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Observation of a relatively low luminosity long duration GRB 201015A by the MAGIC telescopes

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Starting from the first announcement of unequivocal detection of very high energy (VHE) emission from a gamma-ray burst (GRB) by the MAGIC telescopes (GRB 190114C), four additional detections of VHE emission from GRBs by ground-based telescopes were reported. These observations have revealed a new, energetic component that has become an additional probe to explore GRB physics. In order to deepen our understanding of the origin of this new component, and in general of the origin of radiation from GRBs, further observations by VHE instruments are crucial. In this work we report fast follow-up observations by the MAGIC telescopes of GRB 201015A, a GRB detected by the *Swift*/BAT. As measured by BAT, the prompt emission lasted 9.8 ± 3.5 seconds, suggesting that this GRB belongs to the class of long events. This was later confirmed by optical observations, which allowed to measure the redshift (z = 0.42) and found the associated type Ic-BL supernova. Having a prompt isotropic-equivalent energy of $E_{\rm iso} \sim 10^{50}$ erg, this GRB is a relatively low energy event as compared to the population of long GRBs. Observations with the MAGIC telescopes started about 30 seconds after the GRB onset and were performed under good observational conditions. The accurate analysis of the MAGIC data reveals a strong hint of detection and implies a significant energy release in the TeV range, smaller but comparable with that of the prompt emission in the keV-MeV band.

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1. Introduction

Gamma-ray bursts (GRBs) are the brightest explosions in the Universe. They are thought to be originated from the core collapse of massive stars or binary neutron star mergers. The duration of the initial brief emission (prompt emission) in the former events is longer than those in the latter events. A duration of 2 seconds is used to classify them as long or short GRBs. While the prompt emission lasts only several minutes at the longest and shows a complex light curve with sub-second variability, the subsequent emission (afterglow) is detected for several days or longer and its flux, after an initial rise smoothly decreases as a power-law (PL) in time. Once space-borne telescopes detect the prompt emission from GRBs in X-ray and gamma-ray bands, several instruments initiate follow-up observations after receiving the alert from satellites, providing multi-wavelength observations of the afterglow phase.

Afterglow radiation is thought to be produced when the ultra-relativistic jet collides with the surrounding medium. In most cases, multi-wavelength afterglow observations from radio to GeV gamma-rays can be explained by electron synchrotron radiation from the forward shock, with a possible early time contribution from the reverse shock running into the jet. The ground-breaking discovery of a new component beyond synchrotron was made by the MAGIC telescopes with the detection of TeV gamma-rays from the afterglow of the long GRB 190114C [1]. This burst was very energetic ($E_{\rm iso} \sim 3 \times 10^{53}$ erg) and also one of the closest GRBs ever followed by MAGIC. The observational delay of the MAGIC telescopes was one of the shortest, being around 60 seconds. Together with other multi-wavelength data, the TeV emission from GRB 190114C is consistent with being synchrotron self-Compton radiation, and is found to carry a power comparable to that of synchrotron component [2]. Moreover, the afterglow parameters inferred from the multi-wavelength modeling are quite typical for GRBs, suggesting that TeV emission might be commonly in GRB afterglows, at least for bright GRBs.

After GRB 190114C, a few other detections of VHE gamma-ray emission in the TeV range from long GRBs have been reported, both by H.E.S.S. (GRB 180720B [3] and GRB 190829A [4]) and MAGIC (GRB 201216C [5]). In order to understand and confirm how TeV emission is produced and whether there might be more than one production mechanism efficiently producing VHE emission, a larger sample of TeV GRBs is needed. In this proceeding, we report a strong hint of detection of VHE gamma-ray emission from a relatively low luminosity GRB 201015A observed by the MAGIC telescopes.

2. GRB 201015A

GRB 201015A has been detected by the *Swift*-BAT on 15 October 2020, 22:50:13 universal time (UT) (hereafter T_0) [6]. The prompt duration T_{90}, estimated as the duration of the time interval during which between 5% and 95% of the total photon counts are detected, is T_{90} =(9.78 ± 3.47) s in the 15 − 350 keV band. The BAT spectrum is well modeled by a single PL with photon index $\beta = -3.03 \pm 0.68$, suggesting a low peak energy $E_{\rm p} < 10$ keV. The fluence in the 15 − 150 keV band is $S_{\gamma,\rm iso} = (2.0 \pm 0.6) \times 10^{-7}$ erg/cm^2 [7]. There was no onboard trigger by the *Fermi*-GBM around T_0, but a transient source, whose location is consistent with the *Swift*-BAT event, was identified by the GBM targeted search [8].

