Multi-wavelength Observations of Markarian 501

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Simultaneous, multi-wavelength observations of Markarian 501 in the quiescent-state are compared to data from an historically extreme outburst.

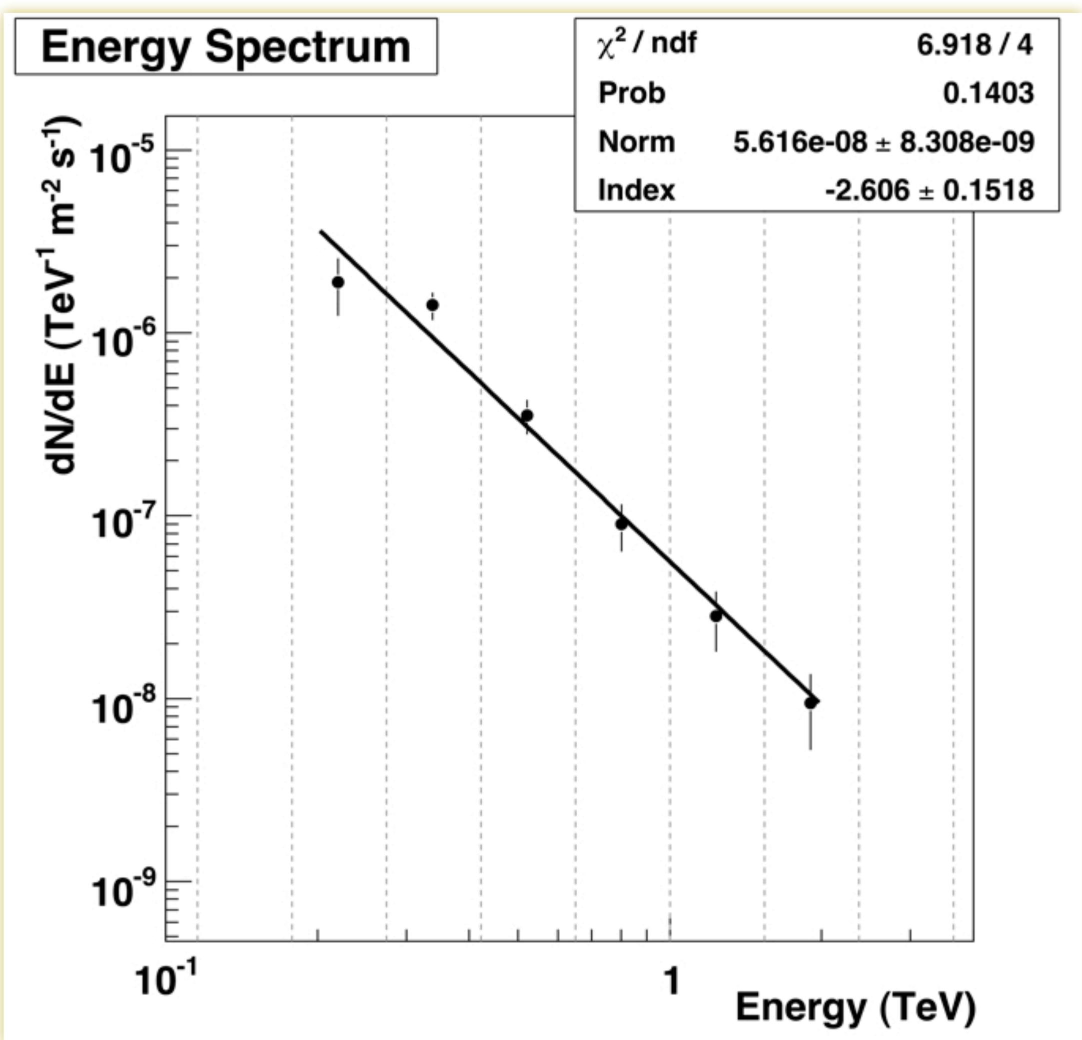
Abstract

The very high energy (VHE; E > 100 GeV) blazar Markarian 501 has a history of extreme spectral variability and is an excellent laboratory for studying the physical processes within the jets of active galactic nuclei. A short term multi-wavelength study of Markarian 501 was coordinated in March 2009 using the Suzaku X-ray satellite as well as the VERITAS and MAGIC experiments (VHE gamma rays). The results of these simultaneous, quiescent-state observations are combined with public data from the Fermi Gamma-ray Space Telescope and compared to historical observations of the source during an extreme outburst, with the goal of examining the spectral variability, particularly how the spectral energy distribution varies with flux. Studies of the broad-band spectral energy distribution and light curves will be presented.

