The structure of the Mg $\text{II}$ broad line emitting region in Type 1 AGNs

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ABSTRACT

We investigate the structure of the Mg $\text{II}$ broad line emission region in a sample of 284 Type 1 active galactic nuclei (AGNs), through comparing the kinematical parameters of the broad Mg $\text{II}$ and broad H$\beta$ lines. We found that the Mg $\text{II}$ emitting region has more complex kinematics than the H$\beta$ one. It seems that the Mg $\text{II}$ broad line originates from two subregions: one which contributes to the line core, which is probably virialized, and the other, 'fountain-like' emitting region, with outflows-inflows nearly orthogonal to the disc, which become suppressed with stronger gravitational influence. This subregion mostly contributes to the emission of the Mg $\text{II}$ broad line wings. The kinematics of the Mg $\text{II}$ core emitting region is similar to that of the H$\beta$ broad line region (seems to be virialized), and therefore the Full Width at Half Maximum (FWHM) of Mg $\text{II}$ still can be used for the black hole (BH) mass estimation in the case where the Mg $\text{II}$ core component is dominant. However, one should be careful with using the Mg $\text{II}$ broad line for the BH mass estimation in the case of very large widths (FWHM $> 6000 \text{ km s}^{-1}$) and/or in the case of strong blue asymmetry.

Key words: galaxies: active – galaxies: emission lines

1 INTRODUCTION

The broad emission lines (widths about several 1000 km s$^{-1}$) are one of the most important characteristics of Type 1 active galactic nuclei (AGN) spectra. They are originating in a broad line region (BLR) that is supposed to be close to the central black hole (BH) and consequently, one can assume that the BLR emission gas kinematics is virialized, i.e. it is following the gravitationally driven rotation (see e.g. Sulentic et al. 2000a; Gaskell 2009; Netzer 2015, etc.). The gas motion in the BLR affects the line profile (Sulentic et al. 2000a) and, in the case of Keplerian-like motion, the broad line width (Full Width at Half Maximum – FWHM) can be used for the BH mass estimation (for review see Peterson 2014).

There are several methods for the BH mass estimation (direct and indirect, see e.g. Peterson 2014). Among them, the reverberation method is the most frequently used one. Using reverberation, one can determine the BLR size, then assuming the virialization in the BLR and measuring the FWHM of a broad line, the BH mass can be obtained (Peterson 1993). Reverberation was also used for establishing the relationships between the BLR size and the continuum luminosity (see e.g. Vestergaard & Peterson 2006; Bentz et al. 2013), which is widely used for the BH mass calculations from one epoch observations.

For this purpose, there are several relationships (in different wavelength bands) between the black hole mass, continuum luminosity and broad line widths, which are defined assuming the virialization in the BLR (see e.g. Vestergaard & Peterson 2006; Onken & Kollmeier 2008; Vestergaard & Osmer 2009; Wang et al. 2009; Trakhtenbrot & Netzer 2012; Tilton & Shull 2013; Mejía-Restrepo et al. 2016; Coatman et al. 2017; Mejía-Restrepo et al. 2018, etc.). Depending on the redshift of an AGN, there is a possibility to use different broad lines, and the most frequently used are H$\beta$, Mg $\text{II}$ and C$\text{IV}$ (see Mejía-Restrepo et al. 2016).

The Mg $\text{II}$ relationship for the BH mass estimation is derived from the H$\beta$ relationship (see e.g. Onken & Kollmeier 2008; Wang et al. 2009; Vestergaard & Osmer 2009; Marziani et al. 2013a; Sulentic et al. 2014; Mejía-Restrepo et al. 2016) based on the reverberation measurements of the H$\beta$ BLR and the continuum luminosity at 5100 Å. The C$\text{IV}$ line parameters, and consequently the estimated BH mass can be compared with those obtained from the H$\beta$ and Mg $\text{II}$ relationship (see e.g. Mejía-Restrepo et al. 2016; Coatman et al. 2017; Mejía-Restrepo et al. 2018). However, one of the problems of this method is the assumption that the BLR gas is virialized, particularly for the Mg $\text{II}$ and C$\text{IV}$ line emitting regions (see Marziani & Sulentic 2012; León-Tavares et al. 2013). The broad C$\text{IV}$ and Mg $\text{II}$ line profiles can be affected by some other effects, as e.g. outflows (see Denney 2012; León-Tavares et al. 2013).
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Therefore, there is a question of validity of using these lines and their robustness for the BH mass measurements. Since C iv and Mg ii lines are very important as BH mass estimators in high redshifted AGNs, it is of great importance to investigate the structure of their broad line emitting regions and to compare it with the Hβ one for a number of AGNs. Here we will focus on the Mg ii broad line emitting region, comparing the Mg ii line shape with the Hβ line profile in order to explore similarities and differences between their emitting regions.

In principle, the Mg ii 2800 Å line can be directly compared with the Hβ and the consistency of the obtained BH mass using these two lines can be checked (see Wang et al. 2009; Marziani et al. 2013a,b; Mejía-Restrepo et al. 2016). However, it seems that the Mg ii emitting line region is more complex (Kovačević-Dojčinović & Popović 2015; Jonić et al. 2016), and in some cases it can be connected with outflows (see, e.g. León-Tavares et al. 2013). There is an indication that in the case of smaller widths of Mg ii (FWHM>6000 km s\(^{-1}\)) there is a good correlation with the Hβ width, and therefore the Mg ii is equally good for BH mass estimation as Hβ (Trakhtenbrot & Netzer 2012). On the other hand, for FWHM Mg ii>6000 km s\(^{-1}\), the difference between the FWHM of these two lines seems to be significant, and there is a question of validity of using Mg ii line for black hole mass measurements. Sulentic et al. (2000b) identified two populations of AGNs according to different spectral properties: Population A (Pop. A), with FWHM of Hβ < 4000 km s\(^{-1}\) and Population B (Pop. B), with FWHM Hβ > 4000 km s\(^{-1}\). Marziani et al. (2013a) found that in Pop. B, the Mg ii lines are about 20% narrower than Hβ and they have more complex shape, in which one very broad, redshifted component is seen.

The aim of this work is to investigate the structure of the Mg ii broad line emitting region and to compare its kinematics with the kinematics of the broad Hβ emitting region, in order to check the validity of using the Mg ii broad line as a BH mass estimator.

The paper is organized as following: In Sec. 2 we describe the sample of AGNs and give the method of analysis. In Sec. 3 we explore the Mg ii line profiles in the sample of AGNs and compare the line parameters with those obtained from Hβ. In Sec. 4 we discuss the obtained results and possible model for the Mg ii BLR, and finally in Sec. 5 we outline our conclusions.

2 THE SAMPLE AND METHOD OF ANALYSIS

2.1 The sample

To investigate the assumption of virialization in the Mg ii and Hβ broad line emitting regions, we used already studied sample of 293 Type 1 AGN spectra from Kovačević-Dojčinović & Popović (2015). This sample was selected from the Sloan Digital Sky Survey (SDSS), Data Release 7 and has S/N > 25 (near Hβ line), good pixel quality, redshift between 0.407 and 0.643 (in order to include both Mg II and Hβ lines), high redshift confidence, and no absorption in the UV Fe ii lines.

Additionally, we excluded the objects with strong noise near the Mg ii line, and with absorption lines which affect the Mg ii profile. The final sample consists of 284 objects.

