GENERATE OF CORONA ON MAGNETIZED DISK

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Abstract
Development of the flow in (r, z)-plane in disk. Discussion conditions for come into being of corona in the select model. Consider what is happening in azimuthal direction.

Introduction

Magneto-hydrodynamics of accretion disk is one from basic question in astrophysics. The problem concern large part from object in universe, like as stars in the beginning or in the end of your life and galaxies. Instabilities in such flow are represent interest for many authors.

In [8] is consider increasing of MRI in protostellar disk in different boundaries: for ideal MHD limed, Ohmic diffusion and others.

[7] Investigate condition for activate buoyancy mode in cases of uniform rotation and compressed and uncompressed limed.

[6] – Combined action of MRI and elliptic instabilities.

In [5] is concentrate attention over vertical flow out of disk, it can to protect disk if angular moment increase inside (central dipole magnetic field).

Here will be present solution for development of the 3D flow in instant Ω^{-1} and comment the results.

Model and results

We consider non-stationary, non-axisymmetric, one-temperature MHD model of Keplerian accretion disk with advection in the central dipole magnetic field and use cylindrical coordinate.

$$\frac{\partial \rho}{\partial t} + \frac{1}{r}\frac{\partial}{\partial r}(r\rho v_r) + \Omega\frac{\partial \rho}{\partial \varphi} + \frac{\partial}{\partial z}(\rho v_z) = 0$$

$$\frac{\partial}{\partial r}(rB_r) + \frac{\partial B_\varphi}{\partial \varphi} = 0$$

$$\frac{\partial v_r}{\partial t} + v_r\frac{\partial v_r}{\partial r} + \Omega\frac{\partial v_r}{\partial \varphi} + v_z\frac{\partial v_r}{\partial z} = -\frac{1}{\rho}\frac{\partial p}{\partial r} + \frac{1}{4\pi\rho r}(B_\varphi\frac{\partial B_r}{\partial \varphi} + rB_z\frac{\partial B_r}{\partial z})$$

$$\frac{\partial}{\partial t}(\Omega r^2) + v_r \frac{\partial}{\partial r}(\Omega r^2) + v_z \frac{\partial}{\partial z}(\Omega r^2) = \frac{1}{4\pi\rho r}[B_r \frac{\partial}{\partial r}(r^2 B_\varphi) + r^2 B_z \frac{\partial B_\varphi}{\partial z}] +$$
$$+\frac{\vartheta}{r}\frac{\partial}{\partial r}[\left(r\frac{\partial \Omega}{\partial r}\right) r^2]$$

$$\frac{\partial v_z}{\partial t} + v_r \frac{\partial v_z}{\partial r} + \Omega \frac{\partial v_z}{\partial \varphi} + v_z \frac{\partial v_z}{\partial z} = -\frac{1}{\rho}\frac{\partial p}{\partial z} - \frac{\partial \Phi}{\partial z} + \frac{B_r}{4\pi\rho}\frac{\partial B_z}{\partial r}$$

$$\frac{\partial v_r}{\partial r} + \frac{v_r}{r} + \frac{\partial v_z}{\partial z} = 0$$

$$\frac{\partial B_r}{\partial t} = \frac{1}{r}\frac{\partial}{\partial \varphi}(v_r B_\varphi) - \frac{\partial}{\partial \varphi}(\Omega B_r) + \frac{\partial}{\partial z}(v_r B_z) - \frac{\partial}{\partial z}(v_z B_r) + \frac{\eta}{r}\left[\frac{\partial}{\partial r}\frac{\partial B_r}{\partial \varphi} + \frac{\partial}{\partial r}\frac{\partial B_\varphi}{\partial \varphi}\right] +$$
$$+\frac{\eta}{r}\frac{\partial}{\partial r}(r\frac{\partial B_r}{\partial r}) + \frac{\eta}{r^2}\frac{\partial^2 B_r}{\partial \varphi^2} + \eta\frac{\partial^2 B_r}{\partial z^2}$$

$$\frac{\partial B_\varphi}{\partial t} = \frac{\partial}{\partial r}(\Omega r B_r) - \frac{\partial}{\partial r}(v_r B_\varphi) + \frac{\partial}{\partial z}(\Omega r B_z) - \frac{\partial}{\partial z}(v_z B_\varphi) + \frac{\eta}{r}\left[\frac{\partial}{\partial \varphi}\frac{\partial B_r}{\partial r} + \frac{\partial}{\partial \varphi}\frac{\partial B_\varphi}{\partial r}\right] +$$
$$+\frac{\eta}{r}\frac{\partial}{\partial r}(r\frac{\partial B_\varphi}{\partial r}) + \frac{\eta}{r^2}\frac{\partial^2 B_\varphi}{\partial \varphi^2} + \eta\frac{\partial^2 B_\varphi}{\partial z^2}$$

