Publ. Astron. Obs. Belgrade No. 84 (2008), 467 - 470 *Contributed Paper*

MODELING OF VARIATIONS IN X-RAY EMISSION FROM ACCRETION DISKS OF ACTIVE GALAXIES

P. JOVANOVIĆ and L. Č. POPOVIĆ
Astronomical Observatory, Volgina 7, 11160 Belgrade 74, Serbia
E–mail: pjovanovic@aob.bg.ac.yu

Abstract. The observed profiles of the Fe Kα line in case of some Active Galactic Nuclei (AGN) show certain variations. In this paper we propose a model of disk emissivity variability to explain the observed Fe Kα line profiles. The disk emission was analyzed using the ray-tracing method in Kerr metric, assuming a modification of the power-law emissivity which allows us to include perturbations in disk emission. When the emissivity law is modified in such way, we find that the corresponding variations in disk emission can explain the observed Fe Kα line profiles if the line is emitted from the innermost part of the accretion disk.

1. INTRODUCTION

The most prominent feature in 3-10 keV X-ray reflection spectrum of approximately 30% of type 1 AGN is the broad Fe Kα line at 6.4 keV. The observed profiles of the Fe Kα line in case of some AGN show certain variations. For example, a narrow component of the Fe Kα line in NGC 3516 is seen to vary systematically in energy and flux at time intervals of 25 ksec (Iwasawa et al. 2004), and also in Mrk 766 (Miller et al. 2006; Turner et al. 2006), possibly in a periodic manner (Fabian, 2006). On the other hand, in the best objects where a very broad Fe Kα line is seen (e.g. MCG-6-30-15 and NGC 4051) amplitude of the line variations are considerably less than expected despite large variations in the continuum (Fabian & Vaughan, 2003; Ponti et al. 2006; Fabian, 2006).

To model the observed variability in the Fe Kα line profiles and intensities, here we consider the perturbations in the accretion disk emissivity, which is analyzed using ray-tracing method in Kerr metric (see Popović et al. 2003 and references therein).

2. A MODEL OF DISK PERTURBING REGION

Surface emissivity of the disk is usually assumed to vary with radius as a power law (e.g. Popović et al. 2003): $\varepsilon(r) = \varepsilon_0 \cdot r^q$, where ε_0 is an emissivity constant and q – emissivity index. Total observed flux is then given by (see e.g. Popović et al. 2006):

$$F_{obs}(E_{obs}) = \int\limits_{image} \varepsilon(r) \cdot g^4 \delta(E_{obs} - gE_0) d\Xi, \qquad (1)$$

where g is the energy shift due to the relativistic effects: $g = \dfrac{\nu_{obs}}{\nu_{em}}$ and the rest energy of the Fe Kα line is: $E_0^{FeK\alpha} = 6.4$ keV. $d\Xi$ is the solid angle subtended by the disk in the observer's sky.

In this paper we propose a modification of the power-law disk emissivity in order to explain the observed profiles. Here, the following emissivity law of the disk is assumed:

$$\varepsilon_1(x_p, y_p) = \varepsilon(r(x_p, y_p)) \cdot \left(1 + \varepsilon_p \cdot e^{-\left(\left(\frac{x - x_p}{w_x}\right)^2 + \left(\frac{y - y_p}{w_y}\right)^2\right)}\right), \qquad (2)$$

where where $\varepsilon_1(x_p, y_p)$ is the modified disk emissivity at the given position (x_p, y_p) of perturbing region (in gravitational radii R_g), $\varepsilon(r(x_p, y_p))$ is the power-law disk emissivity at the same position, ε_p is emissivity of perturbing region and (w_x, w_y) are its widths (also in R_g). Under assumption that perturbation is moving by speed of light c, one can calculate time $t_p\,[s]$ that corresponds to current position (x_p, y_p) using the following expression:

$$t_p\,[s] = \frac{r(x_p, y_p)\,[R_g]}{c\,[m \cdot s^{-1}]} = \frac{r_{x,y} \cdot GM_{BH}}{c^3}, \qquad (3)$$

where $r_{x,y} = \dfrac{r\,(x_p, y_p)}{R_g}$, G is Newton's gravitational constant and M_{BH} is the mass of central black hole.

