PROCEEDINGS OF SCIENCE

The AGN Monitoring Program at the Whipple 10m Gamma-Ray Observatory

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Since September 2005, the Whipple 10 m Gamma-ray Telescope has been used primarily to monitor known TeV AGN. The five Northern Hemisphere blazars that have been previously detected at Whipple, (Markarian 421, H1426+428, Markarian 501, 1ES 1959+650 and 1ES 2344+514) are monitored each night that they are visible. A number of multiwavelength observing campaigns have been undertaken by many collaborators in conjunction with the Whipple program and a significant amount of data has been accumulated. We report here on the status of these multiwavelength observations and present light curves of radio, optical, X-ray and gamma-ray data.

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1. Introduction

Gamma-ray emission from the blazar class of Active Galactic Nuclei (AGN) has been detected in the TeV energy band since 1992 with the observation of gamma rays from Mrk 421 by the Whipple 10 m Gamma-ray Telescope [1]. Subsequently, Whipple detected four other blazars within its sensitivity limits (Markarian 501, H1426+428, 1ES 1959+650, 1ES 2344+514). Blazars are characterized by broadband emission from radio to gamma-rays that shows a double-peaked structure in a νF_ν representation of the Spectral Energy Distribution (SED). The emission varies on timescales from minutes to years across all wavebands, where the peak frequency and amplitude change with the activity level of the blazar. Although many models have been developed (e.g. [2], [3]) to explain the major variability characteristics of blazar emission, there continues to be debate over the details, in particular on the mechanisms responsible for the higher-energy peak of the SED. The lower-energy peak is consistent with a population of energetic electrons in a magnetic field emitting synchroton radiation. To explain the higher-energy peak, the most successful models invoke inverse-Compton up-scattering of either the synchrotron photons themselves or ambient photons from the black-hole accretion disk, or the broad-line emitting regions. Models involving gamma-ray emission of hadronic origin can also not be ruled out. Through multi-band correlation studies over timescales on the order of a year, the broadband variability can provide critical discriminants that may be used to differentiate between emission models. In particular, measurements of the temporal correlation between flux variations at different wavelengths during flares provides simultaneous constraints on the emission models over different energy regimes.

For robust correlation analyses, it is essential to have well-sampled light curves over time periods that are long compared to flaring times. However, it is notoriously difficult to organize comprehensive long-term blazar monitoring campaigns over multiple wavelengths. In particular, gamma-ray telescopes have been a limiting factor, in that the long exposure times required for discovery agendas are incompatible with allocating telescope time for long-term monitoring of any one given source. The VERITAS Collaboration, operating both the Whipple 10 m telescope and the VERITAS array of new generation ultrasensitive gamma ray telescopes [4], is now uniquely positioned to take advantage of the Whipple telescope as a long-term monitoring telescope in the gamma-ray band.

1.1 The Whipple 10 m Gamma-ray Telescope

The Whipple 10 m telescope [5] is situated at the Fred Lawrence Whipple Observatory on Mount Hopkins, Arizona (altitude: 2,300 m a.s.l.). It has been operated as an imaging atmospheric Cherenkov telescope since the mid 1980s and was used to make the discoveries of the first galactic [6] and extra-galactic [1] sources of TeV gamma rays. To date, it has detected nine gamma-ray sources and it remains among the top five most sensitive telescopes for gamma-ray astronomy above $\sim$400 GeV.

