Mapping Quasar Accretion Disks with Microlensing

X. Dai 1, C. S. Kochanek 1, G. Chartas 2, N. D. Morgan 1, C. W. Morgan 1, G. P. Garmire 2, E. Agol 3

(1 Ohio State Univ., 2 Penn. State Univ., 3 U. Washington)

Abstract

Quasar microlensing provides a unique tool to study the structure of quasar accretion disks because the sharp caustics in the magnification pattern provide a means of resolving all parts of the accretion disk and corona. In particular, by comparing the microlensing variability in the optical with that observed by Chandra in the X-rays, we can measure the relative sizes of the optical and X-ray emission regions of quasars. Here we compare the sizes of the optical and X-ray emission regions of two four image lensed quasars RXJ 1113-1231 and Q2237+0305. Like the other lensed quasars for which we have microlensing measurements, the optical sizes generally track the expected scaling of disk size at fixed temperature with black hole mass, r ∝ M^1/2, but the actual scale size is somewhat larger than expected for a thermally radiating thin disk. We clearly see that more massive black holes have cooler disks. The X-ray emission, however, requires a more compact source, with a radius of approximately 20 r_\text{g}, in both cases.

Scientific Motivation

Over the last decade, there has been steady progress toward a "first principles" theory of accretion disks (see review by Blaes 2004, Les Houches, 78, 137). Unfortunately, there has been little progress in observationally testing these theories for quasars, in large part because we cannot resolve the structure of the accretion disk. These problems are particularly acute for the X-ray emission from AGNs. There is a general consensus that the X-ray continuum emission is produced by an unobserved inverse Compton scattering of soft photons by hot electrons (see review of Reynolds & Nowak 2003, Phys. Rep. 377, 399). However, the extent and the geometrical configuration of the X-ray emitting region is an open question. Although the standard disk-corona model is the dominant model, there are alternatives such as the "lamp post" model, multiple hot flares, or hot jet models. The differences between the models lie in the extent of the X-ray source, its height above the accretion disk and whether it is composed of single large emitting region or many variable smaller sources. Moreover, uncertainties in models for the continuum emission lead to uncertainties in models for the relativistic FeKα lines that are probably created by reprocessing of X-ray continuum emission by the accretion disk.

Observations

The optical light curves were obtained with the SMARTS consortium I/M for RXJ 1113-1231 (Morgan et al 2006, astro-ph/0603121) and by OGLE for Q2237+0305 (http://www.astr.obs.uj.edu.pl/~ogle/gc3h/aarhus.html). The X-ray data were obtained by CXO Cycle 7 GO program 07700255, GTO program 07700072, and archival data.

Results and Implications

Fig. 4 shows examples of microlensing light curves that simultaneously fit the optical and X-ray light curves for RXJ 1131-1231. From the statistics of many such trial fits, we find the optical and X-ray size estimates in Fig. 5. The optical size is the point where the disk temperature matches the photon energy kT=1keV, which for this disk theory is $r_\text{eff} \approx \frac{1}{2} \frac{M}{M_\text{BH}}$.

While the results generally match our theoretical expectations, we do find that the disks are larger than expected given the observed quasar fluxes and the thin disk model. Fig. 6 shows the scaling with black hole mass, after scaling the optical sizes by R_\text{opt} \propto M^{1/2}, a common rest wavelength of 3000Å and combining these objects with several other estimates for the optical sizes from Morgan et al. (2006, in preparation). We see in general that the optical sizes increase with black hole mass as predicted by the thin disk theory but are systematically larger, while the two X-ray sizes are scaling more like a multiple of the black hole gravitational radius.

The origin of the optical size offset is unclear. Some of it is probably due to radiation transfer effects - contamination of the continuum emission by a line emission, effects from the disk atmosphere, irradiation of the outer disk by the inner disk - but some of it may also be due to genuine problems in the thin disk model for the release of the accretion energy. These questions can be probed by measuring the disk size as a function of optical wavelength.

The X-rays, however, have a spectacular future as we can see from the extrapolation of the model in Fig. 4. The X-ray microlensing variability should be quite dramatic and by monitoring the lensed quasars with longer exposure times that allow us to determine the flux ratios as a function of energy we should be able to determine the relative sizes of the soft, hard, and the FeKα emitting region. These measurements are possible only with Chandra.