3. RESULTS AND DISCUSSION

For numerical simulations in case of the above disk perturbing model, we adopted the following parameters: disk inclination $i = 35^o$, inner and outer radii of the disk $R_{in} = R_{ms}$ and $R_{out} = 30\ R_g$ (where R_{ms} is the radius of marginally stable orbit), emissivity constant $\varepsilon_0 = 1$, emissivity index $q = -2.5$ and the emissivity of perturbing region $\varepsilon_p = 5$. We made simulations for different positions of perturbing region along x-axis (i.e. for $y_p = 0$) between $x_p = 8$ and 26 R_g in both, positive and negative directions. At the same time, the widths of perturbing region $w_x = w_y$ were varied between 1 and 10 R_g. The corresponding times t_p are calculated for black hole mass $M_{BH} = 1 \times 10^9 M_\odot$.

The obtained results for two different positions of perturbing region are presented in left panels of Figs. 1 and 2, and the corresponding perturbed and unperturbed profiles of the Fe Kα line are given in the right panels of the same Figs. As one can see from these Figs, the perturbing model affects the line flux in only one of "red" (Fig. 1) or "blue" (Fig. 2) spectral bands, while the other one stays nearly constant, as well as the line core. In the first case perturbation moves along positive direction of x-axis (receding side of the disk), while in the second case it moves along negative direction of x-axis (approaching side of the disk). It is even more obvious if we analyze the corresponding simulated light curves which are presented in Fig. 3. From this figure it can be seen that in the first case, displacement of perturbing region results in variations of only "red" light curve (0.1 – 6.1 keV), while in the second case, it affects only the "blue" one (6.7 – 12.8 keV), and these variations are then reflected in

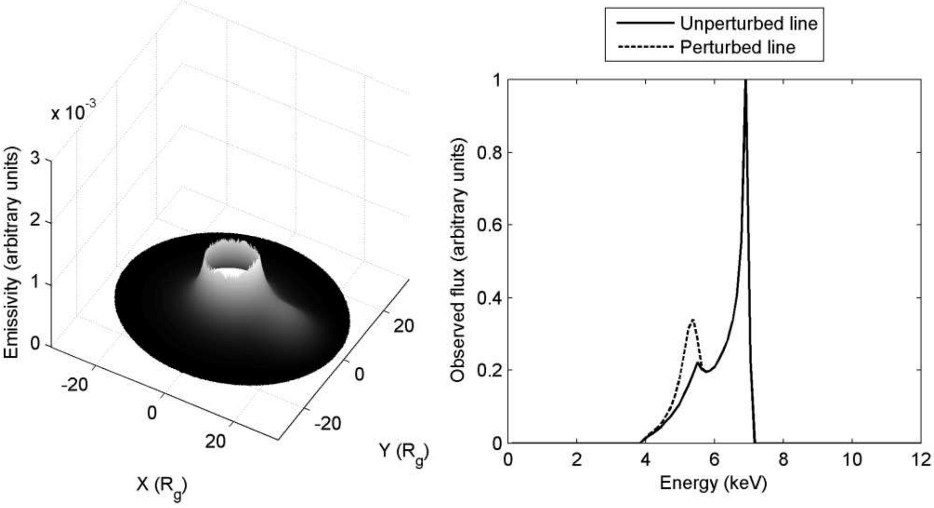

Figure 1: *Left:* shape of perturbed emissivity of an accretion disk in Schwarzschild metric for the following parameters of perturbing region: $x_p = 20\ R_g$, $y_p = 0$ and $w_x = w_y = 7\ R_g$. The values of the remaining parameters are given in §3. *Right:* the corresponding perturbed (dashed line) and unperturbed (solid line) Fe Kα line profiles.

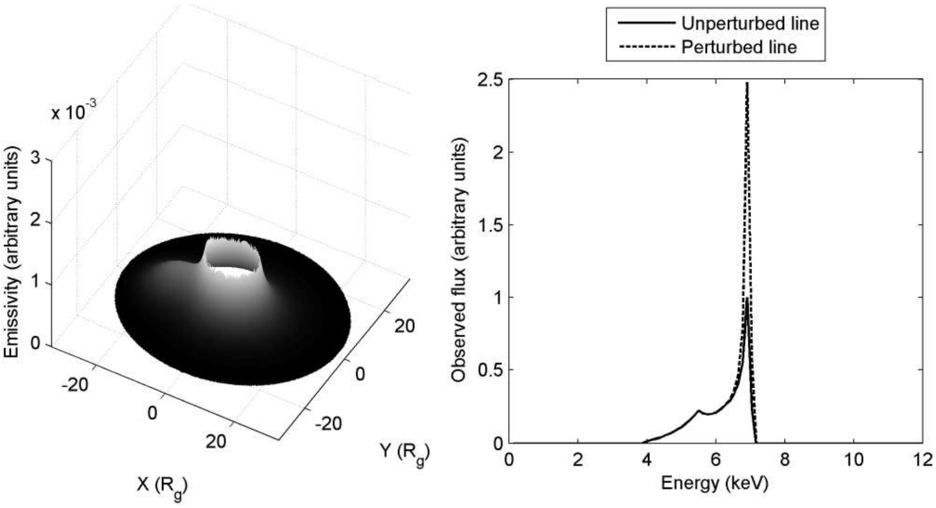

Figure 2: The same as in Fig. 1, but for the following position of perturbing region: $x_p = -20\ R_g$ and $y_p = 0$.

