Statistical analysis of AI $\text{III}$ and C $\text{III}$ emission lines as virial black hole mass estimators in quasars

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ABSTRACT

Aims. We test the usefulness of the intermediate ionisation lines Alm,$\lambda$1860 and C$\text{m},\lambda$1909 as reliable virial mass estimators for quasars.

Methods. We identify a sample of 309 quasars from the SDSS DR16 in the redshift range $1.2 \lesssim z \lesssim 1.4$ to have [O$\text{m},\lambda$13728 recorded on the same spectrum of Alm,$\lambda$1860, Sinn,$\lambda$1892, and C$\text{m},\lambda$1909. We set the systemic quasar redshift using careful measurements of [O$\text{m},\lambda$13728. We then classified the sources as Population A, extreme Population A (xA) and Population B, and analysed the 1900 Å blend using multi-component models to look for systematic line shifts of the Alm,$\lambda$1860 and C$\text{m},\lambda$1909 along the quasar main sequence.

Results. We do not find significant shifts of the Alm,$\lambda$1860 line peak in Pop. B and the wide majority of Pop. A. For Pop. xA, a small median blueshift of $-250$ km s$^{-1}$ was observed, motivating a decomposition of the Alm line profile into a virialized component centred at rest-frame and a blueshifted component for an outflow emission. For Pop. B objects, we proved the empirical necessity to fit a redshifted very broad component (VBC), clearly seen in C$\text{m}$, and analysed the physical implications on a Pop. B composite spectrum using CLOUDY simulations. We find consistent black hole mass estimations using Alm and C$\text{m}$ as virial estimators for the bulk of Population A.

Conclusions. Alm (and even C$\text{m}$) is a reliable virial black hole mass estimator for Pop. A and B objects. xA sources deserve special attention due to the significant blueshifted excess observed in the line profile of Alm, although not as large as those observed in C$\text{m}$.$\lambda$1909.

Key words. quasar main sequence – line profiles – emission lines – supermassive black holes –

1. Introduction

In 1992, Boroson & Green carried out a principal component analysis (PCA) on a sample of $\sim$80 Palomar-Green quasars. Their analysis identified a first eigenvector dominated by an anticorrelation between the [O$\text{m},\lambda$15007 peak intensity and the strength of optical Fe emission. In this first eigenvector (from now on "Eigenvector 1": E1), two dimensions, (1) the full width at half maximum of H$\beta$ (FWHM($H\beta$)) and (2) the Fe emission parameterised by the ratio of the equivalent widths of the Fe emission at 4750 Å and H$\beta$. $R_{\text{FeII}}$ = EW(FeII,$\lambda$4750)/EW($H\beta$) defines what is known as the optical plane of the main sequence of quasars (MS, Marziani et al. 2018). In this way the MS is an empirical sequence based on optical parameters, easy to measure in single-epoch spectra. The spectroscopic trends led Sulentic et al. (2000a) to distinguish two populations: quasars with FWHM($H\beta$) < 4000 km s$^{-1}$ belongs to Population A (Pop. A), while objects with FWHM($H\beta$) > 4000 km s$^{-1}$ are Population B (Pop. B).

The E1 gained two more dimensions over the years, becoming the 4DE1 (Sulentic et al. 2000a,c, 2007). The 4DE1 involves optical, UV and X-ray data, and its additional dimensions are (3) the photon index in the soft X-rays domain (below 2 keV), $\Gamma_{\text{soft}}$ (Wang et al. 1996), and (4) the systematic blueshift of the high-ionisation line C$\text{iv}$.$\lambda$1549 (Sulentic et al. 2000d, 2007), specially prominent among Pop. A objects. The soft X-ray excess (Singh et al. 1985) is a dominant component of the X-ray spectra of many AGN. It was adopted as a critical parameter of the 3DE1 that correlates opposite extremes of populations A and B (Bensch et al. 2015). Sources with higher values of soft X-ray excess (corresponding to a value of the soft-X photon index $\Gamma_{\text{soft}} \approx 3 - 4$) concentrate among the highly accreting Pop. A quasars (Grupe et al. 2004; Sulentic et al. 2007), while Pop. B quasars typically have $\Gamma_{\text{soft}} \approx 2$. The most widely-accepted interpretation of the excess detected in soft X-rays is a measure of comptonized emission in a corona connected with the innermost accretion disk (Walter & Fink 1993; Petrucci et al. 2020 and references therein). The systematic high amplitude of the C$\text{vi}$.$\lambda$1549 blueshift of quasars with high Eddington ratio may indicate the presence of strong outflows most likely originating in a disc wind (Netzer 2015; Coatman et al. 2016, 2017). Sulentic et al. (2007) introduced the line centroid velocity shift at half-maximum (see Zamfir et al. 2010, for a more detailed description) of C$\text{vi}$ as the UV E1 measurement in the 4DE1 parameter space. The observational definition of the accretion and outflow processes is the motivation behind the two additional dimensions. In the following, we shall consider the C$\text{vi}$ only, as it is available for most quasars at $z \gtrsim 1.4$ surveyed by the Sloan Digital Sky Survey (SDSS). The division between the two populations is not enough to reflect the spectral diversity (e.g. Marziani et al. 2010). Sulentic
et al. (2002) made sub-divisions of \( \Delta \text{FWHM}(\text{H} \beta) = 4000 \text{ km s}^{-1} \) and \( \Delta R_{\text{F}} = 0.5 \) to emphasise the trends in spectral properties especially seen in Pop. A sources as a function of \( R_{\text{F}} \) (Du et al. 2016; Shen & Ho 2014; Sun & Shen 2015, e.g.). This division defines the A1, A2, A3 and A4 bins as \( R_{\text{F}} \) increases, and B1, B1+, B1++ (as well as B2, B2+ in the range of \( R_{\text{F}} \) 0.5-1) as \( \Delta \text{FWHM}(\text{H} \beta) \) increases. Spectra belonging to the same bin should have similar characteristics concerning the line profiles and optical and UV line ratios (Sulentic et al. 2007; Zamfir et al. 2010).

A quasar spectrum can be characterised using two physical parameters: the Eddington ratio (defined as the ratio of the bolometric and Eddington luminosities, \( R_{\text{edd}} = \frac{L_{\text{bol}}}{L_{\text{edd}}} \)) and the black hole mass \( (M_{\text{BH}}) \) which can be only coarsely estimated employing the MS of quasars (Panda et al. 2019b). This is why it is necessary to accurately obtain \( M_{\text{BH}} \) either with the reverberation mapping technique (Netzer & Peterson 1997; Panda et al. 2019a; Dalla Bontà et al. 2020) or with methods based on single-epoch spectra (Shen 2013). The \( M_{\text{BH}} \) relates the evolutionary stage of the quasar with the accretion process (Small & Blandford 1992; Di Matteo et al. 2003; Fraix-Burnet et al. 2017). The knowledge of the \( M_{\text{BH}} \) allows us to assess the strength of the gravitational forces and gain inferences on the dynamics of the region surrounding the black hole (e.g., Ferland et al. 2009; Marconi et al. 2009; Netzer & Marziani 2010). The definition of the virial mass as used in this paper is:

\[
M_{\text{BH}} = \frac{f \delta v^2}{G}
\]

where \( r \) is the distance of the line emitting gas from the central black hole, \( \delta v \) is the line broadening due to virial motions, and \( G \) is the gravitational constant. \( f \) is the virial factor dependent on the geometry, orientation and kinematics of the emitting region (e.g., Peterson et al. 1993; Liu et al. 2017; Mejía-Restrepo et al. 2018). The parameter \( f \) is intended to take into account phenomena that affects the measure of the line broadening (usually FWHM or velocity dispersion) and that may include radiation-pressure effects (Netzer & Marziani 2010; Liu et al. 2017), as well non-virial kinematical components due to outflow or inflow. All methods using optical and UV broad lines are based on estimating the distance of the broad line region (BLR) from the central continuum source, \( r_{\text{BLR}} \). At low redshift (\( z \leq 0.8 \)), one can estimate \( M_{\text{BH}} \) using \( \text{FWHM}(\text{H} \beta) \) as the \( \delta v \), but as further in redshift we go, the less practical this measure becomes. So few options are left: (1) following the \( \text{H} \beta \) line into the infrared, a feat suggested by their profiles showing consistent width and shape with the one of \( \text{H} \beta_{\text{osc}} \) (Marziani et al. 2010, 2022). They are symmetric and are usually not affected by strong outflows often observed in the C iv\(1549 \) profile (Marziani et al. 2017; Martínez-Aldama et al. 2018). The rest-frame of the 1900 Å blend based on the quasar redshift derived from the \( [\text{O} \text{iii}] \lambda 13728 \) line (Bon et al. 2020) would prove the effectiveness of Alm and Cun as virial broadening estimators in the absence of systematic blueshifts.

The main objective of the present work is (1) to test the consistency of the Alm and Cun emission lines with the systemic redshift derived from the \( [\text{O} \text{ii}] \lambda 13728 \) line and in the case of a systematic shift is found, to propose a correction; and (2) to probe the usefulness of the IILs Alm and Cun as virial mass estimators. The outline of the paper is as follows. Section 2 is a description of the sample and employed selection criteria. Section 3 describes the analysis of the redshift estimation as well as the multi-component fitting of the 1900 Å blend and \([\text{O} \text{ii}]\lambda 13728 \) region. In Section 4 we present our results for the entire sample and by populations, analysing the trends and correlations obtained along with the physical parameters. Section 5 discusses the virial \( M_{\text{BH}} \) obtained from Alm and Cun, virial luminosity estimates for the extreme Population A sub-sample, and the intercomparison between C iv and Alm, along with a schematic interpretation of the \( \lambda 1900 \) blend in Population B. Section 6 provides the summary and conclusions.

2. Sample description

The spectroscopic quasar sample used in this work was selected from the SDSS data release 16 (DR16, Lyke et al. 2020), limited with the following filters: (1) \( 1.2 < z < 1.4 \) to cover the 1900 Å blend and the \([\text{O} \text{ii}]\lambda 13728 \) doublet line simultaneously; and (2) high \( S/N > 20 \) (measured in the continuum range around 1700 Å) to be able to decompose the blend at 1900 Å. These criteria give us a sample of 1379 objects.

Not all spectra have a visible \([\text{O} \text{ii}] \) emission. To determine the visibility of \([\text{O} \text{ii}] \) in the selected objects, we use a third criterion applied to all spectra normalised by a continuum region
around the line: (3) the ratio \( f_{[\text{OII}]} \) defined as the intensity ratio of \([\text{OII}]\) in the range 3722-3734Å (\( F([\text{OII}]) \)), and the observed continuum over the range 3670-3700Å (\( F(\text{cont}) \), composed of the AGN continuum and strong Fe emission contaminating the region), \( f_{[\text{OII}]} = \frac{F([\text{OII}]) + F(\text{cont})}{F(\text{cont})} \), with the constriction of \( f_{[\text{OII}]} > 1.3 \). Only 309 spectra satisfied this last condition.

