Optical spectropolarimetry monitoring of flaring blazars

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Abstract. Blazars are a subclass of radio-loud active galactic nuclei, with relativistic jets closely aligned with the line of sight. These sources are highly variable across all time-scales, and emit non-thermal emission across all wavelength regimes. Blazar-emission is characterised by a double-humped structure in its spectral energy distribution, indicating different emission mechanisms at play. At optical wavelengths, there is an underlying thermal component from the accretion disc, broad line region, and dusty torus, making it difficult to separate the different emission components. As part of a long term campaign, we are undertaking spectropolarimetric observations of flaring blazars, using the Southern African Large Telescope. This could be used to help disentangle the thermal from the non-thermal emission. We present results on the degree of linear polarisation of a selection of fourteen blazars observed between April 2016 and June 2021 , with emphasis on five sources of interest. Three sources, namely 4FGL J0231.2-4745, PKS 0537-441, and PKS 2023-07 were observed during/around periods of increased activity. The degree of linear polarisation for all three of the above sources was observed to be higher close to the peak of activity, and decreased as it returned to quiescence. Two sources, AP Lib (a BLL) and PKS 1034-293 (an FSRQ) was observed continually over a period spanning roughly one year. Both of these sources showed some variability in polarisation over the period in question.

1. Introduction

Active galactic nuclei (AGN), the central active cores of some galaxies, are believed to be powered by accretion of material onto a central supermassive black hole (SMBH). They display broad-band emission across the entire electromagnetic spectrum which, in some cases, outshines the host galaxy itself [1]. AGN present unique observational signatures across the different wavelength bands, which led to many different classes of AGN being identified [2]. The unified model suggests all AGN consist of a central SMBH and an accretion disc, a dusty absorber or torus, broad- and narrow-line regions, and in some cases, a strong, collimated jet [3], and the type of AGN observed depends strongly on the viewing angle of the observer.

Table 1. List of FSRQs and BLLs observed with the SALT . The mean linear polarisation was measured between 4000 Å and 8000 Å.

Target	Type	Obs. Date	Mean Pol. (%)	Target	Type	Obs. Date	Mean Pol. (%)
4FGL J0231.2-4745	FSRQ	22/10/2019	27.5	PKS 0208-512	FSRQ	05/12/2019	27.4
		29/10/2019	08.7			19/12/2019	05.3
AP Lib	BLL	14/05/2020	05.3	PKS 0346-279	FSRQ	09/02/2018	18.2
		08/06/2020	05.0	PKS 0426-380	BLL	17/01/2017	10.8
		24/06/2020	03.4			20/02/2017	10.9
		07/08/2020	08.9	PKS 0447-439	BLL	21/02/2017	05.1
		04/09/2020	06.3	PKS 0537-441	BLL	14/01/2019	37.4
		18/02/2021	03.4			05/03/2019	12.6
		12/03/2021	05.2	PKS 0837+012	FSRQ	16/03/2021	10.6
		04/04/2021	08.5	PKS 0907-023	FSRQ	19/01/2017	05.1
		11/04/2021	09.1	PKS 1034-293	FSRQ	15/05/2020	16.2
		21/04/2021	11.0			08/02/2021	17.9
		02/05/2021	08.6			17/03/2021	13.8
		08/05/2021	09.6			09/04/2021	12.7
		14/05/2021	07.1			05/06/2021	19.1
		03/06/2021	06.2	PKS 2023-07	FSRQ	14/04/2016	27.5
PKS 0035-252	FSRQ	20/07/2018	02.6			04/10/2018	09.1
PKS 0131-522	FSRQ	19/11/2017	07.8	TXS 0506+056	BLL	14/10/2017	10.7
		22/11/2017	06.4			20/10/2017	08.6

Blazars are a radio-loud subclass of AGN, with relativistic jets that propagate in a direction closely aligned with the observer's line of sight (viewing angle $< 10°$). As a result, the non-thermal emission originating in the jet is highly Doppler boosted, making blazars the brightest gamma-ray sources in the extragalactic sky [4]. Blazar emission is extremely variable on all time-scales (on time-scales from minutes up to several years), with dramatic variation present across the entire electromagnetic spectrum. Blazars are subdivided into two different categories, namely BL Lac type objects (BLLs) and Flat-Spectrum Radio Quasars (FSRQs). These can be distinguished by their optical spectral features: FSRQs display strong, broad emission lines , while BLLs display absorption or weak emission lines, or featureless spectra dominated by the non-thermal jet emission [2].

