What about high redshift sources in the Main Sequence of quasars?

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Abstract. Much effort has been done in order to better understand the active galactic nuclei mechanisms behind the relativistic jets observed in radio-loud sources. These phenomena are commonly seen in luminous objects with intermediate/high redshift such as quasars, so that the analysis of the spectroscopic properties of these sources may be a way to clarify this issue. Measurements are presented and contextualized taking advantage of the set of correlations associated with the quasar Main Sequence (MS), a parameter space that allows to connect observed properties to the relative relevance of radiative and gravitational forces. In the redshift range we consider, the low-ionization H\textsc{i} Balmer line H\textsc{β} is shifted into the near infrared. Here we present first results of a sample of 22 high-luminosity quasars with redshift between 1.4 and 3.8. Observations covering the H\textsc{β} spectral region were collected with the IR spectrometer ISAAC at ESO-VLT. Additional data were collected from SDSS in order to cover the UV region of our sources. The comparison between the strong C IV 1549 high-ionization line and H\textsc{β} in terms of line widths and shifts with respect to the rest-frame leads to an evaluation of the role of radiative forces in driving an accretion disk wind. While for non-jetted quasars the wind properties have been extensively characterized as a function of luminosity and other physical parameters, the situation is by far less clear for jetted sources. The overarching issue is the effect of the relativistic jets on the wind, and on the structure of the emitting region in general. We present results from our analysis of the optical and UV line profiles aimed to identifying the wind contribution to the line emission.

Keywords. Quasars: general – Quasars: emission lines – Galaxies: active

1. Introduction

The fourth-dimensional Eigenvector 1 (4DE1) has been proposed by Sulentic, Zwitter, Marziani, and Dultzin-Hacyan (2000) and allows for the classification of the different low-redshift quasars. The 4DE1 consists of a correlation space that takes into account several key observational optical, UV, and X-ray measures that are related to outflow prominence, accretion mode and other physical parameters.

One important measurement in the 4DE1 context is the full width at half maximum (FWHM) of H\textsc{β}, which can be interpreted as a measure of virialized motions in the accretion disc (Marziani et al. 2018). In addition, another optical property of the Eigenvector 1 is the ratio between the intensities of the Fe II blend at 4570 Å and H\textsc{β} (R_{Fe II}=I(Fe II 4570)/I(H\textsc{β})). This property can reveal more details of the Broad Line Region (BLR), as it is dependent on the ionization state, the electron density, and column density of this region.
increasing FWHM(Hβ), going from B1 to B1++. Also, strong wind components are expected in Pop. A and Pop. B in a high-redshift and high-luminosity context (Vietri et al. [2018] Sulentic et al. [2017]). In these situations there is a broadening of the emission line components such as Hβ and C IV.λ1549 (Sulentic et al. [2007]). In the present work, we report on the behaviour of a sample of 22 high-redshift sources in the context of the Main Sequence of quasars.

2. Sample and Observations

The sample consists of 22 QSOs with a redshift range of \( z = 1.4 \) – \( 3.8 \) and includes both radio-loud and radio-quiet sources. The infrared observations were performed at one of the eight-meter VLT telescopes under the programmes 083.B-0273(A) and 085.B-0162(A) from the European Southern Observatory (ESO). The spectroscopic reduction of the new VLT observations were performed in the standard way using the routines (ESO). The spectroscopic reduction of the new VLT observations were performed in the standard way using the routines (ESO). The spectroscopic reduction of the new VLT observations were performed in the standard way using the routines (ESO). The spectroscopic reduction of the new VLT observations were performed in the standard way using the routines (ESO). The spectroscopic reduction of the new VLT observations were performed in the standard way using the routines (ESO).

The UV spectra were selected mainly from the archive of the Sloan Digital Sky Survey (SDSS). The UV spectral range were observed in the optical domain due to the high redshift of the sample and includes emission lines such as C IV.λ1549, He II.λ1640, and Si IV+O IV].λ1500.