$$\frac{\partial}{\partial r}(r v_r B_z) - \frac{\partial}{\partial r}(r v_z B_r) - \frac{\partial}{\partial \varphi}(v_z B_\varphi) - \frac{9\eta B_z}{r} = 0$$

Present is the mass continuity, magnetic flux conservation, equation of motion, angular momentum conservation, hydrostatic balance, the three components of magnetic induction, without warm in disc, because it is local average for ring. It is comfortable to use with 2D model present in earlier papers.

Here can to use $F_i = F_{i0}\Re_i(x = r/r_0, Z = z/r_0)\exp[k_\varphi(x,Z)\varphi + \omega(x,Z)t] = F_{i0} f_i(x,Z)$ for parameters of disk. In like manner as 2D and keeping approximation for thin disk, but in form $\partial F/\partial z \approx F/z$, $\partial^2 F/\partial z^2 \approx 2F/z^2$ we obtain:

$$f_1(x,Z) = \frac{c_1 + c_3}{x^{13/2} Z^4}\left[1 - (x - x_g)\right] + C_1(Z)$$

$$f_2(x,Z) = -\frac{9c_{z10} + 2}{x} Z + C_2(Z)$$

$$f_9(x,Z) = \frac{c_{z3}}{\left(x - x_g\right)} - \frac{c_{z2} x^2}{2Z^2} - \frac{c_{z4} x^3 Z^2}{3} + C_9(Z)$$

$$f_3(x,Z)=\frac{c_6}{2}x^2Z^4+\frac{c_{z7}x^3Z^2}{3}-\frac{c_5Z^2}{4x^2}+$$
$$+\left(c_1+c_3\right)\left(\frac{x^{3/2}}{2Z^2}-\frac{c_5}{2x^{1/2}}\right)(x-x_g-1)+C_3(Z)$$

$$f_5(x,Z)=\frac{1+c_4}{3x^3}Z+C_5(Z)$$

$$f_6(x,Z)=3\frac{2+\alpha c_{z10}}{4c_8x^{13/2}Z^2}(x-x_g-1)-\left[\frac{c_1}{c_8x^4Z^4}+\frac{2\alpha c_{z10}-1}{c_8x^{11/2}Z^2}\right]\frac{1}{(x-x_g)}+$$
$$+\frac{\alpha c_{10}}{c_8x^{9/2}Z^2}\frac{1}{(x-x_g)^2}+\frac{c_{z9}}{3c_8x^3}+\frac{Z^2}{2x^4}+C_6(Z)$$

$$f_7(x,Z)=-\left[\frac{c_3}{c_1}\frac{x^{1/2}}{Z}+\frac{c_3x^{1/2}}{2c_1c_4Z}-\frac{c_{17}x^{3/2}}{c_1Z^3}\right]\frac{1}{x-x_g}-\frac{c_3}{c_4c_1}\frac{x^{3/2}}{(x-x_g)^2Z}+$$
$$+\frac{5+20c_{z10}}{c_1}\frac{Z}{x^2}-\frac{4c_{z6}}{c_1x}-\frac{c_{z16}+2c_{z10}}{c_1Z}+C_7(Z)$$

$$f_8(x,Z)=\left(-\frac{c_4+1}{k_{\varphi0}}-\frac{2c_4}{c_{z6}}\right)\left(x-1\right)+\frac{\left(c_1+c_3\right)x^{3/2}}{c_{z6}Z^2}(x-x_g-1)-\frac{k_{\varphi0}^2+2}{2k_{\varphi0}}\frac{x^2}{Z^2}+$$
$$+\left(\frac{1+c_4}{Z}-\frac{c_{z5}}{c_{z6}Z^2}\right)x+C_8(Z)$$

Here $f_1(x,Z)$, $f_2(x,Z)$, $f_9(x,Z)$, $f_3(x,Z)$, $f_5(x,Z)$, $f_6(x,Z)$, $f_7(x,Z)$, $f_8(x,Z)$ is corresponding of parameters ρ, v_r, v_z, v_s, B_r, B_φ, ω, k_φ. Obtaining functions give us freedom to select initial distribution upon outer edge of disk $C_i(Z)=f_i(1,Z)$, where $f_i(1,0)=1$. For illustration of model we choose $C_1(Z)$ and $C_5(Z)$ conformable to trends in the solution.

