# VHE Observations of BL Lacertae Objects: 1995-2000

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**Abstract**

The results of observations of 29 BL Lacertae objects taken with the Whipple Observatory 10 m gamma-ray Telescope between 1995 and 2000 are presented.

## 1. Introduction

Among blazars, BL Lacertae objects (BL Lacs) are believed to be the best candidates for VHE emission. Consistent with these expectations, the four confirmed sources of extragalactic gamma rays (E > 250 GeV) are BL Lacs, Mrk 421 [7], Mrk 501 [8], H1426 [5] and 1ES1959 [6]. To improve our understanding of the emission mechanisms in BL Lacs, more need to be detected at very high energies.

## 2. Observations and Analysis

The observations presented here were taken as part of three BL Lac campaigns. The first was a survey of all known (circa 1995) BL Lacs with redshift < 0.1. The second was a search for TeV emission from high frequency peaked BL Lacs in the redshift range from 0.1 to 0.2. More recent observations were taken as part of a "Snapshot Survey" in which many BL Lacs were observed for 10 minutes each on a regular basis in the hope of catching one of them in a flaring state [3].

Throughout the course of these observations, the imaging camera on the

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Whipple telescope was upgraded a number of times, the triggering criteria were changed and different light concentrators were installed in front of the camera. Therefore, the peak response energy of the instrument varied during this period. These observations were all taken in the "TRACKING mode" described in [1].

## 3. Results And Discussion

Tables 1 & 2 summarise the results of the BL Lac observations. No significant excesses were detected from any of the objects on time scales of days, months or years. The mean exposure on each object was 5.5 hours for each season that it was observed. Typically, in order to detect a signal at the $4\sigma$ level during a 5 hour exposure, the object would need to have had a flux of at least 0.4 times that of the Crab above the peak response energy for that season.

Flux upper limits were calculated for each object for each season. Costamante & Ghisellini [2] have made predictions for the TeV flux from fourteen of the BL Lacs included in this paper using two different methods. The upper limits presented here were compared with these predictions; those of six BL Lacs, highlighted in Tables 1 & 2, were found, during a number of observing seasons, to be lower than the predicted fluxes according to the Fossati approach [4] adapted in [2]. It should be noted however, that the upper limits quoted here pertain only to the specific period during which the observations were made. Indeed, 1ES2344, H1426 and 1ES1959 were initially observed as part of this BL Lac campaign and, like the objects listed here, were not detected. In subsequent years, continuous monitoring, similar to that described here, revealed these objects to be TeV emitters when in more active states.

The analysis of these results is ongoing. Spectral energy distributions are being constructed and the flux predictions are being corrected to account for pair-production of the gamma rays with the infra red background radiation so that our upper limits can be compared to these predictions in a more meaningful way.

## 4. References

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**Table 1.** Observation Results - I

