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TeV gamma-ray observations from the blazar, 1ES2344+514 with the Whipple Cherenkov Imaging Telescope

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Abstract. Observations of the blazar, 1ES2344+514 carried out with the 10m Whipple atmospheric imaging Cherenkov telescope were performed in an attempt to confirm the previously reported detection of this source. Results from Oct. 1999 to Dec. 2000 are presented. The results show new evidence of TeV emission from 1ES2344+514 during these observations. During this time, the X-ray and TeV gamma-ray measurements by ASM/RXTE and Whipple 10m telescope, respectively, do not show any episodes of strong flaring activity.

1 Introduction

Blazars are dominated by non-thermal continuum emission. They are characterized by emitting plasma in relativistic motion closely aligned with our line of sight (e.g. Urry and Padovani, 1995). The structure of the relativistic jet remains largely unknown. Variability is caused by changes in electron density or magnetic field strength. A subclass of these objects radiate in GeV-TeV part of the spectrum and can emit up to 90% of their output in gamma-rays during flares. Their spectra usually reveal two broad components. The low energy component peaks in the IR-X-ray range and the high energy component peaks in the MeV-TeV range. Analysis of flaring activity from these objects seems to provide some evidence for correlation between GeV and optical bands in high luminosity blazars (Wagner et al., 1995 and Whehrle et al., 1998) and TeV and X-ray in low luminosity blazars (Macomb et al., 1995, Takahashi et al., 1996, Petry et al., 2000 and Sambruna et al., 2000).

In the synchrotron self-Compton model (Jones et al., 1974), synchrotron photons are scattered to higher energies by their parent electrons. This process is thought to be responsible for the production of X-rays. On the other hand, GeV-TeV emission from blazers is produced through the inverse Compton scattering of soft photons by ultra-relativistic electrons.

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Table 1 summarizes the detection of TeV photons from AGNs. Unfortunately, only two of these detections are independently confirmed (see e.g. Weekes, 2000). Increasing the number of confirmed TeV sources will increase the opportunities to test, in detail, the emission models for these objects, e.g. place constraints on the mechanism responsible for accelerating electrons to TeV energies. In addition, TeV gamma-rays from blazars can be used to probe the intergalactic infrared radiation field.

Only three blazars were found to have their synchrotron peak at or above 100 keV; Mrk 501, 1ES 2344+514 and 1ES 1426+428 (Costamante et al., 2001). The blazar 1ES 2344 is one of the best candidates for monitoring, particularly since it is one of the closest AGN (z=0.044). Very high energy gamma-rays from 1ES2344+514 were first detected by the Whipple Collaboration (Catanese et al., 1998). On Dec. 20th, 1995, the Whipple telescope detected a burst of TeV photons from the source corresponding to a flux (E>350 GeV)=$(6.6\pm 1.9)\times10^{-11}$ photons/cm^2s. The detected flux for non-flaring activity during Oct. 1995-Jan. 1996 was $(1.1\pm0.4)\times10^{-11}$ photons/cm^2s. For the period 1996–97 an upper limit of 8.2×10^{-12} photons/cm^2s was reported. The HEGRA experiment found no evidence in their 1997-98 data for TeV emission from this object (Aharonian et al., 2000). The flux limit given by HEGRA is 2.9×10^{-12} photons/cm^2s (E$>$ 1TeV) for that period.

2 Observations and Data Reduction

The TeV activity of 1ES 2344 was monitored using the 10-m imaging atmospheric Cherenkov telescope at the Whipple Observatory (2.3 km a.s.l.). The observations were made with the present 490 pixel camera (Finley et al., 2001). This camera was installed in Oct. 1999. The first phase of operation involved calibration of the electronics. A mirror recoating program started about the same time. Re-coating the mirrors improved the mirror reflectivity by about 22%

Table 1. Reported detection of TeV photons from AGN. Some characteristics of these sources are also given.

Source	Discovery	Confirmed TeV source	Type	z	EGRET source
Markarian 421	Whipple (Punch et al. 1992)	Yes	HBL	0.031	Yes
Markarian 501	Whipple (Quinn et al. 1996)	Yes	HBL	0.034	Yes
1ES 2344+514	Whipple (Catanese et al. 1998)	Yes*	HBL	0.044	No
1ES 1959+650	TA (Nishiyama et al. 1999)	No	HBL	0.048	No
BL Lac	Crimea (Neshpor et al., 2001)	No	HBL	0.069	Yes
PKS 2155-304	Durham (Chadwick et al. 1999)	No	HBL	0.116	Yes
1H 1426+428	Whipple (Horan, 2001)	No	HBL	0.129	No
3C66A	Crimea (Neshpor et al. 1998)	No	LBL	0.444	Yes

