



Observations of Mrk 421 and Mrk 501 in Spring 2006 with VERITAS

S. J. FEGAN¹ FOR THE VERITAS COLLABORATION².

¹*Division of Physics and Astronomy, University of California at Los Angeles, 430 Portola Plaza, Box 951547, Los Angeles, CA 90095-1547*

² *For full author list see G. Maier, "Status and Performance of VERITAS", these proceedings.*
sfegan@astro.ucla.edu

Abstract: VERITAS, the Very Energetic Radiation Telescope Imaging Array System, is an array of four imaging Atmospheric Cherenkov telescopes in southern Arizona. It is sensitive to gamma rays at energies above 100GeV. Here, we discuss the results of observations of two well known VHE blazars, Markarian 421 and Markarian 501, during Spring 2006 which were made with the first two telescopes during the commissioning phase of VERITAS. During most of this time Mrk 421 was in an unusually active state while Mrk 501 was in a much lower flux state. As such, these observations provided an opportunity to test the sensitivity of the instrument to strong and weak sources. We discuss implications of these observations on our understanding of these objects.

Introduction

The blazars Mrk 421 and Mrk 501 were the first extragalactic sources from which very high energy (VHE; $E > 200\text{GeV}$) gamma-ray emission was definitively observed, when they were detected with the Whipple 10m telescope over a decade ago [1, 2]. They undergo periods of "flaring", characterized by rapid changes in the flux of VHE gamma rays [3], often correlated with an increased flux at hard X-ray energies [4]. During flaring episodes the flux from these objects has been observed to increase by over a factor of ten, making them the brightest sources in the sky in the VHE regime. Flux doubling time scales as short as a few minutes and changes in the shape of the spectrum of VHE gamma rays have also been observed [3, 5]. During the long quiescent periods between flares, often lasting many months, the flux from Mrk 501 was too low to be detected by the previous generation of VHE instruments, such as the Whipple 10m and HEGRA array [6, 7].

Blazars are understood to be members of the broader class of Active Galactic Nuclei (AGN), galaxies in which broadband emission from the central core region dominates the combined luminosity of the billions of stars. Emission from the

core of AGN is thought to be powered by accretion onto a supermassive black hole ($\sim 10^8 M_\odot$). VHE gamma rays seem to be associated with a jet of high-energy particles accelerated close to the black hole, which emanates from the core in a direction perpendicular to plane of accretion. Jets have been observed from many AGN at radio wavelengths. In blazars, the high-energy particles in the jet are thought to be moving directly along our line-of-sight to the AGN, and hence the jet cannot be resolved directly. The VHE gamma rays associated with the flaring are usually explained as arising through inverse-Compton scattering of low-energy photons by relativistic electrons in the jet. These photons could come from the environment external to the jet or through processes in the jet itself, such as synchrotron emission. The role of protons, which must be present in the jet at some level, is unclear. The fast acceleration and cooling times associated with the flaring is indicative of electrons, the slower timescales associated with protons may mean that VHE gamma-ray emission through hadronic processes contributes to the more steady, baseline emission from blazars. Measuring the emission from blazars in all flux states is important to understand the details of relativistic particle populations in the jet.

The VERITAS gamma-ray observatory, an array of four 12m atmospheric Cherenkov imaging telescopes in southern Arizona, U.S.A. [8, 9], represents a significant increase in sensitivity over the previous generation of instruments operating in the VHE regime. This sensitivity is achieved through two primary innovations: large telescopes to collect Cherenkov photons from distant air showers, and stereoscope imaging, in which the development of air showers in the atmosphere is measured from multiple locations on the ground, allowing the properties of the primary, its species, direction, impact point and energy, to be determined. The VERITAS telescopes are separated by approximately 85-100m on the ground, optimized to give good response in the 100-200 GeV energy range. Each camera consists of 499 photo-multiplier tubes and a flash-ADC-based data acquisition system, through which the shower development is digitized with a resolution of 0.15° in the angular domain and 2 ns in the time domain. Readout is initiated by a three level trigger system, which detects potentially interesting signals in individual channels (level 1, or L1), in individual telescopes (L2) or in the full array (L3). Only when two telescopes detect a coincident signal in at least three neighboring camera pixels does the system record an image. These images are stored to disk, along with house-keeping information, including telescope pointing information, rates of triggering of each channel and each telescope, sky temperature, and so on. The events are processed off line using multiple independent analysis packages, see [10] for example. These analyses yield consistent results.

