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Optical polarisation variability of narrow line Seyfert 1 galaxies

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PoS(NLS1-2018)019

We have monitored the *R*-band optical linear polarisation of ten jetted NLSy1 galaxies with the aim to quantify their variability and search for candidate long rotation of the polarisation plane. In all cases for which adequate datasets are available we observe significant variability of both the polarisation fraction and angle. In the best-sampled cases we identify candidate long rotations of the polarisation plane. We present an approach that assesses the probability that the observed phenomenology is the result of pure noise. We conclude that although this possibility cannot be excluded it is much more likely that the EVPA undergoes an intrinsic evolution. We compute the most probable parameters of the intrinsic event which forecasts events consistent with the observations. In one case we find that the EVPA shows a preferred direction which, however, does not imply any dominance of a toroidal or poloidal component of the magnetic field at those scales.

Revisiting narrow-line Seyfert 1 galaxies and their place in the Universe - NLS1 Padova
9-13 April 2018
Padova Botanical Garden, Italy

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1. Introduction: why study Narrow line Seyfert 1 galaxies

The term narrow-line Seyfert 1 galaxies (NLSy1s) labels the subset of active galactic nuclei (AGN) with narrow width of the broad Balmer emission line (FWHM(Hβ)$\leq$ 2000 km s^{-1}), and weak forbidden lines with [O$_{\rm III}$]λ5007/Hβ < 3 [1, 2, 3]. NLSy1s are thus associated with black hole masses in the range 10^6–10^8 M$_\odot$ [4, 5, 6, 7] smaller than those of powerful radio galaxies that typically exceed 10^8 M$_\odot$. The detection of GeV [8, 9, 10, 11] and radio emission [12, 13, 14] from jetted NLSy1s, challenges the current understanding of relativistic jet formation in which powerful relativistic jets are preferentially found in elliptical galaxies with nuclear black hole masses beyond 10^8 M$_\odot$. The systematically lower-mass black holes and the accretion with rates close to the Eddington limit ($0.2-0.9\ L_{\rm Edd}$), make this class of source a unique probe of a previously unexplored parameter space. Here we study the optical polarisation variability of 10 selected jetted NLSy1s. All the details are discussed in section 4.

2. Previous studies: radio variability

For the first four NLSy1s detected in GeV energies we initiated a comprehensive multi-frequency monitoring of their radio emission which is discussed in [13]. The program – which is still ongoing – has been collecting data at 10 frequencies between 2.64 GHz and 142.33 GHz with initially monthly and later biweekly cadence. All sources show blazar-like behaviour characterised by intense variability and pronounced spectral evolution. From the estimates of the brightness temperatures we infer moderate Doppler factors indicative of rather moderately relativistic jets. Similarly, the jet powers we computed placed them in the class of the least energetic blazars (BL Lac objects). Figure 1 illustrates the radio SEDs updated with recently observed data.

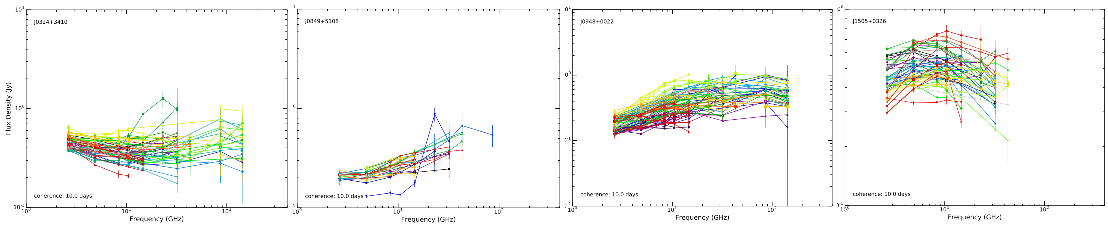

Figure 1: Radio SEDs of the first four NLSy1s that were detected in GeV bands. Till the end of 2015 the nominal cadence is roughly one measurement per month. Afterwards it is almost biweekly.

Later we studied the structural dynamics of the NLSy1 1H 0323+342 with 15 GHz MOJAVE data [15]. We found superluminal components exhibiting speeds up to 6.9 c indicative of a relativistic jet. On the basis of these apparent motions and an estimate of the variability Doppler factor of $\delta_{\rm var} \sim 5.2$, we inferred a viewing angle of less than $\sim 10^\circ$ confirming the "aligned jet" scenario [8].

3. Current study: optical polarisation variability

As a natural next step of our previous studies which indicate the presence of a mildly relativistic jet, we further study the optical polarisation of RL NLSy1s. Specifically, our aim is to

Table 1: List of sources in our sample and their relevant parameters. The last two columns report the median polarisation fraction and its scatter as derived from our study. The radio loudness R is defined as the ratio of the 6 cm flux to the optical flux at 4400 Å [20]. Its values are approximate given the high-amplitude variability of most sources in the radio and optical band.

