PROCEEDINGS OF SCIENCE

Gamma-ray observations of blazars with the Whipple 10 m telescope

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This paper presents a status update of the current blazar monitoring campaign with the Whipple 10 m telescope. The configuration and performance characteristics of the telescope are described along with the scientific motivation behind the campaign. A summary of the results obtained from January 2010 to July 2010 on Markarian 421, Markarian 501, 1ES 1218+304 and 1FGL J2001.1+4351 are also reported.

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1. Introduction

Imaging atmospheric Cherenkov technique (IACT) telescopes operate on the principle that cosmic rays and γ rays striking the atmosphere initiate cascades of charged particles that may be detected from the ground via the Cherenkov light that is emitted as the particles travel relativistically through the atmosphere. Photomultiplier-tube (PMT) cameras are used to image the Cherenkov light and off-line image analysis techniques select candidate γ-ray events and reject background cosmic ray events.

The Whipple 10 m telescope is an IACT instrument, located in southern Arizona, that operates in the 300 GeV to 10 TeV energy range. This instrument has been in operation since 1968 and was the first ground-based γ-ray telescope to detect a galactic source, the Crab Nebula in 1989 [1], and an extragalactic source, Markarian 421 in 1992 [2]. Currently the telescope is operated by the VERITAS (Very Energetic Radiation Imaging Telescope Array System) collaboration as a dedicated blazar monitoring instrument, and is used as a trigger for VERITAS in case of enhanced activity from any of the blazars being monitored.

2. The Whipple 10m telescope

The Whipple 10 m telescope [3] consists of an array of 248 hexagonal mirrors and an imaging PMT camera. The 248 mirrors, which are laid out in the Davies-Cotton solar-collector configuration giving a total reflecting surface of 75 m^2. The imaging camera currently contains 379 individual PMTs providing a field of view of $\sim$2.6° with an angular resolution of 0.117°. In its current configuration the telescope achieves a $5.6\sigma/\sqrt{hr}$ sensitivity on the Crab Nebula.

3. Blazars

An Active Galactic Nucleus (AGN) is a galaxy for which the emission from its galactic core dwarfs that of the normal stellar component of the host galaxy. The galactic cores are believed to be powered by supermassive black holes surrounded by an accretion disk powering two jets of electromagnetic radiation emitted perpendicular to the disk (see figure 1 for an artist's interpretation of an AGN). Blazars are a sub-class of AGNs whose jet is at an observing angle of less than or equal to 10 degrees, making it the most obvious feature of the galaxy. Blazars exhibit broadband non-thermal variable emission with the presence of two peaks, one in the optical-keV range the other in the GeV-TeV range. See figure 2 for an example of a spectral energy distribution (SED) exhibiting both peaks.

Emission models can generally be divided into two groups, where the particle species responsible for the γ-ray emission are either predominately leptonic or hadronic. Both model families attribute the low-energy peak to synchrotron radiation from relativistic electrons within the jets. They differ on the origin of the TeV peak: leptonic models advocate the inverse-Compton scattering mechanism, utilising synchrotron-self-Compton (SSC) interactions or Compton interactions with an external photon field (e.g. see [4], [5], [6]). Hadronic models account for the high-energy peak by neutral-pion or charged-pion decay with subsequent synchrotron and/or Compton emission from decay products, or synchrotron radiation from ultra relativistic protons (e.g. see [7], [8])

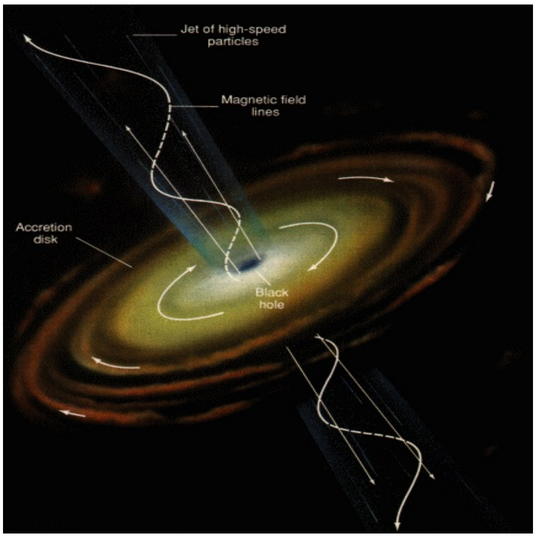

Figure 1: An artist's interpretation of an AGN. [http://www.physics.ucc.ie/gabuzda/pictures/agn.gif]

