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Spectral Energy Distributions of Active Galactic Nuclei from an Accretion Disk with Advective Coronal Flow

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Abstract

To explain the broad-band spectral energy distributions (SED) of Seyfert nuclei and QSOs, we study the emission spectrum emerging from a vertical disk-corona structure composed of a two-temperature plasma by solving hydrostatic equilibrium and radiative transfer self-consistently. Our model can nicely reproduce the soft X-ray excess with α ($L_\nu \propto \nu^{-\alpha}$) of about 1.5 and the hard tail extending to ~ 50 keV with $\alpha \sim 0.5$. The different spectral slopes ($\alpha \sim 1.5$ below 2 keV and ~ 0.5 above) are the results of different emission mechanisms: unsaturated Comptonization in the former and a combination of Comptonization, bremsstrahlung, and reflection of the coronal radiation at the disk-corona boundary in the latter.

Key words: accretion, accretion disks, radiation mechanisms: miscellaneous

1 Introduction

Recent multi-waveband observations of Active Galactic Nuclei (AGNs) have established significant deviations in the spectral shape of big blue bump from a blackbody one. A number of authors have tried to distort the accretion-disk spectrum toward the high energy regime so that the disk can emit substantial soft X-ray radiation as is observed. One promising idea is Comptonization within the disk in the vertical direction (e.g., [1, 2, 3]). The effect of Comptonization is more prominent at higher accretion rates.

However, there still remain discrepancies between models and observations. i) Although Comptonization tends to increase α, the Far-UV (FUV) spectrum

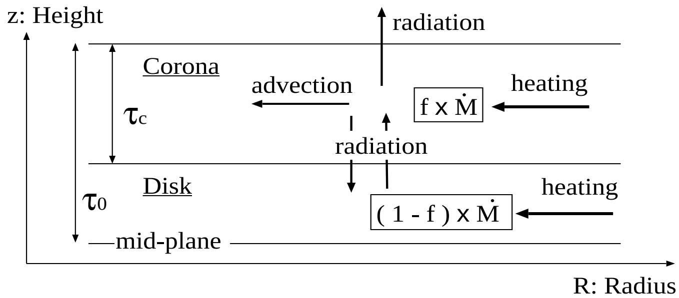

Fig. 1. A schematic view of the configuration of our disk-corona model.

of a Comptonized accretion disk has $\alpha \sim 1$ at best ([1, 3]), whereas observed FUV spectra of distant quasars seem to be steeper ($\alpha \sim$ 1.8–2.2; [4]). ii) The observed spectral index in soft X-rays ($\alpha \sim$ 1.4–1.6; [5]) is not achieved by any disk models since they produce Wien bumps at high energy, thus exhibiting exponential roll-over. iii) Comptonized accretion disks cannot reproduce the hard X-rays. Thus, hard X-ray emission should be treated as an additional component in these models.

We therefore propose a new model, aiming to produce the overall SED by a disk-corona model. The observed composite spectrum is taken from [4, 5] (see [6] for issues to be kept in mind).

2 Basic Assumptions

The numerical code used in this study is basically the same as that of [2, 3] except for some modifications. A constant fraction, f, of mass accretion ($\dot{M}$) is assumed to be dissipated in the corona with a Thomson optical depth of $\tau_{\rm c}$, where we consider advective energy transport of protons as well as radiative cooling of electrons (Figure 1). A remaining fraction, $1-f$, dissipates within the disk layer. The advective cooling rate in the corona is taken from the expression of an optically thin advection dominated accretion flow (ADAF; [7]) The efficiency of the advection is controlled by the viscosity parameter in the corona, α_c.

The heating rate in the disk and corona, $q_{\rm d}^+$ and $q_{\rm c}^+$, are proportional to $(1-f)\dot{M}$ and $f\dot{M}$, respectively, and the advective cooling rate in the corona per unit volume, $q_{\rm adv}^-$, is assumed to be proportional to the matter density. The energy balance in each layer is as follows:

$$\text{Disk}: \quad \text{Protons}: q_{\rm d}^+ = \lambda_{\rm ie} \quad \text{Electrons}: \lambda_{\rm ie} = q_{\rm rad}^- \tag{1}$$

$$\text{Corona}: \quad \text{Protons}: q_{\rm c}^+ = q_{\rm adv}^- + \lambda_{\rm ie} \quad \text{Electrons}: \lambda_{\rm ie} = q_{\rm rad}^-, \tag{2}$$

where $\lambda_{\rm ie}$ is the energy exchange rate due to Coulomb collisions and $q_{\rm rad}^-$ is the radiative cooling rate. We consider free-free emission/absorption and