The spectral energy distributions (SEDs) of blazars are characterised by a double-humped structure. The lower-energy component (radio to optical/UV and sometimes soft X-rays) is powered by synchrotron emission from relativistic electrons in the jet. However, both leptonic and hadronic models have been previously postulated for the high-energy (X-ray to gamma-ray) component. The leptonic model assumes that the high-energy emission is dominated by Compton scattering of low-energy photons, whereas the hadronic model assumes that the high-energy component is produced through proton-synchrotron radiation or photomeson processes [4]. At optical wavelengths, there is also an underlying thermal contribution originating from the accretion disc, dusty torus, broad-line region (BLR) and host galaxy [5]. Since both the leptonic and hadronic models are able to reproduce blazar SEDs, separating the emission regions can be very difficult.

Polarimetry can be used as a diagnostic tool to disentangle the emission components in blazar SEDs. In the optical, it serves as a tool to separate the thermal (non-polarised) contributions from the non-thermal (polarised) contributions, allowing constraints to be placed on the jet's magnetic field structure, the non-thermal electron population, and the state of the accretion disc [5]. Here we present optical spectropolarimetry observations of a selection of blazars observed with the Southern African Large Telescope (SALT).

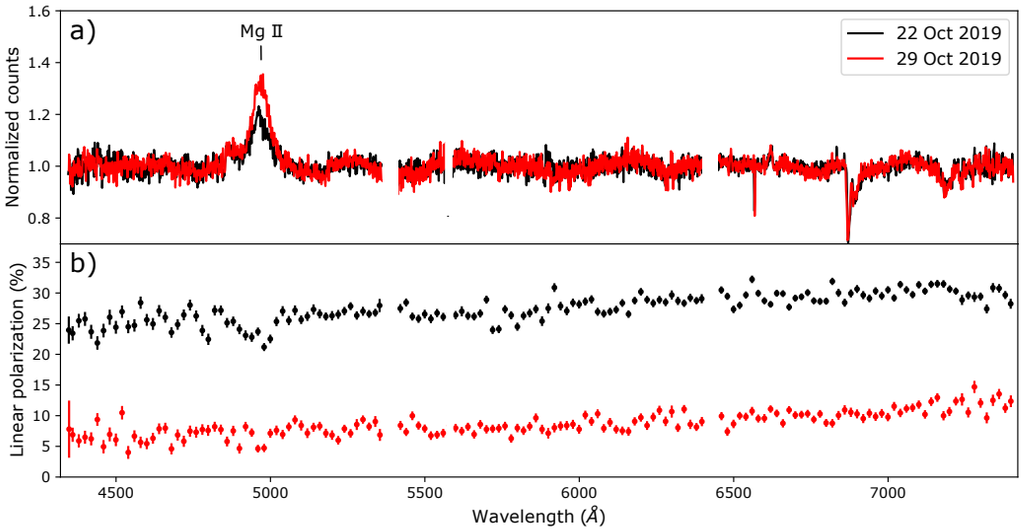

Figure 1. Spectropolarimetry observations of 4FGL J0231.2-4745 taken around a period of increased activity, where a) is the spectra and b) the observed degree of linear polarisation.

2. Observations

The spectropolarimetry observations (listed in Table 1) were taken with the SALT to observe blazars in different states, as well as track the long-term evolution of the degree of polarisation in both BLLs and FSRQs. The observations were performed using the Robert Stobie Spectrograph (RSS) in spectropolarimetry LINEAR mode to measure the degree of linear polarisation [6, 7]. The sources were observed using either the pg0300 grating (with a resolving power of $R = 190$–560 from 3400 Å to 9867 Å) or with two orientations of the pg0900 grating ($R = 620$–1655 from 3750 Å to 9000 Å), with either the argon or thorium-argon arc lamp used for wavelength calibration.

