Publ. Astron. Obs. Belgrade No. 73 (2002), 131 - 136 *Poster*

PATTERN FORMATION AND ANGULAR MOMENTUM TRANSPORT IN ACCRETION FLOWS

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Abstract. The presence of accretion disks around active galactic nuclei and quasars as well as in close binaries and protoplanetary objects made of the investigation of the accretion flows a question not only for astrophysics but also for theoretical hydrodynamics and magnetohydrodynamics. In close binaries a possibility exists for one of the stars to be a compact object and the second at the same time to be a giant, losing mass and originating in this way accretion flow toward the compact one, but this gas has a big angular momentum which must vanish before reaching compact object surface. Physical mechanisms for angular momentum transfer in accretion flows in close binaries are the theme of this work. One of the possibilities is the presence of some structures and shock fronts in the flow, where energy exchange is very effective. Here we present the results of two kinds of numerical simulations, showing the spiral structure formation and the vortices production separately.

1. INTRODUCTION

The accretion onto a compact stellar object is one of the most effective energy transfer mechanisms in the Universe. Because of that the physical behavior of accretion flows is of great interest for the astrophysicists. The availability of accretion disks around active galactic nuclei and quasars as well as in close binaries and protoplanetary objects made the investigation of the accretion mechanisms a more common question not only for astrophysics but also for theoretical hydrodynamics and magnetohydrodynamics. In close binaries with different stellar masses the evolution of both stars runs in different time scales. This gives the possibility for one of the stars to be in a compact object state and the second at the same time to be a giant, losing mass and thus originating accretion flow toward the compact one. The flow can take place through a wind or through the inner Lagrangian point. The presence of gas around the compact object is not the unique condition for accretion. In close binaries this gas has a big angular momentum which must vanish before reaching compact object surface (Papaloizou et. al. 1995). Physical mechanisms for angular momentum transfer in accretion flows in close binaries are the theme of this work. There is not yet common point of view about the most important operator in that. Some of the authors regard the flow as an axis-symmetric one and angular momentum transfer as a result of viscous forces. They try to include all physical processes in the alpha parameter. Others assume that these processes are not sufficiently effective and they search for possibilities for turbulisation of the flow. Some regard as good possibility to remove the angular momentum with the help of hydrodynamical instabilities (Dubrule et. al. 1992). Moreover, for some of them magnetohydrodynamical instabilities are the unique possibility for that (Balbus et. al. 1991, Caroline et. al. 2001). An alternative possibility is the availability of some structures and shock fronts in the flow, where energy exchange is very likely to occur. Our point of view is that spiral shock fronts are present in the flow and there are areas with outflow, which carried away the angular momentum. Spiral shock fronts are formed as a result of tidal forces. During the last years there are observational evidences for that (Marales-Rueda et.al., 2002, Streeght et.al. 1997, 1998). The vortices are other structures but more probable in the active galactic nucleus and quasars. The origin of Rossby solitons are small perturbations in axis-symmetric flows. But because of the large gradient of density and different speed directions along the shocks the conditions for these vortices to occur are present (Filipov 2000, 2001, Dimitrova et. Al. 2002). In this work we present the results of two kinds of numerical simulations, showing the spiral structure formation and the vortices production separately.

2. NUMERICAL MODELS

The models are built under the assumption that the flow may be considered as two-dimensional. For investigation of the structure and dynamics of the flow we use our own large particle method (Dimitrova et.al 1991, Dimitrova 1997b). In thermodynamical equation of the flow we include gravitational forces from both stars as well as both gaseous and radiative pressures. We also include the viscous forces and use full energy exchange equation. This gives the possibility to exchange the binary system parameters, inflow gas parameters, viscous and energy exchange coefficients. The reason for that is to be able to investigate the influence of each of them over total dynamics and structure of the flow. The model is built for the flow through the inner Lagrangian point, but there are no principal restrictions to adapt them for wind flow or protoplanetary system. To find the verticals we use axis-symmetric steady state flow and follow the evolution of small perturbations placed in.

3. SIMULATIONS AND RESULTS

The typical view of steady state accretion flow in close binary through the inner Lagrangian point is presented in Figs. 1 and 2.

In the first we are showing the density distribution and in the second - the velocity is placed at point (-1, 0) in the Figures. The calculations begin with no gas in the area and the field in steady state reached in a system. The calculations are made for a close binary, including a neutron star and a red giant. We have shown the area around the compact star, placed in the point (0, 0) in the Figures. The first Lagrangian point stopped when the stream reached a steady state (no change in parameters). Using different binary parameters we obtained steady states with different maximal density, but the full picture has the same general pattern.

As it is seen from the above pictures, in the accretion flow there are two spirals with high density, whereby the velocity changes its direction. In areas around the

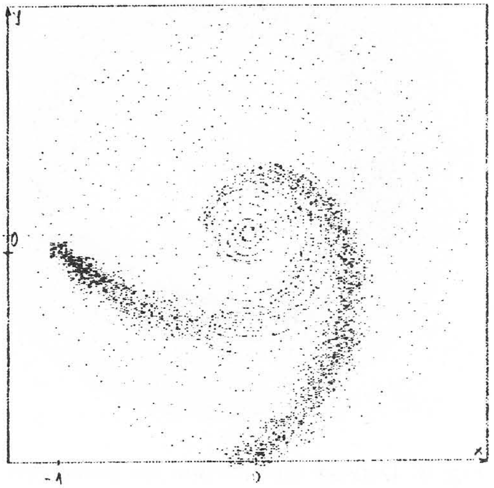

Fig. 1: Density distribution around the compact steady state object.

