

Target of Opportunity Observations of Blazars with the MAGIC Telescope

Elina J. Lindfors¹, Daniel Mazin², Masaaki Hayashida³, Pratik Majumdar⁴, Masahiro Teshima⁵
On Behalf of the MAGIC Collaboration
and
Anne Lähteenmäki⁶

¹ Tuorla Observatory, Department of Physics and Astronomy, University of Turku, 21500 Piikkiö, Finland

² Institut de Fisica d'Altes Energies (IFAE), Barcelona, Spain

³ KIPAC, Stanford Linear Accelerator Center, Menlo Park, CA 94025, USA

⁴ DESY Deutsches Elektronen-Synchrotron D-15738 Zeuthen, Germany

⁵ Max-Planck-Institut für Physik, D-80805 München, Germany

⁶ Metsähovi Radio Observatory, Helsinki University of Technology TKK, 02540 Kylmälä, Finland

E-mail: elilin@utu.fi

ABSTRACT

The MAGIC collaboration has been performing Target of Opportunity observations of blazars, when seen flaring in the optical by the Tuorla blazar monitoring program. In the past three years, there have been 5 optical alerts during good weather conditions and reasonable declination of the source. Three alerts have resulted in discoveries of VHE γ -rays from previously undetected sources. In this paper we discuss the discovered sources, MAGIC observations of BL Lac and 3C 279, and we give an outlook for ToO observations of blazars with MAGIC in the MAXI era.

KEY WORDS: gamma-rays:observations—galaxies:active



Fig. 1. The MAGIC telescope (right) and the MAGIC II telescope, to be inaugurated in September 2008.

1. Introduction

MAGIC is an Imaging Air Cerenkov Telescope (IACT) located on La Palma, Canary Islands. Due to its large collecting area and uniquely designed camera, MAGIC has reached a lower energy threshold (trigger threshold 50-60 GeV, with new trigger 25 GeV (Teshima et al. 2008a)) for γ -ray emission than any existing terrestrial imaging γ -ray telescope. A more detailed introduction to MAGIC can be found in Albert et al. (2008a).

Blazars are the most extreme types of Active Galactic Nuclei (AGN). In these objects the dominant radiation component originates in a relativistic jet pointed nearly towards the observer. Blazars show variable flux in all

wave bands from radio to very high energy (VHE, defined as $E > 100$ GeV) γ -rays. The relationship between the variability at different wave bands appears rather complicated.

The MAGIC collaboration is performing Target of Opportunity observations of sources in high flux state in the optical and/or X-ray band. Alerts of optical high state originate from the Tuorla Blazar Monitoring Program. Optically triggered observations have resulted in the discovery of VHE γ -rays from Mrk 180 (Albert et al. 2006), 1ES 1011+496 (Albert et al. 2007a), and most recently from S5 0716+714 (Teshima et al. 2008b). In addition, parts of the BL Lac data in 2005 (Albert et al. 2007b) and the 3C 279 data in 2006 (Albert et al. 2008b) were taken when the sources were in high optical state, and resulted in the discovery of VHE γ -rays from these sources. Interestingly Mrk 180, S5 0716+714, BL Lac and 3C 279 were also in high X-ray state during the MAGIC discoveries (for 1ES 1011+496 no simultaneous X-ray data exist).

In this paper we discuss the discovered sources, their multiwavelength behavior and the prospects of using X-ray triggers from MAXI.

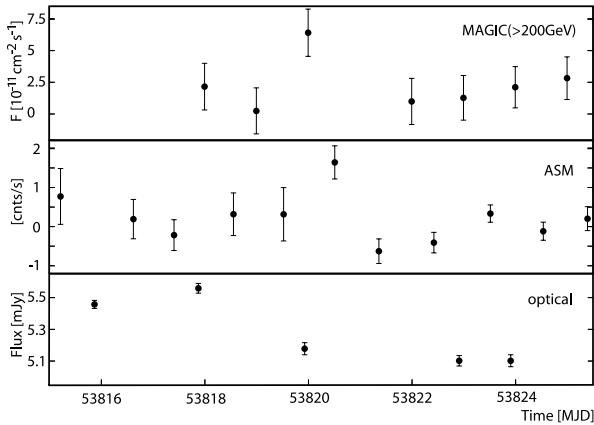


Fig. 2. Lightcurve of Mrk 180 for MJD= 53815-53825 (2006, March 21-31). *Upper panel:* VHE γ -rays measured by MAGIC above 200 GeV. *Middle panel:* ASM count rate, the highest count point corresponds to 3σ detection of the source by ASM. *Lower panel:* Optical flux measured by KVA.