2.2 The analysis

The spectra were corrected for Galactic extinction and cosmological redshift as described in Kovačević-Dojčinović & Popović (2015). In Kovačević-Dojčinović & Popović (2015) the host galaxy contribution is was assumed to be negligible in this sample since majority of objects have high continuum luminosity (see their Fig 1). However, in order to estimate more precisely the continuum luminosity, here we applied the Spectral Principal Component Analysis method (see Connolly et al. 1995; Yip et al. 2004a,b) to subtract the host contribution (see Vanden Berk et al. 2006) and obtain the pure AGN continuum. For the subtraction of the host-galaxy contribution, we followed the procedure described in more detail in Lakićević et al. (2017). We found that in the majority of spectra the host-galaxy component is negligible (as it was assumed

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**Figure 1.** An example of the spectral decomposition to pure-host and pure-QSO contribution, using Spectral Principal Component Analysis (object: SDSS J095912.93+445059.1). Dots - observation, thin solid line - QSO, dotted line - host galaxy and thick solid line - model (QSO+host).

**Figure 2.** The AGN luminosity (after subtraction of the host galaxy contribution) vs. redshift of the sample and their distributions.
The significant host contribution was found only in 43 objects. For majority of these 43 objects, the host contribution is smaller than 15% at 5100 Å. The example of spectral decomposition to pure-host and pure-AGN contribution is shown in Fig. 1. After the host galaxy subtraction, the pure QSO continuum flux is measured at 5100 Å, and continuum luminosity is calculated using the formula given in Peebles (1993), and the cosmological parameters $\Omega_M=0.3$, $\Omega_{\Lambda}=0.7$ and $H_L=0$, and Hubble constant $H_0=70$ km s$^{-1}$ Mpc$^{-1}$. The host-corrected continuum luminosity at 5100 Å vs. redshift and their distributions are shown in Fig. 2.

The procedure for the fitting of the AGN spectra is given in Kovačević-Dojčinović & Popović (2015). After the continuum subtraction, we applied the multi-Gaussian emission line model, in which the complex line shapes are fitted with Gaussians of different widths, shifts and intensities, with the assumption that each Gaussian represents the emission from one emission region (see Popović et al. 2004; Kovačević et al. 2010). To reduce the number of free parameters in the fitting procedure, we assumed that the width and shift of each Gaussian are connected with the kinematical properties of the emission region where the corresponding line component arises. As e.g. the narrow Hβ and [O III] lines are assumed to be emitted from the same region, so the velocity dispersion of the Gaussian of the narrow Hβ and [O III] are assumed to be same, as well their shifts. In this way, all lines or line components, which are supposed to originate from the same emission line region, are fixed to have the same widths and shifts (see Popović et al. 2004).

For this research, it is necessary to extract the pure broad Hβ and Mg II profiles from the complex AGN spectra, which is a very difficult task, with some level of uncertainties. The biggest problem is to remove the overlapping lines, as e.g. Fe II lines in the optical (around Hβ) and in the UV (around Mg II), and the narrow component of the Hβ line.

The model of the line decomposition and the procedure of the spectral fitting in optical $\lambda\lambda$ 4000-5500 Å and UV $\lambda\lambda$ 2650-3050 Å band are presented in detail in Kovačević et al. (2010), Kovačević-Dojčinović & Popović (2015), and here we just recall the important steps for obtaining the broad Hβ and Mg II lines.

2.2.1 The pure broad Hβ profile

The broad Hβ line overlaps with the numerous optical Fe II lines, [O IV] $\lambda\lambda$ 4959, 5007 Â doublet and narrow Hβ component.

In the line decomposition model, the complex optical Fe II bumps are fitted with the Fe II semi-empirical model presented in Kovačević et al. (2010) and Shapovalova et al. (2012). This Fe II model enables very precise fitting of the Fe II bumps in the 4000-5500 Å spectral range (see appendix in Kovačević et al. 2010). The Balmer lines in the range $\lambda\lambda$ 4000-5500 Å (Hα, Hγ and Hβ) are fitted with three components - one narrow and two broad components, one which comes from the Very Broad Line Region (VBLR) and fits the core of the Balmer lines (see Popović et al. 2004; Bon et al. 2006; Hu et al. 2008). The widths and shifts of each line component are thus the same for all considered Balmer lines, which reduces the uncertainties in the Hβ line decomposition.

In some cases, the Balmer narrow lines are very difficult to resolve from the broad line component, especially in so-called Pop. A objects (see Sulentic et al. 2000b). On the other hand, the [O III] lines are well resolved in the majority of spectra. Therefore, the narrow Balmer lines are fixed to have the same width and shift as [O III] lines, since we are assuming that they arise in the same Narrow Line Region (NLR), and thus have the same kinematical properties. In this way, the number of free parameters in the fitting procedure is reduced and more accurate fitting decomposition is achieved.

Nevertheless, there is still some doubt about the non-uniqueness of the Hβ line decomposition to the broad and narrow component. Popović & Kovačević (2011) tested the uniqueness of the Hβ decomposition with this model, and discussed it in the Appendix A (in the same paper). As it can be seen from Popović & Kovačević (2011) the method we applied can reasonable fit the narrow Hβ component, and consequently the narrow Hβ component can be subtracted in order to find the pure Hβ broad component.

2.2.2 The pure broad Mg II $\lambda$ 2800 Å profile

In the UV part of AGN spectrum, the Mg II line is contaminated with the Balmer continuum and numerous UV Fe II lines. In addition, the Mg II line is a doublet with two components which overlap: $\lambda$ 2796 Å and $\lambda$ 2803 Å, that makes the extraction of the single broad profile even more complicated. The ratio of the component intensity is unknown, and it depends on the optical depth of the Mg II emitting region. In the optically thin case, the ratio Int(Mg II $\lambda$ 2796 Å)/Int(Mg II $\lambda$ 2803 Å) is expected to be 2:1, while in the case of fully thermalized lines it should be 1:1 (Lair et al. 1997; Marziani et al. 2013a). For expected values of parameters in the AGN emission region (hydrogen density and ionization parameter) this ratio should be close to 1:1 (Marziani et al. 2013a). Taking into account that the doublet transition wavelength separation is ~

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1 The template is available through Serbian Virtual Observatory (SerVo). [http://servo.aob.rs/FeII_AGN](http://servo.aob.rs/FeII_AGN)
Figure 4. Panel (a): the mean (solid line) and RMS (dashed line) Mg \( \text{II} \) profiles of 284 AGNs. Panel (b): the same for H\( \beta \). Panel (c): the comparison of the H\( \beta \) (solid line) and Mg \( \text{II} \) (dashed line) mean profiles. The horizontal solid lines indicate the widths at half and 10\% of the maximal intensity. Panel (d): the Mg \( \text{II} \) broad line (dashed line) rescaled to have the same FWHM as the H\( \beta \) (dotted line) and their difference (solid line).

Figure 5. Panel (a): the relationship between the widths of the line measured at 10\% and 50\% of the maximal line intensity (FW10\%M vs. FWHM). Panel (b): the relationship between the width and intrinsic shift measured at 10\% of the maximal line intensity (\( z_{10\%} \) vs. (FW10\%M)\(^2\)). The triangles denote the Mg \( \text{II} \) and full circles H\( \beta \) data.

8 Å (\( \sim 260 \text{ km/s} \)) and that the total line width is one order of magnitude larger, Mg \( \text{II} \) can be considered as a single line. Therefore, we assumed that Mg \( \text{II} \) profile and FWHM Mg \( \text{II} \) are not affected by doublet separation.

