SUPER III. Broad Line Region properties of AGN at z~2

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ABSTRACT

Aims. The SINFONI survey for Unveiling the Physics and Effect of Radiative feedback (SUPER) was designed to conduct a blind search for AGN-driven outflows on X-ray selected AGN at redshift z~2 with high (~2 kpc) spatial resolution, and correlate them to the properties of the host galaxy and central black hole. The main aims of this paper are: a) to derive reliable estimates for the black hole mass and accretion rates for the Type-I AGN in this survey; b) to characterize the properties of the AGN driven winds in the Broad Line Region (BLR).

Methods. We analyzed rest-frame optical and UV spectra of 21 Type-1 AGN. We used Hα, Hβ, and MgII line profiles to estimate the black hole mass. We used the blueshift of the CIV line profile to trace the presence of winds in the BLR.

Results. We found that the Hα and Hβ line widths are strongly correlated, as well as the line continuum luminosity at 5100 Å with Hα line luminosity, resulting in a well defined correlation between black hole mass estimated from Hα and Hβ. We estimate using these lines that the black hole mass for our objects are in the range Log(MBH/M⊙)=8.4-10.8 and are accreting at η=0.04-1.3. On the other end, we confirm the well known fact that the CIV line width does not correlate with the Balmer lines and the peak of the line profile is blue-shifted with respect to the [OIII]-based systemic redshift. These findings support the idea that the CIV line is tracing outflowing gas in the BLR for which we estimated velocities up to ~4700 km/s. We confirm the strong dependence of the BLR wind velocity with the UV-to-Xray continuum slope, as well as the bolometric luminosity and Eddington ratio. We inferred BLR mass outflow rates in the range 0.005-3 M⊙/yr, showing a correlation with the bolometric luminosity consistent with that observed for ionized winds in the NLR and X-ray winds detected in local AGN, and kinetic power ~10^{-7} - 10^{-3} L_{bol}.

The coupling efficiency predicted by AGN feedback models are much higher than the values reported for the BLR winds in the SUPER sample, however it should be noted that only a fraction of the energy injected by the AGN in the surrounding medium is expected to become kinetic power in the outflow. Finally, we found an anti-correlation between the equivalent width of the [OIII] line with respect to the CIV velocity shift, and a positive correlation with [OIII] outflow velocity. These findings, for the first time in an unbiased sample of AGN at z~2, support a scenario where BLR winds are connected to galaxy scale detected outflows, and are therefore actually capable of affecting the gas in the NLR located at kpc scale.

Key words. galaxies: active – galaxies: evolution - galaxies: high-redshift - quasars: emission lines – quasars: supermassive black holes

1. Introduction

Supermassive black holes (BH) are thought to be ubiquitous in the center of all massive galaxies (Magorrian et al. 1998; Gebhardt et al. 2000). The black hole mass (MBH) is known to be correlated with the luminosity, velocity dispersion and stellar masses of the host-galaxy, suggestive of co-evolution between the central engine and its host-galaxy (Magorrian et al. 1998; Gebhardt et al. 2000; Ferrarese & Merritt 2000). A pre-requisite for studying the interplay between the central AGN and its host is therefore an accurate measurement of MBH.

A direct measurement of the BH mass is possible via reverberation mapping (RM), a technique which uses the lag between the variability in the AGN continuum and broad emission lines to measure the broad line region (BLR) size.

In addition, RM experiments provide empirical relations between the radius of the BLR (R_{BLR}) and the AGN luminosity, i.e. R_{BLR} ∝ (∫L_{β})^{α}, with α ~ 0.5-0.7 (Kaspi et al. 2000; 2005; Bentz et al. 2009; 2013). This BLR-radius-luminosity relation provides an indirect way for measuring the BH mass when it is not possible to obtain reverberation data (the so-called single epoch (SE) method, see e.g. McLure & Jarvis 2002; Shen 2013).

Line luminosity, e.g. L(Hβ), can be used to replace the continuum luminosity L_{β}.

Assuming that the BLR is virialized and the clouds are dominated by gravitational motions, the BH mass can be estimated as follows:

\[ M_{BH} = f \frac{R_{BLR} V_{BLR}^{2}}{G} \propto \frac{(\int L_{β})^{α}}{G} \]  

where G is the gravitational constant and V_{BLR} is the gas velocity, which can be measured from the width of a specific emission line (full width half maximum, FWHM, or velocity dispersion, σ). The FWHM is more widely used, being less vulnerable to noise in line wings and continuum placement. The alternative velocity dispersion (σ) is less sensitive to the narrow line removal but it is ill-defined for Lorentzian profiles and is sensitive to the quality of the data. In this paper we use the FWHM as indicator of the virial velocity of the gas in the BLR.

The factor f in Eq. 1 depends on the geometry and kinematics of the BLR, and can be determined by comparing the BH mass derived from alternative methods (Woo et al. 2015; Graham et al. 2016). Mejía-Restrepo et al. (2018) suggested a new way to estimate f. This is based on a strong anti-correlation between the BH mass and the FWHM of the broad emission lines, caused probably by line-of-sight inclination effects.
Continuum luminosity at 5100 Å is usually preferred in Eq. (1) given its tight correlation with the BLR size, based on a large number of sources. The line luminosities are useful in case of contamination by host starlight (Greene & Ho 2005) or in case of radio-loud objects, where the continuum is contaminated by the non thermal emission of the jet (Wu et al. 2004).

Different lines have been used to estimate the BH mass, depending on the redshift, i.e. Hβ, Hα, MgII and CIV with different measures of the line width, i.e. FWHM or line dispersion (Vestergaard 2002; McLure & Jarvis 2002; Wang et al. 2009). The Hβ line width was used to measure the R-L relation in most RM studies of low redshift AGN (e.g. Bentz et al. 2009). As earlier studies confirmed, there is a strong correlation among the widths of Hα, Hβ and MgII (Greene & Ho 2005; Shen et al. 2008; McGill et al. 2008; Trakhtenbrot & Netzer 2012; Mejía-Restrepo et al. 2016). Because the majority of RM experiments used low-z AGN, the BH mass estimates based on Balmer lines are considered the most reliable. The use of high ionization lines, as CIV, to measure MBH is instead highly debated in the literature.

It is well known that CIV usually exhibits a shift of the peak to the blue, associated with gas in a non-virial motion (Gaskell 1982; Sulentic et al. 2000; Baskin & Laor 2005; Richards et al. 2011; Denney 2012; Coatman et al. 2017; Mejía-Restrepo et al. 2018; Vietri et al. 2018), which leads to a biased estimation of the BH mass. It is now well-established that the blue-shift of the CIV line peak correlates with AGN properties as its luminosity, Eddington ratio (λedd), and quasar spectral energy distribution properties (e.g. Richards et al. 2011). While these properties are a limitation in the use of CIV as a black hole mass estimator, they offer the possibility to trace AGN winds on the pc-scale of the BLR.

In this paper we analyze the properties of the BLR in the SUPER sample. As described in Circosta et al. (2018), the SUPER survey consists of SINFONI observations of thirty-nine blindly-selected X-ray AGN at redshift = 2. The survey provides high-resolution, spatially resolved SINFONI observations in the H and K bands, with the main scientific goal of inferring the impact of outflows on on-going star formation and link outflow properties with AGN and host galaxy parameters (see Circosta et al. 2018 for further details). The objects are selected from the COSMOS-Legacy (e.g. Civano et al. 2016; Sul et al. 2015; Sul et al. 2020), the wide area XMM-XXL (e.g. Georgakakis & Nandra 2011; Liu et al. 2016; Menzel et al. 2016), Stripe 82 X-ray survey (Lamassa et al. 2016) and WISSH surveys (Bischetti et al. 2017; Martocchia et al. 2017; Duras et al. 2017; Vietri et al. 2018) and about 58% are Type 1 AGN. We focus on the 21 Type-1 AGNs observed with SINFONI (see Fig. 1) both in H and K bands, with the aim of measuring the black hole mass MBH and Eddington ratio from Hβ and Hα emission lines, and compare the results with the MgII and CIV-based measurements, thanks to ancillary UV rest-frame data. Furthermore, we use the CIV line profile to trace the winds at pc-scale in order to derive the energetics of the winds and possibly link the BLR wind properties with the winds located at kpc-scales in the NLR.

Throughout this paper we assume H0 = 70 km s⁻¹ Mpc⁻¹, ΩΛ = 0.7, and ΩM = 0.3, wavelengths in vacuum and line blueshifts defined as positive values.

2. Observations and data reduction

SINFONI observations were carried out as part of the ESO large programme 196.A-0377, with 3"×3" field of view in Adaptive Optics (AO) assisted mode, with a pixel scale of 0.05×0.1 arcsec (final resampled pixel scale 0.05×0.05 arcsec), using H grat.
3. Spectroscopic analysis

We extracted the integrated spectra from a circular region centered at the QSO position, which covers at least 95% of the total emission. The target center was found using a 2D Gaussian fit centered at the QSO position, which covers at least 95% of the total emission.

We extracted the integrated spectra from a circular region centered on the wavelength-collapsed image from the datacube, over the emission. The target center was found using a 2D Gaussian fit centered at the QSO position, which covers at least 95% of the total emission.