Observations of AGN, to measure the properties of the populations of relativistic particles and to reveal the nature of the mechanism responsible for their acceleration, is one of the primary scientific goals of VERITAS. This paper presents the results from the first observations of AGN with VERITAS.

Observations

Mrk 421 and Mrk 501 were observed as part of the process of commissioning VERITAS. The second telescope and the array trigger, which allows the telescopes to operate together, were installed during Spring 2006. A total of ~ 17 hours of ob-

servations were made of Mrk 421 in April 2006, and ~ 18.5 hours of Mrk 501 between April and June. Initially all data were taken in “pairs” mode, in which each half hour observation is matched with a dedicated “off source” observation which is used for the purposes of background estimation. Although this mode represents an inefficient use of the telescope time, the independent background estimate is useful for understanding the performance of the newly constructed instrument. During the spring of 2006, VERITAS transitioned to making almost all observations in “wobble” mode, in which the putative source is always in the field of view of the instrument, offset from the center, so as to allow a simultaneous measurement of the background. Table 1 gives the details of the VERITAS observations of the two blazars.

Results

During the period of the observations, Mrk 421 was in a particularly active state and was consistently detected by VERITAS and, at lower significance, by the Whipple 10m instrument. Figure 1 (left) shows the density of gamma-ray-like events from the 4.5 hours of Mrk 421 “pairs” observations (and for the dedicated background observation), as a function of θ^2 , the squared distance between the target and the reconstructed gamma ray. The clear excess at small values of θ^2 is consistent with emission from Mrk 421 at the 35σ level, with a rate of 5.6 gamma rays/minute after the data selection criteria are applied. Numerous analyses by various groups within the VERITAS collaboration give similar results using different analysis codes and reconstruction methodologies.

The results of the 12.5 hours of wobble mode observations of Mrk 501 are shown in figure 2. In this mode the signal and background are estimated from the same data set. The ‘ON’ curve shows the θ^2 parameter for each event measured from the target position. The ‘OFF’ curve shows the same parameter from three different background positions in the sky (summed into one histogram and divided by three). Therefore each event appears in the plot four times. However, by construction, events can appear only one time in the region $\theta^2 < 0.035$, from which the signal

Table 1: Details of observation presented in this paper. Earlier observations, from April, were made in a mixture of Pairs and Tracking modes. Later observations were largely in Wobble mode.

Target	Period	Pairs [hr]	Wobble [hrs]	Tracking [hrs]
Mrk 421	04/06	4.5	5.0	7.5
Mrk 501	04/06 – 06/06	1.5	12.5	4.5

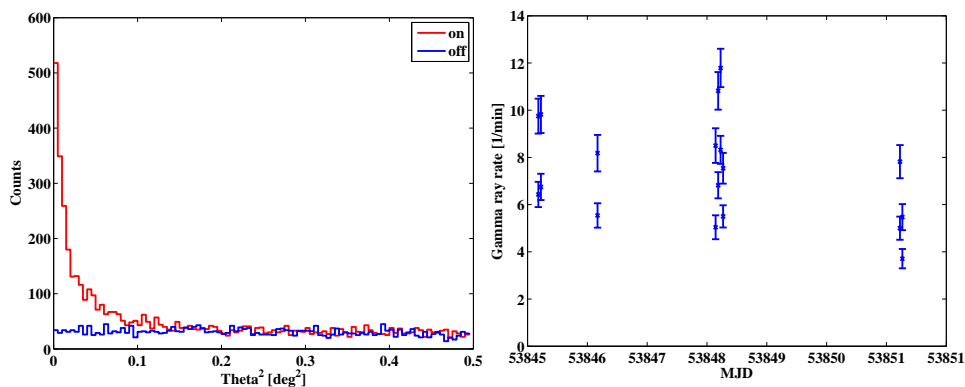


Figure 1: Left: number of gamma-ray-like events as a function of squared angular distance between the reconstructed gamma-ray origin and the target, Mrk 421 (curve marked as “ON”). Also shown is the number from the background observation, in the absence of a source (marked as “OFF”). Right: rate of gamma rays detected from Mrk 421 with VERITAS during April 2006.

and background are estimated. The results indicate a 16σ detection, with a mean rate of 0.8 gamma rays/min.

During the period of the Mrk 501 observations it exhibited in a considerably lower flux state than Mrk 421, but gave a consistently positive signal for VERITAS. The Whipple 10m instrument observed the source simultaneously but lacked the sensitivity to consistently detect it. In addition the All Sky Monitor (ASM), a wide-field 2–10 keV X-ray instrument on the Rossi X-Ray Timing Explorer (RXTE) was unable to detect emission from Mrk 501 during most of this period, figure 3 (right).