Note here that some authors apply the fitting procedure of the Mg \( \text{II} \) with broad and narrow line components (see McLure & Dunlop 2004; Wang et al. 2009; Shen & Liu 2012). However, the Mg \( \text{II} \) abundance and the transition probability for the NLR conditions are too small, so the narrow Mg \( \text{II} \) component seems to be absent or very weak and can be neglected (Wang et al. 2009; Marziani et al. 2013a; Kovačević-Dojčinović & Popović 2015). Moreover, by visual inspection of the Mg \( \text{II} \) lines in our sample, we could not find any spectrum with the prominent narrow Mg \( \text{II} \) line. Therefore, we neglected the Mg \( \text{II} \) narrow line contribution to the broad Mg \( \text{II} \) component.

For the Balmer continuum, we used the model given in Kovačević et al. (2014).
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The UV Fe\textsc{ii} lines around the Mg\textsc{ii} are complex, and there are several theoretical and empirical templates of the UV Fe\textsc{ii} lines (see e.g. Bergeron \& Kunth 1980; Vestergaard \& Wilkes 2001; Tsuchi et al. 2006; Bruhweiler \& Verner 2008; Kovačević-Dojčinović \& Popović 2015). We tested several templates and found that (see more details in Appendix A): (i) the theoretical templates could not fit well the UV Fe\textsc{ii} lines; (ii) the empirical templates are based on I Zw 1 Fe\textsc{ii} emission, which is narrow-line Seyfert 1 galaxy, and one cannot expect that in the case of the broad line AGNs the ratio between the UV Fe\textsc{ii} multiplets is the same as in the case of I Zw 1 (as in the case of the optical Fe\textsc{ii} lines, see Kovačević et al. 2010; Popović \& Kovačević 2011).

To solve this problem, we developed a semi-empirical model of the UV Fe\textsc{ii} lines based on the model given in Kovačević-Dojčinović \& Popović (2015), where the Fe\textsc{ii} multiplet intensities are free parameters, but the line ratios within one Fe\textsc{ii} multiplet are fixed, taking that within a multiplet the intensity ratio of two lines is:

\[
I_1/I_2 = \frac{f_1}{f_2} = \frac{g_1}{g_2} = \frac{\lambda_2}{\lambda_1} \cdot e^{-E_1/E_2kT}
\]  

where \(I_1\) and \(I_2\) are intensities of the lines with the same lower level of transition, \(\lambda_1\) and \(\lambda_2\) are line wavelengths, \(g_1\) and \(g_2\) are corresponding statistical weights of the upper levels, and \(f_1\) and \(f_2\) are oscillator strengths, \(E_1\) and \(E_2\) are energies of the upper level of transitions, \(k\) is Boltzmann constant, and \(T\) is the excitation temperature.

Taking that in our case the \(\lambda_2 \sim \lambda_1\), and \(E_1 \sim E_2\), an approximation can be used as:

\[
I_1/I_2 = \frac{f_1}{f_2} = \frac{g_1}{g_2} = \frac{\lambda_2}{\lambda_1}
\]  

as in the paper of Kovačević-Dojčinović \& Popović (2015). Here we use Eq. (1), to calculate the values of the line ratios within multiplets in Appendix A. In Appendix A we give a detailed discussion about the UV Fe\textsc{ii} semi-empirical model as well as comparison of this model with theoretical and empirical templates. Additionally, using our model we calculated a grid of the UV Fe\textsc{ii} templates in the 2650-3050 Å range with different FWHMs and shifts of the UV Fe\textsc{ii} lines.\(^2\)

The Mg\textsc{ii} line was fitted with two broad Gaussians: one which fits the core, and one which fits the line wings. These two broad Gaussians reproduce well the Mg\textsc{ii} line profiles in our sample.

2 The grid of the UV Fe\textsc{ii} templates is available through SerVo: http://servo.aob.rs/FeII_AGN/link7.html

2.2.3 Measuring the broad line parameters and black hole masses

The Mg\textsc{ii} and H\textsc{β} broad line shapes have been reproduced from the best fit (from two Gaussians), then normalized to one, and FWHM and Full Width at 10% of the Maximal Intensity (FW10\%) were measured. The corresponding intrinsic shifts (\(z_{50\%}\) and \(z_{10\%}\)) are measured as well, as a centroid shift with respect to the broad line peak at 50% and 10% of Maximal Intensity, respectively (see Jonić et al. 2016).

The black holes (\(M_{BH}\)) are estimated from relationships of Vestergaard \& Peterson (2006) which uses the H\textsc{β} parameters, and Vestergaard \& Osmer (2009) which uses the parameters of Mg\textsc{ii} line. In Fig. 3 we show the BH masses derived from H\textsc{β} vs. those derived from Mg\textsc{ii} line and their distributions. As it can be seen in Fig. 3, there is strong correlation between the BH masses derived from these two lines, and their distributions are very similar.

2.2.4 The mean and RMS line profiles

To explore the Mg\textsc{ii} and H\textsc{β} profiles, we found the mean profiles of the normalized H\textsc{β} and Mg\textsc{ii} lines from the sample and the root-mean-square – RMS which indicates the difference in the line profiles (see Fig. 4ab). Comparing the mean Mg\textsc{ii} and H\textsc{β} line profiles we found that the line cores are very similar, and that the difference is seen in the line wings (Fig. 4c).

The slight difference in the line cores is caused by a smaller FWHM Mg\textsc{ii}. Therefore, to subtract two mean profiles, we first rescaled Mg\textsc{ii} to have the same FWHM as H\textsc{β} for each AGN (Fig. 4d). As the result of subtraction, a double peaked feature appeared (see solid line in Fig. 4d). It seems that there is an extra emission in the far (blue and red) Mg\textsc{ii} wings compared to the H\textsc{β} ones, with a bigger difference in the blue wings (see Fig. 4d).

2.3 Connections between the Mg\textsc{ii} and H\textsc{β} line widths/shifts – virialization assumption

To test the virialization in the Mg\textsc{ii} and H\textsc{β} line emitting regions we used the line parameters: intrinsic shifts and FWHMs of all AGNs in the sample. The FWHM can be related with the line dispersion sigma, which is the second moment or variance of the velocity distribution (as e.g. is the case for Gaussian-like profile). In particular case where we assume a Keplerian-like motion, the FWHM is directly connected with the velocity and with the emissivity weighted radius \(R_{FWHM}\), so the mass of the central black hole can be estimated from (see e.g. Peterson 2014):

\[
M_{BH} \sim FWHM^2 \cdot R_{FWHM}
\]

Therefore, in the virialization assumption, the rotating velocity is strongly connected with the FWHM.

Assuming the Keplerian motion, one can write the following:

\[
M_{BH} = R_{BLR} \cdot v^2 G
\]

where \(R_{BLR}\) is the size of the rotating BLR and \(v\) is the velocity of the rotation.

Concerning the line intrinsic shift (asymmetry), it can be caused due to a number of effects, but in the case of full virialization, one can expect the connection between the intrinsic line shift and FWHM.

Namely, if we take that the BH mass can be measured using the gravitational shift (\(z_{g}\)) as (Liu et al. 2017):

\[
M_{BH} \sim R_{BLR} \cdot z_g \sim R_{BLR} FWHM^2
\]

this indicates that a good correlation should be present between \(z_{g}\) and FWHM\(^2\). Since we measured the intrinsic shift at FWHM (\(z_{50\%}\) and \(z_{10\%}\)) in the case of virialization in the total line we expect:

\[
z_{50\%} \sim FWHM^2, \quad z_{10\%} \sim FWHM^2
\]

where \(z_{50\%}\) and \(z_{10\%}\) are measured intrinsic shifts at FWHM and FWHM\(^2\) (see Jonić et al. 2016).

