Proceedings of the VIII Serbian-Bulgarian Astronomical Conference (VIII SBAC)
Leskovac, Serbia, May 8-12, 2012,
Editors: M. S. Dimitrijević and M. K. Tsvetkov
Publ. Astron. Soc. "Rudjer Bošković" No 12, 2013, 375-381

GENERATION AND DEVELOPMENT OF THE DISK CORONA

KRASIMIRA D. YANKOVA

Space Research and Technology Institute - BAS
Acad G. Bonchev Str., Bl. 1, 1113 Sofia, Bulgaria.
E-mail: f7@space.bas.bg

Abstract. This paper considers the magneto-hydrodynamics of the advective accretion disk and its corona. The aim is to build an adequate addition to the disk evolution model, which treats the mechanisms of self-structuring in the system disk-corona. Discussed generation of the corona as a result of influences of the distribution of entropy and the development of advection in disc, over energetics (for individual components or total) of the system.

1. INTRODUCTION

In a series of papers, we develop a model, related to the interaction of the field and the plasma in the accretion disk. Accretion is qualitatively and quantitatively more effective in the presence of a magnetic field, arising more quickly and develop a more diverse range instabilities. Disks around massive objects cannot be cooled efficiently by mechanisms in the disk and its corona emerged. The corona is a macrostructure, which ensures the disk cooling, when the flow in it weakly radiates. It regulates processes in the disk and controls its stability.

2. MODEL OF THE DISK

We built a generalized model for study of magneto-hydrodynamics of the advective accretion disk under the following assumptions:

- Constructing model is non-stationary, no axis-symmetric Keplerian disk in normal magnetic field.
- The central object is a black hole. Unlike the customary consideration of relativistic flows in this case (Beloborodov, 2008), we use pseudo-

Newtonian gravitational potential in the form. $\Phi = -\frac{GM}{\mathbf{r} - r_g}$; $r_g = \frac{2GM}{c^2}$;

$\mathbf{r} = \left(r^2 + z^2\right)^{1/2}$. It is simple and convenient way to include in the consideration of purely Newtonian flow, relativistic effects which such a compact object exercises on the accretion, (Abramowicz, et al., 1988).

- The disc is geometrically thin, optically thick and without self-gravity.
- One-temperature fully ionized plasma. Temperature here is of the order of the temperature of ions, because presence of magnetic field guarantees efficient transfer of heat to the cooling components.
- In this disk there are conditions for thermal-viscous instability, but it is in controlled regime, balanced by magnetic advection; for the difference of the super-Eddington flows which inevitably become two-temperature (Spruit et al., 2001) or quickly depleted (Beloborodov, 2008). Here symbiosis of mechanisms, allowing to reach virial temperature in conditions of non-freefall.
- Own magnetic field is located vertically to the plane of the disc, respectively it is mainly determined by its vertical component, presented openly from the equatorial plane.
- Speed in the form $\boldsymbol{v} = (\boldsymbol{v}_{\mathrm{r}}, r\boldsymbol{\Omega}_{\mathrm{k}} = r\sqrt{\frac{GM}{\boldsymbol{r}(\boldsymbol{r} - \boldsymbol{r}_{\mathrm{g}})^2}}, \boldsymbol{0})$, of its initial size and direction depends on the degree of asymmetry of the disk (elliptical Keplerian orbits) in conditions of axis-symmetric central potential.

Model is based on the fundamental equations of the magneto-hydrodynamics fluids (1). The basic equations of MHD of accretion - disk flow: the continuity equation, equation of motion, equation of the magnetic induction, equation of heat balance and equation of state.

Equations have been obtained in the conditions of two reference systems. Coordinate system tied to the top of the flow and fixed coordinate system with centre in the acceptor. Galilean transformations are applied to the relative motion against each other. The flow will be considered as non-relativistic because $v^2/c^2 \sim 4.10^{-2} \ll 1$.

