BLAZAR MONITORING WITH THE WATCHER ROBOTIC TELESCOPE

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Introduction

The Watcher robotic telescope is located at Boyden Observatory (29° 2′ 19.79″ S, 26° 24′ 17″ E), South Africa. It was built primarily to observe gamma-ray burst afterglows and to provide supporting optical observations for a range of telescopes and observatories that operate in the gamma-ray (MeV to TeV) and X-ray regions of the spectrum. These include Fermi, INTEGRAL, Swift, XMM-Newton and NuSTAR. Watcher is a 40 cm Classical Cassegrain reflecting telescope and is equipped with standard B, V, R, I filters and an Andor iXon electron-multiplying CCD (EMCCD). For most of Watcher's monitoring programmes, the EM mode is switched off, as the targets are typically known, relatively bright, sources.

Since its installation in April 2006, Watcher has been used to monitor many other sources when no GRB is being actively followed, including variable stars, Kuiper Belt objects and Active Galactic Nuclei (AGN). The subset of AGN known as blazars has recently become the focus of an intense monitoring campaign designed to probe the variability timescales in these AGN by providing both short-term and long-term optical variability data for key southern hemisphere sources.

The Watcher Robotic Telescope, Boyden Observatory, Bloemfontein, SA

Motivation

Optical studies of blazars are important because the synchrotron peak of the broad spectral energy distribution is often located in this band. Additionally, the relationship between high-energy and optical variability in blazars is complex. The SSC mechanism can pump up the optical synchrotron photons in the Thomson limit to Fermi-LAT energies. By constraining the optical synchrotron spectrum through multi-wavelength observations, the gamma-ray production capabilities of these sources can be constrained. Dedicated multi-band observations are required to understand (i) the nature of the optical variability, which is a defining characteristic of blazars; (ii) the occurrence (or otherwise) of lags between optical and gamma/X-ray flares and (iii) colour changes as a function of intensity. Furthermore, high cadence observations over successive nights, combined with long-term archival data taken over timescales from weeks to years, can be used to construct the power density spectrum (PDS) of the source. A characteristic break timescale in the PDS appears to scale with black hole mass over many orders of magnitude [1]. Ultimately, the goal of this programme is to gain a better understanding of the blazar central engine and the processes occurring in the relativistic jet.

