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MICROLENSING OF THE X-RAY EMITTING REGION IN ACTIVE GALACTIC NUCLEI

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

Abstract. We studied the effects of microlensing on X-ray radiation from a relativistic accretion disk around central Black Hole of Active Galactic Nuclei. To analyze the disk emission we used the ray-tracing method considering both Schwarzschild and Kerr metrics. Two types of microlenses were considered: straight fold caustic and microlensing magnification map. We concentrated our attention on studying the correlation between the X-ray continuum and Fe Kα spectral line due to microlensing. Our results show that enhancements of the Fe Kα line in three recently observed gravitationally lensed QSOs (MG J0414+0534, QSO 2237+0305, H1413+117) could be interpreted in terms of microlensing, even if an equivalent X-ray continuum amplification is not observed.

1. INTRODUCTION

Recent observational and theoretical studies suggest that gravitational microlensing can induce variability in the X-ray emission of gravitationally lensed QSOs. Microlensing of the Fe Kα line has been reported at least in three macrolensed QSOs: MG J0414+0534 (Chartas et al., 2002), QSO 2237+0305 (Dai et al. 2003), and H 1413+117 (Oshima et al., 2001; Popović et al., 2003; Chartas et al., 2004). Chartas et al. (2002) detected an increase of the Fe Kα line intensity in the image B of MG J0414+0534 which was not followed by the continuum and explained this behavior by assumption that the thermal emission region of the disk and the Compton upscattered emission region of the hard X-ray source lie within smaller radii than the iron-line reprocessing region. Analyzing the X-ray variability of QSO 2237+0305A, Dai et al. (2003) also measured amplification of the Fe Kα line in component A of QSO 2237+0305 but not in the continuum, and suggested that the larger size of the continuum emission region in comparison to the Fe Kα emission region could explain this result. In the case of H 1413+117, Chartas et al. (2004) found that the continuum and the Fe Kα line were enhanced by a different factor. Popović et al. (2006) analyzed this different behavior of the line and continuum variability in the observed events in context of the microlensing hypothesis.

The aim of this paper is to discuss microlensing of the X-ray emitting region in the case of three lensed quasars (MG J0414+0534, QSO 2237+0305 and H1413+117) where microlensing of the Fe Kα line was observed.

2. MICROLENSING OF A COMPACT ACCRETION DISK

To study the effects of microlensing on a compact accretion disk we used the ray-tracing method (see e.g. Popović et al., 2003 and references therein). The emissivity of the disk is one of the important parameters which has influence on the continuum and line shapes. The observed continuum flux is very often fitted with one or two black-body components in the soft X-ray, in addition to the hard X-ray power law (see e.g. Page et al., 2004). In the standard Shakura-Sunyaev disk model (Shakura and Sunyaev, 1973), it is expected that the surface temperature is at least radially dependent and that the effective temperature of radiation is in the range from 10^7 to 10^8 K. The line shape, as well as the continuum distribution, depend on a emissivity law, so we will use here the black body, modified black body and power emissivity laws for both; the Fe Kα and X-ray continuum emission. For more detailed discussion about emissivity laws and the corresponding temperature distributions see Popović et al. (2006).

In most cases a microlens is located in an extended object (typically, the lens galaxy) and can be described by straight fold caustic or by caustic magnification pattern produced by a population of deflectors (stars). For microlens parameters in both cases, we adopted the same values as in Popović et al. (2006).

For the disk inclination we used the averaged value given by Nandra et al. (1997) from the study of the Fe Kα line profiles of 18 Seyfert 1 galaxies: $i = 35°$. The inner radius of the disk, R_{in}, cannot be smaller than the radius of the marginally stable orbit, R_{ms}, that corresponds to $R_{ms} = 6R_g$ (gravitational radius, $R_g = GM/c^2$, where G is gravitational constant, M is the mass of central black hole, and c is the velocity of light) in the Schwarzschild metric and to $R_{ms} = 1.23R_g$ in the case of the Kerr metric with angular momentum parameter $a = 0.998$. To select the outer radius, R_{out}, we took into account some previous investigations of the X-ray variability, supporting very compact X-ray emitting disks ranging from 10 to 100 R_g for a black hole mass in the range $10^7 - 10^9$ $M_\odot$. This range of sizes is also acceptable for the Fe Kα emission region (see e.g. Nandra et al., 1997).

3. RESULTS

The lack of correlation between the X-ray continuum and Fe Kα line due to microlensing can be expected if they originate from separated emitting regions in accretion disk (e.g. Jovanović, 2006). Recent investigations of the Fe Kα line profile from active galaxies show that the line should be emitted from the innermost part of the accretion disk. In particular, Ballantyne and Fabian (2005) found that in the Broad Line Radio Galaxy 4C+74.26 the outer radius of the relativistic iron line should be within 10 R_g. Consequently, here we will assume that the Fe Kα line is formed in the innermost part of the disk ($R_{\rm inn} = R_{\rm ms}$; $R_{\rm out}$ = 20 R_g) and that the continuum (emitted in the energy range between 0.1 keV and 10 keV) mainly originates from a larger region ($R_{\rm inn} = 20$ R$_g$; $R_{\rm out} = 80$ R$_g$).

