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STRUCTURE OF ACCRETION DISK IN THE PRESENCE OF MAGNETIC FIELD

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Abstract. This paper presents our results on the problem of the evolution of the disc. We investigate the development of accretion flow in its interaction with the magnetic field. We analyze the restructuring of the flow under the action of the ongoing processes and activity of instabilities. We consider distribution of entropy and locally heating and how it is tied to the emergence of a crown. We discuss influence of the magnetic fields over viscosity parameter. We investigate distribution coefficients k_φ (r, z) and ω (r, z) and connection with behavior of wave numbers k_φ (K), k_r (K) and ω (K).

1. INTRODUCTION

Accretion processes effective converts mass of a substance into energy. This energy is transformed into radiation and emitted by the disc surfaces. Such objects can process up to 50% of rest mass of matter into energy. They are learned especially actual in the world because they are powerful energy sources in outer space. Accretion discs are among the most widely used objects in the universe, not only in time and space, but also in evolutionary terms. As an example, the quasars are objects with large red displacement and most of them belong to the early universe. On the other hand accretion discs present in almost all stages of evolution of stars and their subsystems- from protostellar, proto-planetary discs through relatively cold discs residues, asteroid belts and rings of planets to accretion discs of compact objects in the ended life of the stars.

In the accretion discs various instabilities and structures are developing, that govern the distribution of energy there. They are expressing into huge numbers of non-stationary phenomena that we observe.

Accretion is qualitatively and quantitatively more effective when the picture include the presence of a magnetic field. In the processes of interaction are formed three main streams: disk corona and jet (Balbus and Hawley, 1998), which are genetically related. Each of these mega-structures has its own energetic, which is part of the total, but some objects may be autonomous subsystem.

For us here is the important role of the principal components - Accretion disk because the process of its evolution to create the conditions for the emergence of other major components of the system. This article will trace in the evolution of the disc, the reasons the birth of its corona. We would like to find out how the interactions of plasma flow and magnetic field in the disc, allowing for the development of a crown.

2. BASIC EQUATIONS

We investigate the basic equations of magneto-hydrodynamics for non-stationary and non-axis-symmetrical accretion flows. We construct model of the disc:

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

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

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

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

$$p = p_r + p_g + p_m$$

It is one-temperature, geometric thin, optical thick Keplerian disc with advection in the normal magnetic field. The fluid is incompressible the disc is without self-gravitation. Different instabilities create the irregular periodicities in changeability of material features, which should not be neglect and can be used. Where $r_0 = 10^n R_g$, F_{i0} are the values of the outer edge of the disc.

$$\mathbf{F}_i = \mathbf{F}_{i0} \Re_i (x = \mathbf{r}/r_0, Z = \mathbf{z}/r_0) exp[k_\varphi (x,Z)\varphi + \omega(x,Z)t] = \mathbf{F}_{i0} f_i (x,Z)$$

The coefficient $\omega(r, z)$ indicates how often the flow deflects, because of meeting structure or a spontaneous disturbance on its way. The coefficient $k_\varphi(r, z)$ is sinus of the central angle (in radians) between such disturbances of one orbit. We are called $\omega(r, z)$ and $k_\varphi(r, z)$ meeting coefficients. Chose of periodic function is not random. It is prompted by analogy with the Poisson distribution in statistics, for encounter the flow with structure or spontaneous disturbance and is associated to the advective nature of the disc. In this way accepting periodicities by t and φ are dependable on the distance from the centre r and height on the equatorial plane z. Such presenting allows keeping non-obvious dependence of leading parameters by time and angle, searching solution only according variables x and Z. Coefficients presents feedback (not-obvious) between flow characteristics and its instabilities, which exist as shown (Balbus and Hawley, 1998) (they do not define it).

Registered in the 2D-solution rings with higher density are short living formations with constant entropy in time and they can be considered locally. It could be assumed in first approximation that angular momentum, sonic and magneto-sonic velocities of such ring are constant. Basic equations are averaged by z. We bring in the physical quantity: local warming with which can express the three wave numbers and we obtained the local dependence of instabilities from warming – wave numbers depending on the disc features. Now is necessary to include global distributions of the flow characteristics, to show dependencies $\omega(K)$, $k_{\varphi}(K)$ and $k_r(K)$ in fixed orbit. Also we obtained the distribution of the average local warming on the disc (feeding up of instabilities) (Yankova and Filipov, 2003).

