THE EFFECT OF CORONAL RADIATION ON A RESIDUAL INNER DISK IN THE LOW/HARD SPECTRAL STATE OF BLACK HOLE X-RAY BINARY SYSTEMS

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ABSTRACT

Thermal conduction between a cool accretion disk and a hot inner corona can result in either evaporation of the disk or condensation of the hot corona. At low mass accretion rates, evaporation dominates and can completely remove the inner disk. At higher mass accretion rates, condensation becomes more efficient in the very inner regions, so that part of the mass accretes via a weak (initially formed) inner disk which is separated from the outer disk by a fully evaporated region at mid radii. At still higher mass accretion rates, condensation dominates everywhere, so there is a continuous cool disk extending to the innermost stable circular orbit. We extend these calculations by including the effect of irradiation by the hot corona on the disk structure. The flux which is not reflected is reprocessed in the disk, adding to the intrinsic thermal emission from gravitational energy release. This increases the seed photons for Compton cooling of the hot corona, enhancing condensation of the hot flow, and reinforcing the residual inner disk rather than evaporating it. Our calculations confirm that a residual inner disk can coexist with a hard, coronally dominated spectrum over the range of $0.006 < \dot{m} < 0.016$ (for $\alpha = 0.2$). This provides an explanation for the weak thermal component seen recently in the low/hard state of black hole X-ray binary systems.

Key words: accretion, accretion disks – black hole physics – X-rays: binaries – X-rays: stars

1. INTRODUCTION

It is well known that black hole X-ray binaries (BHXRBs) exhibit various spectral states. As recently reviewed by Remillard & McClintock (2006), such phenomena are quite common in BHXRBs. It is generally accepted that the transition from a spectrally soft to hard state is caused by a change in the accretion mode in the inner disk regions from a cool, geometrically thin structure at high accretion rates to a hot, geometrically thick, radiatively inefficient accretion flow (RIAF/ADAF) at low accretion rates.

Many theoretical studies have attempted to identify the mechanism responsible for this transition, taking into account processes such as radial conductive energy transport (Honma 1996; Manmoto & Kato 2000) and vertical evaporation (Meyer et al. 2000a; Różańska & Czerny 2000; Spruit & Deufel 2002; Dullemond & Spruit 2005; Mayer & Pringle 2007; Bradley & Frank 2009). Of these, the disk evaporation model is one of the more promising. Thermal conduction between a cool disk and a hot corona can result in either evaporation of the cold disk or condensation of the hot corona (Meyer et al. 2000a, 2000b, 2007; Liu et al. 2002, 2006). At accretion rates higher than the maximal evaporation rate, $\dot{m} \gtrsim 0.03$ (scaled by the Eddington rate $\dot{M}_{Edd} = 1.39 \times 10^{18} M/M_{\odot}$ g s^{-1}), for the specific case of $\alpha = 0.2$, a full disk coexists with a corona. At very low accretion rates, $\dot{m} \lesssim 0.006$, the inner disk completely evaporates into an ADAF. This gives an interpretive framework for features observed in BHRXBs, such as disk truncation as the cause of the spectral state transition (Liu et al. 1999; Meyer et al. 2000b; Liu & Meyer-Hofmeister 2001) and luminosity hysteresis between

the hard-to-soft and soft-to-hard transitions (Meyer-Hofmeister et al. 2005; Liu et al. 2005; Bradley & Frank 2009).

It also predicts more complex behavior at intermediate accretion rates, $0.006 \lesssim \dot{m} \lesssim 0.03$. Here, the disk is truncated into a composite form with a coronal gap settling between an inner disk and an outer disk, with the inner disk carrying a fraction of the mass accretion rate, covered by a corona which carries the remaining material (see, e.g., Figure 1 in Meyer-Hofmeister et al. 2009). This could explain the complex spectra seen in the intermediate state (Liu et al. 2006; Meyer et al. 2007), immediately following the soft state, and predicts that a weak inner cool disk component can coexist with a coronally dominated spectrum (Liu et al. 2007; Taam et al. 2008).

