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# Observations of 1H1426+428 with the Whipple 10 m imaging atmospheric Čerenkov telescope

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**Abstract.** TeV $\gamma$-ray observations of 1H1426+428, an X-ray selected BL Lacertae object at a redshift of 0.129, are reported here. The X-ray spectrum appears to peak near 100 keV; if this is the peak of the synchrotron emission, then this AGN is a prime candidate for TeV $\gamma$-ray emission assuming a Compton-synchrotron model. During the 1999, 2000 and 2001 observing seasons, the source has been intensively studied with the Whipple 10m imaging atmospheric Čerenkov telescope. The average signal recorded over the 2000 observing season (March-June) was above the $4\sigma$ level. The differential flux at 430 GeV was 2.9 $\pm$ 1.1 x $10^{-11}$ cm$^{-2}$s$^{-1}$TeV$^{-1}$.

## 1 Introduction

1H1426+428 is an X-ray selected BL Lacerate object at a redshift of 0.129. Throughout the past few years it has been observed extensively with the Whipple 10m Telescope. Since 1992, the Whipple Collaboration, using the imaging atmospheric Čerenkov telescope on Mt. Hopkins, has been searching for TeV $\gamma$-ray emission from AGN. Initially the search was concentrated on blazars detected by EGRET at any redshift; these observations led to the detection of Mrk 421 (Punch et al., 1992) and upper limits on the flux from some 30 other blazars (Kerrick et al., 1995). A search concentrated on nearby BL Lacs has led to the detection of Mrk 501 (Quinn et al., 1996) and 1ES2344+514 (Catanese et al., 1998). Between 1995 and 1999 the survey included 24 objects, 17 High frequency peaked BL Lacs (HBLs) and 7 Low frequency peaked BL Lacs (LBLs), ranging in redshift from 0.046 to 0.44; the results will be published shortly (Horan et al., 2001). Although none of the observations yielded a statistically significant detection, the largest signal to noise ratio was recorded from 1H1426+428. In this paper we describe the properties of 1H1426+428 which make it particularly interesting for TeV $\gamma$-ray observations. We summarize the observations made in 1999, 2000 and 2001 and compare the TeV observations taken during this period with X-ray observations by RXTE. Finally we discuss the implications of the detection of 1H1426+428 at TeV energies.

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## 2 1H1426+428 at Other Wavelengths

1H1426+428 was detected in the surveys conducted by Uhuru, Ariel 5, and the HEAO 1 Large Area Sky Survey; it was classified as a BL Lac object in 1989 (Remillard et al., 1989 and references therein). It was among the 127 objects presented in a recent analysis (Laurent-Muehleisen et al., 1999) of BL Lac objects contained in the ROSAT All-Sky Survey-Green Bank (RGB) catalog.

In 1998-1999, the *Beppo*SAX collaboration undertook an observing campaign with the aim of finding and studying other sources as “extreme” as Markarian 501 is in its flaring state (Costamante et al., 2000a). The candidates chosen for the *Beppo*SAX survey were selected from the Einstein Slew Survey and the RASSBSC catalogs.

These *Beppo*SAX observations (Costamante et al., 2000a; Costamante et al., 2000b; Costamante et al., 2001) revealed four new “extreme” HBLs, selected to have high synchrotron peak frequencies. These four candidates for TeV emission are: 1ES 0120+340, PKS 0548-322, H2356-309 and 1ES 1426+428 (i.e. 1H1426+428).

The spectra for three of these objects are well fitted by convex broken power laws. However, for 1H1426+428, no evidence for a spectral break up to 100keV was found. Instead, its spectrum is well fitted by a single power-law, with a flat spectral index of 0.92 up to 100keV, thus constraining the peak of the synchrotron emission to lie near or above this value. The best fit of a pure homogeneous synchrotron self compton (SSC) model for 1H1426+428 (Costamante et al., 2000b) predicted detectable $\gamma$-ray emission at TeV energies.

