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Structure of accretion flow in close binary as a function of radial inflow velocity - 2D numerical simulation

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Introduction

With progress in computing machinery and numerical methods during the last decades, numerical models of accretion flows have revealed a lot of detailes, which can not be predicted analitically. The simplest standard model [1, 2] was replaced by two-dimensional [3 - 6] and during the last years by tree-dimensional numerical calculations [7 - 13].

It was shown that an accretion flow possesses a complicated structure and its parameters depend on radial distance from central object as well as on azimutal angle [3, 4, 13-15]. The accretion flow formes two or three spiral shock fronts. These shocks are regarded as a place where the energy and angular momentum transphere is accomplished [16].

Two- and three-dimensional calculations are compared in the paper of Sawada [9]. They showed that the spiral shocks are not different in both cases.

Not yet fully described were all relationships between structure, respectively luminosity and external parameters (such as direction and debit of the inflowing gas stream, and the masses of and distance between the two stars), internal mechanisms (such as type of viscosity and opacity) and their variations.

This paper is one of a series works where We will try to investigate the influence of external parameters on the position, strength and stability of the shock fronts in accretion flow.

In this paper we investigate with a two-dimensional numerical model, the influence of inflow direction on the structure of accretion flow and the luminosity, produced in inner boundary of the flow.

Problem definition

The numerical model is built on the basis of the largescale particle method[17]. This is a combined Lagrangian-Eulerian method. Each time interval is divided into three steps. During the first (Eulerian) step, hydrodynamic equations are solved over fixed Eulerian grid with the aid of suitable scheme of finite differences with out account of gas shift into the cells. During the second (Lagrangian) step we compute the substance fluxes throuth the cell walls. The gas in each cell is considered as a single large particle. During the third final step the new values of parameters (V_r, V_p, ρ and T) are recalculated for each cell in the Eulerian grid. The stability requirement condition is such that the time step should be selected in a way that no large particle would leave its cell.

This method describes well the formation of shock fronts with relatively small number large particles which makes it relatively fast compared to other known methods.

The calculations are performed in a noninertial cilindrical reference frame, centered of the neutron star and corotating with the close binary. In this case the equation system is as follows [1, 4]: Angular velocity of binary system is

$$\Omega_{oth} = \frac{G(M_1 + M_2)^{\frac{1}{2}}}{R_{12}}$$

where M_1 and M_2 are the masses of the stars and R_{12} is the distance between them.

The equation of motion is

$$\frac{d\bar{V}}{dt} = -\frac{1}{\rho}\nabla p - F - \frac{1}{\rho}F_{visc}$$

where

$$F = \frac{GM_1}{r} - \frac{GM_2}{\left[r^2 + R_{12}^2 - 2R_{12}r.\cos\varphi\right]^{\frac{1}{2}}}$$

$$+\frac{1}{2}\Omega_{orb}^2\left[r^2+\left(\frac{R_{12}M_2}{M_1+M_2}\right)^2-2r\frac{R_{12}M_2}{M_1+M_2}\cos\varphi\right]^{\frac{1}{2}}$$

is the sum of gravitational and centrifugal forces.

F_{visc} is the viscouse force. In this calculations We use kinetic viscosity

$$\eta=\eta_0 T^{-\frac{7}{2}}.$$

The equation of continuity is

$$\frac{d\rho}{dt}=-\rho\nabla\vec{V}$$

Equation of state involves both gas and radiative pressure

$$p=p_0\rho T+p_1T^4.$$

We use the energy transfer equation for the case of optically thick flow [1]

$$\frac{ac}{4}T^4=\frac{kL_x}{2\pi r^3}+\frac{3GM_1\dot{M}}{8\pi r^3}\left[1-\sqrt{\frac{R_{in}}{r}\frac{L_x}{n_e r}}\right]\left(1+\frac{3}{8}\tau\right)$$

where the luminousity from the newtron star surface is

$$L_x=G\frac{M_1}{R_1}\dot{M}_{in}$$

and the optical depth is

$$\tau=\int_0^H k\rho\,dz$$

$$k=k_{abs}+k_{es},\ k_{es}=0{,}2(1+X),$$

$$k_{abs}=k_0\rho T^{-\frac{7}{2}},\ k_0=4{,}3\,10^{24}\,Z(1-X)$$

where X and Z are the mass fractions of hydrogen and metal respectively

$K=pAH$, where $p=\frac{1}{8}$, H is the disk height and A is the absorbtion coefficient

$n_e=\frac{2\rho}{m_p(1+x)}$ is the electron density.

