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Accretion disk with magnetic corona in AGN

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Abstract. The fraction of energy generated in the hot corona above an accretion disk in active galactic nuclei can be self consistently determined when heating of the corona by magnetic field reconnection is assumed. The quantitative properties of the corona depend on the model of the cool accretion disk below. We preset how exact vertical structure calculations of an accretion disk influence the main properties of the corona. We show observational constrains of such disk/corona model.

Key words. accretion disks

1. Introduction

Active galactic nuclei (AGN) are believed to be powered by accretion of matter onto supermassive black hole. Nevertheless, the observed X-ray emission from those objects cannot be explained in the frame of existing accretion disk models. Even if we understand the main mechanism of cooling (inverse Compton scattering) of the X-ray source, we do not know what heats the plasma to such high temperatures as 10^9 K.

Heating via magnetic field reconnection is considered to be very important. Magnetic loops from the disk may transport the matter producing a hot corona above the disk. This scenario is well understood on the surface of the the Sun. It is absolutely uncertain in the case of AGN since we don't know the magnetic field in those objects.

In this paper we consider the disk/corona model following Liu et al. (2002). We compute simplified spectrum from such system and give observational constrains of the model.

2. Accretion disk with magnetic corona

We consider a standard accretion disk around black hole of mass $10^8 M_\odot$, where viscous torque is proportional to the total pressure. The vertical structure of the disk is computed using equations described in Różańska et al. (1999) i.e.: hydrostatic equilibrium, equation of state, transfer via diffusion approximation, and viscous energy generation. The opacity is a sum of the electron scattering opacity and the Rosseland mean of absorption, when the latter is a function of density and temperature.

We integrate equations of vertical structure for different distances from the black hole measured in the units of Schwarzschild radius, R_{Schw}, and for different accretion rates in the units of Eddington accretion rate, $\dot{M}_{Edd}$, with the efficiency of accretion for Schwarzschild black hole: $\eta = 1/12$.

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The magnetically heated corona above an accretion disk is assumed to be in equipartition with the gas energy of the disk Liu et al. (2002). The hot corona is in thermal equilibrium, which means that heating via magnetic field is balanced by cooling via Compton scattering of both: the intrinsic disk photons and the reprocessed radiation. The size of magnetic loop is assumed to be constant and equal to 10 R_{Schw} Averaged density of the evaporating plasma is estimated from the energy balance at the disk/corona interface.

The coronal temperature, T, and the coronal density, n are calculated in the following steps: i) for the given R and $\dot{M}$ we calculate the disk structure, ii) knowing P_{gas} at the equatorial plane of the disk we derive strength of magnetic field B, iii) for the given B, and soft photons flux, F_{soft}, and from the conditions of energy equilibrium in the corona and at the disk/corona interface, we calculate temperature and density.

Such a solution depends on the fraction of the accretion energy dissipated in the corona, f_{cor}, and inversely, there is a back reaction: the energy transfered from the disk to the corona by magnetic reconnection affects the disk structure.

It was shown by Liu et al. (2002) that the ratio of energy dissipated in the corona to the total energy generated via accretion is proportional to the strength of magnetic field and Alfven speed:

$$f_{cor} = \frac{B^2}{4\pi} V_A \left[\frac{3GM\dot{M}}{8\pi R^3} \left(1 - \left(\frac{R_{Schw}}{R} \right)^{1/2} \right) \right]^{-1} . \quad (1)$$

The fraction of coronal energy is self consistently calculated by iteration of Eq.1 and solution of the disk structure. Note, that in the magnetic loops model only $1 - f_{cor}$ fraction of total angular momentum is carried by a disk. Contrarily to the accreting corona model, magnetic loops do not explain how the fraction f_{cor} of angular momentum is transfered outward. In case of magnetic loops, angular momentum transfer could be possible only when we additionally assume the existence of magnetically driven winds.

Full results of those computations are presented in Różańska & Czerny (2005). For wide range of accretion rates disks are dominated by radiation pressure, which is in contradiction with the analytical solution presented by Liu et al. (2002). In both considered cases i.e.: for $\dot{M} = 0.5\dot{M}_{Edd}$ and $\dot{M} = 0.1\dot{M}_{Edd}$, self consistent determination of f_{cor} is possible only for specific range of distances from the black hole (see: Fig. 2 and 3 in Różańska & Czerny (2005)). For the case of $\dot{M} = 0.5\dot{M}_{Edd}$, corona extends up to 55 R_{Schw}, for the $\dot{M} = 0.1\dot{M}_{Edd}$, up to 13 R_{Schw}.