Using Eq. (6) we explored the virialization in the Mg\textsc{ii} and H\textsc{β} emitting regions.
3 RESULTS

In order to investigate similarities and differences between the Hβ and Mg II emitting regions, we compared the mean and RMS line profiles of these broad lines (see §2.2.4).

As it can be seen in Fig. 4ab the mean Mg II broad line has Lorentzian-like profile, while the mean broad Hβ mostly has a Gaussian-like profile. The mean Mg II broad line profile (normalized to one) is similar to Hβ in the line core (with slightly smaller FWHM), while in the line wings there is a large difference. The Mg II has more extensive line wings (see Fig. 4cd), and specially, the blue wing tends to be more intensive than the red in comparison with the Hβ ones.

The mean and RMS line profiles are taken from a sample that has the AGN luminosity spanning an order of magnitude from log\(\lambda L_{5100} \sim 44.5\) to log\(\lambda L_{5100} \sim 45.5\) (see Fig. 2) and different black hole masses (see Fig. 3). Therefore, some other effects may affect the broad emission line features such as a flux excess in the red or/and blue side of line profile as e.g. photoionization effects in the BLR, geometry and dynamics of the BLR, etc. However, in this paper we are a priori assuming the virialization in the Mg II and Hβ emitting regions. Therefore, the FWHM should depend on the BH mass \(M_{BH}\), and BLR radius \(R_{FWHM}\), i.e. FWHM \(\sim \sqrt{M_{BH} R_{FWHM}}\).

Taking a sample with different BH masses, one can expect that the RMS of normalized line profiles should have maxima around the velocities that correspond to the \(\lambda_1 = \lambda_0 - FWHM_2\) and \(\lambda_2 = \lambda_0 + FWHM_2\) (since the line maximum is normalized to one). Fig. 4ab shows that the RMS has two maxima around \(\lambda_0 \pm FWHM_2\) in the case of both lines. Additionally, if both broad lines originate from the region with similar kinematics, one can expect that the mean Mg II and Hβ broad lines should have similar profiles, as it is the case with their line cores (see Fig. 4cd). It is clearly seen that there is a large difference in the line wings, where Mg II shows broader and more intensive line wings.

On the other hand, in the case that another geometry dominates the BLR, as e.g. inflow/outflow, one can expect that the RMS would have strong asymmetry (and peaks) in the far blue or red line wings. In other words, the mean and RMS profiles of the sample AGNs with different masses and BLR properties, can give some indications about the difference in the BLR geometry, especially if
we compare mean profiles of two different lines from the sample. Note here that in the case where the kinematics plays an important role in the line shapes, one can expect that in one spectrum the normalized Mg ii and Hβ broad line profiles should have similar (almost the same) shape.

The Mg ii RMS has two peaks (at $\sim-1720$ km s$^{-1}$ and $\sim+1800$ km s$^{-1}$) and is nearly symmetric, while the Hβ RMS has red asymmetry (two peaks at $\sim-1860$ km s$^{-1}$ and $\sim+2080$ km s$^{-1}$). The distance between the RMS peaks in the both lines is very close to the FWHM of their mean profiles.

### 3.1 The Mg ii and Hβ BLR kinematics

Since the FWHM of the broad Hβ and Mg ii lines are in a good correlation (see e.g. Kovačević-Dojčinović & Popović 2015), one can expect that their other parameters are also well correlated. However, the correlation is absent in the case of FW10%M between these two lines (see e.g. Jonić et al. 2016). Here we explored correlation between kinematical parameters of Mg ii and Hβ in more detail (see Fig. 5).

We compared the FW10%M vs. FWHM for both lines (Fig. 5a). The Hβ line parameters are in good correlation: $\rho=0.82$, $P_0<10^{-20}$, where $\rho$ is Spearman correlation coefficient and $P_0$ is P-value of the null-hypothesis. In the case of the Mg ii line the correlation between these parameters is weaker ($\rho=0.42$, $P_0=10^{-13}$).

As mentioned before, if virialization is present in an emitting region, one can expect that the intrinsic shift will be in correspondence with the corresponding width (see Eq. 6). In Fig. 5b we showed the correlations between the intrinsic shifts and widths at 10% of the line maximum. The expected correlation is present in the case of Hβ ($\rho=0.57$, $P_0<10^{-20}$), but in the case of Mg ii there is no trend ($\rho=0.02$, $P_0=0.71$). The big scattering of the points is present, showing randomly strong blue and red shifts in the wings. This indicates that the Mg ii wings probably originate in a region that is more connected with outflows/inflows than with the virial motion of the gas in an accretion disc.

We should note that the relationship between the line profile width and centroid wavelength shift can be questioned, since the gravitational redshift is typically assumed to have a minimal effect on the line profile. To do an additional test of the connection between the intrinsic shift and the gravitational redshift, we explored the intrinsic shift as a function of the $M_{BH}R_{BLR}$ ratio (see Eq. 5), using the BLR size from the $R - L$ relation (given in Bentz et al. 2013) and the single-epoch BH mass.

For the intrinsic shift at 10% of the maximal intensity we rescaled $R_{BLR}$ as:

$$R_{0,BLR} = R_{BLR} \cdot \frac{\text{FWHM (FW10%M)}}{2}.$$

In Fig. 6 we plot the intrinsic shift measured at FWHM (25%) and at FW10%M (10%) as a function of the $M_{BH}R_{BLR}$ for Hβ (Figs. 6ab) and Mg ii (Figs. 6cd). Also we show the binned values (black squares) in order to trace a trend between the intrinsic shift and the $M_{BH}R_{BLR}$ ratio. Figs. 6ab show that the intrinsic shifts follow the expected correlation with the $M_{BH}R_{BLR}$ for Hβ. In the case of the intrinsic shift at half of the maximal intensity for Mg ii, there is some indication of a weak trend with the $M_{BH}R_{BLR}$ only for 25% > 0 (Fig. 6c), but the intrinsic shift of Mg ii wings shows no correlation with the $M_{BH}R_{BLR}$ (Fig. 6d). This implies that there is no virialization in the Mg ii wings. The values of the intrinsic shift in Mg ii are in the range from $-3000$ km s$^{-1}$ to $+2000$ km s$^{-1}$ (see Fig. 6d) which indicates high outflows/inflows, with similar probability. However, as $M_{BH}R_{BLR}$ increases, the range of intrinsic shift gets smaller (between $\pm 1000$ km s$^{-1}$), i.e. this kind of motion is with smaller velocity. These results indicate some kind of ‘fountain-like’ motion that contributes to the extensive Mg ii line wings, which becomes suppressed with stronger gravitational influence.

Additionally, we investigated the influence of the Eddington ratio to the gas velocities in the ‘fountain-like’ region. Therefore, we calculated the $L_{5100}/M_{BH}(Hβ)$ ratio (which is proportional to the Eddington ratio) for a subsample of 52 objects with the luminosities in the narrow range of 45.1 < $\log(L_{5100})$ < 45.2, and we tested if there is a correlation with $z_{50}$, which is probably proportional to the ‘fountain-like’ region velocities. We found that the absolute value of $z_{50}$ ($z_{10}$) has weak correlation with $\log(L_{5100}/M_{BH}(Hβ))$ ($\rho=0.34$, $P_0=0.01$), i.e. the inflow/outflow velocities increase as Eddington ratio increases.

