# Observations of Markarian 421 with the WIYN .9m Telescope for a Multiwavelength Blazar Campaign and IceCube

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## Abstract

This is a report on the recent work of a long term multimessenger and multiwavelength campaign on blazars. We show how we have set up the tools to analyze the data of the WIYN 0.9m optical telescope during two periods in 2008-2009 and 2009-2010. We requested observation time for Markarian 421 and analyzed the image processing and extracted the magnitudes for 4 sources. We present the optical data we collected here as well as a preliminary correlation study. We are mostly interested in the variability in time of the optical emission in order to correlate to other wavelengths. The Whipple/VERITAS data for the same periods are shown as an example of correlation studies in the TeV band and in the optical. The data in various bands will be used to correlate variabilities with the IceCube neutrino data in order to look for possible correlations demonstrating the hadronic component in the emission from these sources.

## A Multiwavelength Campaign of Blazars

In 1992, Whipple discovered the first extragalactic source of TeV gamma-rays: Markarian 421. A multiwavelength campaign of Markarian 421 was launched in 2006. Below you can find the participating observatories, including our own WIYN.

| Waveband | Instrument | Energy Range (eV) |
|---|---|---|
| Radio | RATAN 1 GHz | 3.7 - 4.6 x $10^{-6}$ |
| | RATAN 2.3 GHz | 8.6 - 10.5 x $10^{-6}$ |
| | RATAN 4.8 GHz | 1.8 - 2.2 x $10^{-5}$ |
| | UMRAO 4.8 GHz | 1.8 - 2.2 x $10^{-5}$ |
| | RATAN 8 GHz | 3.0 - 3.6 x $10^{-5}$ |
| | UMRAO 8 GHz | 3.0 - 3.6 x $10^{-5}$ |
| | RATAN 11 GHz | 4.1 - 5.0 x $10^{-5}$ |
| | UMRAO 14.5 GHz | 5.2 - 6.8 x $10^{-5}$ |
| | VLBA 15 GHz | 5.6 - 6.8 x $10^{-5}$ |
| | RATAN 22 GHz | 8.2 - 10.0 x $10^{-5}$ |
| | Metsahovi 37 GHz | 1.5 - 1.6 x $10^{-4}$ |
| Optical | Abastumani | 1.7 - 2.3 |
| | Bell | 1.8 - 2.2 |
| | Bradford | 1.7 - 2.2 |
| | FLWO | 1.8 - 2.3 |
| | Tenagra | 1.7 - 2.2 |
| | Torini | 1.7 - 2.3 |
| | Bordeaux | 2.1 - 2.5 |
| | Bradford | 2.1 - 2.5 |
| | Tenagra | 2.1 - 2.5 |
| | WIYN* | 2.1 - 2.5 |
| | Bradford | 2.7 - 3.2 |
| | Tenagra | 2.6 - 3.2 |
| | WIYN* | 2.6 - 3.3 |
| X-ray | XRT | 0.2 - 10 x $10^{3}$ |
| | ASM | 2 - 10 x $10^{3}$ |
| | PCA | 3 - 25 x $10^{3}$ |
| | BAT | 15 - 50 x $10^{3}$ |
| Gamma-ray | Whipple | 0.2 - 10 x $10^{12}$ |