Data reduction was performed using a modified version of the POLSALT reduction pipeline (https://github.com/saltastro/polsalt.git). The modification allowed the wavelength calibration to be performed using the IRAF/NOAO package (http://ast.noao.edu/data/software). Additional cosmic-ray cleaning was performed in PYTHON using the LACOSMIC package (https://github.com/larrybradley/lacosmic.git). All other reductions followed the standard procedure given by the POLSALT pipeline. The two larger spaces in the spectra are due to gaps in the CCD detector mosaic, and the smaller missing region at ∼5600 Å is due to the removal of a skyline.

3. Results

3.1. Flaring Blazars

Figures 1 - 3 show the spectropolarimetry results on three blazars during both flaring and/or quiescent state. The spectra are normalised with respect to counts, and the degree of linear polarisation is represented as a percentage. Using the normalised spectra allows us to show the relative change in the emission/absorption line strengths. 4FGL J0231.2-4745 (Figure 1) was observed twice around a period of increased gamma-ray, X-ray and optical emission [8, 9, 10], where the gamma-ray flux increased by a factor of ∼60 with respect to the reported catalogue value [8] on 2019 October 19. The observations showed a significant decrease in linear polarisation from the first observation on 2019 October 22 to the second a week later (2019 October 29). There is also an increase in the equivalent width of the Mg II line, which indicates

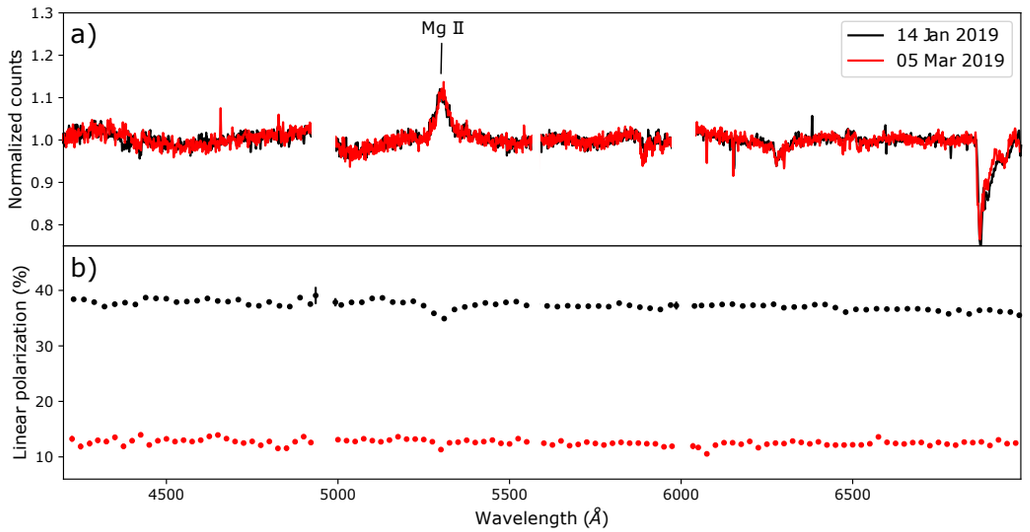

Figure 2. Spectropolarimetry observations of PKS 0537-441 taken around a period of increased activity, where a) is the spectra and b) the observed degree of linear polarisation.

