Observations of 1ES1959+650 with the Whipple 10m Telescope

Jamie Holder for the VERITAS collaboration
Department of Physics, University of Leeds, Leeds, LS2 9JT, Yorkshire, England, UK

Abstract

We present the first strong detection of very high energy γ-rays from 1ES1959+650, a close ($z = 0.048$), X-ray selected BL Lacertae object. Observations were made with the Whipple 10m telescope on Mt. Hopkins, Arizona, using the atmospheric Cherenkov imaging technique. The flux between May and July 2002 was highly variable, with a mean of 0.64 ± 0.03 times the steady flux from the Crab Nebula and reaching a maximum of five Crab, with variability on timescales as short as seven hours.

1. Introduction

The EGRET detector on board the CGRO detected in excess of 66 blazars (Hartman 1999) above 100 MeV; however, only a few have been detected at higher energies ($>$ 300 GeV) by ground based atmospheric Cherenkov telescopes. Markarian 421 (Punch 1992) and Markarian 501 (Quinn 1996) were the first extra-galactic TeV sources to be detected, and unconfirmed detections of 1ES2344+514 (Catanese 1998) and PKS2155-304 (Chadwick 1999) have also been reported. Most recently, the detection of very weak emission from H1426+428 has been confirmed by three groups (Horan 2002, Aharonian 2002a, Djannati-Atai 2002). All of these TeV blazars can be classified as high frequency peak BL Lacs (HBLs) (Padovani & Giommi 1995) on the basis of the location of the lower energy peak in their spectral energy distributions (SEDs), and predictions of TeV emission from other nearby sources of this type have driven observations by atmospheric Cherenkov detectors.

1ES1959+650 ($z = 0.048$) was first suggested as a good TeV candidate of this type by Stecker et al. (1996), who used simple scaling arguments to predict it as the third strongest TeV blazar, after Markarian 421 and Markarian 501, with a flux prediction of 1.9×10^{-11} cm^{-2} s^{-1} above 300 GeV. More recently Costamante & Ghisellini (2002) predicted fluxes above 300 GeV of 7.5×10^{-11} cm^{-2} s^{-1}, based on a simple phenomenological parameterization of the SED, and 0.03 $\times$

pp. 1–7

10^{-11} cm^{-2} s^{-1} using a homogeneous, one-zone synchrotron self-Compton model.

1ES1959+650 is not a particularly extreme example of an HBL; measurements with BeppoSAX in 1997 (Beckmann 2002) placed the lower energy SED peak at 10^{15} Hz (4 eV), as compared to typically $\sim$ 1 keV for Markarian 421 (Maraschi 1999) and $\sim$ 100 keV for Markarian 501 during its 1997 flare state (Pian 1998), although for both of these sources the position of the peak is known to vary widely depending upon the flux level. Giebels et al. (2002) report on X-ray observations of 1ES1959+650 obtained with the USA(1-16 keV) and RXTE (2-16 keV) missions during 2000, which showed threefold increases in the X-ray flux on a timescale of a few days. The flux increase was correlated with spectral hardening, indicative of a shift of the lower energy peak of the SED towards higher frequencies.

Prior to May 2002, only tentative evidence had been presented for TeV emission from 1ES1959+650. A detection with a statistical significance of 3.9 σ was reported by Nishiyama et al. (1997) based on 57 hours of observations with the Utah Seven Telescope Array. More recently, Konopelko et al. (2002) reported a preliminary detection at $\sim$ 5 σ for the HEGRA Cherenkov telescope system. Previous observations of 1ES1959+650 with the Whipple 10m telescope produced an upper limit at a flux level of 1.3×10^{-11} cm^{-2} s^{-1} above 350 GeV (Catanese 1997).

Observations of 1ES1959+650 during May-July 2002 with the Whipple 10m telescope resulted in a clear detection of TeV γ-ray emission from this object (Dowdall, Moriarty & Kosack 2002). We report here the results of follow up observations.

2. Observations and Data Analysis

The configuration of the Whipple 10m γ-ray telescope during these observations is described in detail in Finley et al. (2001). Briefly, the telescope consists of a 10 m reflector and a 490 pixel photomultiplier tube (PMT) camera. For the purposes of this analysis only the high resolution (0.12° spacing) central 379 PMT pixels have been used. Cherenkov images are recorded and parameterized and γ-ray like images are selected using the "supercuts" criteria (Reynolds 1993) optimized on recent data from the Crab Nebula. Following a realignment of the optical system in February 2002, observations of the Crab Nebula showed that the telescope was at its most sensitive since the installation of the current camera, with one hour of Crab observations producing a 6σ detection; however, between February and July 2002 a decrease in the relative efficiency of the telescope of $\sim$ 30% was measured by examining the response to the cosmic ray background.

