Upper Limits on BL Lacs

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Abstract

The HEGRA IACT stereoscopic system, with an energy threshold of about 500 GeV, was used to search for γ-ray emission of several AGN, most of them are low redshift BL Lacs (z $<$ 0.2). Here we show the results of observations that were made since June 1997 at zenith angles up to 40°. No evidence for TeV emission is detected, corresponding upper limits are given.

1 Introduction

The HEGRA Imaging Atmospheric Cherenkov Telescope system (IACT) was used for an extensive search of potential TeV-γ-ray sources like super nova remnants, gamma ray bursts, the galactic plane and other promising objects. The observations have been focused on blazars, since all EGRET detected Active Galactic Nuclei (AGN) at energies $>$ 100 MeV are members of that subclass of AGN (Thompson et al. 1995; Mukherjee et al. 1997). Blazars include both emission lined radio quasars with a relatively flat spectrum (FSRQ) and lineless BL Lac objects (Padovani 1998a). The famous and well-studied blazars Mkn 421 and Mkn 501 are well known TeV-γ-ray sources and regularly monitored by the HEGRA experiment (Aharonian et al. 1997; Aharonian et al. 1999a; Aharonian et al. 1999b; Aharonian et al. 1999c; Bradbury et al. 1997; Kataoka et al. 1999; Krennrich et al. 1999; Petry et al. 1996). The explanation and unification of AGN characteristics are still a subject of discussion e.g. Ghisellini (1998), Padovani (1998b), Sambruna (1998), Ulrich, Maraschi & Urry (1997), and more informations about TeV-γ-ray sources are needed to complete the theoretical concept.

At HEGRA two observation programs with special attention to blazars started in July 1997. The first deals with low redshift blazars in general (z $<$ 0.2), while the second focused on high frequency BL Lac objects (HBLs) with redshifts as large as $z = 0.444$.

2 The HEGRA Cherenkov Telescope System

The HEGRA collaboration operates six IACTs and an array of several particle and Cherenkov detectors dedicated to cosmic ray research (Lindner et al., 1997) which are located on the Roque de los Muchachos (2200 m a.s.l., 28.75° N, 17.89° W) on La Palma, Canary Islands, Spain. The HEGRA IACT stereoscopic system started to take data in 1996 as a system of three CTs and was completed to a five telescope system in September 1998. Each system telescope has a $8.5\,m^2$ reflector area focussing the light onto a high resolution camera with 271 pixels (PMTs), covering a field of view of 4.3° (pixel diameter 0.25°). The system has an energy threshold of $\approx$ 500 GeV and a flux sensitivity νF_ν at 1 TeV of $10^{-11} erg cm^{-2} s^{-1}$ (S/N = 5σ) for one hour observation time. Detailed informations on the IACT system are given in Aharonian et al. (1999a) and Daum et al. (1997).

3 The data sample and selection criteria

According to the two AGN programs initiated in July 1997 two sets of objects and respective data samples are given.

The **low redshift blazar sample** was compiled from several catalogues of quasars, BL Lac objects and other galaxies (Stickel, Meisenheimer & Kühr, 1994; Padovani & Giommi, 1995; Stickel & Kühr 1994; Véron-Cetty, 1995) by taking into account the following selection criteria:

- for FSRQ the radio spectral index is $\alpha \leq +0.5 \quad (S_\nu \propto \nu^{-\alpha})$
- restricting the zenith angle on $ZA \leq 30°$ leads to a declination range of $-2° \leq \delta \leq 58°$ for the HEGRA observation site.
- due to the extragalactic infrared background the constraint for the redshift was $z \leq 0.2$, which was the γ-ray horizon limit for 1 TeV source photons at this time (Funk et al., 1998).

This results in a low redshift blazar sample of about 47 objects, which we continue to observe until 10 hours observation time on each object will be collected. A small subsample of objects that had been observed from October 1998 until November 1998 are shown in table 1.

name	source	z	AGN class	observation period	hours
NGC 0315	0055+300	.017	FSRQ	Oct 98	8.6
NGC 1275	0316+413	.018	FSRQ	Nov 98	16.6
1ES 0323+022	0323+022	.147	HBL	Oct 98	8.6
1ES 0927+500	0927+500	.188	HBL	Oct 98 - Nov 98	12.0
1ES 1741+196	1741+196	.083	HBL	Sep 98	2.3
$[HB]$ 2201+044	2201+044	.027	HBL	Oct 98	13.0
$[HB]$ 2254+074	2254+074	.190	LBL	Nov 98	7.3

Table 1: Summary of the low redshift blazars data sample; for all observations the mean zenith angles are $< 40°$.