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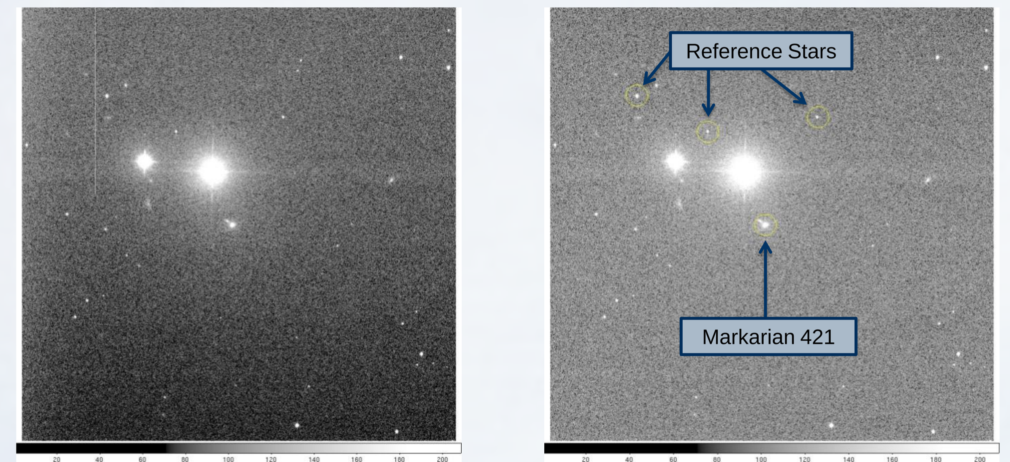
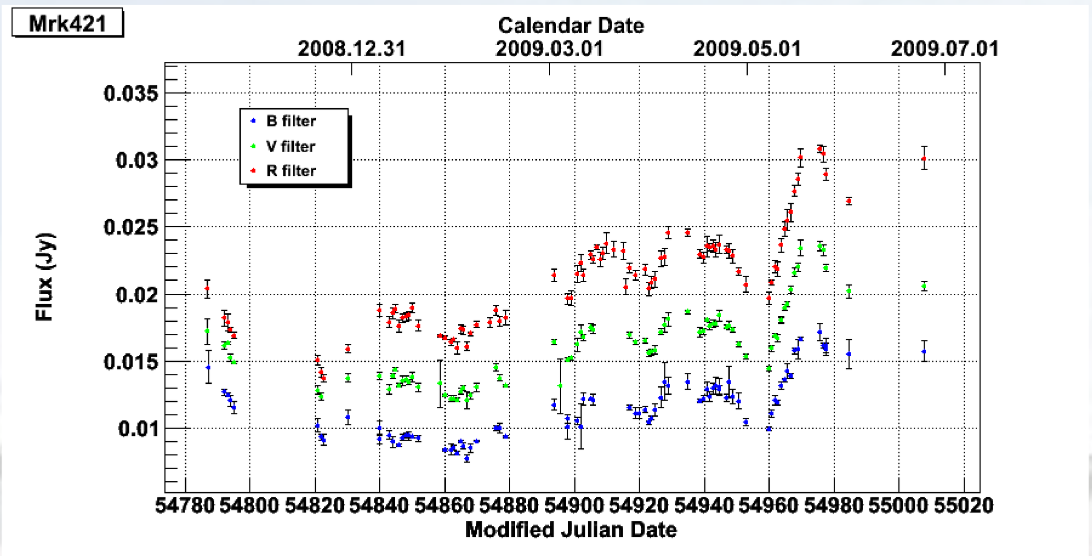
## Monitoring Blazars with WIYN

- National Optical Astronomy Observatory at Kitt Peak
- S2KB Camera
- Johnson B and V and Cousins R optical filters
- Image reduction was performed with IRAF, using bias frames and dome flat fields for each night of data.
- We obtained magnitudes by differential photometry, using three reference stars from Villata et al. (1998).