2. Optically triggered Target of Opportunity observations with MAGIC

The optical monitoring observations are performed with the KVA 35 cm telescope at La Palma, remotely operated from Finland, and the Tuorla 1m telescope. The observations are done in the R-band and the magnitudes are measured using differential photometry with calibration stars in the same CCD frame as the object. From the observed flux the host galaxy contribution is subtracted following Nilsson et al. (2007) to measure the flux of the core. If the core flux increases $\sim 50\%$ (for some extremely variable sources 200%) the MAGIC observations are triggered. The lightcurves are updated to the project web page <http://users.utu.fi/kani/1m/> on a daily basis.

In the past three years, there have been 5 optical alerts during good weather conditions and reasonable declination of the source. For two of the sources the MAGIC observations yielded in upperlimit of VHE γ -ray flux and the publication on these upperlimits is in preparation. Three of the alerts have resulted in the discovery of new VHE γ -ray emitting blazars and are discussed here below.

2.1. Mrk 180

Mrk 180 (1ES 1133+704) is a well-known high frequency peaked BL Lac (HBL) at a redshift of $z = 0.045$ (Falco et al. 1999). In March 2006 it underwent an optical outburst and was observed for 12.4 hours by MAGIC. During these observations VHE γ -ray emission was detected with a significance of 5.5σ . An integral flux above 200 GeV of $(2.3 \pm 0.7) \times 10^{-11} \text{ cm}^{-2} \text{ s}^{-1}$ was measured, corresponding to 11% of the Crab Nebula flux. No significant flux variations were found. Earlier observations

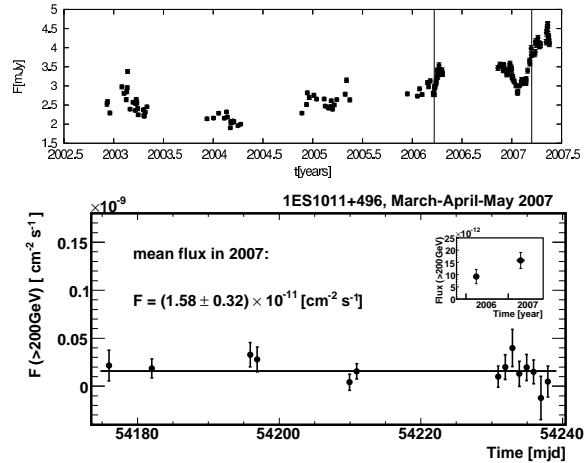


Fig. 3. Optical (top) and VHE γ -ray (bottom) light curves of 1ES 1011+496. The optical lightcurve shows five years of data from the Tuorla blazar monitoring program, and the vertical lines indicate the starting points of the MAGIC observations. The VHE γ -ray lightcurve shows two months of data from March 17th to May 18th 2007. The inset shows the yearly averages.

by other experiments have only set upper limits on the VHE γ -ray emission from Mrk 180. The upper limits are above the flux measured by MAGIC. It is therefore not possible to judge whether the detected VHE γ -ray flux level represents a flaring or a quiescent state of this AGN.

In X-rays the source is usually too weak to be detected with ASM, but at the epoch of the MAGIC observations there was a 3σ detection of the source possibly indicating that the source was in high X-ray state.

