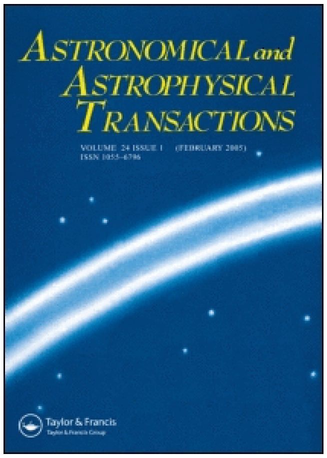

Astronomical & Astrophysical Transactions
The Journal of the Eurasian Astronomical Society
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713453505

Influence of microlensing on the active galactic nucleus Fe Ka line

Popović; Jovanović; Mediavilla; Muñoz

Online Publication Date: 01 January 2003
To cite this Article: Popović, Jovanović, Mediavilla and Muñoz (2003) 'Influence of microlensing on the active galactic nucleus Fe Ka line', Astronomical & Astrophysical Transactions, 22:4, 719 - 725
To link to this article: DOI: 10.1080/1055679031000114890
URL: http://dx.doi.org/10.1080/1055679031000114890

Astronomical and Astrophysical Transactions
Vol. 22, Nos. 4–5, August–October 2003, pp. 719–725

INFLUENCE OF MICROLENSING ON THE ACTIVE GALACTIC NUCLEUS Fe Kα LINE

L. Č. POPOVIĆ[a,*], P. JOVANOVIĆ[a], E. MEDIAVILLA[b] and J. A. MUÑOZ[b]

[a]Astronomical Observatory, Volgina 7, 11160 Belgrad, Serbia;
[b]Instituto de Astrofísica de Canarias, E-382005 La Laguna, Tenerife, Spain

(Received November 25, 2002)

We have studied the influence of gravitational microlensing on the Fe Kα line originating from a compact accretion disc of active galactic nuclei. We found that microlensing can produce line profile deformation as well as a significant amplification of the line flux. The line deformation and line flux amplification depend not only on the parameters of the microlens but also on the disc parameters.

Keywords: X-rays; Quasars; Spectral line; Gravitational microlensing

1 INTRODUCTION

The X-radiation of active galactic nuclei (AGNs) are generated in the innermost region around a central super-massive black hole (BH). In various types of AGN, the existence of accretion discs is well established (Fabian et al., 2000). The accretion discs around the central BH represent an efficient mechanism for extracting gravitational potential energy and converting it to radiation and give us the most probable explanation of the main characteristics of AGNs (high luminosity, compactness, jet formation, rapid time variation in radiation and the profile of Fe Kα line).

An emission line from Fe Kα has been observed at 6–7 keV in the vast majority of AGNs (see for example Nandra et al. (1997) and Fabian et al. (2000)). This line is probably produced in a very compact region near the BH of an AGN (Iwashawa et al., 1999; Nandra et al., 1999; Fabian et al., 2000) and can provide essential information about the plasma conditions and the space geometry around the BH. Many effects can influence the Fe Kα line profile, so that the Fe Kα line can be a tool for plasma diagnosis near a BH.

One of the effects that may produce deformation of the Fe Kα line is gravitational microlensing (Popović et al., 2001b,c, 2003; Chartas et al., 2002). Recent observations of two lens systems seem to support this idea (Oshima et al., 2001; Chartas et al., 2002).

The rapid X-ray variability of many AGNs is also noticeable. This variation is also present in the shape and flux of the Fe Kα line (Iwashawa et al., 1999; Nandra et al., 1999; Vaughan and Edelson, 2001) and is explained as dramatic flare-like events in the

*Corresponding author. E-mail: lpopovic@aip.de

ISSN 1055-6796 print; ISSN 1476-3540 online
DOI: 10.1080/1055679031000114890

accretion disc corona (Fabian et al., 2000). Popović et al. (2001a) showed that, under certain conditions, microlensing from a massive object in the host galaxy could explain the changes in the Hα line profiles in a non-lensed AGN.

In this paper we shall present our investigation on the influence of the gravitational microlens (MLE) on the Fe Kα line originating from an accretion disc. In Section 2 we give the theory, and in Section 3 some of the numerical tests are presented.

