Proceedings of ICRC 2001: 2676 © Copernicus Gesellschaft 2001

ICRC 2001

Observations of PKS 2155-304 by the University of Durham Mark 6 telescope: Results from 1999

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Abstract. We report observations of the southern hemisphere TeV blazar PKS 2155-304 made with the University of Durham Mark 6 Telescope during September, October and November 1999. No evidence of TeV gamma ray emission was found. RXTE observed PKS 2155-304 at this time and showed no evidence for X-ray flaring. Our observations do not contradict the current models for TeV emission from blazars.

1 Introduction

Blazars are a class of active galactic nuclei (AGN) that have jets aligned along or very close to the observer's line of sight. The emission is beamed towards us, preventing gamma-ray absorption by photon photon interaction. It is this characteristic that makes them candidates for VHE gamma-ray emission.

Blazars can be characterised by the shape of their spectral energy distributions. In high energy peaked BL Lacs (HBLs) the X-ray emission comes from the high-energy end of the synchrotron emission. Whereas in low frequency peaked BL Lacs (LBLs) the X-ray emission is from Compton scattering.

Previous surveys of VHE emission (Roberts et al., 1999) have indicated that only close HBLs are observable at TeV energies. This is in accord with both theoretical models of gamma-ray emission from AGNs, (Ulrich et al., 1997) and with the absorption of VHE gamma rays on the cosmic infrared background, (Stecker et al., 1992).

VHE emission from TeV blazars has been observed to be highly variable. Flaring activity has been observed on time scales as short as 15 minutes and can be correlated with the activity at other wavelengths (Quinn et al., 1999). The mechanisms for this variation, the nature of the jets and the way in which the particles are accelerated are still not fully understood.

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Current models proposed for TeV blazars include the Synchrotron Self-Compton models, which involve a single population of relativistic electrons emitting synchrotron radiation from radio to X-rays and inverse Compton radiation from X-rays to gamma-rays. Alternatively, the seed photons which are up-scattered to gamma-ray energies could be external to the jet from, for example, an accretion disk. Hadronic models suggest that protons are accelerated by shocks propagating through a relativistic jet. Alternatively, highly relativistic neutrons, produced by protons close to the central source can interact with ambient photons. They then may travel great distances before undergoing beta-decay into protons, electrons and anti-neutrinos. It is the ultra relativistic protons formed that could produce gamma-rays by interaction with ambient nucleons.

2 PKS 2155-304

PKS 2155-304 is a distant ($z = 0.117$, (Bowyer et al., 1984)) TeV emitting HBL. It is the brightest known BL Lac object at UV wavelengths and the objects maximum power is emitted between the UV and soft X-ray range (Wandel & Urry, 1997). PKS 2155-304 has a history of rapid strong broadband variability and has been the subject of several multiwavelength monitoring campaigns e.g. (Courvoisier et al., 1995; Pesce et al., 1999). It was observed by the Mark 6 telescope during 1996 September/October/November and 1997 October/November. During these observations VHE gamma rays with energy greater than 300 GeV were detected from this object with a time-averaged integral flux of $(4.2 \pm 0.7_{\rm stat} \pm 2.0_{\rm sys}) \times 10^{-11}{\rm cm}^{-2}{\rm s}^{-1}$ (Chadwick et al., 1999). The strongest emission was detected during observation in November 1997, when the object was producing the largest flux ever recorded in hard X-rays. It was also detected as a source of gamma rays of energy greater than 100 MeV. The VHE gamma rays and X-rays show some evidence of correlation, (Chadwick et al., 1999).

Date	No. of ON-source segments
10/08/1999	5
11/08/1999	7
07/09/1999	7
14/09/1999	3
15/09/1999	9
01/10/1999	1
04/10/1999	5
05/10/1999	3
07/10/1999	2
08/10/1999	8
09/10/1999	8
11/10/1999	8
12/10/1999	5
14/11/1999	6
07/11/1999	3
09/11/1999	5
10/11/1999	5
11/11/1999	2

Table 1. Observations of PKS 2155-304 in Standard Chopped Mode.