\([\text{OII}]\) is a relatively weak line that is also affected by the emission of the Fe multiplet (e.g. Vanden Berk et al. 2001). The fact that \([\text{OII}]\) was detected in only 22% of the objects in the initial sample (with S/N > 20) may be due to two reasons. The first one is that it may be severely contaminated by sky subtraction residuals, whose emission is strong at the red end of the spectra. The second reason is attributed to the intrinsic \([\text{OII}]\) emission. We already know the trends of the MS in regards to oxygen, in Sulentic et al. (2000a, right panel of their Figure 2) it is very clear that for Pop. A quasars the oxygen is fainter than in Pop. B, and decreasing along the sequence, indicating that the higher the accretion (bins A3-A4), the less prominent oxygen lines we are observing (Sulentic et al. 2000a; Shen & Ho 2014). So, discarding spectra with no detectable \([\text{OII}]\), Pop. A and B (Sec. 3.3). For this purpose, it was necessary to apply the luminosity dependent criterion of Sulentic et al. (2017) which brings the limit at FWHM \( \approx 4000 \) km s\(^{-1}\) to significantly higher values for sources of bolometric luminosity \( L_{\text{bol}} \geq 46 \) ergs s\(^{-1}\); FWHM\(_{\text{AB}} \approx 3500 + 500(L_{\text{bol}}/3.69 \times 10^{44} \text{ km s}^{-1}\text{applied to the CII] line}) \) to separate Pop. A and B. In our sample, Pop. A FWHM(Alm11860) goes from \( \sim 2500 \) km s\(^{-1}\) to almost 4500 km s\(^{-1}\), and only one source had a value less than 2000 km s\(^{-1}\) (Sec. 4.2).

Afterwards, we looked for extreme Pop. A sources (xA or highly accreting quasars) using the UV line ratio from Marziani & Sulentic (2014, hereafter MS14): Alm11860/Sim11892 \( \geq 0.5 \) and CII11909/Sim111892 \( \leq 1 \) (see Section 3.3 for a more detailed description), finding 11 xA quasar candidates.

The median value of the S/N distribution of our final sample is \( \approx 31 \). The redshift distribution is reported in Figure 1 (left). The 2σ range is small, due to the values of the line wavelength range needed to have both Alm11860 and [OII] recorded on the same spectrum: Alm is at the blue edge and [OII] at the red edge of each spectrum (see Figure 2, upper panel, for an example). This z range is the most relevant condition to ensure that the systemic redshift of the quasar is measured precisely (see also Section 3.1). In Figure 1 (right), the \( L_{\text{bol}} \) distribution of our sample shows that our sample is made of luminous AGN. The luminosity median values are log \( L_{\text{bol}} = 46.8 \) ergs s\(^{-1}\) for Pop. A objects (including xA quasars), and log \( L_{\text{bol}} = 46.6 \) ergs s\(^{-1}\) for Pop B. Previous works usually found 50% Pop. A and 50% Pop. B in flux-limited samples (Zamfir et al. 2010; Marziani et al. 2013). The larger sample size of Pop. A might be due to the flux limit of the Sloan survey along with the relatively high redshift \( z \geq 1 \) (Sulentic et al. 2014) that might have caused a Malmquist-type bias yielding an excess of Pop. A sources (i.e., radiating at relatively high Eddington ratio) with respect to Population B (radiating at lower Eddington ratio).

### 3. Data analysis

Optical spectral data used in this work were wavelength- and flux-calibrated by the SDSS DR16 pipeline. For the Galactic dust extinction, we use the reddening estimates from Schlafly & Finkbeiner (2011) assuming the value of the RV coefficient as 3.1. The Galactic absorption median value was \( \mu_{\lambda}(A_B) \approx 0.14 \), ranging from 0.03 up to \( \sim 0.6 \). We choose to apply this correction only in correspondence of the redshifted 1900Å blend, where the median \( A_B \) implies a flux increase of 14%. The chosen value only affected the luminosity computation, not the spectral slope between the blue and red edge of the 1900Å blend. Redshift and flux corrections of the spectra were first done using the \( z \) values provided by the SDSS DR16. An additional \( z \) correction was applied using the rest-frame estimated with the \([\text{OII}]\), \( \text{[OII]}\), 3.3728 line, as described below.

### 3.1. \([\text{OII}]\) 3.3728 redshift estimation

The SDSS redshift estimates can be biased (Hewett & Wild 2010). We observed discrepancies between the peak and rest-frame wavelength of \([\text{OII}]\) (as seen in Figure 2) after the SDSS-based \( z \) correction. We applied an additional redshift correction using the peak intensity wavelength of \([\text{OII}]\) as described in Section 3.2.2 with a more carefully fitting using the speccf t task (Kriss 1994) from Image Reduction and Analysis Facility (IRAF, Tody 1986).

We compare the differences between the SDSS DR16 redshift and the \( z \) values obtained from the narrow line \([\text{OII}]\) in Figure 2. The median value of \( \Delta z = z_{\text{[OII]}} - z_{\text{SDSS}} = 4.918 \times 10^{-4} \) (roughly \( \sim 70 \) km s\(^{-1}\) in the rest frame, green dotted line of the Figure 2) indicates that the SDSS-\( z \) values were underestimated. A fraction of the objects, \( \sim 25\% \) of the sample, showed a difference in the rest-frame \( z \) higher than 150 km s\(^{-1}\) (up to \( \sim 450 \) km s\(^{-1}\)). The distribution is not symmetric around the median value. The main reason of these systematic differences is probably a bias of the SDSS due to the usage of HILs.

### 3.2. Multicomponent fitting

The UV range covered in the sample is populated by blended, intermediate ionisation lines. To analyse the emission lines of the spectra, multi-component fits were done using the task specfit. This routine allows us to simultaneously fit all components present in the spectrum: continuum, FeII features, and emission lines, computing the \( \chi^2 \) parameter that measures the difference between the original spectra and the fitted one. The task
specfit minimises the $\chi^2$ to find the best fit. Intensity measures of [O\textsc{ii}]\textlambda\,3728 were carried out with the \texttt{splot} task within IRAF.

The primary continuum source in the UV region is well known to be originated from the accretion disk (e.g., Malkan & Sargent 1982; Wandel & Petrosian 1988; Capellupo et al. 2016). In the absence of extinction, the most widely-used model for the continuum is a single power-law over a limited spectral range (see e.g., Śniegowska et al. 2020). We fitted a local continuum for two spectral ranges centred on the 1900 Å blend and [O\textsc{ii}]\textlambda\,3728, the most important emission lines relevant to this work (see Figure 3).

Along the E1 main sequence, it is possible to model the H\beta line profile with three components with blueshifted, unshifted and redshifted centroids (blue [BLUE], broad [BC] and very broad components [VBC], respectively; Marziani et al. 2010). Then, we can use this model for all strong broad lines by varying the relative intensity of the components. The model considering the BC and VBC separation applies to Pop. B sources and is consistent with stratification of the BLR (Sulentic et al. 2000b; Snedden & Gaskell 2007; Wolf et al. 2020). The BC (hydrogen density $n_H \sim 10^{12}$ cm$^{-3}$, ionisation parameter $\log U \sim -2$ and column density $N_z \gtrsim 10^{23}$ cm$^{-2}$) is present in almost all type-1 quasars and corresponds most likely to the virialized part of the BLR, while the VBC can be interpreted as the emitted gas in the innermost BLR (e.g., Sulentic et al. 2000b; Marziani et al. 2003a, 2010; Wang & Li 2011; Wolf et al. 2020). The BLUE component is apparent as a blueshifted excess superimposed to the blue wing of the BC (Leighly & Moore 2004).

The 1900Å blend contains the same emission lines for both Pop. A and B: Al\textsc{iii}, Si\textsc{iii}, and C\textsc{iii}\textlambda\,1909 which are the strongest features (see also Table 1 from Negrete et al. 2012). Figure 3 shows example fits of a Pop. A and B source, where we used a Lorentzian function for Pop. A and a Gaussian function for Pop. B. For Pop. B spectra, we included an additional Gaussian component for the VBC. A detailed description of the phenomenology of the line profiles can be found in Sulentic et al. (2000a,
3.2.1. Region 1: 1750-2050Å.

1. Continuum: We adopt a single power-law to fit the region 1700-2050Å, using a continuum window at 1700 Å as seen in Francis et al. (1991).

2. Feii and Fen: Emission of the Feii multiplets can be strong in the vicinity of CiiiÅ1909, as seen in the average quasar spectrum from Vanden Berk et al. (2001). They appear to be strong when Aliii is also strong (Hartig & Baldwin 1986). Strong Feii and Aliii emission further strengthen the conclusion that the BLR densities, at least in Pop. A sources are very high (on the basis of photoionisation models, $\sim 10^{11} - 10^{12}$ cm$^{-3}$; Korista et al. 1997a; Kuraszkiewicz et al. 2000). We adopted for the Feii template model the one obtained by Vestergaard & Wilkes (2001). The specfit task scaled and broadened the template to reproduce the observed emission (Boroson & Green 1992). In most cases, we fitted the multiplet FeiiUV191 (seen in the blue-ward of the 1900Å blend, Moore 1945) as an isolated Gaussian in the rest-frame. We adopted a Gaussian profile because the feature is a blend of several individual Feii lines belonging to the same multiplet. If the Feii multiplet is prominent, an extra component is added: FeiiÅ1914 to fit an excess seen near the red wing of CiiiÅ1909 associated with unresolved Feii template emission in Pop. A quasars (Negrete et al. 2012). This FeiiÅ1914 emission is a single line, so we fitted it using a Lorentzian profile to be consistent with the profile of the BCs. The spectrum of I Zw 1 shows this effect: both Cni and FeiiÅ1914 are needed to account for the double-peaked feature at 1910Å that is too broad to be explained by a single line (Negrete et al. 2012, 2013). This criterion rests on the assumption that FeiiÅ1914 and the FeiiUV multiplet #191 are enhanced by Lyα fluorescence (Sigut & Pradhan 1998; Johansson et al. 2000).

3. CniÅ1909: Strengths and FWHM were left free to vary in the specfit model with one restriction: FWHM(CniÅ1909) ≤ FWHM(AliiiÅ1860) or FWHM(SiiiÅ1892) to avoid a divergence of the FWHM(CniÅ1909) due to the Feii emission on the red side of the blend. In the case where the model does not successfully follow this condition, the FWHM of both lines were fixed to be the same to avoid a larger FWHM(Cni). We also added a narrow component (NC) if needed with a fixed upper limit of FWHM $\sim$1000 km s$^{-1}$ at the rest-frame wavelength as an initial condition. The distribution of the peak emission around 1909 Å shows a fraction of quasars with a shorter wavelength than the one expected for the laboratory wavelength of CniÅ1909 (Figure 4). This phenomenon could be due to two main reasons. First, we are looking at the prohibited line [Cni]Å1906 (dotted line, Figure 4) also observed in the NLR. Second, a blueshifted emission of Cni NC due to an outflow in the redshifted VBC. For Pop. B objects we included a redshifted VBC whose strengths and FWHM were left free to vary with a FWHM lower limit $\sim$ 7000 km s$^{-1}$. In Figure 5 we illustrate the necessity of using an additional component in the Cni profile. Looking at the residuals and the $\chi^2$ values, the best fit (according to the F distribution for the ratio of the $\chi^2$, Bevington & Robinson 2003) is the one with the VBC as seen for the SDSS spectrum J012726.39+154153.8 with a $\chi^2_{\text{VBC}} \approx 0.1676$ in contrast to $\chi^2 \approx 0.4451$ obtained without VBC, respectively (see section 5.4 for its interpretation).

4. SiiiÅ1892: Strengths and shifts were free to vary, with one restriction: FWHM(SiiiÅ1892) $\geq$ FWHM(CniÅ1909). We had some difficulties due to the nature of the blend itself. The line tended to be blueshifted in order to “fill” its blue side, and therefore, AliiiÅ1860 also presented a blueshift as seen in Martínez-Aldana et al. (2018). In the cases where the shift was completely unreal under a visual inspection, we fixed the central wavelength of Siii to the rest-frame.