* this work

at 310 nm (Badran and Weekes, 2001). As of Dec. 1999, the system was stable and a significant fraction of the mirrors were re-coated and mounted on the telescope. The data considered in this work was taken during the 1999-2000 and the 2000-2001 observing seasons. The discriminator thresholds were reduced on Oct. 25th, 2000 from 36 mV to 32 mV to reduce the energy threshold. At nearly this same time the program of mirror re-coating was completed. As a result the peak energy was reduced from 430 to 390 GeV. The peak energy is defined as the energy at which the rate of photons per unit energy of the Crab Nebula is highest. For these reasons the data were divided into two sets. Table 2 shows the selection criteria (Supercuts, Reynolds et al., 1993) for gamma-ray-like events for the two periods. These two sets of cuts were optimized on data from the Crab Nebula taken during the same period. The Crab rate for the first and second period was found to be 2.5 and 4.2 gammas/min, respectively.

Observations are carried out using two modes; On/Off and Tracking (Catanese et al., 1997). Each (On, Off, or Tracking) observation has a 28 minute duration. Since TeV emission of blazars is highly variable (Gaidos et al., 1996 and Mattox et al., 1997), 10 minute Tracking observations were also taken during a "snapshot AGN" survey carried out in 2001. The objective of the survey was to detect any of a number of potential sources in a flaring state. Only data taken in good weather and with elevation above $55°$ were included in this analysis. In addition, unstable raw data were excluded. Almost all of these data were taken in the Tracking mode. The tracking ratio was calculated using both zenith runs and Off runs from different sources with elevation above $55°$. The calculated tracking ratios are also given in Table 2.

Fig. 1 shows the distribution of the alpha parameter for the On-source data that passed the selection criteria given in Table 2, for the two periods, and the sum of all of the data. The gamma-ray signal is calculated for the $\alpha = 0° - 15°$ region and the background is estimated from the $\alpha = 20° - 65°$ region. The histogram is the distribution obtained from nonsource runs of equal observing time. The significance S is given by

$$S = \frac{N_{on} - rN_{off}}{\sqrt{N_{on} - r^2 N_{off} + (\Delta r)^2 N_{off}^2}}$$

where, r is the calculated tracking ratio and Δr is its statistical error; N_{on} and N_{off} are the number of events in the gamma-ray domain ($\alpha = 0° - 15°$) and the number of events in the background region ($\alpha = 20° - 65°$), respectively.

Table 2. Gamma-ray selection criteria for the two observing periods of the 10 m Whipple telescope with the current 490 pixels camera.

Observing Period (Discriminator Setting)	Parameter	Cuts
Jan. 1–Oct. 24, 2000 (36 mV, 3 fold)	picture/boundary	$\prec$2.25/4.25σ
	Nbr3	on
	Max1/Max2	$\prec$30/30 d.c.
	Distance	0.4-1.0°
	Width	0.05-0.12°
	Length	0.13-0.25°
	Length/Size	$\prec$0.0004°/d.c.
	Alpha	$\prec$15°
	Tracking ratio	3.20±0.02
Oct. 25-Dec. 28, 2000 (32 mV, 3 fold)	picture/boundary	$\prec$5.0/4.5σ
	Nbr3	on
	Max1/Max2	$\prec$50/40 d.c.
	Distance	0.4-1.0°
	Width	0.05-0.13°
	Length	0.09-0.26°
	Length/Size	$\prec$0.0004°/d.c.
	Alpha	$\prec$15°
	Tracking ratio	3.11±0.02

3 Results

Table 3 shows the observing time, the calculated significance of 1ES2344+514 data and the average flux for the two periods. On the basis of these results we believe that we have

Table 3. Results of the 1ES2344+514 observations for 1999-2000 and 2000-2001 seasons.

Period	Hours	Significance	Peak Energy	Flux ($photons/cm^2 s$)
Period I	14.9	3.74	430 GeV	$1.21 \pm 0.34 \times 10^{-11}$
Period II	9.1	1.84	390 GeV	$0.91 \pm 0.51 \times 10^{-11}$
Total	24.0	3.10		

