Disk/corona model: The transition to ADAF

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Abstract

We propose a model of the accretion flow onto a black hole consisting of the accretion disk with an accreting two-temperature corona. The model is based on assumptions about the radiative and conductive energy exchange between the two phases and the pressure equilibrium. The complete model is determined by the mass, the accretion rate, and the viscosity parameter. We present the radial dependencies of parameters of such a two-phase flow, with advection in the corona and the disk/corona mass exchange due to evaporation/condensation included, and we determine the transition radius from a two-phase disk/corona accretion to a single-phase optically thin flow (ADAF) in the innermost part of the disk as a function of accretion rate. We identify the NLS1 galaxies with objects accreting at a rate close to the Eddington accretion rate. The strong variability of these objects may be related to the limit cycle behaviour expected in this luminosity range, as the disk, unstable due to the dominance by the radiation pressure, oscillates between the two stable branches: the advection-dominated optically thick branch and the evaporation branch.

1 Introduction

Broad band spectra of Seyfert galaxies and X-ray binaries in their hard states are well described by models which consist of a standard optically thick disk, disrupted and replaced by an optically thin hot flow in the innermost part (e.g. Loska & Czerny 1997, Esin, McClintock & Narayan 1997). The question remains: which physical mechanism is responsible for such a transition?

Meyer & Meyer-Hoffmeister (1994) suggested in the context of CVs that the accretion flow is basically a two-phase disk/corona flow, with the heat generation in the corona leading to gradual disk evaporation due to the conduction
flux, and finally, to the disappearance of the disk in the innermost part of the flow for low accretion rates.

Here we follow this basic idea but we adjust it to the parameter range appropriate for accreting black holes.

2 Model

The accreting corona is cooled partially by advection, and its temperature is of order of the virial temperature. Since the virial temperature in accreting black holes is orders of magnitude higher than in the case when a white dwarf is the central object because of its large radius, we modify the assumptions of Meyer & Meyer-Hoffmeister considerably. We describe the corona flow as a two-temperature medium (see Witt et al. 1997 and the references therein). We include the effect of Compton cooling in addition to bremsstrahlung cooling. Finally, instead of using the conductive flux at the disk/corona boundary, taken from solar physics, we consider the equilibrium at this boundary, as in Róžańska & Czerny (2000a), and we calculate the evaporation rate, thus allowing for both evaporation or condensation (i.e. the settlement of the coronal material onto a disk). The details of the approach are given in Róžańska & Czerny (2000b).

3 Results

An example of the radial dependence of the fraction of energy dissipated in the corona is shown in Fig. 1. For high accretion rate, the corona strength reaches its maximum at some intermediate radius, condensation prevails in the innermost part of the flow and the disk extends down to the marginally stable orbit. However, if the accretion rate is low, the evaporation is relatively efficient and the disk is replaced by the single phase hot flow at the radius where $f_{\text{cor}} = 1$, i.e. the entire flow is in the form of the hot phase and our solution is replaced by ADAF.

The position of the transition radius is determined by the viscosity $\alpha$ and the accretion rate in Eddington units (with efficiency $1/12$ included):

$$r_{tr} = 4.51 \dot{m}^{-1.33} \alpha_{0.1}^{7} R_{\text{Schw}} \quad \dot{m} < 6.92 \times 10^{-2} \alpha_{0.1}^{3.3}$$

$$r_{tr} = 3R_{\text{Schw}} \quad \dot{m} > 6.92 \times 10^{-2} \alpha_{0.1}^{3.3}$$

(1)

where $\alpha$ is expressed in 0.1 units.
Fig. 1. The global solution for the radial dependence of the fraction of energy generated in the corona for $\alpha = 0.05$ and accretion rates equal to $0.5, 0.05, 6.3 \times 10^{-3}, 3 \times 10^{-3}, 1.13 \times 10^{-3}, 3 \times 10^{-4},$ and $5 \times 10^{-5}$. The transition to ADAF is determined by $f_{\text{cor}} = 1$.

For high accretion rates, the disk is surrounded by a relatively weak corona and the radiation spectra are dominated by the disk component. However, if the accretion is low, the disk evaporates and the spectrum is dominated by the ADAF component. Therefore, our model reproduces all characteristic luminosity states of an accreting black hole without any additional ad hoc assumptions.

The properties of the stationary models form a basis for the discussion of the time evolution of the accretion flow, which is of interest because of the observed variability.

The model stability is well represented by Fig. 2 where the positive slopes mark stable solutions and negative slopes the unstable ones. Since the disk at moderate accretion rates is surrounded by a weak corona, it remains unstable due to the radiation pressure dominance, as in the original model of Shakura & Sunyaev. At still higher accretion rates, the optically thick disk is stabilized by advection while for lower accretion rates, we have a strong departure from the classical models in the form of a new evaporation branch, which joins the optically thick solution to the ADAF solution.

Narrow Line Seyfert 1 galaxies, with their large accretion rates, correspond to the intermediate, unstable branch at luminosities close to the Eddington value ($\dot{m} \sim 1$). According to our model, the accretion flow may have a tendency to
Fig. 2. The relation between the accretion rate and the surface density of the disk/corona system at $10R_{\text{Schw}}$ for the viscosity parameter $\alpha = 0.1$ in the case of AGN ($M = 10^8M_\odot$, continuous line) and GBH ($M = 10M_\odot$, dashed line). Short-dashed lines show the corresponding standard Shakura-Sunyaev model. The continuous line in the lower right part of the diagram shows an exemplary solution for an optically thin flow (Zdziarski 1998).

oscillate on a thermal and viscous timescale between the upper, disk dominated branch and the horizontal evaporation branch with a strong, Comptonizing corona. It may explain why those sources are generally strongly variable and it would suggest that their counterparts among the Galactic sources are those in the Very High State (and not High State, as frequently suggested).

References

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