Blazar Monitoring with the Whipple 10 m Gamma-ray Telescope

JOHN KILDEA

Smithsonian Astrophysical Observatory, Arizona

on behalf of the Blazar Monitoring Program collaborators*

ABSTRACT

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.

To encourage and co-ordinate observations of these AGN at other wavelengths, the observing timetable and preliminary light curves for the TeV observations are provided on a publicly accessible website:
veritas.sao.arizona.edu/content/blogsection/6/40

A number of multiwavelength observing campaigns have been undertaken by numerous 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.

1 Introduction

1.1 The Whipple 10 m Gamma-ray Telescope

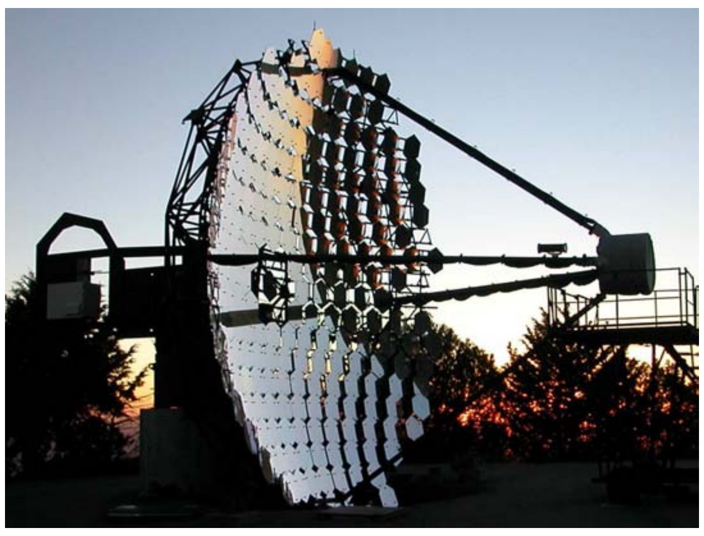

Figure 1: Photograph of the Whipple 10 m Gamma-ray Telescope on Mt Hopkins, Arizona. The telescope uses the Imaging Atmospheric Cherenkov Technique to detect gamma-rays.

The Whipple 10 m telescope [1] 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 discover the first Galactic [2] and extra-galactic [3] sources of TeV gamma rays. To date, it has detected nine gamma-ray sources and it remains a sensitive tool for ground-based gamma-ray astronomy above ~400 GeV.

The Whipple telescope is currently operated by the VERITAS collaboration, which operates the stereoscopic VERITAS array of telescopes [4], also situated at the Fred Lawrence Whipple Observatory.

1.2 The Imaging Atmospheric Cherenkov Technique

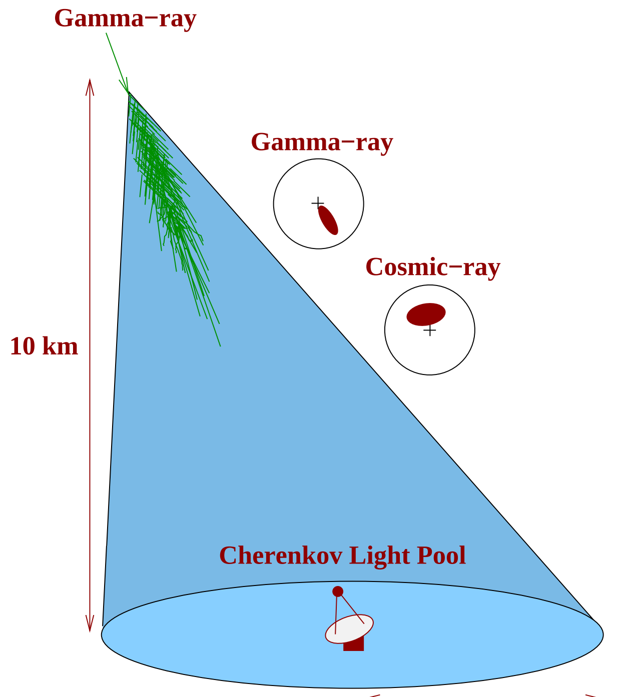

Figure 2: The Imaging Atmospheric Cherenkov Technique. Gamma-ray and cosmic-ray air showers are imaged through the atmospheric Cherenkov light they produce. Differences in the shape and orientation of their focused images allows for rejection of background cosmic rays. As shown, gamma rays are typically elliptical in shape and point to their origin in the field-of-view; cosmic rays are typically more irregular and randomly oriented.