This residual inner disk provides a potential explanation of the recent observation of a weak thermal component in some BHXRBs in the low/hard state (Miller et al. 2006a, 2006b; Tomsick et al. 2008; Reis et al. 2009, 2010; Chiang et al. 2010). However, the calculations to date have only studied evaporation as a means of coupling the disk and corona, whereas radiative coupling from irradiation of the disk by the corona is also important. The corona illuminates the disk, and most of this irradiation is reprocessed, enhancing the luminosity of the disk, and these photons provide additional Compton cooling of the corona so there is strong feedback between the disk and corona (Haardt & Maraschi 1993). Here, we investigate the effect of this additional radiative coupling between the disk and corona, especially to determine whether the inner disk can survive or is completely evaporated by irradiation.

In Section 2, we briefly introduce the disk corona evaporation/condensation model and its extension to incorporate the effect of coronal irradiation. Numerical results from these models are presented in Section 3, showing the strength of the inner disk relative to the corona/ADAF. Our conclusion is presented in Section 4.

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2. THE MODEL FOR AN INNER DISK AROUND A BLACK HOLE INCLUDING IRRADIATION

The disk/corona model adopted here is based on the studies of Liu et al. (2006) and Meyer et al. (2007) with modifications recently incorporated in the works of Liu et al. (2007) and Taam et al. (2008). It is assumed that an ADAF-like corona (given by the self-similar equations of Narayan & Yi 1995, with $\alpha = 0.2$ and $\beta = 0.8$) lies above a thin disk. The corona is heated by the viscous release of gravitational energy of accreted gas and dominantly cooled by vertical conduction and Compton scattering of soft photons emitted by the underlying disk. In the vertical transition layer between the disk and corona, an equilibrium is established between the conductive flux from the upper corona, bremsstrahlung radiation, and vertical enthalpy flux. For a given distance from the black hole, a fraction of the disk gas is heated and evaporated to the corona when the conduction flux is too large to be radiated away. On the other hand, a certain amount of coronal gas is cooled down, condensing to the disk if the bremsstrahlung radiation is more efficient than the conduction. At accretion rates around a few percent of the Eddington value, gas evaporates from the disk to the corona around a few hundred Schwarzschild radii and partially condenses back to the disk in the innermost region (Liu et al. 2006, 2007; Meyer et al. 2007).

2.1. The Condensation Feature Without Irradiation

In the case of conduction-dominant cooling the condensation rate is given as (Liu et al. 2006, 2007; Meyer et al. 2007; Taam et al. 2008)

$$\dot{m}_{cnd}(r) = 3.23 \times 10^{-3}\alpha^{-7}\dot{m}^3 [1 - 6(r/r_d)^{1/2} + 5(r/r_d)^{3/5}], \tag{1}$$

where r_d is the critical radius from which gas flowing changes from evaporation in the outer region to condensation in the inner region. Here, r_d, is expressed as

$$r_d = 0.815\alpha^{-28/3}\dot{m}^{8/3}. \tag{2}$$

In the case of Compton-dominant cooling the condensation rate is

$$\dot{m}_{cnd}(r) = A\left\{2B\left[\left(\frac{r_d}{r}\right)^{1/2} - 1\right] - \int_{r/3}^{r_d/3} x^{1/5}(1 - x^{-1/2})^{-2/5}dx\right\}, \tag{3}$$

where

$$A = 6.164 \times 10^{-3}\alpha^{-7/5}m^{-2/5}\dot{m}^{7/5}\left(\frac{T_{eff,max}}{0.3\ \text{keV}}\right)^{-8/5}, \tag{4}$$

$$B = 3.001\alpha^{-14/15}m^{2/5}\dot{m}^{4/15}\left(\frac{T_{eff,max}}{0.3\ \text{keV}}\right)^{8/5}\left(\frac{r}{3}\right)^{1/2}, \tag{5}$$

and r_d is the critical condensation radius,

$$r_d\left[1 - \left(\frac{3}{r_d}\right)^{1/2}\right]^{-4/7} = 14.417\alpha^{-4/3}m^{4/7}\dot{m}^{8/21} \times \left(\frac{T_{eff,max}}{0.3\ \text{keV}}\right)^{16/7}, \tag{6}$$

