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Evinces of Interaction of Flow in Disk with Magnetic Field

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Abstract. The paper deals with the conditions for corona generation in an advection accretion disk due to the magneto-rotation instabilities. The interaction of the magnetic field with the plasma flow is discussed.

1 Introduction

Magneto-hydrodynamics of accretion disk is one of the basic issues in astrophysics. The accretion process in the presence of magnetic field creates conditions for development of both magneto-hydrodynamics and hydrodynamics instabilities in the plasma. This results in generation of different structures, as one could observe – vortices, spirals, corona, jets, powerful X-ray or/and γ-ray emission and even annihilation lines.

The corona is a macrostructure, which ensures the disk cooling, when the flow in it weakly radiates. Non-linear micro-vortices (MHD and HD) govern the energy distribution in the plasma. The magneto-rotation instability generates corona in the disk.

In the present paper is studied the local condition $v_a \leq v_s$ in generation of magneto-rotation instabilities in the disk at different levels z for different radius r as well as the behavior of the vector field (v_r, v_z) for fixed angle and time.

2 Results

A non-stationary, non-axisymmetric, one-temperature MHD model of Keplerian accretion disk with advection in the normal dipole magnetic field of the central object is proposed. The disk behavior is treated on the basis of the analytic 3D solution obtained in Ref. [2]. The velocity components distribution in (x, z)-plane is shown in Table 1.

One could see that v_z increases much faster then v_r, especially near to the equator.

Table 1.

	0.1	0.3	0.5	0.7	0.9	
0.01	0.90	0.97	0.98	0.99	0.99	v_x
0.04	0.60	0.87	0.92	0.94	0.96	
0.07	0.30	0.77	0.86	0.90	0.92	
0.01	4.95	4.55	3.75	2.55	0.95	$v_z \times 10^3$
0.04	0.31	0.28	0.23	0.16	0.06	
0.07	0.10	0.09	0.08	0.05	0.02	

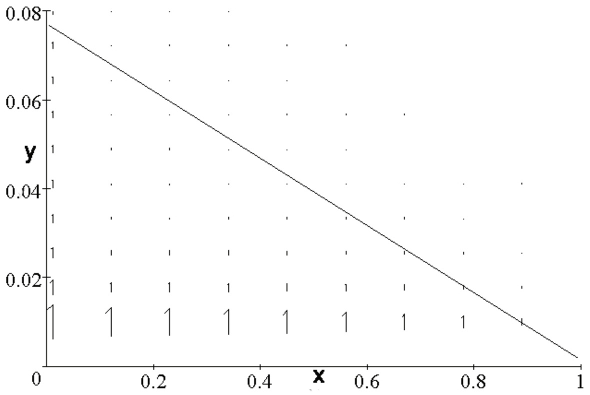

Figure 1. The vector field (v_r, v_z) in (x,z) plane of the disk. It illustrates the the plasma motion in z-direction.

If one assumes that of the outer edge, the velocities v_{r0} and v_{z0} are of the same magnitude, then Figure 1 shows the velocity field of the matter in (x, z) plane. The plasma is elevating along with the magnetic lines, but with the increase of the height, the speed decreases and the material goes back to the disk [1]. This is the reason for harsh retard in the z direction (excluding the jet regions).

The condition $v_a < v_s$. Here, the dimensionless von Alfven and sound speeds are given as a part of the analytical solution for the disk perimeter.

$$\begin{aligned} f_3(x,Z) =& \frac{c_6}{2}x^2Z^4 + \frac{c_{z7}x^3Z^2}{3} - \frac{c_5Z^2}{4x^2} \\ &+ (c_1+c_3)\Big(\frac{x^{3/2}}{2Z^2} - \frac{c_5}{2x^{1/2}}\Big)(x-x_g-1) + C_3(Z) \qquad (1) \end{aligned}$$

$$\frac{v_a^2}{v_{a0}^2}(x,Z) = \frac{(1+c_4)Z^6 + 9Z^4}{9x^{0.5}(c_1+c_3)[1-(x-x_g)]} + C(Z) \qquad (2)$$

where $C_i(Z) = f_i(1, Z)$ are the initial distributions in z and C_i are dimensionless combinations of perimeter values of the outer disk edge.