Data Set

Markarian 501 was observed by Suzaku from 2009-03-23 UT 18:26 to 2009-03-25 UT 07:59. VERITAS provided simultaneous coverage for several hours on 2009-03-24. In addition, public data from the Fermi Gamma-ray Space Telescope was used to include a contemporaneous data point in the broadband SED. The Fermi point includes data from March and April 2009 to increase the significance of the spectral point. The combined data provide excellent coverage of the quiescent state of this extreme VHE blazar, and were compared to archival data from a flare observed in April 1997.

For a broader view of VERITAS data on Markarian 501 from the 2009 season, see poster by A. Konopelko.



Preliminary VHE γ-ray energy spectrum from VERITAS.

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The Observatories

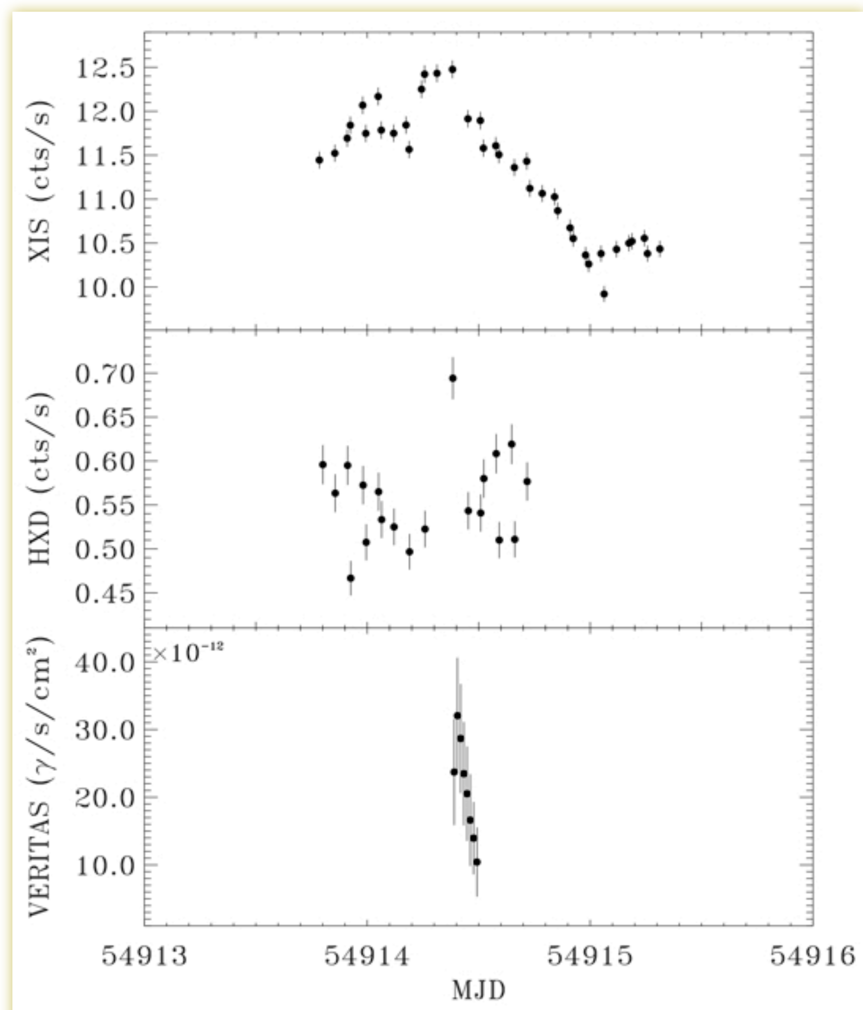
γ-ray

VERITAS, an array of 4 imaging atmospheric Cherenkov telescopes (IACT)s, provided observations at VHE γ-ray energies. The IACTs detect Cherenkov radiation produced by particle showers caused by gamma rays interacting with the Earth's atmosphere. MAGIC also participated in the campaign on Markarian 501, and these data will be included in future work.

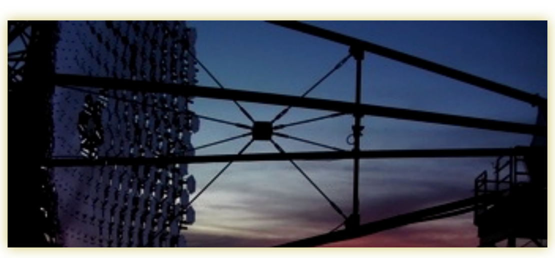
Fermi provides unprecedented sensitivity at energies ranging from 8 keV to 300 GeV and contributed significantly to this study by placing a new constraint on the SED model, where previously EGRET could only place an upper limit.

