Part II

Extragalactic Astronomy and Stellar Clusters

Microlensing Influence on Spectral Line Shapes of AGNs: Accretion Disk Radiation

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Abstract

The gravitational microlensing influence on spectral line profiles originated in Broad Line Regions (BLRs) of Active Galactic Nuclei (AGNs) have been considered. Especially we pay attention on lines created in an accretion disk. The gravitational microlensing effect may significantly change the spectral line profiles emitted from a BLR. Especially in the case where the Einstein Ring Radius, η_0, of a microlens is comparable with dimension of BLR which contributes to red or blue side of a line.

1 Introduction

Emission line profiles of Active Galactic Nuclei (AGNs) usually show variabilities. The nature of the variations in AGNs has been discussed in several papers (see e.g. Foltz et al., 1983, Peterson et al., 1985, 1998, Peterson, 1993, Winge et al., 1996, Wandel et al., 1999, etc.). According to the standard model, the broad emission lines observed in spectra of AGNs are originating in the high-velocity gas of the surrounding Broad Line Region (BLR) ionized by the UV and optical radiation of compact central source. Fluctuations in the ionizing continuum cause the variations in emission line fluxes.

One of the possible cause for line shape variation in AGNs is microgravitaional lensing effect (see e.g. Nemiroff 1988, Mediavilla et al. 2001, Popović et al. 2001a). The influence of microlensing effects on the Active Galactic Nuclei (AGNs) radiation has been discussed in several papers (Ostriker & Vietri 1985, Kayser et al. 1986, Schneider & Weiss 1987, Nemiroff 1988, Irwin et al. 1989, Schneider & Wambsganss 1990, Yonehara et al. 1999, Mineshige & Yonehara 1999, Kraus et al. 1999, Mediavilla et al. 2001). First, it was assumed that only the continuum emitting region of an AGN is sufficiently compact to be subject of microlensing, but recent investigations (see e.g. Wandel et al. 1999) indicate that the Broad Line Region (BLR) of the AGNs is smaller than it was supposed. Gravitational microlensing by stars in a foreground system or a massive object near the source can affect the continuum as well as the emission lines of AGNs where bulk motions of emitting gas give rise to very broad line

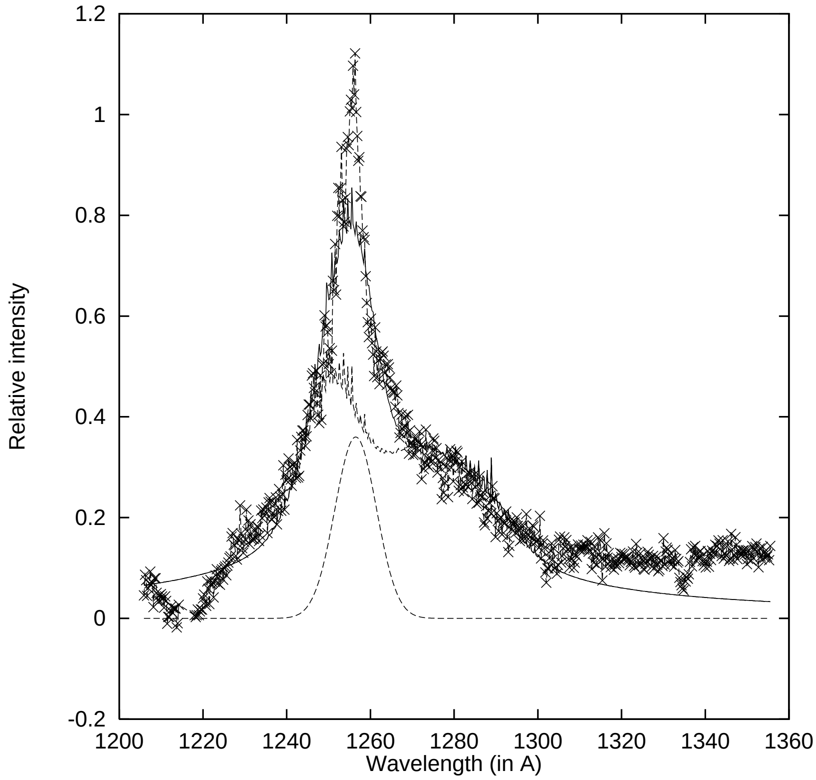

Figure 1: Observed Ly_α of Akn 120 (x-x-), fitted by disk model (dashed line) plus one Gaussian (dashed line).

profiles. Especially, in the case of emitting accretion disk, where dimension of an accretion disk is about 1000 $\Re_g$ ($\Re_g = GM/c^2$ is gravitational radius), the microlensing effect can be very important (Yonehara et al. 1999, Mineshige & Yonehara 1999).

