Investigating the radio-loud phase of broad absorption line quasars

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\section*{ABSTRACT}

Context. Broad absorption lines (BALs) are present in the spectra of \sim{20}\% of quasars (QSOs); this indicates fast outflows (up to \sim{0.2c}) that intercept the observer’s line of sight. These QSOs can be distinguished again into radio-loud (RL) BAL QSOs and radio-quiet (RQ) BAL QSOs. The first are very rare, even four times less common than RQ BAL QSOs. The reason for this is still unclear and leaves open questions about the nature of the BAL-producing outflows and their connection with the radio jet.

Aims. We explored the spectroscopic characteristics of RL and RQ BAL QSOs with the aim to find a possible explanation for the rarity of RL BAL QSOs.

Methods. We identified two samples of genuine BAL QSOs from SDSS optical spectra, one RL and one RQ, in a suitable redshift interval (2.5 < z < 3.5) that allowed us to observe the Mg \textsc{ii} and H\textsc{ii} emission lines in the adjacent near-infrared (NIR) band. We collected NIR spectra of the two samples using the Telescopio Nazionale Galileo (TNG, Canary Islands). By using relations known in the literature, we estimated the black-hole mass, the broad-line region radius, and the Eddington ratio of our objects and compared the two samples.

Results. We found no statistically significant differences from comparing the distributions of the cited physical quantities. This indicates that they have similar geometries, accretion rates, and central black-hole masses, regardless of whether the radio-emitting jet is present or not.

Conclusions. These results show that the central engine of BAL QSOs has the same physical properties with and without a radio jet. The reasons for the rarity of RL BAL QSOs must reside in different environmental or evolutionary variables.

Key words. quasars: absorption lines -- galaxies: active -- galaxies: evolution -- radio continuum: galaxies

1. Introduction

Quasar outflows manifest most spectacularly as broad absorption lines (BALs) in the blue wings of prominent emission lines (e.g. C\textsc{iv}) in \sim{20}\% of optically selected quasars; they trace outflow velocities of up to \sim{0.2c} (Hewett & Foltz\textsuperscript{9}2003). These absorption troughs present a complex structure, and in some cases \sim{20}\% can be detached by several thousand km s\textsuperscript{-1} from the corresponding emission line (Korista et al.\textsuperscript{8}1993). The blue and red edges are often much narrower than the total width of the trough, and span hundreds of km s\textsuperscript{-1}. Troughs are not saturated, indicating that the background nuclear regions are not completely covered. Absorption by individual clouds cannot easily account for these observed features, while an opportunistically oriented outflow could produce such effects. Different authors (Murray et al.\textsuperscript{5}1995, Elvis\textsuperscript{9}2000) proposed that a fast outflow, emerging perpendicularly to the accretion disk, and then radially accelerated, could be at the origin of the BAL phenomenon. In some cases, an indication of the launching point of this assumed outflow originates in a partially absorbed Ly\alpha emission line: this suggests that the outflow is outside the broad emission-line region (BLR), at a distance >0.1 pc from the quasar nucleus. BALs can also be variable and show a disappearance on a time scale of \sim{100} years (Filiz Ak et al.\textsuperscript{4}2012), which suggests a possible reorientation of the outflow. Most of BALs are associated with high-ionisation species, such as C\textsc{iv}, Si\textsc{iv}, N\textsc{v}: quasars (QSOs) showing these features are then classified as Hi-BAL QSOs. A small fraction of these (\sim{15}\%) also show absorption from low-ionisation species such as Mg \textsc{ii} or Al\textsc{iii}, and are known as LoBAL QSOs. An additional class is FeLoBAL QSOs, which are LoBAL QSOs that also show absorption produced by the Fe \textsc{ii} and Fe \textsc{iii} lines. Absorbers similar to quasar BALs are seen in Seyfert 1 galaxies, albeit with lower outflow velocities, typically lower than a few hundred km s\textsuperscript{-1} (see contributions in Crenshaw, Kraemer & George\textsuperscript{9}2002).

No self-consistent physical model exists as yet for the acceleration of the outflowing gas in BAL quasars, or, if the filling factor is small (many small clouds), for its confinement. Possible mechanisms for the acceleration include radiation pressure, pressure from cosmic rays, or centrifugally driven magnetic disk winds (de Kool\textsuperscript{8}1997). Radiation pressure is a popular candidate, but it is unclear how it can be sustained without over-ionising the gas. In this outflow scenario, the observed fraction of BAL QSOs over the total QSO population is explained as an orientation effect (Weymann et al.\textsuperscript{4}1991, Elvis\textsuperscript{9}2000). An evolutionary
scenario, proposed by different authors, suggests that BALs are present in an early stage of the QSO (\(\sim 10\%\)–20\% of the total life), when the dust and gas cocoon is expelled, producing the absorption features [Briggs et al. 1984; Sanders 2002].

