VHE Gamma Rays from PKS 2155–304

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Abstract

The X-ray selected BL Lac PKS 2155–304 has been observed using the University of Durham Mark 6 very high energy gamma ray telescope during 1998. We find no evidence for TeV emission during these recent observations when the X-ray flux was observed to be low. We have reconsidered our measurements made in 1997 November when PKS 2155–304 was in a bright X-ray state and extended X-ray and GeV gamma ray observations were made as part of a multiwavelength campaign. Comparisons are made of the VHE emission during this time with the available data from other wavelengths.

1 Introduction

Evidence exists for at least four close X-ray selected BL Lacs as sources of episodic TeV gamma ray emission (Mrk 421 – Punch et al. 1992, Mrk 501 – Quinn et al. 1996, 1ES 2344+514 – Catanese et al. 1997 and PKS 2155–304 – Chadwick et al. 1999). The discovery of PKS 2155–304 as a VHE gamma ray source was made with the University of Durham Mark 6 telescope on the basis of observations lasting 40 hrs in 1996 and 1997. These results suggested a time variable emitter with the strongest emission in 1997 November at the time of a successful multiwavelength campaign (Chadwick et al. 1999). We have extended the observations of PKS 2155 with further measurements in 1998 August – November.

Date	No. of scans ON source
1998 July 22	1
1998 August 18	5
1998 August 19	7
1998 August 20	4
1998 September 15	5
1998 September 16	2
1998 September 17	4
1998 September 19	3
1998 October 11	2
1998 October 13	2
1998 October 16	1

Table 1: Observing log for our observations of PKS 2155–304 during 1998.

The details of the measurements at X-ray energies in 1997 November are now available from both *RXTE* (Vestrand & Sreekumar 1999) and *BeppoSAX* (Chiappetti et al. 1999), together with data from *CGRO*/EGRET (Vestrand & Sreekumar 1999). During the 36 hour observation with *BeppoSAX* a short interval (2 hrs) of simultaneous X-ray and TeV observations occurred.

We here report the results of our 1998 measurements and reconsider our 1997 November data in the light of the recently available X-ray results from the multiwavelength campaign. All measurements reported here have been made with the University of Durham Mark 6 gamma ray telescope operating at Narrabri, NSW, Australia. The telescope has been described in detail by Chadwick et al. (1997) and Armstrong et al. (1999).

2 New measurements in 1998

Observations in 1998 have involved 9 hrs of exposure ON source and an equal amount OFF source during 1998 August, September and October and the observing log is summarized in Table 1. All analyses reported here have been completed using the same procedures and background suppression used in our previous work on PKS 2155–304 described by Chadwick et al. (1999).

	On	Off	Difference	Significance
Number of raw events	171723	173203	-1480	$-2.5\ \sigma$
Number of size and distance selected events	97279	97493	-214	$-0.48\ \sigma$
Number of shape selected events	6260	6053	207	$1.9\ \sigma$
Number of shape and *ALPHA* selected events	950	992	-42	$-0.10\ \sigma$

Table 2: The results of various event selections for the 1998 PKS 2155–304 data.

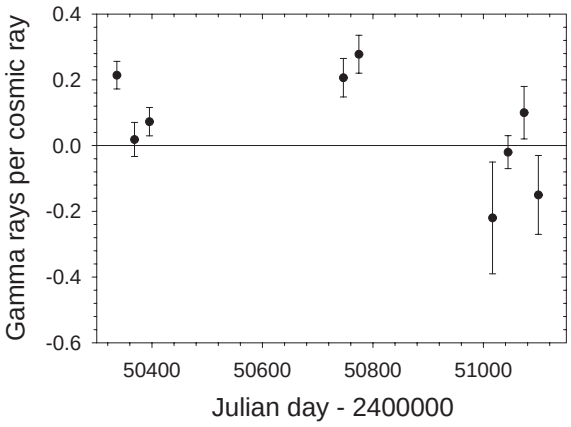

Figure 1: The measured VHE gamma ray flux above 300 GeV from PKS 2155–304 averaged over observing periods of approximately 10 days.

We find no evidence for emission of TeV gamma rays throughout the observation — see Table 2 for the summary of the data analysis. We calculate a time-averaged 3σ flux limit of $4.0 \times 10^{-11}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$ at an energy theshold of 300 GeV for 1998 August – October.