Here we will present two examples which are results of our recent investigations. First, the structure of Akn 120, a double-peaked AGNs, where we have analysed the BLR structure of this object. Second, supposing that the radiation of accretion disk is present in one number of AGNs, we will discuss the influence of gravitational microlensing on spectral line shapes originated from an accretion disk.

2 The model of AGN BLRs: Example of Akn120

It is evident that in the all considered periods the H_β line of Akn 120 has two (sometimes three) peaks (Popović et al. 2001b). The nature of double-peaked lines in AGNs has been discussed in several papers (see e.g. Chen & Halpern 1989, Chen et al. 1989, Zheng et al. 1990, 1991, Goad & Wanders 1996, Popović et al. 1998, Gaskel et al. 1996). The origin of double peaked lines in AGNs can be explained by:

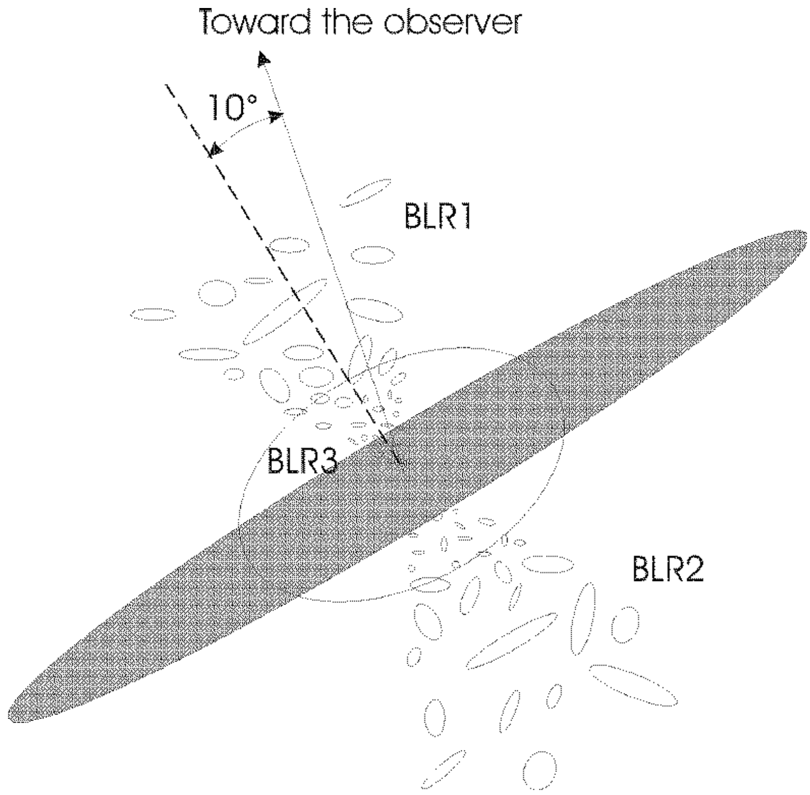

Figure 2: The proposed model of Akn 120, obtained by analyzing the spectral line shapes of this galaxy (Popović et al. 2001a).

– a) emission of the accretion disk or emission from spiral shock waves within a disc (Chen et al. 1989, Chen & Halpern 1989);

– b) emission from the oppositely-directed sides of a bipolar outflow (Zheng et al., 1990, 1991);

– c) emission from a spherical system of clouds in randomly inclined Keplerian orbits, illuminated anisotropically from the center (Goad & Wanders 1996); and

– d) emission of the binary black hole system (Gaskell 1996, Popović et al. 1998).