The z - longitude of the flow is calculated from the hydrodynamical equilibrium equation in z direction

$$H=\left(\frac{P}{\rho}\right)^{\frac{1}{2}}\left(\frac{r^3}{GM_1}\right)^{\frac{1}{2}}.$$

The calculation of H was used only as a verification for reliability of two dimension aproximation.

Calculations and results

The calculations have been performed for the close binary, containing a red giand with mass $M_2=4M_\odot$ wich filled it's Roche lobe. The compact object is neutron star with mass equal to $1{,}5M_\odot$ and radius of 10^6 cm. The magnetic field was assumed to be enough small not to be important for the gas motion. The distance between the binary systems components is 10^{11} cm. We regarded region up to 5.10^{10} cm from the center of neutron star.

The gas stream through the inner Lagrangian point is with constant temp of $M_\odot$ /year and tangential velosity equal to Keplerian one. The change in direction is modelled with variations in radial part of inflow velosity.

Six cases ware calculated. The radial inflow velosity is equal to 0, 0,1, 0,25, 0,5, 10 and 2 times azimutal, wich corresponds to inflow angles equals respectively to 0°,1°,14°,30°,45° and 60° from tangential direction.

The calculations ware interrupted when the X-ray luminosity L_x established a constant value. This corresponds to one stationary station of flow.

In all six cases accretion flows with similar structures are formed . Two spiral shock fronts are clearly detacted [15]. Similar structure was found by other autors [3, 6, 9, 14]. In all their works is examined the case of $M_2=M_1$ and they obtained differend position of the shock fronts.

The surface density in cases of $\alpha=0$ and 60° is shown in Fig. 1. The velocity field and H in case of $\alpha=60°$ are shown in Fig. 2.

The only important difference in structure is that the second shock front is relatively stronger when the inflow angle is larger. The differences in velocity field and H are neglectable. The dependences of the maximal tempepature and surface density from the inflow angle are seen (see Fig.3*a* and *b*). The dependence on the inflow direction show L_x and outflow stream debit trought the outer boundary of examined region too (see Fig.4 *a,b*).

The difference between the parameters of accretion flow when the inflow direction is diferent should be leades the change of the flow whith the change of inflow direction.

