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X-Ray Microlensing of Bright Quasars

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Abstract: We calculate the expected microlens light curves to see what aspects of flow structures can be extracted by microlensing. We specifically pick up a disk-corona model as a model for bright quasars. We then expect distinct behaviour in the soft and hard X-ray microlens variations. Since soft X-ray emission is produced by Compton up-scattering of soft (optical-UV) photons from the innermost part of the disk, while hard X-ray radiation is via bremsstrahlung within the corona of a large volume, the model calculations predict more rapid soft X-ray changes than hard X-ray ones. Further, bright spots (or blobs) on the disk will produce humps in the microlens light curves. Future microlens observations will constrain such emission processes, thereby probing accretion flow structure.

Keywords: accretion, accretion disks — black hole physics — galaxies: active — quasars: general

1 Introduction

It is widely believed that black-hole accretion works as a central engine producing quasar activity, although our understanding of the basic flow structure is still in a stage which is far from satisfactory. One reason is that we are unable to resolve accretion flow structure with any existing telescopes. There exists, however, one potentially useful method to investigate the structure of quasar accretion disks, and that is the technique of using microlensing (Chang & Refsdal 1979, 1984; Blandford & Hogg 1995). Broad-band photometry will be able to detect the colour changes, thereby revealing the structure of quasar accretion disks. Here, we elucidate the theory of microlens diagnostics on quasars. We present expected microlens light variations of luminous quasars based on the disk-corona model by Kawaguchi, Shimura & Mineshige (2001) and compare the results with those of other accretion flow models.

The ideal source for this purpose is Q 2237+0305, the so-called Einstein Cross (Huchra et al. 1985). The Einstein-ring radius on the source plane is $r_{\rm E} \sim 1.5 \times 10^{15}(M_{\rm lens}/{\rm M}_\odot)^{1/2}$ m, whereas a caustic crossing length over the quasar image plane during a time t is $r_{\rm cross} \sim 6.9 \times 10^{11} v_{1000}(t/1\,{\rm d})$ m, where $v_{1000} \equiv v_{\rm t}/1000\,{\rm km\,s}^{-1}$ with $v_{\rm t}$ being the transverse velocity of the lens object on the lens plane. Fortunately, this crossing length is comparable to the Schwarzschild radius for a $10^8{\rm M}_\odot$ black hole, $r_{\rm g} \simeq 3 \times 10^{11}$ m, and is much smaller than $r_{\rm E}$. Namely, due to a finite source-size effect, we are able to resolve the source structure on scales much less than the Einstein-ring radius. By frequent observations we can resolve the disk structure with a good spatial resolution (e.g. Wambsganss, Paczyński & Schneider 1990).

2 Accretion Flow Models and Microlens Variations

We here consider three representative flow models: the standard disk, the optically thin ADAF, and a composite disk-corona model.

In the standard disk model (Shakura & Sunyaev 1973) viscous heating is balanced with radiative cooling. From the basic equations we can uniquely determine effective temperatures as a function of radius for given black-hole mass, M, and mass-flow rate, $\dot{M}$. Here, we set $M = 10^8{\rm M}_\odot$, and $\dot{M}$ is determined so as to reproduce the observed V magnitudes of the Einstein Cross in the absence of microlensing. The resultant total spectrum and the local spectrum emitted from each concentric ring is displayed with thick and thin lines, respectively, in Figure 1 (left top). There are two prominent spectral features: (1) Since the disk emits blackbody radiation with temperature of $T \sim 10^5$ K, emitted photon energy is restricted to optical and UV ranges. (2) Brightness distribution simply reflects the depth of the gravitational potential well. Consequently, the disk is hotter inside and cooler outside.

Microlens light curves reflect such radial changes of the radiation spectra. The inner hot and outer cool character of the standard disk yields a smaller effective size of the region emitting shorter-wavelength radiation, causing more rapid variations in shorter-wavelength radiation than longer-wavelength radiation, as is depicted in the right top panel of Figure 1 (see also Yonehara et al. 1998).

