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Spectroscopic and polarimetric study of radio-quiet weak emission line quasars

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Abstract: A small subset of optically selected radio-quiet QSOs with weak or no emission lines may turn out to be the elusive radio-quiet BL Lac objects, or simply be radio-quiet QSOs with an infant/shielded broad line region (BLR). High polarisation (p $> 3-4\%$), a hallmark of BL Lacs, can be used to test whether some optically selected 'radio-quiet weak emission line QSOs' (RQWLQs) show a fractional polarisation high enough to qualify as radio-quiet analogues of BL Lac objects. To check this possibility, we have made optical spectral and polarisation measurements of a sample of 19 RQWLQs. Out of these, only 9 sources show a non-significant proper motion (hence very likely extragalactic) and only two of them are found to have p $> 1\%$. For these two RQWLQs, namely J142505.59+035336.2 and J154515.77+003235.2, we found the highest polarization to be $1.59\pm0.53\%$, which is again too low to classify them as (radio-quiet) BL Lacs, although one may recall that even genuine BL Lacs sometimes appear weakly polarised. We also present a statistical comparison of the optical spectral index, for a sample of 45 RQWLQs with redshift−luminosity matched control samples of 900 QSOs and an equivalent sample of 120 blazars, assembled from the literature. The spectral index distribution of RQWLQs is found to differ, at a high significance level, from that of blazars. This, too, is consistent with the common view that the mechanism of the central engine in RQWLQs, as a population, is close to that operating in normal QSOs and the primary difference between them is related to the BLR.

1 Introduction

BL Lac objects are AGNs with very weak or absent lines in the optical/UV spectrum and their electro-magnetic spectrum is dominated by nonthermal, variable emission emanating from a relativistically Doppler boosted jet (e.g., Urry & Padovani 1995). Traditionally, BL Lac objects have been discovered from radio and X-ray

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surveys. The two populations of BL Lacs (radio-selected, RBL, or X-ray selected, XBL) are known to have significant differences in parameters, such as the peak frequency of the Spectral Energy Distribution (e.g., Padovani et al. 1995) and optical polarization, p (e.g., Jannuzi et al. 1994). Compared to XBLs, the RBLs show more prominent radio cores, stronger polarization and flux variability, as well as higher luminosities in the radio and optical. It is presently unknown if there exists a tiny subset of BL lacs which is radio-quiet, by analogy to the abundant population of radio-quiet quasars. Stocke et al. (1990) pointed out that unlike the radio dichotomy of quasars, there is no evidence for populations of BL Lac objects distinguished by radio loudness. Optical surveys for Radio-Quiet Weak-Line Quasars (RQWLQs) offer the best route for finding radio-quiet BL Lacs, should they exist. Clearly, discovering even a minuscule population of radio-quiet BL Lacs would have enormous ramifications for understanding the physics of AGN. Perhaps the most practical strategy to search for the putative radio-quiet BL Lacs among the candidates (i.e., RQWLQs) is to look for the characteristic optical signatures of BL Lacs, namely a high (and variable) polarization, and a large ($> 5\%$) intranight flux variability. Several polarimetric searches have reported negative results (e.g., Smith et al. 2007; Diamond-Stanic et al. 2009; Heidt & Nilsson 2011). However, the other signature, namely a strong Intra-Night-Optical-Variability (INOV), has begun to be exploited only in the recent past (see, Gopal-Krishna et al. 2013; Chand et al. 2014 (Paper II); Liu, Y. et al. 2015; Kumar et al. 2015 (Paper III); 2016). Recall that for BL Lacs, INOV amplitudes $\psi > 3\%$ are known to occur with a duty cycle of $\sim 40 - 50\%$ if monitored for more than $\sim$ 4 hours (e.g., Gopal-Krishna et al. 2003; Goyal et al. 2012). So far, we have obtained intranight (differential) light curves of 33 RQWLQs in 60 sessions of minimum 3 hour duration (Kumar et al. 2017). Although we find the duty cycle for INOV detection to be only $\sim 3\%$ which is not unlike that known for radio-quiet QSOs (e.g., Carini et al. 2007; Goyal et al. 2013), two of the RQWLQs did show strong INOV ($\psi > 10\%$): J090843.25+285229.8 and J40710.26+241853.6 (Paper II & III). Thus, the purpose of our present high-sensitivity optical spectroscopy/polarimetry of RQWLQs (Sect. 2) was to find if any of them is strongly polarised and/or shows some spectral features.