Before the advent of the FIRST Bright Quasar Survey (Becker et al. 2001), only a few radio-loud BAL QSOs were identified and studied. Thanks to the better statistics offered by this catalogue, hints of an anticorrelation between the BAL phenomenon and radio-loudness were found: Becker et al. (2001) found that the fraction of BAL QSOs with \(\log R > 2\) (radio-loudness \(R = S_{\text{GHz}}/S_{\text{2500 \&}}\), Stocke et al. 1992) is only \(\sim 25\%\) of the total BAL QSOs population. Gregg et al. (2006), in a work about Fanaroff-Riley II BAL QSOs, found an anticorrelation between radio-loudness and the BALs strength. He accounted for that by referring to the evolutionary scenario, in which the ejected cocoon would stifle the development of the radio-jet and lobes. Hewett & Foltz (2003), studying the intrinsic fraction of BAL QSOs in optically selected samples, suggested that optically bright BAL QSOs are half as likely as non-BALs to have \(S_{\text{GHz}} > 1\) mJy [Becker et al. 2000] first used the radio emission spectral index to derive the jet orientation of BAL QSOs, and noted that this can lie in wide range of possible angles. After these works, different authors presented detailed studies about larger samples of radio-loud BAL QSOs, from which they reported a variety of possible orientations for the outflow, but also a variety of possible morphologies and ages for the radio source (Montenegro-Montes et al. 2008; DiPompeo et al. 2011; Bruni et al. 2012, 2013). This does not suggest a scenario that would be clearly referable to one of the proposed models.

Boroson et al. (2002) classified AGNs based on a principal-component analysis of AGN properties. This sorted the different observed types according to different combinations of \(L/L_{\text{Eddington}}\) (luminosity as a fraction of Eddington luminosity) and \(M\) (the accretion rate). In this scheme, BAL QSOs are predicted to be objects with a high accretion rate, and radio-loud BAL QSOs with an even higher one. BAL outflows are crucial for understanding the physics of AGN because 1) they probe the inner regions of the accretion disk, and probably play a role in the accretion process by helping to shed angular momentum; 2) many BAL quasars are super-Eddington accretors, which offers a unique perspective on the changes in disk geometry (e.g. thickening) with accretion rate; 3) the highly energetic BAL outflows are probably related to other outflows seen in AGN (e.g. in radio galaxies) and their duty-cycle.

In the near-infrared (NIR) domain, it is possible to observe the UV-optical part of the QSO spectrum for objects with a redshift of between \(2.5\) and \(3.5\). In this portion of the spectrum, the BALs can be present at the blue-side of the Mg\(\text{II}\) emission line. Stronger BAL features are associated important with the C\(\text{II}\) emission line, which is detectable in the optical window. From the analysis of the (Mg\(\text{II}\), H\(\beta\)) emission lines and of the adjacent continuum emission, it is possible to study important characteristics of the QSO, from which the possible differences introduced by radio-loudness can be investigated.

- The FWHM of Mg\(\text{II}\) and H\(\beta\) can be indicative of the central BH mass, according to the scaling relations given by Vestergaard et al. (2006) and Vestergaard & Osmer (2009).

- The Eddington ratio of the central BH can be estimated from the luminosity at 5100 Å, as suggested by Kaspi et al. (2000).

- The size of the broad-line region can be related to the luminosity at 5100 Å (Kaspi et al. 2000, 2005; Bentz et al. 2006).

This paper is organized as follows: In Sect. 2 we present the sample selection, in Sect. 3 we describe the observations and data reduction, in Sect. 4 we discuss the data analysis and present the adopted method for estimating the derived quantities, and finally our results.

The cosmology adopted throughout the paper assumes a flat universe and the following parameters: \(H_0=70\) km s\(^{-1}\) Mpc\(^{-1}\), \(\Omega_\Lambda=0.7\), \(\Omega_M=0.3\).