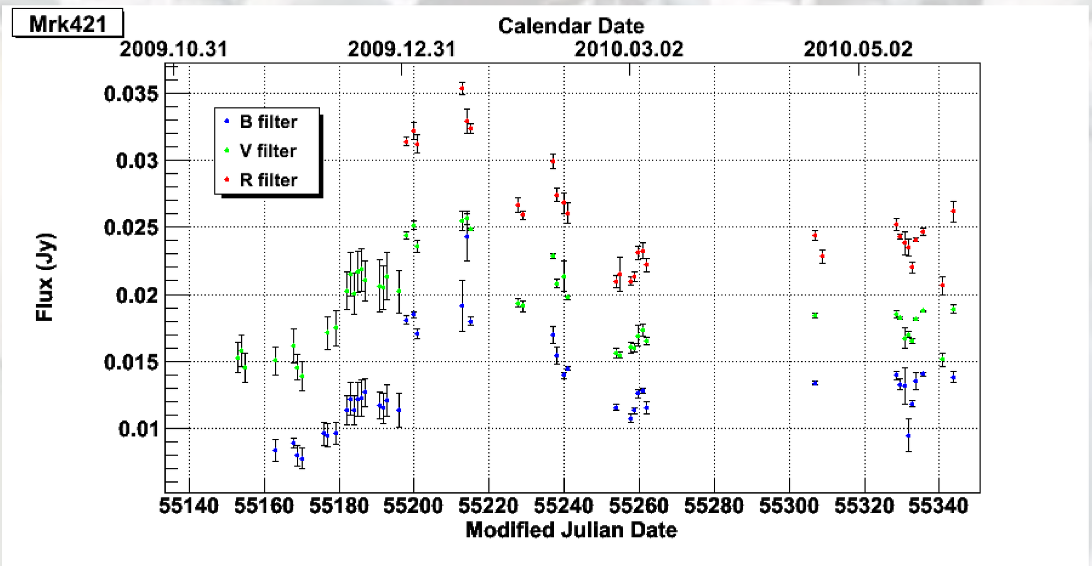



Raw Image    Reduced Image

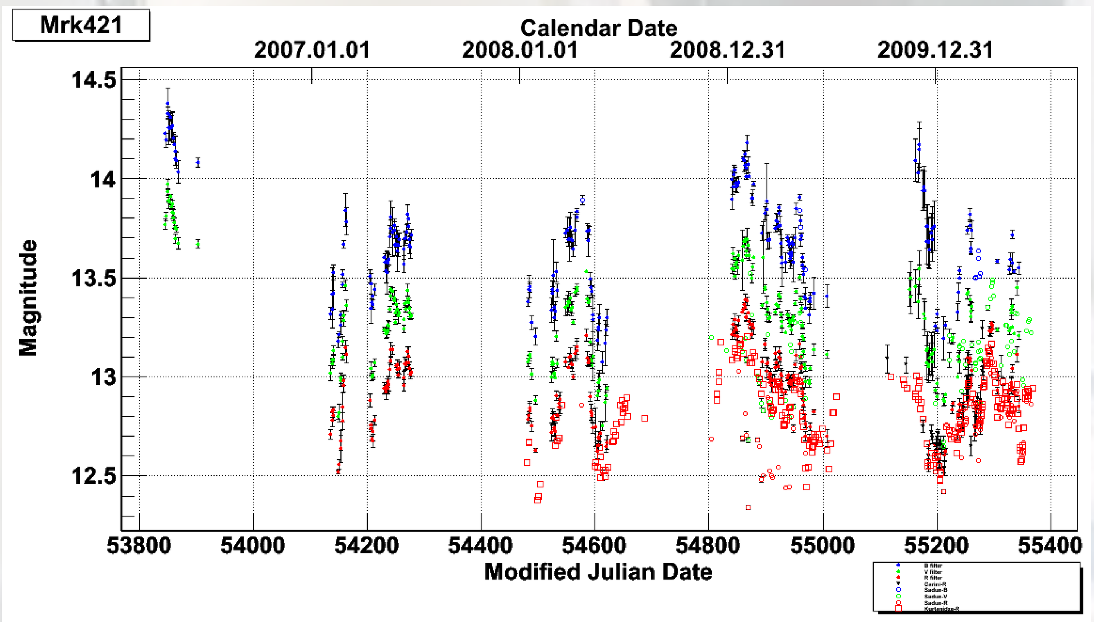
## Light Curves of Markarian 421




WIYN observations for 2009



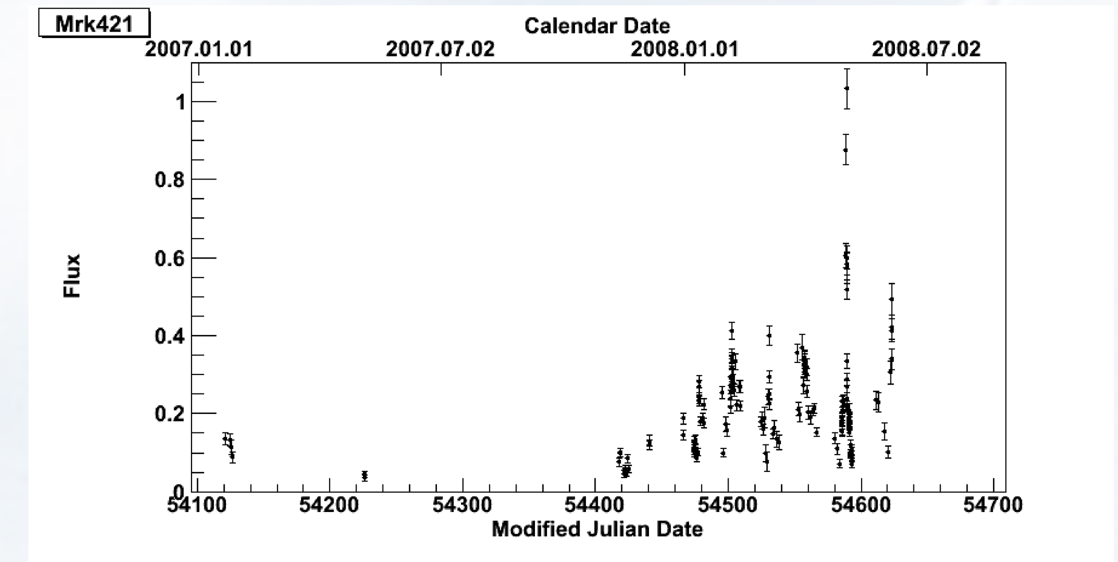

WIYN observations for 2010




WIYN with collaborator observations for 2006-2010

## VERITAS

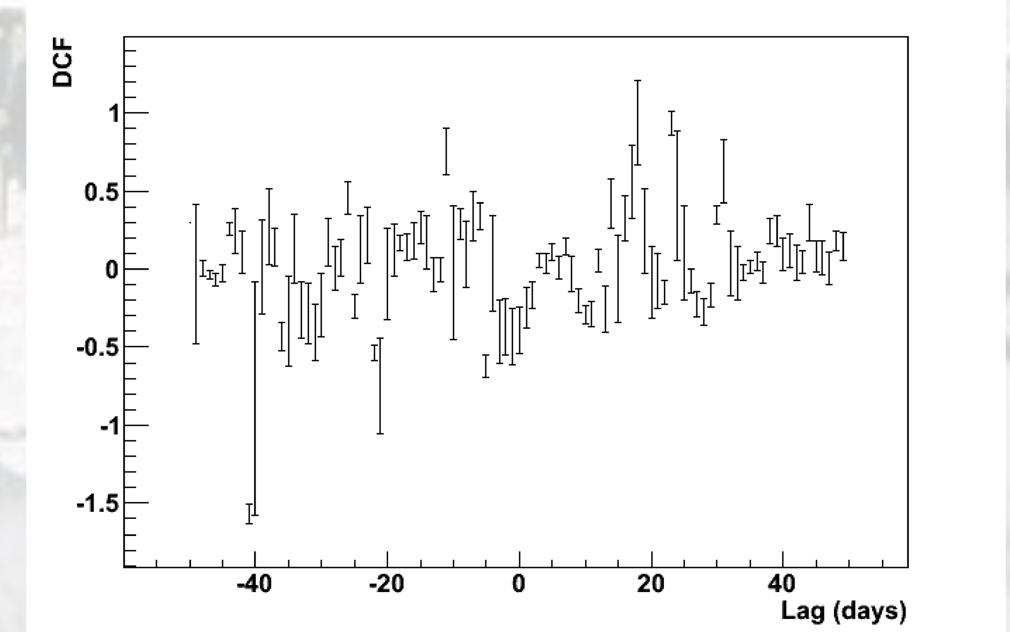
Since IceCube detects neutrinos in the TeV range, we work closely with the VERITAS (Very Energetic Radiation Imaging Telescope Array