Each of the proposed mechanism can explain the double-peaked lines, but the accretion disk model is most often used for the explanation of the double-peaked line profiles, because this model fits well with the widely accepted picture of an AGN, that the 'central engine' consists of a massive black hole fueled by an accretion disk. Moreover, the observations in a wide spectral range (X, UV, optical) indicate that an accretion disk should be present in the central part of most of the AGNs. The geometry of Akn 120 emitting region has been discussed several times (Allion et al., 1988, Zheng et al., 1990, Doroshenko et al., 1999, etc.) and two models were considered: 1) disk model by Allion et al. (1988) and 2) double-stream model by Zheng et al., (1990). Both of the models can explain the double peaked lines, but choosing the model one has to take into consideration line profiles as well as their variations.

We started from next facts mentioned in Popović et al. (2001b): 1) The long-period variation of H_β indicated that three emission regions in central part of Akn 120 exist in all considered periods. The variation of blue and central component may indicate that they are coming from regions which are closer to the central mass, whereas the red component may be produced by stream which is partly obscured by the disk and central region and we can see only a part of the 'red stream'. 2) The shape of Ly_α indicates (especially wings) that the radiation of the disk is present in this line. Concerning these two facts, we suppose that a model with an accretion disk and two regions symmetrical to the disk may well fit the line profiles of hydrogen lines.

Also, the blue boosted and redshifted broad Gaussian components in all considered Akn 120 lines (except C IV line) may indicate that the accretion disk is present. But, concerning variation on longer time-scales, the bumps in the sides of lines vary independently (Gaskell & Snedden, 1999). The disk model cannot explain the shape of all spectral lines Here, we apply the disk model (Chen & Halpern, 1989) to explain the wing shapes. First, we subtracted the narrow lines from H_α, an absorption line from Ly_α and narrow O III lines as well as Fe II template from H_β. Than we fitted these line profiles by a disk model (Chen & Halpern, 1989, Chen et al., 1989) plus one or two Gaussians. The emissivity of the disk as a function of radius is given as

$$\epsilon = \epsilon_0 R^{-p}, \tag{1}$$

where we take that power index is $p = 3$. Also, we express the disk dimension in gravitational radii.

The sample of fitted results is presented in Fig. 1. We fitted the Ly_α profile with disk model with parameters: $i \approx 10^\circ$, $R_{\rm inn} \approx 120\ \Re_g$ and $R_{\rm out} \approx 1150\ \Re_g$ and one Gaussian component which indicate random velocity, w, of 1800 km/s (Fig. 1.). For Balmer lines we could not fit the lines with the disk model and one Gaussian component, then we propose that we can see in central part of these lines the other two regions. Balmer lines were fitted with the next parameters of the disk: $i = 10^\circ$ for both lines and for H_α – $R_{\rm inn} \approx 200\ \Re_g$ and $R_{\rm out} \approx 1000\ \Re_g$, the blue Gaussian component has $w \approx 1900$ km/s and the red one has $w \approx 1500$ km/s; for H_β – $R_{\rm inn} \approx 165\ \Re_g$ and $R_{\rm out} \approx 1000\ \Re_g$, the blue Gaussian component has $w \approx 2100$ km/s and the red one has $w \approx 1700$ km/s

In the case of Akn 120, we have obtained that radiation of an accretion disk can well describe the hydrogen line wing and core of the lines is originated in streams (see Fig. 2). Also, the line profiles of other AGNs can be described by radiation of an accretion disk, e.g. Arp 102B (Chen & Halpern 1989), and III Zw2 (Popović et al. 2000). In next section we will considered the microlensing effect on lines originated in an accretion disk.

3 An example: accretion disk spectral line profiles disturbed by gravitational microlensing

As we mentioned above, the accretion disk model is very often used for explanation of double-peaked AGN line profiles, and as we saw in the case of Akn 120, line shapes partly can be described by disk model. The model of accretion disk has been used several times in fitting double-peaked line profiles (see e.g. Chen & Halpern 1989, Chen et al. 1989, Eracleous & Halpern 1994, Newman et al. 1997, Eracleous 1999).

In order to show the microlensing influence on spectral line profiles in the case of the relativistic accretion disk, as in previous case of Akn 120, we adopt the model proposed by Chen & Halpern (1989) as well as the parameters proposed by the same authors for the Arp 102B disk. They found that the best agreement between model and observation is for a disk with inclination $i = 32^\circ$, inner radius $\xi_{in} = 350\ \Re_g$, outer radius $\xi_{out} = 1000\ \Re_g$, where $\Re_g = GM/c^2 = 1.4745 \cdot 10^{11} M_8$ is the gravitational radius, where $M_8 = 10^8 M_\odot$. The emissivity as a function of radius is given in Eq. (1), where for the case of Arp 102B power index is $p = 3$ (Chen & Halpern 1989).

