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An X-ray microlensing test of AU-scale quasar disk structure

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The innermostregion of quasars can be resolved by microlensing on scales down to a few AU. For this purpose, X-rays originating from the innermost regions can be selectively amplified by microlensing resulting from the "caustic crossing" events, and observations at X-ray bands are most preferable. If the observation has been done, lower limits of black hole mass will be determined, because information about gravitational potential of the black hole which is surrounded by accretion disk will be obtained.

1 INTRODUCTION

Generally, high power energy output from quasars is usually believed to created by the combination of a supermassive black hole with a surrounding accretion disk. This belief is supported by a number of observations such as radio observations of H_2O maser source (Miyoshi et al. 1995) which confirms the existance of huge mass in inner region, or asymmetric Fe line profile (Tanaka et al. 1995) which confirms the existance of relativistic object in inner region. However, the real vicinity of a putative black hole has not been resolved yet.

Now, we present a new method by using microlensing to determine the lower mass limit of a supermassive black hole in Q2237+0305 (e.g., Huchra et al., 1985) or so called 'Einstein Cross', in which quasar almost one microlensing event is detected per one year (e.g., Ostensen et al., 1996).

2 X-RAY MICROLENSING LIGHTCURVE

First, we calculate expected lightcurve of microlensing event of the quasar central engine, here we consider is as an accretion disk.

As an x-ray emitting source, we put an advection-dominated accretion flow (ADAF) which is recently well studied accretion disk model (e.g., Manmoto et al., 1997).

Furthermore, we divide this accretion disk into little pieces radially and azimuthally, (r_i, ϕ_j), with the size $dr_i \times d\phi_j = dr_i \times d\phi$, and caluculate the amplification factor (A) at each piece. For calculating A, we adopt a microlensing event caused by multiple lens objects instead of a single lens object, because especially about this quasar (Q2237+0305), it is well known that the rather high optical depth for microlensing and the effect of lensing galaxy itself induce former case of microlensing event (e.g., Wambsganss & Paczyński, 1994). However, microlensing calculations fully including such an effect is very complicated, and therfore

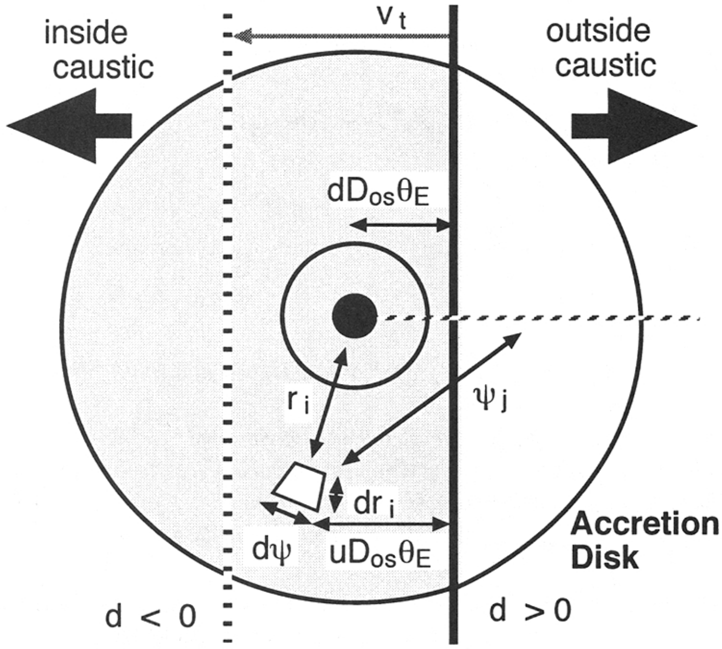

Figure 1: Schematic view of microlensing caused by caustic in our calculation. Here, d is distance between center of accretion disk and caustic, D_{OS} is distance between observer and source, and θ_E is Einstein ring radius. Another characters like r and ψ are the characters which characterize the elements of an accretion disk, i.e., a piece of an accretion disk.

we use analitically approximate formula (e.g., see Schneider et al. 1992) like below

$$A = A(u) = \frac{1}{\sqrt{u}} + A_0 \tag{1}$$

at each piece of accretion disk. Here, A_0 represents a constant amplification due to the initial amplification by the caustic and the effect of other caustics (in this simulation, we set $A_0 = 20.0$), and u is the separation between a caustic and a piece (part) of an accretion disk normalized with typical microlens size, so-called the "Einstein ring radius". This situation is shown in figure 1. If we moves caustic ,i.e. increase or decrease d with an arbitrary velocity, calculate amplification factor $A(u)$ at each piece of an accretion disk and sum up amplified flux from all pieces recurrently, we will obtain expected microlensing lightcurve. The resultant light curve expected by an X-ray observation is shown in figure 2.

3 LOWER MASS LIMIT

From figure reffig1, we can obtain the size of x-ray emitting region, and furthermore, we are able to know the lower mass limit of the central black hole. Details are followings.

