

Optical spectral properties of radio loud quasars along the main sequence

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Abstract. We analyze the optical properties of Radio-Loud quasars along the Main Sequence (MS) of quasars. A sample of 355 quasars selected on the basis of radio detection was obtained by cross-matching the FIRST survey at 20cm and the SDSS DR12 spectroscopic survey. We consider the nature of powerful emission at the high-FeII end of the MS. At variance with the classical radio-loud sources which are located in the Population B domain of the MS optical plane, we found evidence indicating a thermal origin of the radio emission of the highly accreting quasars of Population A.

Keywords. quasars, radio-loud, star formation

1. Introduction

The 4D Eigenvector 1 (E1) is a powerful tool to contextualize the diversity of observational properties in type-1 AGN (see e.g., [Marziani et al. 2018](#) for a recent review). The distribution of the quasars in the E1 optical plane, defined by the FWHM of the H β broad component vs. the FeII strength (parametrized by the ratio $R_{\text{FeII}} = I(\text{FeII}\lambda 4570)/I(\text{H}\beta)$), outlines the quasar Main Sequence (MS). The shape of the MS (Figure 1, left plot) allow us for the subdivision of quasars in two Populations (A and B) and in bins of FWHM(H β) and FeII which define a sequence of spectral types (STs):

1) Pop. A with $\text{FWHM}(\text{H}\beta) \leq 4000 \text{ km s}^{-1}$, and with STs defined by increasing R_{FeII} from A1 with $R_{\text{FeII}} < 0.5$ to A4 with $1.5 \leq R_{\text{FeII}} \leq 2$. STs A3 and A4 encompass the extreme Pop. A of highly accreting quasars radiating near the Eddington limit.

2) Pop. B with $\text{FWHM}(\text{H}\beta) > 4000 \text{ km s}^{-1}$, and STs bins (B1, B1⁺, B1⁺⁺, ...) defined in terms of increasing $\Delta\text{FWHM}(\text{H}\beta) = 4000 \text{ km s}^{-1}$ (see sketch in Figure 1, left plot).

Eddington ratio $\lambda_E = L_{\text{Bol}}/L_{\text{Edd}}$ and orientation are thought to be the main physical drivers of the MS ([Marziani et al. 2001](#); [Sulentic et al. 2017](#)). Eddington ratio changes along the R_{FeII} axis. Pop. B quasars are the ones with high black hole mass (M_{BH}) and low λ_E and Pop. A are fast-accreting sources with relatively small M_{BH} . Radio-Loud (RL) quasars, defined as relativistic jetted sources, are not distributed uniformly along the MS ([Zamfir et al. 2008](#)). They are predominantly found in the Pop. B domain, having $R_{\text{FeII}} < 0.5$ and $\text{FWHM}(\text{H}\beta) > 4000 \text{ km s}^{-1}$. The extreme broad Pop. B⁺⁺ quasar bin ($\text{FWHM}(\text{H}\beta) > 12000 \text{ km s}^{-1}$) contains about 30% of the RLs but only $\sim 3\%$ of quasars ([Marziani et al. 2013](#)).

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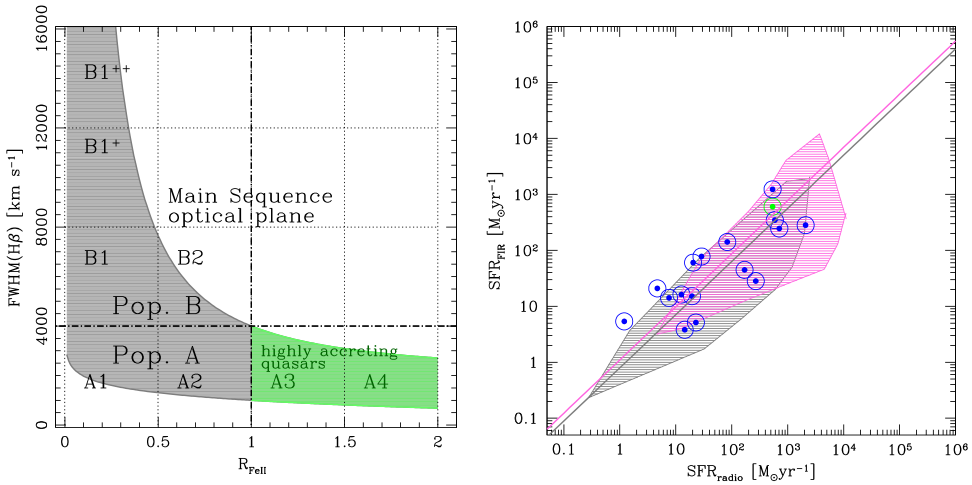


Figure 1. Left: sketch of the optical plane of the MS of quasars and the STs. Green area traces the location of the extreme Pop. A quasars (xAs); Right: FIR vs. radio SFR for the xAs with FIR data. The shaded areas trace the loci of star-forming galaxies (grey) and RQ quasars (pink).