2 Sample and Observation

Londish et al. (2002) have optically identified a sample of 56 featureless continuum objects from the 2dF QSO survey (2QZ). Likewise, Collinge et al. (2005) used the SDSS to extract 386 optically identified BL Lac candidates. Out of these 442 WLQs we extracted a set of 111 WLQs for polarimetry/spectroscopy, by limiting to (i) 8-17h right ascension range, and (ii) $<$ 20-mag (R) (88 out of the 386 and 23 out of the 56 candidates were thus short-listed). Since our observations were scheduled for April, we reduced our list from 111 to 19 RQWLQs by accepting only those in the 10-15h range and at sufficiently low declination for La Silla, and also brighter than 19.5-mag (R), as well as lacking any published polarisation measurement. The selected 19 RQWLQs either have a radio-loudness parameter R $<$ 10 (see, Kellermann et al. 1989), or a non-detection in the FIRST survey (i.e., somewhat conservatively, $<$ 1 mJy at 1.4 GHz, see Becker et al. 1995). Fifteen of these 19 RQWLQs could be covered in both our polarimetry and spectroscopy, 3 in spectroscopy alone, and one in the polarimetry alone. These observations were carried out during 24-28 April, 2006 with the ESO 3.6m telescope equipped with the ESO Faint Object Spectrograph and Camera (EFOSC; Buzzoni et al. 1984). The data were reduced using the standard tasks in IRAF. Using the latest astrometric catalogs, we have found that only 9 of these objects are consistent with zero proper motion and hence are genuine RQWLQs.

3 Results

3.1 RQWLQs Polarisation Properties

Results of our polarimetric observations for the 9 WLQs are listed in Table 1. Only two sources, J142505.59+035336.2 (on 2006.04.28) and J154515.77+003235.2 (on 2006.04.25 and 2006.04.27), showed a fractional polarization p $> 1\%$. The highest p measured is 1.59$\pm$0.53% for J154515.77+003235.2 on 2006-04-27. These two sources had earlier been observed by Smith et al. (2007) and Heidt & Nilsson (2011); they found J142505.59+035336.2

Table 1: Polarization (%) and polarization angle (PA) of 9 genuine 'RQWLQs'.

SDSS Name	P (%)	P.A (degree)	Obs. Date (yyyy.mm.dd)
(1)	(2)	(3)	(4)
J103607.52+015659.0	0.34±0.03	113.44	2006.04.26
J105355.17−005537.7	0.96±0.32	158.42	2006.04.26
J113413.48+001042.0	0.26±0.28	168.16	2006.04.27
J114554.87+001023.9	0.50±0.39	133.93	2006.04.27
J115909.61−024534.6	0.62±0.27	114.23	2006.04.26
J123437.64−012951.9	0.68 ±0.36	85.12	2006.04.27
J125435.81−011822.0	0.64±0.37	117.58	2006.04.28
J142505.59+035336.2	1.03±0.36	141.98	2006.04.28
J154515.77+003235.2	1.03±0.61	35.78	2006.04.25
	1.59±0.53	66.95	2006.04.27

and J154515.77+003235.2 to have p $< 0.9\%$, and $< 0.6\%$, respectively (Smith et al. 2007) and 1.1±0.6% & $<$ 5.6% (Heidt & Nilsson 2011).