We performed separately the fit for the H and K band spectra using the python routine `scipy.optimize.curve_fit`. Finally, we also modeled the HeII λ4686 line with two components: 1) a narrow Gaussian with centroid and velocity dispersion tied to the narrow [OIII] line; 2) a broad Gaussian component with parameters free to vary to reproduce the emission due to the BLR. Only in one case, X_N_160_22, we unambiguously detected the HeII narrow component with FWHM= 920±50. We do not detect the HeII BLR component, this is probably due to the weakness of the HeII line.

1 For the two sources undetected in the H-band (X_N_53_3 and X_N_44_64), we used the redshift obtained from the Hα narrow component.

### Table 1: Properties of the SUPER AGN considered in this paper.

| ID        | RA (2)      | Dec (3)     | z   | z_{OIII} (4) | H  (5) | K  (6) | r_H (7) | r_K (8) | Log (L_{bol}/ergs^{-1}) (9) | Log (L_{5100}/erg s^{-1}) (10) |
|-----------|-------------|-------------|-----|--------------|-------|-------|--------|--------|-----------------------------|-------------------------------|
| X_N_160_22| 02:04:53.81 | -06:04:07.82| 2.445 | 2.442       | 19.22 | 18.79 | 0.5    | 0.4    | 46.74±0.02                  | 45.83±0.06                     |
| X_N_81_44 | 02:17:30.95 | -04:18:23.66| 2.311 | 2.317       | 18.78 | 18.43 | 0.45   | 0.4    | 46.80±0.03                  | 45.75±0.06                     |
| X_N_53_3  | 02:20:29.84 | -05:26:23.41| 2.434 | 2.433       | 20.60 | -     | -0.2   | 0.2    | 46.21±0.03                  | -                             |
| X_N_66_23 | 02:22:33.64 | -05:49:02.73| 2.386 | 2.385       | 20.56 | 20.33 | 0.35   | 0.45   | 46.04±0.02                  | 45.63±0.06                     |
| X_N_35_20 | 02:24:02.71 | 05:11:30.82 | 2.261 | 2.261       | 22.07 | 21.70 | 0.15   | 0.2    | 45.44±0.02                  | 43.95±0.06                     |
| X_N_12_26 | 02:25:50.09 | -03:06:41.16| 2.471 | 2.472       | 19.83 | 19.53 | 0.4    | 0.35   | 46.52±0.02                  | 45.53±0.06                     |
| X_N_44_64 | 02:27:01.46 | -04:05:06.73| 2.252 | 2.244       | 21.31 | 20.77 | -0.2   | -      | 45.51±0.07                  | -                             |
| X_N_4_48  | 02:27:44.63 | -03:42:05.46| 2.317 | 2.315       | 19.57 | 20.43 | 0.25   | 0.35   | 46.16±0.02                  | 45.05±0.06                     |
| X_N_102_35| 02:29:05.94 | 04:02:24.99 | 2.190 | 2.190       | 18.76 | 19.19 | 0.15   | 0.2    | 46.82±0.02                  | 45.52±0.06                     |
| X_N_115_23| 02:30:30.66 | -05:08:14.10| 2.342 | 2.340       | 19.79 | 19.26 | 0.35   | 0.4    | 46.49±0.02                  | 45.55±0.06                     |
| cid_166   | 09:58:58.68 | +02:01:39.22| 2.448 | 2.461       | 18.55 | 18.23 | 0.35   | 0.4    | 46.93±0.02                  | 45.83±0.06                     |
| cid_1605  | 09:59:19.82 | +02:42:38.73| 2.121 | 2.118       | 20.63 | 20.14 | 0.2    | 0.2    | 46.03±0.02                  | 44.84±0.06                     |
| cid_346   | 09:59:43.41 | +02:07:07.44| 2.194 | 2.217       | 19.24 | 18.95 | 0.35   | 0.4    | 46.66±0.02                  | 45.61±0.06                     |
| cid_1205  | 10:00:02.57 | +02:19:58.68| 2.255 | 2.257       | 21.64 | 20.72 | 0.15   | 0.6    | 45.75±0.17                  | 44.91±0.06                     |
| cid_467   | 10:00:24.48 | +02:06:19.76| 2.288 | 2.285       | 19.34 | 18.91 | 0.2    | 0.2    | 46.53±0.04                  | 45.25±0.06                     |
| J1333+1649| 13:33:35.79 | 16:49:30.96 | 2.089 | 2.099       | 15.72 | 15.49 | 0.55   | 0.5    | 47.91±0.02                  | 47.32±0.06                     |
| J1441+0454| 14:41:05.54 | +04:54:54.96| 2.059 | 2.080       | 17.16 | 15.53 | 0.50   | 0.55   | 47.73±0.04                  | 46.66±0.06                     |
| J1549+1245| 15:49:38.73 | +12:45:09.20| 2.365 | 2.368       | 15.92 | 15.34 | 0.50   | 0.65   | 47.33±0.04                  | 47.16±0.06                     |
| S82X1905  | 23:28:56.35 | -00:30:11.74| 2.263 | 2.273       | 19.72 | 19.15 | 0.35   | 0.4    | 46.50±0.02                  | 45.55±0.06                     |
| S82X1940  | 23:29:40.28 | -00:17:51.68| 2.351 | 2.350       | 20.80 | 20.15 | 0.3    | 0.3    | 46.03±0.02                  | 44.98±0.06                     |
| S82X2058  | 23:31:58.62 | -00:54:10.44| 2.308 | 2.315       | 19.79 | 19.29 | 0.35   | 0.35   | 45.39±0.02                  | 45.54±0.06                     |

Notes: (1) Target identification; (2–3) celestial coordinates; (4) redshift from archival optical spectra; (5) redshift from the peak location of the [OIII]λ5008 in the integrated spectra; (6–9) the radius (in arcsec) of the circular aperture centered on the target used to extract the spectrum, for the H and K bands; (10) Logarithm of the bolometric luminosity derived from SED fitting (Cincosta et al. 2018) and (11) Logarithm of the extinction-corrected luminosity at 5100Å derived from the best-fit values of the power-law model representing the AGN continuum (see sect. 3).
Table 2: Properties of BLR components of the Hβ emission line derived from parametric model fits.

| ID          | $\lambda_{H\beta}$ (Å) | FWHM$_{H\beta}$ (km s$^{-1}$) | EW$_{H\beta}$ (Å) | Log (L$_{H\beta}$ / erg s$^{-1}$) |
|-------------|-------------------------|-------------------------------|------------------|----------------------------------|
| X_N_160_22 | 4876 ± 1                | 5190 ± 170                   | 58 ± 2           | 43.99 ± 0.04                     |
| X_N_81_44  | 4873 ± 1                | 5290 ± 170                   | 57 ± 2           | 43.87 ± 0.04                     |
| X_N_12_26  | 4865 ± 1                | 4890 ± 200                   | 51 ± 2           | 43.58 ± 0.04                     |
| X_N_4_48   | 4860 ± 1                | 6710 ± 670                   | 40 ± 4           | 42.95 ± 0.06                     |
| X_N_102_35 | 4872 ± 1                | 4810 ± 160                   | 58 ± 2           | 43.67 ± 0.04                     |
| X_N_115_23 | 4869 ± 2                | 6330 ± 250                   | 56 ± 2           | 43.68 ± 0.04                     |
| cid_166    | 4867 ± 1                | 6970 ± 130                   | 91 ± 2           | 44.17 ± 0.04                     |
| cid_1605   | 4860 ± 1                | 5040 ± 510                   | 156 ± 22         | 43.25 ± 0.06                     |
| cid_346    | 4870 ± 2                | 6280 ± 340                   | 46 ± 2           | 43.63 ± 0.05                     |
| cid_467    | 4875 ± 2                | 9260 ± 760                   | 93 ± 8           | 43.62 ± 0.05                     |
| J1333+1649 | 4841 ± 2                | 6300 ± 250                   | 42 ± 2           | 43.54 ± 0.04                     |
| J1441+0454 | 4855 ± 1                | 4030 ± 100                   | 47 ± 1           | 44.73 ± 0.04                     |
| J1549+1245 | 4867 ± 2                | 16570 ± 690                  | 108 ± 7          | 45.53 ± 0.05                     |
| S82X1905   | 4872 ± 1                | 4960 ± 100                   | 71 ± 1           | 43.80 ± 0.04                     |
| S82X1940   | 4862 ± 1                | 3710 ± 140                   | 75 ± 3           | 43.42 ± 0.04                     |
| S82X2058   | 4860 ± 1                | 6450 ± 150                   | 69 ± 1           | 43.78 ± 0.04                     |

**Notes.** Columns give the following information for the BLR component of the Hβ emission line: (1) Target identification, (2) centroid (Å), (3) full width at half maximum (km/s), (4) rest-frame equivalent width (Å), (5) Logarithm of the extinction-corrected Hβ luminosity.

![Fig. 2: Parametrization of the Hβ-[OIII] region of the SUPER AGN X_N_160_22. The red curve shows the best-fit to the data. Green Gaussian refer to the Gaussian components used to reproduce the line profile of each emission line. Gold Gaussian component indicates the broad component of Hβ associated with BLR emission. FeII emission is marked in magenta. Lower panel shows the fit residuals. Grey bands indicate the sky line residuals masked during the fit procedure. The x- and y-axis show the restframe wavelength and flux (not corrected for extinction), according to the redshift of the target.](image)

3 The H band datacube of cid_1205 is contaminated by a bright stripe at the location of Hβ line, preventing us a reliable measurement of the line parameters. We therefore did not estimate BLR Hβ line parameters for this source.