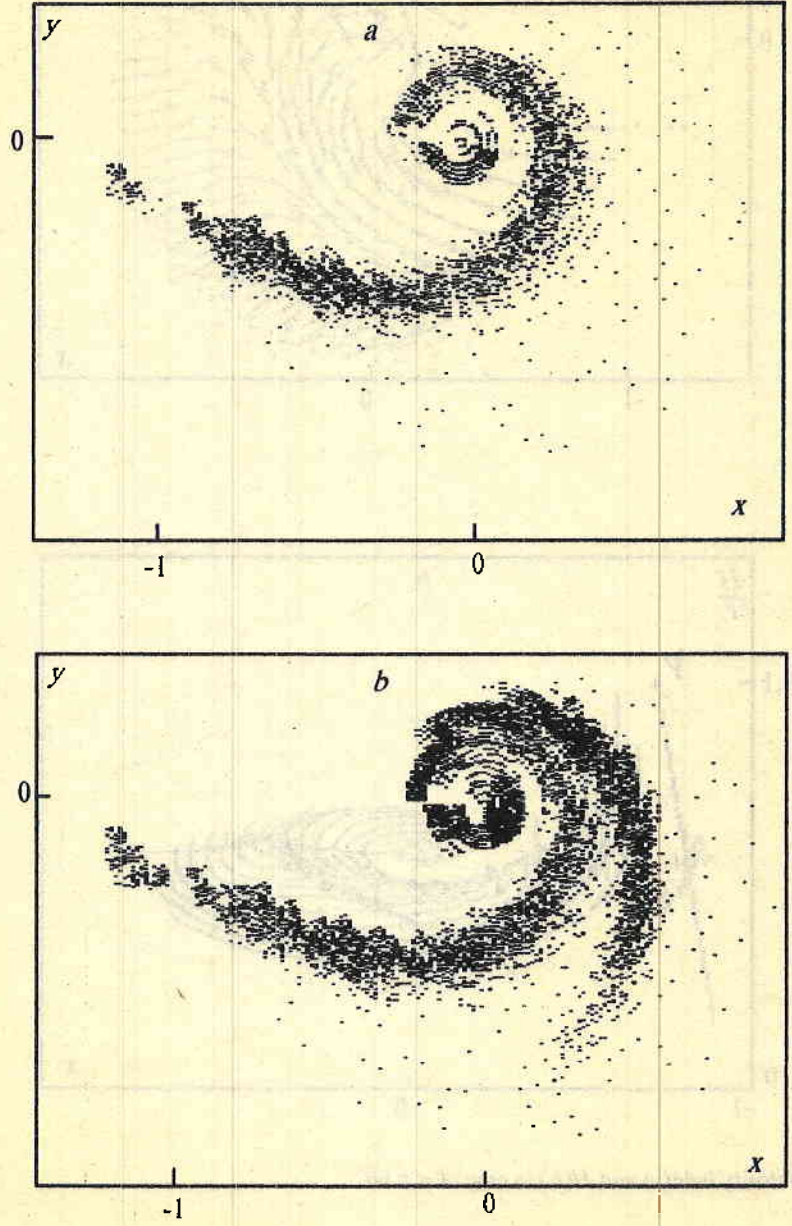

Fig. 1. Surface density in cases of $\alpha=0^\circ$(*a*) and $\alpha=60^\circ$(*b*)