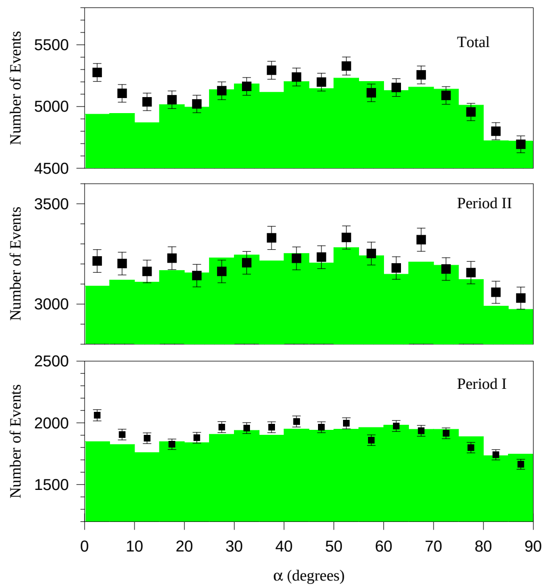

Fig. 1. The α distribution of 1ES2344+514 data. These distributions are for all of the event that passed all cuts listed in Table 2 except for the α cut for period I (bottom), period II (middle) and the total of both periods (top). For comparison, the dark histogram is the expected distribution from a nonsource.

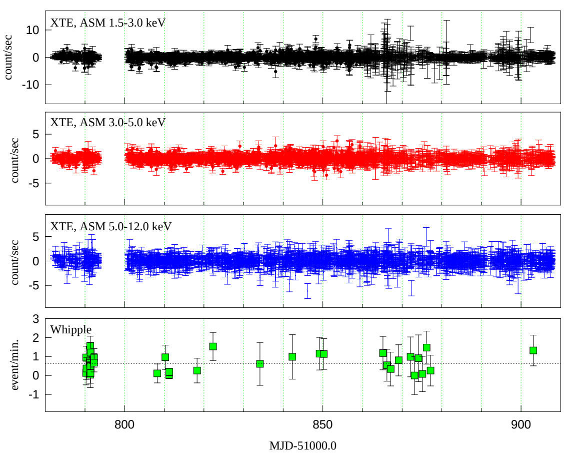

Fig. 2. TeV gamma-ray light curve for all on-source data from 1ES2344+514 (bottom). Also shown are the light curves of ASM/RXTE data in three energy bands.

confirmed 1ES2344+514 as a TeV source at the 3 σ level. The present result together with the previous Whipple detection (Catanese et al., 1998) indicate that the object is a very high energy gamma-ray source.

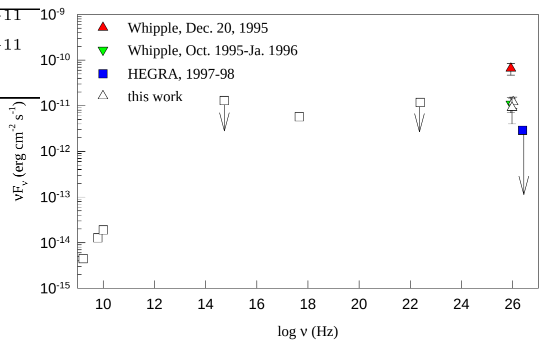

Fig. 3. Spectral energy distribution of 1ES2344+514. The previous Whipple detection and the upper limit from HEGRA are shown together with the estimated average flux from this work. For references for the low energy points, see Catanese et al., 1998

X-ray data from All-Sky Monitor (ASM) on board the Rossi X-Ray Timing Explorer satellite (RXTE) for the same time period were examined. X-ray light curves obtained from the data from the ASM/RXTE detector in three energy bands; 1.5-3.0, 3.0-5.0 and 5.0-12.0 keV are shown in Fig. 2. Also shown is the TeV gamma-ray rate from the source. Neither X-ray (especially the 5.0-12.0 keV range) nor TeV data exhibit any significant variation in the detected rate. This supports the idea that the source was not flaring during the period of the observations, hence these data do not provide a good opportunity for analysis of a possible correlation between X-rays and TeV gamma-rays. Fig. 3 shows the spectral energy distribution for 1ES2344+514. The average flux in this work is consistent with the previous Whipple flux (see Fig. 3). The previous and current Whipple measurements together with the HEGRA upper limit may indicate a sharp decrease of the flux of 1ES2344+514 with energy. The absence of a simultaneous detection of the source by two different experiments does not allow any speculations about the spectral index of the source in the energy range 350 GeV - 1 TeV.

4 Conclusion

1ES2344+514 was observed by the Whipple 10-m gamma-ray telescope for a total of 24 hours. The TeV signal from 1ES2344+514 is consistent with the ASM/RXTE measurements. No obvious flaring activity was observed during 1999-2000 in either X-ray or TeV gamma-ray. The source was, on average, constant at 0.63 ± 0.49 photons/min. during the whole period with no strong indication of flaring activity. The cumulative excess exceeds 3σ. While detection of 1ES2344+514 at TeV energies is not as yet confirmed by independent observations the consistently positive results are suggestive. Continued monitoring of the source with the Whipple Cherenkov telescope is planned.

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