Taking into account the gravitational microlensing effects in the relativistic accretion disk model described by Chen & Halpern (1989) the line shape will be (Popović et al. 2001a)

$$\frac{F_x}{F_0} = \int_{\xi_{in}}^{\xi_{out}} \int_{-\pi/2}^{\pi/2} e^{-\frac{(1+x-D(\xi,\phi))\lambda_0}{2\sigma^2 D^2(\xi,\phi)}} D^3(\xi,\phi) \times$$

$$\times \xi^{1-p} g(\xi,\phi) \cdot A(\xi,\phi)\ d\xi d\phi \qquad (2)$$

where λ_0 is the transition wavelength, σ is velocity dispersion. In the case of Arp 102B σ/λ_0 corresponds to the velocity of 850 km/s (Chen & Halpern 1989).

In Eq. (2)

$$D(\xi,\phi) = \sqrt{(1-3/\xi)}(1 + \frac{\sin i \sin\phi}{\sqrt{\xi}}), \qquad (3)$$

where $x = \lambda_0/\lambda$,

$$g(\xi,\phi) = 1 + \frac{1}{\xi}\frac{2D^2(\xi,\phi)}{D^2(\xi,\phi)\cos^2 i + \xi[D(\xi,\phi) - \sqrt{1-3/\xi}]^2} \qquad (4)$$

For amplification in Eq. (2) we use

$$A(\xi,\phi) = \frac{u^2(\xi,\phi)+2}{u(\xi,\phi)\sqrt{u^2(\xi,\phi)+4}}, \qquad (4)$$

where $u(\xi,\phi)$ in the case of the accretion disk model is given as in (Yonehara et al. 1999)

$$u(\xi,\phi) = \frac{\sqrt{(\xi\cos\phi - \xi_0\cos\phi_0)^2 + (\xi\sin\phi - \xi_0\sin\phi_0\cos i)^2}}{\eta_0},$$

where ξ_0 is the radial distance of the microlens from the disk center and ϕ_0 is the azimuthal position of the microlens. The ϕ is the azimuthal angle defined

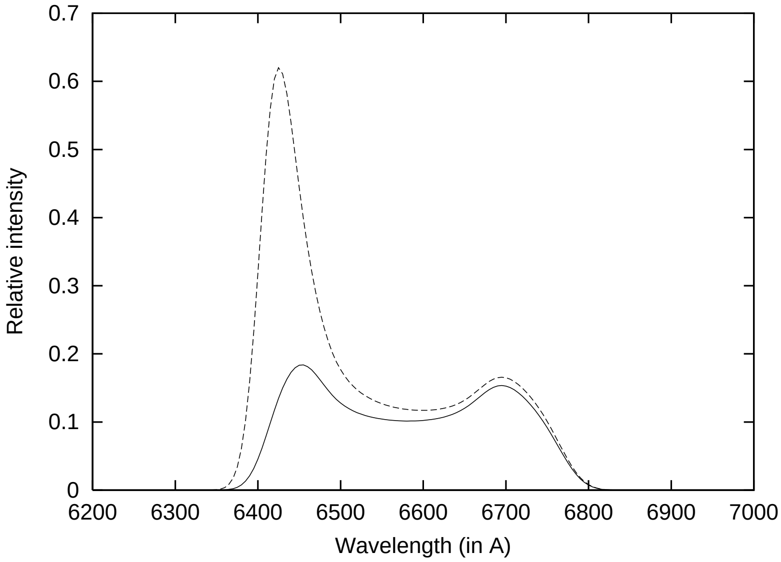

Figure 3: The H_α line profile calculated for a relativistic disk with parameters: $i = 32°$, $\xi_{in} = 350\ \Re_{\rm g}$, $\xi_{out} = 1000\ \Re_{\rm g}$, $\sigma/\lambda_0 = 850$ km/s. The profile deformed by gravitational microlensing is presented with the dashed line. The parameters of gravitational microlens are: $\xi_0 = 500\ \Re_{\rm g}$, $\eta_0 = 500\ {\rm R_g}$, $\phi_0 = -90°$. With the solid line the unperturbed profile is presented.

on the disk, and the disk rotates in the direction of the increasing ϕ. η_0 is the Einstein-Ring Radius (ERR) in gravitational radii.

