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Accretion disk with advection and magnetic field

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Abstract. We investigate the problem for generation of corona in a hot magnetized advective accretion disk. We discuss the appearance and the behavior of the magneto rotational instability (MRI). In this paper, we consider the connection of MRI with the generation of a corona in the disk.
Keywords: Accretion disks, corona, magneto rotational instability

1. Introduction

The effects of development and interaction between magnetic field lines and plasma have been discussed by many authors; in particular Abramowicz et al. (1996), Bardou & Heyvaerts (1996), and Brandenburg & Donner (1997) consider the influence of the magnetic field on the viscosity; Beloborodov (1999) and Iankova (2005)—the arising of the magnetic corona; Brandenburg et al. (1995) and Gammie (2004)—the behavior of the disk-field-star system with time; Primavera et al. (1997)—the numerical description of the parameters of the disk, and Quataert & Narayan (1998)—the magnetic field in advective disks.

Magneto rotation instability (MRI) is an important mechanism for keeping the equilibrium of hot, advective magnetized disks. Hydrodynamic turbulence (HDT) yields the general contribution to the release of energy in the disk, but the MRI has a basic contribution, too. In the proposed model, these both mechanisms are the most effective, however, the viscous dissipation dominates and that helps the disk to cross the whole magnetosphere. Here is presented a 2D global solution of the model. This is an approximate solution, but it gives a good idea for disk's stability and evolution.

2. Magnetohydrodynamic model

Here is constructed a non-stationary, non-axisymmetric, one-temperature MHD model of a Keplerian accretion disk with advection in the normal dipole magnetic field of the central object. The basic equations of the models are:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = 0, \tag{2.1}$$

$$\nabla \cdot \mathbf{B} = 0, \tag{2.2}$$

$$\nabla \cdot \mathbf{v} = 0, \tag{2.3}$$

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla)\mathbf{v} = -\frac{1}{\rho}\nabla p - \nabla \Phi + \frac{1}{4\pi\rho}(\mathbf{B} \cdot \nabla)\mathbf{B} + \nu \nabla^2 \mathbf{v}, \tag{2.4}$$

$$\frac{\partial \mathbf{B}}{\partial t} = \nabla \times (\mathbf{v} \times \mathbf{B}) + \eta \nabla^2 \mathbf{B}, \tag{2.5}$$

$$Q^+ - Q^- = Q_{\rm adv}, \tag{2.6}$$

$$p = p_{\rm r} + p_{\rm g} + p_{\rm m}, \tag{2.7}$$

where Φ is the gravitational potential, ν the kinematic viscosity, p the total pressure (consisting of gas pressure $p_{\rm g}$, radiative pressure $p_{\rm r}$ and magnetic pressure $p_{\rm m}$), and

$$\eta = \frac{c^2}{4\pi\sigma},$$

in which σ is the disk's conductivity. We assume that:

- $B_z \propto \mu/r^3$ at the equatorial plane and is independent on φ and t;
- $\mathbf{v} = (v_r, \Omega_{\rm K} r, 0)$, where

$$\Omega_{\rm K} = \frac{1}{r - R_{\rm g}} \sqrt{\frac{GM}{r}} \quad (R_{\rm g} \text{ is the Schwatzschield radius})$$

because the disk is a Keplerian one;

- $\eta = v_{\rm s} H$ (H being the semi-height of the disk), $\alpha_{\rm m} = 1$, and $T = T_{\rm vir} = GMm_{\rm ion}/(k_{\rm B} r)$ since the disk is advective.

The disk is not axisymmetric, but if it is divided in sectors, than one can use for disk's parameters the following functions:

$$F_i = F_{i0} R_i(x) \exp\left[k_\varphi(x)\varphi + \omega(x)t\right] = F_{i0} f_i(x, \varphi = 0),$$

where $x = r/r_0$, $i = 1, 2, 5$.

The model used in this paper has been elaborated in Iankova & Filipov (2004). Here we show a part of the results describing the radial structure in the moment $t = 1P \sim \Omega_{\rm K}^{-1}$ after the spreading of the disk.