3 Observations

Located in Narrabri, NSW, Australia, the Durham Mark 6 telescope was in operation from July 1995 until December 1999. A more comprehensive description of the telescope can be found in (Armstrong et al., 1999). The Durham Mark 6 Telescope used imaging techniques to separate gamma-rays from the cosmic-ray background.

The Durham Mark 6 telescope consisted of three parabolic flux detectors of 7m diameter and aperture f/1.0. They were mounted on a single altitude-azimuth platform. A 109 element imaging camera (0.25^o pixel size) was mounted at the focus of the central flux detector with low-resolution cameras each consisting of 19 pixels (0.5^o pixel size) mounted at the focus of the outer (left and right) flux detectors. The telescope was triggered by demanding a simultaneous temporal (10ns gate) and spatial (0.5^o aperture) coincidence of the Cherenkov light detected in the three cameras. This triggering system enabled the telescope to detect low-energy gamma rays with high immunity from triggering by noise and local muons. Ongoing simulations suggest that this system had a triggering probability for gamma rays of about 1% at 300 GeV rising slowly to $\sim 40\%$ at 900 GeV for gamma-ray showers falling within 300m of the telescope.

Data were taken in 15 minute segments, in either standard chopped mode or in pseudo chopped mode. In standard chopped (Table 1) mode the off-source observations were taken by alternatively observing regions of sky that differ by $\pm$ 15 minutes in right ascension from the position of the object to ensure that the on and off segments possess identical azimuth and zenith profiles. This off-source/on-source, on-source/off-source observing pattern was routinely used to eliminate any first-order changes in count rate due to any residual secular changes in atmospheric clarity, temperature, and so on. In pseudo chopped mode (Table 2), the on-source position was centred $\sim 0.5^o$ from the centre of the camera. The position was changed every 15 minutes to another position also $\sim 0.5^o$ from the centre of the camera but in another direction. The off-source information was taken from the same dataset but with an assumed source position taken to be the on-source position reflected through the centre of the camera. This pseudo chopped mode had the advantage that the source was constantly being monitored, which is important when observing objects that can flare on short timescales.

Date	No. of segments
08/09/1999	23
11/09/1999	23
13/09/1999	23

Table 2. Pseudo Chopped Observations.

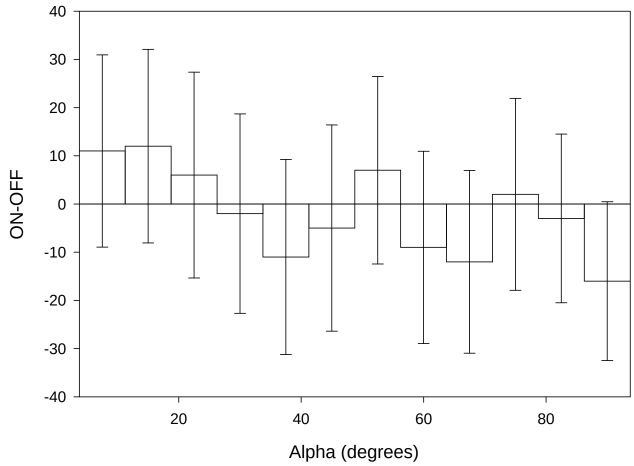

Fig. 1. The alpha plot for data listed in Table 1

Data were accepted for analysis only if (1) the sky was clear and stable and (2) for standard chopped mode the gross counting rates in each on-off pair were consistent at the 2.5σ level. More information on the data analysis procedures for this object can be found in (Chadwick et al., 1999)

4 Results

The dataset was tested for the presence of gamma-ray signals. Only data taken at $z \leq 45^o$ were analysed. This is because of the different analysis procedures for data taken at $z \geq 45^o$.

The selection cuts used and their justification can be found in (Chadwick et al., 1999). Due to the nature of the pseudo chopped mode an extra cut whereby an upper limit to the position of a selected event with respect to the edge of the camera as well as with respect to the position of the source was imposed.

