TeV γ–Ray Observations of the BL Lac Object 1ES 2344+514 with the HEGRA System of Imaging Atmospheric Čerenkov Telescopes

A. Konopelko[1], J. Kettler[1], for the HEGRA Collaboration
[1]*Max–Planck–Institut für Kernphysik, Saupfercheckweg 1, D–69117 Heidelberg*

Abstract

The sensitivity of the HEGRA stereoscopic system of 5 Imaging Atmospheric Čerenkov Telescopes (IACT) now permits the detection of faint TeV γ–ray sources with 1/4 Crab flux within one hour of observation time. In fall of 1998 we undertook a long–term observational program of the BL Lac object 1ES 2344+514. During a period of 4 months this object was monitored with the HEGRA IACT system for 1 hr per night around transit under acceptable weather conditions. We report the results of our search for a γ–ray signal from 1ES 2344+514 on time scales from 20 min up to one month. We also discuss different possible strategies for searching for such highly variable TeV γ–ray sources with imaging atmospheric Čerenkov instruments.

1 Introduction:

1ES 2344+514 is the third BL Lacertae object detected at VHE (>350 GeV) by the Whipple group (Catanese et al., 1998). Its relatively low redshift, z=0.044, limits the attenuation of the VHE emission (below 1 TeV) due to interaction with infrared background photons (Stecker, de Jager, and Salamon, 1992). The emission from 1ES 2344+514 observed in 2 keV X–rays at the level of 1.14 μJy (i.e., about 0.3 of Mrk 421 and Mrk 501 flux) and its 5 GHz radio flux of 231 μJy (i.e., 0.3 and 0.25 of Mrk 421 and Mrk 501 flux, respectively) make this object the weakest detected source of the BL Lac class (such as Mrk 421 and Mrk 501) detected in TeV γ–rays. 1ES 2344+514 belongs to the blazar class of AGN and it is expected to be a highly variable source of TeV γ–rays. Catanese et al. (1998) reported a flare of 1ES 2344+514 on 1995 December 20 with a duration of about 2 hr and with an average flux of $\mathrm{J}_\gamma(>350\,\mathrm{GeV}) = (6.6 \pm 1.9) \times 10^{-11}\,\mathrm{photons\,cm^{-2}\,s^{-1}}$, which is $\simeq 0.63$ of the Crab flux. The energy spectrum of 1ES 2344+514 appears to be a power law with a differential spectral index of 2.48 ± 0.43 (Bussóns Gordo et al., 1998), which is similar to the Crab Nebula spectrum as derived by (Hillas et al., 1998) from Whipple telescope data. We therefore may expect γ–ray emission from 1ES 2344+514 at a level of 0.63 Crab flux, at least above 500 GeV which is the current energy threshold of the HEGRA array of 5 imaging atmospheric Čerenkov telescopes (IACT) (Aharonian et al., 1999).

The observations of 1ES 2344+514 with the HEGRA IACT array reported here were aimed at the measurement of the mean *base line* flux (>0.05 Crab flux) of the source in the TeV energy range (>500 GeV) and the detection of day scale *flaring activities* (>0.5 Crab flux).

2 Observational strategy:

1ES 2344+514 was first observed by the HEGRA telescope system in December 1997. A second observational campaign was carried out with the 5 (4) HEGRA IACTs from August to November of 1998 for about 1 hour of exposure time during each moonless night. The observation time acceptable for the data analysis is approximately 10 hr per month and around 50 hr in total (52 nights in 97/98). In 1998, the object was tracked at zenith angles within the range of 20° to 25°. All observations were performed in the so–called *wobble mode* which permits simultaneous monitoring of cosmic rays in the OFF–source region (for details see Aharonian et al., 1999). Each night of good data taking was accompanied by a systematic daily signal evaluation using standard online tools installed on the observation site (La Palma, Canary Islands). In the case of *flaring activity* (>0.5 Grab flux) detected, the primary aim was to ask for 25 hr of continuous observation in order to evaluate the differential energy spectrum of the TeV γ–ray emission in the energy range $500\ \mathrm{GeV}$ to $5\ \mathrm{TeV}$. However, this condition was not met during the observations.

3 Data quality check:

In order to exclude data taken under less than optimal telescope performance the entire database has been checked very carefully as follows. First, each night the compressed protocols of the system performance are transfered to one of the collaboration host institutes where they are scanned by software tools which closely monitor the status of the telescopes' hardware (e.g., single pixel rates, trigger rates of system telescopes, tracking accuracy etc). This information is accumulated in a corresponding database which is used afterwards for a standard data reduction procedure. The final, condensed data file for each particular run contains all the information needed for data analysis. In addition to that, we developed a specific software tool which allows to control *a posteriori* for each data run

1) the system trigger rate taking into account the zenith angle dependence (currently the system of 5 IACTs gives the raw trigger rate of about 10 Hz) (see Figure 1);
2) the angular shape of the cosmic ray images, tested by a χ^2–criterium for the deviation of the *mean scaled Width* distribution for a single run from the corresponding average distribution filled over an extended sample of runs (see Figure 1);
3) the flatness of the θ^2–distribution for the isotropic cosmic ray images over the full field of view;
4) the image *Size* distributions for each individual telescope.