Using an imaging atmospheric Cherenkov telescope, the Cherenkov light emitted from gamma-ray initiated air showers may be imaged to obtain spatial, temporal, and calorimetric information regarding the instigating high-energy photon. Image-based rejection of cosmic-ray background events is possible due to physical differences in the developments of gamma-ray and hadron showers that are manifested as differences in their focused Cherenkov images. Calorimetric information is provided by the intensity of the Cherenkov light observed, allowing for spectral studies of the emitting gamma-ray source.

* Blazar Monitoring Program Collaborators

VERITAS Collaborators: V. Acciari[a], J. Buckley[b], L. Ciupik[c], A. Falcone[d]L. Fortson[c], J. Grube[e], D. Horan[f], H. Krawczynski[b], M. Lang[g], V. Kuen Lee[b], P. Moriarty[a], A. Smith[d], D. Steele[c], J. Toner[g], T. C. Weekes[h]

External Collaborators: H. Aller[i], M. Aller[i], J. Bloom[j], M. Carini[k], Y. Konovalov[l], O. Kurtanidze[m], A. Lahteenmaki[n], T. Montaruli[o], A. Sadun[p], A. Sillanpaa[q], G. Tosti[r]

(a) Department of Physical and Life Sciences, Galway-Mayo Institute of Technology, Dublin Road, Galway, Ireland
(b) Department of Physics, Washington University, St. Louis, MO 63130, USA
(c) Astronomy Department, Adler Planetarium and Astronomy Museum, Chicago, IL 60605, USA
(d) Dept. of Astronomy & Astrophysics, Penn State University, 525 Davey Lab, University Park, PA 16802
(e) School of Physics and Astronomy, University of Leeds, Leeds, LS2 9JT, UK
(f) Argonne National Laboratory, 9700 S. Cass Avenue, Argonne, IL 60439, USA
(g) Physics Department, National University of Ireland, Galway, Ireland
(h) Fred Lawrence Whipple Observatory, Harvard-Smithsonian Center for Astrophysics, Amado, AZ 85645, USA
(i) Department of Astronomy, University of Michigan, Ann Arbor, MI, 48109-1042
(j) 601 Campbell Hall, University of California, Berkeley, Berkeley, CA 94720
(k) Dept. of Physics and Astronomy Western Kentucky University, 1906 College Heights Blvd #11077, Bowling Green, KY 42101-1077
(l) Radio Telescope RATAN-600, Special Astrophysical Observatory (SAO), Nizhnij Arkhyz, Zelenchukskaya, Karachaevo-Cherkesia, Russia, 369167
(m) Georgian Academy of Sciences, Tbilisi, Georgia
(n) Metsahovi Radio Observatory, Metsahovintie 114, FIN-02540 Kylmala, Finland
(o) University of Wisconsin - Madison, Dept. of Physics, 1150 University Avenue, Madison, WI, USA 53706
(p) University of Colorado at Denver, Campus Box 157, PO Box 173364, Denver, CO 80217-3364
(q) Tuorla Observatory, Vaisalantie 20, FI-21500 PIIKKIO, Finland
(r) Dept. of Physics & INFN Perugia, Italy

2 The Blazar Monitoring Program

2.1 Blazars

Blazars are a subclass of Active Galactic Nuclei (AGN), in which the viewing angle of the jet is very small ($\lesssim 10°$), such that the observer is looking straight down the jet, and the jet is the most obvious feature of the galaxy. The five blazars studied in the Whipple Blazar Monitoring Program are all in the subclass of blazars known as high frequency Bl Lac type objects.

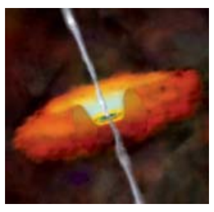

Figure 3: Artist's impression of an active galaxy nucleus, showing a supermassive black hole surrounded by an accretion disk of gas and dust. Jets of high energy charged particles accelerated away from the black hole give rise to the observed non-thermal radiation. AGN in which the jet is aligned with the line of sight of the observer are known as blazars. Image source: NASA/CXC/M.Weiss

Multiwavelength observations of gamma-ray emitting blazars are important in order to test models of non-thermal emission from these objects. Measurements of the temporal correlation between flux variations at different wavelengths during flares are particularly useful, simultaneously providing constraints on the emission models in various energy regimes.

2.2 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 have been observed whenever visible. Through the participation of a large number of other telescopes at various wavelengths, an extensive multiwavelength data set has been accumulated.

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

Table 1: The 5 blazars observed in the Blazar Monitoring Program, their coordinates, redshifts and observing exposures with the 10 m telescope during 2005-2006.