Taking into account that the azimuthal angle increases in the direction of disk rotation, changing the azimuthal positions of the microlens one can see influence of microlensing on a spectral line profiles in the case where the microlens transits near the accretion disk. E.g. if we take that the object is changing the azimuthal angle position (ϕ_0) from -90° to +90° we have the case that motion of the microlens follows the disk rotation.

In Figs. 3-7 the illustrative results of microlensing influence on spectral line profiles originated in the accretion disk as the function of ϕ_0 are presented. The microlens parameters are: $\xi_0 = 500\Re_g$, $\eta_0 = 500\Re_g$. In Fig. 6, the case where the microlens is projected to the center of the observed AGN accretion disk ($\xi_0 = 0$). In this case for any azhimutal position angle, we obtain that the intensity of spectral line is amplified, but the line shape has not deformed.

In Fig. 7 the line profile for different values of ERR is presented. For disk with the mentioned parameters the microlensing influence on line profile for $\eta_0^{\rm min} < 40\Re_g$ cannot be observed.

As one can see, we use the parameters of gravitational microlensing comparable with dimensions of the disk part which contribute to red, and/or red wing of the lines. In this case we have obtained that influence of gravitational microlensing is very important, and can significantly change the line profile (Figs. 3–7).

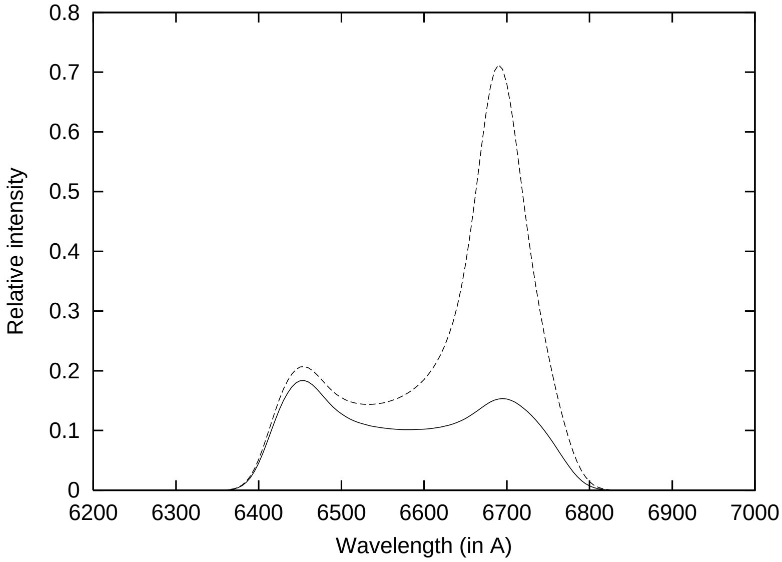

Figure 4: Same as in Fig. 3, but for $\phi_0 = 45°$.

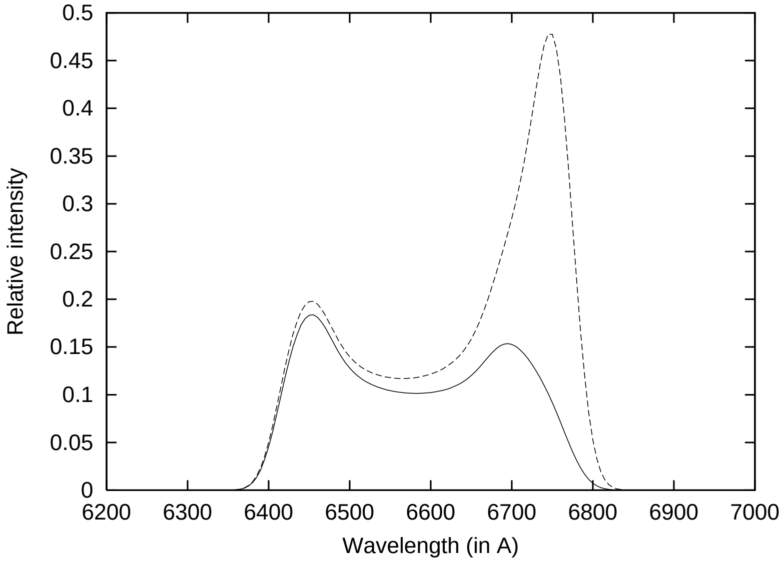

Figure 5: Same as in Fig. 3, but for $\phi_0 = 90°$.

