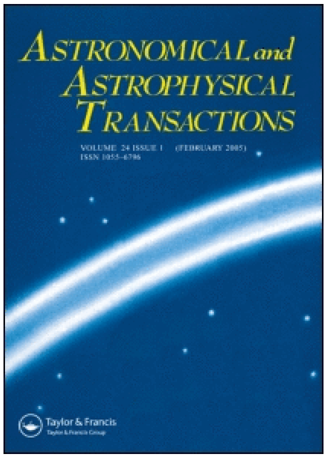


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# Teraelectronvolt observations of the BL Lac object in 2004

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The results of observations of the BL Lac object at the Scientific Research Institute, Crimean Astrophysical Observatory, with the Cerenkov telescope GT-48 in September and November 2004 are presented. The $\gamma$-ray emission from object was detected at the $5\sigma$ level. The flux from BL Lac was within the limits of $0.94 \pm 0.38$ of that of the Crab Nebula ($E \geq 1$ TeV).

*Keywords*: $\gamma$-rays; Active galactic nuclei; Object BL Lac

## 1. Introduction

The detection of teraelectronvolt $\gamma$-rays from active galactic nuclei (AGNs) and the determination of the timescales of their variability may give information about the emitting regions and mechanisms of acceleration of charged particles which are the origin of such high-energy $\gamma$-rays.

Teraelectronvolt $\gamma$-ray emission from AGNs that fall in the blazar class supposedly arise from relativistic jets pointing towards the observer's line of sight. The very-high-energy (VHE) photons could arise from inverse Compton scattering of seed photons on relativistic electrons [1] or may be produced by the decay of neutral pions that may occur in proton–nuclear interactions [2].

The BL Lac object belongs to a marginal class of AGNs, namely BL Lacertaes, which are characterized by extremely rapid variations in their radio and optical fluxes and polarizations [3] and is a prototype for the majority of the members of this class.

From the results of the first observations of BL Lac with the aid of ground-based detectors, it was derived that the upper flux limits equals $1.2 \times 10^{-10}$ photons cm$^{-2}$ s$^{-1}$ ($E > 250$ GeV) at Whipple Observatory [4] and $1.1 \times 10^{-10}$ photons cm$^{-2}$ s$^{-1}$ ($E > 2.2$ TeV) at the Crimean Astrophysical Observatory [5].

Observations of BL Lac using the 10 m optical reflector located at the Whipple Observatory on Mount Hopkins in Arizona in the period between 17 October and 25 November 1995 also

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did not reveal the presence of emission from the object. The upper flux limit at the 99.9% confidence level derived from these observations in energy band above 350 GeV was estimated to be $0.53 \times 10^{-11}$ photons $cm^{-2}$ $s^{-1}$ [6].

Later our observations of BL Lac with the Cerenkov telescope GT-48 in the period between 23 July 1998 and 1 September 1998 revealed that the flux at $E \geq 1$ TeV equals $2.1 \pm 0.4 \times 10^{-11}$ photons $cm^{-2}$ $s^{-1}$ [7].

Our observations of BL Lac were repeated in 2000 and 2002 [8, 9]. They also revealed the flux from the object and positive correlation with optical luminosity.

In this work we present results of observations of BL Lac with the Cerenkov telescope GT-48 in 2004.

## 2. Cerenkov telescope and observations

Cerenkov telescopes detect VHE $\gamma$-rays through registration of Cerenkov light emitted by the extensive air showers (EASs) initiated by them. These showers propagate in the atmosphere in the direction close to the direction of primary $\gamma$-ray propagation and cover an area on the Earth's surface of about $10^4$ $m^2$. The density of the Cerenkov light pool is proportional to energy of the primary $\gamma$ quanta, so that it is possible to determine the direction of the primary $\gamma$-ray propagation and its energy through the detection of Cerenkov flashes emitted by EASs.

The Cerenkov telescope GT-48 consists of two identical altazimuth mountings (sections), each of which is equipped with four cameras. Each 37 pixel camera is placed in a focal plane of four parabolic reflectors with diameters of 1.2 m. The total surface of reflectors on both sections of telescope is 36 $m^2$.

Each pixel in the camera has a viewing angle of $0^\circ.4$; the total field of view of each camera is $2^\circ.6$. Both sections of the telescope operate in a coincidence mode. Signals from pixels from four cameras on each section are linearly added. Cerenkov flashes are detected in the optical band and for an event when the two most intensive pixels have amplitudes of signals exceeding a certain threshold.

Both mountings of the telescope are geared with the aid of a control system with a pointing accuracy of $\pm 0^\circ.05$. The threshold energy for detecting VHE $\gamma$-rays was determined by digital modelling and equals about 1 TeV. Telescope was described in detail by Vladimirsky *et al.* [10].

