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The revised GRV model of accretion disc coronae

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Abstract. A model of accretion disc coronae was developed on the basis of GRV model for the radiation dominated region with MRI taking into consideration. It was found that near the black hole reconnection overwhelms generation. It is estimated that up to 60% of the full magnetic energy generated in disc may be dissipated in the corona.

Key words. Accretion disc: corona – Accretion: MHD – Accretion: MRI

1. Introduction

From the end of 70^{th} the idea that the X-ray spectra of GBHC (galactic black holes candidates) can be explained by the presence of a hot corona around cold accretion disc (AD) have received much attention (Galeev, Rosner, Vaiana 1979,GRV hereafter). Investigation of X-ray spectra of AGN also indicates that the hard X-radiation comes from hot regions above the AD. Most likely, the AD corona is strongly inhomogeneous and heated by reconnecting magnetic loops emerged from the disc (GRV).

The formation of the hot corona in the GRV model implies that a seed magnetic field is amplified due to the processes analogous to turbulent dynamo and the dissipation in disc is too slow to stop the magnetic field amplification. Only nonlinear effects stop such exponential field growth. As the magnetic flux tubes with strong field contain less plasma than their ambient surroundings, they are subject to buoyancy and emerge from the disc forming corona, where reconnection becomes faster.

The corona-disc models can give possibility to explain some features in X-radiation spectra but many questions remain unresolved. For example, GRV model does not take into account cyclotron/syclotron radiation. The magnetic flares also illuminate the underlying disc and reflect there.

As it was found by Beloborodov (1999), in hard state GRV mechanism is able to dissipate only small fraction of total energy released from AD. Recent investigation of MHD turbulence indicates presence of magnetorotational instability efficiently generates magnetic energy in the disc (Balbus & Hawley 1998) and helps to explain the rate of energy dissipation. Many examples show that authors have used GRV model as the basic assumption. It have led us to conclusion that GRV model is needed to be revised. This paper is to be regarded only as a preliminary assessments of basic features of GRV model for radiation pressure dominated region of standard α-disc (Shakura & Sunyaev 1973).

In section 2 we discuss the characteristic time scales. Then in section 3 the properties of magnetic flares are investigated and, finally, conclusion is given in section 4.

2. Characteristic time scales

The ad hoc assumption that the magnetic field amplification due to the differential rotation of AD should be balanced by magnetic reconnection inside the disc was involved by Eardley & Lightman (1975) without consideration of the detailed magnetohydrodynamics. It was proposed that reconnection of the azimuthal component of magnetic field is responsible for the generation of the radial component and the magnetic stress provides the main mechanism for angular momentum transfer.

The principal difficulty of this approach is as follows: magnetized plasma in a gravitationally stratified fluid is in general buoyantly unstable (Parker 1979). Buoyant magnetic flux escape may provide the nonlinear saturation mechanism for magnetic amplification in the radiation pressure dominated region (GRV). Using the estimate of Bisnovatyi-Kogan & Blinnikov (1977) for the convection velocity $v_{\rm conv}[\approx \alpha^{1/3}c_s]$, we obtain the limiting strength of the magnetic field:

$$B_\phi^2/4\pi = \rho c_s^2 \tag{1}$$

where B_ϕ is the strength of the azimuthal magnetic field in AD, ρ is the mass density and c_s is the sound speed. The magnetic field pressure becomes comparable to the gas pressure, as expected from equipartition arguments.

We use the AD model with modified α-parameter: the value of viscosity is defined only by gas pressure and the component of stress tensor is $\nu = \alpha_g(v_s)/\Omega_K$, where $v_S^2 = T_e/m_p$ (Coroniti 1981; Stella & Rosner 1984). So the rate of field generation ($\tau_G^{-1} = 3\alpha_g^{1/3}v_s/R$) (Bisnovatyi-Kogan & Blinnikov 1977) and the upper limit for the Petschek-type reconnection ($\tau_R = h/2.7\times10^{-2}V_A$) (GRV) are

$$\tau_G^{-1} = 5.8\times10^2\alpha_g^{7/30}\dot m^{1/5}m^{-11/10}\times r^{-29/20}(1-r^{-1/2})^{1/5} \tag{2}$$

$$\tau_R = 2.9\times10^{-2}\alpha_g^{-1/2}\dot m^{8/5}r^{3/2} \tag{3}$$

where: h is the half thickness of the accretion disc, $r = R/3r_g$ is normalized radius, and $\dot m = \dot M c^2/L_E$ is the dimensionless accretion rate.