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho v) = 0$$

$$\nabla.v = 0 \quad \nabla.B = 0$$

$$\frac{\partial v}{\partial t} + v.\nabla v = -\frac{1}{\rho}\nabla p - \nabla\Phi + (\frac{B}{4\pi\rho}.\nabla)B + \vartheta\nabla^2 v$$

$$\frac{\partial B}{\partial t} = \nabla \times (v \times B) + \eta \nabla^2 B \qquad \eta = \frac{c^2}{4\pi\,\sigma}$$

$$\rho T \frac{\partial S}{\partial t} - \frac{\dot{M}}{2\pi r} T \frac{\partial S}{\partial r} = Q^+ - Q^- + Q_{mag}$$

$$p = p_r + p_g + p_m$$

Magnetic reconnection - feedback (Papaloizou et al., 1997) one of the fundamental mechanisms associated with the structuring of space plasmas.

- MP of the object can be its own central or external (galactic, from the donor). If its own field is located vertically to the plane of the disc, then moment in it grows inward toward the center. This effect can be compensated from powerful jets that lead the moment (Kuncic et al., 2004). But before reaching the central funnel, redistribution moment shall give an impact: Accelerated rotation releases higher amounts of energy, so by gradient of the entropy directly contributing to advection, and thus influence on the restructuring of the disk as an open system.

$$rT\frac{\partial S}{\partial t} + \frac{3}{2} H v_r \frac{v_a^2}{r} = H\vartheta (r\frac{\partial \Omega}{\partial r})^2 - \frac{c}{\chi H}(v_s^2 - \frac{v_a^2}{2} - RT) + \frac{\eta H}{4\pi\rho}(\frac{B_r}{H} + \frac{3\mu}{r^4})^2$$

- The sign of the entropy determined the basic criterion for development, equilibrium and stability of the disc. If it does not cooling efficiently in time, energy is kept in disk in form of heat and reduces the radial gradient of entropy to the center. This is a prerequisite for the disc to reach a new thermodynamic state, to remain globally stable and not to be destroyed. This transition is irreversible. Instabilities in the disk are feeding by heating, absorb the excess free energy, thus stimulate feedbacks in reshuffling the disk and instabilities become structures (vortices, spirals, corona). The effect is reinforced by the partial detention (slowdown) of the accretion, with due to such a distribution of angular momentum. Then advection helps for smooth transformation of the instabilities in the structures.

In the internal regions of the disc where the flow most difficult emits, advection carries the stored heat from the outer zones.

- More popular models suggest the flow deformation in the form of sharp increase in the radial velocity and significantly falling in orbital velocity to sub-Keplerian values – rotation of vector of the velocity. In this research advection is included in the form of advective term.

$$\frac{\partial(\rho \mathrm{v}_i)}{\partial \mathrm{t}} + \frac{\partial}{\partial \mathrm{x}_j}\left(\rho \mathrm{v}_i \mathrm{v}_j\right) = \rho\left(\frac{\partial \mathrm{v}_i}{\partial \mathrm{t}} + \mathrm{v}_j \frac{\partial \mathrm{v}_i}{\partial \mathrm{x}_j}\right) = \rho \frac{\mathrm{Dv}_i}{\mathrm{Dt}}$$

Operator $\frac{D}{Dt}$ defines the advective term.

This is not the increase in radial velocity, this is shifting of the average flow as a flux with velocity v_i in any direction. There is no rotation of the vector, although this can be considered as particular case (and works fine in the earth's atmosphere). On the total interpretation, however (and for such a powerful attraction by black holes, physically more probably) is, that the decision as a whole is transferred to smaller radii. Orbital rate of course changes, but this is due to the new orbit, and only indirectly connects it with advection. Orbital velocity is Keplerian again, because for such a packet transfer, flow does not change its nature. For a normal field to the disk, the dipole term in the equation of motion B_rB_φ creates the conditions for the radial advection (Campbell et al., 1998) – i.e. determines the direction of displacement of the middle course. Radial pulling into a black hole can reach a speed which is about half of the rate of free fall, without weakening of the orbital rotation; on the contrary, it is accelerated due to the redistribution of the moment. Then, viscose and dynamic time-scale (which is comparable) is shorter than the thermal scale and cooling is inefficient.