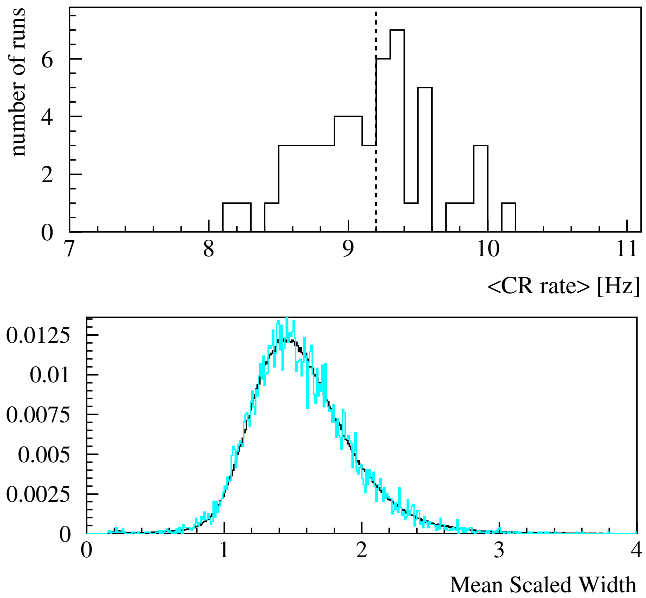

Figure 1: Distribution of the cosmic ray rate (after software trigger), calculated for each data run (upper panel), and the mean scaled Width distribution of the cosmic rays for a single run superimposed with the same distribution derived for the complete run sample used in the analysis (lower panel).

After a detailed check of the data quality we rejected 24 data runs (ca. 8 hr). In addition the same technique was applied to Crab Nebula data taken during the same observation period (see OG.2.2.01). The *clean* Crab Nebula data sample for the same configuration of the IACT system was used for computing the excess rates and upper limits in Crab units. Note that for 1ES 2344+514 data we accepted a few observational nights with relatively poor weather conditions and correspondingly low trigger rate (due to thin high clouds above the island) in order to complete the source light curve. During the 1ES 2344+514 observational campaign, the HEGRA IACT array was operated as a system of four and five telescopes. Due to technical reasons one telescope was not working for one month in 1998 October – 1998 November. Thus, we use for the present analysis 44 runs (14.7 hr) of data taken in 9 nights in the 1997 campaign, and 51 runs (23.8 hr), taken during 26 nights in 1998 September–November with the complete 5 telescope system (configuration 1), and 35 runs (12.1 hr), taken during 16 nights in 1998 August and September with a 4 telescope system (configuration 2).

4 Analysis:

During the presented observations, the HEGRA telescope system recorded a shower event whenever at least two telescopes in the system got a local trigger as 2NN/271$>8\,\mathrm{ph.-e.}$ (signal in two next neigbour of the 271 photomultiplier tubes exceeded a threshold of 8 photoelectrons). In addition as a software trigger we required that the image *Size* (total number of photoelectrons in the image) exceeds 40 ph.-e. and the reconstructed position of the shower axis was not further than 300 m apart from the center of the array. We analysed the 1ES 2344+514 data by two γ–ray selection criteria: $\theta^2 < 0.1\,\mathrm{deg}^2$ and $<\tilde{w}>\leq 1.1$. θ^2 and $<\tilde{w}>$ are the squared angular distance of the reconstructed arrival direction to the actual source position and the mean scaled Width parameter, respectively. This set of the cuts was tested on Monte Carlo simulated air showers (see Konopelko et al., 1999) and on the data sample of Mrk 501 (Aharonian et al., 1999). We analysed simultaneously using the same analysis cuts the Crab Nebula data in order to derive the corresponding γ–ray rate. The mean γ–ray rate from the Crab Nebula after cuts is about 1 photon/min, with a corresponding γ–ray acceptance of 0.6.

