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The Broad Line Region geometry: AGN with single peaked line profiles

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Abstract. Profiles of broad emission lines (BELs) in active galactic nuclei (AGN) are very complex indicating a complex Broad Line Region (BLR) geometry. We discuss several specific broad line profiles in order to constrain possible geometries for the BLR using BELs. Especially, we discuss the possibility that a disk emission is present in the BEL profiles.

Key words. Stars: abundances – Galaxy: Seyfert galaxies – Galaxy: accretion disks

1. Introduction

Broad Emission Lines (BELs) of AGN show high diversity in their shapes and widths. The detailed structure of the innermost part of AGN is still an open question. It is widely accepted that the central engine consists of a super massive black hole fueled by an accretion disk. Using BEL shapes, one can constrain the geometry of the material in the BLR (see Popović 2006). In some rare cases, where the accretion disk clearly contributes to the BELs, we can investigate the disk properties using a broad, double-peaked, low-ionization lines (Chen & Halpern 1989; Chen et al. 1989; Eracleous & Halpern 1994, 2003; Eracleous et. al 2009). The rotation of the material in the disk results in one blueshifted and one redshifted peak, while the gravitational redshift produces a displacement of the center of the line and a distortion of the line profile.

Often BELs show shoulders-like profile in the wings of the line, which could be a fingerprint of the accretion disk emission (Popović et al. 2003; Eracleous & Halpern 2003; Strateva et al. 2003).

To explain the complex morphology of the observed BEL shapes, different geometrical models have been discussed (see in more details Sulentic et al. 2000). In some cases the BEL profiles can be explained only if two or more kinematically different emission regions are considered (see e.g. Marziani et al. 1993; Romano et al. 1996; Popović et al. 2001, 2002, 2003, 2004; Bon et al. 2006; Ilić et al. 2006; Collin et al. 2006; Hu et al. 2008; Bon et al. 2009a,b). In particular, the existence of a Very Broad Line Region (VLBR) with random velocities at 5000-6000 km/s within an Intermediate Line Region (ILR) has also been considered to explain the observed BEL profiles (Corbin & Boroson 1996; Sulentic et al. 2000; Hu et al. 2008; Bon et al. 2009a,b). Even though, the majority of AGN with BELs have

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only single peaked lines, it does not necessarily indicate that the contribution of the disk emission to the BELs profiles is negligible.

2. Two component model

We assumed that the BELs can be kinematically divided into two components, one from the VBLR (contributing to the wings) and other from the ILR (contributing to the core).

The local broadening (σ) and shift (z_l) of each disk element have been taken into account as in Chen & Halpern (1989), i.e. the δ function has been replaced by a Gaussian function:

$$\delta \to \exp \frac{(\lambda - \lambda_0 - z_l)^2}{2\sigma^2}, \tag{1}$$

We express the disk dimension in gravitational radii ($R_g = GM/c^2$, G being the gravitational constant, M the mass of the central black hole, and c the velocity of light).

We assumed that the additional emission region can be described by a surrounding region with an isotropic velocity distribution, i.e. the emission line profile generated by this region can be described by a Gaussian function with broadening w_s and shift z_s. Finally, line profile can be described by the relation:

$$I(\lambda) = I_d(\lambda) + I_s(\lambda), \tag{2}$$

where $I_d(\lambda)$, and $I_s(\lambda)$ are the emissions of the relativistic accretion disk and the non-disk region, respectively.

As it was earlier noted in Popović et al. (2004), this two component model can fit the line profiles of BELs, but is too open to constrain the physical parameters. First of all, the disk model includes many parameters (the size of the emitting region, the emissivity and inclination of the disk, the velocity dispersion of the emitters in the disk, etc.). In order to do numerical tests, one needs to introduce some constraints and approximations.

The parameter σ of the Doppler broadening of the non-disk region and parameter σ that corresponds to the broadening of the random motion in the disk model are connected (see Popović et al. 2004; Bon et al. 2006). As a first approximation we assume that the random velocities in the disk and in the non-disk region are the same. So here we consider a parameter σ = 1000 km/s for both, the Doppler broadening of the non-disk regions as well as the σ in the model of the disk profile (also, see Eracleous & Halpern 2003).

On the other hand, we considered a wide range of disk parameters but with several constraints:

i) The disk inclination affects the emission obtained from the disk. The observed flux from the disk (F_d) is proportional to the disk surface (S_d), as

$$F_d \sim S_{\rm eff} \sim S_d \cdot \cos(i), \tag{3}$$

where i is the inclination, and S_{eff} is the effective disk emittingsurface, therefore, one cannot expect a high contribution of the disk emission to the total line profile for a near edge-on projected disk.

ii) one cannot expect emission of the low ionized lines in the part of the disk closer then the inner radius of R_{inn} > 100 R$_g$. Consequently, the model given by Chen & Halpern (1989) can be properly used, i.e. it is not necessary to include a full relativistic calculation (as e.g. in Jovanović & Popović 2008).

iii) The emissivity of the disk as a function of radius, r, is given by $\epsilon = \epsilon_0 r^{-p}$ but we fixed the value to $p = 3$, since while varying this parameter there were no significant difference between normalized profiles.

iv) Previous estimations of the double-peaked AGN emission lines (see e.g. Perez et al. 1988; Chen & Halpern 1989; Chen et al. 1989; Eracleous & Halpern 1994, 2003) show that the typical dimensions of an accretion disk that emits low ionization lines are of the order of several thousands R$_g$. For that reason we did not consider dimensions of the disk larger than 100000 R$_g$. This was an important approximation to limit the computing time.

v) We consider a systemic velocity shift of the non-disk region (not greater than ± 3000 km/s) to test the possibility of the outflow/inflow.