### 4 DISCUSSION

#### 4.1 Similarities and differences between Mg ii and Hβ emission line profiles

First of all, let us give some general facts about the Mg ii and Hβ line profiles:

- The core and FWHM of the mean profiles of Mg ii and Hβ seem to be very similar, while the difference is bigger in the line wings. The Mg ii line has more Lorentzian-like, and the Hβ has Gaussian-like profile.

- The Hβ line shows virialization in the whole profile, i.e. the relationship between the kinematical parameters (widths and intrinsic shifts) obtained from the Hβ BLR nearly follows those expected in case of the pure Keplerian motion. On the other hand, the Mg ii BLR does not follow this motion.

- It seems that Mg ii shows virialization in the line core, while another effect contributes to the line wings, making them very extensive.

There is a question how much an emitting region with inflows and/or outflows contributes to the total Mg ii emission. At least in the wings, we can expect the contribution of the emitting region with some kind of vertical (to the disc plane) motion.

Since the line profiles can indicate the inflow (red asymmetry) or outflow (blue asymmetry), we divided the sample into three subsamples according to the Mg ii asymmetry (i.e. $z_{50}$ measured at FWHM). The first subsample contains AGNs with the Mg ii blue asymmetry ($z_{50} < -100$ km s$^{-1}$), the second with the red one ($z_{50} > 100$ km s$^{-1}$), and the third contains the AGNs with the symmetric Mg ii profile (intrinsic shift, $z_{50}$, between these two values: $-100 < z_{50} < 100$). We found that most of AGNs (231) have almost symmetric Mg ii mean profile, showing extended wings in Mg ii compared to Hβ, and a big difference in the line wings of these two lines (see Fig. 7b). The red asymmetry is present in 29 AGNs, and as it can be seen in Fig. 7a, the mean line profiles of Mg ii and Hβ are very similar (almost the same) for these objects. Finally, we found 24 AGNs with the significant blue asymmetry, and also with a big difference between the mean Mg ii and Hβ line profiles (see Fig. 7c).

Comparing the mean Hβ and Mg ii line profiles and their RMSs (Fig. 7), one can conclude that in the case of the red asymmetry and symmetric Mg ii profiles, the FWHM and RMSs are similar for both lines in the most of cases (see Fig. 7ab), and the Mg ii line
Therefore, one can conclude that \( z_{50} \) seems to be a good estimator of the central BH mass. In the case of the strong blue \( \text{Mg}\,\!\!\,\,\text{II} \) asymmetry, the mean profiles of \( \text{Mg}\,\!\!\,\,\text{II} \) and \( \text{H}\,\!\!\,\,\text{II} \) are quite different, and the \( \text{Mg}\,\!\!\,\,\text{II} \) line perhaps is not appropriate for BH mass estimation. However, we should note that we have statistically small samples of objects with strong blue and red asymmetry, so the result may be influenced by outliers.

Let us here also recall the results obtained in Marziani et al. (2013a,b). They found a difference in the line profiles of \( \text{Mg}\,\!\!\,\,\text{II} \) and \( \text{H}\,\!\!\,\,\text{II} \) for Pop. A and Pop. B objects (see the definition of Pop. A/Pop. B in Sec. 1). The red asymmetry was observed in the Pop. B objects in both broad lines (\( \text{Mg}\,\!\!\,\,\text{II} \) and \( \text{H}\,\!\!\,\,\text{II} \)) and they supposed that it may indicate an inflow in the BLR. Pop. A objects have more symmetric line profiles, but the blue-shift of \( \text{Mg}\,\!\!\,\,\text{II} \) relative to \( \text{H}\,\!\!\,\,\text{II} \) indicates an outflow (Marziani et al. 2013b). Therefore, one can conclude that the \( \text{Mg}\,\!\!\,\,\text{II} \) line profiles in AGN show both outflows (Pop. A objects) and inflows (Pop. B objects).

We also compared the line profiles of Pop. A and Pop. B objects in our sample. We found that 149 objects from the sample are Pop. A, with the FWHM of \( \text{H}\,\!\!\,\,\text{II} \) smaller than 4000 km s\(^{-1}\), and 135 objects are Pop. B. The comparison of the \( \text{Mg}\,\!\!\,\,\text{II} \) and \( \text{H}\,\!\!\,\,\text{II} \) mean line profiles for both populations is presented in Fig. 8. It can be seen that the \( \text{Mg}\,\!\!\,\,\text{II} \) lines are more extensive than \( \text{H}\,\!\!\,\,\text{II} \) wings, and that \( \text{H}\,\!\!\,\,\text{II} \) is slightly broader than \( \text{Mg}\,\!\!\,\,\text{II} \) in both populations (as it was noted in Marziani et al. 2013a,b). Also, the mean \( \text{H}\,\!\!\,\,\text{II} \) and \( \text{Mg}\,\!\!\,\,\text{II} \) line profiles are different in these two populations. In Pop. A, the mean \( \text{Mg}\,\!\!\,\,\text{II} \) profile is Lorenzian-like, and it shows blue asymmetry in wings (velocities at 10% of line intensity: \( -5780 \) km s\(^{-1}\) to \( +5100 \) km s\(^{-1}\), see Fig. 8a), while the mean \( \text{H}\,\!\!\,\,\text{II} \) has red asymmetry (velocities at 10% of line intensity: \( -3990 \) km s\(^{-1}\) to \( +4590 \) km s\(^{-1}\)). However, if measured at 50% of line intensity, both lines are nearly symmetric (\( \text{Mg}\,\!\!\,\,\text{II} \): \( -1380 \) km s\(^{-1}\) to \( +1350 \) km s\(^{-1}\), \( \text{H}\,\!\!\,\,\text{II} \): \( -1520 \) km s\(^{-1}\) to \( +1560 \) km s\(^{-1}\)). In Pop. B, the red asymmetry in the mean \( \text{H}\,\!\!\,\,\text{II} \) line profile is much stronger compared to Pop. A (velocities at 10% of line intensity: \( -5110 \) km s\(^{-1}\) to \( +6740 \) km s\(^{-1}\), and at 50% of line intensity: \( -2410 \) km s\(^{-1}\) to \( +2750 \) km s\(^{-1}\)), while the \( \text{Mg}\,\!\!\,\,\text{II} \) mean profile is almost symmetric with a slight asymme-

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**Figure 7.** The mean (solid tick line) and the RMS (dashed tick line) \( \text{Mg}\,\!\!\,\,\text{II} \) broad line profiles for sub-samples of AGNs, for which \( \text{Mg}\,\!\!\,\,\text{II} \): (a) has red asymmetry (29 AGNs with \( z_{50} > 100 \) km s\(^{-1}\)); (b) is almost symmetric (231 AGNs with \( z_{50} \) between \( \pm 100 \) km s\(^{-1}\)); and (c) has blue asymmetry (24 AGNs with \( z_{50} < -100 \) km s\(^{-1}\)). The \( \text{Mg}\,\!\!\,\,\text{II} \) asymmetry is measured at FWHM. The corresponding mean \( \text{H}\,\!\!\,\,\text{II} \) and RMS profiles are shown with thin solid and dashed lines, respectively.