We show in Figure 1 the time averaged VHE gamma ray fluxes (normalized to the cosmic ray counting rate — see Chadwick et al. 1999) for all dark periods during which we have observed PKS 2155–304. We note that according to the X-ray measurements made with the ASM on board *RXTE*[1] PKS 2155–304 was in an X-ray low state during our measurements in 1998 August – October. Our failure to detect VHE emission during 1998 is thus consistent with the hypothesis that the X-ray and VHE gamma-ray emission from PKS 2155–304 are correlated (Chadwick et al. 1999). Similar behaviour is observed in the VHE and X-ray emission from Mrk 421 and Mrk 501.

3 Multiwavelength Observations in 1997 November

TeV gamma ray data are available from observations between 17–25 November (see Chadwick et al. 1999). These observations were made as part of a multiwavelength campaign involving GeV gamma ray and X-ray measurements. The GeV gamma ray measurements were made using *CGRO*/EGRET from 1997 Nov 10 – Nov 23 and showed strong GeV emission during the first half of the viewing period (Vestrand & Sreekumar 1999). X-ray observations using PCA and HEXTE on board *RXTE* were made during 1997 Nov 20 – 22 (Vestrand & Sreekumar 1999) and ASM observations are available throughout. *BeppoSAX* observed this object for about 1.5 days during 1997 Nov 22 – 24 (Chiappetti et al. 1999). The X-ray and gamma ray observations clearly show that PKS 2155–304 was in an active flaring state during the middle of November 1997, with X-ray and gamma ray fluxes being as high as ever previously detected — see Figure 2. Recently the CANGAROO group have published data from PKS 2155–304 taken between 1997 Nov 24 and 1997 Dec 1 (Roberts et al. 1999). They fail to detect any TeV emission from PKS 2155–304 during this period, quoting a flux limit $< 9.5 \times 10^{-12}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$ at an energy threshold of 1.5 TeV. Given the non-overlapping observation periods,

[1] Available on the web at http://space.mit.edu/XTE/asmlc/srcs/pks2155-304.html.

the possibility of time variation in the emission and the different thresholds of the telescopes, this null result is not in conflict with our detection.

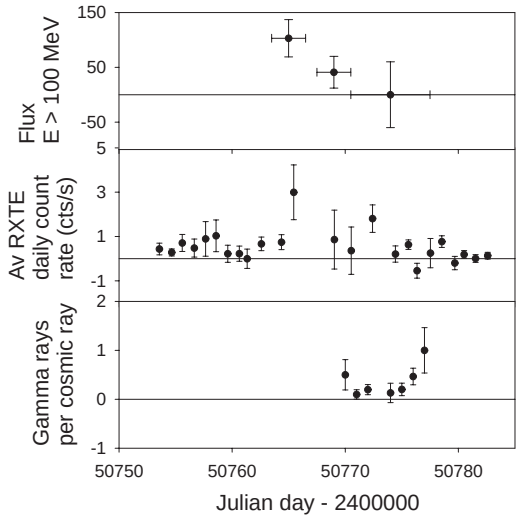

Figure 2: The GeV gamma rays recorded with EGRET (Vestrand and Sreekumar 1999 – upper panel), X-rays recorded with ASM on *RXTE* (centre panel) and VHE gamma ray (present work – bottom panel) during the 1997 November observations of PKS 2155–304.

Our TeV observations, averaged over the total dataset for 1997 November, indicated the strongest emission during any of our observations of PKS 2155 to date (Chadwick et al. 1999). The time averaged flux of VHE gamma rays from PKS 2155-304 for our observations in 1997 November is $(6.0 \pm 2.0_{stat} \pm 3.0_{sys}) \times 10^{-11}$ cm^{-2} s^{-1} for an energy threshold of 300 GeV. The GeV and X-ray observations suggest that a large outburst occurred in early November prior to the TeV observations (Vestrand & Sreekumar 1999). The TeV observations do not contradict this idea.

We have considered on a day by day basis the information available from ground based Cerenkov telescopes, *CGRO*/EGRET, *RXTE* and *BeppoSAX*. The only truly contemporaneous data were recorded by *BeppoSAX* and the Mark 6 telescope on 1997 November 23 between 1100 and 1300 hrs UTC. We reproduce the X-ray data from the paper of Chiappetti et al. (1999) and focus on the interval with VHE observations — see Figure 3(a).