2. Optically bright sample

The original samples of RL and RQ BAL QSOs studied in this work were built in 2007, starting from the fourth data release of the SDSS (DR4; Adelman-McCarthy et al. 2006). As a first step, we selected all the QSOs from the SDSS DR4 with a redshift
AI > 2.5; this threshold allowed us to visualise the C iv emission line in the SDSS spectra so that we would recognise possible BAL features, and the Mg ii and Hβ emission lines in the NIR window. Then, we set an additional upper limit of r < 19.5 to the apparent magnitude in r-band to obtain a better signal-to-noise ratio (S/N) during observations. All spectra satisfying these criteria were visually inspected and classified as BAL or non-BAL QSOs: this yielded 209 BAL QSOs.

As a second step, this list of BAL QSOs was cross-correlated with the FIRST survey to divide them into radio-loud (RL, $S_{1.4GHz} > 1$ mJy) and radio-quiet (RQ, $S_{1.4GHz} = 0$ mJy). From each of these two sub-samples, we selected the 21 RL BAL QSOs and the 23 RQ BAL QSOs with the brightest luminosity in r-band. The definition of radio-loudness considered in this work differs from that used by Becker et al. (2001) since all of our objects have $S_{1.4GHz} > 1$ mJy, we considered this condition sufficient to investigate the findings by Hewett & Foltz (2003), i.e. the rarity of optically bright BAL QSOs among objects with $S_{1.4GHz} > 1$ mJy. At a redshift of 2.5 (lower threshold of our sample) a detected flux density of 1 mJy in the FIRST survey corresponds to a luminosity $L_{1.4GHz} = 10^{27.2}$ erg/s/Hz, which already exceeds the accepted threshold at which a source is considered radio-loud ($L_{1.4GHz} > 10^{25.5}$ erg/s/Hz, Gregg et al. (1996).

To refine the BAL classification and set it in line with our previous work, in 2013 we considered the objects’ spectra from the latest version of the SDSS (DR9, Ahn et al. 2012) and performed a proper calculation of the absorption index (AI), as defined in Bruni et al. (2012). We used the classical definition by Hall et al. (2002):

$$\text{AI} = \int_0^{25000} \left(1 - \frac{f(v)}{0.9}\right) \cdot C dv,$$

but with the change that the parameter $C$ is unity over contiguous troughs of at least 1000 km s$^{-1}$ (as in Trump et al. 2006), and we considered as genuine BAL QSOs only objects with an AI > 100. To perform this calculation, we integrated the spectral region between the peaks of the C iv and Si iv emission lines to up to 25000 km s$^{-1}$ from the former. As a result, five RL and RQ objects were rejected.

Finally, thanks to the joint analysis of the optical and infrared spectra collected for this work (see next section), we were also able to classify the objects into HiBAL, LoBAL, and FeLoBAL QSOs. The final list of 16 RL and 18 RQ BAL QSOs studied here, together with the calculated AI and classification, is presented in Table 1 in Fig 1 the distribution of bolometric luminosity vs redshift is given for the two samples. In Fig 2 we plot the AI vs Log $R^*$ for the 16 RL objects: we find an anticorrelation analogous to that found by Gregg et al. (2006).

4. Results and discussion

We analysed the spectra using the SPLAT$^1$ package from the European Virtual Observatory. We fitted the continuum using a second- or third-grade polynomial function, and the emission lines using a Gaussian with free parameters (centre, peak, sigma). Standard UV and optical-line identifiers were used.

Our main goal was to extract the FWHM of the Mg ii and Hβ emission lines to estimate the central black-hole masses of the two samples. In the wavelength range from 0.8 to 2.4 microns there are two critical intervals because of very low atmospheric transmittance: 1.35 - 1.44 microns and 1.81 - 1.94 microns. When one of the lines fell in these ranges it was not possible to perform the fit, because of the superposition with atmospheric features. We calculated the intrinsic FWHM as

$$\text{FWHM}_i = \sqrt{\text{FWHM}^2_{\text{obs}} - \text{FWHM}^2_{\text{res}}},$$

where FWHM$_{\text{obs}}$ is the value obtained from the Gaussian fit, and FWHM$_{\text{res}}$ is the wavelength uncertainty given by the spectral resolution for the corresponding emission line. The obtained FWHMs are presented in Table 2 together with the continuum luminosity at 3000 and 5100 Å. Mg ii can present a double-peaked emission: in this case, we performed a double-Gaussian profile fit and combined the two FWHM by the quadratic sum.