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**Figure 8.** Comparison between the mean \( \text{Mg}\,\!\!\,\,\text{II} \) and \( \text{H}\,\!\!\,\,\text{II} \) broad line profiles and their difference (dashed line) for the samples of (a) 149 Pop. A objects (FWHM \( \text{H}\,\!\!\,\,\text{II} < 4000 \) km s\(^{-1}\)) and (b) 135 Pop. B objects (FWHM \( \text{H}\,\!\!\,\,\text{II} > 4000 \) km s\(^{-1}\)).
4.2 Mg ii emitting region

Comparing the mean Mg ii and Hβ line profiles in the total sample and five sub-samples (see Fig. 4cd and Figs. 7 and 8), the large difference seems to be visible only in wings. The question is what can cause the difference only in the line wings? We found that the intrinsic shift in the Mg ii wings can be red or blue and that it is not in correlation with the $M_{BH}/R_{H\beta}$ ratio (see Fig. 6d), which indicates that both, inflows and outflows could be present in the Mg ii emitting region. To discuss a model for the Mg ii emitting region, let us recall some results from the laboratory plasma investigations. As it was shown in Kuraïerah et al. (2009, see Fig. 6 in their paper), the kinematics can affect the line profile in the case of 'fountain-like' motion with approaching and receding velocities, that in combination with the Doppler broadening can produce slightly asymmetric Lorentzian-like profiles. Also, recently Czerny et al. (2017) showed that a flow with an orthogonal motion to the disc plane can produce Lorentzian-like profiles. The similar results, with Lorentzian like profile was obtained by Kollatschny & Zetzl (2013), considering some type of turbulent velocities in the model (vertical to the BLR rotation).

In Fig. 9 (upper panel) we fitted the Mg ii mean profile (dashed line) with the Hβ one (solid line), and subtracted the best fit of Hβ from Mg ii (thick double-peak feature shown below). As expected, there is a double peaked structure emerging after the subtraction, showing the maxima at $\pm 7000$ km s$^{-1}$. If there are some kind of outflows-inflows they should have high velocities, i.e. probably the outflows-inflows originate very close to the central BH. One can also consider that this extra-emission may come from the fast motion of the material in the accretion disc, that is very close to the central BH. However, in that case we expect to have boosted blue wing and large red wing that is typical for the relativistic disc (see e.g. the complex profile of NGC 3516, Figs. 7-10 in Popović et al. 2002), which is not the case here (see Fig. 9).

Therefore, we excluded this scenario.

Taking into account the discussion above, we propose the following scenario for the Mg ii line origin (as it is shown in the simple scheme in Fig. 9, bottom):

The line core is originating from the virialized disc-like BLR (represented as a disc in Fig. 9-bottom panel), that may be at slightly larger radius than the Hβ emission region (Mg ii shows a slightly narrower FWHM than Hβ). In the case where the emission from this region is dominant, the FWHM of Mg ii represents the velocity of the emission gas rotation due to gravitational force, and the line can be used as very good BH mass estimator, as it is noted in Trakhtenbrot & Netzer (2012). However, where the 'fountain-like' region is dominant (shown as outflows-inflows in Fig. 9-bottom), one can expect a broader Mg ii line, and in that case, the virialization in the FWHM probably is not present, and therefore Mg ii might not be suitable for the BH mass estimation (León-Tavares et al. 2013). This is in agreement with results obtained by Trakhtenbrot & Netzer (2012), who found that the Mg ii can be used as a good BH mass estimator in the case of FWHM<6000 km s$^{-1}$.

As mentioned above, we found only 3 AGNs with Mg ii FWHM larger than 6000 km s$^{-1}$, for which we compared the mean Hβ and Mg ii line profiles (see Fig. 10). As it can be seen, there is a difference between the mean Hβ and Mg ii lines and their RMS profiles. The Mg ii mean profile shows red asymmetry measured at 10% of line intensity (-7300 km s$^{-1}$ to +7760 km s$^{-1}$) and it is nearly symmetric at FWHM (-3240 km s$^{-1}$ to +3270 km s$^{-1}$), while the Hβ mean profile shows strong red asymmetry measured at
AGNs with FWHM $\text{Mg}^\text{II}$ $> 6000$ km s$^{-1}$. Corresponding RMS profiles are denoted with tick dashed line (for $\text{Mg}^\text{II}$) and thin dashed line (for H$\beta$). The vertical lines show positions of $\lambda_{0}$±FWHM/2, where it is expected to have RMS peaks due to the difference in line profiles.

both 10% ($-5940$ km s$^{-1}$ to $+5940$ km s$^{-1}$) and 50% of line intensity ($-3090$ km s$^{-1}$ to $+3970$ km s$^{-1}$). Additionally, the differences (RMS) in far wings of the mean $\text{Mg}^\text{II}$ are without peaks which are usually seen near $\lambda_{0}$±FWHM/2 in the RMS of H$\beta$.

Therefore, despite our limited number of objects with $\text{Mg}^\text{II}$ FWHM$>6000$, our analysis of these objects is in agreement with previous results. However, since our sample has no statistically significant number of AGNs with very broad $\text{Mg}^\text{II}$ lines, we could not find the strict constraint in the $\text{Mg}^\text{II}$ line parameters (width or asymmetry) which would indicate if $\text{Mg}^\text{II}$ is suitable (or not suitable) for BH mass estimation (see Appendix B).

5 CONCLUSIONS

Here we explored the structure of the $\text{Mg}^\text{II}$ line emitting region in a sample of 284 type 1 AGNs, by comparing the $\text{Mg}^\text{II}$ line parameters with the H$\beta$ ones. We investigated measured line properties and tried to give the possible model of the broad $\text{Mg}^\text{II}$ emitting region.

From our analysis we can conclude the following:

- The mean $\text{Mg}^\text{II}$ line profile has a slightly asymmetric Lorentzian-like profile, and very broad line wings. The shape of the mean $\text{Mg}^\text{II}$ line profile and correlation between the line parameters indicate that there are two $\text{Mg}^\text{II}$ emitting regions: the one similar to the H$\beta$ emitting region that is probably virialized (contributes to the line core), and the second emission region that seems to be ‘fountain-like’. In order to explain the broad blue and red wings, the ‘fountain-like’ emission region should have both – inflows and outflows, with high velocity components orthogonal to the disc, which become suppressed with stronger gravitational influence.

- If the virialized region mostly contributes to the $\text{Mg}^\text{II}$ line flux, the $\text{Mg}^\text{II}$ FWHM should be comparable with the H$\beta$ one, and it can be used for BH mass estimation. However, if the contribution of the ‘fountain-like’ region is more dominant, one can expect to have broader $\text{Mg}^\text{II}$ lines, with extensive wings. This is especially seen in the case of very broad $\text{Mg}^\text{II}$ with FWHM $> 6000$ km s$^{-1}$, or in the case of the $\text{Mg}^\text{II}$ with a strong blue asymmetry; in both cases we found that the FWHM probably does not represent the rotational motion of the emitting gas in the central BH gravitational field.

Therefore, one should be careful when using extremely broad or blue asymmetric $\text{Mg}^\text{II}$ line for BH mass estimation.

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Figure 10. Mean line profiles of $\text{Mg}^\text{II}$ (tick line), and H$\beta$ (thin line) for 3 AGNs with FWHM $\text{Mg}^\text{II}$ $> 6000$ km s$^{-1}$. Corresponding RMS profiles are denoted with tick dashed line (for $\text{Mg}^\text{II}$) and thin dashed line (for H$\beta$). The vertical lines show positions of $\lambda_{0}$±FWHM/2, where it is expected to have RMS peaks due to the difference in line profiles.
APPENDIX A: THE UV AND OPTICAL Fe II LINE SUBTRACTION

There are different UV and optical Fe templates presented in the literature (see e.g. Boroson & Green 1992; Vestergaard & Wilkes 2001; Tsvzuki et al. 2006; Bruhweiler & Verner 2008; Kovačević et al. 2010; Kovačević-Dojčinović & Popović 2015; Mejía-Restrepo et al. 2016, etc.) which are to account for the iron emission contribution to the Hβ and Mg II line profiles. For the subtraction of the optical Fe lines around Hβ we used the model given in Kovačević et al. (2010). The differences between this Fe model and models given in Dong et al. (2008) and Bruhweiler & Verner (2008) are explored and analysed in Appendix B of Kovačević et al. (2010), where it is demonstrated that this template can well reproduce the Fe optical emission around the Hβ line. Barth et al. (2015) compared this template with the ones of Boroson & Green (1992) and Véron-Cetty et al. (2004), and they found that it returns the best χ² values. Since the optical Fe model given in Kovačević et al. (2010) is analysed in number of papers, we will not consider it here in more detail.