2.2. 1ES 1011+496

1ES 1011+496 is an HBL object at a redshift of $z = 0.212$. The MAGIC observations were triggered by an optical outburst in March 2007, and the source was observed from March to May 2007. The 18.7 hours of data show an excess at 6.2σ significance with an integrated flux above 200 GeV of $(1.58 \pm 0.32) \times 10^{-11} \text{ cm}^{-2} \text{ s}^{-1}$. The source has been observed previously by MAGIC in March–April 2006 when the source was in a lower optical state. Those observations only showed weak evidence for a signal at 3.5σ (Albert et al. 2008c). Consequently, the VHE γ -ray flux was $> 40\%$ higher in March–May 2007 than in March–April 2006, indicating that the VHE emission state may be related to the optical emission state. The source is too weak in X-rays to be detected with ASM, so there is no information on the X-ray state of the source.

2.3. S5 0716+714

The BL Lac object S5 0716+714 has been studied intensively at all frequency bands. It is highly variable with rapid variations observed from the radio to X-ray

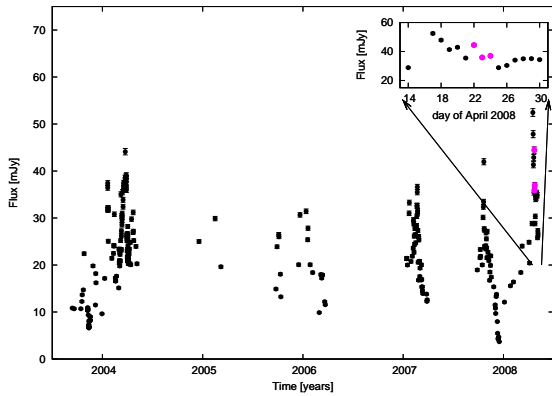


Fig. 4. Long term optical lightcurve of S5 0716+714. The inset shows the lightcurve from April 2008, the pink data points are simultaneous with MAGIC observations.

bands (Wagner et al. 1996). It has therefore been target to several multiwavelength campaigns, the most recent one organized by the GLAST-AGILE Support Program in July-November 2007 (Villata et al. 2008, Giommi et al. 2008a). Due to the very bright nucleus which outshines the host galaxy, its redshift is still uncertain. The recent detection of the host galaxy suggests a redshift of 0.31 ± 0.08 (Nilsson et al. 2008) which is consistent with the redshift $z=0.26$ determined by spectroscopy for 3 galaxies close to S5 0716+714 (Stickel et al. 1993, Bychkova et al. 2006). It can therefore be concluded that $z=0.26$ seems to be a rather likely redshift for S5 0716+714, although considering the lack of lines in the optical spectrum (e.g. Rector et al. 2001), the ultimate proof for the redshift is still missing. S5 0716+714 has a synchrotron peak in the optical band and is therefore classified as LBL (Nieppola et al. 2006) or IBL (Padovani et al. 1995). S5 0716+714, discovered by MAGIC, is only the third LBL (BL Lac (Albert et al. 2007b); W Comae (Acciari et al. 2008)) that has been detected at VHE γ -rays. With a presumable redshift of $z=0.31 \pm 0.08$, S5 0716+714 is the most distant object of the three and the second most distant of all VHE γ -ray emitters (after 3C 279 with $z=0.536$).

In April 2008 the optical flux of S5 0716+714 almost doubled in three nights (14th of April: 29 mJy, 17th April: 52 mJy) reaching its historical maximum on April 17th (see Fig. 4). MAGIC started the observations 5 nights later (April 22nd), when the moon conditions allowed. The observations resulted in the discovery of VHE γ -rays from S5 0716+714, announced in an Astronomer Telegram on April 30th (Teshima et al. 2008b). A detailed paper on the MAGIC results is in preparation. Interestingly, the source was in an all time high state also in the X-rays during the MAGIC observations (Giommi

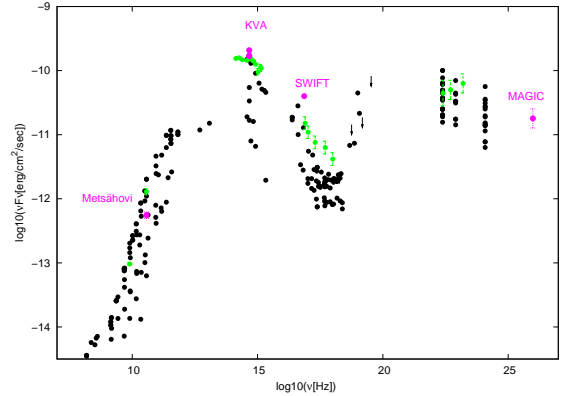


Fig. 5. The spectral energy distribution of S5 0716+714. The black data points are the historical SED from (Ostorero et al. 2006) and the green data points are from the high state of October 2007 (Villata et al. 2008, Giommi et al. 2008a). The pink data points are from April 2008: 37 GHz from Metsähovi Radio Observatory, optical from KVA, X-ray from SWIFT (Giommi et al. 2008b) and γ -ray from MAGIC (Teshima et al. 2008b)