3. Total spectrum from an accretion disk with magnetic corona

The best test for our model is to calculate the total spectrum form an accretion disk/corona system which we present in Fig.1. On each radius we assumed, following Haardt & Maraschi (1991), than only half of radiation from corona is emitted as X-ray power-law. The second half illuminates the disk and it is reprocessed and reemitted with soft disk radiation. Compton amplification factor, A, for each radius depends only on the f_{cor}, and disk albedo is assumed to be 0.15 (Haardt & Maraschi 1991).

The photon index on each radius is computed form Beloborodov (1999), using formula

$$\Gamma = \frac{7}{3} (A - 1)^{-1/10} . \quad (2)$$

The total spectrum is computed by integrating over disk radius: black body emission, from 3 up to 10^5 R_{Schw}, and corona power-law emission from 3 up to the extension of the corona.

For both accretion rates we calculate the average ratio of X-ray to optical luminosity (Zamorani et al. 1981), defined as:

$$\alpha_{ox} = \frac{-\log(l_{2keV}/l_{2500\text{Å}})}{2.605}, \quad (3)$$

where 2.605=$\log(\nu_{2keV}/\nu_{2500\text{Å}})$. For our models this index equals 1.99 for $\dot{M} = 0.5\dot{M}_{Edd}$, and 1.74 for $\dot{M} = 0.1\dot{M}_{Edd}$. Typical observational values of α_{ox} for quasars span from 0.1 up to 2 (Bechtold et al. 2003).

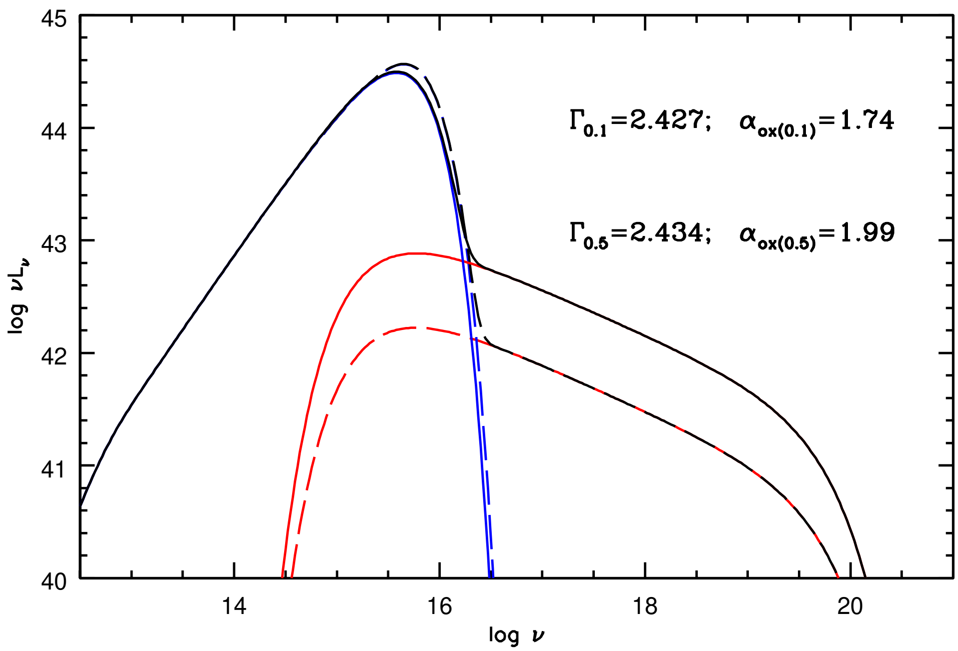

Fig. 1. Total spectrum from the disk corona system for accretion rate 0.5 -dashed line, and for 0.1 - solid line. Blue lines represent disk black body spectra, red lines represent power-law from coronae, and black lines are total spectra for both cases. For higher accretion rate corona is weaker, but more extended.

4. Conclusions

We have calculated the radial structure of the magnetic corona above a vertically integrated accretion disk. Our model is parameterized only by global parameters: mass of the black hole and total accretion rate. For higher accretion rates the corona is weaker, but more extended.

We have calculated α_{ox} index corresponding to the average ratio of X-ray to optical luminosity. For higher accretion rate this index is higher. Our α_{ox} indices do agree with observed indices of high redshift quasars shown by Bechtold et al. (2003), and Strateva et al. (2005), but do not agree with those of Seyfert 1 galaxies (Strateva et al. 2005).

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