The observations of BL Lac ($\alpha = 22$ h 02 m 53 s and $\delta = 42^\circ 17' 49''$) were carried out during 17 moonless nights between 14 September 2004 and 11 November 2004. Observations were made in the ON–OFF mode, when ON runs (source exposure) were followed by OFF runs (background registration). Both ON and OFF runs were 35 min in duration and were carried out at the same level of elevation. In ON runs the source was in the centre of the field of view (FoV) of the camera. The background was registered with shifting on the right ascension by 40 min. A total of 34 ON–OFF pairs were taken at zenith angles of 28° or less.

After cleaning the observational runs with respect to weather conditions, ten ON–OFF pairs were disregarded. The remaining 24 ON–OFF pairs with a total source exposure of 14 h (table 1) and the same time for background registration were used for processing the Cerenkov flash images from EASs triggered by the VHE $\gamma$-rays and cosmic rays.

The cleaned data were subject to the next reduction process.

(i) Events which were registered in a distorted telescope guiding process (*i.e.* a deviation of the optical axes of the telescope mountings from the specific direction by more than $3'$) were disregarded.

Table 1. GT-48 observations log and exposure times of BL Lac.

| Observing period | Modified Julian date | Source exposure (min) |
|---|---|---|
| 14–20 September 2004 | 53263–53269 | 420 |
| 3–11 November 2004 | 53313–53321 | 420 |
| Total | | 840 |

(ii) Data in which of the analogue-to-digital converter maximum (255 discrete units, or 180 photoelectrons) was exceeded in at least one channel were discarded.
(iii) The amplitudes of signals in all channels were corrected using calibration coefficients estimated in each run.
(iv) Flashes whose maximum amplitudes were in the outer ring of camera were disregarded.

## 3. Selection effect

The selection of $\gamma$-ray showers from cosmic-ray showers (mainly protons and nuclei of light elements) is based on differences in their flash images in the FoV of the multipixel camera. The parameters of the two types of flash differ from each other in their forms, angular dimensions and orientations concerning the source position in the FoV of camera. To distinguish between these flashes, the centres of the brightness distribution of each image and processed effective dimensions in the direction of the main axis (*LENGTH*) and in the perpendicular direction (*WIDTH*) were determined [11].

The orientations of images in the FoV of camera were determined by the angular distance from source position (the centre of camera) and the centre of the flash image (*DIST*) and azimuthal width (*AZWIDTH*), the rms image width relative to a new axis which joins the source to the centroid of the image (figure 1). Flashes with small detected amplitudes were disregarded because the parameters of such flashes are determined with high errors.

The boundary parameters for the selection for any criteria were estimated by the maximum value of the signal-to-noise ratio: $Q = (N_s - N_b)/(N_s + N_b)^{1/2}$, where $N_s$ and $N_b$ are the numbers of events in ON and OFF runs respectively. The difference $N_s - N_b = N_\gamma$ is the number of $\gamma$ quanta and $(N_s + N_b)^{1/2}$ is the statistical error of this number.

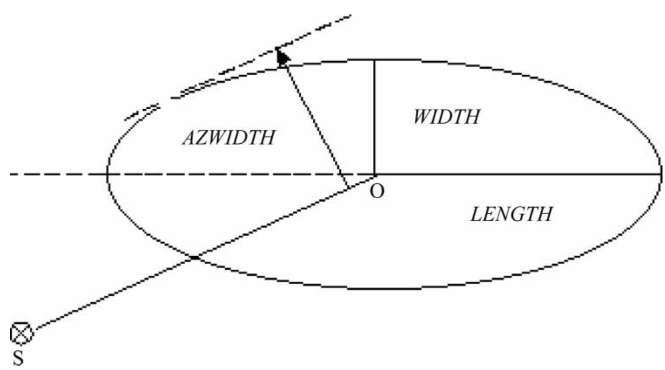


Figure 1. The schematic representation of the main parameters of the flash image: O, the centre of the brightness distribution; S, the position of the source. The length OS corresponds to parameter *DIST*.

## 4. Results of analysis

The selection statistics are summarized in table 2. In the results obtained in 2004, selection by the parameters *AZWIDTH* and *DIST* was used.

From table 2 it may be seen that the reduction procedure has resulted in essential suppression of the background (a decrease in $N_b$ by a factor of about 110 was accompanied by a decrease in $N_s$ by a factor of about 60).

Using the method of trial sources [12, 13] the distribution of the number of selected events over the detector's FoV was constructed and the true position of the $\gamma$-ray source determined. Figure 2 shows a two-dimensional histogram of this distribution and figure 3 shows isophotes of this distribution.

The maximum of the distribution ($\Delta\alpha = 0°.0$ and $\Delta\delta = 0°.1$) coincides with the coordinates of BL Lac within the precision of the determination of source position by the method of trial sources (about 0°.1).

Figure 4 shows the mean count rates of the detected VHE $\gamma$ quanta in September and November 2004. The average count rate for all observation period was $0.106 \pm 0.021$ $N_\gamma$ $\mathrm{min}^{-1}$. From figure 4 it is seen that fluxes of VHE $\gamma$ quanta detected in September and November coincided within statistical errors.

