Coexistence of Corona and Disk in AGN?

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Abstract. We studied the disk corona around a supermassive black hole by including decoupling of ions and electrons and Compton scattering. We found that the mass evaporation rate from the disk to the corona depends strongly on viscosity and total mass accretion rate, smaller viscosity and larger accretion rate result in less efficient evaporation and hence weaker corona. The model predicts weaker contributions to the hard X-rays and a steeper X-ray spectrum in narrow-line Seyfert 1 galaxies (NLS1), consistent with observations. To maintain a corona lying above a thin disk at the innermost region in active galactic nuclei (AGN), a large amount of energy deposit/supply to the corona is required.

1 Introduction

There are strong observational evidences for the existence of hot gas with $T \sim 10^9$K in the neighborhood of an inner accretion disk in AGNs. It is postulated that the hot gas is a corona lying above the thin disk. A self-consistent model, including how the mass and energy exchange between cool disk and hot corona and how the disk and corona are maintained, is to be established.

In this investigation, we extended the disk corona model (Meyer & Meyer-Hofmeister 1994; Meyer et al. 2000) to regions near the central black hole by taking into account both decoupling of ion and electron temperature and Compton scattering. We aim at explaining the AGN spectrum.

2 Properties of the Corona

Numerical calculations of the structure of the disk corona were performed by solving the differential equations of continuity, momentum and energy for a system with black hole mass $M = 10^8 M_\odot$ and viscosity α=0.3 (For detail see Liu et al. 2001). The changes of coronal temperatures with distances are shown Fig. 1. The ion temperature increases towards the central black hole, at values of about $(1/5)T_v$ (T_v virial temperature) in the outer region ($r \sim 10^{17}$cm$\sim 3000 r_g$, r_g Schwarzschild radius) and $(1/3)T_v$ close to the black hole, while the electron temperature almost stops to increase at $T_e \sim 10^9$K from $r \sim 100 r_g$ inwards. This is because viscous heating of ions hardly goes to electrons by collisions but is carried as entropy of ions. The electrons, however, can cool by thermal conduction and radiation and hence keep their temperatures almost constant in the inner region. Such a feature is very similar to the ADAF (e.g. Narayan & Yi

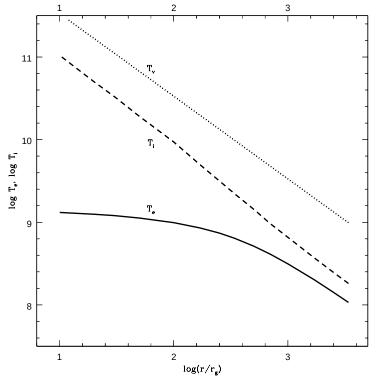

Fig. 1. Temperature distribution along distances. Solid line: electron temperature T_e; dashed line: ion temperature T_i; Dotted line: Virial temperature $T_{\rm v}$.

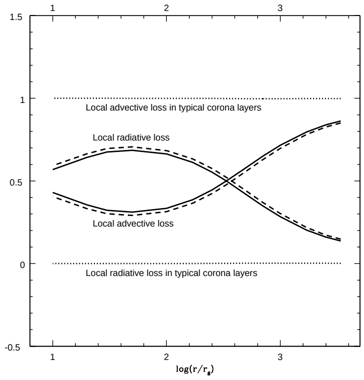

Fig. 2. Radiative fraction and advective fraction of viscous heat along distances. Dotted line: corona layers; Dashed line: transition layers; Solid lines: the transition and corona layers.

1995). Similarity can also be seen from the energy flow in the corona shown in Fig. 2. It is shown that the viscous heat almost advects inwards with the accretion flows with little radiation (a few thousandths at $r \sim 10^{17}$cm). However, if the transition layers between the disk and the upper corona are included, the local radiative fraction of viscous heat is larger in the inner region than that in the outer region. The corona is virtually identical to the ADAFs except there exist transition layers between the disk and corona and vertical advection.