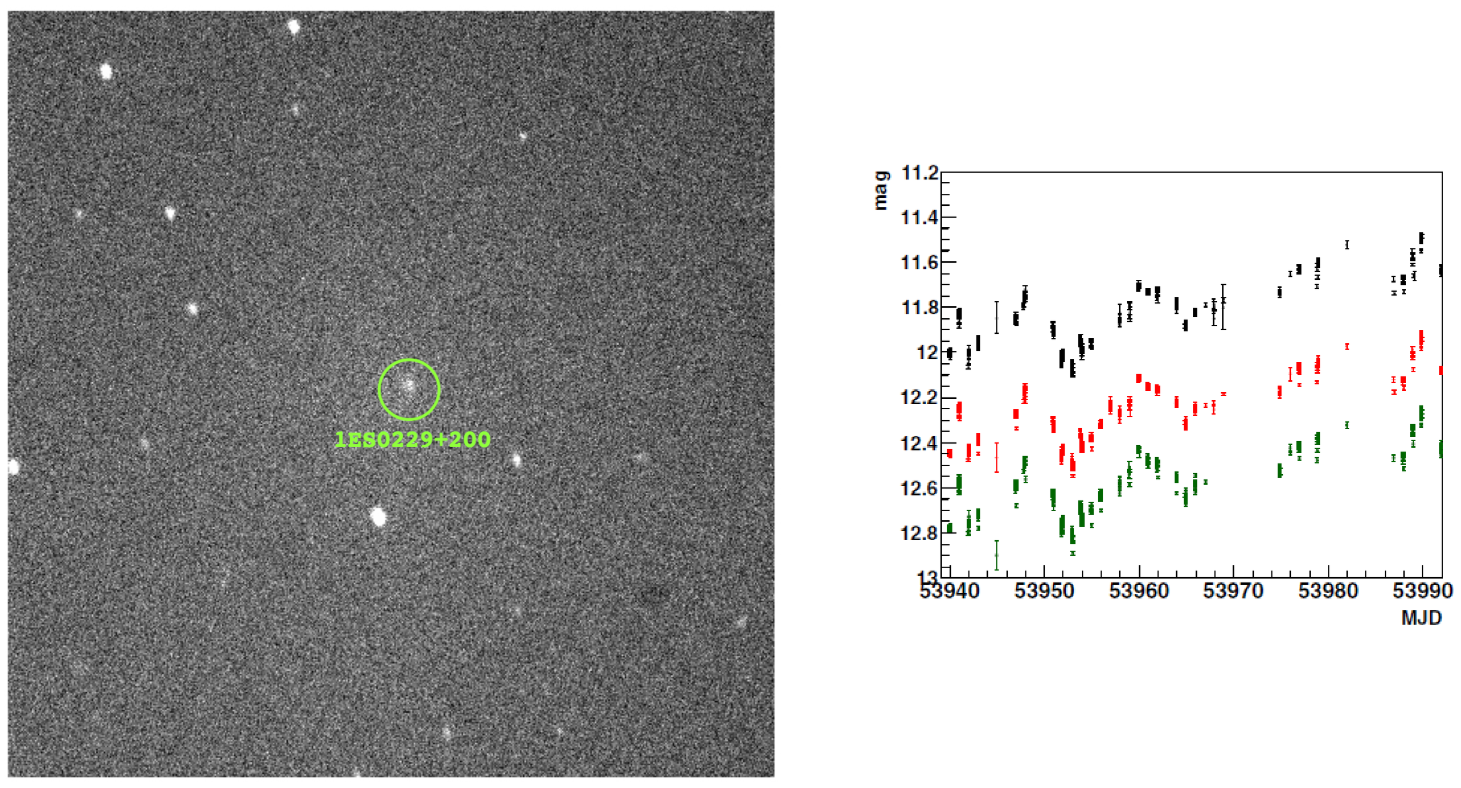

Figure 1: Left: Watcher R-band image of the TeV blazar 1ES 0229+200 from the night of October 1st, 2013, taken as part of the NuSTAR/H.E.S.S. multi-wavelength campaign. The source (typical R-band magnitude ∼ 14.5) is visible in this 60 s exposure. Right: Archival Watcher lightcurve of PKS 2155-304 from 24/07/2006 to 09/12/2006, during the TeV flaring episode. Black: I-band; Red: R-band; Green:V-band [6].

H.E.S.S. Supporting Observations

Given its similar geographical longitude to the H.E.S.S. gamma-ray telescope in Namibia, Watcher's monitoring capability acquires additional relevance since, in blazar sources, changing optical emission has been linked to changes in GeV gamma-ray emission [2, 3, 4]. Watcher supports contemporaneous optical/VHE gamma-ray observations to be undertaken to further explore the nature of correlated optical-VHE variability. Furthermore, long term monitoring of specific sources can be used to trigger H.E.S.S. observations if evidence of flaring is identified in real-time data. As part of a multi-wavelength campaign, including NuSTAR and H.E.S.S., of the TeV blazar 1ES 0229+200, Watcher conducted an intense monitoring programme in October 2013 (Figure 1). This target would not meet the selection criteria for inclusion in the regular blazar monitoring programme as it is relatively faint and northerly and does not appear in the 2nd Fermi Point Source catalogue [5].

Certain VHE gamma-ray binaries are also being monitored. Due to the close interaction between the components in gamma-ray binaries, changes in the optical emission may give rise to gamma-ray variability. Variations in optical emission can also be used to search for orbital periods.

NAME	RA (2000)	Dec (2000)	Class	SED Class	z	USNO B1 mag.	Max. altitude (°)	Observing season (alt>30°)
PKS 2005-489	20 09 25.00	-48 49 53.9	BL Lac	HSP	0.071	11.29	65	May-September
PMN J2022-4513	20 22 26.20	-45 13 31.5	BL Lac			13.91	70	May-September
PKS 2155-304	21 58 52.10	-30 13 30.3	BL Lac	HSP	0.116	12.54	85	June-October
AP Librae	15 17 41.80	-24 22 20.1	BL Lac	LSP	0.048	11.06	88	March-July
CRATES J061733.67-17	06 17 33.60	-17 15 22.2	BL Lac	LSP	0.098	13.15	80	October-February
PMN J0152+0146	01 52 39.50	+01 47 16.9	BL Lac	HSP	0.08	11.82	62	August-December
3C 273	12 29 06.40	+02 03 04.9	FSRQ	LSP	0.158	13.94	62	February-May
4C +04.77	22 04 17.40	+04 40 02.6	BL Lac	ISP	0.027	9.98	58	June-October
BZB J0912+1555	09 12 30.90	+15 55 29.4	BL Lac	HSP	0.212	13.46	48	December-March
S3 1741+19	17 43 57.90	+19 35 08.4	BL Lac	HSP	0.083	11.4	45	May-July

Table 1: Optically bright Fermi blazars selected for Watcher's long-term monitoring programme

Target selection

There are more than 800 blazars (i.e. BL Lacs or FSRQs) in the 2nd Fermi catalogue [2, 5]. A declination constraint of $\leq 20^\circ$ cuts the sample roughly by half. A further cut to include only sources brighter than 14^{th} magnitude (USNO B1 catalogue) is then applied to ensure good photometric accuracy for intra-night variability studies. The details of the remaining 10 sources are given in Table 1.

