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Recent HEGRA observations of BL Lac (2200+420)

O. Mang, M. Schilling, M. Siems, and the HEGRA collaboration

Universität Kiel, Institut für Experimentelle und Angewandte Physik, Leibnizstr. 17–19, D-24118 Kiel, Germany

Abstract. The active galaxy BL Lac is the prototype of the so-called BL Lac objects. All AGN detected in the TeV energy range so far belong to this class of objects. BL Lac has been observed by the HEGRA system of imaging Cherenkov Telescopes for a total time of 10.5 hours from September to November 2000. We compare the results of these observations with X-ray data from the All Sky Monitor aboard the RXTE satellite and present an upper limit on the γ-flux for energies above 0.7 TeV.

1 Introduction

The detection of active galactic nuclei (AGN) as extragalactic sources of TeV γ-radiation and the observation of spectacular outbursts have put these objects in the focus of TeV γ-astronomy. Since all TeV γ-ray emitting AGN known today belong to the BL Lac class, many efforts have been made to improve the understanding of BL Lac-type AGN. One of the goals is the detection of other BL Lac objects in the TeV energy range. The most obvious candidate for this kind of search is the prototype of the class, the active galaxy BL Lacertae (RA 22.0, Dec +42.0).

One of the most striking features of BL Lac-objects is their temporal variability. For the objects Mrk-421 and Mrk-501 strong flares have been observed in the TeV-regime (see e.g. Kohnle et al. (2001) and references therein). Simultaneous observations with the RXTE satellite revealed similar outbursts in X-rays; both lightcurves showed a strong correlation (Sambruna et al., 1999). These multi-wavelength observations are helpful for the distinction of different acceleration scenarios (e.g. proton or electron populations) and have made the SSC (synchrotron-self-compton) model the most probable explanation for the spectra of blazars. For a review of blazar models see e.g. Urry and Padovani (1995).

BL Lac has been known to be variable from the beginning (it was originally discovered as a variable star) and has undergone outbursts in the optical wavelengths and at GeV energies (Bloom et al., 1997). It has been observed by the HEGRA system of Cherenkov Telescopes (see next section) on several occasions over the past years, but no evidence for TeV γ-emission has been found so far (Bojahr et al., 1999).

To determine the state of BL Lac, X-ray data from the All-SkyMonitor (ASM, Remillard and Levine (1997)) aboard the RXTE satellite are used. For example, Mrk-421 showed an increased activity in the ASM data during its recent outburst (Jan.-Mar. 2001). If BL Lac were in a high state and not detected in the TeV energy band, this would limit the spectral energy distribution and thus the parameters of the blazar model for this particular AGN.

2 The HEGRA system of imaging Cherenkov telescopes

The HEGRA collaboration operates a system of five imaging Cherenkov telescopes (CTs) at the *Observatorio del Roque de los Muchachos* on La Palma (Canary Islands). The Observatory is located at an altitude of 2200 m a.s.l., $28.75°$N, $17.88°$ W. Until March 2000, HEGRA also operated an array of scintillation counters and wide-angle Cherenkov detectors, but these were not used in this work. For details see Barrio et al. (1998).

The HEGRA CTs form a square of $100\,m \times 100\,m$ with four CTs located on the corners and one in the centre of the square. Each CT contains 30 circular mirrors with a total reflective area of $8.5\,m^2$ and a high-resolution camera with 271 phototubes in the focal plane.

The arrangement of the CTs allows a stereoscopic observation of the air shower in Cherenkov light and a precise reconstruction of the shower parameters. The energy threshold of the system is $500\,GeV$ near the zenith with an energy resolution of 20%; the angular resolution for the reconstructed shower axis is $\approx 0.1°$. With these parameters, the HEGRA CTs are ideally suited to study TeV emissions from galactic and extragalactic sources and to perform searches for new TeV γ-ray sources. For further details on the HEGRA CTs

Correspondence to: O. Mang (mang@physik.uni-kiel.de)

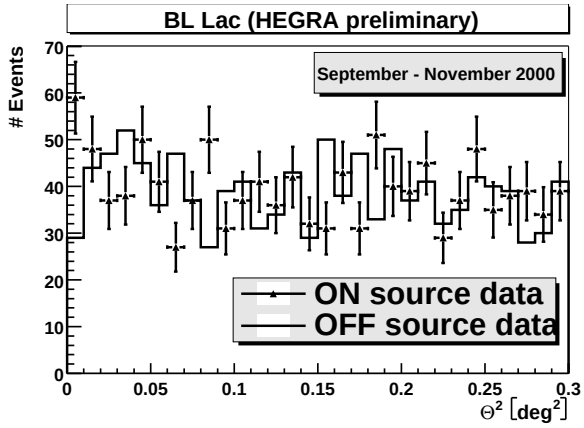

Fig. 1. The Θ^2 plot (see text) for BL Lac with the cut $0.5 < mscw < 1.2$ applied. A TeV γ-signal would be indicated by an excess in the first bins (see Fig. 2).