3.2 Spectroscopic Properties of RQWLQs

Our sensitive ESO 3.6m EFOSC observations were aimed at detecting any faint spectral features in these RQWLQs. Fig. 1 shows their spectra (except for J125435-011822, which could not be observed). Since even the present deep spectroscopy has failed to reveal any spectral features in these sources, we have to rely on their available redshifts based on template fitting method (Hewitt 2010). We next combine this data-set with the redshift and spectral measurements available for the 33 RQWLQs constituting the sample we have monitored for intranight variability (Kumar et al. 2017). The spectra for the combined set of 45 RQWLQs are used here for comparison with large 'control' samples of RQWLQs and of confirmed blazars, as outlined below.

The Control sample of QSOs:
We assembled a control sample of 900 SDSS QSOs such that for each of the 8 RQWLQs we selected 20 normal QSOs matching in redshift within $\mid \Delta z \mid < 0.005$ and in magnitude within $\mid \Delta m \mid < 0.1$. Further, using the same narrow windows we selected a control sample of 120 blazars out of the sample being monitored in the Catalina Real-Time Transient Survey (CRTS, Drake et al. 2009). The spectral slope distribution of these 3 'matched' samples of RQWLQs, QSOs and blazars, are compared in Fig. 2. The KS-test for spectral slopes of these three classes implies that RQWLQs and blazar are different at a significance level of 97.42%. QSOs and blazars are also found to differ at similarly high significance level (i.e 99.97%), whereas the RQWLQs and QSOs differ at a much lower significance level of 61.17%. Note that for fitting the spectral slope, we used the Levenberg-Marquardt least-squares minimization technique (the MPFIT package, Markwardt 2009). In this fitting process, we applied (i) a power law function, i.e $a\lambda^{\alpha}$, to describe the AGN continuum, and (ii) the Fe II template discussed in Kovacevic et al. (2010) to describe the probable optical Fe II lines.

4 Discussion and Conclusion

In our polarimetric study, only J142505.59+035336.2 and J154515.77+003235.2 have shown polarization above 1%, with a maximum of 1.59±0.53% found for the latter (Table 1). Even these values for the two RQWLQs are clearly low compared to those typical of BL Lacs ($> 4\%$, and average $\sim 7\%$, e.g., Heidt & Nilsson 2011). Note also that all the 8 RQWLQs spectra presented here persist to be featureless (Fig. 1), precluding firm redshifts. To get some clue on the continuum emission mechanism in RQWLQs, we have compared the

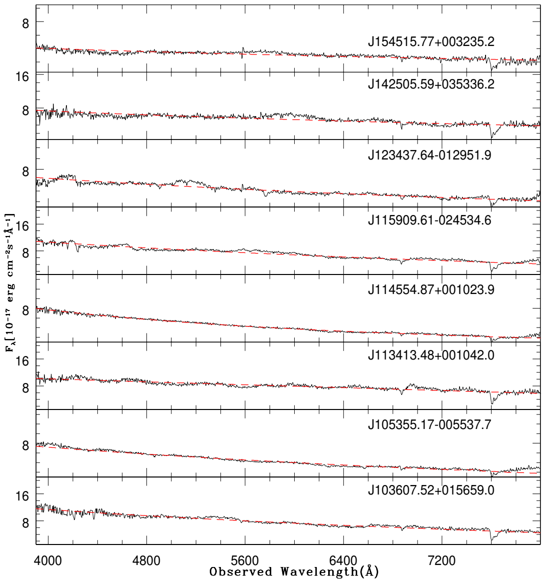

Figure 1: EFOSC spectra of our 8 RQWLQs. Each spectrum is shown with a solid line (black) and the spectral slope fit with a dashed line (red).

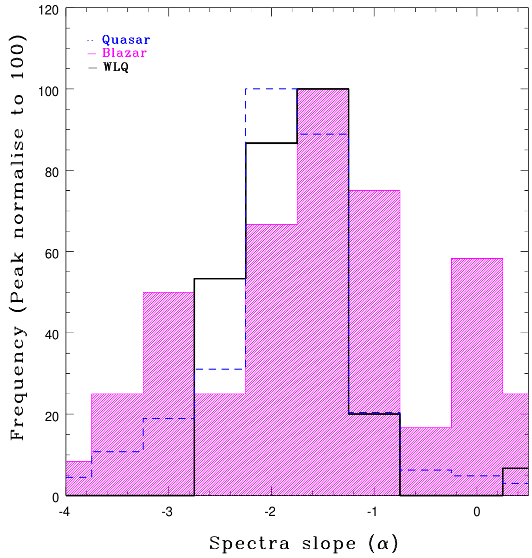

Figure 2: Spectral slope distribution for QSOs (blue dashed line), blazars (magenta shading) and RQWLQs (thick black line).