2 THEORY

To take into account the effect of microlensing on a compact accretion disc, we shall use the ray-tracing method (Bao et al., 1994; Bromley et al., 1997; Fanton et al., 1997; Čadež et al., 1998) considering only those photon trajectories that reach the sky plane at a given observer's angle θobs. We shall adopt the analytical approach proposed by Čadež et al. (1998). If X and Y are the impact parameters that describe the apparent position of each point of the accretion disc image on the celestial sphere as seen by an observer at infinity, the amplified brightness is given by (Popović et al., 2003)

$$I_p = \varepsilon(r) g^4(X, Y) \delta[x - g(X, Y)] A(X, Y), \tag{1}$$

where $x = \nu_{obs}/\nu_0$ (ν_0 and ν_{obs} are the transition and observed frequencies respectively), $g = \nu_{em}/\nu_{obs}$ (ν_{em} is the emitted frequency from the disc), $\varepsilon(r)$ is the emissivity in the disc, $\varepsilon(r) = \varepsilon_0 r^q$ and $A(X, Y)$ is the amplification caused by microlensing. We shall consider two different approximations to estimate the last quantity.

2.1 Microlensing by an Isolated Compact Object

In this case the amplification is given by the relation (see for example Narayan and Bartelmann (1999))

$$A(X, Y) = \frac{u^2(X, Y) + 2}{u(X, Y)[u^2(X, Y) + 4]^{1/2}}, \tag{2}$$

where $u(X, Y)$ corresponds to the angular separation between the lens and source in Einstein ring radius (ERR) units and is obtained from

$$u(X, Y) = \frac{[(X - X_0)^2 + (Y - Y_0)^2]^{1/2}}{\eta_0}, \tag{3}$$

X_0 and Y_0 are the coordinates of the microlens with respect to the disc centre given 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) and η_0 is the ERR expressed in gravitational radii.

The total observed flux is given by

$$F(x) = \int_{image} I_p(x)\, d\Omega, \tag{4}$$

where $d\Omega$ is the solid angle subtended by the disc in the observer's sky and the integral extends over the whole (line) emitting region.

2.2 Microlensing by a Straight Fold Caustic

In most cases we cannot simply consider that microlensing is caused by an isolated compact object but we must take into account that the microdeflector is located in an extended object (typically, the lens galaxy). In this case, when the size of the ERR of the microlens is larger than the size of the accretion disc, we can describe the microlensing in terms of the crossing of the disc by a straight fold caustic (Schneider et al., 1992). The amplification at a point close to the caustic is given by (Chang and Refsdal, 1984)

$$A(X, Y) = A_0 + \frac{K}{[\kappa(\xi - \xi_c]^{1/2}} H(\kappa(\xi - \xi_c)), \tag{5}$$

where A_0 is the amplification outside the caustic and $K = A_0 \beta {\eta_0}^{1/2}$ is the caustic amplification factor, where β is a constant of order of unity (see for example Witt et al., 1993). ξ is the distance perpendicular to the caustic in gravitational radii units, and ξ_c is the minimum distance given by

$$\xi_c = (X_c^2 + Y_c^2)^{1/2}, \tag{6}$$

$$\tan\alpha = \frac{Y_c}{X_c}, \tag{7}$$

and

$$\xi = \xi_c + \frac{(X - X_c)\tan\phi + Y_c - Y}{(\tan^2\ \phi + 1)^{1/2}}, \tag{8}$$