et al. 2008b). The quasi-simultaneous spectral energy distribution of this high state in April 2008 is shown in Fig. 5.

3. Observations in high optical and X-ray state

In addition to optically triggered observations, MAGIC has observed two interesting blazars during high optical and X-ray states. Both observations resulted in the discovery of VHE γ -rays from the sources. The connection between X-ray high states and γ -ray high states is expected from theoretical models (e.g. Ghisellini et al. 1998) and correlated variability between X-rays and γ -rays has been observed in many sources (e.g. Fossati et al. 2008). MAGIC observations of BL Lac and 3C 279 give further confidence that X-ray triggers from MAXI would be highly useful for triggering MAGIC observations. In addition simultaneous radio-optical-X-ray and γ -ray observations can provide strong constraints on the models.

3.1. BL Lac

BL Lacertae (1ES 2200+420, $z=0.069$, Miller et al. 1978) is the prototype for a class of active galactic nuclei, the BL Lac objects. BL Lacertae was observed with the MAGIC telescope from August to December 2005 (22.2 hours) and from July to September 2006 (26.0 hours). A VHE γ -ray signal was discovered with a 5.1σ excess in the 2005 data. BL Lacertae is the first low-frequency peaked BL Lac object for which a clear detection of VHE γ -ray signal below the previous upper limits has been obtained. The 2006 data contain no signal, which is interpreted as a lower VHE γ -ray emission state.

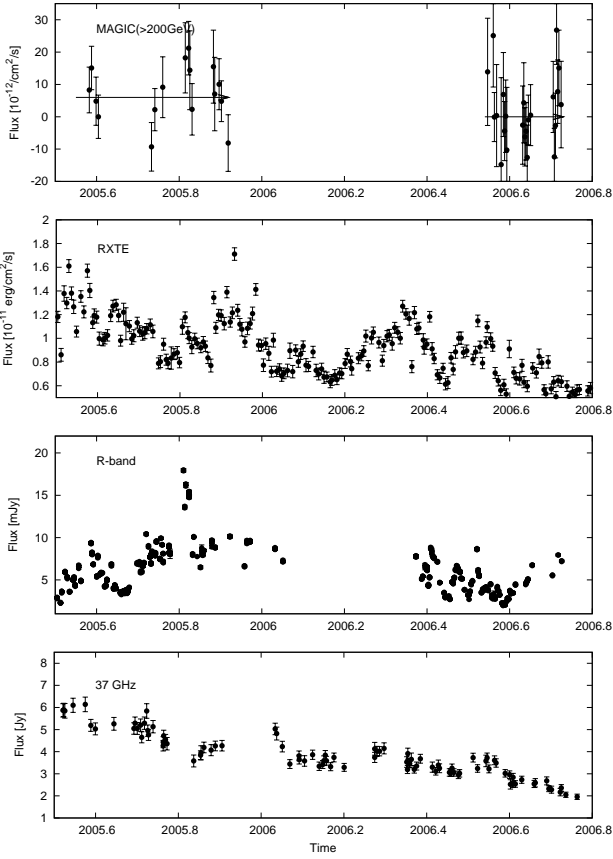


Fig. 6. Lightcurves of BL Lac at VHE γ -rays (top), X-rays, optical R-band and radio (bottom) from 2005.5 (beginning of July) to 2006.8 (end of September). VHE γ -ray (> 200 GeV) lightcurve measured with MAGIC (Albert et al. 2007b, Hayashida et al. 2007) and the horizontal lines represents the average fluxes of the observing periods. X-ray data are from RXTE (Marscher et al. 2008). The optical R-band data are from the Tuorla blazar monitoring program, the host galaxy flux of 1.37 mJy (Nilsson et al. 2007) has been subtracted from the lightcurve. The 37GHz data are from Metsähovi Radio Observatory.