The GTC telescope reported a measurement of the redshift $z = 0.426$ [9], later confirmed by the NOT ($z = 0.423$ [10]). The (isotropic equivalent) prompt emission energy inferred from spectral analysis of *Fermi*-GBM data is $E_{\gamma,\mathrm{iso}} = (1.1 \pm 0.2) \times 10^{50}$ erg [11].

Due to an observing constraint, *Swift*-XRT started observations 3214 s after T_0. Observations up to almost 1 day show that the XRT flux decays as a PL with index $\alpha \sim 1.49$ [14]. Observations by the Chandra X-ray Observatory at later times (8.4 days and 13.6 days after the burst) are inconsistent with the extrapolation of the PL decay identified by XRT, having a flux about 100 times higher than expected [16]. Late time observations (between 18 and 21 days) by XRT confirmed a flattening in the X-ray lightcurve [15].

Inside the *Swift*-BAT error-box, an optical transient was found by the MASTER-Tavrida robotic telescope with a 30 s exposure taken 168 s after T_0 [12], which was later confirmed by the other optical telescopes. Preliminary optical magnitudes for the filters g, r, i reported by the NUTTelA-TAO show a clear initial rise, a peak around 200 s, followed by a decay [13]. The VLA detected a bright radio source with a flux density of about 1.3×10^{-4} Jy at 6 GHz 1.41 days after the burst, whose location is consistent with the optical afterglow position [17]. Late time optical observations identified an associated supernova [18]. The supernova component rose 5 days after the burst and its maximum is between 12 days and 20 days after T_0. The supernova evidence was also confirmed by the LBT telescope [19].

3. MAGIC observations

The MAGIC telescopes consist of two 17 m diameter imaging atmospheric Cherenkov telescopes, located at the Roque de Los Muchachos Observatory in La Palma, Canary Islands, Spain. The telescopes can detect VHE gamma-rays above 50 GeV, with an integral sensitivity above 220 GeV corresponding to about 0.66% of the Crab Nebula flux in 50 h of observations [20]. Thanks to their light-weight structure, the telescopes can point to a target with a repositioning speed of $7\,^\circ\,\mathrm{s}^{-1}$.

On 15 October 2020, at 22:50:32 UT (T_0+19 s), the automatic alert system received an alert by the *Swift*-BAT with the preliminary coordinates of GRB 201015A (right ascension, 23 h 37 m 22 s; declination, +53 d 23 m 36 s). The alert was validated as observable by the system and the automatic repointing procedure started immediately. The MAGIC telescopes started tracking on the target, and observations began at T_0+33 s. The observations were performed under dark conditions and lasted 4 h after T_0. The initial zenith angle of the telescopes was 24° and reached 48° at the end of observations. Quick offline analyses showed a hint of gamma-ray signal from the location of the GRB with significance $> 3\sigma$, that was reported in the Gamma-ray Coordinates Network [21].

Weather conditions during the observation were good for most of the time. However, a total 0.45 h of data in the last half of the observations were estimated to be affected by passing clouds in the field of view of the telescopes. After removing these affected data, we performed the data analysis with the standard MAGIC analysis software [22]. The energy threshold is evaluated to be 140 GeV from Monte Carlo simulated gamma-ray data.

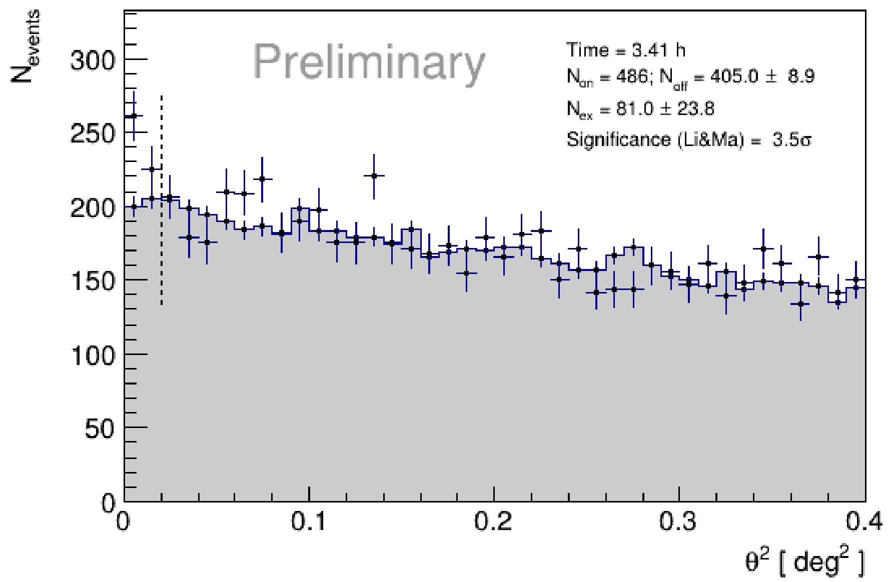

Figure 1: Distribution of the squared angular distance (θ^2) between the position of GRB 201015A and the reconstructed position of the events.