1H1426+428 is routinely monitored by RXTE. However, at the time of the BeppoSAX observation, the observed x-ray flux was not very high, indicating that 1H1426+428, unlike Mrk501 mentioned earlier, was not in a flaring state at the time when the spectrum was derived. This implies that the synchrotron peak could reach values even higher than 100keV in the event of a flare, indicating the presence of highly relativistic electrons. Hence, these observations make 1H1426+428 a prime candidate for TeV emission.

## 3 Observing Technique

The observations reported in this paper were taken with the 10m reflector at the Whipple Observatory in southern Arizona with a variety of camera configurations. The characteristics of this instrument are described in Finley et al. (1999); the image cleaning and data analysis techniques employed are given in Reynolds et al. (1993). Two modes of observation were used: ON/OFF and TRACKING. The bulk of the observations were made in the TRACKING mode, which is described in Catanese et al. (1997). The tracking ratio was calculated using all of the OFF source data available for each observing year, assuming there is no source contribution. In addition, the tracking ratio was checked using the OFF data from 1H1426+428 pairs; within statistical errors, these tracking ratios were consistent with the standard tracking ratio derived from the full yearly database.

For the analysis, the standard cuts for each observing season were used (Finley et al., 2001). These cuts were optimized on contemporaneous Crab data as were the cleaning thresholds.

## 4 Results

### 4.1 1999 Observations

A total of 24.35 hours of observations of 1H1426+428 were carried out in 1999, the main results of which are summarized in Table 1. Part of the rate curve for 1H1426+428 during 1999 is shown in Figure 1 (left panel). It can be seen to rise above its quiescent level for a few nights in mid-March (MJD 51248-51251), perhaps as the result of a flare. Each point corresponds to the total rate calculated for that night so in some cases that is just 28 minutes while at other times it is up to 3 hours. The significance reached a peak value of $3.1\sigma$ on March 14 (MJD 51251) after 2.3 hours. The significance stayed close to this peak value until March 15, 1999 (MJD 51252) before dropping off. Hence almost all the positive effect seen in 1999 can be accounted for by an apparent flare lasting for a few nights. The net excess for the observing season was not significant ($0.9\sigma$).

### 4.2 2000 Observations

1H1426+428 was observed quite extensively during 2000 with a total of 26.17 hours being spent on source. The main results are summarized in Table 1. These observations once again showed evidence for flaring activity, and indicated that some

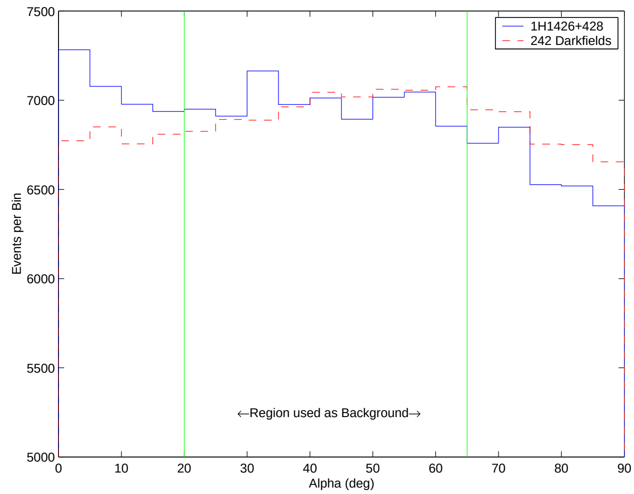


**Fig. 2.** The alpha plot for the 30.55 hours of data taken on 1H1426+428 during 2001.

low-level continuous emission seems to be present. The cumulative significance for the 26.17 hours of TRACKING data taken during 2000 was at the $4.2\sigma$ level. Out of this, 14.2 hours of data were taken in the ON/OFF mode, which amounted to a significance of $0.9\sigma$.

There is a clear rise in the significance around May 30, 2000 (MJD 51694), possibly as the result of a one-day flare. From the 2.6 hours of data taken that night, a signal at the $3.3\sigma$ level was recorded. The rate curve for the year can be seen in Figure 1 (middle panel).

### 4.3 2001 Observations

During 2001, there has once again been evidence for both continuous and flaring emission from 1H1426+428. After 30.55 hours of observation, a signal at the $4.94\sigma$ level has been detected. There were 11.4 hours of data taken in the ON/OFF mode which gave a total significance of $1.1\sigma$. The combined alpha plot for the 30.55 hours of data taken on source is shown in Figure 2, where a clear excess is visible in the 3 leftmost bins, as would be expected for a source of $\gamma$-rays .