The multiwavelength observations simultaneous to 2005 MAGIC observations show very interesting behavior from the X-ray to radio regime. The source was bright in all energy regimes, showing a two-peaked outburst in X-rays and optical and a 180 degree turn in polarization angle, but a single outburst in the radio regime. Marscher et al. (2008) interpreted this as a shock propagating down the jet along a spiral streamline, the first flare occurring during the last 240° twist of the streamline before the flow straightens and becomes turbulent. The passage of the feature through the millimetre-wave core stimulates the second flare. Marscher et al. (2008) also pointed out that the MAGIC lightcurve seems to agree with their scenario as the highly significant detections from 2005.819 to 2005.831 during the first X-ray

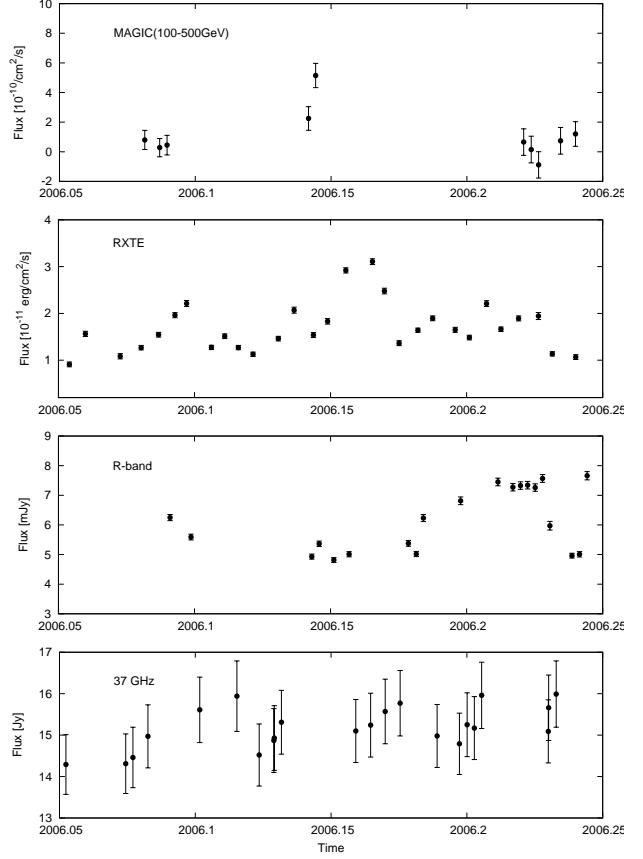


Fig. 7. Lightcurves of quasar 3C 279 at VHE γ -rays (top), X-rays, optical R-band and radio (bottom) from 2006.05 (January 18th) to 2006.25 (April 2nd). VHE γ -ray (100-500 GeV) data are measured with MAGIC (Albert et al. 2008b), and the two high points around 2006.15 (22th and 23rd of February) are the marginal and clear detections, respectively. The X-ray data are from RXTE (Chatterjee et al. 2008), optical from KVA telescope and the 37 GHz data from Metsähovi Radio Observatory.

flare implies that acceleration of electrons with sub-TeV energies was particularly efficient at this time. Although the MAGIC data from 2005 are statistically consistent with constant emission, in the data we find a marginal correlation between γ -rays and X-rays. Future simultaneous MAGIC-MAXI observations should be able to confirm this, as MAXI should be able to monitor BL Lac on a weekly basis (Tomida et al. 2008) and MAGIC-II will improve the MAGIC sensitivity so that monitoring observations of BL Lac become possible.