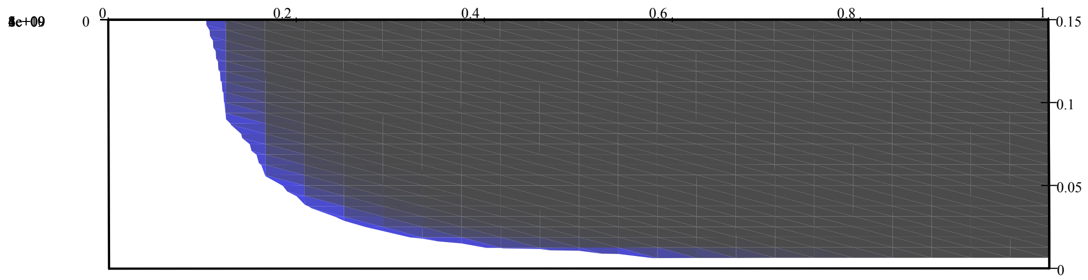

FIGURE 1

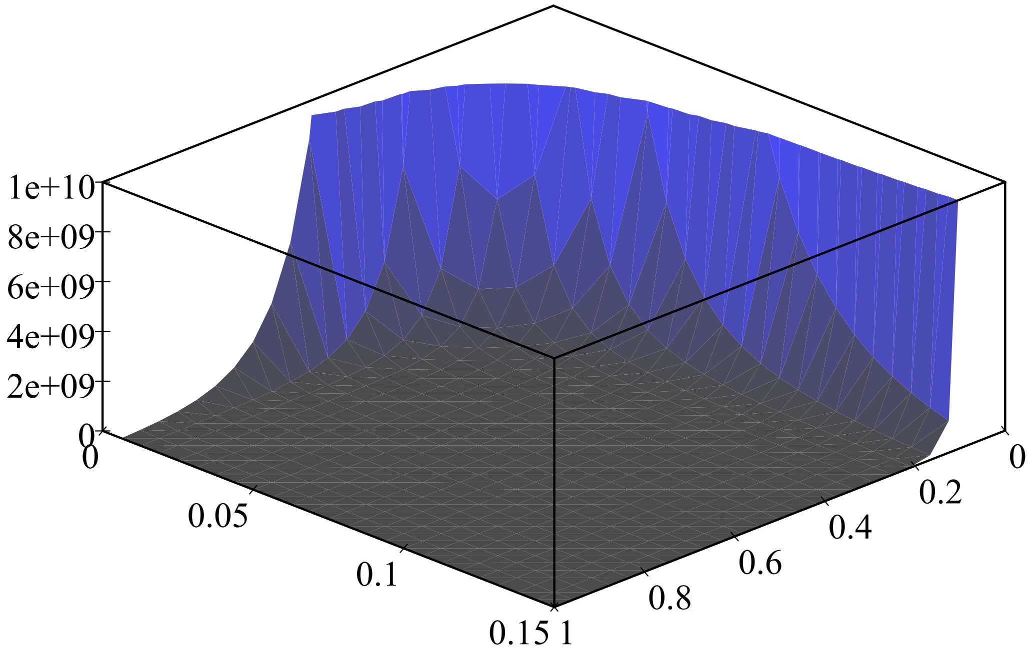

FIGURE 2

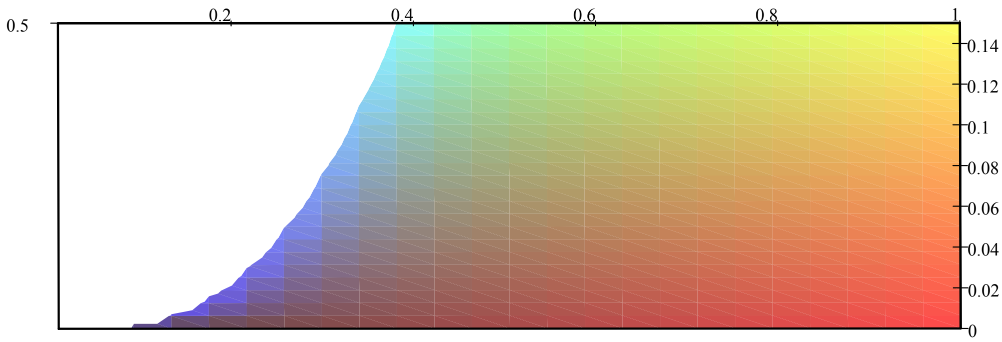

FIGURE 3

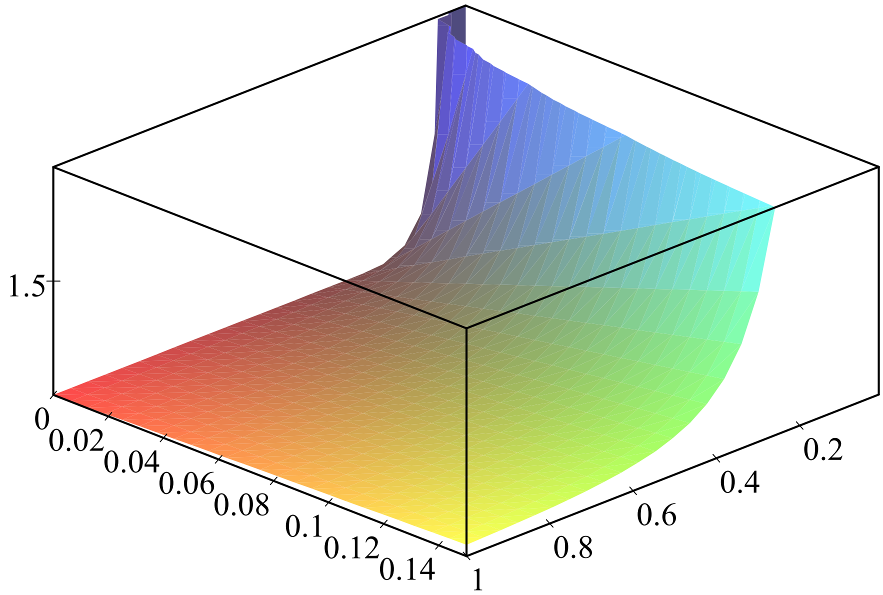

FIGURE 4

Figure 2 and 4 showing developments of ρ and B_r. Left horizontal coordinate is Z, right – x and along vertical is respective parameter. In planes x=1 we can see initial distributions. In planes Z=0 and $Z_{max}=f_4(x)$(=const for convenience) we get increases to center for central plane and surface of disc. The last will be use as initial distributions in model of corona in future investigations. It 2D cannot give us.
Figure 1 and 3 showing dispose of $f_1(x, Z)$=const=1.10^{10} and $f_5(x,Z)$=const=3 in (x,Z) plane.
In developments is easily to visible pores in inner region. They are indicator for skips on parameters (the skips we can see in fig.2-4) and therefore for instability.
Instabilities spring up with changing of magnetic strength. Shear stretching magnetic lines and thereby generating B_φ. The flow involve magnetic lines, bring close them, the plasma attach lines and they are exchanging or curving. Then rotation twists them in stitches. Between neighboring opposite stitches current is $j \sim cB_r/4\pi l$ (l is scale local vortices) and generating B_r. So cycle is closed. The field generating turbulence and turbulence generating field. To exist magneto-rotation instabilities (MRI) is require local in the flow $v_a^2 \leq v_s^2$. While it retain condition in our disk to reach to marginal orbit crossing magnetosphere $|v_a| < |v_\varphi|$, because the flow is supersonic along all disk.

But if strongly is to infringe the condition and $|v_s| < |v_a| < |v_\varphi|$, that automatic forbidden MRI in disk [1]. Increasing B_φ oppress rotation effect, but also saturate the field and activate Parker instabilities. They ouster MRI over surface of disk and is give rise to corona.
At the end alteration φ to have no effect over functions $k_\varphi(x,Z)$ and $\omega(x,Z)$, like as time. Solution on that coordinate is completely determinate in results for fix orbit and instant.

Conclusion

Present in paper model keeping most important qualitys of earlier model 2D:

1. Not necessary independent variables.
2. Simplify calculation, but is keeping nonlinear character of equations.
3. Unopened is set backward bond, which physical exist.

Results clear show existence of instabilities and are convenient for investigation of evolution in earlier stage $[0,1]\Omega^{-1}$, where MRI is appear and in later, where is generating corona.

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