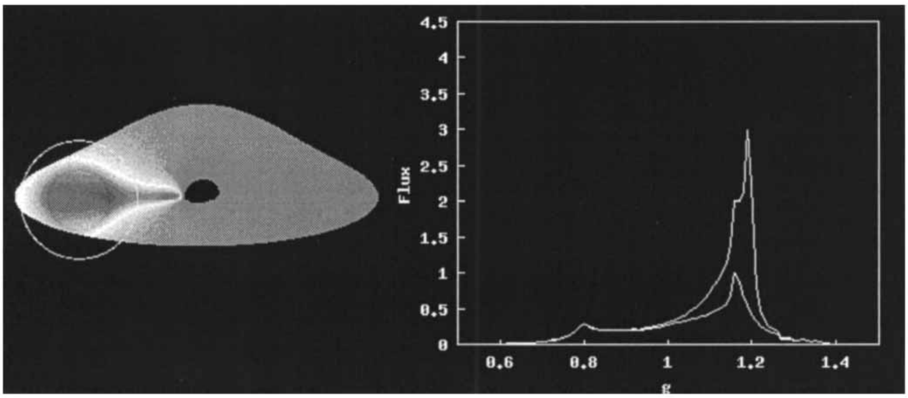

FIGURE 1 The point-like lens crossing the accretion disc in the Kerr metric. (a) An illustration; the parameters of the disc are $i = 75^{\circ}$, $R_{inn} = R_{ms}$, $R_{out} = 30R_g$, $q = 0$ and the ERR is $10R_g$. (b) The corresponding Fe Kα line changes; the undeformed profile is normalized to one and presented as the lower curve.

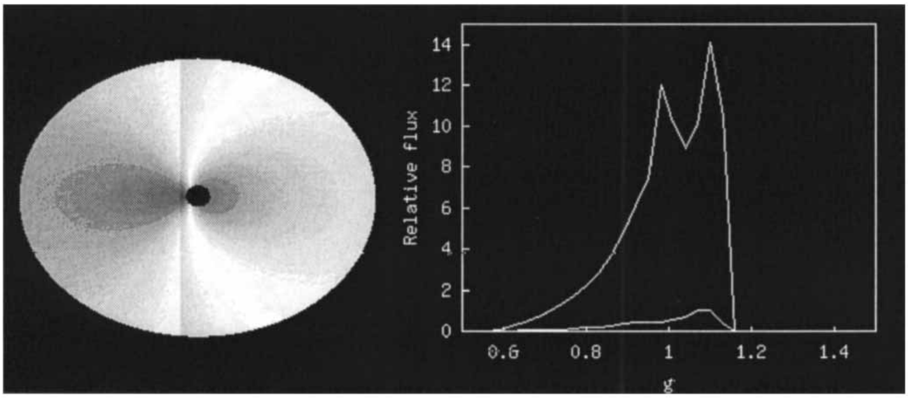

FIGURE 2 The caustic crossing the accretion disc in the Schwarzschild metric. (a) The same as in Figure 1, but with the disc parameters $i = 30°$, $R_{inn} = R_{ms}$, $R_{out} = 100R_g$ and $q = -2.5$. (b) Deformed line due to microlensing effect in comparison with undeformed line (lower curve).

where $\phi = \alpha + \pi/2$. $H(\kappa(\xi - \xi_c))$ is the Heaviside function; $H(\kappa(\xi - \xi_c)) = 1$, for $\kappa(\xi - \xi_c) > 0$; otherwise it is 0. $\kappa = \pm 1$; it depends on the direction of caustic motion; if the direction of the caustic motion is from the approaching side of the disc, $\kappa = -1$; otherwise it is $+1$. Also, in the special case when the caustic crosses perpendicular to the rotating axis, $\kappa = +1$ for the direction of caustic motion from $-Y$ to $+Y$; otherwise it is -1.

Images of the accretion discs showing the effects of caustic crossing are shown in Figures 1 and 2.

3 RESULTS

In order to study the influence of microlensing on the Fe Kα line we have varied the disc parameters as well as the position of the caustic and the caustic direction motion. To test the MLE influence of microlensing on the line shapes due to different positions of the caustic we adopt the disc parameters $i = 35°$, $q = 0$ and $R_{in} = R_{ms}$, where R_{ms} is the radius of the marginal stability orbit, which corresponds to $R_{ms} = 6R_g$ in the Schwarzschild metric and to $R_{ms} = 1.23R_g$ in the Kerr metric with angular momentum $a = 0.998$. We adopt for the outer radius $R_{out} = 100R_g$.

In Figure 3, one can see the influence of microlensing on the line profile for different inclinations of the disc. Figure 3 is the case where the caustic is located at $X_c = -5$ and $Y_c = 0$, and the parameters of the disc are the same as mentioned above, except for the inclination which is varied from $i = 10°$ to $80°$. As one can see from Figure 3, the line may be amplified and it also changes shape significantly because of the microlensing effect. The line profile deformation is higher for higher inclinations. Also, we tested the influence of microlensing in the case of different positions of the caustic. In Figures 4 and 5 we present the deformation of the line for different positions of the caustic. We assume that caustic motion is along the X axis, in both directions: from $-X$ to X in Figure 4 and vice versa in Figure 5. In both cases we can see that the line profile deformations as well as amplifications are different for different caustic positions. Comparing Figures 4 and 5 one can conclude that the line shape deformation and the amplification depend not only on the position of the caustic but also on the caustic motion direction.