The saturation of magnetic field growth is expected when the magnetic field tension suppresses convection, the source for magnetic field generation. Reconnection is therefore unimportant if $\tau_R/t_G > 1$:

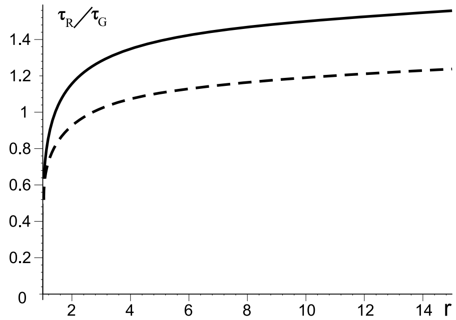

Fig. 1. The ratio τ_R/τ_G vs. normalized radius.The solid curve corresponds to the black hole mass equals 10, the dotted curve — 100 Solar masses.

$$\frac{\tau_R}{\tau_G} = 1{,}56\alpha_g^{-4/15}\dot m^{1/5}m^{-1/10}r^{1/20}(1-r^{-1/2})^{1/5} \tag{4}$$

Comparison of the time scales associated with field growth and reconnection demonstrates that for significant portion of AD no reconnection occurs (Fig. 1). However in the region near a black hole (the extent of it depends upon AD parameters) dissipation is faster than the generation. Therefore the region contained the hot plasma should appear near black hole, similar to the "sombrero" model (Bisnovatyi-Kogan & Blinnikov 1977).

Magnetic flux tubes with strong magnetic field contain less plasma then their ambient surroundings; therefore they are subject to buoyancy forces and will penetrate the accretion disc to form "coronal" loops.

3. Magnetic Field in the Corona

Following Beloborodov (1999) the rate of magnetic energy production per unit area of the disc equals $F_B = 2ht_G^{-1}(B_\phi^2/8\pi)$. Assuming that the magnetic stress $t_{r\phi} = B_\phi B_r/4\pi$ is responsible for the transfer of angular momentum in the disc, one can compare F_B to the total surface dissipation rate $F_t = 3t_{r\phi}c_s$ (Shakura & Sunyaev 1973):

$$F_B/F_t \approx B_\phi H/B_r R. \tag{5}$$

The investigation of MRI in accretion disc shows, that (Balbus & Hawley 1998) about 88% of magnetic energy contains in toroidal field B_ϕ and 9% in B_r, so

$$F_B/F_t \approx 41\dot{m}(1 - r^{-1/2})/r. \quad (6)$$

The dissipation of the magnetic energy in the corona may feed the X-ray luminosity (GRV), while the underlying accretion disc reprocesses the incident X-ray and supplies seed soft photons to the corona. From the equipartition arguments (magnetic energy is equal to the radiation energy):

$$\frac{B^2}{8\pi} = \frac{f\eta L_{\mathrm{Edd}}}{N \cdot 4\pi c(r_{\mathrm{rec}} \cdot 3r_g)^2} \quad (7)$$

and

$$B = 10^8 (f\eta/Nm) r_{\mathrm{rec}}^{-1}. \quad (8)$$

Here f is a fraction of energy, dissipated in corona, η is an efficiency of energy emission in AD-corona system, N is the number of coronal loops. Using equation above we obtain the size of a reconnection region (here we used $m = 10$, $\eta = 0.06$):

$$r_{rec} = (H/3r_g)\alpha_g^{-1/3} = 4.2\dot{m}(1 - r^{-1/2}) \quad (9)$$

and magnetic field in the corona

$$B = 2.5 \cdot 10^7 \frac{f\eta}{Nm} \alpha_g^{1/3} m^{-1/2} \dot{m}^{-1} (1 - r^{-1/2})^{-1}. \quad (10)$$

This estimation shows that till 60% of magnetic energy can dissipate in corona (Fig. 2).

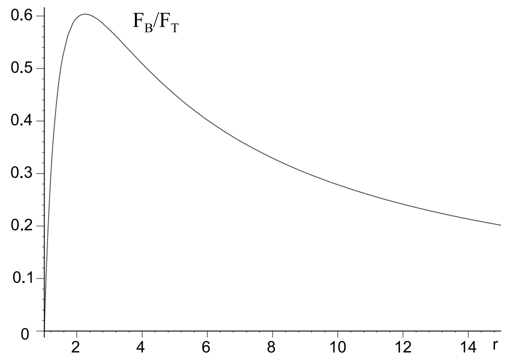

Fig. 2. The rate of the dissipation in corona vs. the rate of total dissipation. $M = 10$.

4. Conclusion

The model of accretion disc corona was developed on the basis of GRV model for the radiation dominated region with MRI taking into consideration. The comparison of the typical rates of field generation and field dissipation shows that in the small part near the black hole reconnection overwhelms generation and there should appear the region contained hot plasma similar to "sombrero" model (Bisnovatyi-Kogan & Blinnikov 1977). Magnetic flux tubes emerging from AD form the structured magnetic corona. Coronal magnetic field is less than the field in AD and the estimation of the dissipation shows that till 60% of full magnetic energy of AD may dissipate in corona.

The presented paper is to be regarded only as a preliminary assessments of basic features of GRV model. Improvement and development of this model is the subject of future work.

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