System) Collaboration. This is early data from their observations of Markarian 421.




## Correlation Among Wavelengths

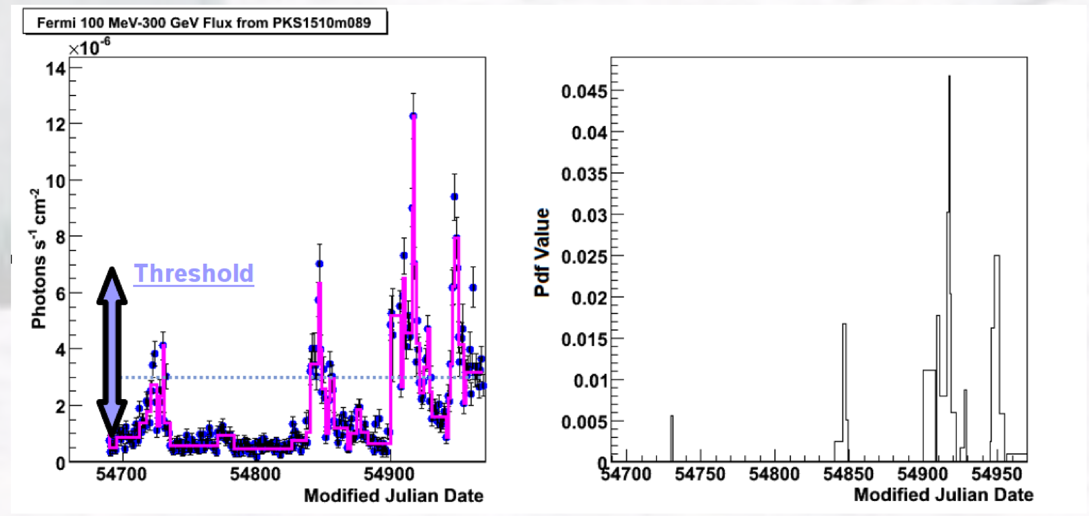
Correlation between the VERITAS very high energy gamma ray data and the red band observed by WIYN was tested using a Discrete Correlation Function (DCF). The DCF (see formula below) includes the possibility of a lagging correlation between wavelengths. There is no statistically significant correlation between the WIYN and VERITAS data.