Imaging Atmospheric Cherenkov Telescopes (IACTs) such as Whipple utilize the Cherenkov light emitted from gamma-ray initiated air showers to form an image on the camera-plane of the longitudinal development of the air shower (Figure 1). The spatial, temporal, and calorimetric information of the originating high-energy photon is then recorded electronically. The imaging technique can reject 99% of the cosmic-ray background while retaining $\sim$50% of the gamma-ray

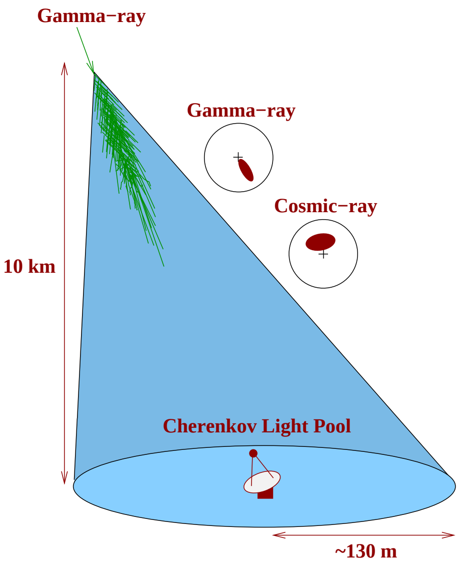

Figure 1: The Imaging Atmospheric Cherenkov Technique. Gamma-ray and cosmic-ray induced air showers are imaged through the atmospheric Cherenkov light they produce. Differences in the shape and orientation of their focused images allows for rejection of background cosmic rays. As shown, gamma ray images are typically elliptical in shape and point to their origin in the field-of-view; cosmic ray images are typically more irregular and randomly oriented.

signal by using the different physical characteristics in the development of gamma-ray and hadron-initiated showers as manifested on the image plane. Calorimetric information is provided by the intensity of the Cherenkov light observed, allowing for spectral studies of the emitting gamma-ray source.

2. Multiwavelength Program Overview

Since September 2005, the Whipple 10 m telescope has been dedicated to AGN monitoring and GRB follow-up observations. The five northern hemisphere blazars that were previously detected by Whipple (Mrk 421, H1426+428, Mrk 501, 1ES 1959+650, 1ES 2344+514) have been observed each night that they were visible (typically above 45°minimum elevation on cloudless, moonless nights). Throughout this period, the VERITAS collaboration continuously recruited participation in these long-term monitoring campaigns by a large number of other telescopes at various wavelengths. Through these efforts an extensive multiwavelength data set is being accumulated with arguably the best gamma-ray coverage to date. In addition to providing the long-term baseline gamma-ray light curve needed for robust correlation analyses, the Whipple 10 m also acts as a trigger for VERITAS observations when any of the five blazars flare. This allows the VERITAS Collaboration to combine data with the greater time-resolution of VERITAS instruments obtained during flaring phases with the Whipple long baseline data.

The list of multiwavelength partners committed to observing or sharing data with VERITAS during any portion of the AGN monitoring campaigns is shown in Table 1. In addition, notices of campaigns are sent to the members of the American Association of Variable Star Observers (AAVSO) [7] and the Whole Earth Blazar Telescope (WEBT) [8]. Campaign managers are identified for each observing season (fall through spring of a given year) and data are obtained through individual contacts from each participating group. Because of the large number of contributions from optical telescopes, particular care is taken to vet and regularize the optical data through a rigorous process as described in [9].

Observatory	Location	Waveband	Data Contact
Whipple	Mt Hopkins, Arizona	> 400 GeV	VERITAS Collaboration
VERITAS	Mt Hopkins, Arizona	>100 GeV	VERITAS Collaboration
Swift-XRT	NASA Satellite	0.2-10 KeV	Falcone
RXTE ASM	NASA Satellite	2-10 KeV	Horan
RXTE PCA	NASA Satellite	3-25 KeV	Grube
Swift-BAT	NASA Satellite	15-100 KeV	Krimm
Abastumani 0.7m	Mt. Kanobil, Georgia	R optical	Kurtanidze
Antipodal	Arizona and India	V optical	Buckley
Bell 0.6m	Kentucky	R optical	Carini
Boltwood	Ontario, Canada	R optical	Boltwood
Bordeaux	France	V optical	Charlot
Bradford 0.36 m	Mt. Teide, Tenerife	R, V, B optical	Sadun
Coyote Hill Obs.	Wilton, CA	R optical	Pullen
MDM 1.3m	Kitt Peak, Arizona	R optical	Boettcher
SAO 48-inch	Mt Hopkins, Arizona	V, B, R optical	Weekes
Swift-UVOT	NASA Satellite	UVW2&1, UVM2, U, B, V optical	Falcone
Tenagra 0.8 m	Arizona	R, V, B optical	Sadun
Tuorla 1.03 m	Tuorla, Finland	R optical	Sillanpaa
AIT 0.4 m	Perugia, Italy	R optical	Tosti
Torino 1.05m	Torino, Italy	R optical	Villata
WIYN 0.9m	Kitt Peak, Arizona	R, V, B optical	Montaruli
PAIRITEL	Mt Hopkins, Arizona	H, J, K Infrared	Bloom
Metsahovi	Finland	37 GHz	Lahteenmaki
RATAN	Russia	0.99-21.7 GHz	Kovalev
UMRAO	Michigan	4.8 GHz, 8 GHz, 14.5 GHz	Aller

