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Original scientific paper

CAN DOUBLE-PEAKED LINES INDICATE MERGING EFFECTS IN AGNs?

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SUMMARY: The influence of merging effects in the central part of an Active Galactic Nucleus (AGN) on the emission spectral line shapes are discussed. We present a model of close binary Broad Line Region. The numerical experiments show that the merging effects can explain double peaked lines. The merging effects may also be present in the center of AGNs, although they emit slightly asymmetric as well as symmetric and relatively stable (in profile shape) spectral lines. Depending on the black hole masses and their orbit elements such model may explain some of the line profile shapes observed in AGNs.

This work shows that if one is looking for the merging effects in the central region as well as in the wide field structure of AGNs, he should first pay attention to objects which have double peaked lines.

1. INTRODUCTION

The double-peaked lines in AGNs have been discussed in several papers (see e.g. Alloin *et al.* 1988, Chen *et al.* 1989, Chen and Halpern 1989, Halpern 1990, Miller and Peterson 1990, Sulentic *et al.* 1995, Gaskell 1996, Eracleous and Halpern 1994, Livio and Pringle 1996, Puchnarewicz *et al.* 1996, Newman *et al.* 1997, Pariev and Bromley 1998, Corbett *et al.* 1998, etc.). The origin of double peaked lines in AGNs can be explained by the following models; *the rotation accretion disk model* (Chen *et al.* 1989, Chen and Halpern 1989, Halpern 1990, Pariev and Bromley 1998) or emission from spiral shock waves within a disc (Chakrabarti and Wiita 1994); *the bipolar outflow model* (Zheng *et al.* 1990, Zheng *et al.* 1991, Robinson 1995, Corbett *et al.* 1998); *photoionization by an anisotropic continuum source* (Goad and Wanders 1996, Koratkar *et al.* 1996); and *the binary black hole model* (Gaskell 1996) which we intend to discuss here in more detail.

The rotation accretion disk model (Chen *et al.* 1989, Chen and Halpern 1989, Halpern 1990, Pariev and Bromley 1998) is very often discussed in order to explain the observed AGN double peaked line profiles. Theoretically, this model is well fitting to widely accepted picture of an AGN, that the 'central engine' consists of a massive black hole fueled by an accretion disk. Also, the observations in wide band of wavelengths (X, UV, optical) indicate that accretion disks should be present in central parts of most of AGNs. The spectral line shapes of well known two Broad Line Radio Galaxies (BLRGs) 3c390.3 and Arp 102B have been usually described by using the accretion disk model (see e.g. Chen and

Halpern 1989, Eracleous and Halpern 1994, Newman et al. 1997), but the polarometric observations of H_α line in these two objects are in contradiction with theoretical predictions (Corbett *et al.* 1998). Corbett *et al.* (1998) suggested that the shape of the polarized H_α line can be explained by the bipolar scattering model, where bipolar outflow exists, and the scattering occurs near the pole of an obscuring torus.

The accretion disk and bipolar outflow models are concurrent in explaining the double peaked lines (see e.g. Livio and Pringle 1996), but although the binary black hole model is mentioned only as an alternative it should be taken into consideration by reason that the double broad line region may be present in the central part of an AGN. Especially in such constellation that we have not been able to resolve.

Moreover, according to some model all of the galaxies should have a black hole in their center. Then the question is: why only a small number of galaxies (about 10%) have active and very luminous nuclei? The answer may be that in these galaxies there is a huge amount of matter near the black hole, in any case more than in the galaxies which have no active nucleus. The next problem is to have a mechanism which can draw such huge amount of matter near the black hole. One of the mechanisms which can provide such conditions is the collision of galaxies or the interaction between several galaxies. This is the reason why the merging effects should be considered in the case of some AGNs (see e.g. Roos 1985, Krivitsky and Kontorovich 1999). In fact some observations indicate that the merging effects are present in several AGNs (see e.g. Hutchings and Neff 1989, Kotilainen *et al.* 1996, Keel 1996, Lucas *et al.* 1999).