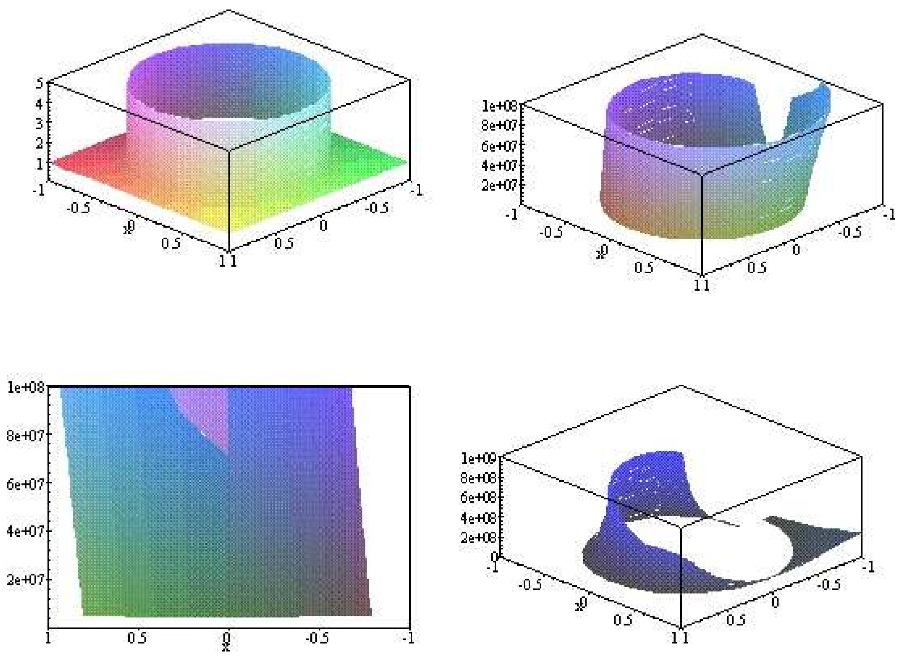

Figure 1. Distribution of the dimensionless density $f_1(x, \varphi)$.

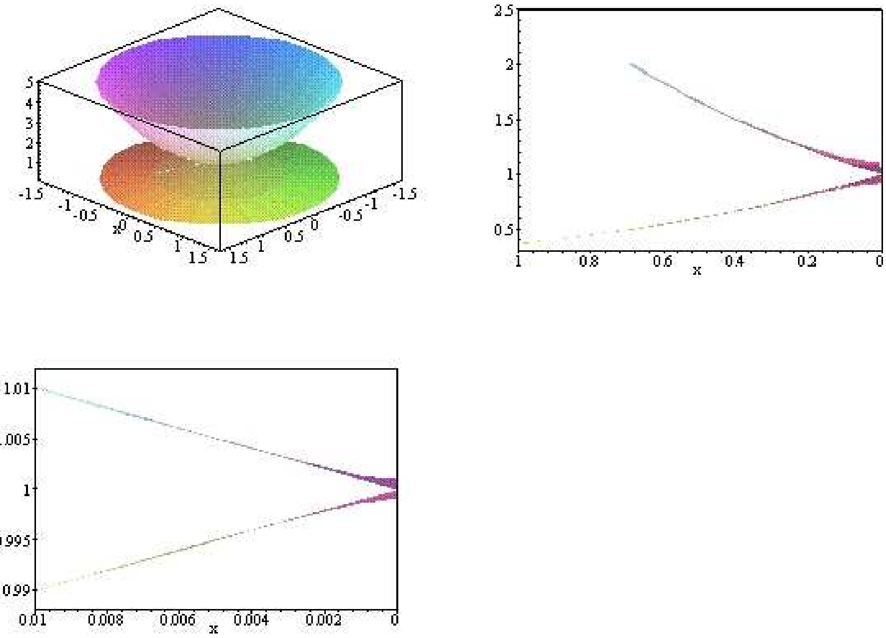

Figure 2. Distribution of the dimensionless radial velocity $f_2(x, \varphi)$.