We have also performed the redshift (z) estimation based on the Hβ emission line and the same value of z was applied for the optical and UV spectra. One example of optical and UV spectra at rest-frame is shown in Fig. [1]. We present the data for SDSSJ161458.33+144836.9, which has a redshift \( z = 2.5698 \). Regarding the radio frequencies data, they were collected from the Faint Images of the Radio Sky at Twenty-Centimeters (FIRST, Becker, White, and Helfand [1994]) and The NRAO VLA Sky Survey (NVSS, Condon et al. [1998]) survey archives.

3. Spectral analysis

In order to perform the spectral analysis, we implemented a minimum-\( \chi^2 \) fit of the continuum and of the individual spectral line components through the specfit routine from IRAF. By performing these fittings, we are able to evaluate the FWHM, peak wavelength, and flux intensities of all the line components. Here we will discuss the fittings of Hβ+[OIII].λ4959, 5007 and C IV.λ1549+He II.λ1640 regions.

For the optical range, we have fit the Hβ+[O III].λ4959, 5007 range. In general, we consider three/four different profiles: a blueshifted component (BLUE), a symmetric and unshifted broad component (BC), a redshifted very broad component (VBC, only for Pop. B sources), and a narrower component (NC), apart from a power law continuum and a scalable Fe II emission template. We used the Fe II template from Boroson and Green ([1992] updated with the improvements of Marziani, Sulentic, Stirpe, Zamfir, and Calvani [2009]). BLUE components are seen as a good indicator of non-virial motion and/or outflowing gas from the central region and the BCs are thought to account for the virialized motion from the Broad Line Region (BLR).

Depending on the classification of the source, we fit the spectra in different ways. In the case the quasar is a Pop. A, the BC is represent by a Lorentzian profile and all the other components by Gaussians. On the other hand, if the source is a Pop. B, then all the components are fitted by Gaussian-like profiles. Our initial guess is that the NC and BC are located in the rest-frame, differently from the BLUE and VBC. Apart from the shift towards lower wavelengths, blueshifted components can also present blueward asymmetries.

[O III].λ4959,5007 emission lines were fitted following a similar approach of Hβ. In this case, the full profile is composed by a narrow component (NC) and a semi-broad component (SBC) for the two populations. The SBC is considered to represent a Lorentzian shape for Pop. A and a Gaussian profile for Pop. B sources. We assume that narrow components of Hβ and [OIII].λ4959,5007 share the same shift, FWHM and asymmetry.

Regarding the UV spectra, we fit the C IV.λ1549+He II.λ1640 emission lines. In the case the source is Pop. A, we reproduce the full profile by including only two profiles: a Lorentzian-like BC placed at rest-frame and a blueshifted component. For Pop. B, we include a VBC in addition to the BC+BLUE and the BC present a Gaussian shape.
4. Results and Discussion

### 4.1. The multicomponent fittings

Examples of the fittings performed for the two populations A and B are shown in Fig. 2. We choose to present SDSSJ120147.90+120630.2 as an example of Pop. A and SDSSJ120147.90+120630.2 as Pop. B. As it can be seen, in the case of the Pop. A source the Hβ BC profile represents the majority of the contribution to the full emission line. In this source there is also a small contribution of the Hβ blueshifted component, which presents a strong asymmetry towards lower wavelengths. For SDSSJ120147.90+120630.2, which is the Pop. B example, the Hβ full profile is strongly affected by the presence of a redshifted very broad component. This effect is seen in all Pop. B sources from our sample.

In the two populations, it is expected that [O III]λλ4959,5007 present a combination NC+SBC, with a significant contribution of blueshifted SBC components. BLUES are seen in all the sample and can indicate outflowing gas as suggested by many authors (Zakamska, Hamann, and Páris 2016; Marziani et al. 2016; Cano-Díaz et al. 2012). In general, [O III]λλ4959,5007 is wider in Pop. A than in Pop. B sources in our sample.

Regarding the UV region, we analyse CIVλ1549+He IIλ1640. In Fig. 2, we show the fittings for one Pop. A and one Pop. B. In all the cases, the BC of CIVλ1549 is set at rest-frame and there is a strong contribution of blueshifted components to the full profile of CIVλ1549. The strongest BLUES components are seen in Pop. A and the redshifted VBC represent a significant part of the full profile of C IV λ1549 in Pop. B quasars. In the case of SDSSJ120147.90+120630.2 (the Pop. A one), it was necessary to include a second blueshifted component in order to fully reproduce the C IV λ1549 full profile. A similar behaviour is also seen in He IIλ1640.