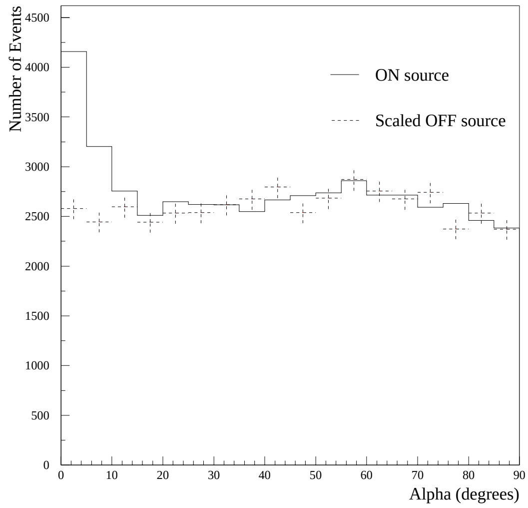

Fig. 1. Distribution of *alpha* for all on and off-source events (the off-source distribution has been scaled so as to match the number of events in the $\alpha > 30°$ region).

The cause of the effect is still under investigation - one explanation may be that it is due to increased atmospheric absorption caused by large forest fires in the region during this period.

Observations of 1ES1959+650 were made during moonless periods between May 16^{th} and July 8^{th} 2002. The total dataset consists of 39.3 hours of on-source data, together with 7.6 hours of off-source data for background comparison. Figure 1. shows the distribution of the Cherenkov image orientation angle *alpha* for the full on-source dataset, together with the distribution for the off-source dataset scaled such that the number of events in the region $\alpha > 30°$ is the same. The average rate of the excess in the on-source γ-ray region at $\alpha < 15°$ is $1.08 \pm 0.05\ \gamma\ \text{min}^{-1}$, corresponding to a detection at $> 20\ \sigma$.

3. Flux Variability

Figure 2. shows the daily averaged rates for 1ES1959+650 for all of the observations. The rates are expressed in multiples of the steady Crab Nebula flux and have been corrected in order to account for the varying zenith angle and changes in telescope efficiency according to the procedure of LeBohec & Holder (2002). This has been tested using Crab Nebula data taken over a wide range of zenith angles and atmospheric conditions. Strong night-to-night variability is

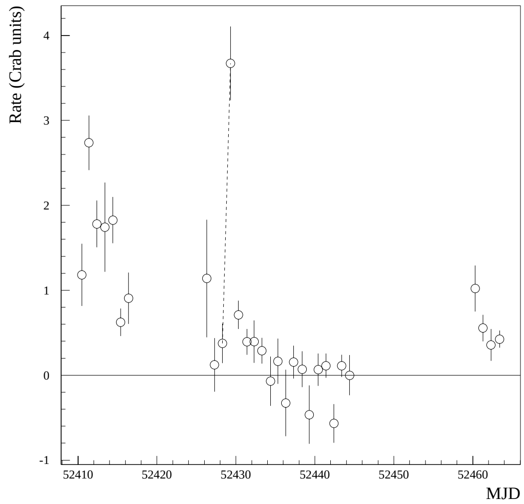

Fig. 2. The daily average γ-ray rates for 1ES1959+650 during 2002. The dashed line indicates the most rapid rate change, corresponding to a doubling time of 7 hours.

evident; the largest change in rate, between MJD 52428 and MJD 52429, corresponds to a doubling time of 7 hours - shorter than has ever been observed in other wavebands for this source. The mean flux over all observations was 0.64 ± 0.03 Crab units.

Figure 3. shows the rate in 5 minute bins for two nights, May 17$^{\text{th}}$ and June 4$^{\text{th}}$, during which the source was most active. The statistical evidence for variability within these nights is given by the χ^2 probabilities of constant emission = 1% and 8% respectively. We conclude that there is no strong evidence for flux variability on this timescale.

4. Discussion

The detection of TeV γ-ray emission from 1ES1959+650 adds another member to the class of TeV blazars, all of which are close BL Lac objects having a low bolometric luminosity and the peaks in their SEDs at high frequency. The rapid flux variability, and the fact that 1ES1959+650 has not been detected during previous observations, indicates that the source was in an unusual flaring state during these observations. The flux level was at times orders of magnitude above the most recent model predictions. Throughout the period of the Whipple observations measurements in the $2 - 12$ keV region by the All-Sky Monitor (ASM) on board RXTE have shown 1ES1959+650 to be active and variable, with

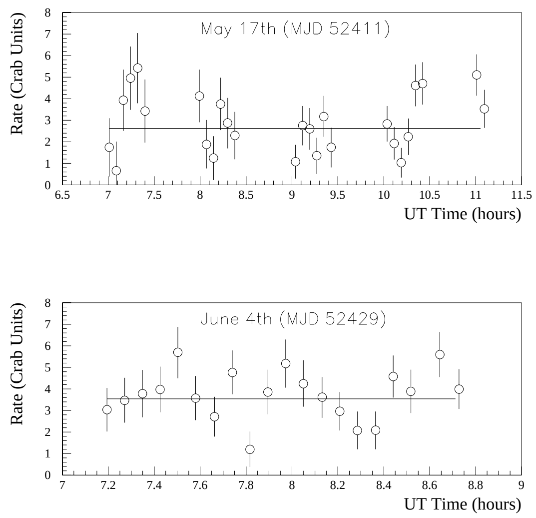

Fig. 3. The γ-ray rates for the two nights showing the most activity (5 minute binning).