For subtraction of the UV Fe lines we used the UV Fe model given in Kovačević-Dojčinović & Popović (2015), which has been improved for the purpose of this investigation. Therefore, here we give more details about improved version of that model.

A1 The improved UV Fe model in the λ1 2650-3050 Å wavelength range

In order to test the model of UV Fe lines given in Kovačević-Dojčinović & Popović (2015), we fitted set of spectra with different width of emission lines. We found that in the case of type 1 AGNs, the model fits very well the Fe lines around Mg II. In order to test the UV Fe model for Narrow Line Seyfert 1 (NLSy1) galaxies, we used the UV spectra of I Zw 1 and Mrk 493. These two NLSy1 galaxies have well resolved UV spectrum, observed with FOS spectrograph of Hubble Space Telescope. We found that in the case of NLSy1 galaxies, where Fe II lines are strong and narrow enough to be distinguished from Mg II, this UV Fe model has a lack of lines at ~ 2825–2860 Å, ~ 2650–2725 Å and ~ 3000 Å.

We improved the model by adding the missing Fe II lines. We add the multiplet 78 (see Bergeron & Kunth 1990), which covers the region at ~ 3000 Å. We could not identify with confidence the rest of emission at ~ 2825–2860 Å and 2690–2725 Å, since there are numerous Fe II lines in that range (several lines at each Å), and they all have high energy of excitation, which is not theoretically expected, since the observed multiplets 60-63 and 78 arise from relatively small energy excitation levels. Since we could not identify the lines, we added two Gaussians at ~2720 Å and ~2840 Å, which represent emission of additional ‘I Zw 1 lines’, assuming that Gaussian intensity ratio is following the one obtained from the best fit of I Zw 1.

The similar procedure was done in Kovačević et al. (2010) with the optical Fe II model, where the small amount of the Fe II emission, which could not be theoretically explained, was added empirically from I Zw 1 spectrum.

We found that in both galaxies, I Zw 1 and Mrk 493, there is the line peak present at 2670 Å, which is probably emission of the Al II 2670 Å line, also noted by Vestergaard & Wilkes (2001) in their analysis of I Zw 1 spectrum. Therefore, to fit the Mg II spectrum in the region of Mg II emission, with empirically added ‘I Zw 1 lines’, we used additional multiplet 78. The example of multiplets emission, with empirically added ‘I Zw 1 lines’ is shown in Fig. A1b.

We assume that the widths and shifts of all UV Fe II lines are the same, since they probably originate from the same emission region, so the improved UV Fe II model has 9 free parameters: width, shift, intensity of ‘I Zw 1 lines’, intensities for each of 5 multiplets, and the temperature, which is used to calculate the relative intensities of the lines within each multiplet (see Eq. (1), Sec. 2.2.2). The relative intensities of the lines within each multiplet were calculated for the T = 5000 K, 10000 K and 50000 K, normalized to the strongest line in the multiplet and shown in Table A1. For calculation of the relative intensities with Eq. (1), we used the updated atomic data from National Institute of Standards and Technology (NIST) Atomic Spectra Database and Kurucz atomic database.

The fits of I Zw 1 and Mrk 493 with improved UV Fe II semi-empirical model are shown in Fig A2. As it can be seen, the improved UV Fe II model can fit very well the UV Fe II lines in NLSy1 galaxies.

Kovačević et al. (2010) have found that the flux ratio of the

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3 The spectra are downloaded from: https://archive.stsci.edu/hst/search.php
4 https://physics.nist.gov/asd
Fe II multiplets is not constant, i.e. it can vary from object to object. In this work, we found that the ratio of the UV Fe II multiplets slightly differs in two observed NLSy1 galaxies: I Zw 1 and Mrk 493. Therefore, the UV Fe II model with free parameters for multiplet intensity enables fitting the objects with different strength of Fe II multiplets, which is not possible with other UV Fe II templates based on I Zw 1 Fe II emission lines, or theoretically calculated, with fixed relative intensities of UV Fe II lines. This is an advantage of the UV Fe II semi-empirical model that we have developed.

We compared this improved UV Fe II model with theoretical models given in Sigut & Pradhan (2003) and Bruhweiler & Verner (2008) and empirical UV Fe II templates based on the spectrum of I Zw 1, and presented in Tsuzuki et al. (2006) and Vestergaard & Wilkes (2001). The applied version of theoretical model from Sigut & Pradhan (2003) was calculated for photoionization model A of the BLR, with included Lyα and Lyβ pumping, and the applied version of theoretical model from Bruhweiler & Verner (2008) was calculated for log[n(H)/cm⁻³]=11, [ξ]/(1 km s⁻¹)=20 and log[Φ(H)/cm⁻² s⁻¹]=20.5.

To test the different UV Fe II templates, we chose three examples of spectra where we obtained different shapes of Mg II lines after applying our improved UV Fe II model: with red asymmetry in Mg II profile (Fig. A3), with blue asymmetry in Mg II profile (Fig. A4), and with no significant asymmetry of Mg II (Fig. A5). We fitted these examples with different templates, and compared the obtained profiles of Fe II and Mg II lines with different Fe II models (see Figs A3, A4 and A5).

It can be seen that all considered UV Fe II templates have different shapes, which result with different spectral decomposition of Mg II UV Fe II lines in all examples, and consequently with different shape of extracted pure Mg II profile. The empirical templates of Tsuzuki et al. (2006) and Vestergaard & Wilkes (2001) are both made using the spectrum of the I Zw 1 galaxy, and therefore these templates are the most similar among the others, and they give the most similar fits of Mg II UV Fe II lines. The improved UV Fe II model presented in this work slightly vary from case to case comparing to the empirical templates, while the theoretical models of
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Sigut & Pradhan (2003) and Bruhweiler & Verner (2008) in some cases have larger incompatibility with other three templates. Namely, the theoretical models of Sigut & Pradhan (2003) and Bruhweiler & Verner (2008) cannot fit well the UV Fe ii bump at \( \sim 2900-3000 \text{ Å} \) range in all given examples (see Fig. A3, A4 and A5, case (b) and (c)). The discrepancy is the strongest in the spectrum shown in Fig. A4, with strong UV Fe ii lines at \( \sim 2900-3000 \text{ Å} \) range.