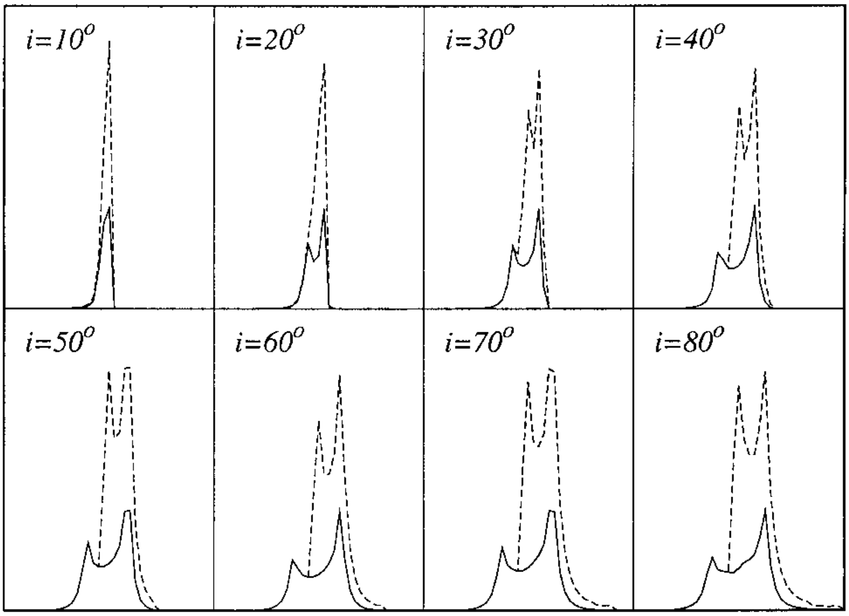

FIGURE 3 The deformation of the Fe Kα line shape (----) due to the influence of microlensing; the ERR is $100R_g$, $X_0 = -5$ and $Y_0 = 0$, for different inclinations i of the disc in the Schwarzschild metric. The relative intensity is in the range from 0 to 3 (the maximum of the unperturbed Fe Kα line is normalized to 1), and v/v_0 is in the range from 0.6 to 1.4.