5. AliiiÅ1860: The doublet was resolved and the blue component shifts, FWHM, and intensity were allowed to vary, with the red one tied to the blue by identical FWHM and fixed wavelength ratio. The ratio between the intensity of the red and blue component of the doublet was kept fixed 0.8 (Laor et al. 1997). Rarely, a different ratio up to 0.98 was assumed according to be observed doublet profile. However doublet total strengths and shifts were left free to vary. Regarding CniÅ1909, the condition FWHM(AliiiÅ1860) $\geq$ FWHM(CniÅ1909) was imposed. The FWHM(Cni) limit comes from the low value of the CniÅ1909 critical density. On the converse the Aliii line, emitted via a permitted transition, has no well-defined critical density (Baldwin et al. 1995; Korista et al. 1997a).

6. Other lines: Two lines not as prominent as those described above in points 3-5 were detected in the blue side of the 1900Å blend: NiiÅ1750 and SiiÅ1816. We assumed them to be at the rest-frame as an initial condition, although their shifts, strength and FWHM were left free to vary.

3.2.2. Region 2: 3550-3950Å.

The [Oii]Å3728 doublet emission line is one of the main emission features of this spectral range. Hence, the components are the same for all spectra:

1. Continuum: A strong pseudo-continuum associated with Feii emission is expected to be present in the spectral range around [Oii]Å3728 between 3500 Å and 3850 Å (Vanden Berk et al. 2001). However, the limited range 3700-3770 Å
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Fig. 5: Analysis of the 1900Å blend (continuum extracted for simplicity in both spectra) of SDSS J012726.39+154153.8 as described for Figure 3. C iii profile fitted with only a BC and BC+VBC, top and bottom, respectively. Abscissa is rest-frame wavelength in Å. Ordinate is the normalised specific flux obtained from specfit.

is smooth enough to permit the use of a power-law to model the sum of the AGN continuum and the FeII emission.

2. [O ii] λ3728: Our spectra have unresolved or almost unresolved [O ii]λλ3727,3729 lines because the spectral resolution at the observed wavelength around 8200 Å is λ/δλ ≈ 2250, so the spectral purity is 3.64 Å, which is larger than the doublet separation. Therefore, we used a single Gaussian fit (Bon et al. 2020).

3.3. Spectral types along the E1

In order to classify the objects, we attempted to use as a first approximation the Sulentic et al. (2000) spectral types. However, this classification is based on the FWHM Hβ that increases systematically for higher L objects, and we expect the same effect for the IILs. We identify 242 and 67 Pop. A and B objects, respectively. In a few cases, we had fits with both profiles, almost ~ 5 % of the sample, but with different FWHM(C ii). For these sources, with a value of FWHM near the 4000 km s⁻¹ limit, it was necessary to choose the best fit according to the χ² values using the F distribution (Bevington & Robinson 2003). To separate highly accreting candidates of spectral type A3 and A4 (xA) from the A1-A2 sources defined in Sec. 1, we used the UV diagnostics ratios of MS14. Pop. A quasars located at the extreme of the MS, are considered to be sources radiating close to the Eddington if they satisfy the following criterion (e.g., Du et al. 2016):

\[ R_{FeII} = \frac{EW(FeII\lambda4750)}{EW(H\beta)} \geq 1.0 \]  

An equivalent condition has been proposed at intermediate to high redshift (z ≥ 1) where the Hβ line is no longer visible in the optical range, using the 1900Å emission line blend of Alm, Si iii, and C iii (MS14). The blend involving these lines constrains the physical conditions in the broad-line emitting gas the same way as extreme optical Fe emission. Measures of high S/N spectra of MS14 yield the selection criterion based on two related ratios:

1. Alm/Si iii ≥ 0.5 and 2. C iii/Si iii ≤ 1.0

The emitting region of the IILs corresponds to the densest emitting region likely associated with the production of IILs like the CaII IR triplet (Matsuoka et al. 2008) and FeII (Baldwin et al. 2004).

We made a bin separation for the bins A1-A2 which we call Pop. A and the A3-A4 bins will be our Pop. xA candidates. In Figure 6 we show the A1-A2 bins in blue, and in magenta we identify 11 xA quasars.

4. Results

Table B.1 of Appendix B lists the results of the line fitting procedures of Sec. 3.2, and the luminosity and M BH computations of Section 5. The Table also reports the redshift from the SDSS and our z estimation using [O ii], the continuum flux and the normalisation at 1700Å, and the line profile classification (Lorentzian or Gaussian). From the specfit analysis we report the intensity, FWHM, shift from the restframe, and EW for each emission line of the 1900Å blend. For the [O ii] region, we report the intensity and FWHM, shift from the restframe, and EW for each emission line of the 1900Å blend. For the [O ii] region, we report the intensity and FWHM. The last part of Table B.1 contains the UV diagnostic lines, black hole mass, Eddington ratio, and virial luminosity (computed only for xA sources, see Sec. 5.2). Table 1 presents a summary of the physical parameter values where we report the median and average values by Population. The reported uncertainties are the semi-interquartile ranges (sIQR) of the parameter distributions. For luminosity estimates we adopted an uncertainty of 10%.

We organise the presentation of our results on line widths and shifts of the 1900Å blend along the MS, separating Pops. Â (A1-A2), xA and B. The MS is expected to trace changes in the dynamical and physical conditions inside the quasars (Marziani 2001). Note that in previous work Pop. A includes spectral types A1-A2 and A3-A4.
Table 1: Average and median values of the sample physical parameters by population.

|                  | Pop A (231 quasars) | Pop xA (11 quasars) | Pop B (67 quasars) | Notes |
|------------------|---------------------|---------------------|--------------------|-------|
|                  | Average  | Median   | Average | Median | Average | Median |          |       |
| FWHM(CuI) BC     | 3330±280 | 3370±280 | 3280±255 | 3420±260 | 4490±180 | 4380±180 | a       |
| FWHM(CuI) VBC    | -        | -        | -       | -      | 8120±410 | 8120±410 | a       |
| FWHM(Alm)        | 3560±270 | 3550±230 | 3560±230 | 3530±250 | 5270±240 | 5300±250 | a       |
| EW (CuI)         | -15.43±2.90| -14.77±2.90| -8.33±1.88| -8.94±1.88| -7.18±1.76| -6.97±1.76| b       |
| EW (Alm)         | -3.55±0.94| -3.27±0.94| -7.08±0.79| -7.05±0.79| -5.02±0.97| -4.92±0.97| b       |
| Alm/SiIII        | 0.48±0.11 | 0.45±0.11 | 0.63±0.02 | 0.60±0.02 | -        | -        | c       |
| CuIII/SiIII      | 2.17±0.58 | 1.88±0.58 | 0.72±0.10 | 0.75±0.10 | 0.94±0.22 | 0.86±0.22 | c       |
| CuIII(BC+VBC)/SiII | -        | -        | -       | -      | 1.68±0.32 | 1.53±0.32 | d       |

Notes. (a) In units of km s\(^{-1}\). (b) Rest-frame equivalent widths reported with normalised spectra at 1700Å in units of Å. (c) UV diagnostic ratio from MS14 for Pop. A sources. (d) UV diagnostic ratio from MS14 for Pop. B sources. (e) Log of M\(_{BH}\) is computed using the scale relations by M22 in units of M\(_{⊙}\). (f) Log of Line luminosity in units of ergs s\(^{-1}\); uncertainties are the 10% of the value. (g) Log of bolometric luminosity in unit of ergs s\(^{-1}\); computed using the continuum window at 1700Å. (h) R\(_{Edd}\) is the Eddington ratio. (i) Log of virial luminosity in units of ergs s\(^{-1}\); uncertainties are the 10% of the value.

Fig. 6: Distribution of Pop. A sources in the plane defined by the ratios CuIII1909/SiII1892 vs. Alm1860/SiII1892. The blue dots are quasars within populations A1-A2 (Pop. A) and the xA sources are in magenta located in the lower-right grey area.

with respect to the [OIII]\(\lambda3728\) rest frame. They may be due to Doppler effect because of radial gas motions plus obscuration along our line of sight. The differences in line widths observed in the same spectrum might be due to emissions from regions of non-virialized motions (e.g., outflows), as usually seen in Pop. A and also in high luminosity Pop. B objects at high luminosity (Sulentic et al. 2017). Line width differences in type 1 quasars are also associated with the stratification of the emitting region, where broader lines trace the kinematics of the regions closer to the SMBH (e.g., Sulentic et al. 2000b; Peterson & Wandel 2000; Snedden & Gaskell 2007; Wolf et al. 2020; Li et al. 2021). Last, FWHM differences may be due to different orientations of the accretion disk (expected to provide the reference plane of symmetry of the BLR) with respect to our line of sight.

4.1. Systematic shifts

In the virialized region one can expect a modest shift (≤ | ± 200| km s\(^{-1}\)) associated with the measurement of the uncertainties. We consider ±200 km s\(^{-1}\)as an uncertainty limit, given the instrumental resolution of the SDSS spectra at their blue side, which is where the 1900Å blend falls in the observed rest frame. Considering our complete sample, the median values of the Alm and CuIII shifts in the histograms of Figure 7a,c are 10±120 km s\(^{-1}\) and 40±190 km s\(^{-1}\), respectively (see also Table 1). In almost 90% of Pop. A and B Alm profiles we find that the shifts are lower than the uncertainty limit. However, Figure 7a shows an asymmetric distribution of Alm1860 shifts with an extended tail of blueshifts reaching several hundred km s\(^{-1}\). Blueshifts larger than 200 km s\(^{-1}\) imply that we are most likely looking at a mixture of two non-resolved components in the line profiles: a
virialized plus an outflow component. Even though a blueshifted component in Al\textsubscript{III} may not be as intense as the blue component of C\textsubscript{IV}1549 it is essential to be aware of its presence: significant shifts would introduce a bias in the estimation of the rest-frame, as the Al\textsubscript{III} blue component would broaden and shift the full profile. The C\textsubscript{III}1909 line shows a more uniform distribution shifts in Pop. \textasciitilde{A} (Fig. 7c), with a slight net shift to the red \sim 100 km s\textsuperscript{-1}, smaller than the typical uncertainty in the individual shift measurements.

4.1.1. Population \textasciitilde{A}

Figure 7a shows that only 39 out of our 231 Pop. \textasciitilde{A} objects have Al\textsubscript{III} blueshifts larger than the uncertainty limit (33 objects have shifts \textasciitilde{-300 km s\textsuperscript{-1}}). This trend can also be seen in Figure 8a where we plot the Al\textsubscript{III} shift as a function of its FWHM in bins\textsuperscript{2} of $\Delta$FWHM(Al\textsubscript{III})=1000 km s\textsuperscript{-1}. The plot shows that, on average, Pop. \textasciitilde{A} sources (blue circles) do not present systematic shifts in Al\textsubscript{III} that significantly affect the FWHM measurements. This behaviour confirms the reliability of the rest-frame of the Al\textsubscript{III}1860 for sources within the A1-A2 populations. In the relations of the Al\textsubscript{III} shift with the bolometric luminosity or Eddington ratio (Figure 8c, e) we also do not find displacements larger than the uncertainty limit. Data were divided in sub-samples of $\Delta$log$L_{bol}$=0.2 dex and $\Delta$R\textsubscript{Edd}=0.5.