The variations of the integrated X-ray continuum and Fe Kα line flux due to caustic crossing over accretion disk are presented in Fig. 1. The results correspond to the black body, modified black body and power emissivity laws, respectively. As one can see from Fig. 1, when the continuum and line emission are separated, considering that inner disk contributes to the Fe Kα line and an outer annulus to the continuum, there is a significant difference between the continuum and the line amplification. The lack of observed associated enhancement of the X-ray continuum in objects with microlensed Fe Kα line can be expected when the microlens crosses the inner part of the disk (Fig. 1). However, the continuum never remains strictly constant during a complete Fe Kα microlensing event. In the best case there is a significant and relatively quick change of the Fe Kα emission while the continuum experiences only a slow increase. This behavior could well approximate non-varying continuum only for observations in a limited temporal window, during the maximum of the Fe Kα line microlensing event.

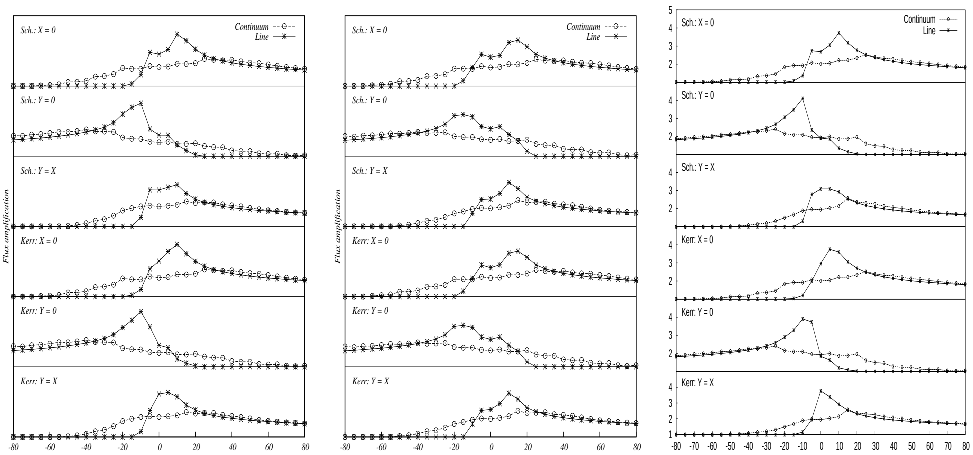

Figure 1: Variations of the Fe Kα line and X-ray continuum flux during a caustic crossing over the accretion disk in Schwarzschild and Kerr metrics in three different directions. The panels correspond (from the left to the right) to the black body, modified black body and power emissivity law, respectively. In the first two panels, the flux axis ranges from 1 to 1.7.

The corresponding total line and X-ray continuum flux variations due to microlensing magnification pattern in the case of the QSO 2237+0305A image are presented in Fig. 2. One can see that there is a global correlation between the total line and continuum flux variation during the complete event. However, the total continuum flux variation is smooth and has a monotonic change, while the total line flux varies very strongly and randomly. In fact, during certain portions of the microlensing event, the total Fe Kα line flux changes, while the continuum flux remains nearly constant.

This is in agreement with the observations of Chartas et al. (2002, 2004) and Dai et al. (2003), and supports the conclusions of these authors that enhancements of the Fe Kα line observed in only one image of quasars MG J0414+0534, QSO 2237+0305 and H1413+117 were caused by microlensing.

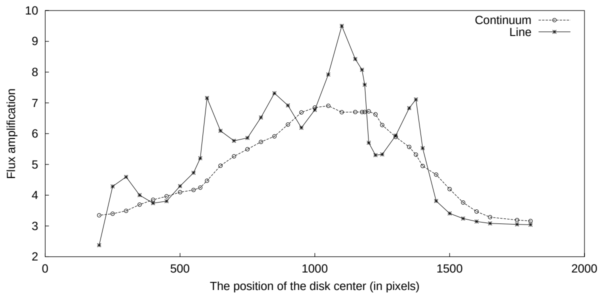

Figure 2: The amplification of the Fe Kα line and the X-ray continuum total flux for different positions of the disk center on the microlensing map of QSO 2237+0305A image.

4. Conclusions

In order to discuss the observed enhancements of the Fe Kα line and absence of corresponding continuum amplifications in the case of quasars MG J0414+0534, QSO 2237+0305 and H1413+117, we performed the numerical simulations of microlensig by straight fold caustic and caustic magnification pattern. According to obtained results we concluded that separation of the Fe Kα line and the X-ray continuum emitters (the case of inner Fe Kα disk plus an outer continuum annulus) allows us to reproduce the line enhancement without the equivalent continuum amplification due to microlensing, but only during the limited time intervals. Also, in a more realistic case of microlensing by a caustic magnification pattern due to a population of low mass deflectors, the observed lack of correlation between the X-ray continuum and Fe Kα emission can be successfully reproduced only if the line and continuum emission regions are separated.

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