Table 3: Properties of BLR components of the Hα emission line derived from parametric model fits.

| ID          | $\lambda_{H\alpha}$ (Å) | FWHM$_{H\alpha}$ (km s$^{-1}$) | EW$_{H\alpha}$ (Å) | Log (L$_{H\alpha}$ / erg s$^{-1}$) |
|-------------|-------------------------|-------------------------------|------------------|----------------------------------|
| X_N_160_22 | 6584 ± 1                | 5410 ± 110                   | 289 ± 7          | 44.46 ± 0.03                     |
| X_N_81_44  | 6580 ± 1                | 6320 ± 120                   | 267 ± 5          | 44.41 ± 0.03                     |
| X_N_53_3   | 6571 ± 1                | 4630 ± 180                   | 415 ± 27         | 43.57 ± 0.03                     |
| X_N_66_23  | 6567 ± 2                | 6105 ± 310                   | 254 ± 15         | 43.86 ± 0.03                     |
| X_N_35_20  | 6564 ± 7                | 6440 ± 1590                  | 317 ± 92         | 42.80 ± 0.08                     |
| X_N_12_26  | 6570 ± 1                | 5270 ± 120                   | 256 ± 7          | 44.03 ± 0.03                     |
| X_N_44_64  | 6567 ± 5                | 7720 ± 720                   | 187 ± 21         | 43.15 ± 0.04                     |
| X_N_4_48   | 6573 ± 2                | 7700 ± 240                   | 377 ± 19         | 44.27 ± 0.03                     |
| X_N_102_35 | 6577 ± 1                | 5190 ± 100                   | 292 ± 7          | 44.16 ± 0.03                     |
| X_N_115_23 | 6572 ± 1                | 6560 ± 130                   | 335 ± 8          | 44.28 ± 0.03                     |
| cid_166    | 6570 ± 1                | 6810 ± 100                   | 437 ± 8          | 44.76 ± 0.03                     |
| cid_1605   | 6569 ± 2                | 3690 ± 230                   | 296 ± 20         | 43.55 ± 0.04                     |
| cid_346    | 6565 ± 2                | 6980 ± 260                   | 205 ± 9          | 44.12 ± 0.03                     |
| cid_1205   | 6564 ± 2                | 5100 ± 230                   | 342 ± 42         | 43.52 ± 0.03                     |
| cid_467    | 6569 ± 2                | 8450 ± 230                   | 458 ± 21         | 44.11 ± 0.03                     |
| J1333+1649 | 6572 ± 1                | 6190 ± 50                    | 217 ± 2          | 45.73 ± 0.03                     |
| J1441+0454 | 6559 ± 1                | 4730 ± 50                    | 360 ± 6          | 44.17 ± 0.03                     |
| J1549+1245 | 6580 ± 1                | 7270 ± 50                    | 304 ± 2          | 45.80 ± 0.03                     |
| S82X1905   | 6571 ± 1                | 4730 ± 50                    | 360 ± 6          | 44.17 ± 0.03                     |
| S82X1940   | 6563 ± 1                | 4370 ± 160                   | 344 ± 16         | 43.35 ± 0.03                     |
| S82X2058   | 6585 ± 1                | 6400 ± 110                   | 322 ± 6          | 44.17 ± 0.03                     |

**Notes.** Columns give the following information for the BLR component of the Hα emission line: (1) Target identification, (2) centroid (Å), (3) full width at half maximum (km/s), (4) rest-frame equivalent width (Å), (5) Logarithm of the extinction-corrected Hα luminosity.
Fig. 3: Parametrization of the H\textalpha\ region of the SUPER AGN X N.160_22. The red curve shows the best-fit to the data. Green Gaussians refer to the narrow and broad components used to reproduce the line profile of H\textalpha, [NII] and [SII]. Gold Gaussian component indicates the broad component of H\textalpha associated with BLR emission. Lower panel shows the fit residuals. The x- and y- axis show the restframe wavelength and flux (not corrected for extinction), according to the redshift of the target

The model fitting is performed in the spectral range of 1210 Å - 2000 Å. We excluded from the fit the heavy blended spectral regions of O\textalpha+SiII \lambda 1305, CII \lambda 1335, the so-called 1600 Å bump, the undefined feature in 1570-1631 Å (see Nagao et al. (2006) for a detailed discussion) and NIV \lambda 1719, AlII \lambda 1722, NIII \lambda 1750 and FeII multiplets, i.e., 1286-1357 Å, 1570-1631 Å and 1687-1833 Å. The measured FWHM_{CIV} of the total profile are in the range ~1300-10000 km/s and the velocities shift, defined as $v_{\text{CIV}} = c \chi/\lambda_{\text{half}}$, with $\lambda_{\text{half}}$ the wavelength that bisects the cumulative total line flux and $c$ the speed of light, are in the range $v_{\text{CIV}} \sim 760$ up to 4700 km/s. The detailed results from the best-fit model of the CIV emission line for 20/21 SUPER targets are reported in Table 4. We note that for the bulk of the SUPER sources, the total CIV profile is blueshifted and therefore it is dominated by gas not at systemic velocity but in an outflowing phase. An example of the fit is shown in the upper panel of Fig. 4 (for the rest of the sample see Appendix A).

MgII \lambda 2800. For 17/21 SUPER sources we were able to model the MgII line, the remaining sources have very low S/N on this line and are affected by strong sky-lines residuals. We modelled first the continuum with a power-law plus the UV FeII+FeII templates from Popovic et al. (2019), convolved with a Gaussian function with a FWHM in the range 1000–5000 km s$^{-1}$. The best fit template was chosen through a $\chi^2$ minimization procedure. A potential velocity shift of the FeII emission lines is not considered in this paper. The MgII line was then generally modelled with a single Gaussian. For three objects, whose spectra were not affected by strong sky residuals, we performed the line fit using two Gaussian components. We used the BIC criterion to compare the models, and the single Gaussian model fit was favoured in all cases. We derived FWHM_{MgII} in the range ~3000-9000 km/s and a velocity shift $v_{\text{MgII}}$ up to 1200 km/s. We note that the MgII emission line and FeII emission surrounding the MgII are affected by sky-line residuals in almost all spectra of the SUPER sample, which can affect the measured line properties. Therefore hereafter the MgII line properties are used with caution.

The result of the emission line fit for the MgII emission line of 17/21 SUPER targets is reported in Table 5 and an example of the fit in the bottom panel of Fig. 4 (for the rest of the sample see Appendix A).

To estimate the uncertainties on the derived parameters for each of the emission lines discussed above and in Sec. 3.1 we created 1000 realizations of each spectrum by adding noise, drawn from a Gaussian distribution with dispersion equal to the rms of the spectrum, to the best-fit model spectrum and repeated the line fitting procedure on these mock spectra. The associated errors are estimated using the 84 and 16 percentiles of the parameter distribution.

4. BLR properties

4.1. Comparison of the broad lines profiles

As described in Sec. 3 the line fitting procedure provided luminosities, emission-line centroids and widths for four broad lines in our AGN sample (H\textalpha, H\beta, CIV and MgII) which we will now compare to derive reliable estimates of the their BH masses. First we compare the best-fit values of the FWHM of the Balmer lines (Fig. 5). The FWHM of H\alpha and H\beta for our sample are very 4

We note that no Balmer continuum model is included. This results in an overestimation of the continuum level.
similar (slope=1.43±0.49), consistent with the 1:1 relation. The only exception is the source J1549+1245, for which the Hγ line shows a much broader FWHM with respect to the Hα line. We also performed a fit excluding this outlier, resulting in a slope of 0.95±0.20.