Conclusions

We have presented the results of observations of Mrk 421 and Mrk 501 taken with the first two telescopes of VERITAS. During this period Mrk 421

was in an active phase, and clearly detectable by VERITAS. Mrk 501 was detectable at a lower flux level. Although it is premature to claim that the VERITAS observations during spring 2006 represent a detection of the baseline emission from Mrk 501, they serve as an indication of the role that this sensitive gamma-ray instrument will play in advancing our understanding of the emission processes in blazars.

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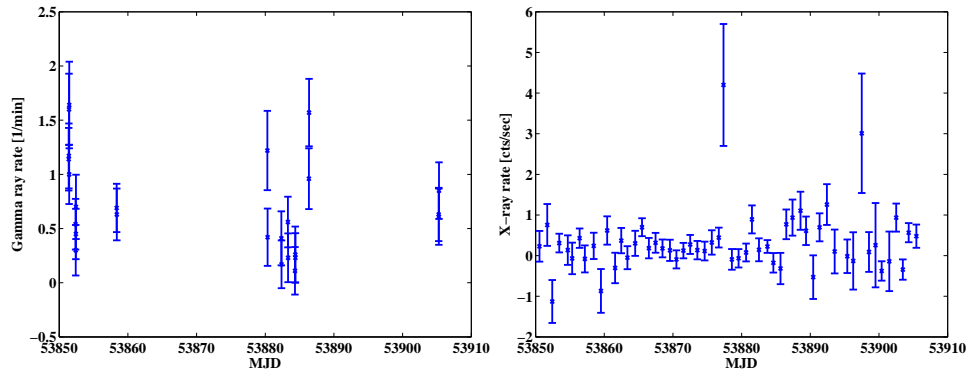


Figure 3: Left: rate of gamma rays detected from Mrk 501 with VERITAS. Right: rate of X-rays detected by ASM on RXTE over the same period

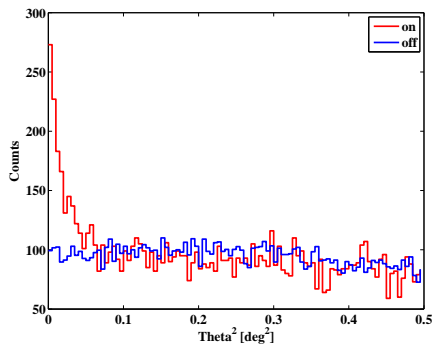


Figure 2: Number of gamma-ray like events for 12.5 hours of Mrk 501 “wobble” observations. A clear excess can be seen, consistent with gamma-ray emission from Mrk 501.

References

- [1] M. Punch, et al., Detection of TeV photons from the active galaxy Markarian 421, *Nature* 358 (1992) 477.
- [2] J. Quinn, et al., Detection of Gamma Rays with $E > 300$ GeV from Markarian 501, *Astrophysical Journal* 456 (1996) L83.
- [3] J. A. Gaidos, et al., Very Rapid and Energetic Bursts of TeV Photons from the Active Galaxy Markarian 421., *Nature* 383 (1996) 319.
- [4] L. Maraschi, et al., Correlated variability of MKN 421 at X-ray and TeV wavelengths on

time scales of hours, *Astroparticle Physics* 11 (1999) 189–192.

- [5] F. Krennrich, et al., Discovery of Spectral Variability of Markarian 421 at TeV Energies, *Astrophysical Journal* 575 (2002) L9–L13.
- [6] F. M. Cawley, et al., The Whipple Observatory High Resolution Camera, *Proceedings of the 21st International Cosmic Ray Conference. Volume 4 (OG Sessions)*, p.224 4 (1990) 224.
- [7] F. Aharonian, et al., The HEGRA Experiment - Status and Recent Results, in: *Proc. 15th European Cosmic Ray Symposium, Vol. 60B of Nuclear Physics Proceedings Supplement*, 1996, pp. 193–198.
- [8] T. C. Weekes, et al., VERITAS: the Very Energetic Radiation Imaging Telescope Array System, *Astroparticle Physics* 17 (2002) 221–243.
- [9] G. Maier, et al., VERITAS: Status and Latest Results, in: *Proc. 29th International Cosmic Ray Conference, Vol. OG2.7*, 2007.
- [10] M. Daniel, et al., The VERITAS Standard Data Analysis, in: *Proc. 29th International Cosmic Ray Conference, Vol. OG2.7*, 2007.