The empirical templates of Tsuzuki et al. (2006) and Vestergaard & Wilkes (2001) fit well all given examples. However, in the case of complex Mg ii UV Fe ii shapes (see Fig A5), the fits with these templates have small discrepancy (at \( \sim 2700-2780 \text{ Å} \) range in Fig. A5 (d), and at \( \sim 2820-2840 \text{ Å} \) range in Fig. A5 (e)). Additionally, the empirical template of Vestergaard & Wilkes (2001) has artificial cut from 2770 Å to 2819 Å (under the Mg ii emission), i.e. the UV Fe ii emission is set to zero in the range 2770–2819 Å, that also can artificially change the Mg ii broad line profiles. Therefore, we developed the semi-empirical UV Fe ii model (an improved template of Kovačević-Dojčinović & Popović 2015) which can fit well all these different Mg ii line profiles (see Fig. A3, A4 and A5, case (a)) and is able to account possible difference between the multiplet intensities which may be caused by slight different physical conditions in the UV Fe ii emitting region. The template is available on-line, through the Serbian Virtual Observatory.\(^5\)

\(^5\) http://servo.aob.rs/
Table A1. The improved UV Fe II \lambda \lambda 2650-3050 Å model: the relative intensities of the UV Fe II emission lines within multiplets calculated for different temperatures (see Eq. (1)) and using updated atomic data. The lines with the strength of four order of magnitude lower than the strongest line from multiplet are excluded from model, since their contribution in flux is negligible.

| Wavelength | Transitions | Relative intensity T=5000 K | Relative intensity T=10000 K | Relative intensity T=50000 K |
|------------|-------------|-------------------------------|-------------------------------|-------------------------------|
| multiplet $a^3D - z^6F^o$ (60) | $a^4D_{27} - z^6F^o_{52}$ | 0.008 0.009 0.009 | 0.006 0.006 0.006 | 1.000 1.000 1.000 |
| multiplet $a^3D - z^6F^o$ (61) | $a^4D_{27} - z^6F^o_{52}$ | 0.010 0.010 0.011 | 0.001 0.001 0.001 | 0.028 0.032 0.035 |
| multiplet $a^3D - z^4F^o$ (62) | $a^4D_{27} - z^4F^o_{52}$ | 0.002 0.003 0.003 | 0.017 0.019 0.021 | 0.031 0.036 0.041 |
| multiplet $a^3D - z^4D^o$ (63) | $a^4D_{27} - z^4D^o_{52}$ | 0.132 0.139 0.144 | 0.120 0.131 0.140 | 0.056 0.063 0.068 |
| multiplet $a^3P - z^3P^o$ (78) | $a^4P_{35} - z^3P^o_{42}$ | 0.117 0.128 0.138 | 0.189 0.200 0.210 | 0.045 0.049 0.053 |

'I Zw 1 lines' - relative intensity of Gaussians

2715 0.357
2840 1
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Figure A3. Fits of SDSS J135045.66+233145.2 with different UV Fe II templates: (a) this work, (b) Bruhweiler & Verner (2008) (BV2008), (c) Sigut & Pradhan (2003) (SP2003), (d) Tsuzuki et al. (2006) (T2006), (e) Vestergaard & Wilkes (2001) (VW2001), and (f) comparison of the UV Fe II lines (bottom) and Mg II profiles (top) obtained from the best fit using different UV Fe II models (for colored version of this Figure see electronic version). We obtained the Mg II profile with red asymmetry after decomposition with our improved UV Fe II model (a).
Figure A4. The same as in Fig. A3 but for object SDSS J105540.81421241.2, for which we obtained the Mg II profile with blue asymmetry with our decomposition model.
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Figure A5. The same as in Fig. A3 but for object SDSS J122454.46212246.4, for which we obtained nearly symmetric Mg ii profile with our decomposition model.
APPENDIX B: CONTRIBUTION OF THE 'FOUNTAIN-LIKE' REGION AND THE ACCURACY OF THE BH MASS MEASUREMENTS

We analysed the different parameters of Mg\textsc{ii} lines, trying to find some Mg\textsc{ii} line properties which indicate dominant emission from the 'fountain-like' region and some quantitative constraints of Mg\textsc{ii} parameters for which Mg\textsc{ii} line is reliable (or not reliable) for the single epoch Mg\textsc{ii} estimation.

Previously, in Sec. 3.1 we explored the correlation between the intrinsic shift ($z_{10\%}$) and the width (FW10\%M) that indicates virialization in the Mg\textsc{ii} emitting region. As it can be seen in Fig. 5b, the objects with the Mg\textsc{ii} lines with approximately $z_{10\%} < -800$ km s$^{-1}$, or FW10\%M $> 12250$ km s$^{-1}$, do not follow the linear correlation. In these cases, the emission of the 'fountain-like' region is probably dominant in the wings of the Mg\textsc{ii}. However, we could not find the strict constraint in the Mg\textsc{ii} line parameters which would guarantee that the M$_{BH}$ estimated using the Mg\textsc{ii} FWHM is reliable, or opposite, that it is much different from the M$_{BH}$ estimated using H$\beta$.

Additionally we explored the correlation between the contribution of the 'fountain-like' region to the FWHM and FW10\%M of Mg\textsc{ii}.

To estimate the contribution of the 'fountain-like' region, we normalized the intensities of H$\beta$ and Mg\textsc{ii} to 1, then rescaled the Mg\textsc{ii} to have the same FWHM as H$\beta$, and measured the flux of the difference between these two line profiles [F(Mg\textsc{ii})-F(H$\beta$)]. Roughly, it can be assumed that this difference is in correlation with the contribution of the 'fountain like' region to the Mg\textsc{ii} line profiles. Taking 1$\sigma$ criteria, we divided our data in two subsamples: one where the disagreement between the BH masses calculated using H$\beta$ and Mg\textsc{ii} parameters are $<1\sigma$ ('good BH measurements'), and another where disagreement is $>1\sigma$ ('bad BH measurements'). The 1$\sigma$ = 0.19 for log[M$_{BH}$(H$\beta$)/M$_{BH}$(Mg\textsc{ii})] distribution.

In Figs. B1 and B2 we present the FWHM and FW10\%M of Mg\textsc{ii} as a function of the estimated 'fountain-like' emission$^6$. As it can be seen in Fig. B1ab, there is no correlation between the FWHM Mg\textsc{ii} and the 'fountain-like' contribution, in the both cases: in so-called 'good BH measurements' and 'bad BH measurements'. However, there is a high correlation between FW10\%M Mg\textsc{ii} and 'fountain-like' contribution in both cases (see Fig. B2ab). For subsample of 'good BH measurements', the correlation is higher ($\rho=0.86$, $P_0 < 10^{-20}$), compared the one for 'bad BH measurements' ($\rho=0.73$, $P_0=10^{-17}$). In the case of 'good BH measurements', the correlation is higher probably because the 'fountain-like' region contributes more to the far line wings (FW10\%M), and do not affect the FWHM that is used for BH estimates. In the case of the 'bad BH measurements' the correlation is smaller and scattering of the points is higher, which may indicates that the 'fountain-like' contribution is likely to be more important in the line center, and therefore the mass (and FWHM) measurements may be partly affected by contribution of this region.

Figure B1. The relationship between the FWHM Mg\textsc{ii} and [F(Mg\textsc{ii})-F(H$\beta$)]/F(Mg\textsc{ii}), where F(Mg\textsc{ii}) and F(H$\beta$) are fluxes of Mg\textsc{ii} and H$\beta$ normalized to 1, and fitted to have the same FWHM. Panel (a): for subsample with log[M$_{BH}$(H$\beta$)/M$_{BH}$(Mg\textsc{ii})] $< -0.19$ or log[M$_{BH}$(H$\beta$)/M$_{BH}$(Mg\textsc{ii})] $> 0.19$ ($\rho=-0.946$, $P_0=0.65$) larger than 1$\sigma$.

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$^6$ We should note here that negative contribution denotes that the H$\beta$ is broader in wings, and therefore the contribution of the 'fountain-like' is insignificant or contributes to the central part.
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Figure B2. The same as in previous figure but for FW10%M Mg ii and the \( \frac{[F(Mg ii) - F(H\beta)]}{F(Mg ii)} \).