$$UDCF_{ij} = \frac{(a_i - \bar{a})(b_j - \bar{b})}{\sqrt{(\sigma_a^2 - e_a^2)(\sigma_b^2 - e_b^2)}} \qquad DCF(\tau) = \frac{1}{M}\sum UDCF_{ij}$$

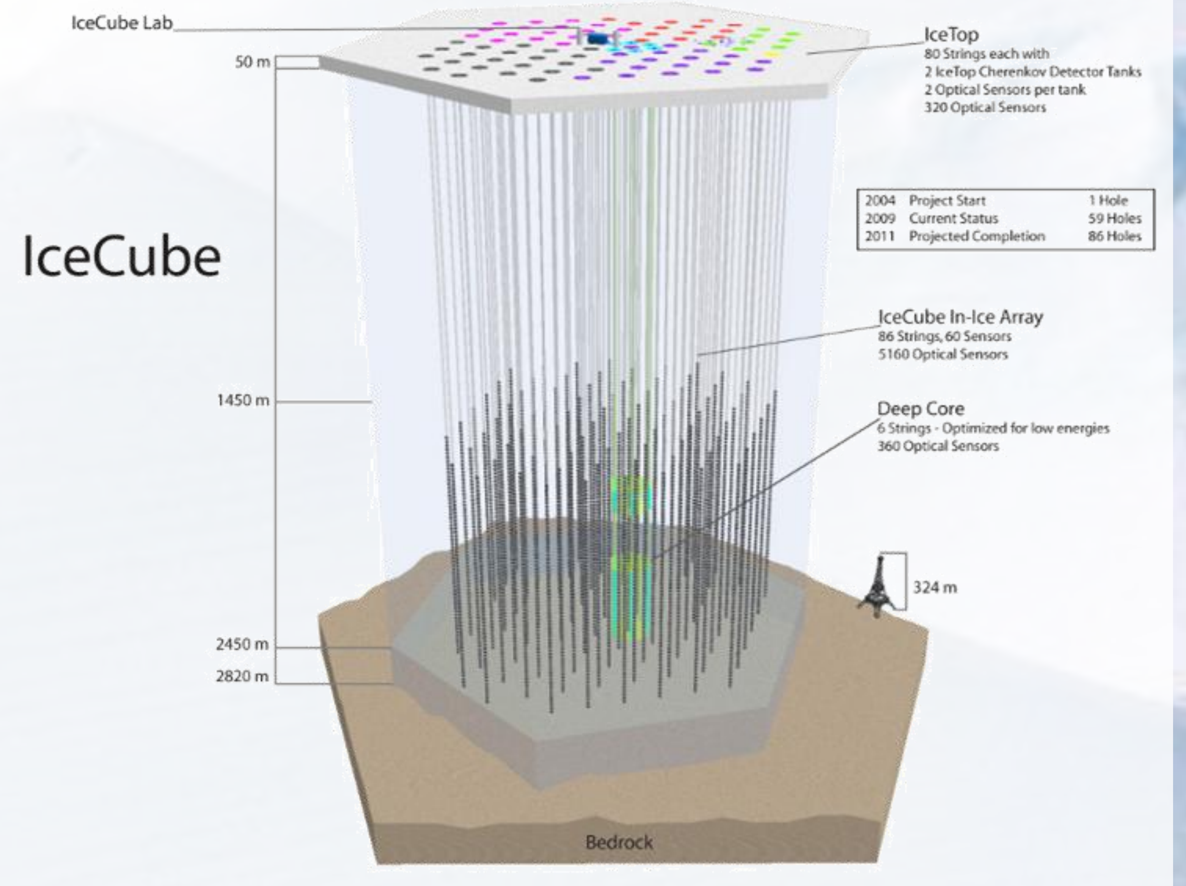



## Maximum Likelihood Ratio Test

Flares and high states seen in light curves allow IceCube to perform a time dependent search for point sources of neutrinos. The signal to noise ratio is maximized by a threshold photon flux, which in turn creates a probability density function.




## Neutrinos and Blazar Models (Future Work)




IceCube detects neutrinos using the Cherenkov Effect in the natural ice beneath the South Pole. The IceCube point source search uses the variables of time, position in the sky, and energy to best characterize signal against background using a maximum likelihood method. The detection of neutrinos from blazars would help determine which blazar models most accurately describe their mechanisms.

## Conclusion

- Mrk421 optical curve is variable with no obvious periodicity
- Mrk421 optical data does not correlate significantly with VHE data

## Acknowledgements

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