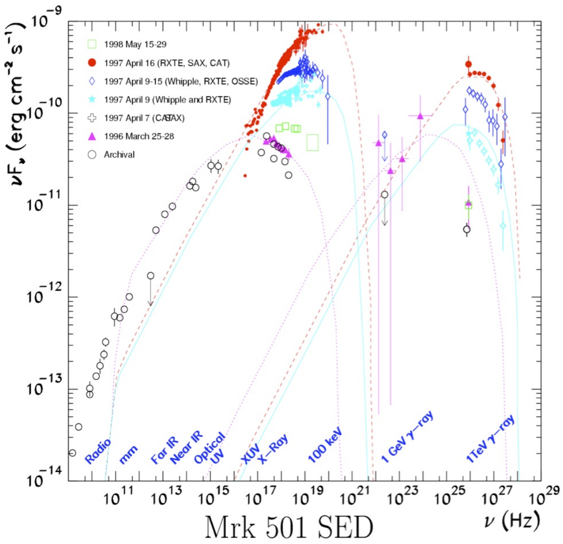

Figure 2: An example of the SED of Markarian 501 showing the peaks of emission at both X-ray and TeV wavelengths. [Courtesy of James H. Buckley]

4. Scientific Motivation

Long-term monitoring is needed to record both the long-term and short-term variability in the emission from blazars. Periods of intense, short-term variability are known as flares. These flares occur so rarely that a large amount of observing time must be dedicated to a handful of sources in order to increase the likelihood of seeing flaring activity.

Short-term variability is crucial to the calculation of the size of the photon emission region. A pulse of temporal width δT provides an upper limit on the size of the emitting source given by $R < c\,\delta T$. Where R is the size of the emitting region and c is the speed of light. Long-term monitoring is also needed in order to trigger multiwavelength (MWL) campaigns. When a source enters a flaring period VERITAS is alerted, along with a numerous MWL partners, to a target of opportunity (ToO). Broadband observations of correlated variability are critical for testing the predictions of different theoretical models.

5. Results from January 2010 to June 2010

From January 2010 to June 2010 four sources were monitored, with a total of 190 hours of data collected. See Table 1 for each sources positional information, number of hours spent on source and significance level achieved. These data will form part of a multi-year data set on Markarian 421 and Markarian 501. The Whipple 10m telescope's extensive coverage of these two sources at TeV energies is unique.

Table 1: Tabulation of data taken from January 2010 to June 2010

Source	RA	DEC	z	Hours on Source	Significance
Mrk421	11 04 27.3	+38 12 31.7	0.031	108	67
Mrk501	16 52 52.2	+39 45 36.6	0.034	53	17
1ES 1218+304	12 21 21.9	+30 10 37.1	0182	13	0.504
1FGL J2001.1+4351	20 01 11.9	+43 51 51	?	16	-0.277

5.1 Markarian 421

Markarian 421 is one of the most active VHE blazars and was the first to be discovered at TeV energies. Its SED has peaks at the keV and TeV energies and it has been known to demonstrate rapid, sub-hour scale flaring behaviour (e.g. see [9]). It has a redshift of 0.031 making it the closest known TeV blazar. Figure 3 shows the daily averaged lightcurve of Markarian 421 for 2010, revealing clear day-scale variation (a χ^2 test for constant emission returns a probability of 0). A search within each night revealed no significant evidence for hour-scale variability.

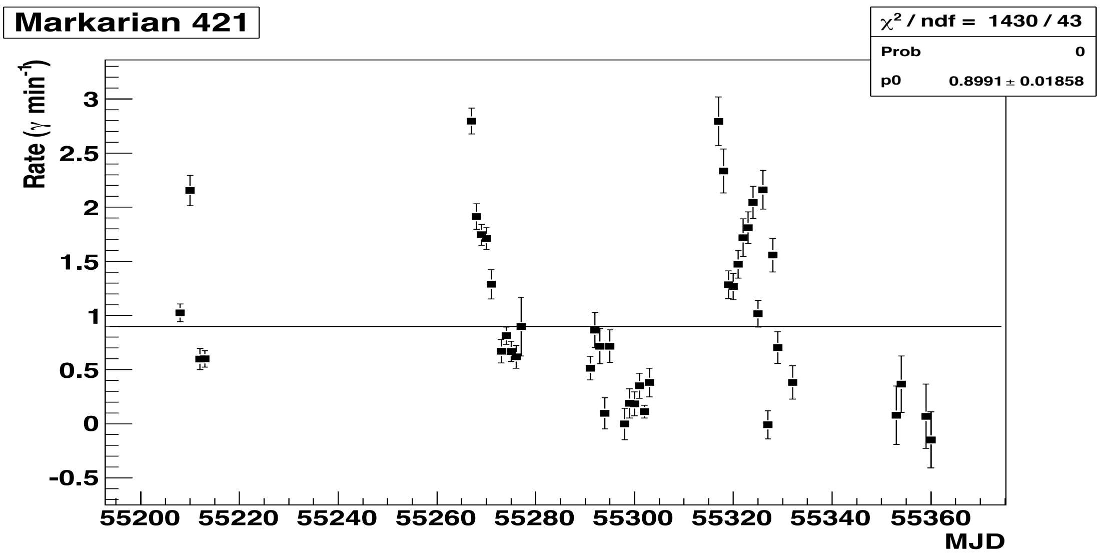

Figure 3: Daily averaged lightcurve of Markarian 421 between January 2010 and June 2010.