$T_{eff,max}$ is the maximal disk temperature, which depends on the condensation rate integrated from the outer edge of the inner disk (r_d) to the distance $r_{tmax} = 49/12$,

$$T_{eff,max} = 1.3348 \times 10^7 m^{-1/4}\dot{m}_{cnd}^{1/4}(r_{tmax})\ \text{K}. \tag{7}$$

The radial distribution of disk temperature is approximately expressed as

$$T_{eff}(r) = 2.05T_{eff,max}\left(\frac{3}{r}\right)^{3/4}\left[1 - \left(\frac{3}{r}\right)^{1/2}\right]^{1/4}. \tag{8}$$

For a black hole with given mass m (in units of solar mass), accretion rate $\dot{m}$, and viscosity parameter α, the condensation rate can be determined by Equation (1) or Equation (3). In the Compton-dominant case, an effective temperature ($T_{eff,max}$) is presumed for calculating the condensation rate, with which a new temperature is derived from Equation (7). Iterative calculations are carried out until the presumed temperature is consistent with the derived value. Compton cooling becomes dominant when the accretion rate ($\dot{m}$) is high or/and the disk is heated to a high temperature (for details, see Liu et al. 2007). At low accretion rates, Compton cooling is either negligible or only dominant in a very narrow inner region. In this case, the total condensation rate (and hence the disk temperature) is an integral over the conduction-dominant region and Compton-dominant region (if it exists), and the size of the inner disk is determined by Equation (2).

2.2. Inclusion of Irradiation

Since the inner disk is optically thick, the irradiating photons are primarily reprocessed as blackbody radiation. These additional soft photons propagate through the corona and lead to more efficient Compton scatterings. This leads to enhanced coronal cooling, so a greater amount of coronal gas condenses into the inner disk. Therefore, the effect of the irradiation is to increase the condensation, building up a relatively strong inner disk. This increase is dependent on the irradiative luminosity, the absorption/scattering of the associated photons by the inner disk, and the covering factor of the inner disk as seen from the ADAF. The value of the albedo is usually taken as a constant equal to 0.15 (Haardt & Maraschi 1993). Both the irradiation luminosity and covering factor are determined by the accretion rate, the latter dependence resulting from the dependence of the inner disk size on the accretion rate.

2.2.1. The Covering Factor of a Disk to an ADAF

Assuming that the radiation from the ADAF can be represented as a point source lying above the disk center at a height of H_s, the covering factor of a disk ring at distances between $R_{in} \leqslant R \leqslant R_{out}$ is given by

$$f = \int_{R_{in}}^{R_{out}} \frac{H_s}{4\pi(R^2 + H_s^2)^{3/2}}2\pi R\,dR$$
$$= \frac{1}{2}\left[1 + \left(\frac{R_{in}}{H_s}\right)^2\right]^{-\frac{1}{2}} - \frac{1}{2}\left[1 + \left(\frac{R_{out}}{H_s}\right)^2\right]^{-\frac{1}{2}}. \tag{9}$$

For a disk characterized by $R_{in} = 0$ and $R_{out} = \infty$, Equation (9) yields $f = 1/2$, indicating that half of the ADAF radiation is intercepted by a full disk. For a small disk ring characterized by $3R_s \leqslant R \leqslant 10R_s$, the covering factor is 0.2, provided that the height of the irradiation source is $H_s = R_{in} = 3R_s$ (R_S is the Schwarzschild radius). Therefore, only a small fraction of the ADAF radiation illuminates the truncated inner disk ring.