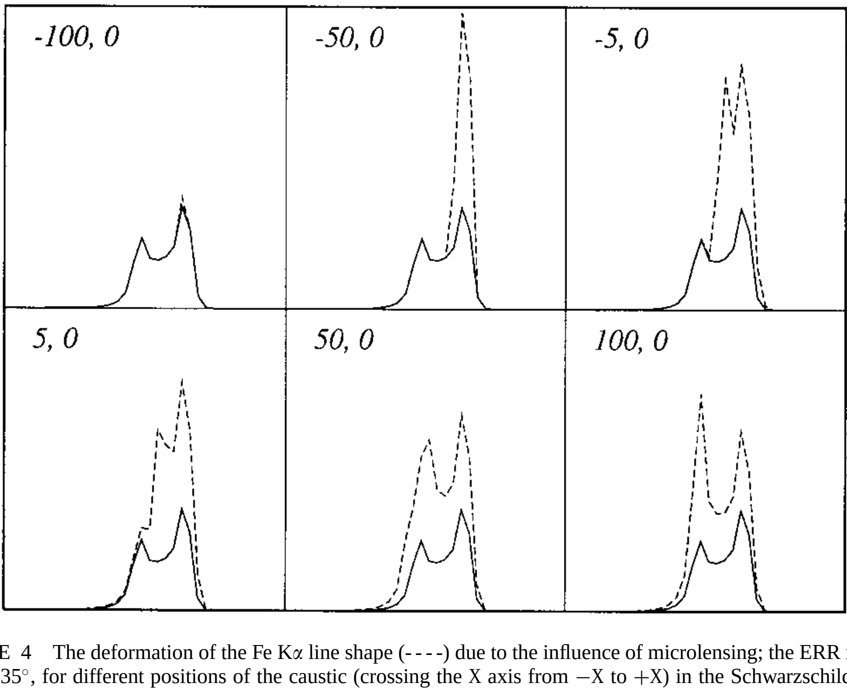

FIGURE 4 The deformation of the Fe Kα line shape (----) due to the influence of microlensing; the ERR is $100R_g$ and $i = 35°$, for different positions of the caustic (crossing the X axis from $-X$ to $+X$) in the Schwarzschild metric. The relative intensity is in the range from 0 to 3 (the maximum of unperturbed Fe Kα line is normalized to 1), and v/v_0 is in the range from 0.6 to 1.3.

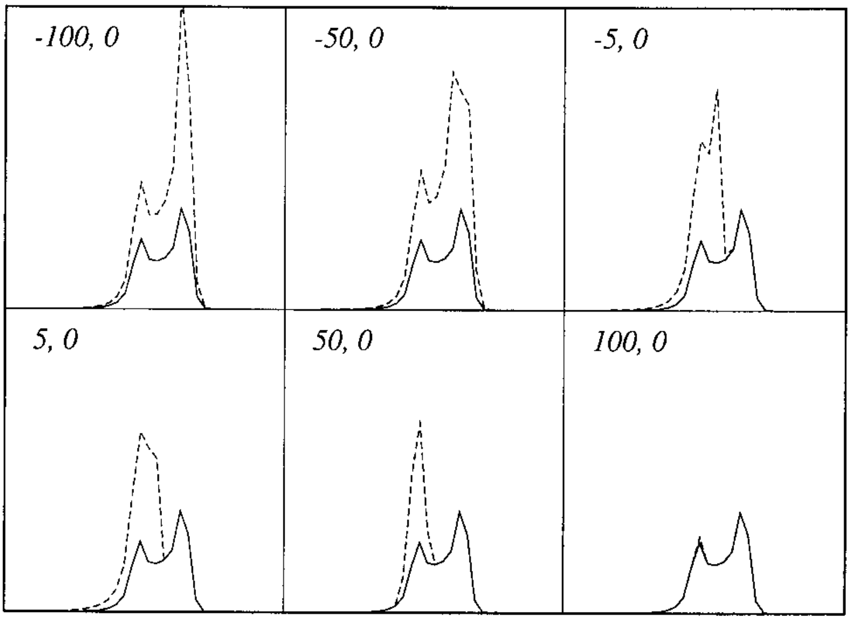

FIGURE 5 The same as Figure 4, but for the direction of the caustic from +X to −X.

On the other hand, we fixed the parameters of the caustic and the caustic position ($X = -5$; $Y = 0$) and we varied the emissivity index. The results are presented in Figure 6. Comparing Figures 3 and 6, one can conclude that the line shape deformation and the amplification depend not only on the caustic parameters (and position) but also on the disc parameters.

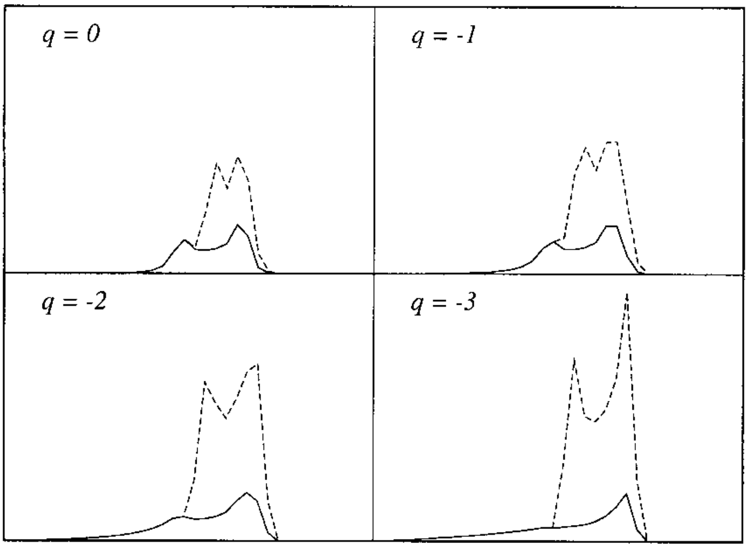

FIGURE 6 The deformation of the Fe Kα line shape (----) due to the influence of microlensing; the ERR is $100R_g$, $X_0 = -5$ and $Y_0 = 0$ for different emissivity indices q. The relative intensity is in the range from 0 to 5.5 (the maximum of the unperturbed Fe Kα line is normalized to 1), and v/v_0 is in the range from 0.6 to 1.3.