#### Table 1. Measurements of the FWHM of full profile of Hβ and C IVλ1549 emission lines for the complete sample.

| Source identification | Pop. | FWHM(Hβ) (km s⁻¹) | FWHM(C IV) (km s⁻¹) |
|-----------------------|------|--------------------|----------------------|
| HE0001-2540           | B    | 6632 ± 529         | -                    |
| [HB89] [029]+073      | B    | 4971 ± 375         | -                    |
| CTQ0408               | B    | 6405 ± 399         | -                    |
| SDSSJ13003.18+1457.37 | A    | 3830 ± 342         | 8848 ± 562           |
| BQ05-2659             | B    | 5342 ± 438         | -                    |
| SDSSJ114358.52+052444.9 | B   | 5944 ± 465         | 7078 ± 766           |
| SDSSJ115954.33+021921.1 | B   | 6944 ± 543         | 5741 ± 585           |
| SDSSJ120147.90+120630.2 | B   | 5839 ± 521         | 4995 ± 475           |
| SDSSJ13212.33+142037.1 | A   | 3450 ± 314         | 5549 ± 399           |
| SDSSJ135851.78+050522.8 | A   | 3548 ± 312         | 7565 ± 633           |
| Q1410+096             | A    | 3394 ± 299         | 6311 ± 552           |
| SDSSJ141546.24+112943.4 | B   | 5595 ± 549         | -                    |
| B1422+231             | A    | 5136 ± 452         | -                    |
| SDSSJ153830.55+085517.0 | A  | 5107 ± 450         | 5819 ± 448           |
| SDSSJ161458.33+144836.9 | A  | 3722 ± 327         | 5790 ± 554           |
| PKS1937-101           | A    | 5298 ± 466         | -                    |
| PKS2000-330           | A    | 5118 ± 276         | 4950 ± 346           |
| SDSSJ210524.47+0000407.3 | A  | 5032 ± 443         | -                    |
| SDSSJ210831.56-063022.5 | A  | 5243 ± 365         | 9389 ± 519           |
| SDSSJ23329.46+005052.9 | A    | 5171 ± 405         | 7978 ± 524           |
| PKS2126-15            | A    | 4391 ± 451         | -                    |
| SDSSJ233808.54+012507.2 | A   | 4098 ± 360         | 6504 ± 398           |

#### Table 1. Measurements of the FWHM of full profile of Hβ and C IVλ1549 emission lines for the complete sample.

#### Figure 2. From left to right: Fittings of the C IV λ1549+He II λ1640 and Hβ+[O III] λλ4959,5007 emission lines. Top panels: Pop. A source SDSSJ12012.33+142037.1. Bottom panels: Pop. B source SDSSJ120147.90+120630.2. Pink dashed lines show the final fitting. Black and blue lines indicate broad and blueshifted components, respectively. Very broad components are shown by red lines. Orange and green lines represent narrow and Fe II components. Residuals are shown in the bottom of each plot.
a small shift to the blue, in a bin going from -1000 km s$^{-1}$ to 0 km s$^{-1}$. The sources that present [O III]λ4959,5007 blueshifts at half flux intensity larger than 2000 km s$^{-1}$ are Pop. A quasars. Similar behaviour happens in the C IV,λ1549 profile, shown in the left histogram of Fig. [3]. The sources that present larger c(1/2) for C IV,λ1549 are the Pop. A3 sources due to the presence of strong blueshifted components. Grey data on the right plot of Fig. [3] are from Sulentic et al. [2007], which is a sample with 70 low-redshift and low-luminosity RQ sources. In this case, the shifts at half intensity are very low when compared with our sample, with an averaged maximum of ≥ 1000 km s$^{-1}$.