2.3 Program Participants

A total of 18 telescopes participated in the Blazar Monitoring Program. A breakdown of the telescopes, by wavelength, is provided below.

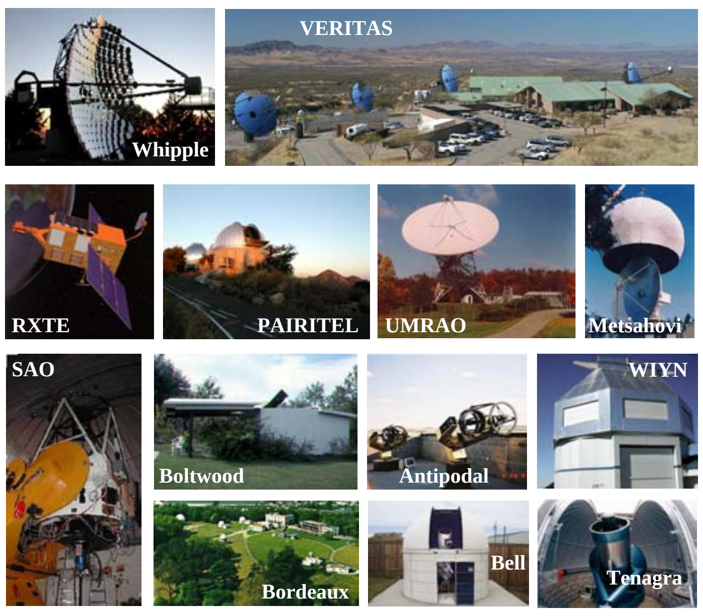

Figure 4: Some of the telescopes that participated in the Blazar Monitoring Program.

Gamma-ray

- Whipple 10 m telescope [> 400 GeV] and VERITAS [>100 GeV], Mt Hopkins, Arizona

X-ray

- RXTE (All Sky Monitor [2-10 keV] and Proportional Counter Array [3-25 keV])

Optical [R, B, V]

- SAO 48-inch, Mt Hopkins, Arizona
- Boltwood, Ontario, Canada (Boltwood)
- Antipodal, Arizona and India (Lee & Buckley)
- Bordeaux, France (Charlot)
- 0.6m Bell Observatory (Carini)
- Coyote Hill Observatory (Pullen)
- Sbadell (Ros)
- Tenagra 32-inch (Sadun)
- Tuorla, Finland (Sillanpaa)
- Perugia, Italy (Tosti)
- WIYN, Kitt Peak, Arizona (Steele/Fortson)

Infrared [H, J, K]

- PAIRITEL, Mt Hopkins, Arizona (Bloom)

Radio

- UMRAO, Michigan (Allers) [4.8 GHz, 8 GHz, 14.5 GHz]
- Metsahovi, Finland (Lahteenmaki) [37 GHz]
- RATAN, Russia (Konovalov) [0.99-21.7 GHz]

3 Results

3.1 Markarian 421 (Gamma-ray)

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.

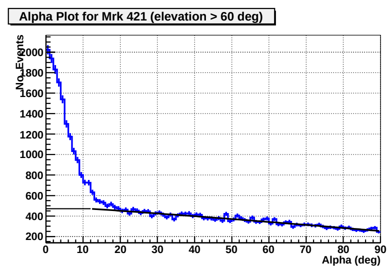

Figure 5: ALPHA distribution for 98 hours of high elevation 2005-2006 Markarian 421 data, recorded with the Whipple 10 m telescope. The ALPHA parameter is a measure of the angle the shower axis makes with the direction to the source location in the field of view. The distribution of ALPHA is expected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

References

[1] Kildea, J. et al. 2007, Astroparticle Physics, submitted
[2] Weekes, T. C., et al. 1989, Astrophysical Journal, 342, 379
[3] Punch, M. et al. 1992, Nature, 358, 477
[4] See VERITAS talk by D. Kieda, this conference

3.2 Markarian 421 (Multiwavelength)

The Markarian 421 nightly-averaged lightcurves, obtained in all observed wave bands during the 2005-2006 observing, season are shown in Figure 6. A spectral energy distribution (SED) analysis of these data is ongoing, with the data divided into three subsets, low, medium and high states, for the analysis. A paper detailing the analysis and results is in progress.