The process of powering an AGN by the binary black hole engine (see e.g. Taniguchi and Kaburaki 1997, Zier and Biermann 1999, Krivitsky and Kontorovich 1999, Taniguchi 1999) has been investigated to model the stellar distribution in the AGN (Zier and Biermann 1999) or the electro-magnetic field structure and the conditions for forming of jets (Taniguchi and Kaburaki 1997). Here we will discuss the influence of merging effects on spectral line shapes at the final stadium where close binary nucleus should be present.

Thus, taking into account that the structure of central part of an AGN can be probed by analyzing the emission line profiles, we give in this paper the emission line profiles for different parameters of the components and orbital elements.

2. THE MODEL

In order to show the effects of the double nuclei existence in the central part of AGNs on spectral line shapes we use a model of close binary nuclei, supposing that each of the nuclei has a Broad Line Region (BLR). Also, we suppose that these two BLRs have circular orbits and axial synchronous rotation with the orbital period P. Considering the case of spherical BLRs, we have divided the BLR's surfaces into N surface elements. Concerning Roche model (see e.g. Djurašević 1992) the shape of the nuclei emitting surfaces, in a coordinate system (x,y,z) with center in the nucleus with higher mass (the primary), is determined by the potential

$$\Omega = \frac{1}{r} + q\left[\frac{1}{\sqrt{1+r^2-2\tau r}} - \tau r\right] + \frac{1+q}{2} r^2(1-\nu^2), \tag{1}$$

where Ω is the dimensionless potential, $q = M_2/M_1$ is the ratio of the masses of the secondary (M_2) and the primary (M_1) nucleus, respectively, $\vec{r}$ the position vector of a surface element, and τ, μ, and ν are coefficients of transformation between rectangular and spherical coordinate systems:

$$x = r\cos\theta = r\tau$$
$$y = r\sin\theta\cos\phi = r\mu$$
$$z = r\sin\theta\sin\phi = r\nu$$

In order to calculate the radiation which can detect an observer, we will introduce a stationary coordinate system $(\overline{x}, \overline{y}, \overline{z})$ centered in the center of mass of the system. We suppose that the motion is in the xy plane, and that i is the inclination of the orbit. If we take that the $O\overline{x}$ is the line-of-sight direction and that the center of the secondary nucleus is located on the x axis, then the angle between these two axes α is the phase angle, and e.g. for $\alpha = 0$ we have that the secondary eclipses primary nucleus (phase is $\Phi = 0.5$).

The velocity of a surface element in the system (x, y, z) is

$$\vec{v}_0(x, y) = \vec{\omega} \times \vec{r} = [-y\omega, x\omega, 0],$$

where $\omega = 2\pi/P$ is the angular velocity.

The velocity of the primary center is

$$V_{c1} = +\frac{q}{1+q}\sin i \sin\alpha\,\omega,$$

and that of the secondary, center is

$$V_{c2} = -\frac{1}{1+q}\sin i \sin\alpha\omega.$$

Now we can find the velocity for a surface element in the system of an observer

$$V_r = v_r + V_{c1,2},$$

where v_r is the projection of the line-of-sight velocity of a surface element, and in the case of the primary nucleus we have

$$v_r^p = -\omega\, y\, a_x + \omega\, x\, a_y$$

and for the secondary

$$v_r^s = \omega[(1-x)\, a_y + y\, a_x,$$

where $a_x = \sin i \cos\alpha$ and $a_y = \sin i \sin\alpha]$

In this paper we suppose that each of the surface elements is emitting a line. We suppose that all the surface elements emitt a Gaussian profile with the same width (W).

$$\frac{I_\lambda}{I_0} = \exp\,[-\frac{(\lambda - \lambda_0(1 + v_r/c))^2}{W^2}],$$

where λ_0 is the transition wavelength.

3. RESULTS AND DISCUSSION

Using the model described above, we have computed the line profile using different parameters and component masses. We have analyzed the H_β line, and we take that the width of each Gaussian is about 1850 km/s. We supposed that random velocities of each surface element were $\approx$ 2000 km/s and obtained very broad lines (about 5000 – 6000 km/s) due to the rotation of the spherical emitting regions. The illustrative results of the modelling are presented in Figs. 1-10.

