2D MODELLING OF THE GAS FLOW STRUCTURE IN THE SYMBIOTIC STAR Z ANDROMEDAE

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ABSTRACT. The 2D gasdynamical simulations of gas flow structure in the symbiotic star Z And have been carried out for different stellar wind regimes. Since the mechanisms of gas acceleration in stellar atmospheres are not well studied, the parametric representation of gas accelerating force was used. The calculations for various stellar wind velocity regimes have shown that for realistic cases the accretion discs in the system were formed.

Key words: Stars: binary: symbiotic; stars: gas flow; stars: individual: Z And.

1. Problem setup

Z Andromedae is one of the most famous representatives of symbiotic stars. It is generally admitted to be the binary system with the components not filling the Roche lobe. Therefore, the mass exchange in Z And should be driven by the stellar wind. Previous studies (e.g. Bisnovatyi-Kogan et al. 1979, Bisikalo et al. 1994, Bisikalo et al. 1996) have shown that the general structure of the gas flow in binary systems with components not filling the Roche lobe, is defined first and foremost by the stellar wind parameters and it is very important to fix the velocity regime of the stellar wind.

Unfortunately, the wind velocity regime is not well-known due to the absence of an avowed mechanism of gas acceleration in stellar atmospheres. To avoid this ambiguity we use in the model the additional artificial force that accelerates gas. This force can be written in the following form:

$$\mathbf{F} = \alpha \frac{GM_1}{r^2}\frac{\mathbf{r}}{|\mathbf{r}|}$$

where M_1 is the mass of the primary component, G - gravitational constant, r - distance from the center of the primary component, α is the dimensionless parameter. This force has been included in the original Roche potential and all the simulations were carried out using the modified Roche potential.

This approach allowed us to obtain all possible stellar wind velocity regimes by varying the parameter α without taking into account the detailed mechanisms of gas acceleration.

In this work the results of 2D gasdynamical calculations for $\alpha = 0.3, 0.5, 0.7, 0.8, 0.9$ are presented.

2. The model

In the gasdynamical model we use the 2D system of Euler equations in rotational coordinate frame:

$$\frac{\partial \rho}{\partial t} + \frac{1}{r}\frac{\partial(r\rho u)}{\partial r} + \frac{1}{r}\frac{\partial(\rho v)}{\partial \varphi} = 0$$

$$\frac{\partial(\rho u)}{\partial t} + \frac{1}{r}\frac{\partial(r\rho u^2 + rP)}{\partial r} + \frac{1}{r}\frac{\partial(\rho u v)}{\partial \varphi} =$$

$$= \frac{P}{r} - \rho\frac{\partial \Phi}{\partial r} + \rho\frac{v^2}{r} + 2\Omega v\rho$$

$$\frac{\partial \rho v}{\partial t} + \frac{1}{r}\frac{\partial \rho u v}{\partial r} + \frac{1}{r}\frac{\partial(\rho v^2 + P)}{\partial \varphi} = -\frac{\rho}{r}\frac{\partial \Phi}{\partial \varphi} - \rho\frac{uv}{r} - 2\Omega u\rho$$

$$\frac{\partial(\rho E)}{\partial t} + \frac{1}{r}\frac{\partial(r\rho u h)}{\partial r} + \frac{1}{r}\frac{\partial(\rho v h)}{\partial \varphi} = -\rho u\frac{\partial \Phi}{\partial r} - \rho\frac{v}{r}\frac{\partial \Phi}{\partial \varphi}$$

here ρ denotes density, u and v are r and φ components of the velocity vector respectively, P is the pressure, $E = \varepsilon + \frac{|\mathbf{u}^2|}{2}$ – total specific energy, ε – specific internal energy, Ω is the system's angular velocity.

The modified Roche potential after including the accelerating gas force has the following form:

$$\Phi(\mathbf{r}) = -\frac{GM_1}{|\mathbf{r}-\mathbf{r}_1|} + \alpha\frac{GM_1}{|\mathbf{r}-\mathbf{r}_1|} - \frac{GM_2}{|\mathbf{r}-\mathbf{r}_2|} - 1/2\,\Omega^2\,(\mathbf{r}-\mathbf{r}_c)^2$$

where $\mathbf{r}_1$, $\mathbf{r}_2$ are radius-vectors of centers of components, $\mathbf{r}_c$ – radius-vector of the mass center of the binary system, M_2 is the mass of the secondary component (accretor).

