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HOW MICROLENSING CAN CONTRIBUTE TO QSO VARIABILITY?

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Abstract. We study the infuence of gravitational microlensing on the AGNs X-ray radiation in order to explain the recently observed shape variations of X-ray continuum and Fe Kα line in the high-redshifted lensed quasars MG J0414+0534, QSO 2237+0305 and H1413+117. Assuming that the X-ray radiation is originating in accretion disc, we used the ray tracing method considering both geometries, Schwarzschild and Kerr, to analyze the amplifications of X-ray continuum and the Fe Kα line flux due to microlensing by a caustic microlens. Different sizes of emission regions, as well as different emissivity laws and different microlens parameters are used in our study. Our results show that the observed Fe Kα amplification without corresponding amplification of X-ray continuum can be expected when their emitting regions have different dimensions. Moreover, here we will discuss the optical depth for microlensing of QSO X-ray emitting region by cosmologically distributed gravitational microlenses which could be localized in galaxies (or even in bulge or halo of gravitational macrolenses) or could be distributed in a uniform way.

1. INTRODUCTION

Recent observational and theoretical studies suggest that gravitational microlensing can induce variability in the X-ray emission of lensed QSOs. Microlensing of the Fe Kα line has been reported in at least three macrolensed QSOs: QSO J0414+0534 (Chartas et al, 2002), QSO 2237+0305 (Dai et al, 2003), and H1413+117 (Oshima et al, 2001). The influence of microlensing in the Fe Kα spectral line shape was discussed in Popović et al. (2001); Chartas et al. (2002) and Popović et al. (2003). Popović et al. (2003) show that objects in a foreground galaxy with even relatively small masses can bring observable changes in the Fe Kα line flux. Such effects could be caused by stellar mass objects located in a bulge or/and in a halo of foreground galaxy as well as by cosmologically distributed objects. Thus, the observations of the X-ray continuum and the Fe Kα line in multi-imaged AGNs open new possibilities to study the unresolved X-ray emitting structure in QSOs.

Here we present our investigations regarding the continuum and Fe Kα line variability due to microlensing. Also, we discuss the optical depth of high-redshifted QSOs.

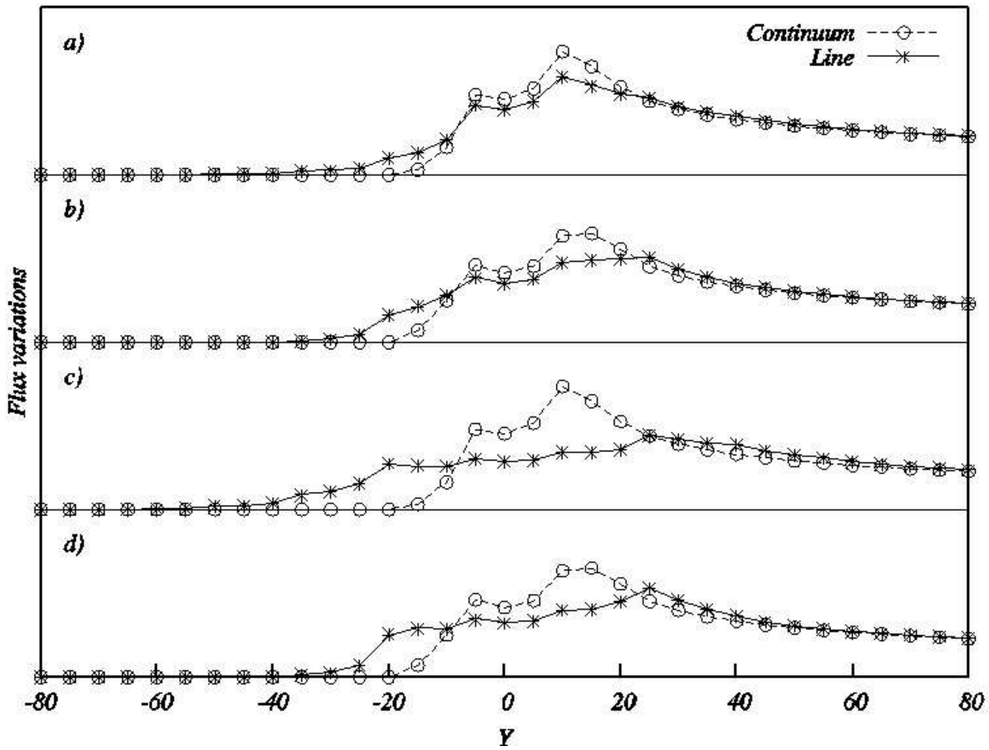

Figure 1: The variations of normalized total line and continuum flux in interval from 0.1 to 10 KeV due to caustic crossing (ERR=$50R_g$) parallel to the rotation axis for different Y positions in Schwarzschild metric. Figures correspond to: a) black body radiation in the case (II), b) modified black body in the case (II), c) black body radiation in the case (III), d) modified black body in the case (III). Flux variations are presented in the range from 1 to 1.7.