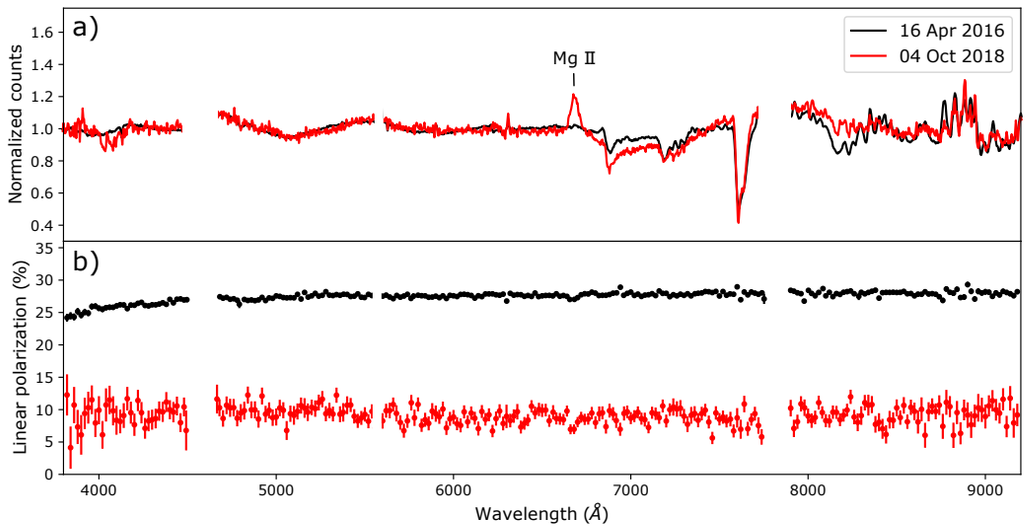

Figure 3. Spectropolarimetry observations of PKS 2023-07 taken during a flaring and non-flaring state, where a) is the spectra and b) the observed degree of linear polarisation.

a decrease of the non-thermal emission component between the two observations. In FSRQs, the non-thermal, beamed jet-emission often outshines the host galaxy, BLR, and accretion disc. Hence, a strengthening of the non-thermal component during a flare can cause the emission lines originating in these regions to appear less prominent/weaker than during quiescence [2].

PKS 0537-411 (Figure 2) was observed at the start of a period of increased activity following a quiescent period [11]. The two observations were taken 50 days apart. While the observations show no significant change in the equivalent width of the Mg II line, they show a large change in the degree of linear polarisation (decrease from 37% to 13%). The publicly available data from the monitoring of *Fermi*-LAT sources indicated that, in the weekly bins, there

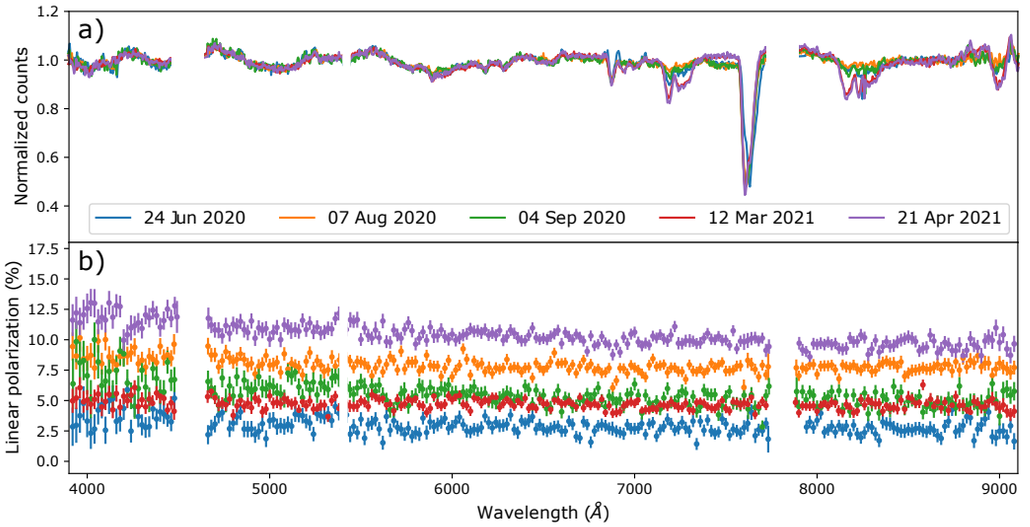

Figure 4. Long-term spectropolarimetry observations of AP Lib, a BLL. Observations were taken from 14 May 2020 to 3 June 2021 . Here, only a selection of five observations are shown, with each colour representing an observation date, and a) is the spectra and b) the observed degree of linear polarisation.

was a decrease in the flux (>100 MeV) by a factor of ∼1.8 between these two observations (https://fermi.gsfc.nasa.gov/ssc/data/access/lat/msl_lc/).