The next solution is an optically-thin advection-dominated accretion flow (ADAF, Ichimaru 1977; Narayan & Yi 1995; Abramowicz et al. 1995). In this model, it is advective energy transport (energy flow carried by accreting material) that is balanced with viscous

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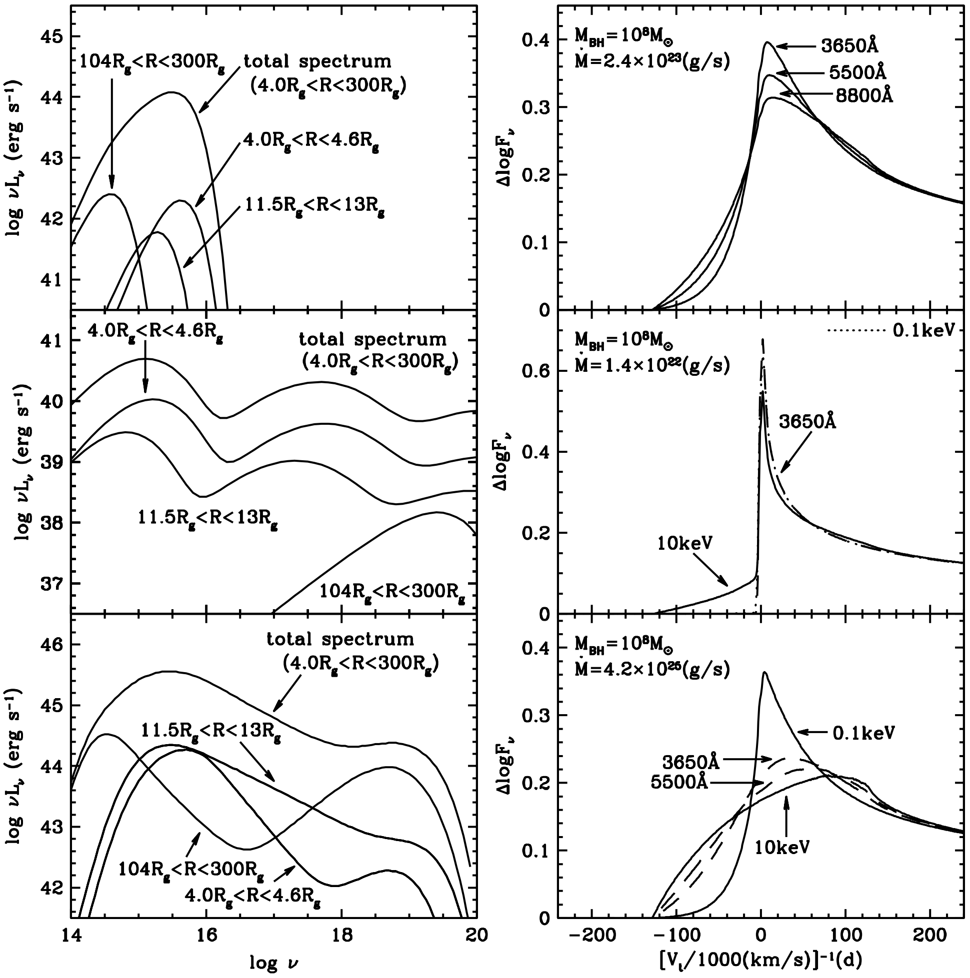

Figure 1 Left panels: Spectral energy distribution in the rest frame of a standard disk (top), an optically thin ADAF (middle), and a disk-corona model (bottom), all with the contributions by individual concentric rings plotted with thin lines. Right panels: Caustic crossing light curves of the standard disk (top), the ADAF (middle), and the disk-corona model (bottom). We set $\Delta F_\nu = 0$ outside the caustic.

heating. In contrast with the standard disk, in which accretion energy efficiently turns into radiation energy, accretion energy of gas in ADAF turns into its internal energy, with little being radiated (Ichimaru 1977). In a word, an ADAF is a faint hot flow, which contrasts with a cool and bright standard disk. In Figure 1 (left middle) we display the spectral energy distribution of a typical ADAF, calculated by Manmoto, Mineshige & Kusunose (1997). Two unique spectral features are: (1) Emitted photon energy is spread over a large frequency range, from radio (via synchrotron) to hard X–γ rays (via inverse Compton). (2) Radiation energy does not reflect the depth of the potential well, where photons are emitted.

The left middle panel of Figure 1 shows that the emission is dominated by that from the innermost part within $r \sim 10\, r_g$. This is because large magnetic field and electron energy densities are achieved only in that compact region, thus efficient synchrotron radiation in the radio region is possible there (radio photons are Compton upscattered to produce optical emission and X-rays). Its consequence is that microlens of ADAF produces rather abrupt changes both in the optical and soft X-ray fluxes as are displayed in the right middle panel of Figure 1.