2. MICROLENSING OF A COMPACT ACCRETION DISC

Taking into account the previous results, we modeled the behavior of X-ray continuum and Fe Kα line during a microlensing event for different sizes of the continuum and the Fe Kα line emission regions. We assumed that X-ray continuum and Fe Kα line originated in an accretion disc with black body emission (Planck function) and that the microlensing event could be described by a caustic crossing. However, in the innermost part of the accretion disc the Planck function cannot be used properly and, therefore, we also used the standard Shakura-Sunyaev approach, where the disc emission was described by a "modified" black body radiation law (Shakura and Sunyaev, 1973).

For the disc inclination we adopted the averaged values given by Nandra et al. (1997) from the study of the Fe Kα line profiles of 18 Seyfert 1 galaxies: $i = 35^o$ and for caustic parameters we addopted ERR=50 Rg, A_0=1 and β=1. The inner radius,

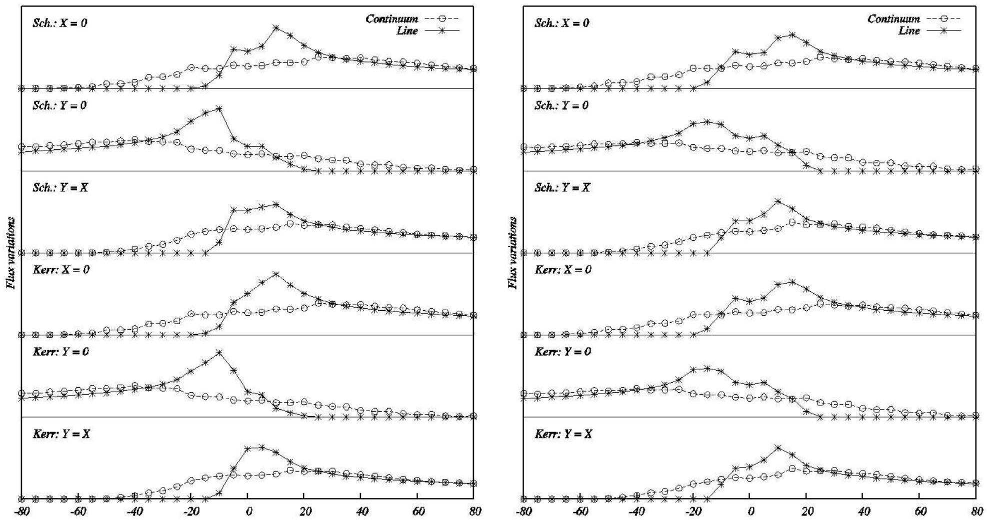

Figure 2: The variations of normalized total line and continuum flux in interval from 0.1 to 10 KeV for the case (IV) due to caustic crossing (ERR=$50R_g$) in three different directions. On the left are presented results for black body radiation and on the right for modified black body radiation. First three figures on each side correspond to Schwarzschild and last three to Kerr metric. Flux variations are presented in the range from 1 to 1.7.

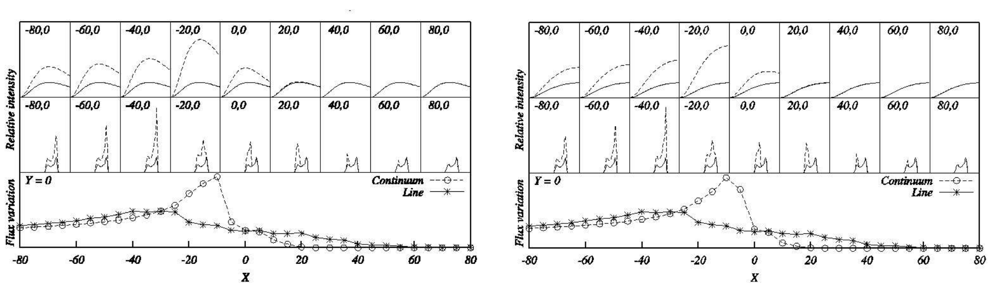

Figure 3: The variations of X-ray continuum and Fe Kα line for an highly inclined disc ($i = 75^o$) and ERR=2000 R_g in the case of black body radiation (left) and modified black body radiation (right). The other disc characteristics correspond to the case (III).

R_{in}, cannot be smaller than the radius of the marginal stability orbit, R_{ms}, that corresponds to $R_{ms} = 6\ R_g$ in the Schwarzschild metric and to $R_{ms} = 1.23\ R_g$ in the case of the Kerr metric with angular momentum parameter $a = 0.998$.