4.3. The location in the optical plane

Fig. [4] shows the location of the sample in the 4DE1 optical plane. Blue and red points indicate Pop. A and Pop. B, respectively. Grey data are from the sample of Zamfir, Sulentic, and Marziani [2008] and characterize the Main Sequence of quasars at low redshift. As can be seen, our data present a displacement towards higher values of FWHM(H$\beta$) when compared to the sample of Zamfir, Sulentic, and Marziani [2008]. From Table [1] we can see that there are some sources that present a FWHM(H$\beta_{\text{max}}$) larger than 5000 km s$^{-1}$ as SDSSJ210524.47+000407.3 for instance. This is an expected behaviour in a high-luminosity context and the boundary FWHM(H$\beta$) = 4000 km s$^{-1}$ should be a proxy used for lower redshifts (Marziani, Sulentic, Stirpe, Zamfir, and Calvani [2009], Sulentic et al. [2009]).

5. Conclusions

We analysed a sample of 22 high-redshift and high-luminosity QSOs, and found 14 of them to be Pop. A and 8 to be Pop. B quasars. The study is performed under the 4DE1 context, taking advantages of optical and UV properties from the sample. The main conclusions are:

- Pop. B sources present broader full profiles of H$\beta$ than Pop. A, especially due to the virial VBC component shifted to the red;
- In general, C IV,λ1549 emission line present very strong blueshifted components in the profile, indicating that winds and outflowing gas, or even jets may perform an important role in the quasar;
- There is a clear displacement to larger FWHM(H$\beta$) in the 4DE1 optical plane when considering high redshift sources like our sample.

However, a more detailed study is needed in order to perform a complete analysis to clarify the situation of high-redshift and high-luminosity sources in the complete context of the 4DE1.

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References

Becker, R.H.; White, R. L.; and Helfand, D. J. 1994, Astronomical Data Analysis Software and Systems III, 61, 165

Boroson, T. A.; and Green, R. F. 1992, ApJS, 80, 109

Cano-Díaz, M.; Maiolino, R.; Marconi, A.; Netzer, H.; Shemmer, O.; Cresci, G. 2012, A&A, 537, L8

Condon, J. J.; Cotton, W. D.; Greisen, E. W.; Yin, Q. F.; Perley, R. A.; Taylor, G. B.; and Broderick, J. J. 1998, May, AJ, 115(5), 1693-1716

Martínez-Aldama, M. L.; del Olmo, A.; Marziani, P. et al. 2018, A&A, 618, A179

Marziani, P.; Dultzin, D.; Sulentic, J. W. et al. 2018, March, Frontiers in Astronomy and Space Sciences, 5, 6.

Marziani, P.; Sulentic, J. W.; Stirpe, G. M.; Dultzin, D.; del Olmo, A.; and Martínez-Carballo, M. A., 2016, Ap&SS, 361, 3

Marziani, P.; Sulentic, J. W.; Stirpe, G. M.; Zamfir, S.; and Calvani, M. 2009, A&A, 495(1), 83-112

Sulentic, J. W.; del Olmo, A.; Marziani, P.; Martínez-Carballo, M. A.; D’Onofrio, M.; Dultzin, D.; Perea, J.; Martínez-Aldama, M. L.; Negrete, C. A.; Stirpe, G. M.; Zamfir S. 2017, A&A, 608, 18

Sulentic, J.; Marziani, P.; and Zamfir, S. "The Case for Two Quasar Populations" Open Astronomy, vol. 20, no. 3, 2011, pp. 427-434.

Sulentic, J.; Marziani, P.; Stirpe, G.; Zamfir, S.; Dultzin, D.; Calvani, M; Repetto, P.; Zamanov, R. The Messenger, vol. 137, p. 30-33

Sulentic, J. W.; Bachev, R.; Marziani, P.; Negrete, C. A.; and Dultzin, D. 2007, ApJ, 666, 757

Sulentic, J. W.; Zwitter, T.; Marziani, P.; Dultzin-Hacyan, D. 2000 ApJ, 536, 1

Vietri, G., Piconcelli, E., Bischetti, M., et al. 2018, A&A, 617, A81. doi:10.1051/0004-6361/201732335

Zakamska, N. L.; Hamann, FW.; Pâris, I. et al. 2016, MNRAS, 459(3), 3144-3160

Zamfir, S.; Sulentic, J. W.; Marziani, P.; and Dultzin, D. 2010, April, MNRAS, 403(4), 1759-1786

Zamfir, S.; Sulentic, J. W.; and Marziani, P. 2008, MNRAS, 387, 856