Regarding the behaviour of C\textsubscript{III} in Pop. \textasciitilde{A} sources, in Figure 7b we find 11 objects (\textasciitilde{4\%}) that show blueshifts larger than -300 km s\textsuperscript{-1}. As observed for Al\textsubscript{III} relations, in C\textsubscript{III}, we do not see clear tendencies of $L_{bol}$ and R\textsubscript{Edd}(C\textsubscript{III}) with the shift (Fig. 8d,f), although \textasciitilde{17\%} Pop. A sources shows a displacement as large as \textasciitilde{-300 km s\textsuperscript{-1}} (52 objects, Figure 7c). This displacement toward the red is most likely due to the effect of the strong Fe\textsubscript{II} emission heavily blended with C\textsubscript{II}.

4.1.2. Extreme Population \textasciitilde{A}

The spectral fitting of our 11 xA objects are shown in Figure A.1 of Appendix A. Figures 8a(c), present our xA sub-sample in magenta points which show Al\textsubscript{III}1860 blueshifts reaching several hundred km s\textsuperscript{-1}. However, those shifts are much lower than those found in C\textsubscript{IV}1549 (e.g., Sulentic et al. 2007; Section 5.3). Nine out of 11 xA sources of Figure 8c show a blueshift in Al\textsubscript{III}, with a median shift of \textasciitilde{−340 km s\textsuperscript{-1}} and a maximum of \textasciitilde{−1000 km s\textsuperscript{-1}}. The Figure reveals that there is no dependence on luminosity for the Al\textsubscript{III} shift. Figure 8e shows that not only a blueshift is detected for xA sources but that the blueshift is also significant, \textasciitilde{10\%} of the FWHM. In the other hand, we note that 50 Pop. A objects (\textasciitilde{17\%} of the sample) have R\textsubscript{Edd} higher than the one of xA sources. As described in Sec. 3.3 and discussed in Section 5.1, we expect a higher R\textsubscript{Edd} for xA objects.

C\textsubscript{II}1909 shifts in Pop. xA sources seem to be slightly redshifted (the median shift is 50\textpm120 km s\textsuperscript{-1}), so we do not take them into account for the analysis. A redshift of \textasciitilde{−300 km s\textsuperscript{-1}} was find in three xA spectra were C\textsubscript{II} is weak and is also affected by the Fe\textsubscript{II} emission at \textasciitilde{1915 - 1920 Å}.

4.1.3. Population \textasciitilde{B}

Our Pop. B sample is represented by red squares in Fig. 8. In general, the Pop. B Al\textsubscript{III} profile show small displacements from the rest frame wavelength within the uncertainty limit. Figure 8a shows that the shift distribution is symmetric around 0. Figures 8c,e are consistent with this trend: symmetric displacements around 0 shift, and no dependency on the bolometric luminosity or Eddington ratio obtained with Al\textsubscript{III}.

In Fig. 8b we observe a peak in the C\textsubscript{III} shift with a median value of 160\textpm90 km s\textsuperscript{-1}. As seen in Fig. 5, this small redshift could indicate that sources above the 4000km s\textsuperscript{-1} limit tends to “cover” the VBC spectral range. This behaviour has also been observed for the LIL H\textbeta line (Zamfir et al. 2010). From Figure 8d,f we observe a consistent behaviour for both C\textsubscript{II} and Al\textsubscript{III}: there is no significant dependency on L\textsubscript{bol} and R\textsubscript{Edd}.

4.2. Line widths

4.2.1. Population \textasciitilde{A}

From our spectral fitting, 111 Pop A objects (excluding the 11 xA sources) have FWHM of C\textsubscript{II} and Al\textsubscript{III} not forced to be equal. We call them Pop. \textasciitilde{A}. In Figure 9 we show Pop. \textasciitilde{A}+ quasars in blue and xA quasars as magenta points. The grey line indicates the 1:1 relation, the black line is the best fit for the Pop. \textasciitilde{A}+ sources. Using the least-square method it yields the equation: FWHM(C\textsubscript{II}) \textasciitilde{(663 \textpm 348) + (0.709 \textpm 0.061) FWHM(Al\textsubscript{III})}. The Al\textsubscript{III} FWHM median value is 3550\textpm230km s\textsuperscript{-1}. The orange line is set at FWHM(C\textsubscript{II}) = 0.9 FWHM(Al\textsubscript{III}), according to the findings of Marziani et al. (2022, hereafter M22). The value that relates the FWHM of C\textsubscript{II} and Al\textsubscript{III} should be in the range 0.8 – 1.1 for Pop A1-A2 sources. Indeed, as seen in Fig. 9 we have three objects with FWHM(C\textsubscript{II}) BC \textasciitilde{1.1 FWHM(Al\textsubscript{III})}. This behaviour indicates that A1-A2 lines are narrower than H\beta by \textasciitilde{10\%}.

\textsuperscript{2} Throughout Figure 8, we report the median values for each bin.
Fig. 8: Behaviour of Al\textsubscript{iii}λ1860 (left) and C\textsubscript{iii}λ1909 (right) by population. a,b: shift with respect to rest-frame vs. FWHM. c,d: shift vs. log $L_{\text{bol}}$. e,f: ratio of shift over FWHM vs. $R_{\text{Edd}}$. g,h: FWHM vs log $L_{\text{bol}}$. Lines are the luminosity-dependent limit between Pop. A and B. of Sulentic et al. (2017, gold) and the empirical separation of Sulentic et al. (2000c, dashed). Colour-coding: Pop. A (blue circles), Pop. xA (magenta stars) and Pop. B (red squares). Reported values are sub-sample medians, error bars are sIQRs. Marker sizes are as indicated in the legend of each plot.
VBC is present, it might be very weak, probably unresolved and not dominant in the emission line profile. A VBC might not be detected and lost in the spectral noise.

In Section 5.4 we derive constraints on the Alm and Sim sources.

5. Discussion

The M_{BH} computations are closely related to the FWHM of prominent broad components and the underlying continuum. Therefore, the decomposition of the line profile becomes important to isolate the virialized component from other components, either coming from an outflow (blueshifted) or possibly coming from an inflow region (redshifted, Wang et al. 2017). We explore different M_{BH} estimators (Sections 5.1 and 5.2) not as affected by shifts as CIV 1549 (Sect. 5.3). For Pop. B objects, we analyse the possibility of a VBC in Alm and Sim (Section 5.4).

5.1. Virial mass and Eddington ratio estimates with Alm λ1860

Using the FWHM of two prominent lines of the 1900Å blend, Alm and CIII, we compute the virial M_{BH} with two methods: (1) M22 (equations 3-4) derived from the comparison of the FWHM of Hβ with Alm and CIII; (2) Vestergaard & Peterson (2006, hereafter VP06, Equations 5 and 7) that are based on the Hβ and CIV 1549 line widths.

The M22 scaling laws take the form:

\[
\log M_{BH}(\text{Alm}) = (0.5800^{0.035}_{-0.040})\log L_{1700,44} + 2\log(\frac{\lambda_{1860}}{\text{FWHM(Alm)}}) + (0.51^{+0.05}_{-0.05})
\]

\[
\log M_{BH}(\text{CIII}) = (0.645^{0.045}_{-0.045})\log L_{1700,44} + 2\log(\frac{\lambda_{1549}}{\text{FWHM(CIII)}}) + (0.355^{+0.075}_{-0.045}).
\]

Here ξ is a correction needed in the FWHM (Section 4.2.1), for \( ξ_{\text{Alm}} \approx 1 \) and \( ξ_{\text{CIII}} \approx 1.25 \).

VP06 use the optical continuum luminosity \( L_{C}(5100\AA) \) along with FWHM(HδC) and the UV continuum \( L_{C}(1350\AA) \) along with FWHM(CIV 1549). Considering the different continuum windows of these equations, we found it necessary to extrapolate the continuum obtained from specfit to a wavelength as close as possible to 5100 Å or 1350 Å. We applied the “surrogate” lines Alm 1860 and CIV 1909 in both equations of VP06. This means that we can directly compare the M_{BH}(Alm) and M_{BH}(CIII) from the scaling relations of M22 to the ones of VP06 using FWHM Alm 1860 or CIV 1909 in place of FWHM CIV 1549 or Hβ.

The comparison of M_{BH} from equations 3 and 4 is presented in Figure 10 along with the residuals of each set with \( \delta \log M_{BH} = \log M_{BH}(\text{Alm}) - \log M_{BH}(\text{CIII}) \). In the Figure, the grey line indicates the 1:1 relation, and the black line is the best fit for the Pop. A sources using the least-square method. For the M22 results (Figure 10a) the equation is \( M_{BH}(\text{CIII}) \approx (-1.017 \pm 0.095) + (1.131 \pm 0.085) \log M_{BH}(\text{Alm}) \); the rms of the linear fit is 0.043 and the deviation from the 1:1 relation is 0.14. In the other two panels of Figure 10, we used Eq. 7 of VP06 by replacing the FWHM of CIV with the FWHM of Alm and CIII. Figure 10b shows the relation for M_{BH}(Alm) using Eq. 3 vs.

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4.2.3. Population B

The highest value of Alm FWHM observed in Pop. B objects is 6500 km s\(^{-1}\). Only one object shows a FWHM of 4000 km s\(^{-1}\), indicating that the Alm line is broader than in Pop. A spectra but not as wide as the CIII VBC. The median values are FWHM (CIII) BC=5300±250 km s\(^{-1}\) and FWHM (CIV) VBC=8124±410 km s\(^{-1}\). The inclusion of a VBC of CIII in the red side of the Pop. B spectra is evident as seen in Figure 5. In Pop. B objects we do not expect strong contribution of Fe, so the residual seen in the fit with no VCB (Fig. 5, upper panel) should be also part of CIII.

The case of a VBC in Alm and Sim is not so evident. It could be that for Alm and Sim it is also necessary to add a VBC due to the large FWHM observed (up to ~6500 km s\(^{-1}\) for Alm and 5800 km s\(^{-1}\) for Sim). In the case of Alm, the blending is not extremely severe, so we are able to efficiently deblend the BC (as seen in Figure 3). The blend profile suggests that if Alm and Sim are not extremely severe, we are able to efficiently deblend the BC (as seen in Figure 3). The blend profile suggests that if Alm and Sim are not extremely severe, we are able to efficiently deblend the BC (as seen in Figure 3).
Fig. 10: Upper panels: log space of $M_{\text{BH}}$(Al\textsc{iii}$\lambda$1860) vs. $M_{\text{BH}}$(C\textsc{iii}$\lambda$1909) computed with the scale relations of M22 and VP06 for the Pop. $\tilde{A}^*$ sources [FWHM(C\textsc{iii}) $\neq$ FWHM(Al\textsc{iii})]: a) log $M_{\text{BH}}$(Al\textsc{iii}) vs. log $M_{\text{BH}}$(C\textsc{iii}) both using M22 SR; b) log $M_{\text{BH}}$(Al\textsc{iii}) using Eq. 3 by M22 vs. Eq. 7 by VP06; c) log $M_{\text{BH}}$(C\textsc{iii}) using Eq. 4 by M22 vs. Eq. 7 by VP06. Lower panels: Residuals of each $M_{\text{BH}}$ computation, $\delta\log M_{\text{BH}}$. Colour-code as Figure 9. Dashed line traces the 1:1 relation; the filled line is the best fit obtained using the least-square method and the red line is the median value of $\delta\log M_{\text{BH}}$. The uncertainties of the Pop. $\tilde{A}^*$ sample are marked with a cross and calculated as the sIQR.