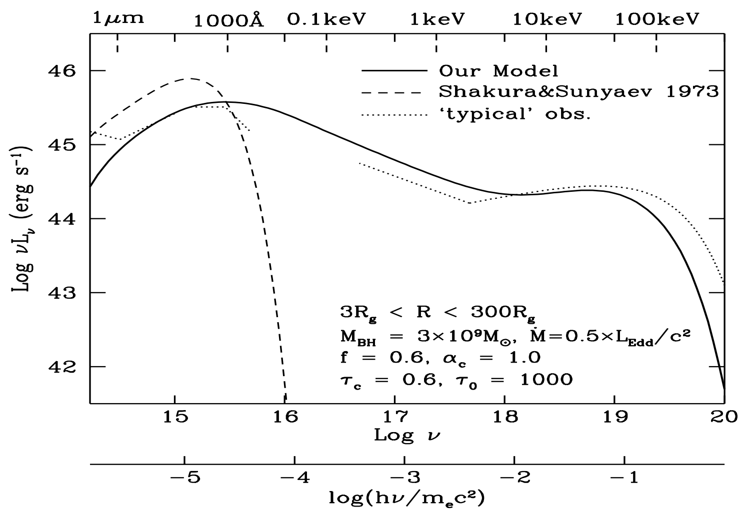

Fig. 2. Resultant spectrum of the whole disk-corona integrated over 3–300 $R_{\rm g}$ (thick line; from [8]). Parameters used in this model are listed in the figure. With those parameters, advective cooling in the corona is comparable to the radiative cooling at $R = 5R_{\rm g}$; $q^-_{\rm adv}/q^+_{\rm c} \sim 0.5$. The dashed line is the integrated spectrum of the standard disk with the same black-hole mass $M_{\rm BH}$ and $\dot{M}$. Dotted lines indicate the observed 'typical' spectra which we aim to fit with our models.

Thomson/Compton scattering as radiation mechanisms. The Comptonization is described by the Kompaneets equation.

We divide the disk-corona from $300R_{\rm g}$ to $3R_{\rm g}$ into 20 rings so that each ring radiates approximately the same luminosity (cf. [1, 3]). In total, the input parameters required for the calculations are $M_{\rm BH}$, $\dot{M}$, f, $\tau_{\rm c}$, τ_0, and α_c. The number of input parameters is similar to that of the relevant observed parameters which we aim to reproduce simultaneously; e.g., L_X, $\alpha_{\rm ox}$, $\alpha_{\rm UV}$, $\alpha_{\rm opt}$, α_{ROSAT}, α_{ASCA}. The spectrum of the whole disk-corona system is obtained by summing up the emergent spectra of all the rings.

3 Results

We first show the most successful case with $M_{\rm BH} = 3 \times 10^9 M_\odot$ and $\dot{M} = 0.5\ L_{\rm Edd}/c^2$ that corresponds to a luminosity of about 5% of the Eddington luminosity, $L_{\rm Edd}$. The thick line in Figure 2 shows an example of the resultant broad-band spectra. A significant fraction $f = 0.6$ of mass accretion occurs via the corona. It turns out that the height of the disk-corona boundary measured from the mid-plane at $R = 5R_{\rm g}$ is 0.03 $R_{\rm g}$, and that of the surface of the corona is 0.3 $R_{\rm g}$. Then, the disk-corona system is indeed geometrically thin.

The presence of multiple spectral components is the most noteworthy feature of the present model. This is because different radiative mechanisms play roles

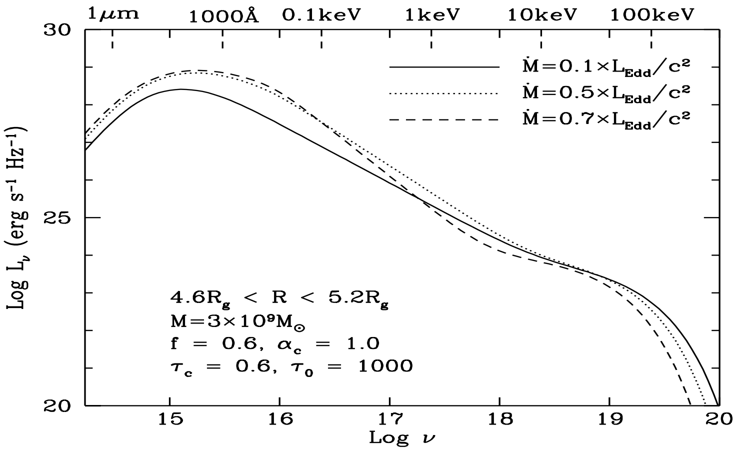

Fig. 3. Accretion-rate dependence of the emergent spectra for a fixed black-hole mass ($M_{\rm BH} = 3 \times 10^9 M_\odot$).

in different wave-bands; thermal radiation of the disk in Opt./UV, unsaturated Comptonization in FUV/soft X-rays, and a combination of unsaturated Comptonization, bremsstrahlung, and reflection in hard X-rays. We wish to stress that the underlying radiative processes in soft–hard X-rays are distinct from the traditional explanation, in which the UV–soft X-ray component is due to blackbody radiation whereas the hard power-law component is due to Comptonization. Note that the hard X-ray emission in our model looks only apparently like a power law with $\alpha \sim 0.5$–1.0.

The accretion-rate dependence of the emergent spectra is shown in Figure 3. As the accretion rate increases, the cut-off frequency of hard X-rays (i.e., coronal electron temperature) decreases due to the increasing efficiency of Compton cooling. Then, the spectral slope at $\sim$ 0.03–1 keV gets steeper; $\alpha = 1.4$, 1.7 and 2.1 for $\dot{M}/(L_{\rm Edd}/c^2) = 0.1$, 0.5 and 0.7, respectively. The qualitative trend that higher $\dot{M}/L_{\rm Edd}$ leads to larger α_{ROSAT} is quite reminiscent of the cases of Narrow-Line Seyfert 1s. More detailed results and discussion will be presented elsewhere ([8]).

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