Since the optically thin ADAFs are too faint to explain the luminosity of bright quasars, we need an alternative model for making high-energy emission possible from luminous AGNs. We finally consider a composite disk-corona model by Kawaguchi et al. (2001), since they could, for the first time, reproduce the observed broad-band spectral properties of quasars. The calculated spectrum is shown by the thick line of Figure 1 (left bottom). According to this model, the big blue bump is caused by thermal emission from the disk body at small radii, the soft X-ray excess is inverse-Compton scattering of the soft photons from the inner disk, and the hard X-rays are bremsstrahlung radiation from the coronae at large radii. The contributions of the individual rings are also displayed by thin lines in Figure 1.

Importantly, soft X-rays are only from the vicinity of the black hole, as in the case of ADAF, while hard X-rays are from rather wide areas. Such unique emission properties produce interesting features in the multi-wavelength

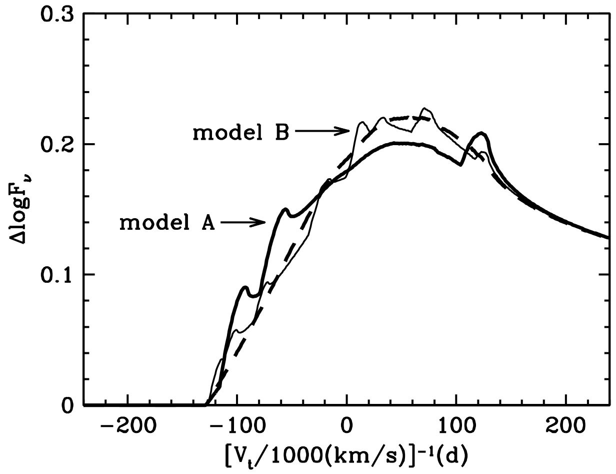

Figure 2 Microlens light curves of a disk with multiple blobs. The thick dashed line represents the case with no blobs, and the two solid lines represent the cases with 3 (model A) and 12 (model B) blobs.

microlens light curves (see the right bottom panel of Figure 1). Soft X-ray radiation shows a relatively sharp peak around the caustic crossing time, while hard X-ray variations are rather smooth. These features are closely related to distinct emission mechanisms in different X-ray energy bands, as described above.

3 Inhomogeneous Disk Structure

So far we have assumed a homogeneous, steady disk structure. However, the most striking feature of quasar light lies in its rapid variability. Probably such variation is caused by local, transient brightening or flares. We then expect a rather inhomogeneous disk structure full of blobs, spots, or filaments, if viewed with X-rays from its vicinity (just like the X-ray image of the Sun). Recently performed three-dimensional (3D) magnetohydrodynamical (MHD) simulations also support this view (Machida, Hayashi & Matsumoto 2000).

To demonstrate such effects, we perform some simple calculations: we put 3 (model A) or 12 (model B) blobs on a disk with a flat brightness distribution. The resultant light variations are plotted in Figure 2 in comparison with the case with no blobs (dashed line). Although the total blob luminosity is only 20% of the total in this model, microlens light variations record dramatic changes. In reality, moreover, positions and luminosities of blobs are likely to be time-varying, creating more complex variations. We may be able to obtain information regarding the site and emission processes of the intrinsic variability, when densely sampled microlens light curves at various wavelengths are available. More details will be published elsewhere (Takahashi, Yonehara & Mineshige 2001).

References

Abramowicz, M. A., Chen, X., Kato, S., Lasota, J.-P., & Regev, O. 1995, ApJ, 438, L37

Blandford, R. D., & Hogg, D. W. 1995, in IAU Symp. 173, Astrophysical Application of Gravitational Lensing, ed. C. S. Kochanek, & J. N. Hewitt (Dordrecht: Kluwer), p. 355

Chang, K., & Refsdal, S. 1979, Nature, 282 561

Chang, K., & Refsdal, S. 1984, A&A, 132, 168

Huchra, J., Gorenstein, M., Horine, E., Kent, S., Perley, R., Shapiro, I. I. & Smith, G. 1985, AJ, 90, 691

Ichimaru, S. 1977, ApJ, 214, 840

Kawaguchi, T., Shimura, T., & Mineshige, S. 2001, ApJ, 546, 966

Machida, M., Hayashi, M., & Matsumoto, R. 2000, ApJ, 532, L67

Manmoto, T., Mineshige, S., & Kusunose, M. 1997, ApJ, 489, 791

Narayan, R., & Yi, I. 1995, ApJ, 452, 710

Shakura, N. I., & Sunyaev, R. A. 1973, A&A, 24, 337

Takahashi, R., Yonehara, A., & Mineshige, S. 2001, PASJ, 53, 387

Wambsganss, J., Paczyński, B., & Schneider, P. 1990, ApJ, 352, 407

Yonehara, A., et al. 1998, ApJ, 501, L41; Erratum, 511, L65