Fig. 3 shows the rate of mass evaporating from the disk to the corona along distances, where the Compton cooling is not included. The evaporation rate, which is roughly the coronal flow rate, increases with decreasing distance r, reaches a maximum of 0.012 Eddington rate ($\dot{M}_{\rm Edd}$) at distance $r \sim 340 r_g$, and then decreases towards the black hole. The maximum is caused by the change in the dominant process that removes the frictional heat.

Fig. 3 also shows the evaporation rate for a larger viscosity, $\alpha = 0.9$. The maximal rate for $\alpha = 0.9$ is $0.14\dot{M}_{\rm Edd}$ occurring at the distance $r = 30 r_g$, about 10 times larger at a distance about 10 times smaller than that for $\alpha = 0.3$. The increase of viscosity increases the mass evaporation since larger viscosity leads to more efficient heating and faster accretion in the corona, both of which need larger mass supply by evaporating the underlying disk.

The effect of Comptonization with a total mass accretion rate of $0.05 M_\odot$/yr in both the disk and corona is shown in Fig. 4 along with the non-Compton results. The Compton cooling largely restrains the evaporation at small distances, the evaporation rate at $r = 10^{16}$cm decreases more than 10 times and influences are even stronger with larger mass accretion rate in the disk. At very high accretion rate the coronal gas in the innermost region may fall back to the disk by efficient Compton cooling.

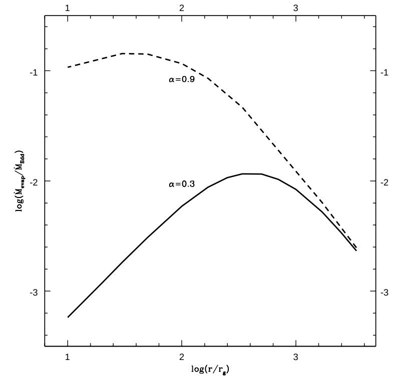

Fig. 3. Mass evaporation rate along distances. Solid line: α=0.3; Dashed line: α=0.9.

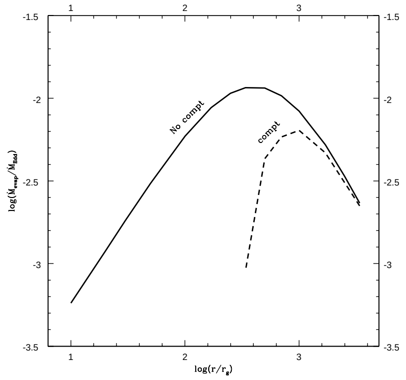

Fig. 4. Mass evaporation along distances. Solid line: without Comptonization; Dashed line: with Comptonization.

3 Discussion and Conclusion

The disk evaporation by the corona above provides a mechanism for transition from the outer disk to the inner ADAFs. At small accretion rates, a large part of the disk is depleted by efficient mass evaporation and the accretion is dominated by coronal flows/ADAFs; At rates around the maximal evaporation rate, the corona coexists with an outer disk and probably an interior disk fed by the corona; At even large rates, the innermost corona cools down through strong Compton cooling and the thin disk dominates the accretion. Since the critical evaporation rate depends on viscosity and total mass flow rate, the dominant accretion mode is determined by and depends strongly on total accretion rate and viscosity.

In luminous AGN the mass accretion rate is rather high, Comptonization by strong radiation from the disk removes viscous heat in the corona and restrains evaporation. Instead of evaporation, coronal gas falls back to the disk in the region close to the black hole and no corona is maintained in this region. Consequently there is little radiative contribution to hard X-rays from the innermost region. This implies a steeper hard X-ray spectrum in brighter objects as observed in NLS1.

To keep the corona coexistent with the disk down to the last stable orbit, a large fraction of accretion energy released in corona is necessary. The model shows that the corona could extend close to the black hole with very large viscosity, the detailed value of α depends on the mass incoming rate.

References

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