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OBSERVATIONS OF BL LACERTAE WITH MAGIC TELESCOPE

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RESUMEN

BL Lacertae fue observado con el telescopio MAGIC de agosto a diciembre de 2005 (22.2 horas) y de julio a septiembre de 2006 (26.0 horas). En 2005 se detectó, con un nivel de significación 5.1 σ, una fuerte emisión de rayos γ de muy alta energía (VHE). BL Lacertae es el primer objeto BL Lac con un pico de emisión a bajas frecuencias, en el cual se detecta este tipo de emisión. En los datos de 2006, no hay detección en la región de los rayos γ, lo que se atribuye a un menor nivel de flujo en este periodo. En este trabajo mostramos que también se observa una caida en el flujo óptico y milimétrico, lo cual sugiere una conexión entre estas tres bandas de emisión.

ABSTRACT

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 very high energy (VHE) γ-ray signal was discovered with a 5.1 σ 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 upperlimits has been obtained. The 2006 data contains no signal, which is interpreted as lower VHE γ-ray emission state. In this paper we show that the drop in flux level was also seen in the optical and millimetre regimes, suggesting a connection between these energy bands.

Key Words: BL Lacertae objects: individual (BL Lac) — gamma-rays: observations

1. INTRODUCTION

BL Lacertae (1ES 2200+420, z=0.069, Miller et al. 1978) is the prototype of a class of active galactic nuclei, the BL Lac objects, which are well known for their pronounced variability at all wavelengths, from the radio to the γ-ray band. The spectral energy distribution of these objects is characterized with a two-bump structure. It is normally attributed to a population of relativistic electrons in the magnetic field of the jet, where the first peak is due to synchrotron emission and the second peak is caused by inverse Compton scattering of low-energy photons. The low energy photons can be external to the jet (EC; Dermer & Schlickeiser 1993) or are produced within the jet via the synchrotron radiation (SSC; e.g. Maraschi et al. 1992). Models based on the acceleration of hadrons can also sufficiently describe the observed SEDs and light curves (Mannheim et al. 1993). Based on the peak frequency of the low energy bump, BL Lac objects are divided into two subclasses; those with peak on submillimetre to optical band are called low-frequency peaked BL Lacs (LBL) and those with peak on UV to X-ray regime are called high-frequency peaked BL Lacs (HBL). BL Lacertae is an LBL object with synchrotron peak frequency at 2.2×10^{14} Hz (Sambruna et al. 1999).

The number of Very High Energy (VHE) emitting objects has been steadily increasing since the inauguration of the new generation Cerenkov telescopes MAGIC and HESS. Currently the number of known VHE emitting AGN is 18 (see e.g. `http://www.mppmu.mpg.de/~rwagner/sources/` for an up-to-date source list) 16 of which are HBLs, one is a radio galaxy, M87 (Aharonian et al. 2006), and BL Lacertae is the first detection of a LBL which is consistent with previous upper limits. There has been a detection claim from the Crimean Observatory (Neshpor et al. 2001) of BL Lacertae and another LBL 3c66A. However, observations of BL Lac with HEGRA from the same observing period showed no signal and the derived upper limit for the flux was lower than the flux claimed by the Crimean Observatory.

In optical and radio frequencies BL Lacertae has been studied in great detail by the WEBT collaboration (`http://www.to.astro.it/blazars/webt`), the most recent publication (Villata et al. 2004) showing the extensive lightcurves of the source from 1968-2003. The historical lightcurves show that the radio flux at 37 GHz varies from $\sim 2-14$ Jy and at optical R-band core flux (i.e. host galaxy subtracted) from $\sim 2-70$ mJy.

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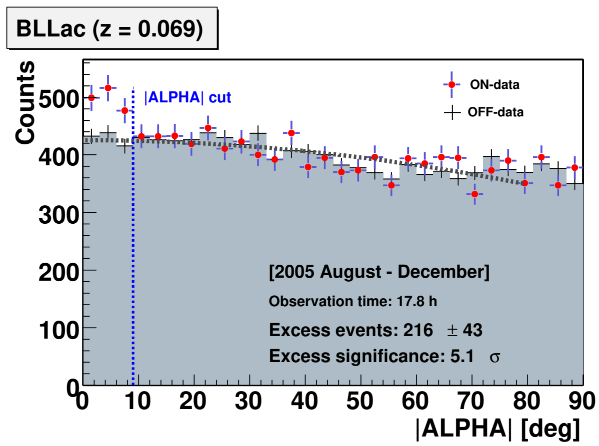

Fig. 1. ALPHA-distribution of the 2005 data. The filled circles represent ON-data. The light crosses correspond to normalized OFF-data and a dotted curve describes a second order polynomial fit to the distribution of the OFF-data. The vertical line indicates the ALPHA selection condition, which yielded to a total excess of 216 events at a significance level of 5.1σ.

In this paper we present the results of the observations of BL Lacertae with the MAGIC telescope and the simultaneous and quasi-simultaneous optical (from the Tuorla blazar monitoring program `http://users.utu.fi/kani/1m`) and radio data (37 GHz from the Metsähovi Radio Observatory) and discuss the possible connection among these three energy regimes.

2. OBSERVATIONS AND RESULTS

The MAGIC telescope is located at the Canary Island of La Palma and is the largest Imaging Atmospheric Cerenkov Telescope in the world with a 17 meter diameter dish (for a detailed description see Albert et al. 2007a). BL Lac was observed for 22.2 hours from August until December 2005 in the so called ON-OFF mode. The data was processed with the standard MAGIC analysis and reconstruction software (Bretz et al. 2005, Albert et al. 2007a). Data runs with anomalous trigger rates due to bad observation conditions were rejected from further analysis, which resulted in 17.8 hours of ON-data. The significance of the excess is shown in Figure 1 and is 5.1 σ. The details of the analysis are discussed in Albert et al. (2007b).