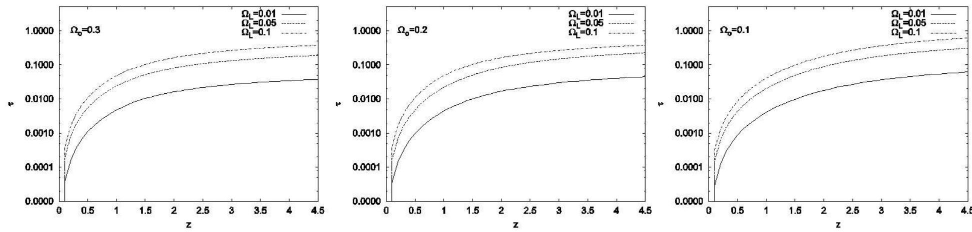

Figure 4: The calculated optical depth as a function of red-shift for different values of cosmological parameters Ω_L and Ω_0.

To explain the lack of the X-ray continuum response to the microlensing events detected in the Fe Kα line, we considered four cases of disc sizes for both continuum and line emitters:

- the inner and outer radii of both emission regions are the same, $R_{in} = R_{ms}$ and $R_{out} = 20\ R_g$
- the inner radii are the same, $R_{in} = R_{ms}$, but the outer radius of the X-ray continuum disc is smaller, $R_{out} = 20\ R_g$, than the radius of the line emission disc, $R_{out} = 80\ R_g$
- the continuum emission disc has radii $R_{in} = R_{ms}$, $R_{out} = 20\ R_g$ and the line emission disc $R_{in} = 20\ R_g$ and $R_{out} = 80\ R_g$
- the continuum emission disc has radii $R_{in} = 20R_g$, $R_{out} = 80\ R_g$ and the line emission disc $R_{in} = R_{ms}$ and $R_{out} = 20\ R_g$.

The corresponding results are presented in Fig. 1. and Fig. 2.

The observed BAL QSOs have highly inclined discs ($i > 60^o$), and the corresponding variations of X-ray continuum and Fe Kα line due to microlensing by solar mass deflectors are presented in Fig. 3. for both radiation laws.

In order to discuss the contribution of microlensing to X-ray variability of high-redshifted QSOs, we calculated optical depth (probability that at any instant of time the source is covered by a deflector) for microlensing caused by stellar mass objects. We considered the deflectors in the halo and bulge of host galaxy, as well as at the cosmological distances between observer and source. According to the cosmological SN (Supernovae) Ia data and CMB anisotropy one could take for the parameters of standard cosmological model $\Omega_\Lambda \sim 0.7$ and $\Omega_0 \sim 0.2$ (Zakharov et al. 2004). Optical depth is calculated using three different values for the matter fraction in compact lenses, $\Omega_L = 0.01$, $\Omega_L = 0.05$ and $\Omega_L = 0.1$ (see Fig. 4). The first value could be adopted if we assume that 20% of baryon matter could form microlenses, the second one if almost all baryon matter could form microlenses and the last one if about 30% of non-baryonic dark matter forms objects with stellar masses (Zakharov et al. 2004).

3. RESULTS

From our calculations we can conclude:

1. Not only the Fe Kα line could experience significant amplification by a microlensing event, but also the continuum (even for very small mass microlenses). Thus, the absence of continuum amplification in the observed Fe Kα microlensed QSOs should be related to the structure of the accretion disk and/or the geometry of the event.

2. Segregation of the emitters allows us to reproduce the observed flux variability. If the Fe Kα emitters were distributed in a structure inner to the continuum disc the simulations reproduce satisfactorily the observed Fe Kα enhancement without continuum amplification.

3. In the case of observed BAL QSOs where inclination is greater than 60^o, microlensing by solar mass deflectors, having ERR$\sim$2000 R_g, can explain observed flux variations.

4. The optical depth in the bulge and halo of host galaxy is $\sim 10^{-4}$, so microlensing by the deflectors from host galaxy halo and bulge have minor contribution in X-ray variability of QSOs.

5. The optical depth for cosmologically distributed deflectors could be $\sim 10^{-2}$–0.1 and can significantly contribute to the X-ray variability of high-redshifted QSOs. The value 0.1 corresponds to the case when compact dark matter forms cosmologically distributed microlenses.

6. The optical depth for cosmologically distributed deflectors is higher for $z > 2$ and after $z > 2$ slowly increases. It indicates that the contribution of microlensing into X-ray variability of QSOs with redshift $z > 2$ may be significant as well as that this contribution could be nearly constant for high-redshifted QSOs. It is in good agreement with the fact that the AGNs of the same X-ray luminosity are more variable at $z > 2$ (Manners, et al, 2002).

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