As one can see from Figs. 1-10 the line shape very strongly depends on mass ratio and orbital elements of the components. We have three characteristic cases:

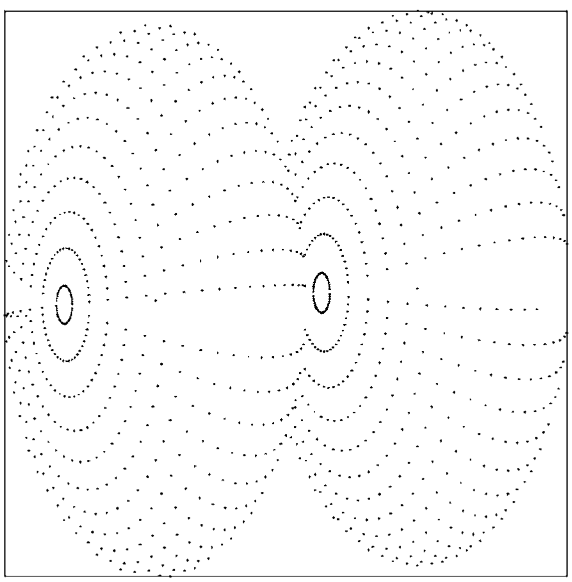

Fig. 1. *The model of close binary BLRs. The used parameters are: i=90, d_{AB}=0.3pc, T=300 years, ϕ=0.9 and q=1.*

1. The case corresponding to inclination angle i = 90°, and phase angle α = 90°. Depending on the mass of the components we will have: a) the case where masses are similar, in which two strong and sharp peaks (Fig. 1 and 2) are present in the observed line; and b) if the primary has the mass one order larger than the secondary, then a blue or a red bump in the line shape wings may be present (Figs. 3 and 4). One should notice that the displacement between peaks depends on the angular velocity ω. In this case an accretion disk around orbital plane may be also present (Taniguichi and Kaburaki 1997) and may significantly influence the line profile. It may cause very strong short period variation of line shapes, and very complex shape of lines.

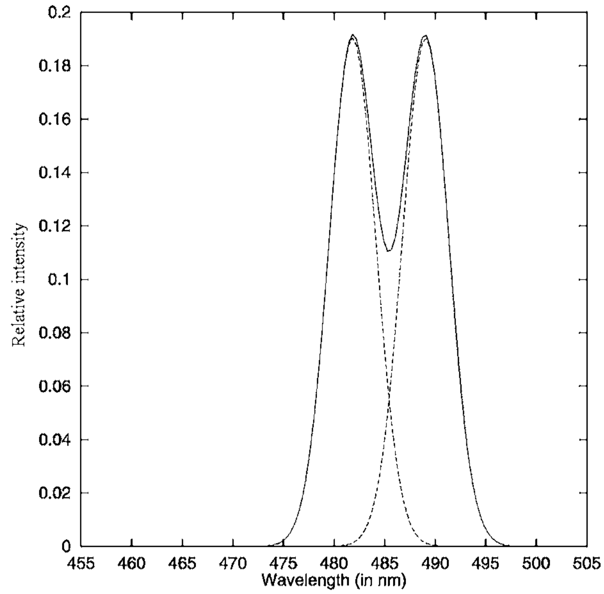

Fig. 2. *The shape of H_β line corresponding to model present in Fig. 1 (The contribution of each of BLR is presented by dashed lines).*

