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The disk contribution to the shape of the Balmer broad emission lines in AGNs

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Abstract. In order to study Balmer emission line profiles of the H_β and H_α lines of the sample of 15 Seyfert 1 galaxies, the two-component model of the broad-line region (BLR) has been proposed. The proposed two-component model, consisting of Keplerian relativistic disk and an outer structure surrounding the disk. Using the high resolution Hβ and Hα line profiles observed with Isaac-Newton Telescope (La Palma) and spectra obtained from HST, the substructure of line profiles (such as shoulders or bumps) which can indicate a disk or disk-like emission in the BLR, have been studied. By applying the Gaussian analysis it was found that BLR have complex structure and the two-component model was applied, assuming that the line wings originated in a very broad line region (VBLR) and the line core in an intermediate line region (ILR). The VBLR is assumed to be an accretion disk and ILR spherical emission region. The model can very well fit the Hα and Hβ line profiles of AGNs.

Key words. AGN – galaxies: Seyfert – line: profiles – quasar – Active Galactic Nuclei – Broad Emission Lines – accretion disk

1. Introduction

The concept of disk geometry in the Broad Line Region (BLR) is very attractive because of the most widely accepted model for Active Galactic Nuclei (AGNs) which includes a super-massive black hole fed by an accretion disk. Recently, Popović (2003) investigated the physical processes in the BLR using a Boltzmann-plot method, and found that physical conditions in regions which contribute to the line core and line wings are probably different. This supports the idea that the broad optical lines originate in more than one emission region.

The aim of this paper is to test the validity of the two-component model of BLR which contains an accretion disk and one additional emission region, i.e. to try to find evidence that suggests that the disk emission can contribute to the line emission even if they have single-peaked line profiles. To find the substructure connected with disk emission one should obtain the spectral lines with a relatively high spectral resolution and S/N ratio. The spectra were observed with the Isaac Newton Telescope (INT) 15 AGNs (see Table 1) which have been previously observed in the X-ray (Fe Kα line, see e.g. Nandra et al. (1997); Sulentic et al. (1998)) and where, according to the X-ray results the signature of the optically emmitting disk is expected to be seen.

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The observed AGN do not have the double-peaked Hα and Hβ lines.

2. Observations and data reduction

The observations were performed with the 2.5 m INT at La Palma at January 2002 (12 AGN sample) and 1998 (IIIZw2). Also HST observations were used, obtained with STIS on January 2000 (NGC 3516). The spectral resolution was $\sim$ 1 Å. The Hα and Hβ were observed for all galaxies, except Mrk 141 where only the Hα region was obtained. Also, after calibration of the spectra, the Hβ line of Mrk 493 was too weak and the red wing of the 3C 273 Hα was too noisy, and for these two spectra we used the low resolution spectra observed with the HST (on Sep 4, 1996 and Jan 31, 1999) with G400 and G750L gratings, respectively (Popović et al. 2001, 2002, 2003, 2004).

3. Line profile analysis

To analyze the shape of the Hβ and Hα lines, first each line was fitted with the sum of Gaussian components. The χ^2 minimalization routine was used to obtain the best fit parameters. Also it was assumed that the narrow emission lines can be represented by one or more Gaussian components. In the fitting procedure, a minimal number of Gaussian components was needed to fit the lines. To limit the number of free parameters in the fit some *a priori* constraints have been accepted(Popović et al. 2001, 2002, 2003).

4. Two-component model for BLR

The two component model represents an approach to the line profile decomposition where a disk shapes the wings of the lines, and a spherical medium that surrounds the disk, represented with a Gaussian profile, gives the core of the lines.

The Keplerian relativistic model of Chen & Halpern (1989) was used for the disk emission model. The emissivity ϵ of the disk as a function of radius, R, is given as $\epsilon = \epsilon_0 R^{-p}$, where p is emissivity parameter. Generally, when trying to fit the double-peaked line profiles by disk emission one should leave the index p as a free parameter. But the two facts should be taken into account: (1) we have single-peaked lines here, i.e. the profile coming from the disk is not *a priori* well defined; (2) we are going to use a two-component model which includes more parameters than the disk model alone. We should therefore include some constraints. Since the illumination is due to a point source radiating isotropically, located at the center of the disk, the flux in the outer disk at different radii should vary as r^{-3} (Eracleous & Halpern 1994). However, the power index $p \approx 3$ can be adopted as a reasonable prescription at least for Hα (Eracleous & Halpern 2003).

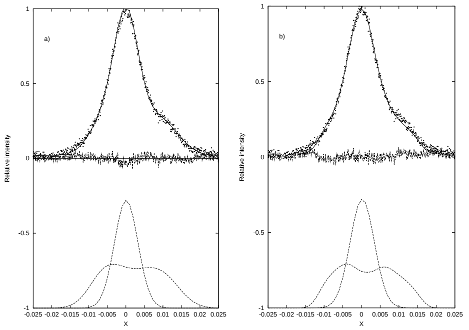

Fig. 1. Two fits of 3C 273 with the two-component model the disk parameters are: a) $i = 14°$, R_{inn}=400 R_g, R_{out} =1420 R_g, W$_d$=1620 km/s, p=3.0 (W$_G$=1350 km/s); b) $i = 29°$, R_{inn}=1250 R_g, R_{out} =15000 R_g, W$_d$=700 km/s, p=2.8 (W$_G$=1380 km/s)

The disk dimension have been expressed 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). The local broadening parameter (σ) and shift (z_l) within the disk have been taken into account as in Chen & Halpern (1989), i.e. the δ function has been replaced by a Gaussian function. On the other hand, it was assumed that the kinematics of the additional emission region can be described as the emission of a spherical region with an isotropic velocity distribution, i.e. with a local broadening w_G and shift z_G. Consequently, the emission line profile can be

Table 1. The parameters of the disk: z_l is the shift and $W_l = \sqrt{2}\sigma$ is the Gaussian broadening term from disk indicating random velocity in the disk, R_{inn} are the inner radii, R_{out} are the outer radii. The z_G and W_G represent the parameters of the Gaussian component.