3. Results

In this section, we present the main results of the analytical solving to Eqs. (2.1)–(2.7), averaged over the axial coordinate z. One can see in Fig. 1 the beginning of the spiral as a leap in the density function at the position $0.9x$.

It becomes clear from Fig. 2 that the two wings are individual along the whole disk. One observes simultaneous increasing and decreasing of the radial velocity. Hence, the fluid flows in both directions independently. Such a behavior of the velocity shows the existence of micro-vortices along the whole disk. The smooth growth of the magnetic field component up to $0.5x$ (Fig. 3) hints that in the outer disk instabilities with magnetic character do not exist—this is naturally, because the field of the central object rapidly falls off with the distance and the effects from the field created in outer regions of the disk are respectively repressed by the rotation.

4. Conclusion

The main results can be summarized as follows:

(*a*) A leap of the radial component of magnetic field occurs at $\sim 0.5x$. Hence, the MHD instabilities are expected below $500 R_{\mathrm{g}}$.

(*b*) A density's leap appears at $\sim 0.9x$, which means that in the layer $(0.5\text{–}0.9)x$ instabilities with hydrodynamic character are expected only.

(*c*) The existence of magneto rotational instabilities (MRIs) depends on the local condition $v_{\mathrm{A}}^2 < v_{\mathrm{s}}^2$ in the flow. However, if that inequality is not satisfied (for example if the sound speed is smaller than the Alfvénic one, $v_{\mathrm{s}} < v_{\mathrm{A}}$), then the MRIs automatically become forbidden. Therefore, in the inner region (below $0.4x$) the instabilities exist in smaller heights where the sound velocity v_{s} is sufficiently large. It is possible that the

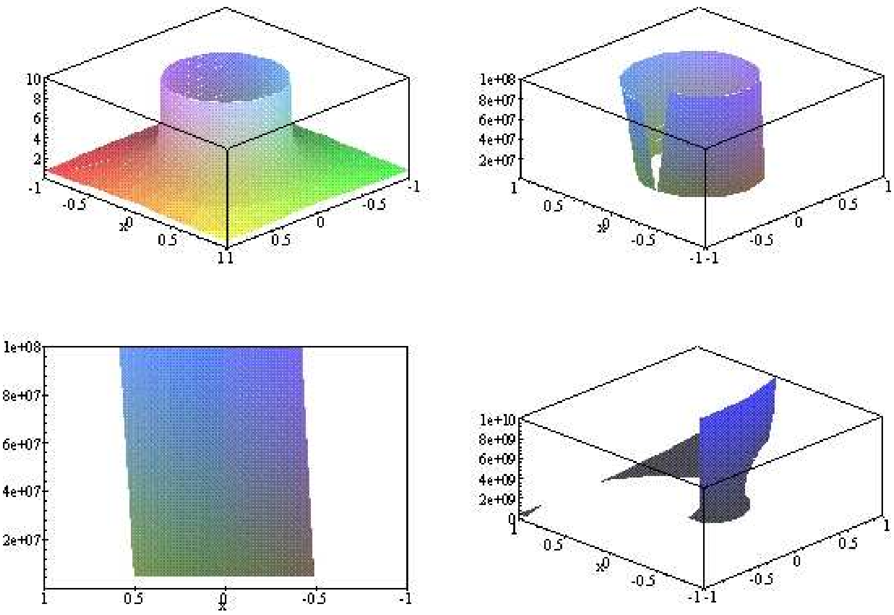

Figure 3. Distribution of the dimensionless radial magnetic field component $f_5(x, \varphi)$.

MRIs will not be concentrated around the equatorial plane. They will emerge with the magnetic field lines on the surface or above the disk [Iankova (2007)]. Estimated from observations, numerical results and simulations, the outer radius of the disk's corona varies from 15–250R_g [Novak et al. (1999)] for a spherical corona to 320–640R_g for non-spherical coronas [Pottschmidt et al. (1998)]. Our results belong notably to the second type of coronas.

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