PKS 2023-07 (Figure 3) was observed once during a flaring state in April 2016 [12], and once during a quiescent state in October 2018. The optical spectrum clearly shows the switch from being dominated by the non-thermal synchrotron emission where no emission lines are observable during the flare, to showing a Mg II emission line during the quiescent state. The degree of polarisation changed by roughly 18% between the two observations.

3.2. Long-term Monitoring

Long-term monitoring of AP Lib (a BLL) and PKS 1034-293 (an FSRQ) has been performed over approximately one year (May 2020 to June 2021) to study the long-term variation in polarisation. Although there were no large changes in the degree of linear polarisation for either of the sources, there was definite variation over time. The spectropolarimetry results are shown in Figures 4 and 5, respectively, where the spectra are normalised with respect to counts.

4. Discussion and Conclusion

To date, the degree of polarisation has been successfully measured for fourteen blazars, both BLLs and FSRQs, during both flaring and/or non-flaring states. For the two sources presented in Figures 1 - 2, observations were taken during periods of increased activity. For these sources, the degree of linear polarisation decreased substantially after the initial observations. The blazar presented in Figure 3 was observed during a flare, along with a follow-up observation taken some time later during quiescence. We expect the thermal component to contribute more at shorter wavelengths. Therefore, there should be a general decrease in the degree of linear polarisation towards the bluer end, and it appears to be the case for the three blazars in question.

For the two long-term sources, both AP Lib (BLL, Figure 4) and PKS1034-293 (FSRQ, Figure 5), displayed some variability in polarisation over the observational period. The FSRQ source had a higher mean polarisation (12-20%) than the BLL (3-12%), while the BLL showed

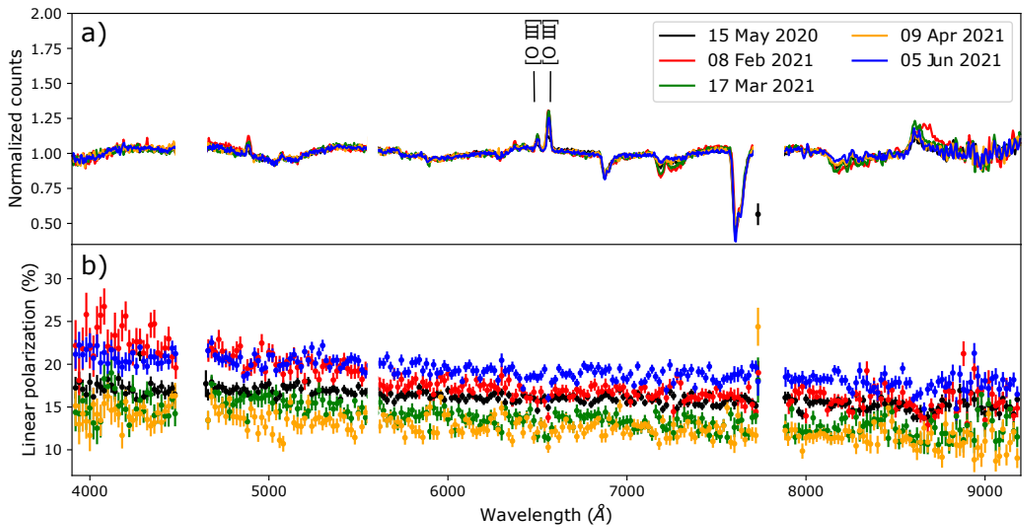

Figure 5. Long-term spectropolarimetry observations of PKS 1034-293, an FSRQ. Observations were taken from 14 May 2020 to 05 June 2021, with each colour representing an observation date, and a) is the spectra and b) the observed degree of linear polarisation.

a slightly larger range in polarisation. However, this may be due to observational bias and can only be confirmed through more observational data.

These are the initial results from an ongoing, long-term project. The variation found in the degree of linear polarisation will now be compared to the multi-wavelength behaviour of these sources. The change in the measured polarisation could be used in the modelling of the blazars' jet-behaviour.

Acknowledgments

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