In the following, we show the adopted methods and the results obtained following the various relations in the literature. The derived quantities are compared between the RL and RQ samples by mean of the Student’s t-test, assuming different variances for the distributions (Welch t-test). This test allows us to compare the mean values of the studied quantities, while a point-to-point comparison might be misleading, given the quite large uncertainties of the resulting estimates.

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$^1$ http://star-www.dur.ac.uk/~pdraper/splat/splat-vo/splat-vo.html
4.1. Black-hole mass estimation

As a first step, we inferred the different properties of the two groups of BAL QSOs by estimating the central black-hole (BH) mass. If they were an intrinsically different group of objects, different physical properties would be present, and the central black-hole mass can be an important variable for the dynamics of the central environment of the AGN.

In the literature, various relations are present to infer the mass of the central BH from single-spectra epochs: these are empirical relations, derived from reverberation mapping (RM, see Peterson 2011 for a review), related to the FWHM of the strong UV emission lines in the optical-UV domain (C\(\text{iv}\), Mg\(\text{ii}\), H\(\beta\)) and with the continuum luminosity at a given wavelength. These relations are applicable with the caveats that no absorption is present in the line profile, and a good S/N is available from measurements, otherwise the uncertain FWHM measurement can introduce errors or even systematic biases in the final estimate. For this reason, we decided to discard the C\(\text{iv}\) line from this analysis, since it presents the BAL feature.

Another important condition for performing a good estimate through scaling relations is that the chosen formulae are on the same mass-scale: at present, the only sets of relations for H\(\beta\) and Mg\(\text{ii}\) with this property are those presented by Vestergaard et al. (2006) and Vestergaard & Osmer (2009). Thus, the two relations we used for our estimate are the following:

\[
M_{\text{BH}} [M_{\odot}] = 10^{6.66} \left( \frac{\text{FWHM}(\text{Mg}\text{II})}{1000 \text{ km s}^{-1}} \right)^2 \left( \frac{L_{\lambda}(3000 \text{ Å})}{10^{42} \text{ erg s}^{-1}} \right)^{0.50}
\]

from Vestergaard & Osmer (2009), where \(L_{\lambda}(3000 \text{ Å})\) is the rest-frame luminosity at 3000 Å. This relation is given with a 1-\(\sigma\) scatter of 0.55 dex.

The second estimator we used has been derived by Vestergaard et al. (2006), and is related with the H\(\beta\) line:

\[
M_{\text{BH}} [M_{\odot}] = 10^{6.91} \left( \frac{\text{FWHM}(\text{H}\beta)}{1000 \text{ km s}^{-1}} \right)^2 \left( \frac{L_{\lambda}(5100 \text{ Å})}{10^{42} \text{ erg s}^{-1}} \right)^{0.50}
\]

where \(L_{\lambda}(5100 \text{ Å})\) is the rest-frame luminosity at 5100 Å. This relation is given with a 1-\(\sigma\) scatter of \(\pm 0.43\) dex.
These relations take advantage of the most recent updated analysis of the reverberation-mapping sample [Peterson et al. 2004] and of the improved radius-luminosity (R-L) relations between the BLR size and continuum luminosity [Kaspi et al. 2005; Bentz et al. 2006]. Results are presented in Table 2 together with the FWHM of the lines as extracted from the spectra and the continuum luminosity. We applied the K-correction both to the continuum and the FWHM.

The obtained masses can span more than one order of magnitudes for both samples. In some cases, the estimate from Mg ii could not be performed because of the strong absorption of the line. Estimates from the Hβ line were possible only when the line had a sufficiently S/N to allow a Gaussian fit. The estimates from the Mg ii line give average values of 10.07 dex $M_\odot$ ($\sigma = 0.41$ dex) for RL BAL QSOs and 10.00 dex $M_\odot$ ($\sigma = 0.42$ dex) for RQ BAL QSOs. Estimates from the Hβ emission line were possible only for a few objects (five RL vs six RQ), and present an average value of 9.68 dex $M_\odot$ ($\sigma = 0.24$ dex) for RL and 9.98 dex $M_\odot$ ($\sigma = 0.14$ dex) for RQ objects. Comparing the two distributions from the Mg ii estimator with the Student’s t-test (ST), we obtained a probability of 33% for the two distributions to be different, which is far below the conventional 95% threshold. Thus, we do not see any significant difference for the BH mass distributions of RL and RQ BAL QSOs.