### Table 4: Properties of CIV1549 emission line derived from parametric model fits (see Sect.3.2.)

| ID       | $\lambda^{1549}_{\text{rest}}$ (Å) | FWHM$_{\text{CIV}}$ (km s$^{-1}$) | EW$_{\text{CIV}}$ (Å) | $v_{\text{shift}}$ (km s$^{-1}$) | Log (L$_{\text{CIV}}$/ erg s$^{-1}$) | Log (L$_{1550}$/ erg s$^{-1}$) |
|----------|---------------------------------|---------------------------------|----------------|----------------|-------------------------------|-------------------------------|
| X_N_160_22 | 1548±1 | 2800±200 | 25±1 | -390±50 | 44.45±0.07 | 46.46±0.06 |
| X_N_81_44 | 1546±1 | 2800±200 | 36±2 | -90±100 | 44.37±0.07 | 46.25±0.06 |
| X_N_53_3 | 1547±1 | 2800±200 | 17±2 | 530±120 | 44.18±0.08 | 46.32±0.06 |
| X_N_66_23 | 1547±1 | 2800±200 | 26±8 | 510±340 | 43.70±0.13 | 45.78±0.07 |
| X_N_35_20 | 1547±1 | 2800±200 | 33±14 | 1030±380 | 44.27±0.09 | 45.70±0.07 |
| X_N_12_26 | 1547±1 | 2800±200 | 23±1 | -280±340 | 44.33±0.07 | 46.40±0.06 |
| X_N_4_48 | 1549±1 | 2800±200 | 56±8 | -360±210 | 44.12±0.09 | 45.82±0.07 |
| X_N_102_35 | 1548±1 | 2800±200 | 35±2 | -270±140 | 44.64±0.07 | 46.49±0.06 |
| X_N_115_23 | 1549±1 | 2800±200 | 42±5 | -150±160 | 43.77±0.08 | 45.50±0.07 |
| cid_166 | 1548±1 | 2800±200 | 35±2 | -220±250 | 44.03±0.08 | 45.99±0.06 |
| cid_1605 | 1548±1 | 2800±200 | 42±5 | -60±300 | 43.77±0.11 | 45.95±0.06 |
| J1333+1649 | 1548±1 | 2800±200 | 12±0 | 680±30 | 45.15±0.07 | 47.47±0.06 |
| J1441+0454 | 1548±1 | 2800±200 | 20±0 | 880±40 | 44.96±0.07 | 47.05±0.06 |
| J1549+1245 | 1548±1 | 2800±200 | 22±1 | -410±30 | 45.07±0.07 | 47.15±0.06 |
| S82X1905 | 1548±1 | 2800±200 | 20±4 | 530±320 | 43.93±0.10 | 45.98±0.06 |
| S82X1940 | 1548±1 | 2800±200 | 37±2 | 1240±190 | 43.98±0.09 | 45.63±0.07 |
| S82X2058 | 1548±1 | 2800±200 | 30±4 | 910±270 | 44.09±0.09 | 46.09±0.06 |

Notes. Columns give the following information for the BLR component of the CIV emission line: (1) Target identification, (2) centroid (Å), (3) full width at half maximum (km/s), (4) rest-frame equivalent width (Å), (5) velocity of the CIV at 50% of the cumulative line flux, (6) Logarithm of the extinction-corrected CIV luminosity and (7) Logarithm of the extinction-corrected luminosity at 1350 Å derived from the best-fit values of the power-law model representing the AGN continuum (see Sect.3).

### Table 5: Properties of MgII12800 emission line derived from parametric model fits (see Sect.3.2.)

| ID       | $\lambda^{12800}_{\text{rest}}$ (Å) | FWHM$_{\text{MgII}}$ (km s$^{-1}$) | EW$_{\text{MgII}}$ (Å) | $v_{\text{shift}}$ (km s$^{-1}$) | Log (L$_{\text{MgII}}$/ erg s$^{-1}$) | Log (L$_{1239}$/ erg s$^{-1}$) |
|----------|---------------------------------|---------------------------------|----------------|----------------|-------------------------------|-------------------------------|
| X_N_160_22 | 12800±1 | 3620±180 | 25±1 | -390±50 | 44.45±0.07 | 46.46±0.06 |
| X_N_81_44 | 12800±1 | 3910±250 | 36±2 | -90±100 | 44.37±0.07 | 46.25±0.06 |
| X_N_53_3 | 12800±1 | 2880±120 | 17±2 | 530±120 | 44.18±0.08 | 46.32±0.06 |
| X_N_66_23 | 12800±1 | 3180±80 | 26±8 | 510±340 | 43.70±0.13 | 45.78±0.07 |
| X_N_4_48 | 12800±1 | 8730±1040 | 83±10 | 1030±380 | 44.27±0.09 | 45.70±0.07 |
| X_N_12_26 | 12800±1 | 4110±190 | 23±1 | -280±340 | 44.33±0.07 | 46.40±0.06 |
| X_N_115_23 | 12800±1 | 4320±550 | 56±8 | -360±210 | 44.12±0.09 | 45.82±0.07 |
| cid_166 | 12800±1 | 5910±340 | 35±2 | -270±140 | 44.64±0.07 | 46.49±0.06 |
| cid_1605 | 12800±1 | 4210±420 | 42±5 | -150±160 | 43.77±0.08 | 45.50±0.07 |
| cid_346 | 12800±1 | 5460±660 | 29±4 | -220±250 | 44.03±0.08 | 45.99±0.06 |
| cid_467 | 12800±1 | 5830±1340 | 17±4 | -60±300 | 43.77±0.11 | 45.95±0.06 |

Notes. Columns give the following information for the BLR component of the MgII emission line: (1) Target identification, (2) centroid (Å), (3) full width at half maximum (km/s), (4) rest-frame equivalent width (Å), (5) velocity of the MgII at 50% of the cumulative line flux, (6) Logarithm of the extinction-corrected MgII luminosity and (7) Logarithm of the extinction-corrected luminosity at 3000 Å derived from the best-fit values of the power-law model representing the AGN continuum (see Sect.3).

The good agreement between the FWHM of the Balmer lines and the MgII line is consistent with several previous results. In particular Greene & Ho (2005), analyzing a sample of 229 AGN at $z \sim 0.3$ and Log (L$_{1550}$/ erg s$^{-1}$) ~ 42.45, found such a strong correlation (red-dashed line in Fig. 5). More recently, Mejia-Restrepo et al.
We now compare the FWHM of the MgII with those of the Balmer lines. In this case, excluding the outlier X_N_4_48 showing a very broad FWHM of the MgII, we find a significant positive correlation between the MgII vs Hα and Hβ measurements, respectively (Fig. 6), consistent with several previous studies (e.g. Shen & Liu 2012, Mejía-Restrepo et al. 2016). As indicated by the slope values reported in Table 6, the MgII line is systematically narrower than the corresponding Hα. We find that on average the MgII lines are narrower than the Hβ lines, which is consistent with the 30% value reported by Mejía-Restrepo et al. 2016. The most likely explanation for this difference in line width is that MgII is emitted from a region in the BLR further out from the central SMBH than the regions emitting Hα and Hβ. Finally, one of our objects, X_N_4_48, shows FWHM(MgII) > FWHM(Hα,Hβ) (however affected by large uncertainties) which may not be surprising given the size of our sample; Marziani et al. (2013) reported that such extreme population, which they named broad-MgII, represents ≈ 10% of bright quasars.

A completely different story is suggested by the comparison of the FWHM of the CIV with the previous emission lines: Hβ, Hα and MgII show a very poor correlation with the CIV FWHM (see Fig. 7 and Table 6). Reverberation mapping experiments, also performed on high redshift quasars (Lira et al. 2018), predict that the emission line region of CIV is located closer to the central SMBH than that producing the Balmer lines. In this case, excluding the outlier X_N_4_48, we find a significant positive correlation between the CIV vs Hα measurements, respectively (Fig. 6), consistent with several previous studies (e.g. Shen & Liu 2012, Mejía-Restrepo et al. 2016). We find that on average the MgII lines are narrower than the Hα lines, which is consistent with the 30% value reported by Mejía-Restrepo et al. 2016. The most likely explanation for this difference in line width is that MgII is emitted from a region in the BLR further out from the central SMBH than the regions emitting Hα and Hβ. Finally, one of our objects, X_N_4_48, shows FWHM(MgII) > FWHM(Hα,Hβ) (however affected by large uncertainties) which may not be surprising given the size of our sample; Marziani et al. (2013) reported that such extreme population, which they named broad-MgII, represents ≈ 10% of bright quasars.
Fig. 6: Comparison between the FWHM of the BLR component of Hβ and Hα emission lines with MgII line for the SUPER targets (blue diamonds). The SDSS sample from Shen & Liu (2012) and the sample from Mejia-Restrepo et al. (2016) are also shown (magenta and green triangles, respectively).

4.2. Comparison of continuum and line luminosity

In order to correct the BLR line luminosity for dust extinction we use the ratio of the broad Balmer lines. For a low density environment such as the NLR, the intrinsic Balmer ratio is equal to 2.74 ± 2.86 assuming a case B recombination (Osterbrock & Ferland 2006). The BLR luminosities are significantly higher, and line optical depths and collisional effects can lead to different Balmer decrements (Netzer 2013). While studies of large samples of AGN suggest that this is generally the case, the mean L_Hβ/L_Hα of the sources with the bluest continua are surprisingly similar to the Case B prediction with values ≈ 3 (Baron et al. 2016). We also find a similar ratio, with a median value of 3.37 ± 0.09.