spectral slope distribution of the 45 RQWLQs with those of the redshift-luminosity matched large samples of 900 QSOs and of 120 blazars (the slope is parametrized in terms of the best-fit power-law to the continuum spectrum). From Fig. 2 we infer that the RQWLQs differ, statistically, from blazars at a high significance level (97.42%), but from the QSOs at a low significance (61.17%). Thus, the present study of spectral and polarization properties of RQWLQs supports the premise that, at least in statistical terms, the central engine of RQWLQs has a much greater resemblance to that operating in QSOs, rather than blazars (for which the relativistic nonthermal jet dominates the spectrum). In this framework, the abnormal weakness of broad emission lines in RQWLQs points to a broad-line region which is either still forming (e.g., Hryniewicz et al. 2010), or is effectively shielded from the ionizing photon flood coming from the central engine (e.g., Lane et al. 2011).

References

Abazajian K., Adelman-McCarthy J. K., Agüeros M. A. et al. 2004, AJ, 128, 502
Becker R. H., White R. L., Helfand D. J. 1995, ApJ, 450, 559
Buzzoni B., Delabre B., Dekker H. et al. 1984, The Messenger, 38, 9
Carini M. T., Noble J. C., Taylor R., Culler R. 2007, AJ, 133, 303
Chand H., Kumar P., Gopal-Krishna 2014, MNRAS, 441, 726
Collinge M. J., Strauss M. A., Hall P. B. et al. 2005, AJ, 129, 2542
Diamond-Stanic A. M., Fan X., Brandt W. N. et al. 2009, ApJ, 699, 782
Drake A. J., Djorgovski S. G., Mahabal A. et al. 2009, ApJ, 696, 870
Gopal-Krishna, Stalin C. S., Sagar R., Wiita P. J., 2003, ApJ, 586, L25
Gopal-Krishna, Joshi R., Chand H. 2013, MNRAS, 430,130
Goyal A., Gopal-Krishna, Wiita P. J. et al. 2012, A&A, 544, A37
Goyal A., Gopal-Krishna, Wiita P. J., Stalin C. S., Sagar R. 2013, MNRAS, 435, 1300
Heidt J., Nilsson K. 2011, A&A, 529, A162
Hryniewicz K., Czerny B., Niko lajuk M., Kuraszkiewicz J. 2010, MNRAS, 404, 2028
Jannuzi B. T., Smith P. S., Elston R. 1994, ApJ, 428, 130
Kellermann K. I., Sramek R., Schmidt M., Shaffer D. B., Green R. 1989, AJ, 98, 1195
Kumar P., Gopal-Krishna, Chand H. 2015, MNRAS, 448, 1463
Kumar P., Chand H., Gopal-Krishna 2016, MNRAS, 461, 666
Lane R. A., Shemmer O., Diamond-Stanic A. M. et al. 2011, ApJ, 743, 163
Londish, D., Croom, S. M., Boyle, B. J. et al. 2002, MNRAS, 334, 941

Markwardt C. B., 2009, in Astronomical Society of the Pacific Conference Series, Vol. 411, Astronomical Data Analysis Software and Systems XVIII, Bohlender D. A., Durand D., Dowler P., eds., p. 251
Padovani P., Giommi P. 1995, ApJ, 444, 567
Smith P. S., Williams G. G., Schmidt G. D., Diamond-Stanic A. M., Means D. L. 2007, ApJ, 663, 118
Stocke J. T., Morris S. L., Gioia I. et al. 1990, ApJ, 348, 141
Urry, C. M., Padovani P. 1995, PASP, 107, 803