daily average fluxes reaching $\sim$ 20 mCrab in May and July. Target of opportunity observations with the RXTE small field of view instruments were triggered following the γ-ray detection and will be reported on elsewhere (Krawczynski, private communication). The rapid flux variability observed at TeV energies implies a small emission region in the jet with a high Doppler factor (Mattox 1993); contemporaneous X-ray and TeV γ-ray data will allow us to constrain the jet parameters when modelling the emission processes.

Analysis of the Whipple data is ongoing, but attempts to reconstruct the source spectrum have been hampered by the effects of the decreased telescope efficiency during the observation period. The HEGRA collaboration measure a rather steep spectrum (spectral index $\alpha = 3.2 \pm 0.3$) for observations prior to 2002, while the spectrum during the flaring period exhibits pronounced curvature and deviates significantly from the spectrum seen during the quiescent state (Horns 2002). The majority of models for the EBL lead to predictions of a cut-off in the γ-ray region beginning below $\sim$ 10 TeV for a source at $z = 0.048$ (Gould & Schrèder 1967, Primack 2001). Deviations from a pure power law have now been resolved in the spectra of both Markarian 421 (Krennrich 2001, Piron 2001, Aharonian 2002b) and Markarian 501 (Samuelson 1998, Aharonian 1999, Djannati-Atai 1999) and the spectrum of the most distant TeV blazar, H1426+428, is measured to be very steep ($\alpha = 3.50 \pm 0.35(\text{stat}) \pm 0.05(\text{syst})$) (Petry 2002), but it is not yet clear whether these features are due to absorption on the EBL or are intrinsic to the sources. Clearly, further observations and spectral analysis of 1ES1959+650 may help to resolve this question.

5. References

1. Aharonian, F. A. et al. 1999, A&A, 349, 11
2. Aharonian, F. A. et al. 2002a, A&A, 384, L23
3. Aharonian, F. A. et al. 2002b, A&A, 393, 89
4. Beckmann, V. et al. 2002 A&A, 383, 410
5. Catanese, M. et al. 1997, 4th Compton Symp., AIP Conf. Proc. 410, 1376
6. Catanese, M. et al. 1998, ApJ, 501, 616
7. Chadwick, P. M. et al. 1999, Astropart. Phys., 11, 145
8. Costamante, L. and Ghisellini, G. 2002, A&A, 384, 56
9. Dowdall, C., Moriarty, P. & Kosack, K. 2002, I.A.U. Circular No. 7903
10. Djannati-Atai, A. et al. 1999, A&A, 350, 17
11. Djannati-Atai, A. et al. 2002, A&A, 391, L25
12. Finley, J. P. et al. 2001, 27th ICRC, Hamburg, 7, 2827
13. Giebels, B. et al. 2002, ApJ, 571, 763
14. Gould, R.J. & Schrèder, G. 1967, Phys. Rev., 155, 1408
15. Hartman, R. C. et al. 1999, ApJs, 123, 79
16. Horan, D. et al. 2002, ApJ, 571, 753
17. Horns, D. et al. 2002, High Energy Blazar Astronomy, Turku, Finland
18. Konopelko, A. et al. 2002, APS/HEAD Meeting, Albuquerque, B17
19. Krennrich, F. et al. 2001, ApJ, 560, L45
20. LeBohec, S. & Holder, J. 2002, Astropart. Physics, in press
21. Maraschi, L. et al. 1999, ApJ, 526, L81
22. Mattox, J.R. et al. 1993, ApJ, 410, 609
23. Nishiyama, T. et al. 1999, 26th ICRC, Salt Lake City, 3, 370
24. Padovani, P. & Giommi, P. 1995, ApJ, 444, 567
25. Petry, D. 2002, ApJ, 580, 104
26. Pian, E. 1998, ApJ, 492, L17
27. Piron, F. et al. 2001, A&A, 374, 895
28. Punch, M. et al. 1992, Nature, 358, 477
29. Primack, J. R. 2001, High Energy Gamma-Ray Astro., AIP 558, 463
30. Quinn, J. et al. 1996, ApJ, 456, L83
31. Reynolds, P.T. et al. 1993, ApJ, 404, 206
32. Samuelson, F.W. et al. 1998, ApJ, 501, L17
33. Stecker, F.W., De Jager, O. C. & Salamon, M. H. 1996, ApJ, 473, 75