phase of GRBs. This is particulary relevant in the so called "Swift era" and for the incoming additional GRB monitoring by AGILE and GLAST.

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