2.2.2. The Irradiations from the Corona

Assuming that the total intrinsic luminosity of the corona above and below the disk is given as $L_{c,in}$, the illumination flux to the disk surface per unit area is

$$F_{ir} = \frac{1}{2} L_{c,in} (1-a) \frac{H_s}{4\pi \left(R^2 + H_s^2\right)^{3/2}}, \qquad (10)$$

where a fraction of the irradiation flux, a, is assumed to be reflected at the disk surface. To simplify the calculation of the condensation/evaporation rate, Equation (10) is approximated as

$$F_{ir} \approx \frac{3 L_{c,in} (1-a)}{8\pi R^3} H_s \left[1 - \left(\frac{3R_s}{R}\right)^{1/2} \right], \qquad (11)$$

which is equivalent to assuming the covering factor per unit surface area, $\frac{H_s}{4\pi(R^2+H_s^2)^{3/2}} = \frac{3H_s}{4\pi R^3}[1-(\frac{3R_s}{R})^{1/2}]$. The coefficient of 3 in Equation (11) is a normalization factor determined by the fact that a full disk covers half of the sky of a corona as shown in Section 2.2.1 (that is, $f \approx \int_{3R_s}^{\infty} \frac{3H_s}{4\pi R^3}[1-(\frac{3R_s}{R})^{1/2}]2\pi R dR = 1/2$). The expression for F_{ir} given by Equation (11) is close to the exact expression for the irradiating flux given by Equation (10) at $R = (49/36)R_s$ where a standard disk reaches its maximal temperature and, hence, is a good approximation.

The illumination flux heats the optically thick disk and is eventually re-emitted as soft photons. Thus, the radiative flux from the disk is composed of both accretion released energy and irradiative energy by the corona, which we express as

$$F_d = \sigma T_{eff}^4 = \frac{3GM\dot{M}_{cnd} \left[1 - \left(\frac{3R_s}{R}\right)^{1/2} \right]}{8\pi R^3}$$
$$\times \left[1 + \frac{6L_{c,in}(1-a)}{\dot{M}_{cnd}c^2} \frac{H_s}{3R_s} \right]. \qquad (12)$$

The corresponding disk temperature is modified by irradiation as

$$T_{eff}(r) = 2.05 T_{eff,max} \left(\frac{3}{r}\right)^{3/4} \left[1 - \left(\frac{3}{r}\right)^{1/2} \right]^{1/4}$$
$$\times \left[1 + \frac{6L_{c,in}(1-a)}{\dot{M}_{cnd}c^2} \frac{H_s}{3R_s} \right]^{1/4}. \qquad (13)$$

Therefore, the disk temperature is raised by a factor of $[1 + \frac{6L_{c,in}(1-a)}{\dot{M}_{cnd}c^2} \frac{H_s}{3R_s}]^{1/4}$. This factor is added to the expression of $T_{eff,max}$ (Equation (7)) in calculating the condensation rate with Equations (3)–(6).

3. RESULTS

Given the mass of a black hole and an accretion rate, the condensation rate, corona luminosity, and size of an inner disk can be calculated. From these quantities, the covering factor and, hence, the irradiating flux at any given distance can also be determined. As the density of the soft photons, representing reprocessed irradiating photons and photons originating from the viscous dissipation in the disk, differs from the unirradiated case, iterative calculations are performed until the derived soft photon density is consistent with the presumed one. For $M = 10\,M_\odot$, $\alpha = 0.2$, $H_s = 3R_s$, $a = 0.15$, $\dot{m} \equiv \dot{M}/\dot{M}_{Edd} < 0.03$ (so that a composite corona/ADAF geometry can form), we
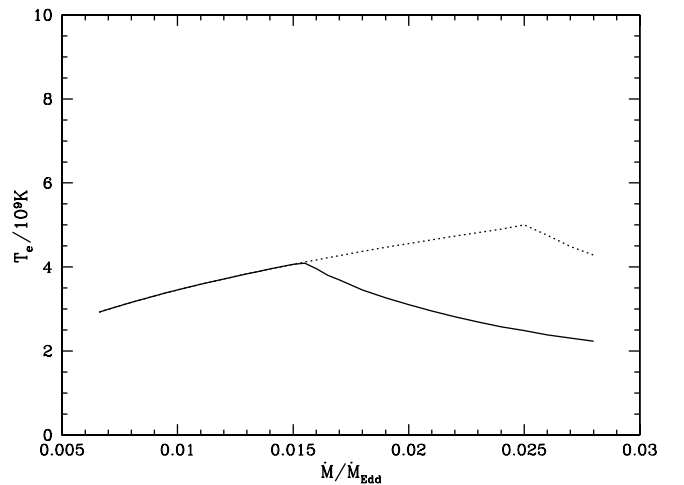