Figure 1 shows the number of excess events against alpha (a pointing parameter) for standard chopped data. Gamma-ray events from a point source will appear as an excess of

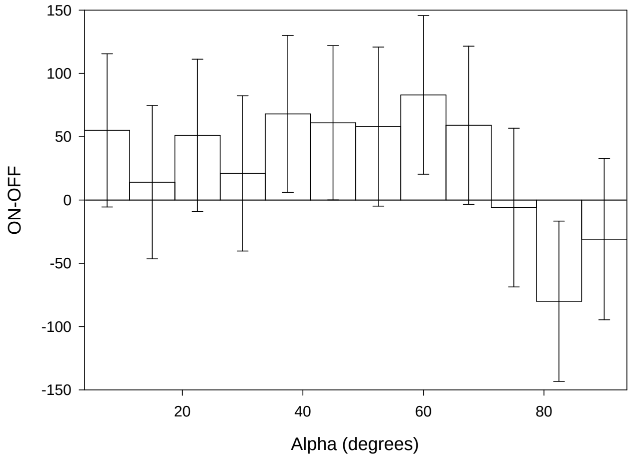

Fig. 2. The alpha plot for data listed in Table 2

events at small values of alpha. This excess is not seen here. Each night was looked at individually to check for any outbursts. No evidence for emission on a day to day level was found. Similarly figure 2 shows the number of excess event against alpha for psuedo chopped data. No evidence for gamma-ray emission was found here.

Figure 3 shows the X-ray variability of PKS 2155-304 around the time of our observations. The upper panel shows the RXTE ASM dwell by dwell observations of PKS 2155-304. PKS 2155-304 was not seen to be flaring in X-rays at this time.

5 Discussion

Current models for VHE emission include the inverse Compton scattering of low energy photons by the relativistic jet. These soft photons may be synchrotron photons (Synchrotron Self Compton) or photons produced in the disc or broad line region.

From the standard chopped observations (Table 1), a 2σ upper limit to emisson at energies $> 1.5\mathrm{TeV}$ of $(0.8 \pm 0.2_{\mathrm{sys}}) \times 10^{-11}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ is derived from simulations. Fossati et al. (1998) and Ghisellini et al. (1998) have introduced simple models to account for the phenomenology of gamma-ray bright blazars. The results of observations by the Durham Mark 6 telescope do not contradict either of these models.

With the next generation of atmospheric Cherenkov telescopes such as HESS, observations at greater sensitivity and resolution will be possible. Future observations with such experiments will help to discriminate between the models for gamma-ray production. It is predicted that for HESS to detect PKS 2155-304 in the high X-ray state observed in 1997 (Chadwick et al., 1999) to a significance of 8σ would require only 1 hour of observation. This was calcuated using a simulation of the HESS response (Konopelko, private communication).

Acknowledgements. We would like to thank the Particle Physics and Astronomy Research Council for their support of the project and the University of Sydney for the lease of the Narrabri site. This paper uses quick look results provided by the ASM/RXTE team.

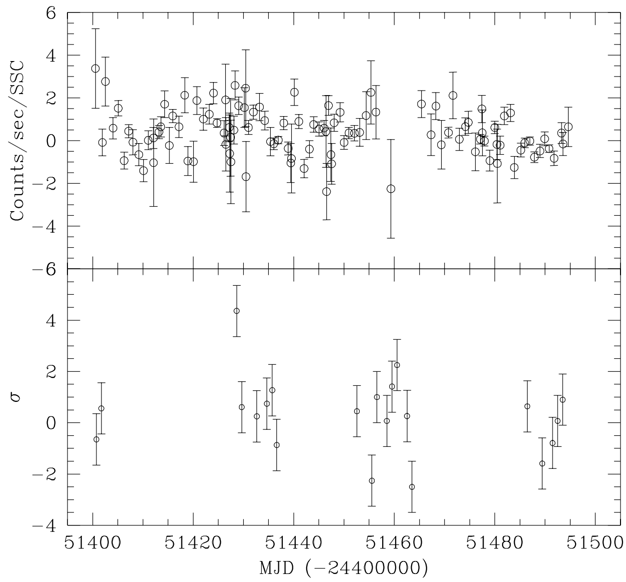

Fig. 3. This graph shows the RXTE All Sky Monitor (ASM) observations in the upper panel and the University of Durham Mark 6 results of observations in the lower panel for PKS 2155-304 from August to November 1999. SSC refers to the Scanning Shadow Cameras, three of which make up the ASM.

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