The relationship between the Balmer decrement and the color excess is given by:

\[
E(B-V) = \frac{E(H\beta - H\alpha)}{k(H\beta) - k(H\alpha)} = \frac{2.5}{k(H\beta) - k(H\alpha)} \log \left( \frac{L_{H\beta}/L_{H\alpha}^{obs}}{L_{H\beta}/L_{H\alpha}^{int}} \right)
\]

(2)

Table 6: Spearman test results for the SUPER sample. We derived linear relations using the BCES (Y|X) regression (Akritas & Bershady 1996).

| Correlation                  | Slope  | \(\rho\) | P-value |
|------------------------------|--------|----------|---------|
| FWHM H\beta vs. FWHM Hα     | 1.43±0.49 | 0.88    | 6E-6    |
| FWHM H\beta vs. FWHM Hα     | 0.95±0.20 | 0.87    | 2E-5    |
| FWHM H\beta vs. FWHM MgII    | -0.05±0.70 | 0.39    | 0.15    |
| FWHM H\beta vs. FWHM MgII    | 2.89±1.89 | 0.66    | 0.01    |
| FWHM Hα vs. FWHM MgII        | 1.15±0.63 | 0.41    | 0.11    |
| FWHM Hα vs. FWHM MgII        | 0.63±0.23 | 0.50    | 0.04    |
| FWHM H\beta vs. FWHM CIV     | -0.32±0.14 | -0.32   | 0.24    |
| FWHM H\beta vs. FWHM CIV     | -0.32±0.14 | -0.33   | 0.23    |
| FWHM Hα vs. FWHM CIV         | -0.13±0.11 | -0.15   | 0.54    |
| Log L_{H\beta} vs Log L_{5100} | 0.84±0.05 | 0.79    | 6E-5    |
| Log L_{H\beta} vs Log L_{5100} | 0.97±0.06 | 0.94    | 6E-8    |
| Log L_{1350} vs Log L_{5100}  | 0.78±0.15 | 0.78    | 7E-5    |
| Log L_{3000} vs Log L_{5100}  | 0.97±0.19 | 0.86    | 2E-5    |
| Log L_{H\beta} vs Log L_{464} | 1.09±0.08 | 0.78    | 4E-4    |

Outliers objects showing a very broad FWHM of H\β (J1549+1245, see Fig. 3) and MgII emission lines (X_N_4_48, see 6) have been included (1) and excluded (2) from the fit.

where \(k(H\beta)\) and \(k(H\alpha)\) are the reddening curves evaluated at H\β and H\alpha wavelengths respectively, the \(L_{H\beta}/L_{H\alpha}^{obs}\) and \(L_{H\beta}/L_{H\alpha}^{int}\) are the observed and intrinsic Balmer decrement respectively. Based on the observed Balmer decrement, we derived the color excess E(B-V) assuming a foreground screen, a Cardelli et al. (1989) extinction law, and \(L_{H\beta}/L_{H\alpha}^{int}=3\) (Baron et al. 2016). We derived a median E(B-V) of 0.12 mag with a standard deviation of 0.03 mag. We use this median value of E(B-V) to correct the emission lines and continuum luminosities. This means that the luminosities are corrected by a factor of
Finally, we use extinction-corrected $L_{5100}$ to derive the bolometric luminosity assuming a bolometric correction factor, $f_{\text{bol}} = L_{\text{bol}}/L_{5100}$ where $L_j$ is the monochromatic luminosity. We used the prescription from Runnoe et al. (2012):

$$\log(L_{\text{bol}}) = 4.891 + 0.912 \log(L_{5100})$$

(3)

The bolometric luminosities obtained from Eq. [3] are consistent with those derived from the SED fitting Circosta et al. (2018). We will use the latest as our fiducial values in the rest of the paper.

4.3. SMBH masses and Eddington ratios

As mentioned in Sect. II the BH mass can be estimated from single-epoch spectra assuming that the BLR is virialized. Based on the comparison of the FWHM for the broad lines observed (see Sec. 4.1), we will estimate the virial BH mass from those of three emission lines: Hβ, Hα and MgII. The virial BH mass calibrations used for the broad Hβ line, available for 16 SUPER targets, is from Bongiorno et al. (2014):

$$\log(M_{\text{BH}}/M_\odot) = 6.7 + 2.06 \log\left(\frac{\text{FWHM}_{\text{H}\beta}}{\text{km s}^{-1}}\right) + 0.55 \log\left(\frac{L_{5100}}{10^{44}\text{ erg s}^{-1}}\right)$$

(4)

where FWHM is the best-fit full width at half maximum of the broad component of Hβ and $L_{5100}$ is the best-fit extinction-corrected continuum luminosity at 5100 Å. This $M_{\text{BH}}(H\beta)$ is derived assuming $f = 1$.

The Greene & Ho (2005) calibration was used to derive the BH mass from the broad Hα, available for 21 SUPER targets:

$$\log(M_{\text{BH}}/M_\odot) = 6.3 + 2.06 \log\left(\frac{\text{FWHM}_{\text{H}\alpha}}{\text{km s}^{-1}}\right) + 0.55 \log\left(\frac{L_{5100}}{10^{44}\text{ erg s}^{-1}}\right)$$

(5)

with the best-fit value of the FWHM of the profile of Hα line and extinction-corrected Hα luminosity $L_{\text{H}\alpha}$.

We used the Bongiorno et al. (2014) calibrated formula for the MgII emission line, available for 17 SUPER targets:

$$\log(M_{\text{BH}}/M_\odot) = 6.6 + 2 \log\left(\frac{\text{FWHM}_{\text{MgII}}}{\text{km s}^{-1}}\right) + 0.5 \log\left(\frac{L_{3000}}{10^{43}\text{ erg s}^{-1}}\right)$$

(6)

with the best-fit value of the FWHM of the profile of MgII line and extinction-corrected luminosity $L_{3000}$ at 3000 Å.

In Mejia-Restrepo et al. (2018) the authors found a relation between the virial factor $f$ and the width of the broad lines:

$$f = \left(\frac{\text{FWHM}_{\text{obs}}(\text{line})}{\text{FWHM}_{0}^{\text{obs}}(\text{line})}\right)^{\beta}$$

(7)

where FWHM_{obs}(line) is the observed FWHM of a broad line, Hα, Hβ and MgII in our case, with FWHM_{0}^{obs}=4000±700 and $\beta$=1.00±0.10 for the Hα line, FWHM_{0}^{H\beta}=4500±1000 and $\beta$=1.17±0.11 for the Hβ line and FWHM_{0}^{MgII}=3200±800 and $\beta$=1.21±0.24 for the MgII line.

We derived this virial factor $f$ for both Hα, Hβ and MgII. The mean values are $f=0.77±0.20$, $f=0.70±0.12$ and $f=0.74±0.23$ for Hβ, Hα and MgII, justifying the assumption of $f = 1$ in Eq. [4][5] and [6]
Regarding CIV-derived masses, this can not be used to estimate BH mass due to the non-virialized CIV emitting gas motion discussed earlier.

The Hβ, Hα-based and MgII BH masses are listed in Table 7. The values of the BH mass of the SUPER sample derived from Hα and Hβ lines are fairly in agreement as shown in Fig. 9. The SDSS AGN from the Shen & Liu (2012) and Mejía-Restrepo et al. (2016) samples are also plotted. A correlation is also found between the Balmer-based and MgII-based BH masses (see Fig. 10), however the MgII line profile is affected by strong sky-line residuals in almost all spectra of the SUPER AGN, which can affect the measured line properties and hence the derived BH mass.

We used as fiducial virial BH masses the values derived from the Hβ emission lines, which we prefer over the Hα line because the latter is blended with the [NII]λλ 6548,6583 doublet implying a less reliable measure, for all but five SUPER targets (i.e. X_N_53_3, X_N_66_23, X_N_35_20, X_N_44_64 and cid_1205), for which we used the BH mass values derived from Hα because the Hβ line is not detected in those sources.

We found that SUPER sample hosts BH with log $M_{BH}=8.4-10.8 M_\odot$. From the BH mass and the bolometric luminosity derived from the Spectral Energy Distribution fitting (see Circosta et al. [2018]), we derived the Eddington ratio for a solar composition gas, defined as:

$$\lambda_{\text{Edd}} = \frac{L_{\text{Bol}}}{1.5 \times 10^{38} M_{\odot}}$$  \hspace{1cm} (8)

We find values in the range $\lambda_{\text{Edd}}=0.04-1.3$ (see Table 7).

Fig. 11 shows the comparison of $M_{BH}$, $L_{\text{Bol}}$ and $\lambda_{\text{Edd}}$ measured for the SUPER sample with those derived from a sample of ∼23000 SDSS AGN at $1.5 \leq z \leq 2.2$ with MgII-based BH mass (Shen et al. [2011], contour lines). The bolometric luminosity in fraction of 0.1, 0.5 and 1 Eddington luminosity is also reported. The SUPER sample spans two order of magnitude in bolometric luminosity and in Log $(M_{BH}/M_\odot)$.

5. BLR winds

5.1. Connection between CIV velocity shift and AGN properties

As discussed in Sect. 4.1, the FWHM of the CIV line does not correlate with those of the Balmer lines, suggesting a different kinematical state for the gas traced by the CIV emission. Indeed, this line is known to be dominated by non virialized motion components, making the profile asymmetric towards the blue-side of
two orders of magnitude in bolometric luminosity and a wide literature). Here we further investigated these correlations, with the velocity shift of the collected dataset (WISSH and samples from Vietri et al. 2018). We have included in the same figure the WISSH targets presented and c the speed of light. In Fig. 12 we can see that 85% of the SU-2700 km/s and equivalent width ≥ 18 Å up to ~80 Å and 15% have velocity larger than 2000 km/s up to ~4700 km/s and EWCIV ∼ 20–30 Å. We have included in the same figure the WISSH targets presented in Vietri et al. (2018) to probe the high-end of luminosity distribution (Lbol > 10^{47}–10^{48} erg/s). We overall confirm with our sample the same anti-correlation between the equivalent width and the velocity shift of the CIV line previously reported in the literature (e.g. Sulentic et al. 2007 | Richards et al. 2011 | Vietri et al. 2018).