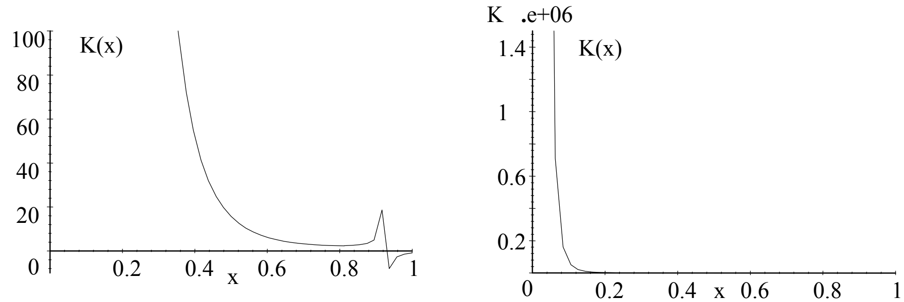


Figure 1. Distribution of average local heating in the disc at the moment t ~ 1P, in small (a) and large increases (b).

3. RESULTS

The results obtained from (Yankova and Filipov, 2003) local solution shown disc as a self-structuring system. Describe the influence of magnetic viscosity over the full vertical structure and advection as a precondition to reorder the disk.

Here are shown the results of two real objects:

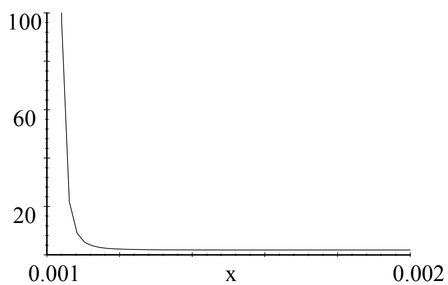
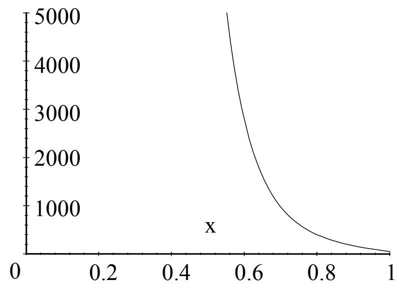


Figure 2a. Distribution of the dimensionless gradient function of entropy in the disc for t = 1P.



Distribution of the dimensionless gradient function of entropy in the disc for t ≈ 0.

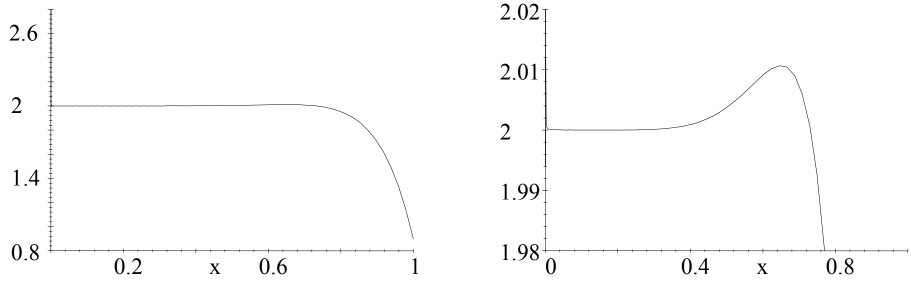


Figure 2b. Maximum at $x \sim 0.65 (650R_g)$. Minimum at $x \sim 0.16$ ($160R_g$).

In Fig. 2 we see the distributions of the Cyg X-1 have weak negative gradient of entropy in the range x ~ 0.16 ÷ 0.65, from which it follows that a significant proportion of the energy remains in the disk and supplies instability. Its local disk warming (Fig. 3) reflects the areas in which the disk cools efficiently (x> 0.2) or low (x <0.2).