The **high frequency BL Lac sample** was compiled by using the information from the X-ray and the γ-ray band as measured with the RXTE All sky Monitor (1.3 -12.0 keV) and with EGRET (30 MeV - 20 GeV). The 9 objects of this sample and their observation time are shown in table 2.

name	source	z	AGN class	observation period	hours
1ES 0145+13.8	0145+138	.125	HBL	28.Nov 97	1.1
1ES 0219+42.8	0219+428	.444	HBL	31.Oct 97	1.3
1ES 0229+20.0	0229+200	.139	HBL	01.Dec 97	1.3
MS 0317.0+1834	0317+183	.190	HBL	30.Nov 97	1.3
1ES 0414+00.9	0414+009	.287	HBL	25.Nov 97 - 05.Dec 97	3.2
1ES 0647+25.0	0647+250	?	HBL	28.Nov 97	0.6
3C 197.1	0818+472	.128	HBL	30.Nov 97 - 05.Dec 97	14.5
BL Lac	2200+420	.069	HBL	30.Jul 97 - 13.Aug 97	9.2
BL Lac	2200+420	.069	HBL	29.May 98 - 01.Jun 98	5.4
1ES 2344+51.4	2344+514	.044	HBL	23.Dec 97 - 31.Dec 97	15.8

Table 2: Summary of the X-ray selected BL Lacs (HBL) data sample; for all observations the mean zenith angles are $< 40°$.

4 Upper limit calculation

To avoid systematic errors due to Monte Carlo simulations of the airshowers and the detector response in the data analysis one can determine the **upper flux limits** or measured fluxes **in Crab units** and afterwards convert them into absolute flux upper limits or flux values. Therefore the number of events in the ON-source region

(ON_S) and the number of events in the OFF-source region (OFF_S) and the observation time T_S for each single zenith-angle intervall (I_{ZA}) of the data sample of each observed source need to be known, and also for the Crab reference data sample (ON_C, OFF_C, T_C). Due to technical problems the CT-system partly operated only as a four or even three telescope system thus different experimental setups had to be considered in the analysis. For the γ-hadron-separation the following cuts were applied: the mean scaled width $MSW < 1.2$ (definition see Konopelko, 1995), the squared angular distance of the reconstructed shower direction to the source direction $\theta^2 < 0.05\, deg^2$.

The upper (lower) limits of the number of counts $MAX_S(MIN_C)$ from the source (Crab) on a 99% confidence level were calculated by using the probability density function of the number of source events (Helene, 1983). The upper limits in Crab units UL_S are given by

$$UL_S = \frac{MAX_S}{MIN_C} \times \frac{T_C}{T_S}$$

To convert the upper limits given in Crab units into upper limits in absolute flux units the assumed source energy spectrum was adopted from the Mkn 501 energy spectrum in 1997 (Aharonian et al., 1999b): $dN/dE \propto E^{-2.2}$. From 0.5 TeV to 20 TeV the integral Crab flux is $F_{Crab} = 5 \cdot 10^{-11}\, cm^{-2}\, s^{-1}$ (Konopelko et al., 1998) so that the upper limits on the integral energy flux of the sources are obtained by

$$UL_{int} = UL_S \cdot 2.25 \cdot 10^{-11} E_{thres}^{-1.2}\; cm^{-2}\, s^{-1}$$

5 Results

The analysis of the **HBL data sample** did not show positive evidence for TeV-γ-ray emission from any of this objects, see for more details Aharonian et al. 1999d. Based on a few hours of observation upper limits of a few times $10^{-12} cm^{-2} s^{-1}$ with a confidence level of 99% can be obtained (see table 3). These upper limits in Crab units are free from systematic errors but due to the uncertainty on the absolute energy scale of the CT-system of 15% the upper limits in absolute flux units obtain uncertainties of about 20%.

A preliminary analysis of the **low redshift blazar data sample** did not reveal positive evidence for TeV-γ-ray emission for any object of this sample. But using the same detector with no major changes and a data sample with comparable ranges in redshift, zenith angle and observation times the expected upper limits will

name (1)	UL_S (2)	E_{thres} (3)	UL_{int} (4)
1ES 0145+13.8	.23	580	9.9
1ES 0219+42.8	.40	630	15.7
1ES 0229+20.0	.25	540	11.8
MS 0317.0+1834	.42	530	20.2
1ES 0414+00.9	.65	910	16.4
1ES 0647+25.0	.31	510	15.6
3C 197.1	.14	840	3.9
BL Lac (1997)	.11	580	4.8
BL Lac (1998)	.15	870	4.0
1ES 2344+51.4	.10	990	2.3

Table 3: Upper limits in Crab units of the HBL data sample with 99% confidence level: *(1)* name of the source, *(2)* upper limits in Crab units, *(3)* mean energy threshold of the observations in GeV, *(4)* upper limits on integral flux above energy threshold E_{thres} in units of $10^{-12} cm^{-2} s^{-1}$ with an assumed diffential spectral index $\alpha = -2.2$.

be in the order of a few times $10^{-12}\,cm^{-2}\,s^{-1}$ and will be given at the time of the conference.

The absorption due to the extragalactical diffuse infrared background (DIRB) was not taken into consideration. Based on recent Monte Carlo studies (Wang, Y. 1999) which were consistent with the IRAS source counts and other infrared redshift survey data, the influence of the DIRB is expected to be rather small for energy thresholds of about 1 TeV and redshifts lower than 0.2.

6 Conclusions

Several studies exemplify that two of the BL Lacs objects (Mkn 421, Mkn 501) show high variability. e.g. in 1996 Mkn 501 was detected showing low rates (Bradbury et al. 1997) but was in a high TeV-γ-ray flaring state in 1997. It is however not yet ruled out that one of the here analyzed objects may appear in a high state. Therefore our AGN observation program will be continued monitoring the established TeV sources on a regulary basis and searching for new ones gathering about 10 hours observation time on each object.

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