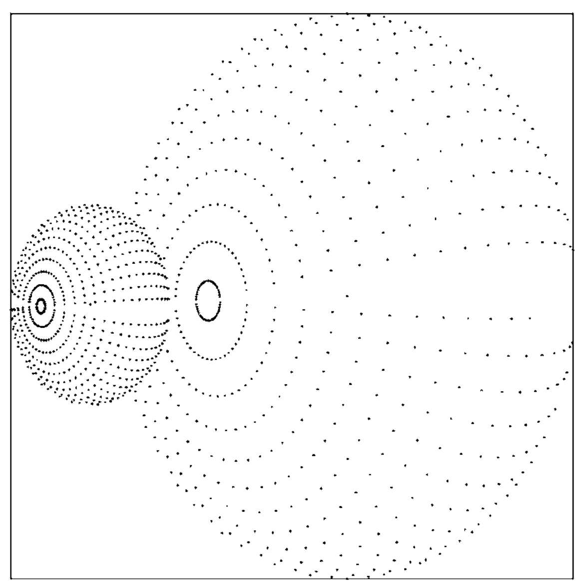

Fig. 3. *Same as in Fig 1. but for q=0.1.*

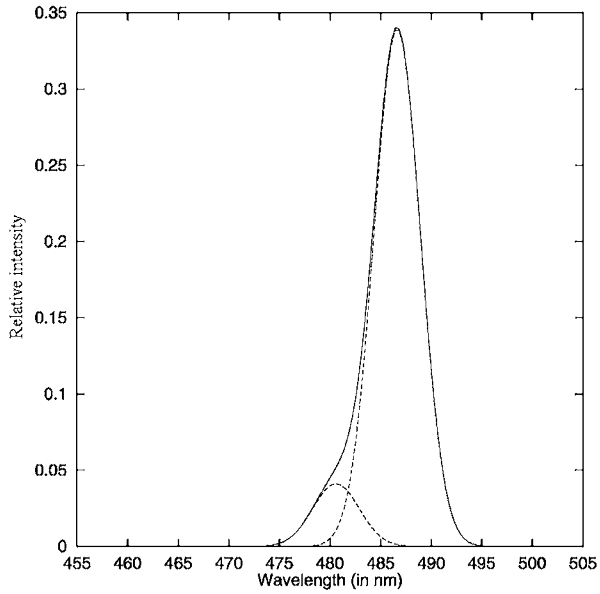

Fig. 4. *The corresponding shape of H_β line in the model presented in Fig. 3.*

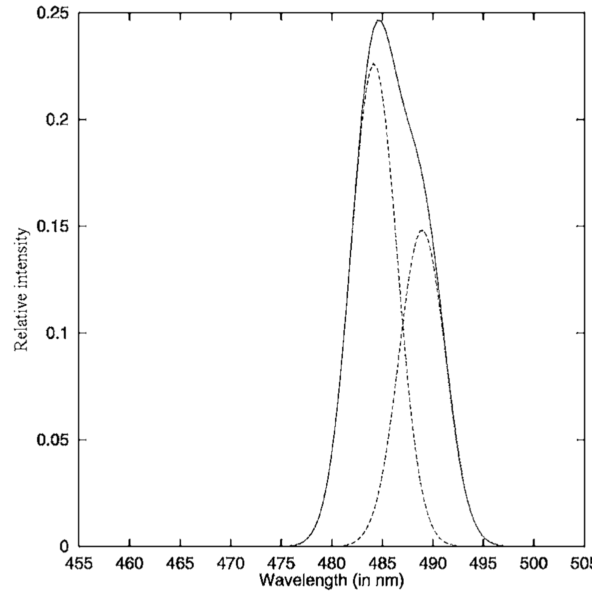

Fig. 6. *The corresponding shape of H_β line in the model presented in Fig. 5.*

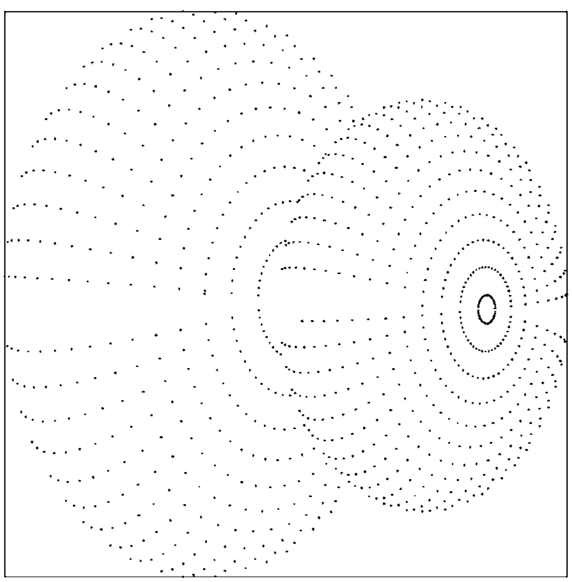

Fig. 5. *Same as in Fig 1. but for q=0.5 and* Φ*=0.57.*

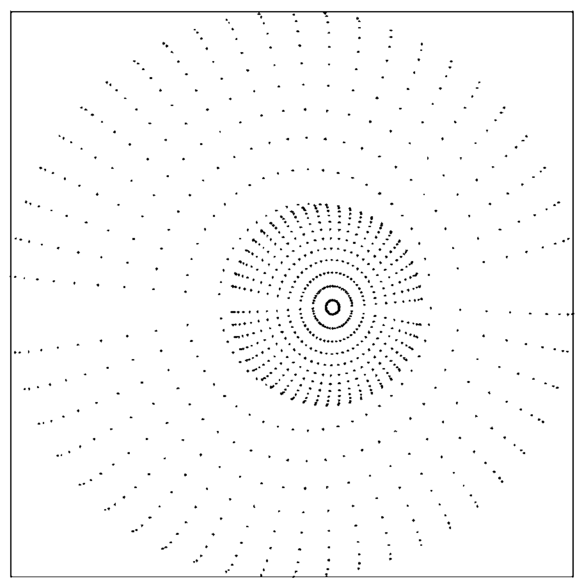

Fig. 7. *Same as in Fig 1. but for q=0.1 and* $\Phi = 0.5$.

2. The eclipsing case in which two effects in the line shape may be present. First, when the primary eclipses the secondary, the profile is defined by the kinematics of the emitting gas in the primary nucleus, and the effects of the binary black hole are not present, then the primary will simply obscure the secondary. Second, when the secondary eclipses the primary, the situation is more complex (Figs. $5-8$), and different effects may be present. If BLRs are stable then we can see slightly asymmetric or symmetric lines (Figs. 7 and 8). Also, in this case the gravitational microlensing may influence the line shape profile (see e.g. Popović *et al.* 2000, Mediavilla *et al.* 2000). If the primary is one order or over more massive than the secondary, only the microlensing effects may significantly change the line profile (Popović *et al.* 2000).

3. The third case is when the inclination angle is small or even $i = 0°$. Then the line profile can appear symmetric, but concerning the gas motion

(Taniguici and Kaburaki 1997) the biconical effects may influence the spectral line shapes. In this case we also may have double peaked lines, but due to the motion of the emission gas in jets. For other inclination angles in such system we can observe different shapes of line profiles; double-peaked, asymmetric (toward blue and red) and ideally symmetric (Figs. 9 and 10).