3.2. 3C 279

Flat Spectrum Radio Quasar 3C 279 ($z=0.536$) was the first blazar identified as a γ -ray source with the Compton Gamma Ray Observatory. It was observed with the MAGIC telescope over 10 nights between late January and April 2006 (total of 9.7 hours) and the VHE γ -ray

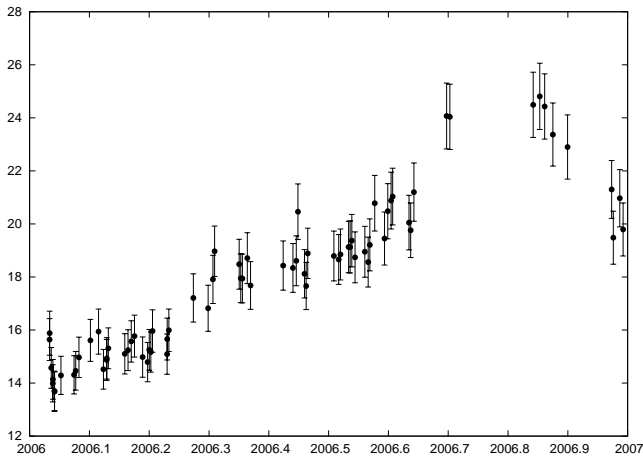


Fig. 8. 37 GHz lightcurve of 3C 279 from 2006 showing that during the MAGIC detections the radio flux was steadily increasing (see text).

signal was detected on the night of February 23rd with a significance of 6.1σ . Also data on the night before shows hint of signal.

During the MAGIC observations 3C 279 was in optical high state (low state being ~ 3 mJy), but the nights of MAGIC detections did not show any short time flaring activity in the optical regime. The actual optical flare occurred 15 days after the MAGIC detection. Also the long time X-ray lightcurves (Chatterjee et al. 2008) show that during the MAGIC observations, the source was in high state in the X-ray bands. It seems however that the flare reached its highest flux at the X-ray and optical band *after* the MAGIC observations, but the sampling of the MAGIC lightcurve is rather poor (see Fig. 7). Interestingly, it seems that radio flux was increasing during the MAGIC detection (see Fig. 8), in agreement with the findings of Lähteenmäki & Valtaoja (2003) and Lindfors et al. (2006) for γ -ray flares seen by EGRET, suggesting that the γ -ray flares in this source occur far away from the central engine well outside the BLR. As BLR is usually assumed to be origin for external photons to be scattered to γ -rays, this challenges the current models (e.g. Hartman et al. 2001) for emission of γ -rays in this source. Observations with Fermi Gamma-ray Space Telescope, simultaneous to X-ray with MAXI, VHE γ -ray, radio and optical observations should allow us to solve the mystery of the γ -ray emission site and mechanisms in 3C 279 as well as other blazars.

4. Discussion and Outlook

The optically triggered Target of Opportunity observations have resulted in the discovery of three new VHE

γ -ray emitting blazars. The observation strategy has proved successful, although the ultimate proof for the connection between the optical and the VHE γ -rays is still missing. The optically triggered observations will be continued, and follow-up observations of discovered sources will be performed in order to further study the connection between the flaring in the optical and VHE γ -ray regimes.

The prospects for using X-ray triggers from MAXI are good. For the five sources discussed here, four were in high state in X-rays at the time of discovery of VHE γ -ray emission, and for one we have no simultaneous data. However, the information on high X-ray state was in all cases received after the MAGIC observations had already started. With fast alerts from MAXI we foresee X-ray triggered observations of several blazars. These observations will hopefully increase the number of known VHE emitting AGN (currently 23, see e.g. <http://www.mppmu.mpg.de/~rwagner/sources> for up-to-date source list) and increase our knowledge of the population of γ -ray emitting blazars. The long-time X-ray lightcurves from MAXI in combination with lightcurves from other energy regimes will have a crucial role in answering the many open questions in the blazar field.

5. Acknowledgements

MAGIC enjoys the excellent working conditions at ORM and is supported by the German BMBF and MPG, the Italian INFN, the Spanish MCI-NN, ETH research grant TH 34/04 3, the Polish MniSzW Grant N N203 390834, and by the YIP of the Helmholtz Gemeinschaft. E.J.L. wishes to acknowledge the support by the Academy of Finland grants 122352 and 121148. D.M.'s research was supported by a Marie Curie Intra European Fellowship within the 7th European Community Framework Programme.

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