Follow-up observations were carried out from July to September 2006 for 26.0 hours, using the so-called wobble mode (Daum et al. 1997). This data showed no significant excess. The analysis of this data is presented in Hayashida et al. (2007).

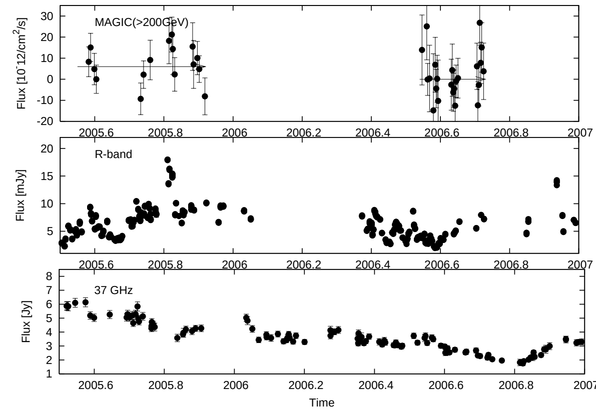

Fig. 2. Top: VHE γ-ray (> 200GeV) lightcurve measured with MAGIC. The horizontal lines represents the average fluxes of the observing periods. Middle: The optical R-band lightcurve measured with KVA and Tuorla telescopes. The host galaxy level of 1.37 mJy has been subtracted from the lightcurve. Bottom: The radio lightcurve at 37GHz from Metsähovi Radio Observatory.

Optical R-band observations were performed with the 1.03 m telescope at the Tuorla Observatory, Finland and 35 cm KVA telescope on La Palma, Canary Islands as a part of the Tuorla Blazar monitoring program (`http://users.utu.fi/kani/1m/`). Photometric measurements were made in differential mode, i.e. by obtaining CCD images of the target and calibrated comparison stars in the same field of view (Fiorucci & Tosti 1996; Fiorucci et al. 1998; Villata et al. 1998). The magnitudes of the source and comparison stars are measured using aperture photometry and the (color corrected) zero point of the image determined from the comparison star magnitudes. Finally, the object magnitude is computed using the zero point and a filter-dependent color correction. Magnitudes are then transferred to linear fluxes using the formula $F = F_0 * 10^{(\mathrm{mag}/-2.5)}$, where mag is the object magnitude and F_0 is a filter-dependent zero point (in the R-band the value F_0=3080 Jy is used, Bessell 1979). Finally the host galaxy flux (1.37 mJy, Nilsson et al. 2007) was subtracted from the total flux.

The 37 GHz radio Observations were performed as a part of Metsähovi Radio Observatory AGN monitoring program using the 13.7 m radio telescope in Metsähovi. For the details of the observing methods and data reduction see e.g. Teräsranta et al.(1998).

Figure 2 shows the lightcurves from MAGIC, Tuorla/KVA and Metsähovi in 2005 and 2006. It is clearly visible that the optical state during the MAGIC observations in 2005 (average 9.2 mJy) was higher than the optical state in 2006 (average 4.2 mJy). The same is true for radio observations: the average flux on 2005 observing epoch was 5.5 Jy, while it was only 2.6 Jy in 2006. The MAGIC lightcurve shows no statistically significant variability and the average flux for 2005 is $(6.0 \pm 2.0) \times 10^{-12}$ cm^{-2} s^{-1} with photon index -3.6 ± 0.5.

3. DISCUSSION

BL Lacertae is the first LBL with clear detection of VHE γ-ray emission. The observed flux level is similar to one predicted by Böttcher & Reimer (2004) for hadronic models based on the data from a multiwavelength campaign in 2000 (Böthcer et al. 2003), and exceeds the one predicted for leptonic models by an order of magnitude. However, the optical state in 2005 was slightly higher than during the multiwavelength campaign in 2000 and the spectral energy distribution can also be explained with a leptonic model (Ravasio et al. 2002; Albert et al. 2007b).

The optical lightcurve shows a flare around the end of October 2005 reaching ~ 20.0 mJy. Comparison with the historical lightcurve of Villata et al. (2004) shows that this is only a minor flare. For example the flare in 1997 reached almost 70 mJy. In the 37 GHz lightcurve the increasing flux in November 2005 and rapidly decreasing flux in January 2006 suggests that there might also be a minor flare at radio frequencies around December 2005. Unfortunately there is a gap in the radio lightcurve in December 2005 due to poor observing conditions. The average optical and radio fluxes are higher during 2005 MAGIC observations than 2006 observations. As the 2005 MAGIC observations yielded in a firm detection while the 2006 observations showed no signal, it seems that the γ-ray flux was following a similar trend. This has been suggested previously for BL Lacertae by the EGRET observations: the observations during the low states yielded to no significant detection (Catanese et al. 1997) while the observations during the major optical flare in 1997 yielded a 10σ detection (Bloom et al. 1997). Interestingly, there was also a radio outburst in 1997, which started few months later than the optical outburst. This would imply that the flares might have followed a similar trend, although the 2005 flare was minor compared to 1997 flare.

MAGIC has also been observing HBLs during optical flares. The observations have resulted in the discovery of VHE γ-ray emission from Mrk 180 (Albert et al. 2006) and 1ES 1011+496 (Albert et al. 2007c). In these sources no connection with the radio emission was seen, as HBLs are generally weaker at radio frequencies than LBLs (e.g. Nieppola et al. 2006). However, these discoveries further suggest that the optical state might be a good indicator of VHE emission state for all BL Lacertae objects.

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