A sharp increasing part of figure 2 directly reflects the time during a caustic sweep in front of an X-ray emitting region. Although there is the observational limit, it was possible to estimate the size of the emitting region. If we set the time of a sharp increase part of lightcurve as $t_{\rm cross}$ (from the beginning of the sharp rise to the peak of lightcurve), the size of such an x-ray emitting region ($r_{\rm cross}$) is estimated as $r_{\rm cross} \simeq v_t \cdot t_{\rm cross}$.

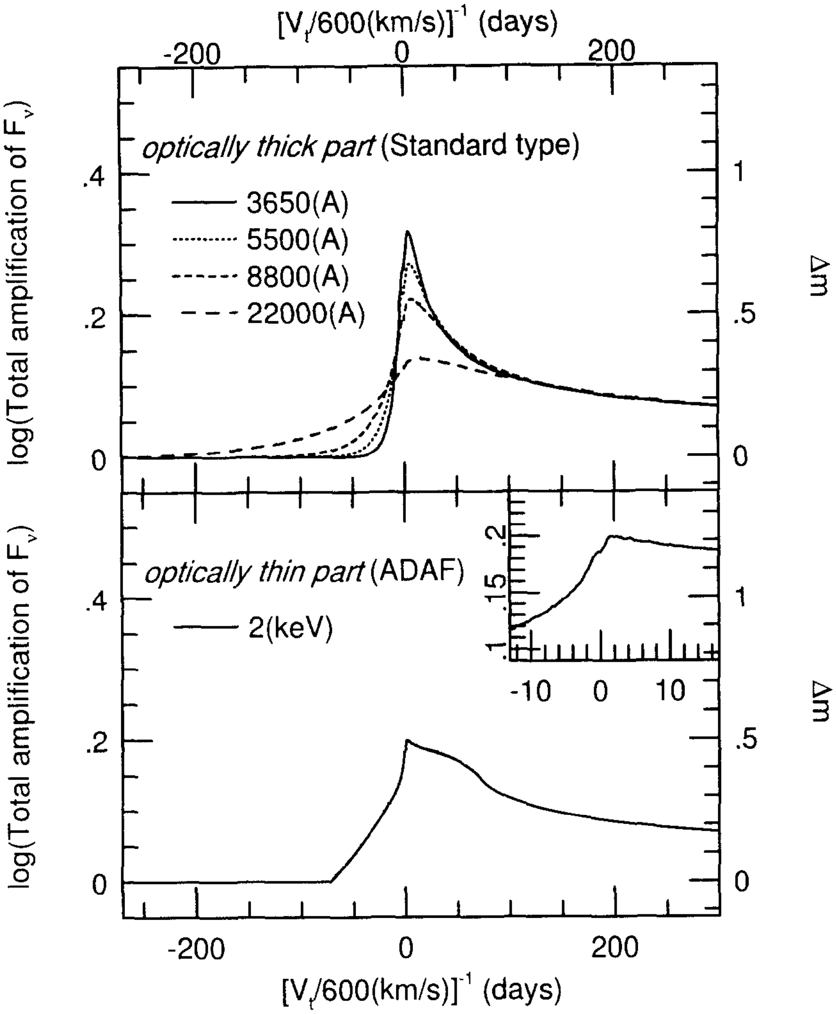

Figure 2: Microlensing light curves of an optically thick region (upper) for the U-band (3650Å; solid curve), the V-band (5500Å; dotted curve, the I-band (8800Å; dashed curve), the K-band (22000Å; long-dashed curve), and of an optically thin region (lower) for 2 keV X-rays (by the solid curve), respectively. In each curve, relative flux differences with respect to the values in the absence of a microlensing are plotted. The same light curves but on extended time scales are inserted in the upper right box of each panel. The mass of a lens object is assumed to be $1.0M_\odot$. Here, v_t is transverse velocity of a caustic at lens plane

Since a plasma emitting X-ray is within the potential of the central black hole with mass M, we have

$$\frac{kT_e}{m_p} \leq \frac{GM}{r}, \tag{2}$$

where, k being the Boltzmann constant, T_e the electron temperature, and m_p the proton mass, namely,

$$M > 2.0 \times 10^5 M_\odot \left(\frac{r_{\rm cross}}{2.5 \times 10^{14}{\rm cm}}\right) \left(\frac{T_e}{10^9{\rm K}}\right). \tag{3}$$

From the simulated lightcurve, we can expect that the sharp rise of x-ray lightcurve follows after the sharp rise of optical lightcurve at rather long wavelength. Therefore, optical monitoring of such a quasar available us to detect the sharp rise part of lightcurve at x-ray fairly well. After we observe the lightcurve at X-ray every 6 days and assume that the transverse velocity of the caustic is $\sim$ 600km s^{-1}, we can achieve a spatial resolution of 2.5×10^{14}cm (normalize value of $r_{\rm cross}$ at equation (3)) on the disk plane, and thus, we are able to set a lower mass limit of $\sim 10^5 M_\odot$ for typical $T_e \sim 10^9$K. This method can determine the lower mass limit in very small sizes (AU-scale). Recently, observation of such a microlensing event with AXAF is accepted and future observation will determine such a mass limit.

Details are shown in Yonehara et al., 1998 (see also, Yonehara et al., 1999).

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