In Vietri et al. (2018) we have reported a strong dependence of velocity shift of the CIV emission line on physical parameters as bolometric luminosity and Optical-to-X-ray spectral slope (αOX), as well as Eddington ratio, despite the non-homogeneous parametrization of bolometric luminosity, BH mass and CIV velocity shift of the collected dataset (WISSH and samples from literature). Here we further investigated these correlations, with the advantage of using an unbiased sample as SUPER, covering two orders of magnitude in bolometric luminosity and a wide range of BH mass and Eddington ratio. We will also populate the high-luminosity range by adding to the SUPER sample the Type-1 AGN from the WISSH survey (Vietri et al. 2018). We computed αOX for each of our SUPER quasars following the definition:

$$\alpha_{\text{OX}} = \frac{\log(L_{2\text{keV}}/L_{2500\text{A}})}{\log(v_{\text{CIV}}/v_{\text{LyA}})}$$

where L_{2500} and L_{2keV} are the restframe monochromatic luminosities at 2500 Å and 2keV. For the calculation of αOX we used the rest-frame 2500 Å monochromatic luminosity obtained by SED fitting (Circosta et al. 2018) and derived the L_{2keV} assuming L_{2–10keV} = 1.61 × L_{2keV}, adopting a power-law X-ray model with Γ = 2. As shown in the three panels of Fig. 12, there is indeed a strong correlation between the v_{CIV} with all three of the above mentioned physical quantities: bolometric luminosity, Eddington ratio and αOX. In particular, in the top panel of Fig. 12 the data points in the plane EWCIV vs. v_{CIV} are color-coded according to the αOX values: most of the SUPER sources with v_{CIV} < 2000 km/s have αOX > -1.6, while the WISSH targets, which are sampling the high luminosity end of the quasar population, have mostly lower values of αOX. This parameter can be used as a measurement of the hardness of the ionizing SED, whereby...
larger values of \( \alpha_{\mathrm{OX}} \) corresponds to large amount of ionizing radiation for a given optical-UV luminosity. In the context of a disc-wind scenario, this behaviour suggests that the objects with harder SEDs produce larger amounts of high-ionization gas, i.e. higher values of CIV equivalent width. If the ionizing radiation overionizes the gas, the continuum-driving (bound-free absorption) mechanism becomes inefficient, which could explain the smaller velocity shift of the CIV. Instead, the 15% of the SUPER sample (and the WISSL quasars), which shows softer SEDs, produces high velocity BLR winds \( (v_{\mathrm{CIV}} > 2000 \, \text{km/s}) \). Therefore, the acceleration is probably correlated with the hardness of the ionizing continuum, the ionization parameter and \( \alpha_{\mathrm{OX}} \) but more specific calculations are required to demonstrate these connections.

In the medium and bottom panels of Fig. 12 the plane EW(CIV) vs. \( v_{\mathrm{CIV}} \) is color-coded according to the bolometric luminosity and Eddington ratio, respectively. SUPER sources with \( v_{\mathrm{CIV}} < 2000 \, \text{km/s} \) have luminosity range \( \log \left( \frac{\text{L}_{\text{bol}}}{\text{erg s}^{-1}} \right) \) ≈ 45.4-46.9, with an exception for a BAL source, J1549, with \( \log \left( \frac{\text{L}_{\text{bol}}}{\text{erg s}^{-1}} \right) \) = 47.7, and \( v_{\mathrm{CIV}} > 2000 \, \text{km/s} \) in the range \( \log \left( \frac{\text{L}_{\text{bol}}}{\text{erg s}^{-1}} \right) \) = 46.7-47.9. The high velocity shift end is also strongly populated by the WISSL sample, with \( \log \left( \frac{\text{L}_{\text{bol}}}{\text{erg s}^{-1}} \right) \) > 47. On the other hand, SUPER sources with \( v_{\mathrm{CIV}} < 2000 \, \text{km/s} \) have Eddington ratio in the range 0.06-0.62 with a median value of 0.18, while for the high velocity winds the range is 0.23-1.27 with a median value of 0.56. We computed the Spearman’s rank correlation coefficient, \( \rho \), and associated \( p \)-value to quantify the strength and significance of each correlation, considering both SUPER and WISSL samples. We focused on the sources with reliable CIV velocity shift, therefore we excluded the source J1549, whose peak and half of the profile are totally absorbed by the presence of a BAL. We find that the \( v_{\mathrm{CIV}} \) correlates with \( \alpha_{\mathrm{OX}} \) with a coefficient \( \rho = 0.79 \) and \( p \)-value \( < 10^{-5} \) (taking into account upper limits by using the Astronomical Survival Analysis (ASURV) package, available under IRAF/STSDAS [Lavalley et al. 1992; Feigelson & Nelson 1985; Isobe et al. 1986]), with \( \log \left( \frac{\text{L}_{\text{bol}}}{\text{erg s}^{-1}} \right) \) and \( \lambda_{\text{edd}} \) with a coefficient \( \rho = 0.64 \) and \( p \)-value \( = 2 \times 10^{-5} \) and with \( \lambda_{\text{edd}} \) with a coefficient \( \rho = 0.62 \) and a \( p \)-value \( = 5 \times 10^{-5} \). These values confirm the visual impression from Fig. 12 that the properties of the CIV line correlate with all three of these parameters but the highest significant correlation is with \( \alpha_{\mathrm{OX}} \). Recently Zappacosta et al. [2020] reported on the WISSL sources a significant correlation between the luminosity in the 2-10 keV band (\( \text{L}_{2-10 \text{keV}} \)) and the blueshift of the CIV line, i.e. objects exhibiting high velocity shift have lower \( \text{L}_{2-10 \text{keV}} \). With the SUPER sample we are not able to significantly investigate this relation. Indeed the narrow velocity range spanned by the SUPER sample (compared to the wide range probed by the WISSL sample, see Fig. 12 and possibly dependent on \( \text{L}_{\text{bol}} \) e.g. [Fiore et al. 2017]) would require a much larger number of sources in order to significantly place constraints on a possible existing correlation at lower luminosities.

While we are using CIV to trace the AGN winds in the BLR, the main aim of our survey is to trace the AGN driven outflows in the NLR using the [OIII] line [Kakkad et al. 2020]. It is therefore interesting to compare the properties of the winds traced at such different physical scales. In Fig. 13 it is shown the [OIII] equivalent width as a function of \( v_{\mathrm{CIV}} \). The strength of the [OIII] seems to decrease at increasing CIV velocity shift, i.e. for \( v < 2000 \, \text{km/s} \) the EW(OIII) range probed is 6-207 Å with a mean (median) value of 36(21) Å and for \( v > 2000 \, \text{km/s} \) the range is 5-17 Å with a mean(median) value of 11(12) Å. Furthermore, we also compare the kinematic properties of the CIV and [OIII] emission lines. We used the non-parametric definition \( v_{10} \), i.e. the velocity of the [OIII] at 10% of the cumulative line flux, to trace the [OIII] outflow velocity (see Kakkad et al. 2020).

We found a significant correlation between \( v_{\mathrm{OIII}}^{10} \) and the CIV blueshift, with a Spearman correlation coefficient \( \rho = 0.54 \)
and p-value=0.007. We also test for the presence of a correlation between \( v_{50}^\text{CIV} \) and \( W_{50}^\text{OIII} \) i.e. the width containing 80% of the line flux and \( v_{\text{max}} \), defined as the shift between the systemic velocity and the broad Gaussian component of [OIII] plus twice the velocity dispersion of the broad Gaussian. In our analysis of the NLR winds we use a cut of \( W_{50} \) larger than 600 km/s to distinguish between targets with and without AGN outflows (Kakkad et al. 2020). In this case we report a marginally significant correlation with \( W_{50} \), i.e. \( \rho=0.42 \) and p-value=0.05 and a weaker not significant correlation with \( v_{\text{max}} \), i.e. \( \rho=0.32 \) and p-value=0.13.

Our findings are in agreement with those presented by Coatman et al. (2019), despite the lower statistical significance of our correlations which is likely due to the smaller sample. They analyzed the integrated spectra of 213 quasars in the luminosity range of \( \log (L_{\text{bol}}/\text{erg s}^{-1})=46-49 \) with redshift \( z\approx2-4 \) and found a significant correlation (p-value= \( 6\times10^{-7} \)) between \( v_{10} \) and \( v_{50}^\text{CIV} \), with \( \rho=0.46 \). They demonstrated that the correlation is independent of the bolometric luminosity, however we note that both \( v_{10}^\text{OIII} \) and \( v_{50}^\text{CIV} \) correlate with bolometric luminosities for the SUPER and WISSH samples, although with a large scatter. While their analysis was limited by the lack of spatially resolved data to locate the scale at which the gas traced by the [OIII] emission was located, we inferred from the SINFONI IFU data that the [OIII] emission is extended on kpc scales (Kakkad et al. 2020), therefore supporting the idea that BLR outflows may affect the galaxy-scale wide gas in the NLR.

5.2. Outflow energetics

Our estimate of the ionized gas mass, \( M_{\text{out}} \), is somewhat different than the one used in Vietri et al. (2018) which followed the expression given in Marziani et al. (2016). That approximation was based on a spherical gas distribution and did not take into account the dependence on the gas temperature. Here we assume a thin-shell geometry for the outflowing gas and normalize the results using photoionization calculations typical of BLR conditions.