We restricted our consideration to an ideal gas model with adiabatic index $\gamma = 5/3$ and equation of state:

$$P = (\gamma - 1)\rho\varepsilon$$

To solve this system of equations the explicit finite-difference Roe scheme with restrictions of flows in Osher forms (Roe 1986, Chakravarthy and Osher 1985) was used.

The boundary and the initial conditions were determined as follows:

- The gas is injected from the donor's surface with radial velocity $v = 25$km/s;
- We adopted free-outflow conditions at the accretor and at the outer boundary of the calculation domain;
- The initial conditions corresponded to the background gas with the following parameters were used:

$$\rho_0 = 10^{-5}\rho(R_1), \quad P_0 = 10^{-4}\rho(R_1)\, c^2(R_1)/\gamma,$$

$$\mathbf{V}_0 = 0.$$

where R_1 is the radius of the donor.

The coordinate system was defined as follows: the origin of coordinates is located in the center of the mass-losing star, X-axis is directed along the line connecting the centers of stars, from the mass-losing star to the accretor, Y-axis is directed along the orbital movement of the accretor. The calculations region was adopted as $[-A \ldots 2A] \times [-{}^3/_2A \ldots {}^3/_2A]$. All the calculations were carried out for 301×301 computational grid.

The parameters for Z And required for our calculations were taken from the work by Fernandez-Castro et al. (1988): the mass of the primary (mass-losing) component $M_1 = 2M_\odot$ and it's radius $R_1 = 77R_\odot$, the mass of the secondary component $M_2 = 0.6$. $M_\odot$ and the radius $R_2 = 0.07R_\odot$, the orbital period of the system $P = 758.8$ days, separation between the components $A = 482.53R_\odot$. These parameters result in the Roche lobe radius $(R/A) = 0.48$. The orbital velocity of the system $V_{\rm orb} = 32$ km/s.

3. Results

The results of numerical simulations for different values of α parameter show that up to α=0.8 there are no steady state solution. The matter firstly injected into the system falls back to the donor's surface and finally there is no matter left to form the disk (the obtained densities don't exceed the background value). The situation is rather different for greater values of $\alpha \geq 0.8$ – here the stationary regime takes place in few orbital periods. The accretion disk and the bow shock wave in front of the secondary component are formed. Here the gas densities are significantly greater than the background values.

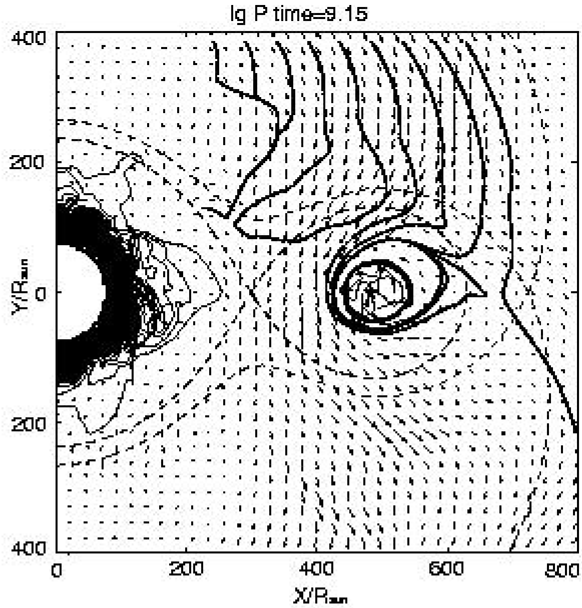

Figure 1: Fields of pressure and velocity vectors in equatorial plane for run with α=0.7. The length of the longest arrow corresponds to the velocity value of 100 km/s