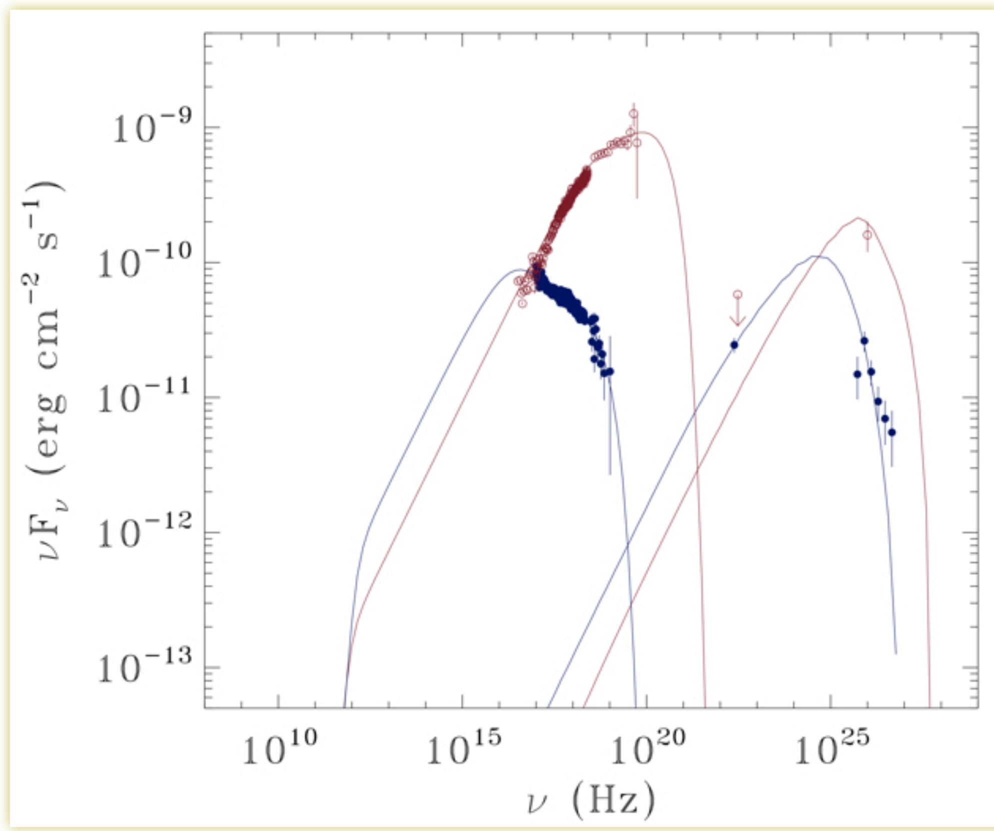
X-ray

Suzaku, formerly Astro-EII, covers the energy range 0.2 - 600 keV by utilizing two instruments: the X-ray imaging spectrometer (XIS; 0.2 - 12.0 keV) which uses X-ray CCDs and the hard X-ray detector (HXD; 10 - 600 keV). This broad energy range enables better constraints to be placed on the SED's synchrotron peak and matches well to the energy range of the archival Bepposax data.



Preliminary Multi-wavelength Light Curve. Moderate variation is observed at all energies. HXD and XIS in units of (cts/s). VERITAS in units of γ/s/cm^2 (above 300 GeV)





Broadband SED and preliminary model fit. Archival data from Bepposax, EGRET and Whipple of the April 1997 massive flare shown in red. 2009 quiescent state data shown in blue. Note the increase in flux of at least an order of magnitude at X-ray and VHE γ-ray energies. *Bepposax data courtesy Elena Pian; Pian et al., ApJ 492, L17, 1998. Whipple and EGRET data from Catanese et al., ApJ 487,L143, 1997*

SED Modeling

The model used is a simple Synchrotron Self-Compton code written by H. Krawczynski[3]. Here it assumes a spherical blob of radius 1 x 10^{15} cm, filled with a homogenous non-thermal electron population and uniform magnetic field. The population, with γ_{min} = 1, is described by a broken power law.

From the data alone, the synchrotron emission must peak above 5.49E+19 Hz during the flaring state and below 9.90E+16 Hz during the quiescent state. The SED model implies that the difference must be even greater.

[3]http://jelley.wustl.edu/multiwave/spectrum/?code

Model Component	1997 Model	2009 Model
Doppler Factor	15	15
Magnetic Field (G)	0.6	0.95
γ_{max}	3.00E+06	3.50E+05
γ_{break}	3.00E+05	2.00E+04
Index 1 (γ_{min} - γ_{break})	1.9	1.9
Index 2 (γ_{break} - γ_{max})	2.6	3.4
normalization	0.8	0.8

Summary

- This data set provides the highest quality sampling of Markarian 501's quiescent state SED and allows detailed comparison with the flaring state.
- The synchrotron peak of the SED shifts by at least 3 orders of magnitude in frequency between the flaring and quiescent states.
- The preliminary SSC model appears to indicate that during the flaring state electrons are accelerated up to energies an order of magnitude higher than those in the quiescent state.
- The predominant change in the SED model is the spectrum of the electron population. However, this is match is not unique due to the number of free parameters.