The expression we use is similar to the one given in Baron & Netzer (2019), and in several earlier publications, for the [OIII] line. It assumes a line emission coefficient, \( \gamma_{\text{CIV}} (L_{\text{line}} \propto \gamma_{\text{CIV}} n_{\text{e}}) \) given by:

\[
\gamma_{\text{CIV}} = C_{\text{CIV}} \times h\nu_{\text{CIV}} \frac{n(C^{+3}) n(C)}{n(C) n(H)} \quad (10)
\]

where \( C_{\text{CIV}} \propto \exp\frac{-5.69}{\sqrt{T}} \) and \( n(C^{+3})/n(C) \) is the fractional ionization of C^{+3}. The line luminosity is obtained by integrating the emissivity over volume and the associated mass is \( M_{\text{out}} \propto L(C^{+3}) / n_{\text{e}} \gamma_{\text{CIV}} \).

Using known atomic rates, and calibrating the above expressions against photoionization calculations (see e.g. the specific calculations in Netzer 2020) of a thin-shell of gas with constant density, we get:

\[
M_{\text{out}} \approx 100 \frac{L_{\text{CIV}}}{n_0 n(C^{+3})/n(C)} M_\odot. \quad (11)
\]

where \( n_0 \) is the electron density in units of \( 10^6 \text{ cm}^{-3} \) and \( L_{\text{CIV}} \) is the CIV luminosity in units of \( 10^{45} \text{ erg/s} \). This estimate is appropriate for the highly ionized part of the cloud, for \( 1.5 \times 10^4 K < T < 2 \times 10^4 K \) and for metallicity in the range 1-5 solar. To derive the mass of the wind we used the CIV luminosity of the total profile, based on the fact that the bulk of our sources show blue-asymmetry according to the CIV shifts.

It is important to note that higher metallicity \( (n(C)/n(H)) \) tends to cool the gas which compensates for much of the influence of the temperature on the excitation rate. Thus, the main dependence is on the fractional ionization which is determined by the ionization parameter and not on the carbon abundance. This is why the carbon abundance term is not part of the mass equation.

The fractional ionization of carbon scales with the hydrogen ionization parameter, \( U \), and depends also on the metallicity through the gas temperature. For \( U = 0.05 \), \( n(C^{+3})/n(C) \approx 0.5 \). The mass obtained here is about an order of magnitude smaller than the one obtained by using the Marziani et al. (2016) expression. We derived the following range of outflowing mass: \( M_{\text{out}} = 0.1-290 M_\odot \), assuming \( n = 10^6 \text{ cm}^{-3} \).
For the mass outflow rate we use the expression for a thin outflowing shell,

\[ M_{\text{out}} = \frac{v}{r_{\text{CIV}}} \approx 0.005 M_{\odot} \frac{v_{5000}}{r_{\text{pc}}} \, \text{M}_\odot/\text{yr}, \quad (12) \]

where \( v_{5000} \) is the outflow velocity in 5000 km/s and \( r_{\text{CIV}} \) is the outflow radius estimated from the CIV radius-luminosity relation from [Lira et al. 2018].

The inferred outflow radius \( R \approx 0.002-0.2 \) pc is listed in Table 8 along with the mass outflow rates; \( M_{\text{out}}=0.005-3 \) \( \text{M}_\odot/\text{yr} \) with a mean value of \( 0.4 \) \( \text{M}_\odot/\text{yr} \). This is a factor 3 smaller than the one used in [Vietri et al. 2018] for a spherical geometry.

The two main uncertainties in the above mass and mass outflow rate estimates are the unknown gas density and level of ionization. A lower limit on the density is imposed from the very different shape of the C III]1909 line profile which does not show a blueshifted wing and similarly from other semi-forbidden lines like O III]1664 (e.g. [Richards et al. 2011]; [Netzer 2013]. This limit is about \( 3 \times 10^{-3} \) cm\(^{-3}\). The upper limit is more difficult to establish. Photoionization calculations ([Netzer 2013]) suggest several other strong broad lines, like NV, H\( \beta \), that will show blueshifted wings under such conditions. However, we lack high quality spectra of these lines. In eq [11] we used \( n_e=10^{9.5} \) cm\(^{-3}\). As for the level of ionization of the outflowing gas, this can be high and results in little C\(^{+3}\). This will increase both \( M_{\text{out}} \) and \( M_{\text{tot}} \). Finally, without proper modeling, we lack information about the amount of neutral gas that can be part of the outflow. Such gas will increase both \( M_{\text{out}} \) and \( M_{\text{tot}} \).

In Fig. 14 we plot the derived mass outflow rate of the CIV winds as a function of the bolometric luminosity for the SUPER sample. We include also the WISSH sample to populate the high-luminosity part and added the correlation of mass outflow rate vs. bolometric luminosities from a compilation of ionized and X-ray winds (see [Fiore et al. 2017]). For the BLR \( M_{\text{out}} \) and \( L_{\text{bol}} \) we derive a Spearman correlation coefficient \( \rho = 0.8 \) and null hypothesis \( P = 1 \times 10^{-8} \), with a log linear slope \( \log (M_{\text{out}}/M_{\odot}\text{yr}^{-1}) \propto 1.01 \pm 0.09 \log (L_{\text{bol}}/\text{erg s}^{-1}) \). Interestingly, the mass outflows of the BLR winds seem to have a correlation with bolometric luminosity of the central AGN as steep as that observed for the ionized winds in the NLR and X-ray traced winds close to the accretion disk. The different normalization could be probably due to the efficiency of the coupling with the ISM, which changes in terms of density and composition, but a similar slope suggests that the winds at different scales are linked, namely they have the same functional dependency with a basic physical property of the SMBH, its bolometric luminosity.

The \( M_{\text{out}} \) values inferred for the BLR winds are lower than the one derived for X-ray winds. Further, the range probed by the BLR winds in terms of mass outflow rate is lower than that of the NLR winds measured for the 18 objects for which we can sample both regions (see also [Kakkad et al. 2020] for the [O III] analysis). In Fig. 14 we plot the mass outflow rates for the SUPER NLR winds assuming a bi-conical outflow model and an electron density from 500 cm\(^{-3}\) - 10000 cm\(^{-3}\), as reported in [Kakkad et al. 2020]. For 6 out of these 18 objects, the mass outflow rate of the BLR winds are consistent with the lower limit found from the NLR analysis.

\[ E_{\text{kin}} = \frac{1}{2} M_{\text{out}} v_{\text{out}}^2 \]

\[ = \frac{1}{2} M_{\text{out}} v_{\text{CIV}}^2 \]

\[ \approx 7 \times 10^{38} \text{ erg s}^{-1} \]

\[ \times 10^{-7} \times L_{\text{bol}} \text{ up to } 2 \times 10^{37} \text{ erg s}^{-1}, \]

\[ \text{for the SUPER object with the most blue-shifted CIV line profile, i.e. J1441+0454.} \]

\[ \text{We show in Fig. 15 the kinetic power derived using the CIV total profile as a function of bolometric luminosity for the SUPER sample (diamonds).} \]

\[ \text{We also populated the high-luminosity part of the plot, adding the values estimated in a consistent way for the WISSH sample.} \]

\[ \text{Performing a Spearman test on } E_{\text{kin}} \text{ and } L_{\text{bol}} \text{ for both samples, the quantities are strongly correlated with a log linear slope of } 2.14 \pm 0.25 \text{ and a Spearman correlation coefficient } \rho \approx 0.74 \text{ and two-sided null hypothesis of } p = 3 \times 10^{-7}. \]

\[ \text{The bulk of the kinetic power for the BLR winds in the SUPER sample is in the range } E_{\text{kin}} \sim 10^{-7} \times L_{\text{bol}} \text{ up to } 10^{-6} \times L_{\text{bol}} \text{ at high bolometric luminosity.} \]

\[ \text{It is often reported that the coupling efficiency predicted by feedback models is significantly higher, e.g. 5%. On the other end, only a fraction of the injected energy will become kinetic power in the outflow, while the rest will be used in doing work for example against the ambient pressure and the gravitational potential (see [Harrison et al. 2018]).} \]

\[ \text{From the comparison with the NLR outflows in the SUPER sample, we find that in the majority of the cases (12 out of 18) the NLR} \]

kinetic power is larger, in five objects they are comparable, and in one case it is the BLR kinetic power to be larger. Anyway, we do not further speculate on such comparison given the large uncertainties affecting these measurements.

Another fundamental parameter of the outflow is the momentum rate defined as $P_{\text{out}} = M_{\text{out}} v_{\text{out}}$. In Fig. 16 we plot the outflow momentum load, defined as the momentum rate divided by the AGN radiation momentum rate ($P_{\text{AGN}} = L_{\text{bol}}/c$), as a function of the outflow velocity. The values estimated for the BLR winds of the SUPER sample are very low $\sim 10^{-5} : 10^{-2}$. For the X-ray winds the theoretical momentum flux is expected to be comparable to $L_{\text{AGN}}/c$, i.e. a momentum load close to unity (i.e. a momentum conserving outflow). Fig. 16 shows the expected momentum load for a momentum-conserving wind model (dashed line). The bulk of the winds in the BLR show lower values than momentum driven winds (with the larger values for the sources with the larger BLR winds velocities) suggesting that a different form of driving mechanism may be acting at these scales.