Fig. 11: Distribution of log $M_{\text{BH}}$(Al\textsc{iii}$\lambda$1860) vs. $R_{\text{Edd}}$. Colour-code is as follows: the scale relations of M22 in blue, red and magenta and for the one of VP06 (Equation 5) in light blue, orange and light magenta for Pops. $\tilde{A}$, B and xA, respectively.

VP06 Eq. 7. There is very good agreement between the estimations: log $M_{\text{BH}}$(Al\textsc{iii})$_{M22}$ $\approx$ $(−0.249 \pm 0.045) + (1.037 \pm 0.065)$ log $M_{\text{BH}}$(Al\textsc{iii})$_{VP06}$ with a Pearson correlation of 0.98; the standard error (STD err) of the linear fit is 0.015 and the deviation from the 1:1 relation is 0.08. Figure 10c displays the relation of $M_{\text{BH}}$(C\textsc{iii}) using Eq. 4 vs. VP06 Eq. 7. In this case, we also observe a good agreement between each estimation. The resultant equation is log $M_{\text{BH}}$(C\textsc{iii})$_{M22}$ $\approx$ $(0.609 \pm 0.085) + (0.935 \pm 0.065)$ log $M_{\text{BH}}$(C\textsc{iii})$_{VP06}$ with a Pearson correlation of 0.99; the STD err of the linear fit is 0.012 and the deviation from the 1:1 relation is 0.04. The scatter of Figure 10b,c is smaller than in Figure 10a due to fact that the equations of M22 are based on VP06.

As for the case of Eq. 5 of VP06 by replacing the FWHM of H\textsc{$\beta$} for the FWHM of Al\textsc{iii} and C\textsc{iii}, we observed a discrepancy between estimations, a much larger scatter and systematic changes associated probably to the extrapolation of the continuum from $\approx$ 4000Å to 5100Å. We see a similar situation for Al\textsc{iii} and C\textsc{iii} for both comparisons, both of them with a Pearson correlation of $\sim$0.8 and a resultant equation of log $M_{\text{BH}}$(Al\textsc{iii},C\textsc{iii})$_{M22}$ $\approx$0.6 log $M_{\text{BH}}$(Al\textsc{iii},C\textsc{iii})$_{VP06}$. These findings proves that Al\textsc{iii} and C\textsc{iii} are equivalent as virial broadening estimators for quasars (with a Pearson correlation coefficient of 0.93 for M22) at intermediate $z$ from observations obtained from large surveys such as the SDSS.

In HILs such as C\textsc{iv}$\lambda$1549, the contamination of an outflow introduces a bias in the black hole mass estimations (see Sec. 5.3), because of over-broadening of the lines. The dynamic associated with a virialized system is different from the outflow that emerges from a system dominated by radiation pressure. A similar effect could be seen in the III Al\textsc{iii} for xA objects, but the contribution of the outflow is much lower than in the case of C\textsc{iv}$\lambda$1549. This accounts for the good agreement found between
the scaling laws for CIV1549 by VP06 and the one of M22. The CIV1549 scaling law of VP06 was built around the assumption that the CIV1549 FWHM was as good as Hβ for virial mass estimation. Using the Cm11909 (or Alm11860), we use a line that is truly equivalent to Hβ (M22) and is not strongly affected by any non-virial component.

Several authors proposed that the Eddington ratio is driving the E1 MS (Marziani et al. 2001, 2003b; Shen & Ho 2014; Sun & Shen 2015). Trends in R_{edd} are also reflected in the X-ray properties (Boller et al. 1996; Wang et al. 1996; Laor et al. 1997), CIV1549 line profiles (Wills et al. 1999; Sulentic et al. 2000c, 2007), and in virial BH mass estimates using the width of the broad emission lines (Laor 2000; Boroson 2002; Dong et al. 2011). The distribution of M_{BH}(Alm) vs R_{edd} is shown in Figure 11. Eddington luminosities have been calculated based on masses obtained from the FWHM(Alm11860) following the relation: L_{Edd} = 1.5 × 10^{38}(M_{BH}/M_\odot) [\text{erg s}^{-1}] (e.g., Netzer & Marziani 2010; Netzer 2015). The bolometric correction for L_{bol} (1700Å), 6.3 was taken from MS14, and from Richards et al. (2006) the ones for 1350Å (5.75) and for 5100Å (10.3).

Fig. 11 shows that Pops. B and Â appear to be segregated mainly on the basis of R_{edd}: few Pop. B sources are in excess of R_{edd} ≈ 0.5. The wide majority of Pop. A is constrained in the range 0.4 ≤ R_{edd} ≤ 1.2. A minority of data points scatter in the range 1.2 ≤ R_{edd} ≤ 3. If orientation plays a role, and if pole-on orientation leads to narrower lines (McLure & Jarvis 2002; Collin et al. 2006; Decarli et al. 2011; Mejía-Restrepo et al. 2017, 2018), the M_{BH} might be severely underestimated and R_{edd} overestimated. A similar effect has been already seen in the M_{BH} vs. luminosity diagram (e.g., Marziani et al. 2006).

We also analysed the parameter space of the UV diagnostic ratios vs. R_{edd} plane for the Pop. Â sources, however, we found no strong correlations (Figure 12). Table 1 reports the median values of the line ratios. The condition Cm111909/Siness11892 ≤ 1 seems to be sufficient to identify xA quasars. Yet, xA quasars are not associated with the highest R_{edd} (see also Figure 11). This might be a consequence of an overbroadening due to an outflow component, increasing M_{BH} for xA sources and therefore lowering R_{edd}. The median excess in the virial luminosity (rose bars in Fig. 13) suggests a median M_{BH} overestimate δ log M_{BH} ≈ 0.2. Pop. Â sources with R_{edd} ≥ 2 might be oriented preferentially pole-on, leading to a strong underestimate of the black hole mass and hence to an overestimate of the Eddington ratio (as observed in Figure 11, the R_{edd} is up to ~2.5).

5.2. Virial luminosities and outflow broadening

The physical parameters of xA quasars are correspondingly extreme, with maximum radiative output per unit of mass close to their Eddington limit. This condition is predicted by accretion disk theory at high accretion rates: radiative efficiency low and Eddington ratio saturating towards a limiting value ( Mineshige et al. 2000; Sadowski 2011; Sadowski et al. 2014, and references therein). We also expect that the intensity ratios of the intermediate and low ionisation lines in xA quasars remain almost the same: only the line width increases with luminosity (Negrete et al. 2012, 2013). The spectral invariance with luminosity implies that the radius of the emitting regions should rigorously scale as L^{1/2}; if not, the ionisation parameter U should change with luminosity (Marziani et al. 2021). Putting together these considerations: (1) L/L_{Edd} = const., (2) r ∝ L^{1/2}, together with (3) the definition of Eq. 1 M_{BH} ∝ rFWHM^2, we obtain a relation linking luminosity and line width, known as the “virial luminosity equation” (MS14):

\[ L_{\text{Vir}} = L_\odot \cdot (\text{FWHM})_\lambda^{1000} \text{ erg s}^{-1} \]  

(5)

where \( L_\odot = 7.88 \times 10^{44} \) and the FWHM is of the virialized BC in units of 1000 km s^{-1} (see eq. 6 in MS14 for the complete derivation). The FWHM of Alm is the adopted virial broadening estimator for our work. We calculated L_{Vir} for the 11 xA sources and the average and median values are reported in Table 1. However, there are two effects that can significantly affect the luminosity estimations: an outflow that broadens the virial component, and an orientation effect that narrows it.

For xA sources, the Alm shift/FWHM ratio can be up to ~0.1 (Fig. 8,e). The dominant effect on our sources may be due to an outflow since the virial luminosities are larger than the cosmological ones. We have 11 extreme sources, of which six objects have δ log L = log L_{bol} − log L_{Vir} ≈ −0.2 (magenta bars in Figure 13). SDSS J003546.29, J152314.49 and J023055.54 showed a difference between the cosmological and virial luminosities under -0.2 and are sources with an Alm blueshift. SDSS J003546.29 having a δlogL=-0.75 and shift Alm=-1000 km s^{-1}.

5.3. CIV1549 and ALM11860 inter-comparison

The blueshift of CIV1549 is usually evidence of strong outflows (e.g. Richards et al. 2011) that, most likely, results from the presence of a radiation line-driven accretion-disc wind (Gallagher et al. 2015 and references therein). Therefore, a prominent blue component over the line profile is expected, especially at high/intermediate redshift (Martinez-Aldama et al. 2018). However, when compared to samples with lower redshift, Pop. A sources at intermediate redshifts tend to show broader and more blueshifted components of CIV. They are indicative of wind activities surrounding the central region (Deconto-Machado et al. 2021). Therefore, black hole masses based on the FWHM(CIV) emission line can be overestimated by a factor of 4-5 at large blueshifts and are biased due to this non-virial component (Coate et al. 2016; Denney 2012).

A sub-sample from Shen et al. (2011) was extracted to compare the CIV1549 profile with our Alm sample. The criteria used were: luminosity distribution consistent with the one of the Alm11860 sample. The results are shown in Fig. 14, for the FWHM and peak shift of the line. The blue lines show the distribution of bootstrap replications of the bolometric luminosity distribution, for 300 objects pooled out of ~50,000 sources from the Shen et al. (2011) catalogue. The luminosity distributions of the bootstrapped samples overlay the one of the present samples since the source from Shen et al. (2011) where pooled preserving the relative prevalence of the Alm11860 luminosity been (shaded histogram in Fig. 14). For both CIV1549 FWHM and shift, the distribution imply extremely high probabilities that they are not consistent. In particular, the FWHM CIV1549 appears to be systematically broader than the one of Alm by ~1500 km s^{-1}. While the Alm blueshifts are modest (within |δv| ≤ 500 km s^{-1}, and the distribution appears centred at rest frame and only slightly skewed to the blue, the CIV1549 line presents a systematic blueshift by ~ -600 km s^{-1}.

The CIV1549 shift has been analysed with respect to Hβ (e.g., Leighly & Moore 2004; Marziani et al. 2010; Sulentic et al. 2017; Vietri et al. 2018), and interpreted as a strong wind contribution affecting the CIV1549 profile in the form of an excess
blueshifted emission. The same difference has been revealed in a detailed same-source, inter-line comparison between Al\textsc{iii} and C\textsc{iv}1549 in \approx 20 xA sources (Martínez-Aldama et al. 2018). Fig. 14 provides a statistical confirmation that the C\textsc{iv}1549 blueshifted emission is broadening and shifting considerably the C\textsc{iv}1549 profile with respect to the one of Al\textsc{iii}1860.

### 5.4. A model for the Population B C\textsc{iii}1909 profile

Is our model of the 1900 blend adequate? This work has convincingly shown the need to include a VBC to account for the C\textsc{iii}1909 profile. Even if the Sim\textsc{iii}1892 is heavily blended, the fits detect an emission peak between Al\textsc{iii} and C\textsc{iii}1909, implying that the Sim\textsc{iii}1892 core component is always prominent. There is no doubt about the existence of a core component (i.e., the BC) for Al\textsc{iii}. However Al\textsc{iii} is the weakest line in the blend, and some VBC emission could be lost in noise.

We can analyse the expectation of VBC emission considering that (1) the velocity field of the emitting regions is predominantly virial in Pop. B sources, as established by early reverberation mapping studies (Peterson & Wandel 1999, 2000), and that (2) the VBC is a heuristic representation of the innermost part of the BLR. This VBC could be physically associated to inflowing gas (Wang et al. 2017; Giustini & Proga 2019) or due to an effect of the gravitational redshift (Netzer 1977; Zheng & Sulentic 1990; Corbin 1995; Liu et al. 2017; Mediavilla et al. 2018). This component has been observed in sources with masses in the range 10^5–10^{10} M_\odot (Bon et al. 2015), comparable to the Pop. B mass values of the present sample, with mean log M_{BH}= 9.1 [M_\odot].