Table 1: List of the partners participating in multiwavelength monitoring campaigns in any portion of the years 2005-2008.

Name	R.A.	Dec.	z	Exposure 2005-2006 (hrs)	Exposure 2006-2007 (hrs)
Markarian 421	11 04 27.3	38 12 32	0.031	168	86
H 1426+428	14 28 32.7	42 40 20	0.129	60	83
Markarian 501	16 53 52.2	39 45 36	0.033	31	69
1ES 1959+650	19 59 59.9	65 08 55	0.048	110	37
1ES 2344+514	23 47 04.8	51 42 18	0.044	55	67

Table 2: The 5 blazars observed in the Blazar Monitoring Program, their coordinates, redshifts and observing exposures with the 10 m telescope since September 2005. The 2007-2008 observing campaign is ongoing at this time.

3. Results

3.1 Markarian 501, H 1426+428, 1ES 2344+514 and 1ES1959+650

Gamma-ray excesses, at the 5σ and 7σ significance levels were detected from Markarian 501 during the 2005-2006 and 2006-2007 observing seasons respectively. The RXTE ASM X-ray [10] and Whipple gamma-ray light curves for Markarian 501 during 2005-2008 are shown in Figure 2 below. None of the remaining blazars, H 1426+428, 1ES 2344+514 and 1ES1959+650, exhibited bright outbursts of gamma-ray emission during the 2005-2007 observing seasons. Analysis of these data is ongoing and the 2007-2008 observing campaign has recently finished.

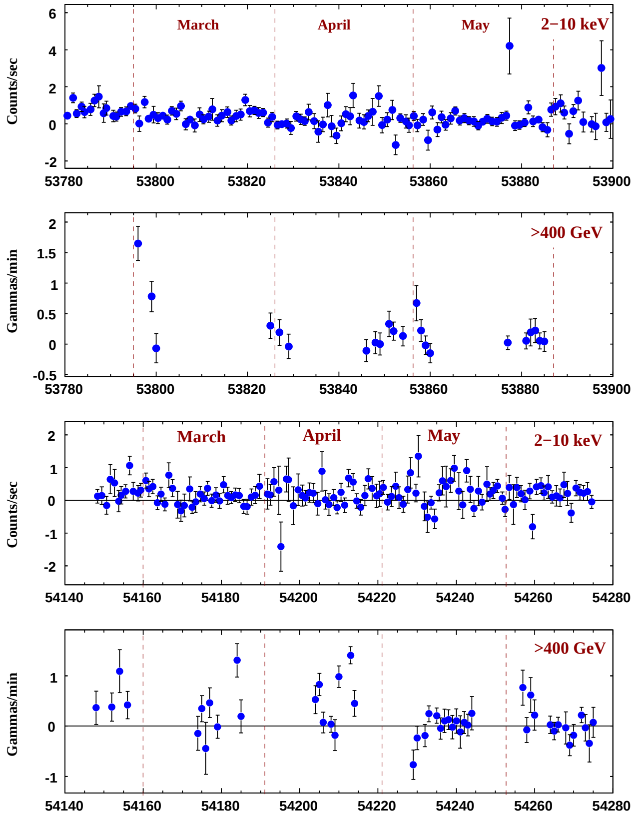

Figure 2: ASM X-ray and Whipple gamma-ray lightcurves for Markarian 501 during 2006 (top two panels) and 2007 (bottom two panels). The x-axes are in MJD. The Whipple data are for observing elevations >60°. The 2008 observing campaign began in March 2008.