ID	Survey ID	Redshift	R	Notes	$\langle\hat{p}\rangle$	σ_p
J0324+3410	1H 0323+342	0.062900	318	Fermi	0.012	0.016
J0849+5108	SBS 0846+513	0.584701	1445	Fermi	0.100	0.078
J0948+0022	PMN J0948+0022	0.585102	355	Fermi	0.024	0.028
J1305+5116	WISE J130522.75+511640.3	0.787552	223		0.040	0.030
J1505+0326	PKS 1502+036	0.407882	1549	Fermi	0.010	0.002
J1548+3511	HB89 1546+353	0.479014	692		0.021	0.024
J1628+4007	RX J16290+4007	0.272486	29		0.000	…
J1633+4718	RX J1633.3+4718	0.116030	166		0.024	0.004
J1644+2619	FBQS J1644+2619	0.145000	447	Fermi	0.022	0.015
J1722+5654	SDSS J172206.02+565451.6	0.425967	234		0.000	…

quantify the variability of the optical polarisation and compare it with that of typical blazars. The ultimate aim, however, is to examine whether long rotations of the optical polarisation plane similar to those systematically found in blazars [16] occur also in the case of NLSy1s. And, if so, what is their association with the activity in the GeV energy bands.

4. Sample and dataset

We focus on a sample of 10 jetted NLSy1s (table 1) with estimates of the SMBH mass ranging from approximately a few 10^6 to a few 10^8 $M_\odot$, with the majority to lie between 10^{7-8} $M_\odot$. Five of them are detected by *Fermi* while the remaining five were selected mostly on the basis of their radio-loudness, optical brightness, visibility with the Skinakas telescope and redshift. The latter meant to minimise the host galaxy contribution. Among them, SDSSJ1722+5654 stands out because of its high-amplitude optical variability of ~ 3 mag [17]. The RoboPol [18] dataset that has been pivoting our research has been augmented with data from the KANATA, Perkins and Steward [19] observatories whenever possible. The $n \times \pi$ ambiguity innate in the solution of the equation giving the electric vector position angle (EVPA): $\mathrm{EVPA} = 0.5\tan^{-1}(U/Q)$ is resolved by the "minimum angle variability" assumption. That is, from the family of solutions we chose the one for which the absolute difference to the previous angle is a minimum. In table 1 we also tabulate the median polarisation fraction and its scatter as derived from our study. Figure 2 shows the EVPA and p curves for the two best-sampled sources, namely J10324+3410 (upper panel) and J1505+0326 (lower panel). In these plots the reported polarisation fraction has been de-biased (i.e. treating the Rice bias as described in [21]) and the $n \times \pi$ ambiguity has been removed from the EVPA as discussed earlier.

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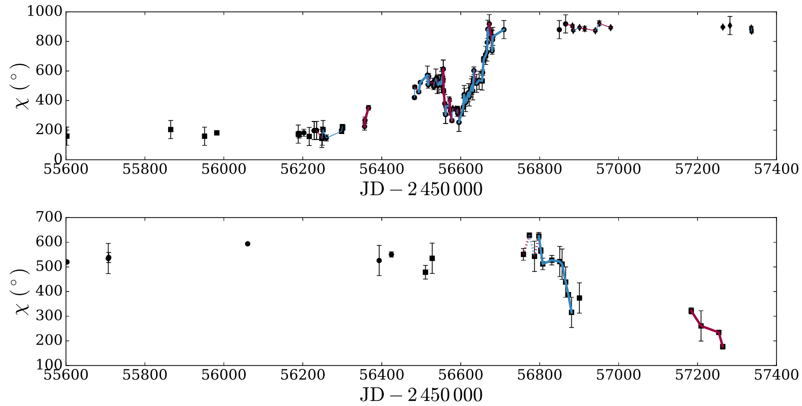

Figure 2: The EVPA (χ) as a function of time. The coloured lines mark periods of significant monotonous – within the uncertainties – EVPA evolution. Upper panel is for J10324+3410 and lower panel is for J1505+0326. Solid lines mark periods of long rotations (i.e. at least three sequential data points and angle larger than 90°). *Red* and *blue* connecting lines are used alternatively for ease of visualization.

5. EVPA variability

We study the variability of both polarisation parameters and search for candidate long rotations of the EVPA. Such events are sought among periods of significant EVPA variability (after accounting also for the uncertainties in the EVPA), that (i) consist of at least 3 data points, and (ii) cover polarisation angles more than 90°.

5.1 J1505+0326: a possible long rotation of the polarisation plane

We start with J1505+0326 (Fig. 2 lower panel) because it: (i) comprises a study case for our approach for the assessment of the reliability of the detected long rotation, and (ii) because it is the case with the largest probability that the detected apparent rotation is driven by an intrinsic event. From the periods of significant EVPA variability two qualify to long ones and are marked with solid lines in Fig. 2. For the longest event (lower panel, blue solid line) the polarisation plane rotates by almost -309.5° at a mean rate of $\Delta\chi/\Delta t \approx -3.7$ deg d^{-1}.