Figure 1. Variation of the electron temperature in the corona with respect to the mass accretion rate for the cases with irradiation (solid line) and without irradiation (dotted line). Irradiation does not affect the temperature at low accretion rates, while it leads to lower temperatures at higher accretion rates. The maximum temperature corresponds to the transition where the dominant cooling process changes from conduction at low accretion rates to Compton scattering at high accretion rates.

calculate the condensation of this coronal flow to an inner, residual disk and determine the relative strength of the corona with respect to the disk.

Figure 1 shows the electron temperature in the corona as a function of mass accretion rate. There is a marked change in behavior at $\dot{m} = 0.015$, with irradiation making very little difference below this point. This is because at low mass accretion rates the cooling in the corona is dominated by vertical heat conduction rather than by Comptonization. Thus, increasing the soft photons from the reprocessed radiation flux makes little difference to the coronal temperature, so the condensation rate is unaffected. However, at higher mass accretion rates, Compton cooling of the corona becomes important and the inner disk is large. The inner disk subtends a large angle to the corona radiations, further increasing irradiation. Thus, the seed photon luminosity largely increases, leading to a decrease in electron temperature of the corona. This decreases the conductive heating to the transition layer, and so leads to an increase of the condensation rate. We show this in Figure 2, defined as the integrated condensation rate from the outer edge of the inner disk to the innermost stable circular orbit, ISCO (so the mass flow rate through the innermost part of the corona at the ISCO is $\dot{m} - \dot{m}_{cnd}$). However, this increased condensation has very little effect on the size of the residual inner disk (Figure 3) as by this stage the outer edge of the inner disk is already fairly large. Irradiation is preferentially to the inner disk so the increased condensation adds material to the inner disk rather than increasing its outer radius.