Our VHE observations occur at the time which Chiappetti et al. (1999) define as a region of low X-ray intensity defined on the basis of the MECS (medium energy) count rate, beginning about 2 hours after the peak of the second X-ray flare detected by *BeppoSAX*. We show in Figure 3(b) the results of our VHE observations for individual 15 min scans on 1997 Nov 23, along with data taken on 1997 Nov 22 which were obtained about three hours before the *BeppoSAX* observation commenced. We have no evidence for strong flaring activity within the simultaneous VHE data obtained on 1997 Nov 23, consistent with the low X-ray state. The VHE data taken on 1997 Nov 22 are at the same activity level as on Nov 23. The X-ray data show that an X-ray flare peaked about 2 hrs after our VHE observation on November 22nd finished and that the typical time scale for X-ray flaring is such that the flare is likely to have commenced after our observation terminated. The VHE data yield a flux of $(2.0 \pm 5.0_{stat} \pm 1.0_{sys}) \times 10^{-11}$ cm^{-2} s^{-1} for the observation on 1997 Nov 22 and $(7.0 \pm 4.5_{stat} \pm 3.5_{sys}) \times 10^{-11}$ cm^{-2} s^{-1} for the observation on 1997 Nov 23, both at an estimated energy threshold of 300 GeV.

4 Discussion

In common with the VHE observations of the Northern hemisphere blazars, the VHE emission from PKS 2155–304 is time variable and appears to be correlated with X-ray emission, consistent with the unified model of AGNs. We will continue to monitor this object with the Mark 6 telescope and we plan to observe it intensively when there is any indication of flaring activity at X-ray energies from the ASM quick look analysis or at any other wavelengths. The 1997 multiwavelength campaign has yielded the first simultaneous observations of VHE gamma rays from this object at the same time as data from high throughput X-ray instruments. Unfortunately, the VHE coverage did not overlap one of the short (2hr duration) X-ray flares. However, the sensitivity of the Mark 6 telescope is such that a flare of comparable X-ray intensity to that of

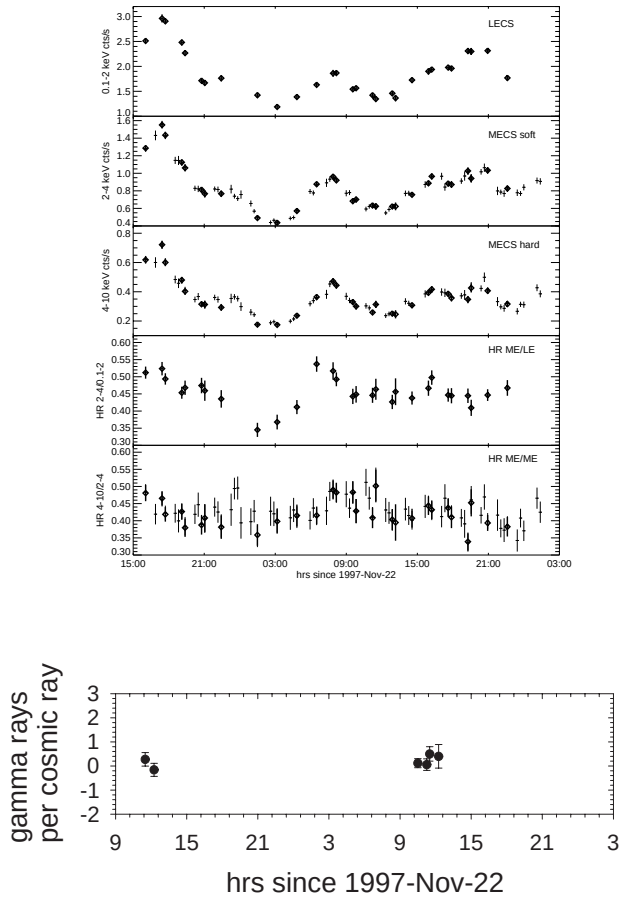

Figure 3: (a) The X-ray light curves (upper three panels) and hardness ratios (lower two panels) recorded with *BeppoSAX* during the 1997 November observations of PKS 2155–304 (taken from Chiappetti et al. 1999). Also shown (b) are the VHE gamma ray results from the present work.

1997 Nov 22 should be resolvable in its VHE emission.

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