In this way, three empirical approaches are in order: (1) a fit with only the BCs (M1); (2) a fit in which one VBC is assumed for C\textsc{iii}1909 only (as done for all Pop. B sources, M2); (3) a fit in which 3BCs and 3VBCs are introduced, with restriction on consistent shifts and widths for the BCs and VBCs (M3) as seen in Figure 15a. This last option implies 8 free parameters (peak shifts and wavelengths are locked). It is probably the most appropriate in physical terms, but is very difficult to implement for individual sources. The three fits were carried out on an average composite for all Pop. B sources, and the resulting ratios are reported for the three models in Table 2. The basic inference is that the BC ratios Al\textsc{iii}1860/Sim\textsc{iii}1892 and Sim\textsc{iii}1892/Cm\textsc{iii}1909 remain consistent if different models are assumed. A second result is that the VBC/BC ratio is <1 and \ll 1 for Sim\textsc{iii}1892 and Al\textsc{iii}1860, respectively.

The physical implications for the line emitting regions have been analysed using CLOUDY 17.02 (Ferland et al. 2017) arrays of photoionisation simulations computed for an unrelated work (Sniegowska et al. 2021). Briefly, they assumed a standard AGN continuum implemented in CLOUDY, solar metallicity, canonical value of the Hydrogen column density (10^{23} cm^{-2}), no micro-turbulence. They were computed for an array of ionisation parameter and density covering the ranges (in log) –4.5 – 1, and 7 – 14 [cm^{-3}], respectively.

Fig. 16 shows the behaviour of the ratios Al\textsc{iii}1860/Sim\textsc{iii}1892, Sim\textsc{iii}1892/Cm\textsc{iii}1909 and Al\textsc{iii}1860/Cm\textsc{iii}1909 as a function of ionisation parameter and hydrogen density. The typical ratios measured on the Pop. B sample and on the composite spectrum indicate that the BC is emitted in a region of moderate density and high ionisation (U \sim 10^{-1}, n_H \sim 10^{11} cm^{-3}). Similar values are found for the VBC.

To push the analysis one step forward we consider the ratios estimated for Model 4 (a synthetic model with VBC and BC for the three lines, Table 2) as seen in Figure 15b. This model was made using M3 flux values as an initial condition, then let the model adapt to the better statistical values (along very well defined physical ranges) varying the fit with a million random iterations. The significance of \chi^2 variations is described by F
Fig. 14: Left: inter-comparison between the AlⅢ1860 of the present sample (hatched histograms) and the CⅣ1549 FWHM distribution of the sample of Shen et al. (2011), for matching luminosity distributions (top panel). The bottom panel thin blue lines show the binned distributions of bootstrap replications of the Shen et al. (2011) data; the thick blue line is their average. Right: same for peak shift.

statistics appropriate for ratios of \( \chi^2 \) values (Bevington & Robinson 2003), \( F = \chi^2 / \chi_{\text{min}}^2 \), with degrees of freedom \( v = 165 \). \( F \approx 1.30 \) provides 2\( \sigma \) confidence ranges on the parameters. The final fluxes obtained for the M4 BC and VBC fluxes are the ones that satisfies \( F \) within a 2\( \sigma \) confidence level (\( F(2\sigma) \), Figure 15b). In the Figure 15b we can see the distributions in light-dark red, green and blue for AlⅢ BC - VBC, respectively. The dotted line of each distribution are the median values used in the UV ratios in Table 2. Our synthetic models that satisfied the condition of the \( F(2\sigma) \) showed Gaussian distributions for the BC and VBC fluxes centred in one very well defined value, except for SiⅢ BC - VBC (Figure 15c,d). The median values are marked for each distribution and corresponds to the dotted black lines of Figure 15b.

Fig. 17 shows the regions in the parameter plane that are consistent with the ratios built from the three lines in the blend. For the BC there is a very well defined (\( U, n_\text{H} \)) region where the three ratios cross; it means that in this region the values of \( (U, n_\text{H}) \) are able to reproduce the observed ratios: \( \log U \sim -1.00^{+0.12}_{-0.28}, \log n_\text{H} \sim 10.78^{+0.28}_{-0.08} \text{ cm}^{-3} \). Similar values are derived if the BC and VBC are added together: \( \log U \sim -1.03^{+0.31}_{-0.19}, \log n_\text{H} \sim 10.72^{+0.19}_{-0.15} \text{ cm}^{-3} \), where the uncertainty range has been set from the ±1\( \sigma \) uncertainties for the individual line ratios. These values indicate moderate density and fairly high ionisation as expected for Population B sources (Negrete et al. 2013, 2014). We warn that our single zone model is certainly not adequate to represent the complexity of the emitting region. In the case of Pop. B, there is a most likely a range of densities, column densities, and ionisation parameters that makes the locally-optimised cloud model ( Baldwin et al. 1995; Korista et al. 1997b) the most appropriate.

The case of the VBC deserves special attention. We are dealing with emission that is well-constrained only in the case of CⅣ,1909, and that is presumably much weaker than the corresponding BC emission for AlⅢ1860 and SiⅢ,1892. Using the ratios of the best fit to the synthetic spectrum we obtain \( \log U \sim -0.72^{+0.27}_{-0.15}, \log n_\text{H} \sim 10.27^{+0.19}_{-0.09} \text{ cm}^{-3} \). Due to the very low SiⅢ,1892/CⅣ,1909 and AlⅢ1860/SiⅢ,1892 intensity ratios derived from the fit (actually consistent with 0 within the uncertainties), the lower limit of both \( U \) and \( n_\text{H} \) are practically unconstrained.

Further clues can be obtained considering that the line width should be inversely proportional to the square root of the radius of the emitting region: \( \text{FWHM} \propto 1/r^2 \), as per Eq. 1. The BC over VBC FWHM ratio is \( \approx 0.8 \), implying that the ratio of the radii should be \( \approx 0.64 \). For constant \( n_\text{H} \), this would imply an increase in \( \delta \log U \sim +0.38 \). The diagnostics from the blend for the VBC are very poor (a more refined analysis should involve measurements of at least CⅣ1549 and HenⅠ1640 which are not covered in the spectra of our sample). However, there is slight increase in \( U \) moving from the BLR to the VBLR that does not suggest any gross inconsistency with the virial approach.

Fig. 16 indicates that that, for a likely value of \( n_\text{H} \sim 10^{11} \text{ cm}^{-3} \), moving from \( \log U \sim -1 \) toward higher \( U \) values, we may expect a lowering of the SiⅢ,1892/CⅣ,1909 ratio to level that may make the VBC of SiⅢ,1892 difficult to detect. At the same time, the AlⅢ1860/SiⅢ,1892 ratio might increase sharply for \( \log U \gtrsim -0.5 \), reaching \( 1 \) for \( \log U \gtrsim -0.0 \). At that value of the ionisation parameter, the AlⅢ1860 VBC should be stronger than the one of CⅣ,1909. The composite profile (Fig. 15) disfavours the possibility that the AlⅢ1860 VBC and in turn the \( U \) could be that high: in Pop. B, the intensity of AlⅢ1860 is lower than the one of SiⅢ,1909 (Bachev et al. 2004; Kuraszkiewicz et al. 2004; Lira et al. 2017, 2018). Ionisation parameter \( \log U \sim -0.25 \) might be a possibility entailing AlⅢ1860/CⅣ,1909\( \approx 0.3 \), AlⅢ1860/SiⅢ,1892\( \approx 2 \), and SiⅢ,1892/CⅣ,1909=0.15 (assuming \( n_\text{H}= 10^{11} \text{ cm}^{-3} \)).

In summary, these consideration justify the neglect of a SiⅢ,1892 VBC. The possibility of an AlⅢ1860 VBC domi-
Fig. 15: Upper left: specfit model (M3) of the composite spectra of Pop. B sources with VBC (in red) added to the profile of Al\textsc{iii}, Si\textsc{iii} and C\textsc{iii}]. Abscissa scales are rest-frame wavelength in Å. Ordinate scale is the specific flux in units of $10^{-17}$ ergs s$^{-1}$ cm$^{-2}$ Å$^{-1}$. Upper right: Synthetic model (M4) with BC+VBC in all three lines with the median value (dashed line) and their uncertainties regions of each profile in light and dark tone: red, green and blue for Al\textsc{iii}, Si\textsc{iii} and C\textsc{iii} BC - VBC respectively. Grey lines are the M3 flux values as the initial condition. Lower panels: Gaussian distributions of the BC - VBC fluxes obtained with a million random iterations of M3 with values that satisfies the condition of $\chi^2(M4)/\chi^2_{\text{min}}(M4) < F(2\sigma)$.

nating the Al\textsc{iii}1860 cannot be excluded if the ionisation parameter is high. Against this prospect goes the empirical fact that the FWHM of Al\textsc{iii}1860 and Si\textsc{iii}1892 BC are consistent.

6. Summary and conclusions

The present investigation has shown that the intermediate ionisation lines are little affected by outflows, and that the Al\textsc{iii} and C\textsc{iii} are equivalent (with some caveats) as virial broadening estimators for quasars, providing a suitable tool for $M_{\text{BH}}$ estimates at intermediate $z$ from observations obtained from a big survey such as the SDSS. More in detail, the results of the present investigation can be summarised as follows:

- We carried out a redshift correction of the sample spectra using the narrow LIL [O\textsc{ii}] rest-frame wavelength. The restframe of the 1900Å blend corrected in redshift for the [O\textsc{ii}]

line proved the effectiveness of Al\textsc{iii} and C\textsc{iii} as rest-frame estimators.

- We subdivided the sample into Population A and B. We took into account the luminosity-dependent relation of Sulentic et al. (2017). Within Pop. A, extreme Population A have been considered separately.

- Pop. A quasars constitute 78% of the sample with 11 sources classified as extreme accretors, and 22% as Pop. B quasars out of a sample of 309 objects. We observed a bias against high Eddington ratio sources due to the absence of [O\textsc{ii}] in the spectra, and a Malmquist-type bias at low Eddington ratio.

- Applying the specfit routine of IRAF, we were able to fit the most prominent emission lines of the 1900Å blend simultaneously, proving that we can measure widths of Al\textsc{iii} and C\textsc{iii} (and Si\textsc{iii}) even if they are blended.

- In terms of tendencies observed for each population: Pop. A has shown no shifts in the median sub-samples from the
Alm profile, Pop. B shows symmetric shifts around 0; only Pop. xA show a median blueshift of ~300 km s^{-1} indicating a mixture of two unresolved components: a virialized plus an outflow component. The xA sub-sample showed an Alm shift/FWHM ratio \sim 10 to 15%, indicating that the displacement significantly affects the line width.

The virial black hole mass estimations of our sample using the FWHM (Alm) are consistent with the ones obtained with FWHM(Ciii), using the VP06 and M22 scale relations.

Our xA sample (11 quasars) showed a broad consistency between the cosmological and virial luminosity computed with \textit{MS14}; however, an excess in the virial luminosity with respect to the concordance one indicates that in this case the Alm width is affected by a non-virial broadening.