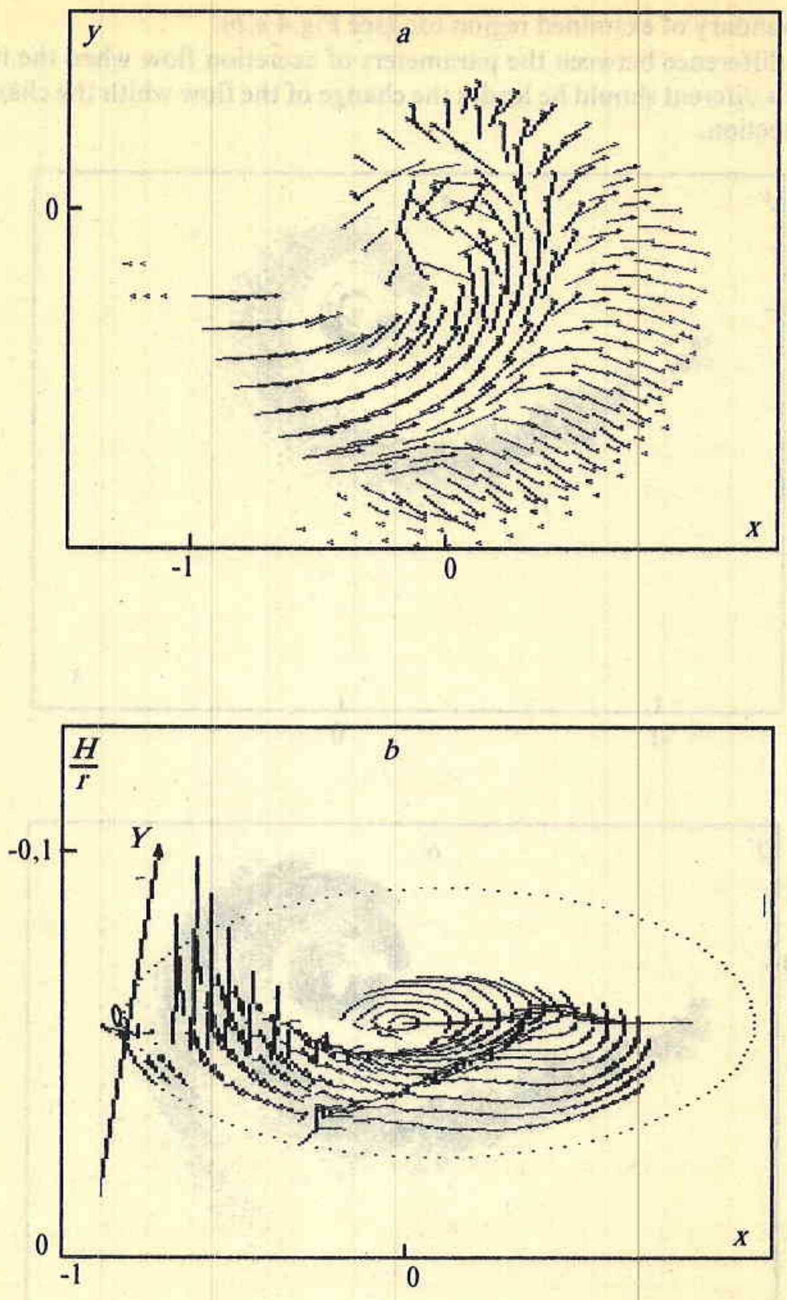

Fig. 2. Velosity field(a) and $H(b)$ in case of $\alpha = 60^\circ$

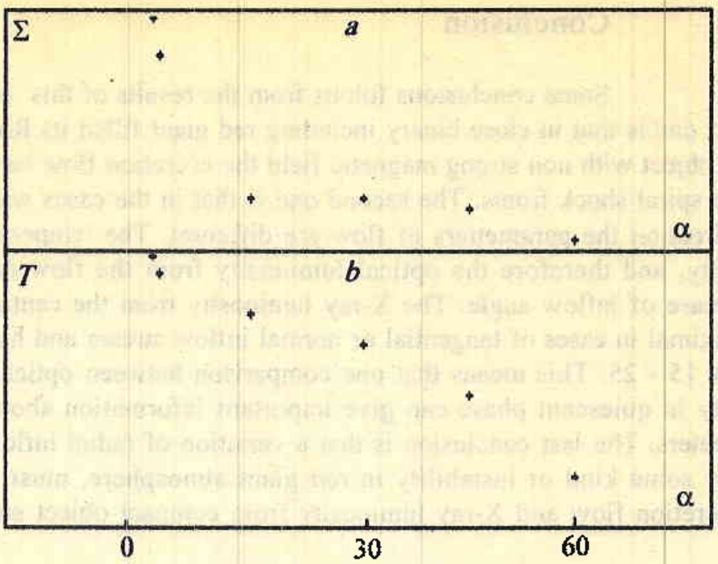

Fig. 3. Dependence of the maximal temperature (*a*) and maximal surface density (*b*) from the inflow angle. The spots corresponds to the case of α=0°, 1°, 14°, 30°,45° and 60°. Amplitude of changes in temperature is 5 times and in surface density - 30

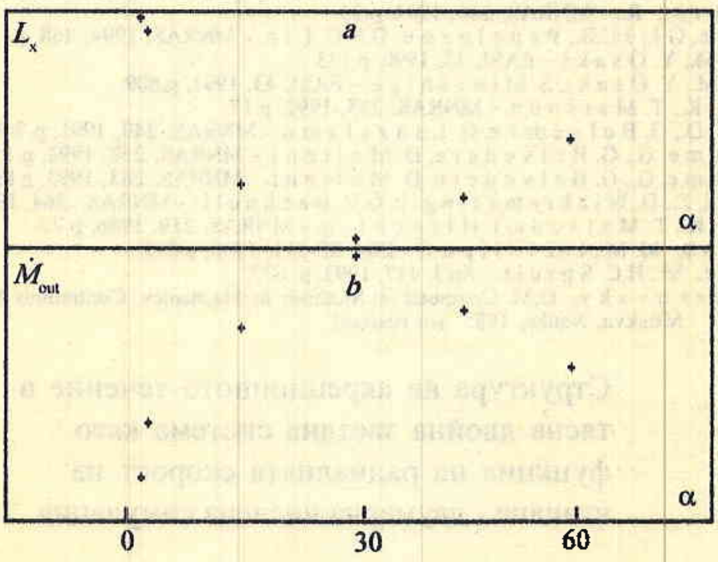

Fig. 4. Dependence of the X-ray luminosity from the newtron star surface (*a*) and the outflow temp trougth the out boundary (*b*) from the inflow angle . The spots corresponds to the case of α = 0°,1°,14°,30°,45° and 60° Amplitude of changes in both values is 20

Conclusion

Some conclusions folous from the results of this investigation. The first one is that in close binary including red giant filled its Roche lobe and compact object with non strong magnetic field the accretion flow has a structure with two spiral shock fronts. The second one is that in the cases with different inflow direction the parametters of flow are different. The temperature and surface density, and therefore the optical luminosity from the flow decreased with the increase of inflow angle. The X-ray luminosity from the central object surface is maximal in cases of tangential or normal inflow stream and have minimal value for 15 - 25. This means that one comparison between optical and X-ray luminosity in quiescent phase can give important information about inflow stream parameters. The last conclusion is that a variation of radial inflow velocity, forced by some kind of instability in red giant atmosphere, must defy the change in accretion flow and X-ray luminosity from compact object surface.

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Структура на акреционното течение в тясна двойна звездна система като функция на радиалната скорост на втичане - двумерна числена симулация

Мария Димитрова

(Резюме)

В работата е представен двумерен числен модел на газовото течение в тясна двойна звездна система, съдържаща червен гигант

и неутронна звезда, което се осъществява през вътрешната точка на Лагранж. Обсъжда се структурата на течението.

Изследвано е влиянието на радиалната компонента на скоростта на втичащия се газов поток върху структурата на течението. Показано е, че в зависимост от радиалната скорост на втичане течението достига стоционарно състояние с различни максимална температура, повърхнинна плътност и съответно притежава различна рентгенова светимост.