Advection in similar conditions can work for relatively lower temperatures in the outer regions of the disk. Early appearances guarantee the flow to remain optically thick at temperatures of order (2-s) of higher than normally accepted, whatever show some of the new observations.

3. RESULTS

Processed results for key moments t = 1P and t ≈ 0 indicates that the disk develops spherical radiative (non-convective) corona.

- Co consideration of the radial and vertical structure of the disc:
- Monitoring of the development of the condition of stratification $|v_a| \leq |v_s|$; co set with that of the vector field of the velocity (v_r, v_z) (Iankova, 2007), gives an estimate of external radius of the corona on the disc.
- The behavior of local heating obtained (build) in the local model (Iankova, 2009a)

$$K(x) = \frac{\text{warming}}{cooling}$$

- along with $\partial_t s$, shows that the internal structure of the disk gradually changed to create a dynamic quasi-steady state - that is relatively stable, but very far from equilibrium (Yankova, 2012).
- By K(x) we can also be assessed independently of the outer radius of the corona on the disc.

- Comparing the coefficients of the meeting of the global model with wave numbers in the local model (Iankova, 2009a,b, Yankova, 2012), provides independent confirmation of the idea for birth of the corona.
- In terms of our model this radius was obtained for the disk in system Cyg X-1. The expected result for the outer radius of the corona, with the coordination of observations, numerical results and simulations ranged from 15-250R_g (Novak et al., 1999) for a spherical corona to 320-640R_g for non-spherical (Pottschidt et al., 1998). In coincidence the object, evaluating value corresponds to the results of the first interval for spherical corona.

Well to note that in this case, we consider, disk and crown, without a common energetic.

To suture results in a complete model of the system we will use the output values of the perimeters from the disk surface for initial values in the functional distributions of the perimeters in the corona.

4. ADAPTATION - FORMULATION OF THE PROBLEM

Again we are based on fundamental equations of fluid MHD (1). To construct a model of the corona one should consider the general problem to adapt the system of the disk to the new conditions.

The flow in the disk is directed toward the center and is localized in the plane of the equator. Matter can be optically thick and dominated by gas or radiant pressure. Equilibrium is maintained by rotation.

Corona has reverse flow, optically thin and has a magnetic pressure.

Due to the specific nature of the almost spherical flow kinetic viscosity drops to zero α = 0, and density decreases for orders of magnitude in the corona.

Weak rotation can not stabilize the instabilities and fell restrictions on the magnetic viscous coefficient (Iankova, Filipov, 2008):

$$\begin{aligned}\nabla \times (\eta \nabla \times B) &= \nabla\left[\eta \times (\nabla \times B)\right] = \\ &= (\nabla . \eta) \times (\nabla \times B) + \eta \times (\nabla . \nabla \times B) = \\ &= (\nabla . \eta) \times (\nabla \times B) ? \pm \eta \nabla^2 B\end{aligned}$$

Then the adapted system in cylindrical coordinates is:

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

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

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

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

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

$$\frac{\partial v_r}{\partial r} + \frac{v_r}{r} + \frac{\partial v_z}{\partial z} = 0 \qquad p = R\rho T + \frac{B^2}{8\pi} + \frac{aT^4}{3}$$