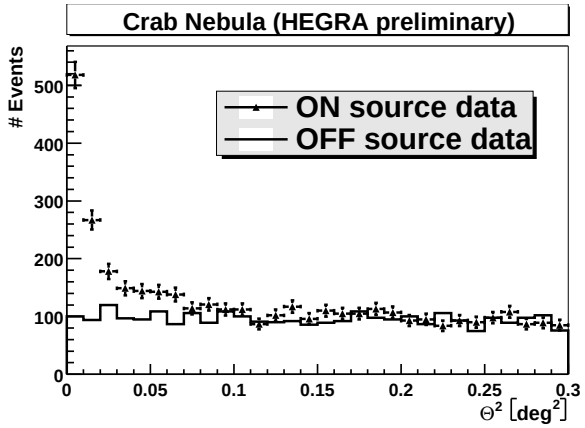

Fig. 2. The corresponding plot for the Crab Nebula based on a data set of 10.8 hours, collected during the same time as BL Lac-data, with $\vartheta < 30^\circ$. The γ-signal is clearly visible in the first bins.

see Daum et al. (1997a) or Daum et al. (1997b).

3 The data sample

The data used in this analysis were taken with all five CTs operational during September–November 2000 with zenith angles $15^\circ < \vartheta < 45^\circ$, yielding a total dataset of 10.5 hours.

A dataset from the Crab Nebula taken during the same time was used as a reference. Assuming a Crab-like spectrum for BL Lac, one can derive an upper limit expressed in "Crab flux units". This way a treatment of systematic errors and uncertainties from simulations can be avoided.

Since the energy threshold depends not only on the hardware of the instrument, but also on the zenith angle, a restricted dataset was used to derive the upper limit. Only data with a zenith angle $\vartheta < 30^\circ$, where the change in the energy threshold is small, have been selected. This restriction reduces the dataset to 6.3 hours with an averaged zenith angle of $\vartheta = 27.8^\circ$, resulting in a threshold energy of 0.7 TeV. Only data taken under good weather conditions were chosen for this analysis.

For comparison, a datasample recorded by the AllSky-Monitor (ASM) aboard the RXTE satellite was used. The *ASM QuickLook data* are publicly available[1] and provide a measure for the X-ray activity of objects in its field of view. We use data that cover the whole period of the HEGRA observations of BL Lac mentioned above.

4 Analysis and Results

The HEGRA datasamples were subjected to the standard reconstruction and filter algorithm. The main parameters of the stereoscopically reconstructed showers are the angular distance Θ of the shower direction to the direction of the observed object and the *mean scaled width* of the shower image.

[1] http://xte.mit.edu/ASM_lc.html

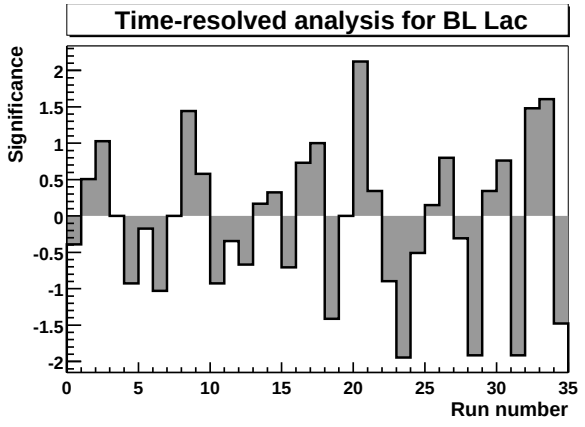

Fig. 3. A time resolved analysis shows the significance of every single data run (duration 20 minutes). No evidence for an outburst of BL Lac can be found.

The width of the shower image is scaled taking into account the size (i.e. number of photons) and the width of a corresponding γ-shower, the zenith angle and the distance of the shower impact point, and then averaged over all telescopes. For a detailed description see Konopelko et al. (1995).

Fig. 1 shows the Θ^2 plot for BL Lac with standard cuts. Using the square of the angular distance Θ as the abscissa results in bins of equal solid angle. The leftmost bins ($\Theta^2 < 0.05$) reveal no excess events from the direction of the observed AGN. Fig. 2 shows data of the Crab Nebula, the first bins exhibit a very strong γ-signal.

To test the data set for possible outbursts or flares of BL Lac, the data have been divided into datasets for individual nights and also individual data runs of 20 min. duration (Fig. 3). Neither method revealed a signal on short timescales.