The blazar monitoring campaign during the austral Winter of 2013 focused on the blazars PKS 2155-304 and PKS 2005-489, both of which have a long history of variability and activity in multiple bands. The main aim of this monitoring campaign is to investigate the properties of the central black hole by examining the variability of these sources over a range of different time scales.

PKS 2155-304

PKS 2155-304 is a high frequency peaked BL Lac source, first discovered by the HEAO 1 X-ray satellite [8]. It is one of the brightest X-ray sources in the southern skies and is one of the most distant sources detected at TeV energies. PKS 2155-304 is a notable source due to its history of variability in multiple wavelengths, in particular during 2006 when it exhibited major flaring, notable at TeV energies [6]. Watcher collected extensive multi-filter data at that time (Figure 1, right).

Watcher has been observing PKS 2155-304 since 2006 and has included this source in the recent monitoring campaign, which involves a very high sampling rate on a nightly basis in the V, R and I bands. The data analysis plan is to combine archival Watcher data taken since 2006, with the recent high cadence data in order to create a power density spectrum for this source.

Source	Date	R	V	I	Total
(z)	*(dd/mm/yy)*				
PKS 2005-489	12/07/13	114	107	115	336
0.07	18/07/13	14	2	12	28
	20/07/13	174	149	178	501
	21/07/13	13	11	16	40
	23/07/13	29	30	30	89
	25/07/13	19	18	19	56
	26/07/13	30	26	29	85
	31/07/13	60	60	60	180
	02/08/13	29	29	30	88
	03/08/13	29	29	30	88
	07/08/13	12	12	13	37

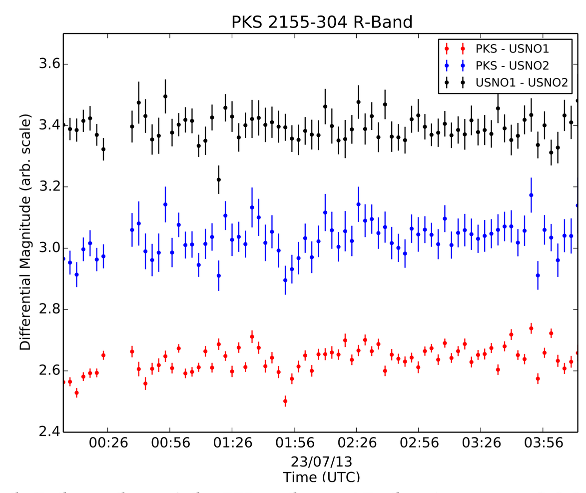

Figure 2: Left: Summary of PKS 2155-304 observations in V, R and I bands with Watcher (July-August 2013). Right: Preliminary R-band differential lightcurve of PKS 2155-304 for the night of 23/07/2013.

PKS 2005-489

PKS 2005-489 is one of the optically brightest BL Lac objects visible in the southern hemisphere (Table 1). It was discovered during the Parkes 2.7 GHz survey in 1975 [9]. Multi-wavelength studies have shown the source to vary on timescales of days to years and it has undergone periods of high activity in recent years, with X-ray flux varying by a factor of ∼ 50 between 2004 and 2009.

Source	Date	R	V	I	Total
(z)	*(dd/mm/yy)*				
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0.07	18/07/13	14	2	12	28
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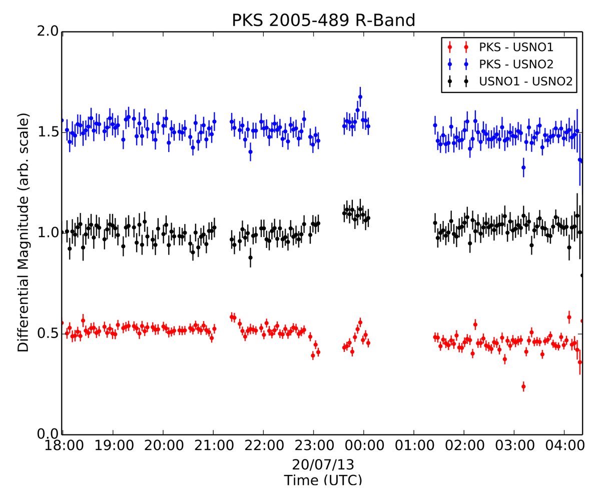

Figure 3: Left: Summary of PKS 2005-489 observations in V, R and I bands with Watcher (July-August 2013). Right: Preliminary R-band differential lightcurve of PKS 2005-489 for the night of 20/07/2013.

For scheduling reasons, high cadence observations of a maximum of two targets at a time is ideal. Monitoring of the other candidates for long-term variaibility studies is carried out in parallel on a ∼ weekly basis. The existing analysis pipeline is being modified to cater for the differential photometry that will be used in the blazar analysis. Statistical tests to quantify the source variability are being implemented with a view to construct the power density spectrum. Initial analysis suggests that both blazars remained quiet over the observing period.

Acknowledgements

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