### 4.2. Eddington ratio

From the continuum luminosity we can derive another quantity useful to test the differences between the two groups of BAL QSOs: the Eddington ratio. Boroson et al. (2002) explained the observable spectral characteristics of QSOs as driven from two principal quantities: the Eddington ratio ($L_\text{bol}/L_\text{Edd}$) and the accretion rate ($\dot{M}$). In their diagram BAL QSOs occupy a corner because they are peculiar objects with both high $\dot{M}$ and $L_\text{bol}/L_\text{Edd}$.

To perform the calculation, we used the bolometric luminosity from the quasar catalogue of Shen et al. (2011) and our mass estimate from the Mg ii line. Only estimates with an error <50% of the value are reported. In three cases (0800+44, 1347+46, 1537+58) we used the estimate from the Hβ line, since the former had an error >50% of the value. Results are presented in Table 2. No objects from the RL or RQ samples show a super-Eddington luminosity. Mean values are 0.09 ($\sigma = 0.08$) for RL and 0.16 ($\sigma = 0.09$) for RQ samples. An ST test gives a probability of 90% for the two distributions to be different, which still does not suggest a significant intrinsic difference in the accretion rate for the two groups of objects.

### 4.3. Broad-line region radius

Vestergaard et al. (2006) derived relation (4) starting from the broad-line region (BLR) radius, obtained from RM, and from the velocity of hydrogen clouds, approximated by the FWHM of the Hβ emission line. It has been found that the BLR radius is correlated with the continuum luminosity [Kaspi et al. 2000; 2005]. Bentz et al. (2006) updated these results taking into account the contribution of the host galaxy starlight. This last version is consistent with the method of Vestergaard et al. (2006), and is

$$R_{\text{BLR}} = A \cdot \left[ \frac{L_{\lambda}(5100)}{10^{44}\text{erg s}^{-1}} \right]^{0.5} \text{It} - \text{days},$$

where the coefficient $A$ is the scaling factor. The main difference with respect to the formula proposed by Kaspi et al. (2005) is the exponent of the luminosity, given as 0.69±0.5 in that work, which corresponds to the slope of the correlation in logarithmic scale. The value of the constant $A$, as the value of the slope, depends on the method used to interpolate data (BCES or FITEXY, see Bentz et al. 2006 for further details): both authors used the two methods and compared the values obtained for the scaling factor. In this work we decided to use the mean value proposed by Kaspi et al. (2005) for the scaling factor ($A = 22.3 ± 2.1$) and applied the correction provided by Bentz et al. (2006) for the slope.

We obtained a mean BLR radius of 427 light-days for RL ($\sigma = 191$) and 501 light-days for RQ BAL QSOs ($\sigma = 155$). A Student’s t-Test results in a probability of 77% for the two distributions to be different, which again does not suggest different geometries for the two samples.

### 4.4. Previous works in the literature

In the past years, the interest of the community in the BAL phenomenon has increased thanks to the better capabilities offered by new-generation instrumentation. In particular, during the elaboration of our work, three infrared studies of radio-loud BAL QSOs have been published. DíPompeo et al. (2013) found a mid- to near-infrared excess in a sample of 72 RL BAL QSOs, with respect to unabsorbed QSOs. The authors suggested that this effect might be due to the evolutionary stage of the objects, but since their previous study of the same sample in the radio band suggested a mild orientation, a merging of the evolutionary and orientation scenario is considered to explain the phenomenon. Runnoe et al. (2013) presented a spectroscopic study of eight RL BAL QSOs and found no significant differences between RL and RQ BAL QSOs, but dissimilar properties between RL BAL and RL non-BAL QSOs. Eddington ratios have been calculated in that work, which yielded only one super-Eddington BAL RL QSO with a ratio higher than 8 (12.5%). Finally, a Herschel-ATLAS study of far-infrared properties of BAL QSOs (Cao Orjales et al. 2012) showed that there are no differences in terms of star formation rate between Hi-BAL and non-BAL QSOs, which excludes the possibility that the BAL class is in a particular young, star-formation phase.

These results confirm the controversial and heterogeneous observational properties found in previous works about BAL QSOs and provide no clear evidence about the nature of these objects.

### 5. Conclusions

We investigated the spectral properties of RL vs RQ QSOs in the NIR domain by measuring the main emission lines and continuum to estimate physical quantities related to the central kpc of these objects. Our sample is composed only of optically bright BAL QSOs ($\sigma < 19.5$), which needs to be considered in a comparison with other samples. The results can be summarised as follows:

- the central BH masses do not show significant differences between RL and RQ BAL QSOs. This excludes the scenario in which possible differences due to the BH mass are at the origin of the rarity of RL BAL QSOs.