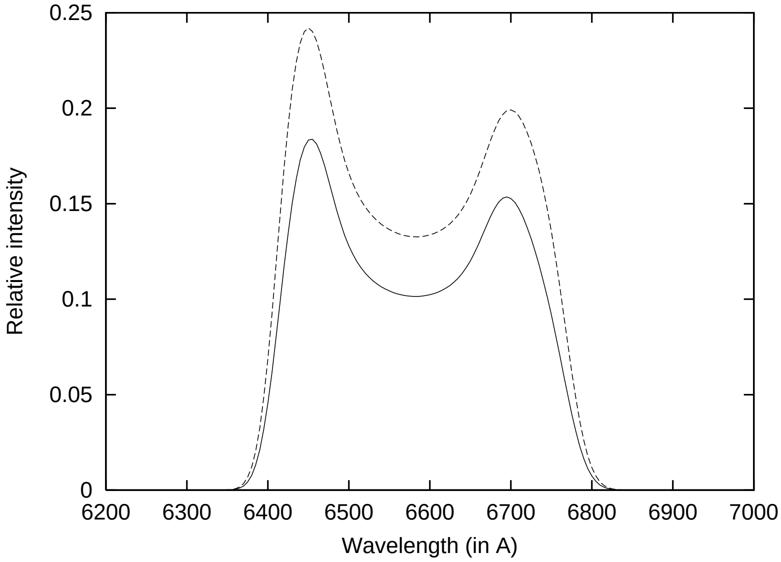

Figure 6: Same as in Fig. 5, but for $\xi_0 = 0$.

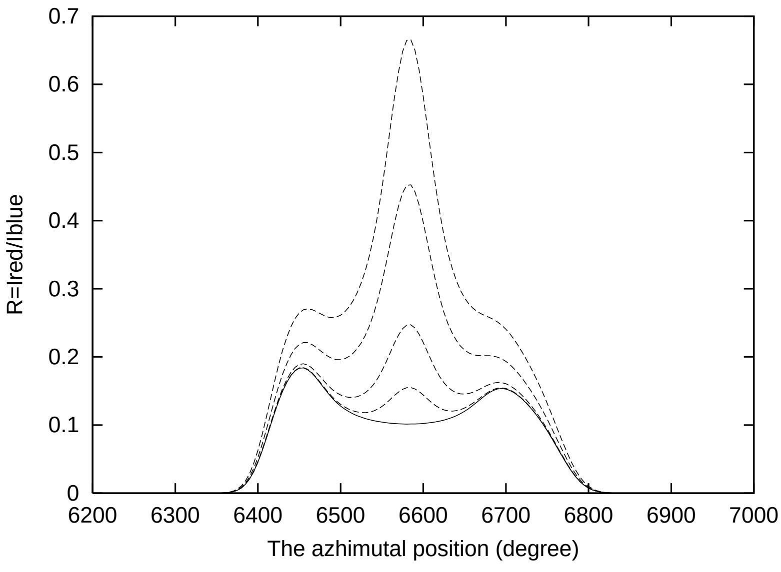

Figure 7: The line profiles for different Einstein-ring radius of the lenses $\eta_0 = 100\ \Re_g$, $200\ \Re_g$, $400\ \Re_g$ and $600\ \Re_g$, respectively. The intensity of central part is higher for higher η_0 The calculations were performed for $\xi_0 = 500\ \Re_g$ and $\phi_0 = 0°$.

4 Conclusion

The results we obtained in this paper can generally be applied in the case of an emitting accretion disk. Consequently one should emphasize, following that the gravitational microlensing may significantly change spectral line profiles emitted from an accretion disk (Figs. 3-7), that for such changes it is important that η_0 is comparable with dimension of disk part which contributes to the red or the blue side of a line, $d = \xi_{\rm out} - \xi_{\rm in}$

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