total line flux in $0.1 - 12.8$ keV energy band. In both cases the "core" light curve (6.1 – 6.7 keV) stays almost constant. Thus, this model could satisfactorily explain the observed variations of the Fe Kα line flux. Besides, we are able to obtain the realistic durations of disk emissivity perturbations when we assume central supermassive black hole with mass $M_{BH} = 1 \times 10^9 M_\odot$.

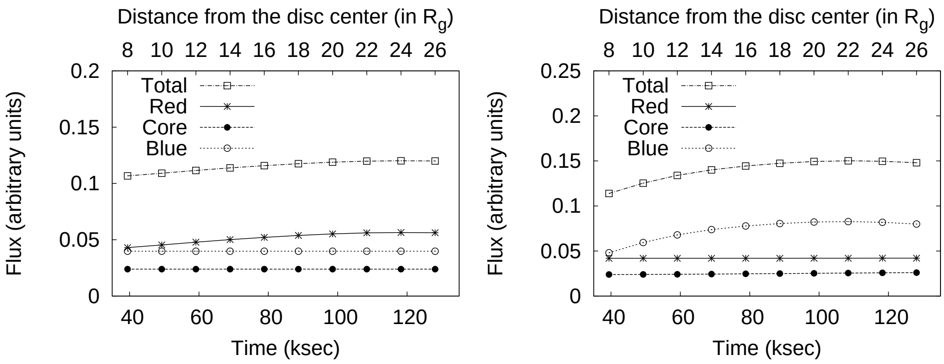

Figure 3: The simulated light curves in case of displacements of perturbing region along the positive (left panel) and negative (right panel) directions of x-axis. Light curves correspond to the following spectral bands: total flux (black) to 0.1 – 12.8 keV, "red" to 0.1 – 6.1 keV, "core" to 6.1 – 6.7 keV and " blue" to 6.7 – 12.8 keV.

4. CONCLUSIONS

Perturbations of accretion disk emissivity were analyzed using numerical simulations based on a ray-tracing method in Kerr metric from wich we can conclude the following:

(i) observed variations of the Fe Kα line flux could be caused by perturbations in the disk emissivity
(ii) a model of disk perturbing region was developed
(iii) this model affects the line flux in only one of "red" or "blue" spectral bands, while the other one stays nearly constant, as well as the line core. Thus it results in variations of only one of the "red" or "blue" light curves, and therefore, this model could satisfactorily explain the observed variations of the Fe Kα line flux
(iv) there are only small differences between the Fe Kα line flux variability in Schwarzschild and Kerr metrics for both models
(v) realistic durations of disk emissivity perturbations in both analyzed models were obtained for central black hole mass $M_{BH} = 1 \times 10^9 M_\odot$

Acknowledgements

This work has been supported by the Ministry of Science of Republic of Serbia through the project "Astrophysical Spectroscopy of Extragalactic Objects" (146002).

References

Fabian, A. C.: 2006, *AN*, **327**, 943.
Fabian, A. C., Vaughan, S.: 2003, *MNRAS*, **340**, L28.
Iwasawa, K., Miniutti, G., Fabian, A. C.: 2004, *MNRAS*, **355**, 1073.
Miller, L., Turner, T. J., Reeves, J. N., George, I. M., Porquet, D., Nandra, K., Dovciak, M.: 2006, *A&A*, **453**, L13.
Ponti, G., Miniutti, G., Cappi, M., Maraschi, L., Fabian, A. C., Iwasawa, K.: 2006, *MNRAS*, **368**, 903.
Popović, L. Č., Mediavilla, E. G., Jovanović, P., Muñoz, J. A. : 2003, *A&A*, **398**, 975.
Popović, L. Č., Jovanović, P., Mediavilla, E.G., Zakharov, A. F., Abajas, C., Muñoz, J. A. & Chartas, G.: 2006, *ApJ*, **637**, 620.
Turner, T. J., Miller, L. J., George, I. M., Reeves, J. N.: 2006, *A&A*, **445**, 59.