4. Results

The distribution of the squared angular distance (θ^2) between the target position and the reconstructed position of the events is shown in Figure 1. The number of excess events is 81.0 ± 23.8. The significance of the gamma-ray signal at the GRB position is calculated using Equation (17) of Li&Ma [23], and is 3.5σ. Figure 2 shows a significance (test statistic) sky map, centered at the GRB refined coordinates by the NOT (right ascension, 23 h 37 m 16.41 s; declination, +53 d 24 m 56.5 s [24]). At this position, we find a significance compatible with the one reported in Figure 1.

5. Discussion and conclusion

We presented the analysis of MAGIC observations performed starting $\sim$ 33 seconds after the onset of GRB 201015A. A strong hint of detection (at the level of 3.5σ) is found. The energy released in the VHE range is smaller but comparable to the one released during the prompt emission phase. A further refinement of the data analysis is planned, to confirm the significance of the excess. GRB 201015A would be one of the five GRBs detected by a Cherenkov telescope, together with GRB 190114C, GRB 180720B, GRB 190829A, and GRB 201216C. Also in this case, the GRB belongs to the class of long events, and is detected at TeV energies during its afterglow phase. Located at a distance very similar to that of GRB 190114C ($z \sim 0.42$), its energy release in the prompt phase was however about 3×10^3 times smaller ($E_{\gamma,\mathrm{iso}} \sim 10^{50}$ erg). In spite of this, the MAGIC telescopes found evidence of > 140 GeV emission from this relatively faint GRB. From preliminary estimates, we find that the ratio between the TeV flux at a given time and the prompt emission energy is the same for the two GRBs.

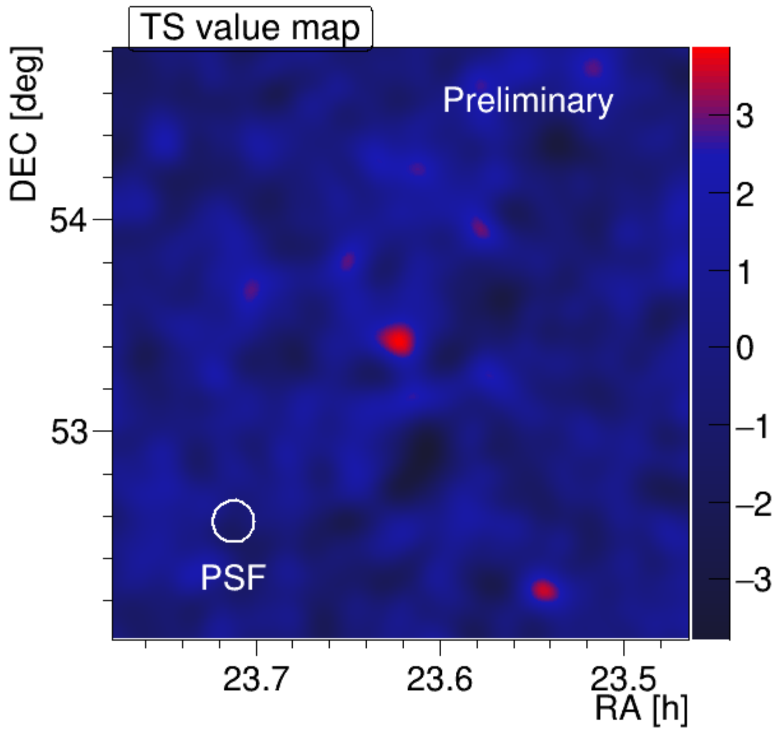

Figure 2: Significance sky map.

The possibility that GRBs with a relatively low energetic can produce TeV radiation at a level that is detectable also from relatively large ($z = 0.4$) redshift has of course a large impact both on theoretical models and on future prospects for detections of GRBs with the current and the upcoming generation of Cherenkov telescopes.

Acknowledgements

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