Object	i	$z_l^{min,max}$	$W_l^{min,max}$ (km/s)	R_{inn}^{min} (R_g)	R_{out}^{max} (R_g)	$z_G^{min,max}$	W_G (km/s)	p^{min}
3C 120	8-30	-300,+300	1050,1500	350	20000	+30,+300	900±150	2.0
3C 273	12-30<	-30,+300	690,1760	400	15400	+30,+60	1380±150	2.3
MRK 1040	5-27<	-250,+300	800,1400	100	18000	0±30	500±200	1.3
MRK 110	7-50	-320,+300	450,1250	400	49000	+150±30	960±50	1.7
MRK 141	12-33	-630,-450	700,1500	300	10000	+200,+300	1620±100	2.1
MRK 493	5-30<	-480,+60	360,560	600	124000	+60±30	360±50	1.8
MRK 817	12-35	-450,+300	850,1200	140	14000	0,+130	1550±100	1.8
MRK 841	15-50	-750,-150	1070,1800	450	27400	-300±30	1500±100	2.1
NGC 3227	12-34	-780,-300	900,1550	350	12000	-300,300	1500±100	2.1
NGC 4253	5-25<	-630,-90	280,850	500	69500	-90,-30	550±50	2.0
PG 1116	8-30<	-450,0	1100,1800	500	15800	0,+90	1400±250	2.2
PG 1211	8-30	-660,0	540,1100	600	67400	+90±30	600±300	1.9
IIIZw2	7-17	-700,-600	1200,2800	400	1300	120±10	1140±20	-3.0
Akn 120	9-11	-1000,1500	2200,2500	160	1000	300±100	2000±100	3.0
NGC 3516*	6-16	-900,-600	600,850	400	1550	150 ± 200	1470± 160	3.0

*The value for inclinations are taken from (Popović 2005)

described by a Gaussian function. The whole line profile can be described by the relation:

$$I(\lambda) = I_{AD}(\lambda) + I_G(\lambda)$$

where $I_{AD}(\lambda)$, $I_G(\lambda)$ are the emissions of the relativistic accretion disk and of an additional region, respectively.

Before performing the fitting the spectra have been 'cleaned' by subtracting (i) from the Hβ line the narrow Hβ and [OIII] lines, the He I and the Fe II template; (ii) from the Hα the narrow Hα and [NII] lines (Popović et al. 2004). Furthermore, the intensities of the Hα and Hβ lines were normalized to unity and the wavelength have been converted into velocity scale: $\lambda \rightarrow X = (\lambda - \lambda_0)/\lambda_0$. These conversions allowed us to compare the Hα and Hβ high resolution profile. It was found that in the chosen AGN sample the Hα and Hβ have similar profiles. That concept supports the case that both lines are formed in the same emission region. Using the previous results of fitting the two component model of IIIZw2, NGC 3516 and AKN120, where the disk stratification was obtanied by Popović et al. (2002); Popović (2003); Popović et al. (2003), the two-component model was tested on the sample of 12 more AGNs. In order to do this, first an averaged line profile from the Hα and Hβ lines, for each AGN, were found (here it should be noted that in the case 3C 273 only the high resolution Hβ, and in the case of Mrk 493 and Mrk 141 only the Hα were used). The averaged profile for each AGN was fitted with the above described two-component model.

When a chi-square minimization including all the parameters was attempted, it was found that the results are very dependent on the initial values given to the parameters. As mentioned above, the reason for this is that a two-component model was applied on single-peaked lines, so the number of free parameters is too large. To overcome this problem, the additional constraint were used, that the disc component fits the line wings, and the spherical component the line core .

More details of fitting procedure could be found at Popović et al. (2002); Popović (2003).

5. Results and Discussion

As one can see from Fig. 1, the line profiles can be well fitted with the two-component model, but without constraining some of the parameters (e.g. the emissivity index, the inclination, the inner and outer radii). It is therefore not possible to find an unique solution for the model. Or one should arbitrarily constraints at least one of the disk parameters[1]. The fitting tests described above allow us to get rough estimates of the kinematical parameters of the two-component model. The results of the fitting are presented in Table 1.

Concerning the spherical emission region it could be pointed out that: i) the red-shifts are consistent with the cosmological ones, they are in the interval ± 300 km/s; (ii) the random velocities in this region are also different for different objects, they are in the interval from ~400 to 1600 km/s.

6. Conclusions

The BLR kinematics of a sample of 15 AGN were tested using high-resolution spectra of the Hβ and Hα lines assuming two-component model.

After Gaussian analysis, the two-component model was aplied, which comprises a VBLR and an ILR. The VBLR was identified with an accretion disk which contributes to the line wings. The cores of the lines are assumed to originate in the ILR with a spherical geometry. This two-component model has been applied to the observed line profiles and it has been concluded that: (i) The model can very well fit the observed line profiles, but it is very hard to obtain the disk parameters without imposing at least one constraint because of the large number of parameters and the lack of two peaks in the line profiles. They can be only roughly estimated by using fitting tests (see Table 1). (ii) The random velocities in the spherical emission region and the random velocities in the disk are similar. This indicates that these two regions are linked through a common process, like for a wind produced by the disk. In order to find constraints for the model parameters, further investigations are planed, on larger sample of Sy1's and quasars, and to determine the connection between the disk parameters and random velocities of the surrounding gas.

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[1] e.g. the dimensions of BLR obtained from reverberation studies might be used as a constraint.