3.2 Markarian 421 (2005-2006)

The Markarian 421 nightly-averaged lightcurves, obtained in all observed wave bands during the 2005-2006 observing season are shown in Figure 3. Significant variability was detected from Markarian 421 across all wavelengths. At TeV energies, it was detected both by the Whipple 10 m telescope and by the VERITAS array. A total of 168 hours of data were obtained using the 10 m telescope. The Alpha plot for all high-elevation data recorded using the 10 m telescope is shown in Figure 5. A spectral energy distribution (SED) analysis of these data is complete, with the data divided into three subsets, low, medium and high states, for the analysis. A paper detailing the analysis and results has been submitted to the Astrophysical Journal [7].

3.3 Markarian 421 (2006-2008)

Strong outbursts of gamma-ray emission were observed from Markarian 421 during the 2006-2007 and 2007-2008 observing seasons. The ASM and Whipple 10 m lightcurves are presented in Figure 4. Final analysis of the lightcurves accumulated at lower energies is in progress. Markarian 421 was also observed by VERITAS during early 2008. Results of the VERITAS observations are presented in this volume by Benbow et al.

4. Conclusion

The first 2.5 years of the blazar monitoring program with the Whipple 10 m telescope have been very successful. A large number of observatories participated in the program, providing good coverage over a wide range of energies. Significant variability was detected from Markarian 421 at all wavelengths. Final analysis of the 2005-2006 data, including spectral energy distributions at different flux levels and correlation analyses are reported in [9]. A second paper reporting the flaring activity of Markarian 501, and final results on the remaining sources, H 1426+428, 1ES 2344+514 and 1ES1959+650 is in preparation.