5.2 Markarian 501

Markarian 501 also has a well cataloged history of flaring (e.g. see [9]). Whilst being at a similar distance to Markarian 421, Markarian 501 is significantly weaker on average. This source has been intensively monitored in the past and it displays quite different time characteristics to Markarian 421. Figure 4 shows the daily averaged lightcurve of Markarian 501 for 2010. A χ^2 test provides evidence for significant day-scale variability (the probablility for the constant emission is $\sim 1 \times 10^{-29}$) but a search for variability on shorter timescales revealed no significant events.

An event rate of greater than 4 times the Crab rate per run (28 minutes on source), as needed to trigger VERITAS observations, was not detected, but periods of increased activity in both Markarian 421 and 501 were observed.

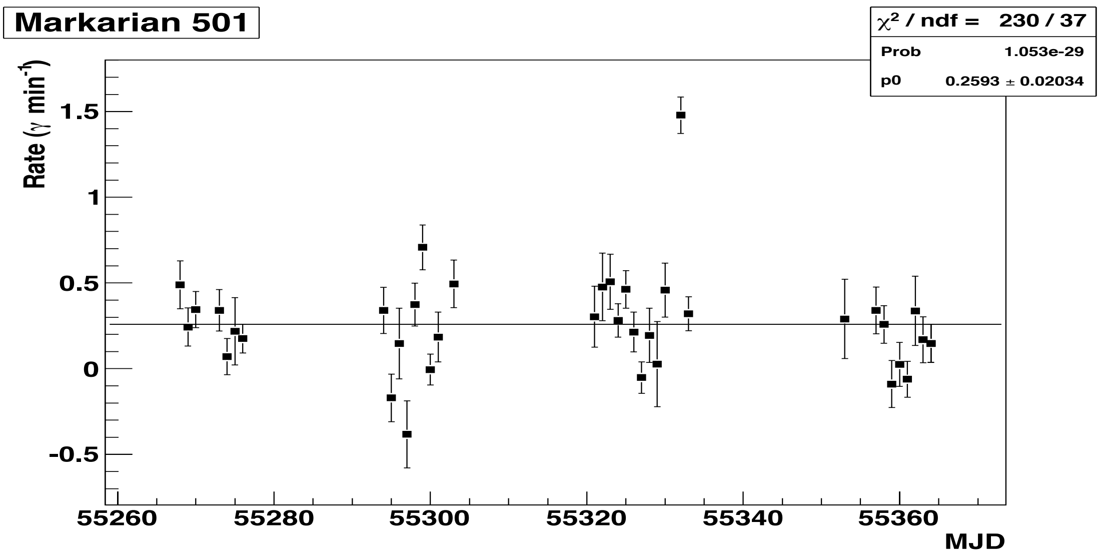

Figure 4: Daily averaged lightcurve of Markarian 501 between January 2010 and June 2010.

5.3 Other Sources

There is considerable interest in 1ES 1218+304, a distant (z=0.182) blazar which has a hard spectrum, since he recent discovery of day-scale flaring [11]. Its average TeV flux is 7% of the Crab Nebula making it a relatively bright blazar. A significance level of 5σ needed for a confirmed detection of 1ES 1218+304 was not achieved in the observing season from January 2010 to June 2010.

The brightest non-VHE detected object in the 1FGL photon sky maps above 30 GeV [12] is 1FGL 2001.1+4351, a likely blazar. It is firmly detected out to 100 GeV and the extrapolation of its spectrum to >1 TeV is 40 Crab, but its redshift is unknown. A significance level of 5σ needed for a confirmed detection of 1FGL 2001.1+4351 was not achieved in the observing season from January 2010 to June 2010

6. Summary

The Whipple 10m blazar monitoring campaign continued from January 2010 to July 2010. 190 hours of data were collected on four sources. Markarian 421 and 501 were both detected with high significance, and both demonstrated variability in their emission from night to night. Data from each night were examined for variability but no significant hour-scale variability was observed.

The next observing season is scheduled to start in October 2010. The list of observed blazars will be expanded to include VER J0521+211, RGB0710+591, 1ES0229+200, 1ES1959+650 and 1ES2344+514. By doing this we will make use of the full range of scientific capabilities of the Whipple 10m Telescope.

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