| Object | $z$ | Period[a] | Exp. [hrs] | Total $\sigma$ | Flux [Crabs] | Flux[b] | $E_{peak}$[c] [GeV] |
|---|---|---|---|---|---|---|---|
| 1ES0033+595⋆ | 0.086 | 95/12 | 1.85 | -0.59 | <0.200 | <2.10 | 350 |
| 1ES0145+138 | 0.125 | 96/10-96/11 | 7.85 | -1.01 | <0.093 | <0.98 | 350 |
| | | 98/11-98/12 | 2.29 | 0.22 | <0.512 | <3.50 | 500 |
| | | 98/12-99/01 | 1.98 | -0.50 | <0.357 | <3.34 | 500 |
| RGB0214+517⋆ | 0.049 | 99/12-00/01 | 6.01 | 0.29 | <0.165 | <1.45 | 430 |
| 3C66A[†,⋆,d,e] | 0.444 | 95/10-95/11 | 8.00 | -2.00 | <0.056 | <0.59 | 350 |
| 1ES0229+200⋆ | 0.140 | 96/11-96/12 | 7.85 | 0.15 | <0.113 | <1.19 | 350 |
| | | 98/11-98/12 | 2.30 | -1.08 | <0.326 | <2.23 | 500 |
| | | 98/12-99/01 | 1.78 | -0.40 | <0.403 | <3.76 | 500 |
| 1H0323+022⋆ | 0.147 | 96/11-96/12 | 10.18 | 1.02 | <0.181 | <1.90 | 350 |
| | | 97/01 | 0.91 | 0.20 | <0.298 | <3.13 | 350 |
| | | 98/12-99/01 | 3.18 | 1.69 | <0.509 | <4.75 | 500 |
| EXO0706.1+5913 | 0.125 | 96/12 | 5.55 | -1.16 | <0.087 | <0.91 | 350 |
| | | 97/01-97/03 | 3.69 | 0.76 | <0.161 | <1.69 | 350 |
| | | 98/11 | 1.83 | -0.40 | <0.524 | <3.58 | 500 |
| | | 98/12-99/02 | 1.90 | 0.07 | <0.459 | <4.29 | 500 |
| 1ES0806+524⋆ | 0.138 | 96/02-96/03• | 5.57 | 0.46 | <0.104 | <1.09 | 350 |
| | | 00/01-00/03 | 4.16 | -0.29 | <1.293 | <11.4 | 430 |
| PKS0829+046[†,e] | 0.180 | 95/01-95/04 | 11.07 | 1.25 | <0.117 | <1.47 | 300 |
| 1ES0927+500 | 0.188 | 96/12 | 5.08 | -1.92 | <0.064 | <0.67 | 350 |
| | | 97/01-97/04 | 5.04 | -1.03 | <0.076 | <0.80 | 350 |
| S40954+658[†,e] | 0.368 | 95/02-95/03 | 3.70 | -1.09 | <0.096 | <1.21 | 300 |
| 1ES1028+511⋆ | 0.361 | 98/12-99/02 | 4.43 | 0.57 | <0.287 | <2.68 | 500 |
| 1ES1118+424 | 0.124 | 98/02-98/04 | 7.30 | -0.25 | <0.218 | <1.49 | 500 |
| | | 98/12-99/02 | 3.60 | 0.27 | <0.310 | <2.90 | 500 |
| | | 00/01-00/05 | 6.97 | -0.62 | <0.116 | <1.02 | 430 |
| Mrk40 | 0.021 | 00/01-00/04 | 10.16 | 2.59 | <0.206 | <1.81 | 430 |
| Mrk180⋆ | 0.046 | 95/01-95/04• | 5.55 | -0.10 | <0.108 | <1.36 | 300 |
| | | 95/12-96/05• | 20.46 | -0.26 | <0.105 | <1.10 | 350 |
| | | 97/01• | 0.79 | -0.17 | <0.303 | <3.18 | 350 |
| 1ES1212+0748 | 0.130 | 99/02 | 1.13 | 0.44 | <0.778 | <7.26 | 500 |
| | | 00/01-00/05 | 3.70 | 1.30 | <0.321 | <2.82 | 430 |
| ON325[†,⋆] | 0.237 | 99/02 | 0.97 | 1.27 | <0.882 | <8.23 | 500 |
| | | 00/01-00/05 | 5.05 | 0.88 | <0.215 | <1.89 | 430 |
| 1H1219+301⋆ | 0.182 | 95/01-95/05 | 2.77 | 2.71 | <0.226 | <2.85 | 300 |
| | | 97/02-97/06 | 11.27 | 0.99 | <0.079 | <0.83 | 350 |
| | | 98/01-98/03 | 1.38 | -1.96 | <0.356 | <2.43 | 500 |
| | | 98/12-99/02 | 2.94 | -0.08 | <0.296 | <2.77 | 500 |
| | | 00/01-00/04 | 3.69 | 0.04 | <0.191 | <1.68 | 430 |