6. Conclusions

We present the results of the analysis of 21 Type-1 X-ray selected AGN from the SUPER survey (Circosta et al. 2018) with near-infrared SINFONI IFU and UV spectroscopy. The analysis presented in this paper had two main goals: 1) derive BH masses and Eddington ratios by using virial BH mass estimators based on H\textalpha, H\textbeta, MgII; 2) trace AGN-driven winds in the broad line region (BLR) using the blueshift of the CIV line profile. Our main finding can be summarized as follows:

(i) We find that the H\textalpha and H\textbeta line width correlate with each other as does the line continuum luminosity at 5100 Å with the H\textalpha line luminosity, resulting in a well defined correlation between BH mass estimated from H\textalpha and H\textbeta. The SUPER AGN exhibit SMBHs with mass in the range $M_{\odot}/M_{\odot} = 8.5-10.8$ and Eddington ratios in the range $0.04 < \lambda < 1.3$.

(ii) We confirm that the CIV line width does not correlate with the Balmer lines and its peak is blueshifted with respect to the [OIII]-based systemic redshift. We interpret this findings as the presence of outflows in the BLR with derived velocities up to $\sim 4700$ km/s.

(iii) As found previously in Vietri et al. (2018), we confirm the strong correlation between $v_{\text{CIV}}$ and the UV-to-X-ray continuum slope, bolometric luminosity, and Eddington ratio, by analysing an unbiased sample of sources. We interpret this in the context of the disc-wind scenario where a high UV luminosity is necessary to launch the wind and softer SEDs can prevent overionization, producing high velocity BLR winds.

(iv) We compare the properties of the BLR and NLR winds, as traced by CIV and [OIII] respectively. We find an anti-correlation between the [OIII] equivalent width and $v_{\text{CIV}}$ and a significant correlation between $v_{\text{OIII}}$ and $v_{\text{CIV}}$. From SINFONI IFU data, we know that the gas emitting [OIII] is located at kpc scales. We therefore interpret the correlation found as supporting a scenario where BLR winds are capable of affecting the gas in the NLR emission located at kpc scales, likely partially blocking the ionizing photons of the NLR or sweeping up the gas in the NLR.

(v) We derive mass outflows rates in the range $0.005-3 M_{\odot}/yr$ for the BLR winds. The mass outflow rate of the BLR winds shows a correlation with bolometric luminosity as steep as that observed for winds at sub-parsec scales and in the NLR. The kinetic power of the BLR winds inferred is $E_{\text{kin}} \sim 10^{67-4} \times L_{\text{bol}}$, and in the 28% of the SUPER sample, the kinetic power of the BLR and NLR winds are comparable. Despite the fact that these values are below the coupling efficiency predicted by AGN feedback models, we have to bear in mind that only a fraction of the injected energy will become kinetic power in the outflow.

(vi) The momentum fluxes of the BLR winds normalized by the AGN radiation momentum rate inferred for the SUPER sample are well below the theoretical expectation of a momentum,
indicating for these winds that a different driving mechanism may be acting at these scales.

As discussed in this paper we are now able, for the first time in an unbiased sample of AGN at z ~ 2, to trace the presence of AGN-driven outflows at z ~ 2 from pc- up to kpc-scales. Moving to even larger scales, the advent of state-of-art IFU facilities as VLT/MUSE has allowed to uncover the elusive material of the circum-galactic medium as recently reported by Travascio et al. (2020) by analyzing the VLT/MUSE obser-

Table 8: Properties of the CIV outflows derived from the total profile of the CIV emission line

| ID        | v_{peak}  | R [pc] | v_{50}  | M_{out} [M_\odot] | M_{out} [M_\odot] | Log(E_{kin}/erg s^{-1}) | Log(P_{out}/g cm s^{-2}) |
|-----------|-----------|--------|--------|------------------|------------------|----------------------|----------------------|
| X_N_160_22 | -30       | 0.06   | 250    | 68.46            | 0.10             | 39.31                | 32.21                |
| X_N_81_44  | 700       | 0.04   | 700    | 37.37            | 0.26             | 40.60                | 33.06                |
| X_N_53_3   | 540       | 0.03   | 470    | 29.40            | 0.17             | 40.07                | 32.69                |
| X_N_66_23  | 110       | 0.02   | 240    | 14.14            | 0.06             | 39.02                | 31.93                |
| X_N_35_20  | 950       | 0.01   | 950    | 2.31             | 0.06             | 40.23                | 32.55                |
| X_N_12_26  | 430       | 0.04   | 920    | 19.43            | 0.17             | 40.66                | 33.00                |
| X_N_4_48   | 260       | 0.03   | 50     | 16.28            | 0.01             | 36.87                | 30.47                |
| X_N_102_35 | 400       | 0.06   | 190    | 87.51            | 0.11             | 39.09                | 32.11                |
| X_N_115_23 | 70        | 0.04   | 140    | 38.84            | 0.05             | 38.51                | 31.66                |
| cid_166    | 780       | 0.06   | 850    | 109.30           | 0.52             | 41.07                | 33.45                |
| cid_1605   | -120      | 0.02   | -120   | 12.64            | 0.03             | 38.07                | 31.29                |
| cid_346    | 2230      | 0.05   | 2230   | 28.72            | 0.50             | 41.89                | 33.30                |
| cid_1205   | -250      | 0.02   | -250   | 0.14             | 0.005            | 37.98                | 30.88                |
| cid_467    | 210       | 0.05   | 280    | 51.23            | 0.11             | 39.42                | 32.28                |
| J1333+1649 | 2160      | 0.15   | 2300   | 285.46           | 1.56             | 42.42                | 34.36                |
| J1441+0454 | 3320      | 0.11   | 4690   | 189.15           | 2.85             | 43.29                | 34.93                |
| S82X1905   | 1070      | 0.04   | 1070   | 27.36            | 0.30             | 41.03                | 33.30                |
| S82X1940   | 430       | 0.03   | 430    | 16.40            | 0.11             | 39.81                | 32.47                |
| S82X2058   | 680       | 0.05   | 740    | 25.86            | 0.16             | 40.44                | 32.87                |

Notes: Columns give the following information: (1) Target identification, (2) the velocity at the peak of the CIV total profile, (3) CIV BLR radius derived from the CIV radius-luminosity relation from Lira et al. (2018), (4) velocity of the CIV at 50\% of the cumulative intensity at the peak of the CIV total profile, (5) CIV BLR radius derived from the CIV radius-luminosity relation as described in sect. 5.2, (6) kinetic power of the outflow and (7) outflow momentum load.

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Appendix A: Integrated spectra of Type-1 SUPER sample

Fig. A.1: Integrated spectra from CIV-MgII region (upper panels) to Hβ-Hα region (lower panels) of the SUPER targets X_N_160_22. The grey curve shows the observed spectrum, the red curve shows the reproduced overall emission line model, the magenta curve shows the iron emission, the blue navy curves show the continuum model and the green curves show the individual Gaussian components used to reproduce the profiles of all the emission lines. The BLR component is shown as gold Gaussian profile. The red vertical lines indicate the location of each line at systemic velocity. The vertical grey regions mark the channels with strong skylines which were masked during the fitting procedure. The x- and y-axis show the rest frame wavelength and flux (not corrected for extinction), according to the redshift of each target.
Fig. A.2: X_N_81_44. The modeling is the same as in Fig. A.1.

Fig. A.3: X_N_53_3. The modeling is the same as in Fig. A.1.
Fig. A.4: $X_{N_66_23}$. The modeling is the same as in Fig. A.1

Fig. A.5: $X_{N_35_20}$. The modeling is the same as in Fig. A.1
Fig. A.6: X_N_12_26. The modeling is the same as in Fig. A.1

Fig. A.7: X_N_44_64. The modeling is the same as in Fig. A.1
Fig. A.8: X_N_4_48. The modeling is the same as in Fig. A.1.

Fig. A.9: X_N_102_35. The modeling is the same as in Fig. A.1.
Fig. A.10: X_N_115_23. The modeling is the same as in Fig. A.1

Fig. A.11: cid_166. The modeling is the same as in Fig. A.1
Fig. A.12: cid_1605. The modeling is the same as in Fig. A.1.

Fig. A.13: cid_346. The modeling is the same as in Fig. A.1.
Fig. A.14: cid_1205. The modeling is the same as in Fig. A.1.

Fig. A.15: cid_467. The modeling is the same as in Fig. A.1.
Fig. A.16: J1333+1649. The modeling is the same as in Fig. A.1

Fig. A.17: J1441+0454. The modeling is the same as in Fig. A.1
Fig. A.18: J1549+1245. The modeling is the same as in Fig. A.1. We added one Gaussian component around 6380 Å to reduce the $\chi^2$ of our fit (e.g. Carniani, S. et al. 2016)

Fig. A.19: S82X1905. The modeling is the same as in Fig. A.1
Fig. A.20: S82X1940. The modeling is the same as in Fig. A.1

Fig. A.21: S82X2058. The modeling is the same as in Fig. A.1