

## Joint Multi-Wavelength Observations of Blazars with WIYN-VERITAS-IceCube

M. Bayer<sup>1</sup>, J. Dumm<sup>1</sup>, K. Larson<sup>2</sup>, T. Montaruli<sup>1,4</sup>, D. Steele<sup>3</sup>

<sup>1</sup> Department of Physics, University of Wisconsin, Madison, WI 53706, USA

<sup>2</sup> College of Wooster

<sup>3</sup> Adler Planetarium

<sup>4</sup> on leave University of Bari, Italy

Email: mbayer@icecube.wisc.edu, kl Larson@icecube.wisc.edu,  
jdumm@icecube.wisc.edu, tmontaruli@icecube.wisc.edu,  
dsteele@adlerplanetarium.org

**Abstract.** We describe the beginnings of a multi-wavelength analysis of TeV blazars using observations from the WIYN 0.9m optical telescope, the VERITAS gamma-ray telescope, and the AMANDA/IceCube neutrino detector. Optical data were taken for Mrk 421, Mrk 501, and 1ES 1959+650 in coincidence with gamma-ray observations over a two-month period in April–June 2006. In the future we hope to use a statistical analysis of TeV flares in order to determine the significance of time-correlated neutrino detection with AMANDA/IceCube.

### 1. Introduction

Observations of TeV blazars seem to be well explained by leptonic synchrotron inverse-Compton models, but there may be an hadronic mechanism involved as well. The detection of neutrinos from these sources would provide evidence for such a mechanism. Given the possible correlation between TeV photons and neutrinos from pion decays, neutrino discovery potential can be enhanced by looking for coincidences with TeV flares or by studying correlations with X-ray and gamma-ray behavior.

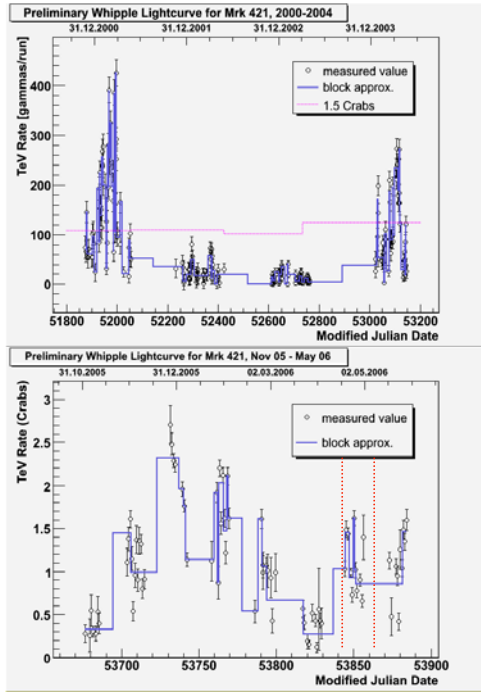
We aim at studying three blazars (Markarian 421, Markarian 501, and 1ES1959+650), collecting data from three experiments: the WIYN 0.9m optical telescope, the Whipple/VERITAS TeV gamma-ray observatory, and the AMANDA/IceCube neutrino detectors. Data from the VERITAS telescopes on high states and flux variability would allow us to determine the timing dependence for a possible neutrino signal, forming the basis of a blinded neutrino analysis. The optical data from the WIYN telescope would then help characterize the blazars' Spectral Energy Distribution (SED) outside of the TeV range. In this paper we show our first results concerning optical observations and Whipple data.

### 2. The VERITAS Whipple gamma-ray telescope

In hadronic blazar models, neutrino and gamma-ray emissions should be correlated, both coming from the decay of pions. If these models are correct, neutrino detection should be more likely during “flares”, periods of high gamma- and X-ray activity. We have used long-term Whipple data to analyze the frequency of flares and preliminary data to compare with our optical observations.

In order to characterize periods of flaring we used a modified version of a statistical method developed by Scargle that calculates likelihoods in order to divide a light curve into regions of

relatively constant flux [6]. The goal of the method, first applied to gamma-ray data by Flaccomio and E. Resconi, is to smooth out purely statistical fluctuations [7]. To obtain an estimate of flaring probability, we could then calculate the percentage of time the source spent above a threshold value, taken to be 1.5 Crabs. In the case of Mrk 421 we observed in the TeV data a variation of the flux up to 1.5 Crabs during the observation time of the WIYN experiment.



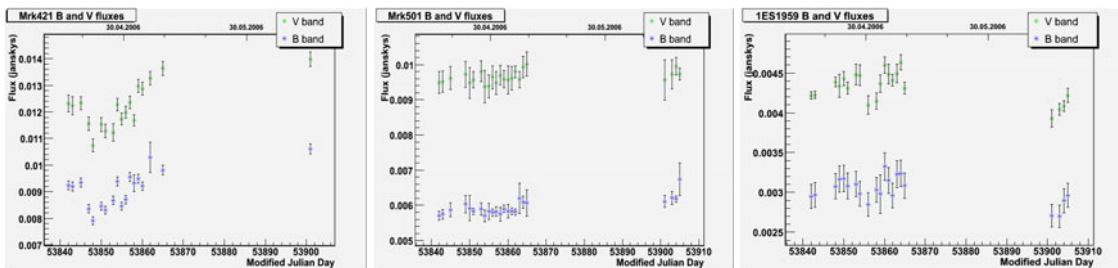
**Figure 1.** Four years of Whipple data on Mrk 421 with likelihood blocks overlaid. The data are daily averages in units of photons per run, which last about 28 minutes. The blue lower line following the data is from the block method. The pink upper line marks 1.5 crabs, which changes from year to year with telescope calibration.