**Table 2.** Observation Results - II

| Object | $z$ | Period[a] | Exp. [hrs] | Total $\sigma$ | Flux [Crabs] | Flux[b] | $E_{peak}$[c] [GeV] |
|---|---|---|---|---|---|---|---|
| WComae[†,e] | 0.102 | 95/02-95/04 | 14.33 | -0.57 | <0.052 | <0.66 | 300 |
| | | 96/01-96/05 | 15.73 | -0.29 | <0.055 | <0.58 | 350 |
| | | 99/01-99/02 | 4.43 | -0.03 | <0.312 | <2.92 | 500 |
| | | 00/01-00/04 | 4.72 | -0.58 | <0.148 | <1.30 | 430 |
| MS1229.1+6430 | 0.170 | 95/02-95/04 | 1.39 | 1.32 | <0.286 | <3.60 | 300 |
| | | 99/02 | 2.04 | -0.76 | <0.446 | <4.16 | 500 |
| | | 00/01-00/05 | 6.01 | 0.35 | <0.170 | <1.50 | 430 |
| 1ES1239+069 | 0.150 | 99/01-99/02 | 1.73 | 0.78 | <0.616 | <6.04 | 500 |
| | | 00/01-00/05 | 5.08 | 0.11 | <0.197 | <1.73 | 430 |
| 1ES1255+244 | 0.141 | 97/02-97/05 | 5.54 | 1.19 | <0.112 | <1.18 | 350 |
| | | 98/03 | 0.46 | 0.13 | <1.112 | <7.60 | 500 |
| | | 99/02 | 1.73 | 0.15 | <0.508 | <4.75 | 500 |
| | | 00/01-00/05 | 4.16 | -0.54 | <0.164 | <1.45 | 430 |
| OQ530[*] | 0.151 | 95/03-95/05 | 7.39 | -0.73 | <0.058 | <0.73 | 300 |
| 4U1722+11[⋆,f] | 0.018 | 95/04-95/05• | 2.77 | -0.08 | <0.124 | <1.56 | 300 |
| IZw187[⋆] | 0.055 | 95/03-95/04• | 2.31 | -1.27 | <0.086 | <1.08 | 300 |
| | | 96/04-96/05• | 2.32 | 0.61 | <0.150 | <1.58 | 350 |
| 1ES1741+196[⋆] | 0.084 | 96/05-96/07• | 9.23 | -1.02 | <0.053 | <0.56 | 350 |
| | | 98/05 | 0.46 | -0.08 | <1.168 | <7.99 | 500 |
| 3C371[*] | 0.051 | 95/05-95/06 | 13.04 | 0.41 | <0.190 | <1.23 | 300 |
| BLLac[†,⋆,d,e] | 0.069 | 95/07• | 4.62 | 1.07 | <0.109 | <1.37 | 300 |
| | | 95/10-95/11• | 39.09 | -1.48 | <0.038 | <0.40 | 350 |
| | | 98/05-98/06 | 0.92 | 0.47 | <1.722 | <8.02 | 500 |
| 1ES2321+419 | 0.059 | 95/10-95/11 | 6.42 | -1.07 | <0.101 | <1.06 | 350 |

[†] Low frequency peaked BL Lacs; all others are high frequency peaked BL Lacs.
[⋆] Included in the list of Costamante et al. [2] as a possible TeV emitter.
[a] Seasons during which the flux upper limit from this object was found to be lower than that predicted in [2] adapting the model of [4] are marked with a •.
[b] The integral flux upper limits are quoted above the peak response energy for the observation period in units of $10^{-11}$ cm$^{-2}$ s$^{-1}$.
[c] The peak response energy is the energy at which the collection area folded with an $E^{-2.5}$ spectrum reaches a maximum. The fact that it has increased somewhat over time simply reflects the fact that the energy at which the telescope is most efficient at detecting gamma rays has increased; e.g., the collection area at 300 GeV in the 1999-2000 season, was greater than that at this energy in 1995.
[d] Unconfirmed source of TeV gamma rays.
[e] EGRET source of >100 MeV gamma rays.
[f] This redshift estimate is based on just one absorption line [9].