Fig. 4 shows the integrated X-ray flux of BL Lac as measured by the ASM at the time of the HEGRA observations. Except for the date MJD 51873 (Nov. 25^{th} 2000) no indication for an increase in the flux has been seen. Since the

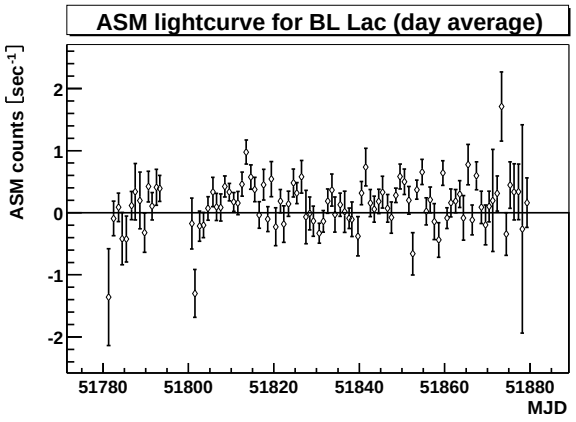

Fig. 4. Daily average of BL Lac for the HEGRA observation period measured by the RXTE AllSkyMonitor. The data contain no strong hint of increased X-ray activity. *ASM QuickLook data provided by the ASM/RXTE team.*

errors of the ASM data are an underestimate in many cases, this is probably still compatible with a zero flux and not a significant increase of the X-ray flux.

Comparing the dataset of BL Lac with the one of the Crab Nebula and assuming a Crab-like spectrum for BL Lac, one can derive a preliminary upper limit for the γ-ray flux above $0.7\,TeV$ for BL Lac of 25% of the flux of the Crab Nebula at a confidence level of 99% (CL 99%). For this purpose, the data have been normalized w.r.t. observation time using

$$\frac{N_{BL\ Lac,max}}{N_{Crab,min}} \times \frac{T_{Crab}}{T_{BL\ Lac}} \qquad (1)$$

with $N_{object,[max|min]}$ being the maximum and minimum number of excess events, respectively, and T_{object} being the observation time for the corresponding object. The upper limit has been calculated according to the method of Helene (1983).

The flux limit of this work is compatible with values previously published by HEGRA. The latest values (also at CL99%) are 7% of the Crab flux from measurements with the stand-alone CT of HEGRA (Mang et al., 1999) and 11%, determined also with the HEGRA system of CTs (Bojahr et al., 1999).

5 Conclusions

The HEGRA Experiment has recently conducted new observations of BL Lac. During the year 2000, 10.5 hours of observation time were devoted to this AGN. So far, no indication of activity in the γ-ray regime above 1 TeV could be observed. Only an upper limit on the flux of 25% (CL 99%) of the Crab flux could be determined from these observations, using the 6.3 hours dataset with zenith angles below 30°. This is compatible with flux limits that were previously published by the HEGRA collaboration; the best upper limit so far is at 7% of the Crab flux, assuming a constant quiescent state of BL Lac. The results given here are preliminary; refined results will be presented at the conference.

The comparison with X-ray data from the RXTE/ASM instrument shows that BL Lac was in a rather quiet state during the HEGRA observations and therefore no increased activity (if any) in the TeV-regime could be expected.

To improve the result and hopefully catch a more active state of BL Lac, further observations have been scheduled for autumn 2001 with a total time of ca. 70 hours. This will substantially increase the chance of a detection of BL Lac or at least yield greatly improved flux limits.

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References

Konopelko, A. et al., 1995, Proc. "Towards a Major Atmospheric Cherenkov Detector IV", Padova

Barrio, J.A. et al., Status and New Results of the HEGRA Experiment, Proc. of the 16^{th} European Cosmic Ray Symposium, 507–510, 1998

Bloom, S.D., Bertsch, D.L., Hartmann, R.C. et al. 1997, ApJL 490, L145.

Bojahr, H. et al., Upper limits on BL Lacs, Proc. of the 26^{th} ICRC, Salt Lake City, USA, Vol.3 pp.410–413, 1999

Daum, A. et al., The HEGRA stereoscopic system of imaging Cherenkov Telescopes, Proc. "Towards a Major Atmospheric Cherenkov Detector V", Kruger Park, SA, 1997

Daum, A., Hermann, G. et al., The stereoscopic system of imaging atmospheric Cherenkov telescopes of the HEGRA-Collaboration, Proc. of the 25^{th} ICRC , Durban, SA, 1997

Helene, O., Upper limit of peak area, NIM 212, 319, 1983.

Kohnle, A. et al., Observations of Mkn 421 and Mkn 501 in 2000 and 2001 with the HEGRA stereoscopic IACT system, these proceedings

Mang, O., Schilling, M., Rauterberg, G. et al., Search for TeV gamma emissions from BL Lacertae with the HEGRA equatorial mount Cherenkov telescope, Proc. of the 26^{th} ICRC, Vol.3 pp434–436, 1999

Remillard, R. and Levine, A.M., 1997, Proc. of the Workshop "All-Sky X-ray Observations in the Next Decade", Waco, Japan

Sambruna, R., the HEGRA collaboration et al., 2000, Correlated intense X-ray and TeV activity of Mrk-501 in 1998 June, Astrophysical Journal Vol.538, Iss.1, pp.127–137

Urry, C.M. and Padovani, P., 1995, Unified schemes for Radio-Loud Active Galactic Nuclei, PASP (September 1995 issue)