There was evidence for a one-day flare on February 20 (MJD 51960) with a significance of $3.87\sigma$ detected on that night. The rate curve for the 2001 data is shown in Figure 1 (right panel).

### 4.4 Spectral Energy Distribution

Using all of the 2000 1H1426+428 data, a differential energy flux point was calculated. For this calculation, a peak energy response of 430GeV was used. A differential flux point was also calculated using the 2001 data, assuming a peak energy response of 390GeV. These points are added to the spectral energy distribution (Costamante et al., 2000a) and can be seen in Figure 3. No account is made for any absorption of the TeV photons by the infrared background.

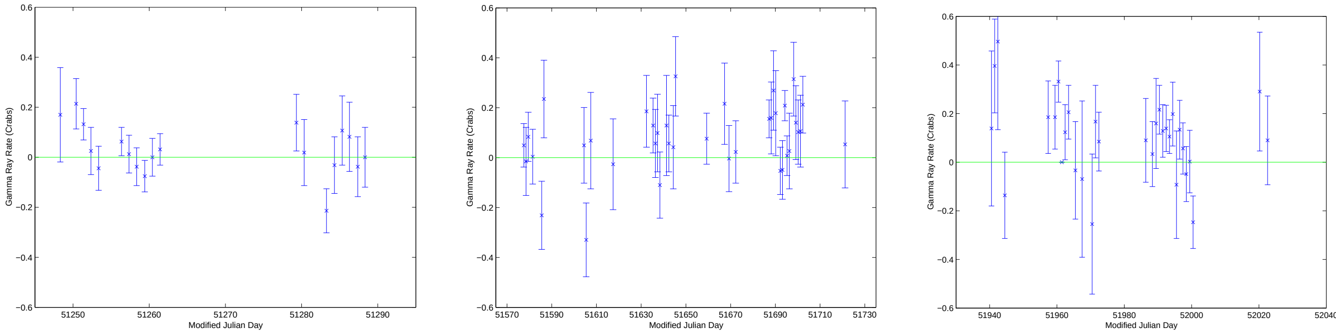


**Fig. 1.** The light curves for 1H1426+428 for 1999, 2000 and 2001; *left* March 11, 1999 (MJD 51248) to April 20, 1999 (MJD 51288); *middle:* February 3, 2000 (MJD 51577) to June 26, 2000 (MJD 51721); *right:* January 31, 2001 (MJD 51940) to March 24, 2001 (MJD 52022).

**Table 1.** 1H1426+428 results from 1999 - 2001

| Period | Exp. (hrs) | Total $\sigma$ | Max. $\sigma$ Month | Max. $\sigma$ Night | Flux[a] ($cm^{-2}$ $s^{-1}$$TeV^{-1}$) | Peak Response Energy (GeV) |
|---|---|---|---|---|---|---|
| 1999/03 - 1999/06 | 24.35 | 0.88 | 1.57 | 2.13 | <6.7 x $10^{-11}$ | 500 |
| 2000/02 - 2000/06 | 26.17 | 4.19 | 3.49 | 3.33 | 2.9 $\pm$ 1.1 x $10^{-11}$ | 430 |
| 2001/01 - 2001/04 | 30.55 | 4.94 | 4.68 | 3.87 | 4.9 $\pm$ 1.5 x $10^{-11}$ | 390 |

[a] The differential fluxes are quoted at the peak energy response for the observation period, as given in column 7.

