# MHD of accretion-disk flows

Krasimira Yankova
Space Research and Technology Institute, Bulgarian Academy of Sciences, BG-1113, Sofia
f7@space.bas.bg
(Summary of Ph.D. Dissertation; Thesis language: Bulgarian
Ph.D. awarded 2013 by Space Research and Technology Institute, BAS)

**Abstract.** Accretion is one of the most important problems of astrophysics concerning the transfer of matter and the transformation of energy into space. Process represents a falling of the substance on a cosmic object from the surrounding area and is a powerful gravitational mechanism for the production of radiation. Accretion disc effectively converts the mass of the substance by viscous friction and released potential energy transformed into radiation by particle collisions.

Accretion onto compact object shows high energy efficiency and temporal variability in a broad class of observational data in all ranges. In the disks of these objects are developed a series instabilities and structures that govern the distribution of the energy. They are expressed in many variety non-stationary phenomena that we observe. That is why we propose generalized model of magnetized accretion disk with advection, which preserves the nonlinearity of the problem. We study interaction of the plasmas flow with the magnetic field, and how this affects the self-organizing disk. The aim of the work is to describe the accretion flow in detail, in his quality of the open astrophysical system, to investigate the evolution and to reveal the mechanisms of the structuring the disk-corona system for to interpret correctly the high energy behavior of such sources.
**Key words:** Close binary systems; Active galactic nuclei

We have developed a new model of the accretion disc's magnetohydrodynamics, based on some specific advective hypothesis, presented in Yankova, 2013. The basic equations of magneto-hydrodynamics for non-stationary and non-axisymmetrical accretion flows are investigated. We constructed geometrically thin, optically thick, one-temperature Keplerian disc in a normal magnetic field, around a black hole. 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 accretor. The flow will be considered non-relativistic because $v^2/c \approx 4.10^{-2} << 1$. For the gravitational potential we have selected the Pseudo-Newtonian form. It is simple and convenient way relativistic effects, which such a compact object exercise on the accretion, to be included in consideration of purely Newtonian flow (Abramowicz et al., 1988).

Advection defined by conditions of the complete advective term hypothesis, 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 one or more orders higher than normally accepted. The hypothesis represents new interpretation of physics in the left part of the equation for movement:

$$\frac{\partial (\rho v_i)}{\partial t} + \frac{\partial}{\partial x_j}(\rho v_i v_j) = \rho\left(\frac{\partial v_i}{\partial t} + v_j \frac{\partial v_i}{\partial x_j}\right) = \rho \frac{D v_i}{D t}$$

In contrast to models with radial advection or orbital advection, the complete advective term, doesn't indicate the individual modification of one or other of the velocity components. This means it arises a shifting of the average flow with velocity $v_i$ in any direction. In a case, when the advection is non-dominant mechanism, there isn't a condition of flow deformations. The full advective term transfers the solution as a whole. In contrast to the other models, no rotation or lengthening of the velocity vector appears here.

On the base of the new hypothesis we introduced a modification function $F_i = F_{i0}\Re_i\left(x = \frac{r}{r_0}\right)\exp\left[k_\varphi(x)\varphi + \omega(x)t\right] = F_{i0}f_i(x)$ for leading parameters in model's equations and we obtained global solutions for the 2D and 3D structures. Where $F_{i0}$ are functional values of the outer edge of disc $r_0$.

The solution has been investigated for two crucial moments of the disk evolution. When analyzing the results for radial and vertical structures of the disk self-organization we have demonstrated the appearance of a spiral, the presence of micro-vortices (microstructures) and the formation of short-living pseudo-rings with the higher density in inner regions. The model allows us to: observe the evolution of the disc; investigate the emergence of instability in it; study the generation of its corona.

In the modelling process we have introduced new quantities coefficients "coefficients of meeting". They define expression on the feedbacks, which are resulting from the impact of nonlinear effects on the nature of the flow. They correlate with wave numbers from the local model. Coefficients have not concrete relationship to one given disturbance, because they are global feedbacks. They have a relation to their general distribution in the stream as a whole.