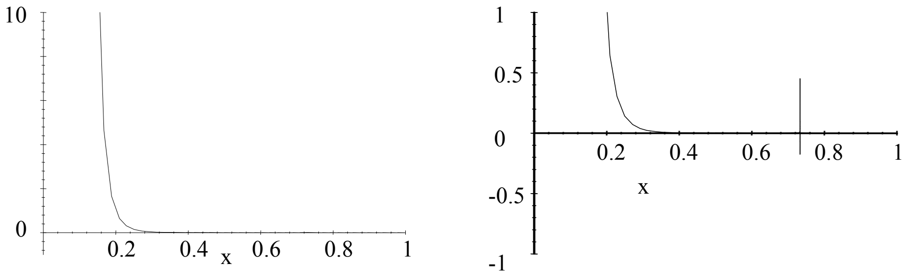


Figure 3. Distribution of the function of local warming K (x) when t = 1P~ Ω_0^{-1}. Disturbance of the inflow reaches ~ 731-732$R_{g.}$

Distribution K (x) of SgrA* (Figure 4) can be concluded that almost all disk is cooling successfully on behalf of advection and increase the amount of instability. This has all the wave numbers decreased with increased warming in the ring (we showed it in), which strengthens the argument for the belief that this disc MRI increased size. Number born instability essentially is not reduced, decreasing the number of existing item k in time. For mutual growth, they are swallowed. So fall ω (K).

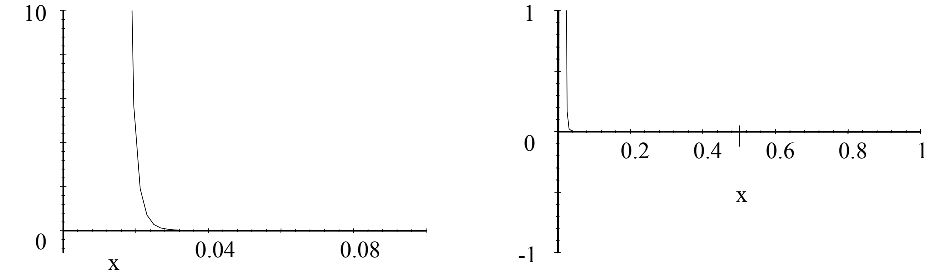


Figure 4. Distribution of the function of local warming to the point of inflow ($\varphi_0 = 0$) when $t=1P \sim \Omega_0^{-1}$.

Disturbance in the spiral reaches ~ $50R_g$ the disk and is even less than Cyg X-1.

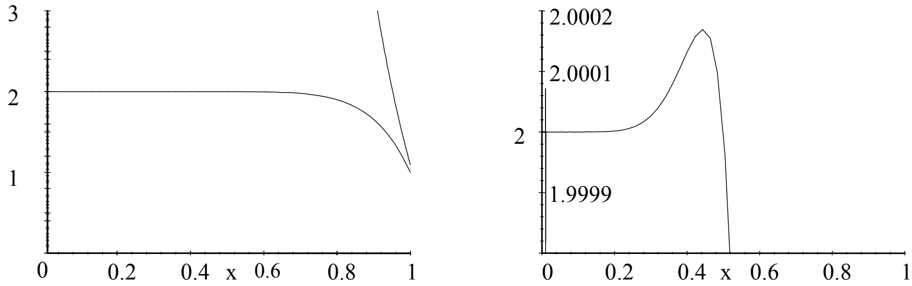


Figure 5a. Distribution of the dimensionless gradient function of entropy in the disc for $t=1P \sim \Omega_0^{-1}$.

Maximum at x ~ 0.44 ÷ 0.45 (44 ÷ $45R_g$)

No minimum.

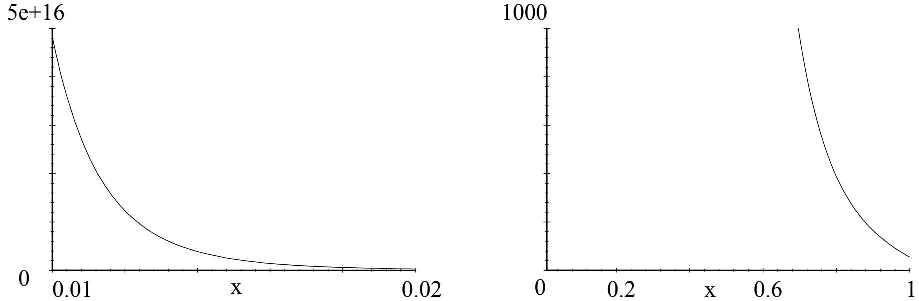


Figure 5b. Distribution of the dimensionless gradient function of entropy in the disc for $t \approx 0$.