References

[1] Punch, M. et al. 1992, Nature, 358, 477

[2] Böttcher, M. 2007, Ap&SS, 309, 95

[3] Sambruna, R. M. 2007, Ap&SS, 311, 241

[4] Maier, G. et al. 2007, Proceedings of the 30 th ICRC, Merida

[5] Kildea, J. et al. 2007, Astroparticle Physics, 28, 182

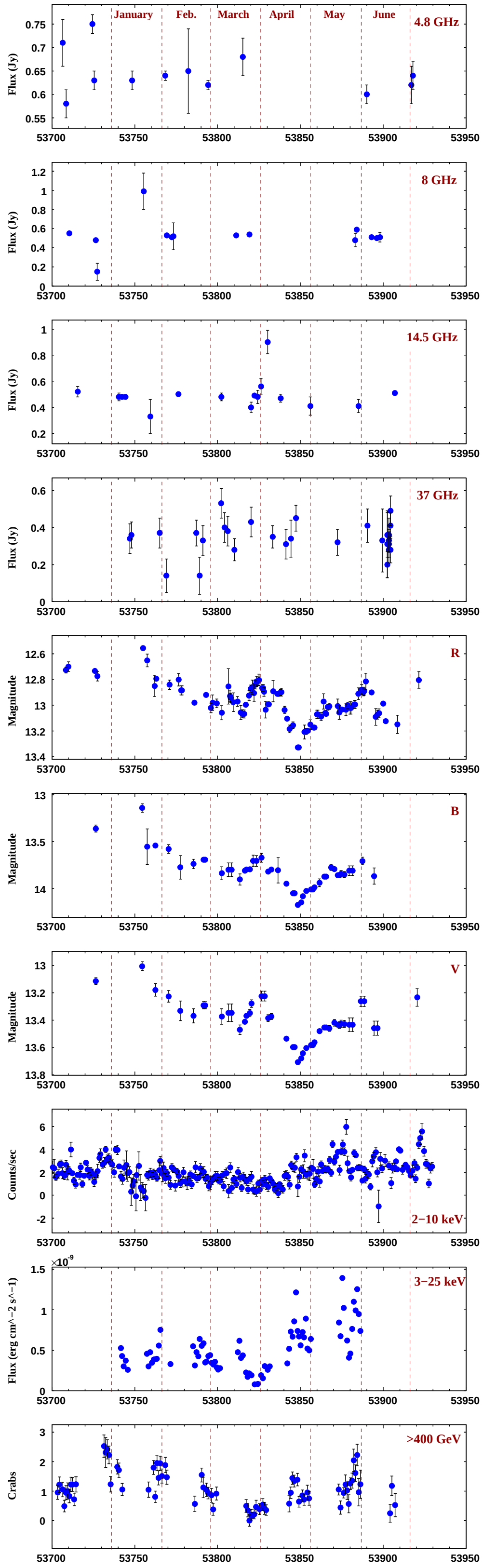

Figure 3: Multiwavelength lightcurves for Markarian 421 during 2005-2006. X-axes are in MJD.

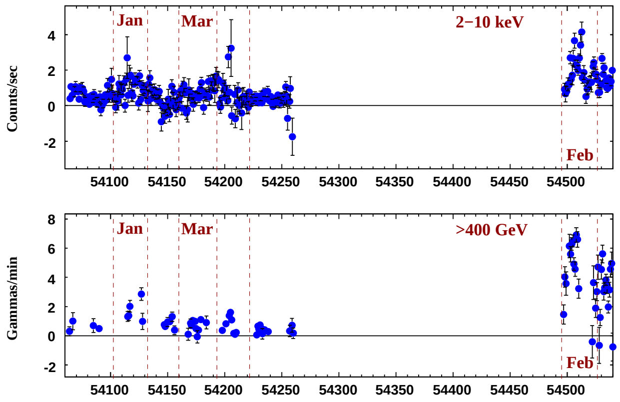

Figure 4: ASM X-ray and Whipple gamma-ray lightcurves for Markarian 421 during 2006-2007 and early 2008. The Whipple data have not been corrected for elevation dependence.

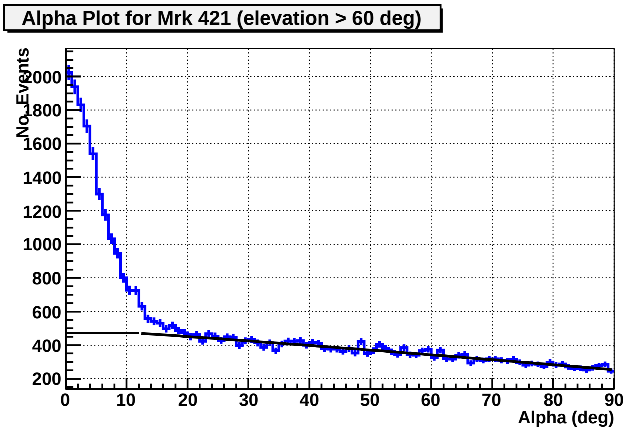

Figure 5: Alpha distribution for 98 hours of high elevation 2005-2006 Markarian 421 data, recorded with the Whipple 10 m telescope. The Alpha parameter is a measure of the angle the shower axis makes with the direction to the source location in the field of view. The distribution of Alpha is expected to peak at low values for a gamma-ray source. The significance of this Markarian 421 detection is ∼98σ.

[6] Weekes, T. C., et al. 1989, Astrophysical Journal, 342, 379

[7] AAVSO website: http://www.aavso.org/

[8] WEBT website: http://www.to.astro.it/blazars/webt/

[9] Horan, D. et al., 2008, submitted to ApJ in July 2008

[10] Swank, J. H. 1994, American Astronomical Society Meeting, 185, 6701