The "coefficients of meeting" brings besides physical and mathematical advantages in the model:

o Coefficients defining the essential about physics of the object feedbacks.

o This presenting allows us to preserve the implicit dependence of the leading parameters on time and angular space coordinate.

o Equations remain nonlinear.

o Modification in the parameters $F_i$, whose coefficients of periodicity are depending on the distance to the centre r, permit to reduce the number on the variables. So from purely physical reasons (feedbacks) the system PDE is confined to the system ODE.

In the results of 2D-structure of the disc short-live formation-rings with enhanced density appear (Iankova, 2007).

We are building a model of such a formation and obtaining local heating and getting the local dependencies of instabilities from warming: $\omega$(K) and $k_\varphi$(K), and $k_r$(K) of an orbit r; and local developments of the flow's characteristics.

We created new physical object which describes a physical effect of the local warming in the ring, it carries information about the development of the instabilities in dependence from the energetics of the disc. It is displayed as an expression of the direct connection. We obtained averaged distribution of its development on the disc.

The behavior of averaged local heating obtained (build) in the local model:

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

along with $\partial_t s$, show that gradually changed the internal structure of the disk to create a dynamic quasi-steady state - that is relatively stable, but very far from equilibrium. The sign of the entropy determined the basic criterion for development, equilibrium and stability of the disc. Negative entropy gradients create conditions for absorption of energy from existing instabilities and thus stimulate feedbacks in rearranging the disc.

Analyzed results on MHD model for the key moment's $t = 1P$ and $t \approx 0$:

∘Co consideration of the radial and vertical structure of the disc;

∘The development of the condition of stratification $|v_a| \leq |v_s|$; co set with that of the vector field of the velocity $(v_r, v_z)$; are connected with MRI existence. In this way method for estimation of the outer radius of the disc corona is obtained.;

∘Comparing the coefficients of the meeting of the global model with wave numbers in the local model;

indicate that the disc develops spherical radiative (non-convective) corona (Iankova 2007, 2009).

Model has been applied for two specific cases of typical representatives of the stars and super-massive BH: Cyg X-1 and SgrA*.

Results adequately describe physical processes related to both objects and describe well processes for the individual events, which provide the opportunity to be compared with other sources:

- Auto-structuring of the disc and its evolution;
- Emergence of instabilities in it;
- Generation of disc corona.

o It is shown that MRI will leave internal areas of the disc. This effect combined with the behavior of the local heating, gives us method for assessment of the outer radius of the corona.

o It has been found a presence of fluidic lightguide in the disc of the Cyg X- 1, it is factor providing advection in a relatively cool environment.

o Prerequisites have been found for the emergence of magnetic Turing instabilities in disk of the SgrA*. They are associated with two-dimensional MRI that develop in inverse scale.

o Chaotic behavior is demonstrated in development entropy which indicates, in the disk of the center on our galaxy, characterized precession in the sheaf of accretion fibers and then it is rolled as a ball in the region of ergosphere.

The developed model of advection accretion disk is applicable to active and inactive galactic nuclei, as well as black holes with stellar mass.

This model gives a wide field of applications to real sources and can be used in the future to investigate such problems as: stability, formation of the disk corona, advection in the disc and interaction in the corona-disk system in poorly studied objects.

## References

M. A. Abramowicz, Czerny, B., Lasota, J. P., Szuszkiewicz, E.,1988 *Astrophysical Journal* **332** 646-658

Kr.D. Iankova, 2007 *Conf. Ser.Black Sea School on Plasma Physics* http://sp.phys.uni-sofia.bg/Kiten06/Pres/Iankova.pdf

Kr.D. Iankova, 2007 *Bulg. J. Phys.* **34** no.s2 326-329

Kr.D. Iankova, 2009,Theoretical modeling of accretion discs. Correlation of the global coefficients with the distributions of local wave numbers in the disc *Proceedings of International Conference MSS-09 "MODE CONVERSION, COHERENT STRUCTURES AND TURBULENCE"* 409-414.

K. Yankova, 2013 *Proceedings of 8th SBAC, Publ.Astron. Soc. Rudjer Boskovic* **12** 375 $http://wfpdb.org/ftp/8_SBAC_D1/pdfs/34.pdf$