While irradiation of the disk makes little difference to the corona at the lowest mass accretion rates at which the composite geometry can exist, it does make a difference to the observed emission from the inner disk because the intrinsic accretion-heated inner disk emission is extremely dim compared to the corona illumination. Figure 4 shows the inner disk temperature for the irradiated and non-irradiated cases. Irradiation heating means that the disk has a higher temperature (and luminosity) than expected from its mass accretion rate alone. This can be compared to the compilation of observations of the residual thermal emission in BHXRBs of Reis et al. (2010), where the typical temperature of the soft component is ∼0.2 keV.
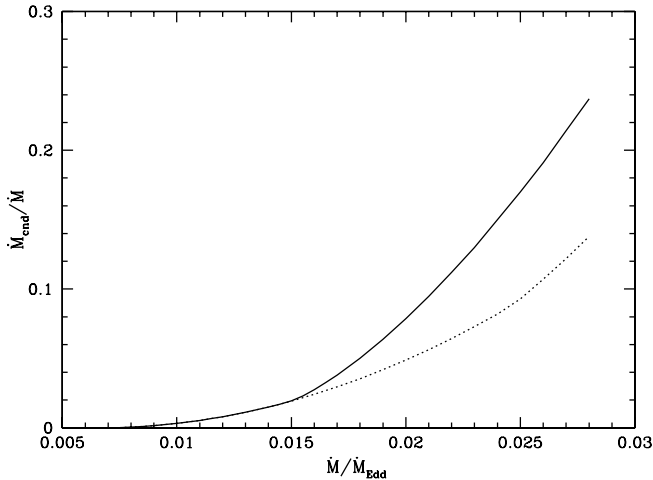
Figure 2. Comparison of the condensation fraction of the coronal accretion flow for the cases with irradiation (solid line) and without irradiation (dotted line). The condensation fraction is unaffected by the irradiation at low accretion rates, while it is increased by the irradiation at high accretion rates.
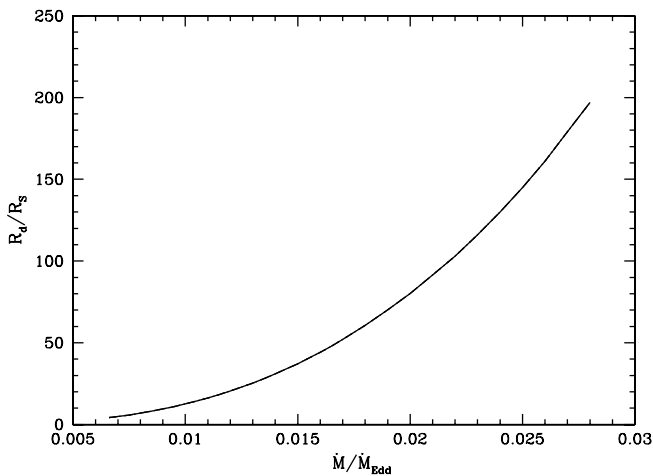

Figure 4. Maximal effective temperature of the inner disk heated by accretion and irradiation is shown as a function of the mass accretion rate. The solid line corresponds to the case with irradiation and the dotted line for the case without irradiation.

Figure 3. Size of the inner disk is shown as a function of the accretion rate. The two curves including irradiation and excluding irradiation overlap, indicating that there is no influence from irradiation.

There is probably a color temperature correction of $\sim$1.6–1.8 between the observed and effective temperatures (Shimura & Takahara 1995), so the data probably correspond to an effective temperature of $\sim$0.10–0.15 keV, matching well with the predictions of the irradiated inner disk for low mass accretion rates ($\dot{m} \lesssim 0.02$).

The enhanced luminosity of the disk also impacts on the observed spectrum of the corona. At the lowest luminosity the coronal radiation is dominated by bremsstrahlung rather than Compton scattering, so the (small) increase in seed photon flux makes little difference to the spectrum. However, Comptonization increases in importance as the mass accretion rate increases, and is comparable to bremsstrahlung from the transition layer at $\dot{m} = 0.015$. Above this, Comptonization is dominant, and the ratio of (reprocessed) disk to coronal emission sets the slope of the Comptonized spectrum so that the larger this ratio, the softer the spectrum (Haardt & Maraschi 1993).

Most of the spectra in Reis et al. (2010) show a weak soft component coexisting with hard spectra, with $\Gamma < 1.8$. From Compton cooling models, both numerical (EQPAIR: Coppi 1991) and analytic (Pietrini & Krolik 1995) require that the ratio $L_d/L_c < 0.3$. This ratio can be estimated analytically as a
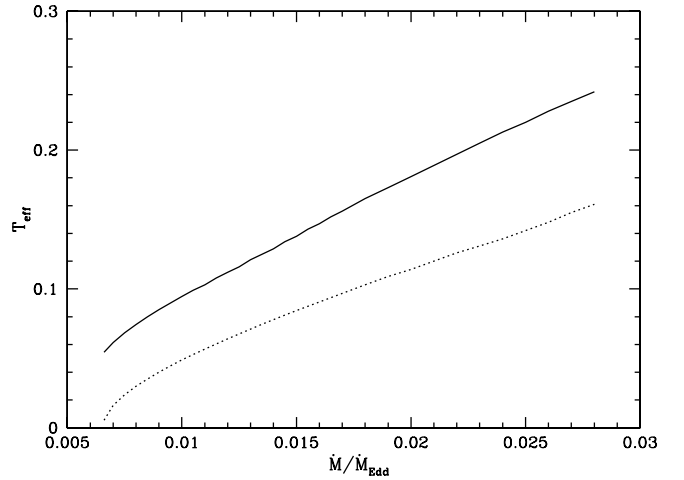
function of the covering fraction of the disk, f, and its albedo, a, so that $L_d/L_c = f(1-a)/[1-f(1-a)]$ (Haardt & Maraschi 1993). This is a lower limit as there should be some intrinsic dissipation from the material accreting through the disk. Hence, $\Gamma < 1.8$ (equivalent to $0.3 > L_d/L_c > f(1-a)/[1-f(1-a)]$) requires $f < 0.27$ for $a = 0.15$. Such a low covering fraction requires that the residual inner disk is rather small, corresponding to $R_{\text{out}} = 13.5R_s$. Such a small disk is only possible at very low mass accretion rates, so there is very little range in $\dot{m}$ over which the residual disk can coexist with a hard spectrum.