**Figure 2.** Recent data from the Whipple webpage [9] converted to crabs and separated into blocks. The red dotted lines mark the period overlapping with WIYN observations. The borders of the blocks are arbitrarily set midway between adjacent data points, but large gaps in data were not counted in calculations of flaring frequency.

We calculated the flaring probability by tabulating both telescope runs and daily averages, obtaining values of 39% and 24%, respectively (see Fig. 1, 2). The discrepancy reflects problems with both methods. The telescope runs are biased towards periods of high flux—if the source was in a high state, Whipple took more data—while the daily averages ignore the real possibility of flares on shorter timescales. In either case the data suffer from gaps. Because of these concerns it may be better to use an instrument with more regular observations, such as an X-ray satellite.

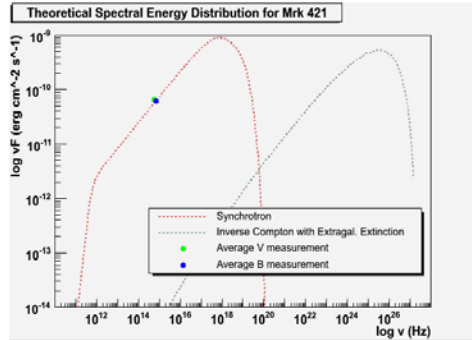
### 3. The WIYN 0.9m optical telescope

To help characterize blazar spectra outside the high energy bands, we requested observation time from the 0.9m WIYN telescope in coincidence with VERITAS observations. Time was allocated in the period between 18 Apr- 10 May and a few days in June 2006, before the telescope suffered a technical malfunction. We received images in the B and V optical bandpasses (corresponding to effective wavelengths of about 365 and 440 nm, respectively), then reduced and calibrated them using standard comparison stars [1] to obtain fluxes (see Fig. 3).

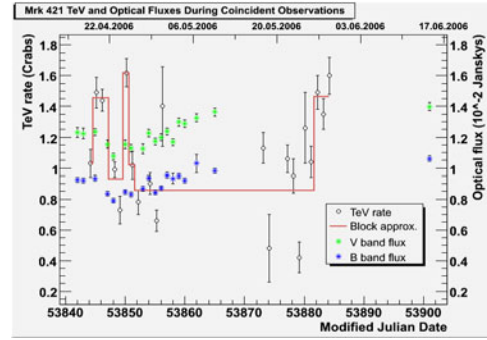


**Figure 3.** Flux plots for Mrk 421, Mrk 501, and 1ES1959+650. The flux is in units of Janskys, where 1 Jansky =  $10^{-23}$  erg s $^{-1}$  m $^{-2}$  Hz $^{-1}$ .

For comparison, in Figure 4 we have plotted the average optical flux values for Mrk 421 alongside the predictions of a leptonic Synchrotron Self-Compton model for blazar emission. Parameters for the Spectral Energy Distribution (SED) curve come from a previous analysis of gamma- and X-ray data [2] and the code to generate it comes from the VERITAS collaboration [8].



**Figure 4.** An SED plot for Mrk 421, with the WIYN optical data that we analyzed superimposed (data are not yet corrected for host galaxy light).



**Figure 5.** Preliminary Whipple data, likelihood blocks, and optical results for Mrk 421 in the period from 17 Apr – 15 June 2006. No correlation is observed.

#### 4. The IceCube / AMANDA neutrino telescope

Figure 5 shows the optical data for Mrk 421 superimposed on VERITAS data for the same period. No neutrino data are shown here in order to preserve the statistical purity of the sample until the analysis has been fully optimized. In past point-source searches, however, the AMANDA detector has been shown to have sensitivity to a neutrino flux comparable to the TeV flux of the blazar Mrk 501 in a high state [10]. If we focus on flaring periods defined by the gamma-ray or X-ray data, however, the significance of observing a neutrino event in that period increases compared to a generic point-source search. Alternatively, instead of confining a search to specific flares, we could take longer time periods and study the correlation between neutrino events and high-flux behavior in gamma rays. Both approaches hold promise for discovering or limiting a hadronic component to blazar radiation.

#### References

- [1] Villata M et al 1998 *Astron. Astrophys. Suppl. Ser.* **130** 305
- [2] Blazejowski et al 2005 *ApJ* **630** 130B
- [3] Krennrich F et al 2002 *ApJ* **575** L9
- [4] Grube et al 2005 *ICRC proceedings*
- [5] Rebillot et al 2006 *ApJ* **641** 740R
- [6] Scargle J D 1998 *ApJ* **504** 405
- [7] Resconi E 2006, *IceCube: Multiwavelength Search for Neutrinos from Transient Point Sources*, these Proceedings
- [8] Krawczynski H., available at [jelley.wustl.edu/multiwave/spectrum/](http://jelley.wustl.edu/multiwave/spectrum/)
- [9] Available at [veritas.sao.arizona.edu/VERITAS\\_whipple.html](http://veritas.sao.arizona.edu/VERITAS_whipple.html)
- [10] Ahrens J et al 2004 *Phys. Rev. Lett.* **92** 071102