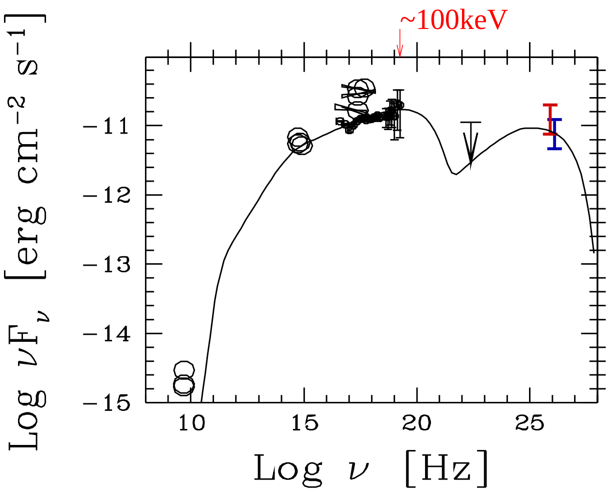


**Fig. 3.** The SED of 1H1426+428 from Costamante et al.(2000a) with a pure homogeneous SSC model fitted to the data. The points derived from the Whipple 2000 & 2001 data are shown.

### 4.5 Comparing the $\gamma$-ray & X-ray Flux from 1H1426+428

The $\gamma$-ray rates for 1999, 2000 and 2001 were compared with the X-ray flux from the All Sky Monitor (ASM) instrument on board the Rossi X-ray Timing Explorer (RXTE) (Levine et al., 1996). No correlation was found between the Whipple daily averages and the ASM "one-day average" data points for the full 1999, 2000 or 2001 datasets.

## 5 Discussion

Observations of 1H1426+428 with the Whipple telescope have been consistently positive since 1995 (Horan et al., 2001), although the statistical significance has not always been high. There have been 3 occasions in the 1999-2001 observing seasons when there was evidence for a flaring signal from 1H1426+428, in 1999 a flare at the 3.1$\sigma$ level, in 2000 a flare at the 3.3$\sigma$ level and in 2001 a flare at the 3.9$\sigma$ level. Also, during 2000 after 27.09 hours of observation, there is evidence for a signal at the 4.2$\sigma$ level and during 2001, after 30.01 hours of observation, there is evidence for a signal at the 4.9$\sigma$ level.

Since 1H1426+428 was on the very short list of predicted TeV emitters published by the *Beppo*SAX collaboration (Costamante et al., 2000a) and was also singled out as the most probable TeV emitter amongst these, due to the high value of its synchrotron peak, we conclude that the detection is significant and does not suffer any significant statistical penalty from being one on a list of 24 possible sources.

After 18.1 hours of observations on 1H1426+428, the CAT collaboration derived an average flux above 250 GeV, of 9.5 $\pm$ 8.6 x $10^{-11}$ $cm^{-2}$ $s^{-1}$ (Piron, 2000).

## 6 Conclusion

If independently verified, the results reported here represent an important addition to the catalog of TeV-emitting BL Lacs. That the source was predicted to be a TeV $\gamma$-ray source based on its X-ray spectrum is important in that it signifies the maturity of the observational techniques and the theoretical understanding of BL Lacs. It reinforces the symbiosis between observations at X- ray wavelengths, particularly in hard X-rays, and those at TeV energies, in particular those with good sensitivity below energies of 1 TeV. The existence of a population of sources whose most prominent emission is at energies of 10-100 keV and 300-1000 GeV points to a fruitful overlap between the next generation of ground- based atmospheric Čerenkov telescopes (Krennrich et al., 1999) and the hard X-ray experiment, EXIST (Grindlay et al., 1999). It is remarkable also in that this source, like the other extreme blazars, Markarian 501 and 1E2344+514, is not included in the 3rd EGRET Catalog, demonstrating that while the AGN seen by EGRET and ground-based telescopes have many similarities, they also have significant differences.

Although the properties of 1H1426+428 reported here are relatively poorly defined in comparison with the better studied TeV BL Lacs, they agree in principle with the characteristics now well established for Markarian 421 and Markarian 501 (and to a lesser extent, 1E2344+514). Time variability on time-scales from days to years is evident in 1H1426+428. There is no clear evidence for a correlation of X-ray and TeV $\gamma$-ray fluxes but the sensitivity of observations to date is limited and even in the stronger sources this correlation has been shown to be complicated.

1H1426+428 is the most distant of the TeV-detected BL Lacs classified as HBL, and hence it has promising implications for the detection of more BL Lacs at $z > 0.1$. Deeper detections of such sources, which allow for more accurate measurements of the TeV energy spectrum, may significantly limit the density of the intergalactic background light.

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