We also tested the line deformation by changing the inner and outer radii, and we found that the effect has not become enhanced as in the case of the inclination and emissivity index variation.

4 CONCLUSIONS

In order to discuss the influence of microlensing on the shape and amplification of the Fe Kα line, we have developed a ray-tracing model. Here we consider the Schwarzschild metric and we performed several numerical tests varying the caustic position and the disc parameters. The main conclusions of our work are as follows.

(i) Microlenses of very small projected ERR can cause a line profile deformation as well as a significant amplification of the line flux.
(ii) The amplification and the line profile deformation depend not only on the parameters of the caustic (and the caustic position) but also on the disc parameters.
(iii) The effect of microlensing on Fe Kα spectral line strongly depends on inclination and emissivity of the accretion disc, and slightly on the inner and outer radii of the disc.

Acknowledgements

This work is a part of the project P1196 'Astrophysical spectroscopy of extra-galactic objects' supported by the Ministry of Science and Technologies and Development of Serbia and project P6/88 'Relativistic and theoretical astrophysics' supported by the Instituto de Astrofísica de Canarias.

References

Bao, G., Hadrava, P. and Ostgaard, E. (1994). Astrophys. J., 435, 55.
Bromley, B. C., Chen, K. and Miller, W. A. (1997). Astrophys. J., 475, 57.
Čadež, A., Fanton, C. and Calivani, M. (1998). New Astron., 3, 647.
Chang, K. and Refsdal, S. (1984). Astron. Astrophys., 132, 168.
Chartas, G., Agol, E., Eracleous, M., Garmire, G., Bautz, M. W. and Morgan, N. D. (2002). Astrophys. J. (in press).
Fabian, A. C., Iwasawa, K., Reynolds, C. S. and Young, A. J. (2000). Publns Astron. Soc. Pacif., 112, 1145.
Fanton, C., Calivani, M., Felice, F. and Čadež, A. (1997). Publns Astron. Soc. Japan, 49, 159.
Iwashawa, K., Fabian, A. C., Young, A. J., Inoue, H. and Matsumoto, C. (1999). Mon. Not. R. Astron. Soc., 306, L19.
Nandra, K., George, I. M., Mushotzky, R. F., Turner, T. J. and Yaqoob, T. (1997). Astrophys. J., 477, 602.
Nandra, K., George, I. M., Mushotzky, R. F., Turner, T. J. and Yaqoob, T. (1999). Astrophys. J., 523, L17.
Narayan, R. and Bartelmann, M. (1999). In: Dekler, A. and Ostriker, J. P. (Eds.), Formation of Structure in the Universe. Cambridge University Press, Cambridge, p. 360.
Oshima, T., Mitsuda, K., Fujimoto, R., Iyomoto, N., Futamoto, K., et al. (2001). Astrophys. J., 563, L103.
Popović, L.Č., Mediavilla, E. G., Jovanović, P. and Muñoz, J. (2003). Astron. Astrophys., 398, 975.
Popović, L.Č., Mediavilla, E. G. and Muñoz, J. (2001a). Astron. Astrophys., 378, 295.
Popović, L.Č., Mediavilla, E.G., Muñoz, J., Dimitrijević, M. S. and Jovanović, P. (2001b). Serb. Astron. J., 164, 73.
Popović, L.Č., Mediavilla, E. G., Muñoz, J., Dimitrijević, M. S. and Jovanović, P. (2001c). GLITP Workshop on Gravitational Lens Monitoring, La Laguna, Tenerife, Spain, June 4–6, 2001.
Schneider, P., Ehlers, J. and Falco, E. E. (1992). Gravitational Lenses. Springer, Berlin.
Vaughan, S. and Edelson, R. (2001). Astrophys. J., 548, 694.
Witt, H. J., Kayser, R. and Refsdal, S. (1993). Astron. Astrophys., 268, 501.