- The Eddington ratio distributions derived for our samples of RL and RQ BAL QSOs are similar. This suggests similar accretion rates for the two groups of objects.

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Table 2. Measured (rest-frame) and derived quantities for the sample of 16 RL (top) and 18 RQ (bottom) BAL QSOs. Column 6 reports the bolometric luminosity from \(L_{\text{bol}}\) and \(L_{\text{edd}}\)

| ID     | FWHM Mg II (km/s) | FWHM Hβ (km/s) | log(l(L/M_0)) | log(l(L/M_0)) | log(l(L/M_0)) | log(M/M_0) | log(M/M_0) | BLR radius (light-days) | L_{bol}/L_{edd} |
|--------|-------------------|----------------|---------------|---------------|---------------|------------|------------|---------------------------|----------------|
| 0844+05 | 9110±1380         | 3610±1380     | 47.42         | 47.35         | 47.61         | 10.49±0.13 | 9.70±0.33  | 1080±250                  | 0.11±0.03      |
| 1110+42 | 13770±1700        | -              | 46.79         | 46.34         | 46.94         | 10.53±0.11 | -           | 330±17                    | -              |
| 1152+04 | 5350±1380         | -              | 46.55         | 46.28         | 47.13         | 9.59±0.22  | -           | 309±15                    | -              |
| 1159+41 | 5450±1520         | -              | 46.59         | 46.19         | 47.28         | 9.63±0.24  | -           | 279±14                    | -              |
| 1214+51 | 7780±1650         | 4150±1650     | 46.78         | 46.55         | 46.67         | 10.03±0.19 | 9.42±0.35  | 419±21                    | 0.03±0.01      |
| 1236+45 | 12970±1680        | 6667±1680     | 46.98         | 46.72         | 47.40         | 10.57±1.11 | 9.92±0.22  | 513±26                    | 0.05±0.01      |
| 1307+04 | 7990±1490         | -              | 47.00         | 46.69         | 47.30         | 10.16±0.16 | -           | 491±25                    | 0.11±0.04      |
| 1327+03 | 9860±1570         | -              | 46.54         | 46.19         | 46.95         | 10.12±0.14 | -           | 279±14                    | 0.05±0.02      |
| 1359+47 | 4250±1690         | -              | 46.50         | 46.23         | 46.52         | 9.37±0.35  | -           | 291±15                    | -              |
| 1413+42 | 5960±1570         | -              | 46.72         | 46.45         | 47.18         | 9.77±0.23  | -           | 374±19                    | -              |
| 1426±31 | 7030±1630         | -              | 46.69         | 46.62         | 46.91         | 9.91±0.20  | -           | 455±23                    | -              |
| 1459+42 | 7520±1510         | -              | 46.60         | 46.05         | 47.44         | 9.91±0.18  | -           | 236±12                    | 0.27±0.11      |
| 1516+43 | 5830±1650         | 4340±1650     | 46.77         | 46.56         | 47.13         | 9.77±0.25  | 9.47±0.33  | 426±21                    | -              |
| 1624±37 | 10850±1370        | -              | 46.85         | 46.68         | 47.42         | 10.36±1.11 | -           | 486±24                    | 0.09±0.02      |
| 1625±48 | 15080±1610        | -              | 46.91         | 46.67         | 47.42         | 10.67±1.0  | -           | 484±24                    | 0.04±0.01      |
| 1637±32 | -                 | -              | 46.65         | 46.52         | 47.21         | -           | -          | 405±20                    | -              |

We did not find any significant difference between the mean BLR radius of RL and RQ BAL QSOs. This implies a similar geometry and dynamic for the central region of RL and RQ BAL QSOs.

In a future work, we will investigate the optical spectroscopic properties of the same samples with high-resolution spectra collected at the William Herschel Telescope (WHT, Canary Islands).

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Fig. 3. TNG spectra of the RL (first 16 panels) and RQ (second 18 panels) BAL QSOs from our optically bright sample. Units are $10^{-16}$ erg/s/cm$^2$/Å vs μm. Regions where atmospheric transmittance becomes critical have been blanked (1.35 - 1.44 μm and 1.81 - 1.94 μm). Dashed lines indicate the position of the Mg ii (left side) and Hβ (right side) emission lines at rest-frame.
Fig. 3. Continued.
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