5 Results:

The data from the first observational campaign in December 1997 did not indicate any TeV γ–ray emission, and our analysis gives an 99% CL upper limit of $0.9 \cdot 10^{-12}\mathrm{ph\,cm^{-2}\,s^{-1}}$ above 1 TeV. All data from the 1998 campaign corresponding to the system *configuration 1* show an excess at the 3.3σ level (723 ON events and 603 OFF events). The expected number of counts from the Crab Nebula for the same exposure time is 1453. We estimate a 99% CL upper limit at the level of (0.14$\pm$0.10) Crab flux. All data corresponding to the system *configuration 2* give a negative excess of -0.8σ, with a corresponding 99% CL upper limit of (0.095 ± 0.11) Crab flux. The light curve of the excess rate is shown in Figure 3. The 1998 October data show a 3.1σ excess at the level of 0.13 Crab. During the 4 month 1998 observational campaign, the highest duirnal excess rate (27 ON events, 8 OFF events) was detected on MJD 51129 with a 3.2σ significance. This rate corresponds to 0.63 Crab flux. Figure 2 shows the distribution of the events from the position of 1ES 2344 for this night. The flatness of the ON distribution might indicate, that the excess flux is not coming from 1ES 2344. In Figure 3 we show the light curve of the X–ray ASM data for the corresponding observation period. No significant correlation between the ASM data and the 1ES 2344+514 excess rate light curve was found.

Finally, taking into account the number of trials, we cannot conclude that the data analysis did reveal a γ–ray signal from 1ES 2344+514, neither on diurnal nor on the long term time scales.

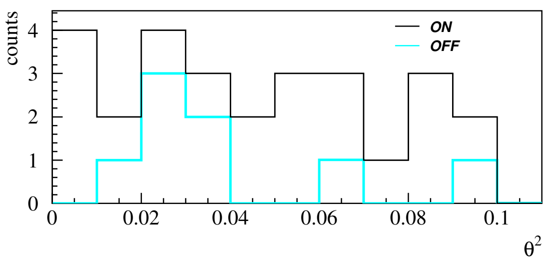

Figure 2: The θ^2 distribution of the events passing cuts in ON and OFF region for MJD 51129.

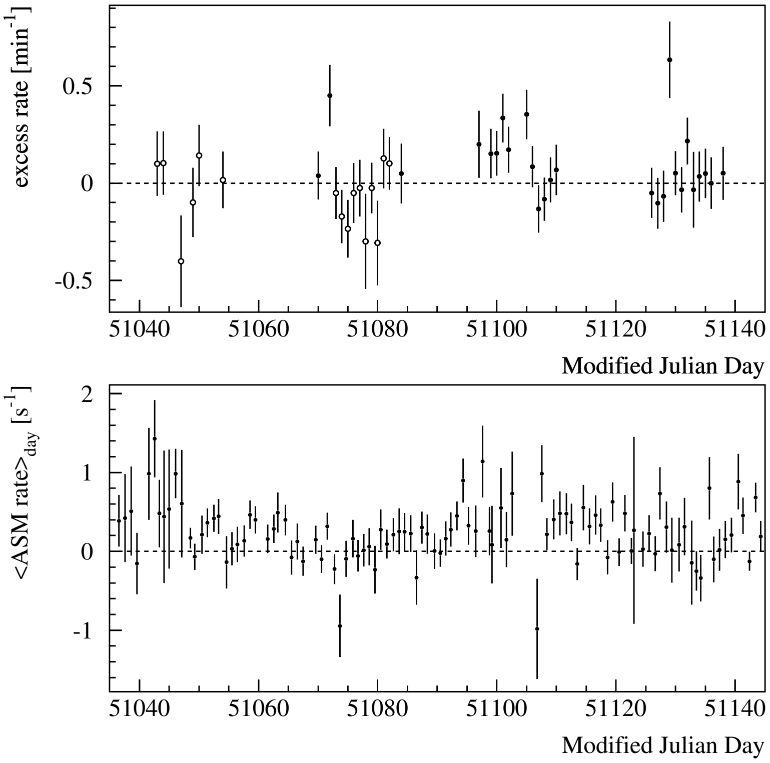

Figure 3: Light curve of the excess rate for 1ES 2344+514 observations with the HEGRA IACT array during the period from 1998 August to 1998 November (upper panel). The X–ray RXTE ASM light curve for the corresponding observation period (the data are extracted from the RXTE ASM Web page) (lower panel).

6 Discussion:

One would expect flaring activity on a time scale of the order of less than 1 day for a highly variable BL Lac object such as 1ES 2344+514. Working with the widely believed SSC model of TeV γ–ray emission, we expect a simultaneous X–ray/TeV γ–ray activity of the BL Lac object and the continuous monitoring of the object with the ASM onboard RXTE could serve as a guide for TeV γ–ray observations, in general. However, the limited day scale resolution of the ASM as well as time delay of few days for the data analysis currently do not permit the effective use of X–ray data for firm predictions of TeV γ–ray activity at such short time scales. Motivated by these factors we tried a different observational strategy for the 1998 data by monitoring the source for approximately 1 hr per night. Our daily upper limits as well as our upper limit on the baseline emission from the 1998 1ES 2344+514 data are consistent with the detection reported by Catanese et al., (1998). In order to increase our sensitivity level we plan to continue monitoring 1ES 2344+514 in the period 1999/2000 with at least 2 hrs per night over the range 1999 August – 2000 January giving about 100 hours in total.

7 References:

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