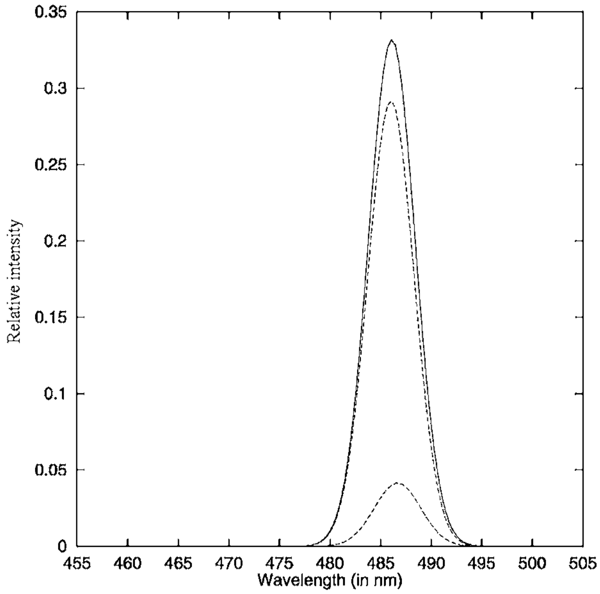

Fig. 8. *The corresponding shape of H_β line in the model presented in Fig. 7.*

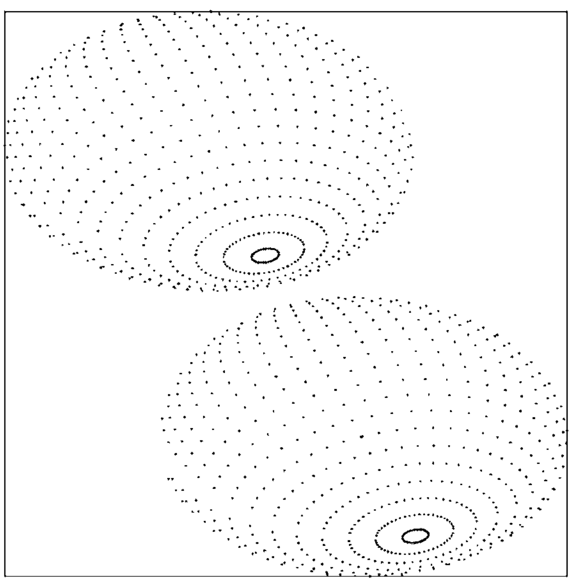

Fig. 9. *Same as in Fig 1. but for i=45° and* $\Phi = 0.55$.

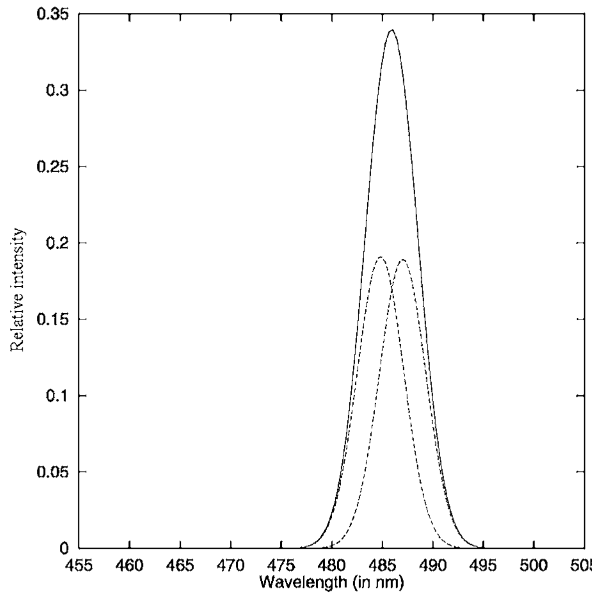

Fig. 10. *The corresponding shape of H_β line in the model presented in Fig. 9.*

5. CONCLUSION

As one can see from the present investigation, the merging effects can explain many of the double peaked line shapes. Moreover, such model, can also describe symmetrical as well as asymmetrical spectral line shapes. The line shapes in a close binary black hole system depend on the phase and inclination, as well as on the emission surfaces of both nuclei.

The fact that the so called 'new class' of the AGN with double-peaked lines have about 20%-100% starlight continuum around H_α line, compared to less than 10% in a typical AGN, points out that they should be monitored in order to investigate the merging effects in the central region as well as in their wide field.

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МОГУ ЛИ ЛИНИЈЕ СА ДВА ПИКА УКАЗИВАТИ НА СУДАРЕ У АГЈ?

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Оригинални научни рад

Разматра се утицај могућих судара у централном делу активних галактичких језгара (АГЈ) на облик спектралних линија. Представљен је модел тесно двојних језгара активних галаксија. Нумерички експерименти показују да линије са два пика могу бити израчене од једног таквог система, али и да судари језгара могу такође бити у центру АГЈ и ако оне немају линије са два пика. У зависности од маса компоненти и њихових орбита добијају се разни профили линија који могу објаснити посматране емисионе линија код АГЈ.