However, this conclusion is very dependent on the assumed albedo. A more reflective disk (so that less of the irradiating luminosity is reprocessed) can give harder spectra for larger inner disks. However, hard spectra peak at high energies, where Compton downscattering means that the energy cannot be completely reflected. This leads to a maximum possible albedo of $a \sim 0.6$, corresponding to a covering fraction $f < 0.58$. This estimate does not appear to constrain the disk size. We note that the disk accretion could contribute a luminosity comparable with the reprocessed disk luminosity in the case of a large albedo, $a = 0.6$. Including this effect, the covering factor required to produce spectra $\Gamma < 1.8$ is smaller.

We confirm these estimates with the numerical results of L_d/L_c from our models. This ratio is shown in Figure 5 for the representative albedos of 0.15 and 0.6, and the requirement that the ratio is less than 0.3 in order to produce hard spectra ($\Gamma < 1.8$) directly constrains $\dot{m} < 0.01$ or 0.016 for $a = 0.15$ and 0.6, respectively.

Thus, the model can indeed produce a residual inner disk temperature and hard coronal luminosity to match the observations of the small thermal component seen together with a hard X-ray continuum, but only for a limited range in the mass accretion rate of $0.006 < \dot{m} < 0.01$ for mostly neutral reflection or $0.006 < \dot{m} < 0.016$ for a highly ionized disk. Thus, the model predicts that the composite geometry (outer disk, coronal gap, with mass accretion rate in the innermost regions split between a weak disk and coronal flow) can only be seen over a range in luminosity of at most a factor of ~ 7 assuming an efficiency of the coronal flow $\eta \propto \dot{m}$. Even this maximum range in luminosity is slightly smaller compared to the observations of Reis et al. (2010). These show the thermal component
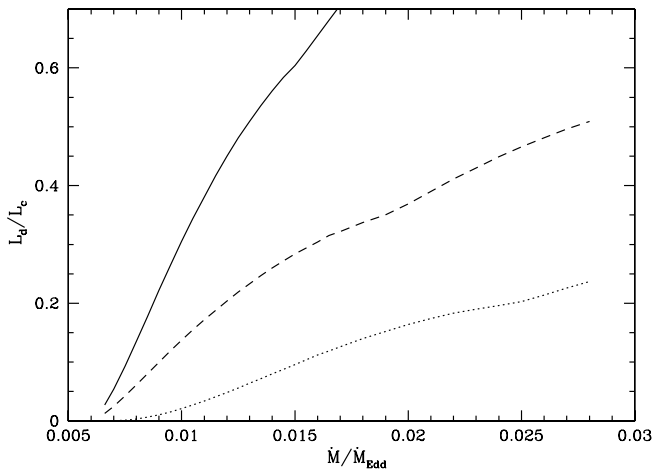
Figure 5. Ratio of the luminosity from the disk relative to the corona is shown as a function of the mass accretion rate. The solid line corresponds to the case with irradiation and the dotted line to the case without irradiation. Here, L_c denotes the emergent coronal luminosity where the fraction absorbed by the inner disk is deducted from the coronal emission. The luminosity ratio is significantly increased by the irradiation; however, it steeply drops to zero when the accretion rate decreases to the critical value of ~0.006. The influence of the albedo is shown by the dashed line, where $a = 0.6$ is assumed. The effect of irradiation is much reduced if a larger fraction of the irradiation flux is reflected at the disk surface.