We considered the following parameters to study the simulated and observed BELs profiles:

i) The flux ratio between the disk (F_d) and the non-disk region (F_s):

$$Q = \frac{F_s}{F_d}, \tag{4}$$

where

$$F_{tot} = F_s + F_d = (1 + Q)F_d$$

Using this parameter, the total line profile (normalized to the disk flux)[1] can be written as:

$$\frac{I_{tot}(\lambda)}{F_d} = \frac{I_d(\lambda)}{F_d} + Q\frac{I_s(\lambda)}{F_s}, \tag{5}$$

where $I(\lambda)$ is the wavelength dependent intensity. The composite profile is normalized according to,

$$\Im(\lambda) = \frac{I_{tot}(\lambda)}{I_{tot}^{max}}, \tag{6}$$

where I_{tot}^{max} is the maximum intensity of the composite line profile.

ii) For the composite line profile $\Im(\lambda)$ we measured full widths at 10%, 20%, 30% and 50% of the maximum intensity, i.e. $w_{10\%}$, $w_{20\%}$, $w_{30\%}$ and $w_{50\%}$. Then we define coefficients k_i (i = 10, 20, 30) normalized to the Full Width at Half Maximum (FWHM), as $k_{10} = w_{10\%}/w_{50\%}$, $k_{20} = w_{20\%}/w_{50\%}$ and $k_{30} = w_{30\%}/w_{50\%}$. It is obvious that the coefficients k_i are functions of the radius R and other parameters of the disk. Using these normalized widths we can compare results from AGN with different random velocities.

iii) We also measured the asymmetry (A_i) at i =10%, 20%, 30% of maximum intensity of the modeled and observed lines as

$$A_i = \frac{W_i^R - W_i^B}{FWHM}, \tag{7}$$

where W_i^R and W_i^B are red and blue half widths at i = 10%, 20% and 30% of the maximum intensity, respectively.

We simulated only the disk profiles, taking into account different values of the disk parameters. An extensive discussion about possible disk line profiles is given in Dumont & Collin-Souffrin (1990). In the first instance, the relative importance of the disk contribution to the core or to the wings depends on the disk inclination. The contribution of the disk to the center of the line or to the wings is not so much sensitive to the outer radius, but significantly depends on the disk inclination. A face-on disk contributes more to the core of the line, while a moderately inclined disk (40° $> i >$ 20°) contributes significantly to the line wings. For $i >$ 40° the disk emission will strongly affect the far wings of the composite profile. Another very important parameter is the flux ratio between components, Q.

We found that the presence of the disk emission is difficult to detect in the line profile when the contribution of the disk is smaller than 30% of the total line emission ($Q > 2$): in the case of a low inclination both the disk and non-disk region contributes to the line core and it is very hard to separate the disk and nod-disk region. In the case of a highly inclined disk, the disk emission spreads in the far wings, and could not be resolved from the continuum, especially if the observed spectrum is noisy. For the case of dominant disk emission ($Q < 0.3$), if the inclination is low, the line will be shifted to the red, and if the inclination is high, two peaks or at least shoulders should appear in the composite line profile. Consequently, further in the paper we will consider only cases where 0.3< Q <2 (see more details in Bon et al. 2009a)

2.1. Results from the line profiles simulations

From the simulations mentioned above we infer the following results:

(i) To detect disk emission in a BELs, the fraction of the flux emitted by the disk in the total line profile should be higher than 30%. A

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[1] This is taken from technical reasons to simulate different contributions of the disk and the non-disk component. First we normalized both line profiles to their fluxes, and after that we rescaled the non-disk component multiplying with Q, then whole profile is given in units of the disk flux.

dominant disk ($Q < 0.3$) will be clearly present in the total line profile (peaks or shoulders in the line profiles).

(ii) In the case of a nearly face-on disk ($i < 5°$), the disk emission may contribute to a slight asymmetry towards the red (due to the gravitational redshift), but it is hard to detect this asymmetry. In the case of an edge-on disk, the emission from the disk will contribute to the far wings and then it may be difficult to separate it from the continuum.

(iii) These two parameters, the flux ratio between components and disk inclination, are crucial for the line shapes in the two-component model.

(iv) In the simulated line profiles the asymmetry was mostly $A_i > 0$. For low inclination ($i < 10°$), the asymmetry weakly depends on Q.

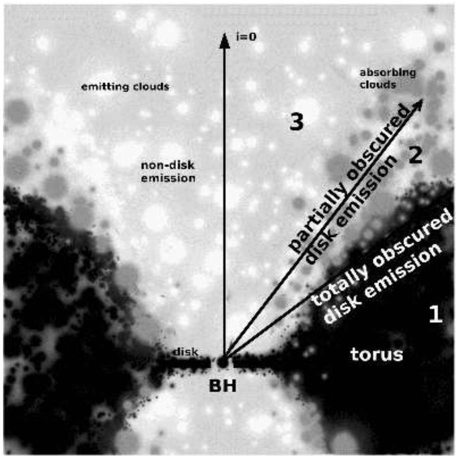

Fig. 1. Obscuration of the disk emission: 1) torus, 2) absorbing material around the torus and 3) the region without absorption (see text in §5).

3. Conclusions

From our investigations we can conclude that there could be a high probability that the disk emission flux might be present in the single peaked emission line profiles, but with the disk inclinations mainly smaller than $i < 25°$. Such small inclinations and large discrepancies from simulated profiles for higher inclinations should be discussed in the contest of unified model, i.e. possible disk orientation to the torus or partial obscuration by the torus (see Fig 1.).

Both of the values ($i > 25°$ and $Q > 1$) may indicate that we have a low inclined disk which contribution to the total line flux is smaller than the non-disk emitting region.

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