The comparison of the Alm and a large numbers of C iv bootstrapped samples extracted from \textit{Shen et al. (2011)} matching the luminosity distribution showed that the Alm and C iv FWHM and shift distributions differ fundamentally, in the sense that the C iv1549 FWHM and shift distributions are much broader than those of Alm. Shift amplitudes of C iv1549 are a factor ~10 larger than the Alm ones.

Our single zone model proved that there is a very well defined region in the log plane $n_H$, $U$ for the BC and BC+VBC models for the composite Pop. B spectra. As for the case of only VBC, $n_H$, $U$ are not fully constrained. Nonetheless, the appearance of the blend and the intensity ratios of the components are consistent with the predominance of a virial velocity field, with a stratification of emission properties.

In conclusion, we can use the IILs Alm and Ciii as a reliable surrogate mass estimator for Pops. A and B objects. Highly acreting quasars show smaller blueshifts (on average \sim 1000 km s^{-1}) compared to the ones observed in C iv, and the method discussed in this paper may provide slight $M_{BH}$ overestimates by a factor \leq 2 as described in Secs. 5.1 and 5.2.

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Table 2: UV diagnostic ratios of \textit{MS14} values obtained on an average composite for all Pop. B sources with different considerations for the Alm, Ciii] and SinI] profile lines.

|          | M1       | M2       | M3       | M4       |
|----------|----------|----------|----------|----------|
| Alm BC/ SinI]BC | 0.62±0.19 | 0.65±0.39 | 0.61±0.06 | 0.37±0.73 |
| Ciii]BC/ SinI]BC | 1.34±0.25 | 1.28±0.32 | 1.16±0.07 | 1.39±0.79 |
| Alm BC/ Ciii] BC | 0.46±0.14 | 0.51±0.28 | 0.53±0.08 | 0.27±0.78 |
| Alm VBC/ SinI]VBC | -        | -        | 0.42±0.06 | 0.19±3.95 |
| Ciii]VBC/ SinI]VBC | -        | -        | 2.87±0.07 | 1.65±2.23 |
| Alm VBC+ BC/ SinI]BC | -        | -        | 0.58±0.12 | 0.32±1.10 |
| Ciii]VBC+ BC/ SinI]BC | -        | -        | 1.45±0.14 | 1.46±0.90 |
| Alm VBC/ Alm BC | -        | -        | 0.15±0.03 | 0.17±2.45 |
| SinI]VBC/ SinI]BC | -        | -        | 0.21±0.01 | 0.33±2.23 |
| Ciii]VBC/ Ciii]BC | -        | -        | 0.51±0.01 | 0.39±0.79 |

Notes. (a) Model 1: Fit with only BCs as shown in Figure 5 (top panel). (b) Model 2: Fit with only a VBC in C iii as described in section 3.2 (Figure 3, bottom panel). (c) Model 3: Fit with BC + VBCs in all three lines as Figure 15a. (d) Model 4: Synthetic model fit with BC+VBC in all three lines as Figure 15b.
Fig. 16: From top to bottom, maps of intensity ratios as a function of ionisation parameter and Hydrogen number density: log Al\textsc{iii}λ1860/Si\textsc{iii}λ1892, log Si\textsc{iii}λ1892/C\textsc{iii}λ1909 and log Al\textsc{iii}λ1860/C\textsc{iii}λ1909.

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Fig. 17: Isophotes tracing the loci of the parameter plane ($\log U$, $\log n_{\text{H}}$) consistent with the observed intensity ratios Al\textsc{iii}λ1860/Si\textsc{iii}λ1892, Si\textsc{iii}λ1892/C\textsc{iii}λ1909 and Al\textsc{iii}λ1860/C\textsc{iii}λ1909 (shown in log scale in the Figure). The crossing region defines the ($U$, $n_{\text{H}}$) parameter range consistent with the values of the three ratios. Up: BC only, middle: VBC, bottom: BC+VBC.
Appendix A: Extreme accretor sources multi-component fits

The results of line profile fitting for the 1900Å blend are shown in the following Figure A.1. Notes for some of the objects within the xA sub-sample:

- J152314.49+375928.9: One of the highest blueshift sources: shift(Al\textsc{iii}) = -849.96±25 km s\(^{-1}\), with a FWHM(Al\textsc{iii}) = 4000±400 km s\(^{-1}\). This source is also the one with an additional component in Fe\textsc{ii}\(\lambda 1914\) due to the high amount of iron emission observed in the red side of C\textsc{iii}.
- J100827.67+210931.1: Brightest quasar with a log L_{bol} = 47.06, with a FWHM(Al\textsc{iii}) = 3612±362 km s\(^{-1}\). It gives us also one of the most massive xA quasar with a log M_{BH}(Al\textsc{iii}) = 8.92.
- J235157.59+003610.6: This object was affected by the host galaxy emission, it was fitted with positive continuum and a few absorption lines in the red side of Si\textsc{iii}\(\lambda 1892\) and C\textsc{iii}\(\lambda 1909\) are observed.
- J095531.45+174340.3: One of the brightest sources with a log L_{bol} = 47.04, with a relatively high shift(Al\textsc{iii}) = -427±43 km s\(^{-1}\).
- J092612.68+202326.6: This object presented an Al\textsc{iii} redshift of 262±27 km s\(^{-1}\) with a FWHM(Al\textsc{iii}) = 3771±370.
- J003546.29-034118.2: Highest blueshifted source, shift(Al\textsc{iii}) = -1011.69±81 km s\(^{-1}\), FWHM(Al\textsc{iii}) = 4194.93±342 km s\(^{-1}\). With a δlogL_{Vir} = -0.75.

Appendix B: Line fitting procedures and derived computations header table

Data obtained for this work and can be described as follows by number of columns in Table B.1:

1. file SDSS name,
2-5. z of this work obtained with [O\textsc{ii}]\(\lambda 3728\) (∆z = z_{[OII]} - z_{SDSS}) and the SDSS extracted values with errors,
6. signal-to-noise ratio around 1700Å,
7-10. continuum flux at 1700Å and its normalisation flux with errors,
11. assigned profile of the C\textsc{iii}\(\lambda 1909\) line: Gaussian or Lorentzian, for xA sources it was added to the name the notation ”xA”
12-13. power-law index - α with error for REGION 1,
14-41. flux, equivalent width, FWHM, shift of Al\textsc{iii}\(\lambda 1860\), Si\textsc{iii}\(\lambda 1892\) and C\textsc{iii}\(\lambda 1909\) BC,
42-45. UV diagnostics ratios with errors,
46-69. flux and FWHM of N\textsc{iii}\(\lambda 1750\), Si\textsc{ii}\(\lambda 1816\), Fem(UV191), Fem(UV34), C\textsc{iii}VBC and NC with errors obtained by specfit,
70. power-law index - α for REGION 2,
71-74. flux and FWHM of [O\textsc{ii}]\(\lambda 3728\) with errors,
75-80. continuum flux at 1350Å and pseudo-continuum flux at 3700Å with errors,
81-83. logarithmic line luminosity at 1860Å, 1892Å and 1909Å,
84-85. logarithmic bolometric luminosity,
86. FWHM using the luminosity-dependant criterion,
87-88. logarithmic black hole mass using C\textsc{iii}\(\lambda 1909\) and Al\textsc{iii}\(\lambda 1860\),
89-92. eddington ratio using C\textsc{iii}\(\lambda 1909\) and Al\textsc{iii}\(\lambda 1860\) with errors,
93-94. logarithmic virial luminosity for Pop. xA sources with errors.
Fig. A.1: Analysis of the 1900Å blend as described in section 3.2 for the 11 x A sources in our work. Abscissa scales are rest-frame wavelength in Å. Ordinate scale is the specific flux. Black lines identify the BC of Alm1860, SiII1892 and CII1909. Dashed blue line is the multi-component model obtained by specfit. Green lines trace the adopted FeII (pale) and FeIII template (dark).
Table B.1: Header description of the sample with individual measurements.