Table 2. Selection statistics.

| Selection method | $N_s$ | $N_b$ | $N_s - N_b$ | $Q$ |
|---|---|---|---|---|
| Without selection | 12 560 | 12 377 | 183 | 1.16 |
| Selection by amplitudes of signals, forms and dimensions of flash images | 430 | 351 | 79 | 2.83 |
| Selection by orientation of flash images | | | | |
| In September | 113 | 73 | 40 | 2.93 |
| In November | 90 | 41 | 49 | 4.28 |
| In the observing period | 203 | 114 | 89 | 5.00 |

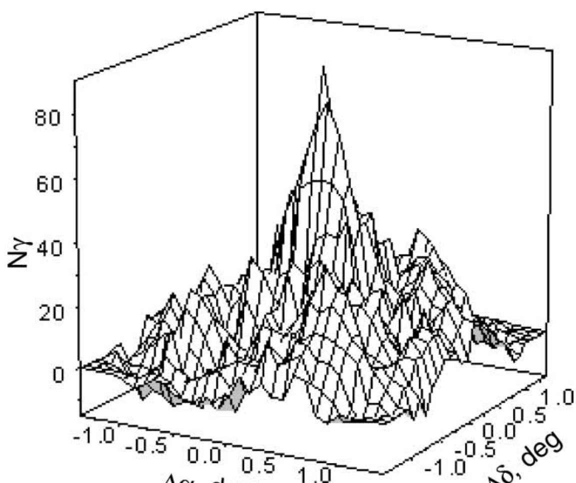


Figure 2. The stereoimage of the distribution of $\gamma$-quanta arrival directions. $\Delta\alpha$ and $\Delta\delta$ are deviations from the source position in the FoV of the camera on the right ascension and declination.

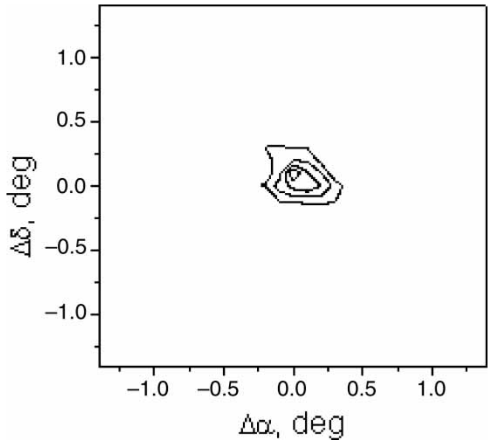


Figure 3. Isophotes of the distribution of γ-quanta arrival directions. The external isophote equals 48 events, and the isophote step is 11 events.

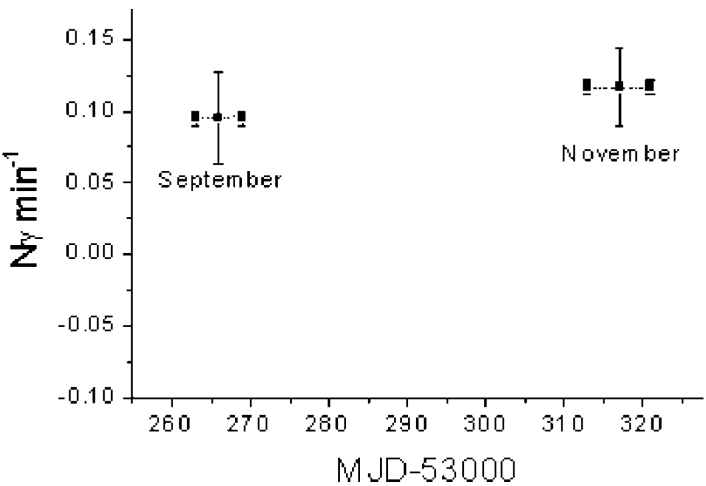


Figure 4. Distribution of the mean detection rates of VHE γ quanta for different periods. The error bars are purely statistical.

For flux estimation we have processed the Crab Nebula data gathered in the 2002–2004 observation seasons with a total source exposure of 15 h. The same selection criteria were applied as for BL Lac. The resulting $\gamma$ rate equals $0.113 \pm 0.024$ $N_\gamma$ $min^{-1}$. By comparison with the BL Lac count rate the flux from BL Lac was derived to be within the limits of $0.94 \pm 0.38$ of that of the Crab Nebula ($E \geq 1$ TeV). So the estimated flux in the VHE band was close to the flux from the Crab Nebula.

## 5. Conclusion

We can be confident that at the $5\sigma$ level the detected VHE $\gamma$-rays are truly emitted by BL Lac. The average detection rate of VHE $\gamma$ quanta from BL Lac according to our observations of this object in 1998 was $0.095 \pm 0.013$ $N_\gamma$ $min^{-1}$ [7], so that the results of our observations of BL Lac in 2004 ($0.106 \pm 0.021$ $N_\gamma$ $min^{-1}$) also agree with this value.

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