together with hard spectral index ($\Gamma < 1.8$, so J1650−500 with $\Gamma = 2.1$ excluded) over a range of about a factor of 10 in L_X/L_{Edd} (more if XTE J1118+480 is included), but we note that there are substantial uncertainties in system parameters, so this can be consistent with the data. A bigger discrepancy is that the mass accretion rate of $\dot{m} = 0.006$–0.016 in the model corresponds to a luminosity of $L/L_{Edd} \approx (1$–$9) \times 10^{-3}$ (assuming a self-similar ADAF with energy conversion efficiency $\eta = 0.1 \times \frac{\dot{m}}{0.03}$), somewhat smaller than that seen in the data which cluster around $L/L_{Edd} \lesssim (5$–$9) \times 10^{-3}$ (Reis et al. 2010). However, the scaling from the mass accretion rate to luminosity is dependent on the model parameters chosen, particularly on α (Esin et al. 1998).

At higher mass accretion rates, the spectrum softens strongly as the increased seed photon flux leads to increased Compton cooling of the corona. This means that the *spectral* transition is triggered earlier than expected from the statement that the disk should exist at all radii. Models with $\dot{m} \sim 0.02$ do not have a continuous disk. There is still a coronal gap, but the spectrum is formed mainly in the innermost regions, and at these radii the disk covers almost half the sky as seen from the corona. Comptonized emission calculated from such a composite accretion flow with electron temperature and optical depth determined by our model for $\dot{m} \sim 0.02$ yields a photon index $\Gamma \sim 2$. Thus, the transition from the low/hard to intermediate state occurs at $\dot{m} \sim 0.02$ or $L/L_{Edd} \sim 1.3 \times 10^{-2}$.

4. CONCLUSIONS

We investigate the influence of coronal radiation on the properties of an existing residual inner disk. For accretion rates close to the hard-to-soft transition rate ($\dot{m} \sim 0.03$), the disk is only truncated in a very narrow radial extent by mass evaporation. In this case, the disk is described by a geometrically thin inner region, a narrow geometrically thick intermediate region, and a geometrically thin outer region. Here, we find that including irradiation results in efficient Compton cooling and condensation of coronal gas to the inner disk, with the emergent

spectrum much softer than predicted without reprocessing. This means that the transition from the intermediate to low/hard state occurs at a lower mass accretion rate, at $\dot{m} \sim 0.016$–0.02 for the specific parameters assumed here, rather than at $\dot{m} \sim 0.03$ without irradiation.

Below this, evaporation from the outer region results in an increased radial extent of the ADAF region and a smaller inner disk. The resulting geometry leads to a greater fraction of photons which can escape from the ADAF without irradiating the inner disk. Therefore, at sufficiently low accretion rates ($\dot{m} \lesssim 0.015$), the irradiation of the inner disk is small and the resulting Compton cooling does not significantly influence the dynamical process in the corona. Consequently, the condensation rate is not affected, while the inner disk is heated to a higher effective temperature by irradiation.

Thus, a weak, inner disk can exist in the low/hard state even if irradiation is taken into account. The ratio of luminosities emergent from the disk and corona decreases with decreasing mass accretion rates, until $\dot{m} \sim 0.006$ at which mass condensation no longer occurs and the inner disk cannot be sustained. Our results are in broad agreement with recent X-ray observational results that systems with a weak disk can exist in the low/hard spectral state (Reis et al. 2010).

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