4. DISCUSSION

With a sufficiently weak magnetic field members of turbulent viscosity in the disk as a result of SFI + MRI, both factors leading to linear instability can be ignored: 1) in the kinetic viscosity the relay criterion is met because on the disc for a smooth profile $\Omega(r)$**;** 2) in a differential system with a rotating magnetic field always leads to displacement dynamo, but not to the dynamo action. After an initial increase magnetic energy decreases due to dissipation of the field and the dynamo establish in state, where only offset losses. Oscillating field is obtained if α is negative in one hemisphere, than the energy transferring periodically from toroidal to radial component of the field and vice versa. While the dynamo number $D < D_{cr}$, (as for $D > 0$ there is stability, but for $D < 0$ – oscillation) and $D \approx D_{cr}$. That is reason for self-excitation dynamo and MRI appearing. Thay works for a small scale, when there is no stratification and for a big one, when there $v_{ms} < v_s$. The negative α-effect is caused by the fluctuations of v_z, which control the magnetic buoyancy due to shifting. If shifting in the disc is negative, the buoyancy dominates and the α-effect is negative, however, the advection leads to a positive α-effect. Consequently, the effect changes its sign for small shifting (weak field). The negative α-effect could generate a dipole field. 3D-simulations indicate that MRI could support such field even in a global model (Brandenburg and Subramanian, 2004).

Then the disc non-linear effects provide reallocation of the energy, the field and the angular moment. Coefficient $\alpha_t = \alpha + \alpha_m$

$$\alpha_t = \frac{v_t^2 + v_{ms}^2}{v_s^2}, \quad \text{where} \quad \alpha = \frac{\left\langle \overline{v_r}\,\overline{v_\varphi} \right\rangle}{v_s^2} \sim v_t^2 \tau_t \quad \text{and} \quad \alpha_m = \frac{\left\langle \overline{b_r}\,\overline{b_\varphi} \right\rangle}{4\pi \rho v_s^2}.$$

Most energy has found itself in long wave modes; the main transport of moment also comes from them. MRI is fast growing. Non-linear saturation is the increasing range of their modes (E_k and E_m are increasing exponentially). The growing strongly depends on the configuration of main field. From toroidal field where they are missing to vertical - uniform where are best expressed while $v_a < v_s$. Approximation of the main field in our case strongly recalls the last. For the vertical field (may be not uniform), the asymmetric MR- mode grows the fastest. Saturation from reconnection and dissipation of magnetic field created a powerful magnetic pressure, which with the help of the instabilities of Parker and RTI is transporting and formed strongly magnetize corona. This preserves the equilibrium of energies $E_m \sim E_k$ in the disk and magnetic field cannot inhibit rotation effects and to quench magnet-rotation instability (Brandenburg and Subramanian, 2004).[1]

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[1] Biskamp D., MHD Turbulence, Cambridge University Press.

Reconnections of the magnetic lines are reducing and the distance between the loops increases, so the surplus magnetic energy is released in the new configuration. Back in the presence of negative entropy gradient (figures 2 and 5) of creating conditions for increased instability in energy absorption. Stabilize them as structures and leads to a new disk (using an irreversible transition) state.

As shown in (Yankova, 2009) the coefficients of meeting correlate to the wave numbers of the local model, but in the outer regions there is no mechanism to distinguish functions. In inland areas, the prohibiting the existence of MRI distinguishes them quite clearly and could see the functions separately. The same is shown here, but for each object (figures 6÷10). This is a convenient indicator to assess what is happening. Finally, as shown and referred to summarize the results may predict that MRI leave internal regions of the disk before they are ruined, as entities.

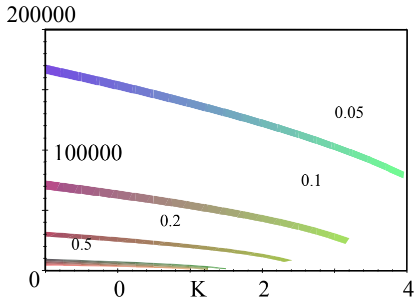
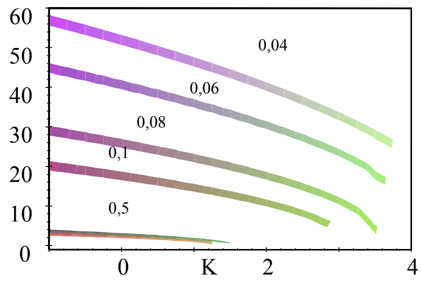