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

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

$$\frac{\partial}{\partial r}(rv_r B_z) - \frac{\partial}{\partial r}(rv_z B_r) - \frac{\partial}{\partial \varphi}(v_z B_\varphi) - \frac{9\eta B_z}{r} - \left(\frac{\eta}{r} + \frac{\partial \eta}{\partial r}\right)\left[\frac{\partial B_r}{\partial z} - \frac{\partial B_z}{\partial r}\right] +$$
$$+\frac{1}{r}\frac{\partial \eta}{\partial \varphi}\left[\frac{1}{r}\frac{\partial B_z}{\partial \varphi} - \frac{\partial B_\varphi}{\partial z}\right] = 0$$

$$\frac{\partial S}{\partial t} + \frac{3}{2}\frac{v_r v_s v_a^2}{\Omega r^2 T} = \frac{\eta v_s}{\Omega r T}\frac{1}{4\pi\rho}(\frac{\partial B_r}{\partial z} - \frac{\partial B_z}{\partial r})^2 - \frac{c\rho}{\tau r T}(v_s^2 - \frac{v_a^2}{2} - RT)$$

Before we verify that our main modification

$$F_i = F_{i0}\Re_i(x = r/r_0, Z = z/r_0)\exp[k_\varphi(x,Z)\varphi + \omega(x,Z)t]$$

for the leading perimeters of the disc is applied in the new conditions, one should be noted that in this system is still incomplete adaptation and it can not be subjected to numerical treatment.

For example: The field cannot remain now in its simplest form, valid for equatorial plane and becomes:

$$B_z = \frac{\mu}{r^3}\frac{\sqrt{4r^2 + z^2}}{\left(r^2 + z^2\right)^2}$$

Also we have not given specific form of opacity $\tau = \frac{\rho v_s}{\Omega}\chi$; $\chi = ?$, and η magnetic viscosity itself.

5. COMMENTS AND EXPECTED RESULTS

Full adaptation of the model is forthcoming. It is following from its natural development in a vertical direction. The aim is to connect the physics of the corona with reordering in the disc as an open system, where the two streams do not have a total global energetic; to build an adequate addition – a model for the evolution of the corona which treats mechanisms of the self-structuring and investigates the emergence of instabilities in the disk's corona, in order to obtain a complete picture of the processes in the system disk-corona.

Literature

Abramowicz, M. A., Czerny, B., Lasota, J. P., Szuszkiewicz, E.: 1988, *ApJ,* **332,** 646.

Beloborodov, Andrei M.: 2008, in Cool Discs, Hot Flows: The Varying Faces of Accreting Compact Objects, *AIP Conf. Proc.*, **1054**, 51, arXiv:0810.2690v1.

Campbell, C. G., Papaloizou, J. C. B., Agapitiu, V.: 1998, *MNRAS,* **300,** 315.

Iankova, Krasimira: 2007, *V BSCASS,* Heron Press Ltd. Science series, p. 326. http://aquila.skyarchive.org/5_BSCASS/create/presentations/ Iankova.pdf

Iankova, Kr. D., Filipov, L.: 2008, *SRI-BAS,* p. 88, http://www.space.bas.bg/SENS-2007/1-16.pdf

Iankova, Kr. D: 2009a, *Publ. Astr. Soc. "Rudjer Bošković",* **9,** 327. http://aquila.skyarchive.org/6_SBAC/pdfs/31.pdf

Iankova, Krasimira: 2009b, *Proceedings of the International Conference MSS-09“ Mode Conversion, Coherent Structures And Turbulence",* Space Research Institute, Moscow, p. 409.

Kuncic, Zd., Bicknell, G.V: 2004, *ApJ*, **616**, 669, arXiv: astro-ph/0402421v1.

Novak, M. A., Wilms, J., Vanghan, B., Dove, J., Begelmeni, M.: 1999, *AJ,* **515,** 726.

Papaloizou, J. C. B., Terquem, C.: 1997, *MNRAS,* **287,** 771.

Pottschidt, K., Konig, M., Wilms, J., Staubert, R.: 1998, *A&A*, **334**, 201.

Spruit, H. C., Deufel, B., Dullemond, C. P.: 2001, *Hot and very hot gas around black holes*, http://www.mpa-garching.mpg.de/HIGHLIGHT/2001/highlight0110_e.html

Yankova, Krasimira: 2012, *Publ. Astron. Soc. “Rudjer Bošković”*, **11,** 375. http://aquila.skyarchive.org/7_BSAC/html/papers.html