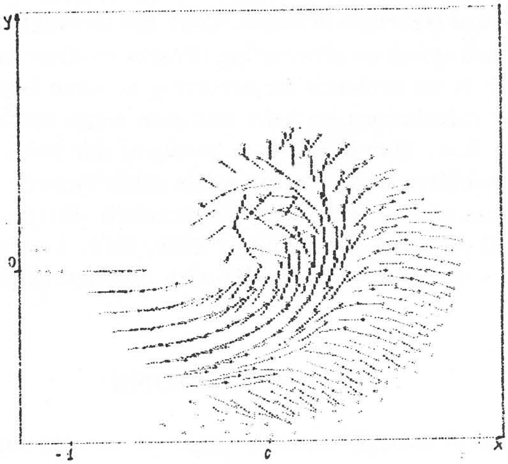

Fig. 2: Velocity field around the compact steady state object.

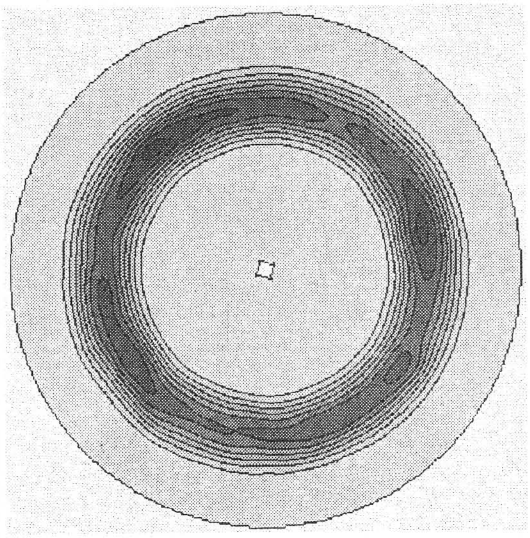

Fig. 3: Density distribution for perturbed flow.

points (-1, 0) and (1, 0) some amount of the gas leaves the system. This outflow takes away some angular momentum. This is in our view the true mechanism for angular momentum transporting away. In our previous investigations we show that the spiral structure does not strongly depend on viscous mechanisms and inner energy transfer processes (Dimitrova 1998), but the boundary conditions act on it very strongly (Dimitrova 1999). In all cases, wherever the spirals exist, they ensure the angular momentum transporting away. In the cases with nonstationar inflow stream (Dimitrova, 1997a) the spiral structure is stable. Only the second front becomes larger. In the places beyond each spiral we observe big density gradient and an exchange of the velocity direction. It is an evidence for occurring of some kinds of hydrodynamical instabilities. In our calculations we have not seen some vertical or other patterns, typical of nonstable flow. But it can be a result of our not sufficiently small cells. To investigate the stability of the flow we made other numerical model, using FEMLAB. We started from steady state axially symmetric distribution and searched for a solution with small perturbations (Filipov 2000, 2001, Lavelace, et. Al., 1999)) In the following Figures we show some results with different perturbation number and initial distributions.

4. DISCUSSIONS

There is not a good enough common point of view about mechanisms, ensuring angular momentum transport away and energy transfer mechanisms in accretion flows as a whole. Most of the authors are looking for some turbulisation processes (Papaloisou et. Al. 1995). But, if we accept the spiral shock structure of the flow, we have no need of any kind of additional turbulisation actions. The shocks themselves are the place for all energy exchanges and at the same time - the condition for occurring of instabilities. Many scientists assume that if the gravitational force from

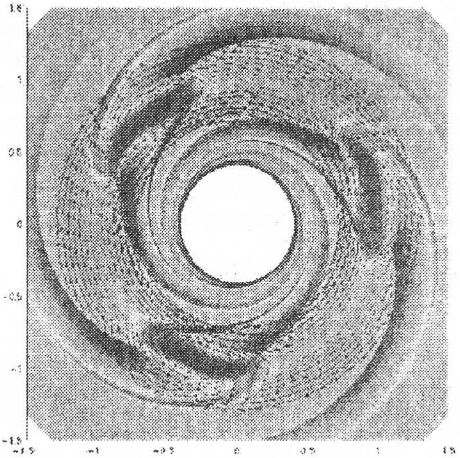

Fig. 4: Density and velocity distribution for m=3.

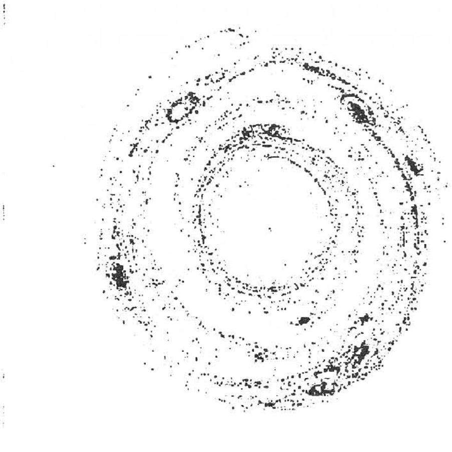

Fig. 5: Density distribution for m=4.

the second star is not strong, the spiral does not exist. The latest observational data (Streeght 1998, 1999) show the presence of such spiral flows in close binaries. There are evidences for presence of such structures in many cataclysmic variables (Murales-Rueda et. al. 2002). In our investigations of systems with second star of smaller mass, the second spiral is not so clearly seen, but still exists and the velocity fields have the same distribution (Dimitrova 1998). More than this, in some protoplanetary disk models we see the same kind of spiral structure (Burkert et. al. 1997). Planets or secondary stars are formed along these formats. The structure is stable in non-stationar flows. All this means in our opinion, that the spiral structure is something deeply intrinsic for rotating in gravitational field gas flows. It allows energy transfer as well as conditions for instability occurrence.

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