Figure 6. Contours $\kappa_r(K)$ for x~const. Cyg X-1



Contours $\kappa_r(K)$ for x~const. SgrA*

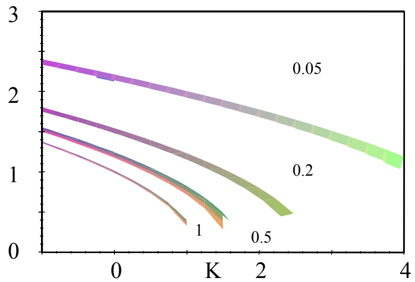
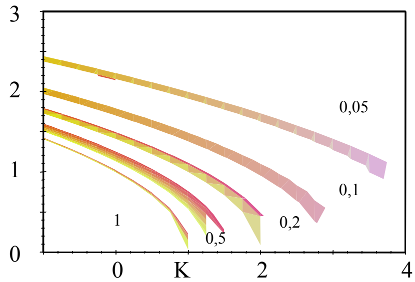


Figure 7. Contours $\kappa_\varphi(K)$ for x~const. Cyg X-1



Contours $\kappa_\varphi(K)$ for x~const. SgrA*

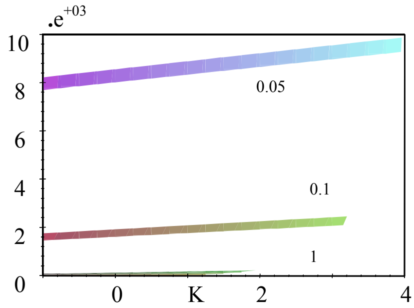
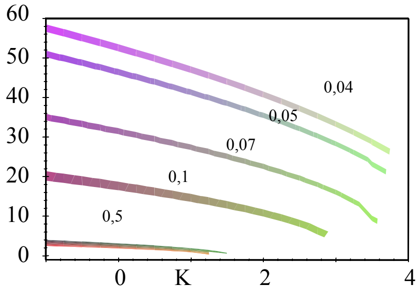


Figure 8. Contours ω(K) for x~const. Cyg X-1



Contours ω(K) for x~const. SgrA*

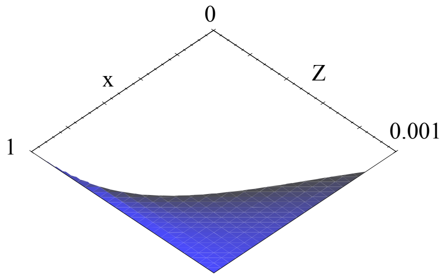
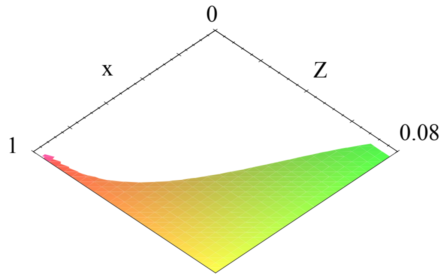


Figure 9. $f_7(x, Z)$ – dimensionless function of distribution coefficient ω (r, z) for Cyg X-1 at the moment $t \approx 1P \sim \Omega_0^{-1}$.



$f_7(x, Z)$ – dimensionless function of distribution coefficient ω (r, z) for SgrA* at the moment $t \approx 1P \sim \Omega_0^{-1}$.

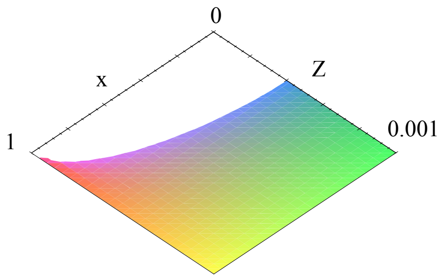
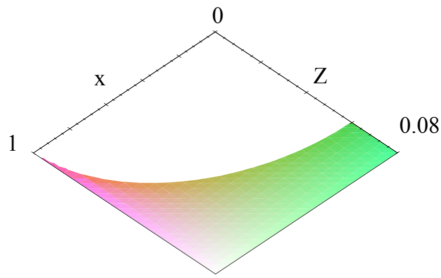


Figure 10. $f_8(x, Z)$ – dimensionless function of distribution coefficient $k_\varphi(r, z)$ for Cyg X-1 at the moment $t \approx 1P$.



$f_8(x, Z)$ – dimensionless function of distribution coefficient $k_\varphi(r, z)$ for SgrA* at the moment $t \approx 1P$.

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