2. Sample

We selected quasars from the SDSS-BOSS DR12 Quasar Catalog (Pâris *et al.* 2017) with $m_i \leq 19.5$ and redshift ≤ 1 and cross-matched with the VLA FIRST radio survey at 20cm (Becker *et al.* 1995). A detailed description of the sample and the performed analysis can be found in Ganci *et al.* (2019). The classification of the quasars was carried out according to three criteria:

- Radio power, based on the $R_K = f_{\text{rad}}/f_{\text{opt}}$ parameter (Kellermann *et al.* 1989), defined on the basis of the 1.4 GHz and g magnitude estimates. Sources with $\log R_K < 1.0$ are classified as Radio-Detected (RD); those with $1.0 \leq \log R_K < 1.8$ as radio-intermediate (RI) and for $\log R_K \geq 1.8$ as RL.
- Radio morphology as Core Dominated (CD) and FR II sources, selected using the statistical procedure defined by de Vries *et al.* (2006).
- Optical ST classification in terms of the MS.

The final sample consist of 355 objects, 289 CD and 66 FR II. There are a total of 38 RD, 139 RI and 178 RL objects.

3. Results

We have analyzed the source distribution along the MS. Table 1 shows a summary of the number of sources for both Pop. A and B and for the particular case of the extreme accreting Pop. A quasars (xAs, STs A3-A4), according to its radio loudness and radio morphology. From this analysis we found:

- The most populated STs are the Pop. B bins (72% of the sources), especially B1 (36%) and B1⁺ (22%) at variance with optically selected samples (Marziani *et al.* 2013) where B1 and A2 are the most populated STs.
- RD sources are only present in CD radio morphology (21 Pop. A, and 17 Pop. B).
- RLs sources have also only CD morphology, but are more numerous in Pop. B (70%).
- RLs are significantly more numerous in Pop. B for the CD morphology and FR II sources appear only in RL class, and are almost exclusively Pop. B (95%).

The most powerful radio quasars are located in Pop. B both for FR II and CD radio morphologies and they are most likely jetted RL quasars, meanwhile Pop. A shows almost

Table 1. Number of sources by population and radio-loudness.

	CD			FRII		
	RD	RI	RL	RD	RI	RL
Pop. B	17	96	81	-	-	63
Pop. A	21	43	31	-	-	3
xA (STs A3-A4)	5	17	5	-	-	-

exclusively CD morphology, with about 28% of the CD objects classified as Pop. A but with significant lower radio power than CD Pop. B sources.

The spectral analysis of the SDSS-BOSS spectra of the sample confirms the systematic differences between Pop. A and Pop. B, and the trends associated with the quasar MS, similar for all radio classes.

- The centroid at half maximum of $H\beta$ passes from redshifted in Pop. B, due to the presence of the very broad component characteristic of this population of quasars, to clearly blueshifted in xAs.

- Equivalent width of $H\beta$ remains roughly constant in Pop. B quasars, but dramatically decreases in Pop. A.

- From the B1⁺⁺ to the A4 STs, λ_E increases and M_{BH} decreases, independently of the radio classes.

A very interesting result from our analysis is that about 80% (22/27) of the xA CD have a radio emission in the loud range (RI and RL). Are these RL and RI xAs truly jetted sources?, or is its radio power dominated by thermal emission? We have investigated the possible origin of their radio emission by analyzing its FIR luminosity and through the FIR-radio star formation rate (SFR) relation (Bonzini *et al.* 2015), since RL jetted sources are expected to have FIR luminosity significantly lower than the one expected for their radio power. We show in Figure 1 (right) the FIR and radio power SFR for the xAs sources with FIR data available from both this sample and the xAs in Bonzini *et al.* (2015) sample (see Ganci *et al.* 2019), together with the location of the star forming galaxies (gray shaded area) and radio-quiet (RQ) quasars (pink area). xAs sources have both high radio power and SFR. They are placed in the RQ and star-forming galaxies regions, suggesting that their radio power is due to the thermal emission. And none of the other sources, included in Table 1, that fall in the RL region (outside and to the right of the shaded areas) is an xA source.

It is therefore reasonable to suggest that most of the xAs that are RI and RL are non-jetted sources and they might be truly “thermal sources”. Our study (Ganci *et al.* 2019) supports the suggestion that RI and RL A2, A3, A4 sources could be thermal in origin.

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