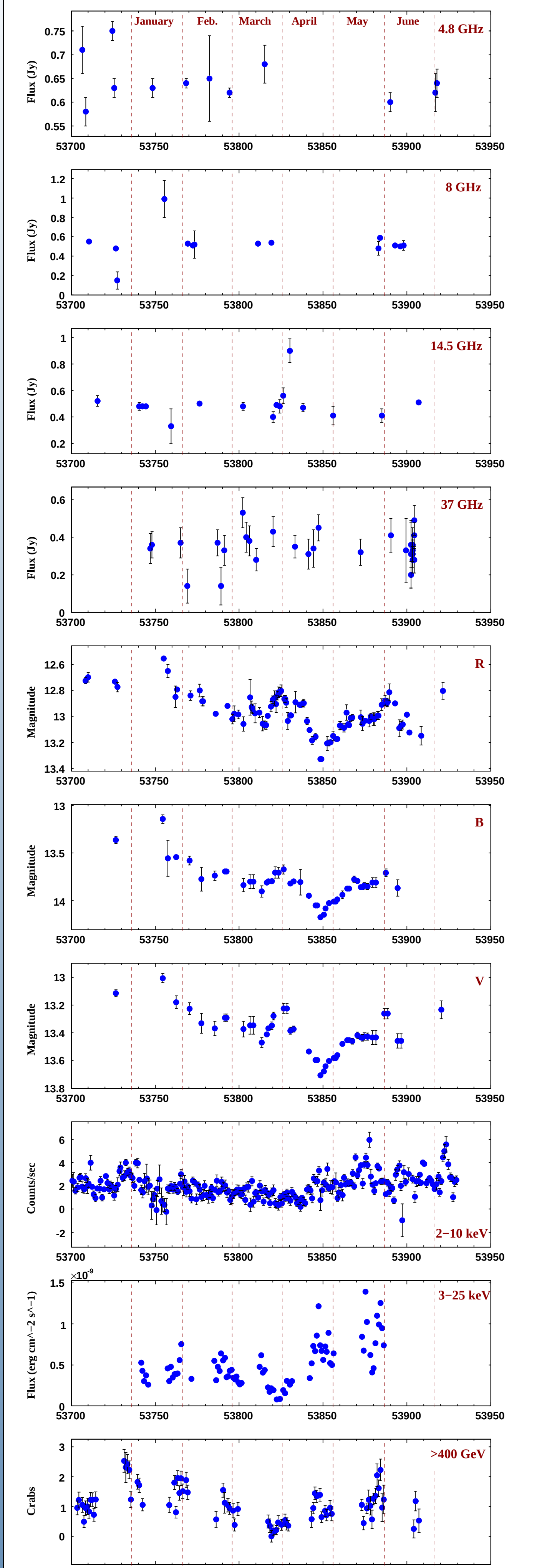

Figure 6: Multiwavelength lightcurves for Markarian 421 during 2005-2006.

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

A gamma-ray excess, at the 5σ significance level was detected from Markarian 501 during the 2005-2006 observing season. Most of this excess is attributed to a large flare at the beginning of March 2006. The ASM X-ray and Whipple gamma-ray lightcurves for Markarian 501 are shown in Figure 7 below.

None of the remaining blazars, H 1426+428, 1ES 2344+514 and 1ES1959+650, exhibited significant levels of gamma-ray emission within the sensitivity of the Whipple 10 m telescope during the 2005-2006 observing season. An analysis to produce upper limits from these data is ongoing.

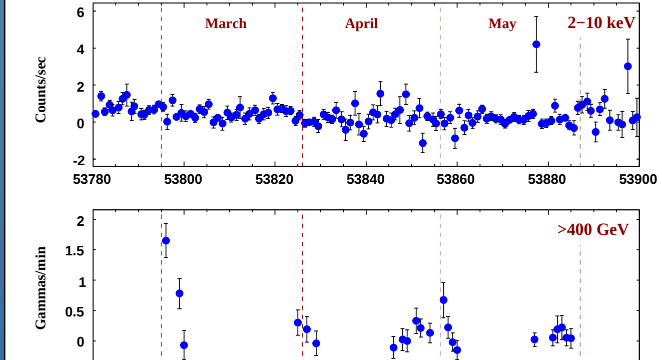

Figure 7: ASM X-ray and Whipple gamma-ray lightcurves for Markarian 501 during 2005-2006. The Whipple data are for observing elevations >60°.

4 Conclusion

The first year of the blazar monitoring program with the Whipple 10 m telescope was 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 these data, including spectral energy distributions at different flux levels, is in progress and will be reported in an upcoming paper. A second paper reporting the flaring activity of Markarian 501 during 2005-2006, and upper limits on the remaining sources, H 1426+428, 1ES 2344+514 and 1ES1959+650 is also in progress.

The second season of the blazar monitoring program is well underway. The sensitive VERITAS [4] array is now up and running at the Whipple Observatory and results from 10 m observations are being used to trigger VERITAS AGN observations.