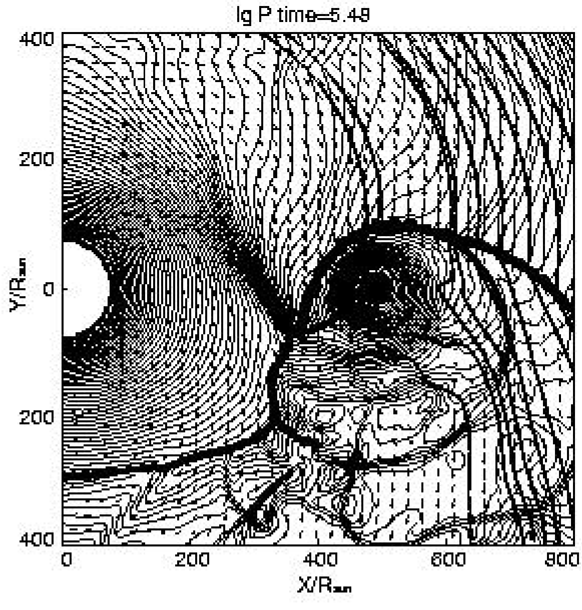

Figure 2: Fields of pressure and velocity vectors in equatorial plane for run with α=0.9. The length of the longest arrow corresponds to the velocity value of 100 km/s

Table 1: Radial velocities and accretion rates

1	2	3	4
α	T	v_{rad}	Accr. rate
0.3	10.94	60	$< 10^{-5}$
0.5	6.53	65	$< 10^{-5}$
0.7	5.60	65	10^{-5}
0.8	5.69	63	4×10^{-4}
0.9	5.48	71	5×10^{-3}

These conclusions are illustrated by Figures 1,2. In these figures fields of pressure in the equatorial plane are presented for two values of α parameter (α=0.7 and α=0.9). All the distances are given in the units of solar radius. The radius of the circle with center at the origin of the coordinate frame corresponds to the donor's surface. The flow lines are shown by solid lines. The flows are directed along the velocity vectors (shown by arrows). The dashed lines mark the Roche equipotentials. The accretor is marked by the asterisk.

In the Figure 1 the non-steady case with α=0.7 is presented. Here we can see that by the moment of 9.15 orbital periods there are no matter between the components (the observed picture corresponds to the densities less then background value). The gas is concentrated near the donor's surface. In this case almost all the gas ejected has returned to the donor's surface.

Figure 2 illustrates the case of α=0.9 where the steady state picture with the disk and the bow shock wave (the bold line resulting from the isobars condensation) located in front of the accretor on the way of it's orbital motion takes place. The figure corresponds to the time of 5.48 orbital periods. The calculations for values of α >0.8 also showed that the disc size was greater for the smaller value of α.

The relative accretion rates and radial velocities at infinity have been also calculated. The radial velocities are all of the order of 60–70 km/s. The accretion rates don't exceed the values 5×10^{-3}. These results are presented in the Table 1. Here 1^{st} column – the value of α parameter, 2^{nd} column – T – time in orbital periods, 3^{rd} column – V_{rad} – radial velocity at infinity (km/s), 4^{th} column is the relative accretion rate.

4. Conclusions

Different gas flow regimes for the symbiotic system Z And have been considered within the framework of 2D gasdynamical model. Calculations for the various stellar wind velocity regimes ($\alpha = 0.3, 0.5, 0.7, 0.8, 0.9$) have been carried out.

The results show that for small stellar wind velocities ($\alpha < 0.8$) no steady disk can be formed. Solutions with $\alpha < 0.8$ are not steady state ones. The gas ejected during the first phase falls down to the donor star. This process is rather slow and at the time $T \sim 5 - 10P_{orb}$ we still have some matter in the system.

The calculations for $\alpha = 0.8$ and 0.9 show the presence of the disk as well as of bow shock waves located in front of the compact star on the way of its orbital motion. For these runs ($\alpha \geq 0.8$) we have found that:

- the disk size decreases with increasing of α;
- the accretion rate does not exceed 0.5 % that is smaller than the value of 5% estimated in Bisikalo et al. (1996) for symbiotic systems. This may be due to the difference in the considered parameters. It is also smaller than the value 2% obtained by Fernandez-Castro et al. (1988) for Z And.

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