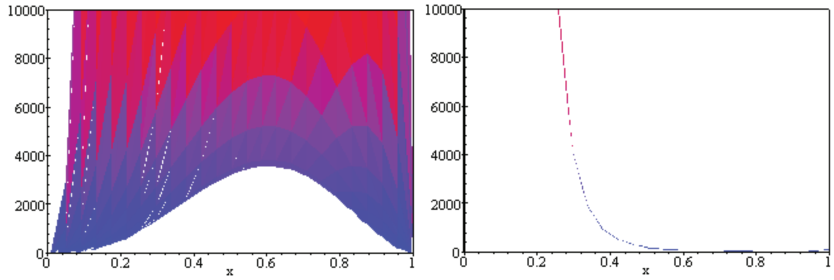

Figure 2. The profiles along x for $z = 0.04$ of $v_s(r,z)$ (left) and $v_a(r,z)$ (right). The maximum of $v_s(r,z)$ at $(0.5, 0.7)x$ is observed per each value of z, which belongs to the disk.

Under the assumption $v_{s0} \sim v_{a0}$, Figures 2 and 3 illustrate the role of the condition $v_{a2} < v_{s2}$. In Figure 2 one could see a maximum of v_s (it becomes more profound near to the equator – Figure 3) and a shallow minimum of v_a in the vicinity of $x = 1$. This implies that in the region $(0.4; 1)x$, the condition is valid for each z, which belongs to the disk. The minimum of v_a excludes the outer edge, where the condition depends on the initial distributions.

However, whence the maximum v_s is reached for $x < 0.4$, the condition is fulfilled for even smaller values of z (Figure 3).

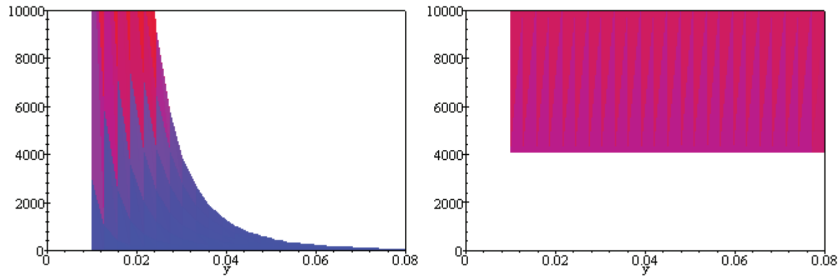

Figure 3. The profiles along z for $x = 0.3$ of $v_s(r,z)$ (left) and $v_a(r,z)$ (right).

3 Conclusion

The appearance of MRIs requires the condition $v_{a2} < v_{s2}$ to be locally fulfilled. When this inequality is no longer valid and $|v_s| < |v_a| < |v_\varphi|$, MRIs are automatically forbiden. Therefore, in the inner region (less than $0.4x$), the instabilities could be developed for smaller height, where the values of v_s are sufficiently high.

It is quite possible the behavior of the vector filed (v_r, v_z) to be explained by Parker instabilities (an abrupt decrease ofv_z along z and an increase toward the disk center – Figure 1, Table 1) in the inner region (where B_φ rapidly approaches a constant value). Then MRI will not concentrate within the disk plane. They will rise up along with the magnetic lines of the surface or above the disk.

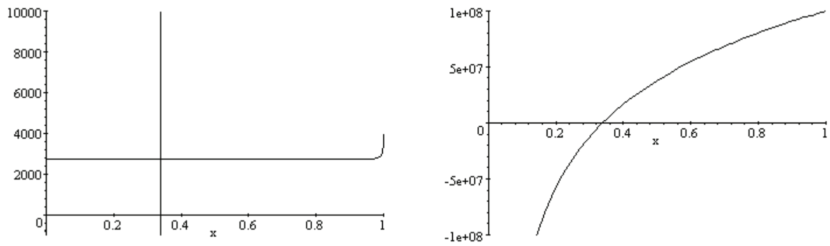

Figure 4. Distribution of $v_s(r)$ versus $v_a(r)$ (left), and of $v_s(4)$ (right).

To illustrate what is going, Figure 4 plots a solution, which is analogous to that obtained in [3] for a 2D model, and applied for the case of Cyg X1

$$f_3(x) = -5.5 \times 10^{-10} x^6 - 2 \times 10^{-4} x^5 - 2.4 \times 10^4 (x-1) + 8.8 \times 10^7 \frac{(x - x_g - 1)}{x^{1/2}} + 1 \qquad (3)$$

$$\frac{v_a^2}{v_{a0}^2}(x) = \frac{0.28x^{6.5} + 0.5x^{8.5} + 0.22x^{10.5} + x^{4.5}}{0.2x^{0.5} + 3.6 \times 10^3[1 - (x - x_g)] + 0.8x^{10.5}} + 0.9. \qquad (4)$$

It is clear that the distributions are crossing each other at ca. 340Rg, i.e. at this point the condintion breaks down. The estimate value (on the basis of observations, numerical results and simulations) of the outer radius of the disk's corona of the object considered, varies from 15–250Rg [4] for spherical corona to 320–640Rg [5].

References

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