First we discuss the reliability of the observed event. The combination of relatively sparse sampling and the large uncertainties in the EVPA, make the direction of evolution of the EVPA uncertain making the rotation event itself, unreliable. This is the consequence of the fact that the large EVPA uncertainties may allow both χ and $\chi+\pi$ to be valid solutions for the angle. We assume that each measurement of the Q and U indeed described the true source polarisation state. By allowing Stokes parameters to oscillate within the range of the observed uncertainties we produce a large number of EVPA curves and compared them to the observed event. We find that the probability for such a curve to be within 1σ of the observed rotation is around 23%.

We then investigate whether the observational noise alone can produce the observed event while the EVPA remains unchanged, i.e. $d\chi_{\rm intr}/dt = 0$. After 25×10^4 iterations we find that the probability of finding a full rotation, is

$$P\,(\text{full rotation};\, |\Delta\chi_{\rm intr}| \geq 309.5^\circ|\, d\chi_{\rm intr}/dt = 0) = 6\times10^{-4} \tag{5.1}$$

fairly lower than the 23% estimated earlier. From this we conclude that although it is indeed possible that noise alone can cause the observed phenomenology, it is much more unlikely that an intrinsic evolution of the EVPA is driving the observed behaviour.

On the basis of the assumption that the intrinsic event is obeying a constant rotation rate ($d\chi_{\rm intr}/dt =$ constant) we compute the most probable rate and examine whether the observed rotation is consistent with the predictions of this assumption. We find that for a full rotation over an angle within 1σ of the observed one the most probable rate is -3.1 deg d^{-1}. The distribution of the simulated events shows that indeed the observed angle of rotation is consistent wit the assumption of a constant rotation rate.

5.2 J0324+3410: the randomness of the EVPA

Intrigued by the dependence on the synchrotron peak frequency of the randomness of the EVPA [22, 23], we examined the distribution of the EVPA in the best-sampled case in our dataset, J0324+3410 (Fig. 3). As shown in the left panel of Fig. 3 , the EVPA exhibits a preferred angle which can be approximated by the median of $-6.7°$. In [15] we show that the 15 GHz radio jet has a position angle of around 124°. Assuming then that the transmitting plasma is transparent at optical wavelengths the projected magnetic field (perpendicular to the observed EVPA) will be at 40.7° with the radio jet; this orientation is ambiguous as to whether a poloidal or a toroidal configuration is dominant in that part of the flow (Fig. 3 right hand panel).

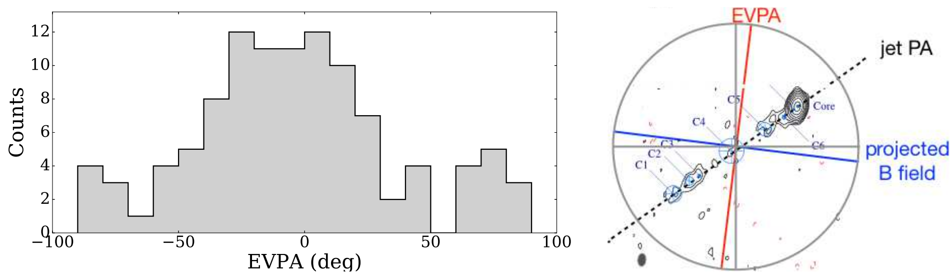

Figure 3: The distribution of the EVPA in the range $[-90, +90]$ for J10324+3410. Right hand panel shows the inferred orientation of the projected magnetic field to the radio jet.

6. Conclusions

After the systematic multi-frequency radio monitoring presented in [13] and the study of the structural evolution of J0324+3410 [15], we have monitored the *R*-band optical polarisation of a total of 10 jetted NLSy1 galaxies five of which have been detected by *Fermi*-GST. Our findings show that the EVPA undergoes significant variability. In the two best-sampled cases we find candidate long rotations of the polarisation plane similar to those found in blazars. We assess the reliability of these events and we conclude that (at least in one case) although pure noise can induce the observed behaviour, it is much more likely that an intrinsic evolution of the EVPA is taking place. Denser sampling will be necessary for proving the case. Nevertheless, this is the first report of such candidate events in this class of sources; yet another indication for the operation of a blazar-like jet. In the case of J0324+3410 we show that EVPA shows a preferred orientation which corresponds to a projected magnetic field of around 40° to the radio jet. This orientation is ambiguous with regards to whether a toroidal or a poloidal field dominates at those scales.

Acknowledgements

This conference has been organized with the support of the Department of Physics and Astronomy "Galileo Galilei", the University of Padova, the National Institute of Astrophysics INAF, the Padova Planetarium, and the RadioNet consortium. RadioNet has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730562. The RoboPol project is a collaboration between Caltech in the USA, MPIfR in Germany, Torun Centre for Astronomy in Poland, the University of Crete/FORTH in Greece, and IUCAA in India. Data from the Steward Observatory spectropolarimetric monitoring project were used. This program is supported by Fermi Guest Investigator grants NNX08AW56G, NNX09AU10G, NNX12AO93G, and NNX15AU81G. The authors wish to thank the internal MPIfR referee Dr N. MacDonald for the careful reading of the manuscript and the detailed and useful comments.

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PoS(NLS1-2018)019