| COL | Identifier | Type     | Units             | Description                                      |
|-----|------------|----------|-------------------|--------------------------------------------------|
| 1   | SDSS       | CHAR     | NULL              | File name                                        |
| 2   | z          | FLOAT    | NULL              | $z$ for this work, measured using [OIII]3728 (see text) |
| 3   | $z_{\text{ERR}}$ | FLOAT     | NULL              | $z$ (this work) error                           |
| 4   | z\_SDSS    | FLOAT    | NULL              | $z$ given by the SDSS database                   |
| 5   | z\_SDSS\_ERR | FLOAT     | NULL              | $z$ given by the SDSS database                   |
| 6   | SN         | FLOAT    | NULL              | S/N Ratio measured around 1700Å                   |
| 7   | C1700      | FLOAT    | ergs s$^{-1}$ cm$^{-2}$ Å$^{-1}$ | Continuum Flux at 1700Å |
| 8   | C1700\_ERR | FLOAT    | ergs s$^{-1}$ cm$^{-2}$ Å$^{-1}$ | Continuum Flux at 1700Å error                   |
| 9   | N1700      | FLOAT    | NULL              | Continuum normalisation at 1700Å                 |
|10   | N1700\_ERR | FLOAT    | NULL              | Continuum normalisation at 1700Å error           |
|11   | CI\_PROF   | CHAR     | NULL              | Cm],[1909 BC Line Profile. $G = $ Gaussian, $L =$ Lorentzian |
|12   | ALPHA\_R1  | FLOAT    | NULL              | Power Law Index - $\alpha$ in Region 1 (see text) |
|13   | ALPHA\_R1\_ERR | FLOAT     | NULL              | Power Law Index - $\alpha$ error                 |
|14   | FLUX\_FEIII | FLOAT    | $10^{-17}$ergs s$^{-1}$ cm$^{-2}$ Å$^{-1}$ | FeII Flux |
|15   | FLUX\_FEIII\_ERR | FLOAT | $10^{-17}$ergs s$^{-1}$ cm$^{-2}$ Å$^{-1}$ | FeII Flux error |
|16   | SHIFT\_FEIII | FLOAT    | Å                  | Feu Flux shift with respect to the Rest-frame     |
|17   | SHIFT\_FEIII\_ERR | FLOAT | Å                  | Feu Flux shift with respect to the Rest-frame error |
|18   | EW\_CI\_IIIBC | FLOAT | Å                | Cm],[1909 BC Equivalent Width                    |
|19   | EW\_CI\_IIIBC\_ERR | FLOAT | Å                | Cm],[1909 BC Equivalent Width error               |
|20   | FLUX\_CI\_IIIBC | FLOAT    | $10^{-17}$ergs s$^{-1}$ cm$^{-2}$ Å$^{-1}$ | Cm],[1909 BC Flux |
|21   | FLUX\_CI\_IIIBC\_ERR | FLOAT | $10^{-17}$ergs s$^{-1}$ cm$^{-2}$ Å$^{-1}$ | Cm],[1909 BC Flux error |
|22   | SHIFT\_CI\_IIIBC | FLOAT    | km s$^{-1}$      | Cm],[1909 BC shift with respect to the Rest-frame |
|23   | SHIFT\_CI\_IIIBC\_ERR | FLOAT | km s$^{-1}$      | Cm],[1909 BC shift with respect to the Rest-frame error |
|24   | FWHM\_CI\_IIIBC | FLOAT    | km s$^{-1}$      | Cm],[1909 BC Full Width at Half Maximumum       |
|25   | FWHM\_CI\_IIIBC\_ERR | FLOAT | km s$^{-1}$      | Cm],[1909 BC Full Width at Half Maximumum error |
|26   | EW\_CI\_III | FLOAT    | Å                  | Sin],[1892 Equivalent Width                      |
|27   | EW\_CI\_III\_ERR | FLOAT | Å                  | Sin],[1892 Equivalent Width error                |
|28   | FLUX\_CI\_III | FLOAT    | $10^{-17}$ergs s$^{-1}$ cm$^{-2}$ Å$^{-1}$ | Sin],[1892 Flux |
|29   | FLUX\_CI\_III\_ERR | FLOAT | $10^{-17}$ergs s$^{-1}$ cm$^{-2}$ Å$^{-1}$ | Sin],[1892 Flux error |
|30   | SHIFT\_CI\_III | FLOAT    | km s$^{-1}$      | Sin],[1892 shift with respect to the Rest-frame |
|31   | SHIFT\_CI\_III\_ERR | FLOAT | km s$^{-1}$      | Sin],[1892 shift with respect to the Rest-frame error |
|32   | FWHM\_CI\_III | FLOAT    | km s$^{-1}$      | Sin],[1892 Full Width at Half Maximumum |
|33   | FWHM\_CI\_III\_ERR | FLOAT | km s$^{-1}$      | Sin],[1892 Full Width at Half Maximumum error |
|34   | EW\_AI\_III | FLOAT    | Å                  | Alm],[1860 Equivalent Width                      |
|35   | EW\_AI\_III\_ERR | FLOAT | Å                  | Alm],[1860 Equivalent Width error                |
|36   | FLUX\_AI\_III | FLOAT    | $10^{-17}$ergs s$^{-1}$ cm$^{-2}$ Å$^{-1}$ | Alm],[1860 Flux |
|37   | FLUX\_AI\_III\_ERR | FLOAT | $10^{-17}$ergs s$^{-1}$ cm$^{-2}$ Å$^{-1}$ | Alm],[1860 Flux error |
|38   | SHIFT\_AI\_III | FLOAT    | km s$^{-1}$      | Alm],[1860 shift with respect to the Rest-frame |
|39   | SHIFT\_AI\_III\_ERR | FLOAT | km s$^{-1}$      | Alm],[1860 shift with respect to the Rest-frame error |
|40   | FWHM\_AI\_III | FLOAT    | km s$^{-1}$      | Alm],[1860 Full Width at Half Maximumum       |
|41   | FWHM\_AI\_III\_ERR | FLOAT | km s$^{-1}$      | Alm],[1860 Full Width at Half Maximumum error |
|42   | AI\_III\_SII | FLOAT    | NULL              | UV Diagnostic ratio Alm],[1860/Sim],[1892 |
|43   | AI\_III\_SII\_ERR | FLOAT | NULL              | UV Diagnostic ratio Alm],[1860/Sim],[1892 error |
|44   | CI\_SII\_SII | DOUBLE   | NULL              | UV Diagnostic ratio Cm],[1909/Sim],[1982 |
|45   | CI\_SII\_SII\_ERR | FLOAT | NULL              | UV Diagnostic ratio Cm],[1909/Sim],[1892 error |
|46   | FLUX\_SII | FLOAT    | $10^{-17}$ergs s$^{-1}$ cm$^{-2}$ Å$^{-1}$ | Nut],[1750 Flux |
|47   | FLUX\_SII\_ERR | FLOAT | $10^{-17}$ergs s$^{-1}$ cm$^{-2}$ Å$^{-1}$ | Nut],[1750 Flux error |
|48   | FWHM\_SII | FLOAT    | km s$^{-1}$      | Nut],[1750 Full Width at Half Maximumum       |
|49   | FWHM\_SII\_ERR | FLOAT | km s$^{-1}$      | Nut],[1750 Full Width at Half Maximumum error |
|50   | FLUX\_FEIII | FLOAT    | $10^{-17}$ergs s$^{-1}$ cm$^{-2}$ Å$^{-1}$ | Sin],[1816 Flux |
|51   | FLUX\_FEIII\_ERR | FLOAT | $10^{-17}$ergs s$^{-1}$ cm$^{-2}$ Å$^{-1}$ | Sin],[1816 Flux error |
|52   | FWHM\_FEIII | FLOAT    | km s$^{-1}$      | Sin],[1816 Full Width at Half Maximumum |
|53   | FWHM\_FEIII\_ERR | FLOAT | km s$^{-1}$      | Sin],[1816 Full Width at Half Maximumum error |
|54   | FLUX\_FEII | FLOAT    | $10^{-17}$ergs s$^{-1}$ cm$^{-2}$ Å$^{-1}$ | Feu Flux |
|55   | FLUX\_FEII\_ERR | FLOAT | $10^{-17}$ergs s$^{-1}$ cm$^{-2}$ Å$^{-1}$ | Feu Flux error |
|56   | FWHM\_FEII | FLOAT    | km s$^{-1}$      | Feu Full Width at Half Maximumum |
|57   | FWHM\_FEII\_ERR | FLOAT | km s$^{-1}$      | Feu Full Width at Half Maximumum error |

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Table B.1: continued.

| COL | Identifier | Type         | Units                                      | Description                                                        |
|-----|------------|--------------|--------------------------------------------|-------------------------------------------------------------------|
| 58  | FLUX_CIIINC | FLOAT        | $10^{-17}$ ergs s$^{-1}$ cm$^{-2}$ Å$^{-1}$ | Cm$\lambda$1909 NC Flux                                          |
| 59  | FLUX_CIIINC_ERR | FLOAT  | $10^{-17}$ ergs s$^{-1}$ cm$^{-2}$ Å$^{-1}$ | Cm$\lambda$1909 NC Flux error                                     |
| 60  | FWHM_CIIINC | FLOAT        | km s$^{-1}$                                | Cm$\lambda$1909 NC Full Width at Half Maximum                      |
| 61  | FWHM_CIIINC_ERR | FLOAT  | km s$^{-1}$                                | Cm$\lambda$1909 NC Full Width at Half Maximum error               |
| 62  | FLUX_CIII_VBC | FLOAT        | $10^{-17}$ ergs s$^{-1}$ cm$^{-2}$ Å$^{-1}$ | Cm$\lambda$1909 VBC Flux                                          |
| 63  | FLUX_CIII_VBC_ERR | FLOAT  | $10^{-17}$ ergs s$^{-1}$ cm$^{-2}$ Å$^{-1}$ | Cm$\lambda$1909 VBC Flux error                                    |
| 64  | FWHM_CIII_VBC | FLOAT        | km s$^{-1}$                                | Cm$\lambda$1909 VBC Full Width at Half Maximum                    |
| 65  | FWHM_CIII_VBC_ERR | FLOAT  | km s$^{-1}$                                | Cm$\lambda$1909 VBC Full Width at Half Maximum error              |
| 66  | FLUX_FE1914 | FLOAT        | $10^{-17}$ ergs s$^{-1}$ cm$^{-2}$ Å$^{-1}$ | Fem$\lambda$1914 Flux                                            |
| 67  | FLUX_FE1914_ERR | FLOAT  | $10^{-17}$ ergs s$^{-1}$ cm$^{-2}$ Å$^{-1}$ | Fem$\lambda$1914 Flux error                                      |
| 68  | FWHM_FE1914 | FLOAT        | km s$^{-1}$                                | Fem$\lambda$1914 Full Width at Half Maximum                       |
| 69  | FWHM_FE1914_ERR | FLOAT  | km s$^{-1}$                                | Fem$\lambda$1914 Full Width at Half Maximum error                 |
| 70  | ALPHA_R2    | FLOAT        | NULL                                       | Power Law Index - $\alpha$ in Region 2 (see text)                  |
| 71  | FLUX_OII    | FLOAT        | $10^{-17}$ ergs s$^{-1}$ cm$^{-2}$ Å$^{-1}$ | [Oii]$\lambda$3728 Flux                                          |
| 72  | FLUX_OII_ERR | FLOAT        | $10^{-17}$ ergs s$^{-1}$ cm$^{-2}$ Å$^{-1}$ | [Oii]$\lambda$3728 Flux error                                    |
| 73  | FWHM_OII    | FLOAT        | km s$^{-1}$                                | [Oii]$\lambda$3728 Full Width at Half Maximum                    |
| 74  | FWHM_OII_ERR | FLOAT        | km s$^{-1}$                                | [Oii]$\lambda$3728 Full Width at Half Maximum error               |
| 75  | C1350       | FLOAT        | $10^{-17}$ ergs s$^{-1}$ cm$^{-2}$ Å$^{-1}$ | Continuum Flux at 1350 Å                                         |
| 76  | C1350_ERR   | FLOAT        | $10^{-17}$ ergs s$^{-1}$ cm$^{-2}$ Å$^{-1}$ | Continuum Flux at 1350 Å error                                    |
| 77  | C3700       | FLOAT        | $10^{-17}$ ergs s$^{-1}$ cm$^{-2}$ Å$^{-1}$ | Pseudo-continuum Flux at 3700 Å                                  |
| 78  | C3700_ERR   | FLOAT        | $10^{-17}$ ergs s$^{-1}$ cm$^{-2}$ Å$^{-1}$ | Pseudo-continuum Flux at 3700 Å error                            |
| 79  | C5100       | FLOAT        | $10^{-17}$ ergs s$^{-1}$ cm$^{-2}$ Å$^{-1}$ | Continuum Flux at 5100 Å                                         |
| 80  | C5100_ERR   | FLOAT        | $10^{-17}$ ergs s$^{-1}$ cm$^{-2}$ Å$^{-1}$ | Continuum Flux at 5100 Å error                                    |
| 81  | LOG_L1860   | DOUBLE       | ergs s$^{-1}$                              | Logarithmic Line Luminosity at 1860 Å                            |
| 82  | LOG_L1892   | DOUBLE       | ergs s$^{-1}$                              | Logarithmic Line Luminosity at 1892 Å                            |
| 83  | LOG_L1909   | DOUBLE       | ergs s$^{-1}$                              | Logarithmic Line Luminosity at 1909 Å                            |
| 84  | LOG_L_BOL   | DOUBLE       | ergs s$^{-1}$                              | Logarithmic bolometric Luminosity at 1700 Å                       |
| 85  | LOG_L_BOL_ERR | DOUBLE  | ergs s$^{-1}$                              | Logarithmic bolometric Luminosity at 1700 Å error                 |
| 86  | FWHM_AB     | DOUBLE       | km s$^{-1}$                                | FWHM$_{AB}$ using Sulentic et al. (2017) criterion                |
| 87  | LOG_MBH_CIII | FLOAT       | NULL                                       | Logarithmic Black Hole Mass in solar masses of Cm$\lambda$1909   |
| 88  | LOG_MBH_AIII | FLOAT       | NULL                                       | Logarithmic Black Hole Mass in solar masses of Alm$\lambda$1860   |
| 89  | REDD_CIII   | FLOAT        | NULL                                       | Eddington Ratio using Cm$\lambda$1909 line                       |
| 90  | REDD_CIII_ERR | FLOAT      | NULL                                       | Eddington Ratio using Cm$\lambda$1909 line error                  |
| 91  | REDD_ALIII  | FLOAT        | NULL                                       | Eddington Ratio using Alm$\lambda$1860 line                      |
| 92  | REDD_ALIII_ERR | FLOAT     | NULL                                       | Eddington Ratio using Alm$\lambda$1860 line error                 |
| 93  | LOG_L_VIR   | DOUBLE       | ergs s$^{-1}$                              | Logarithmic Virial Luminosity for Pop. xA sources                 |
| 94  | LOG_L_VIR_ERR | FLOAT      | ergs s$^{-1}$                              | Logarithmic Virial Luminosity for Pop. xA sources error           |