THREE-DIMENSIONAL HYDRODYNAMICAL MODELING OF MASS TRANSFER IN THE CLOSE BINARY SYSTEM LYR WITH AN ACCRETOR WIND.III

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ABSTRACT. The present paper continues our work on numerical modelling of formation of the accretion disc in CBS β Lyrae taking into account the stellar wind of the accretor. On having used methods of additional reduction of numerical viscosity, as well as different variants of the stellar wind and terms of its displacement out of the orbital plane while forming a disc, we defined the disc parameters close to the observational ones, and also jet like structures, where gas velocity equals to the velocity of the accretor's stellar wind.

Key words: Stars: binary: hydrodynamical modeling: individual: β Lyr.

1. Introduction

β Lyrae is a well investigated binary system at stage of rapid mass transfer with complex structure of gas envelope. Many parameters of this binary are received quite precisely and presented in the summarizing article of Harmanec et al. (1996): P=12.9d, Sp=B6-8II+B0-3V, $\dot{P}$ =19/year, $\dot{M} = 3 \times 10^{-5} M_{\odot}$/year, A = $58 R_{\odot}$ $M_a = 12 M_{\odot}, R_a = 6 R_{\odot}, T = 30000K$, $M_{don} = 2.9 M_{\odot}, T_{don} = 13000K$, $vsini_{don} = 55 km/s$, where index a means the accretor, and index don is the donor.

But parameters of the donor were defined not so accurately as it is closed for observing with a thick accretion disc. The complex structure of gas envelope was specified on the results of observations for different waves length ranges. Modelling of light curve of this binary for the waves of length from 3000 to 10000 $\AA$, Linnell (2000) received parameters of optically and geometrically thick cylindrical accretion disc with $R_d = 30 R_{\odot}$, $h_d = 8 \div 12 R_{\odot}$, $T_d = 9000K$, $M_d = 3.6 \times 10^{-6} \div 3.4 \times 10^{-4} M_{\odot}$, $vsini_d = 180 km/s$, where the index d means a disk. To explain a Balmer jump in the observing energy distribution in the spectrum of this binary Linnell (2000, 2003) assumed that there was a dispersing envelope (corona) above the disc with particles concentration $N_e = 10^{11} cm^{-3}$ in height $h = 14 R_{\odot}$ and temperature 30000 K. As assumption of Harmanec et al (1996) the basic part of emission in lines H_{α} and HeI $\lambda 6678 \AA$ the given system is formed in the bipolar jet-like structures, moving perpendicularly to the orbital plane; moreover, it is possible that envelope absorption lines are also generated there. Gas velocity at such structures at the angle of orbit slope to the vision ray 83^o is about 700-1000 km/sec. shells absorption lines are formed in the same place too. The observation in a radio range have allowed to find out the extended environment surrounding this system and reaching to distance near 40 AU with temperature of 11000 K. The given environment is connected to a stellar wind of the donor that is estimated to be equal $\dot{M} = 6 \times 10^{-7} M_{\odot}$/year.

The main goal of our first work on three-dimensional hydro dynamical modelling of forming an accretion disc in CBS β Lyrae with the regard for the accretor's stellar wind Nazarenko, Glazunova (2006) was to simulate an accretor's stellar wind with the velocity profile close to the model by Castor et al. (1975), to compute a disc model with different velocities of the stellar wind (700 and 1200 km/sec) and to determine the disc's parameters and possible jet like structures. In the mentioned paper the term of wind displacement by the stream was a linear decrease of the wind velocity to zero in the set field of computation at co-ordinate z ±0.04. The following results were received: while interacting the stream displace the wind out of the space fields, near to the orbital plane, where the disc with $R_d = 25 R\odot$ $h_d = 6 R_{\odot}$ $T_d = 15000 \div 20000$ K $N_e = 10^{12} \div 10^{14} cm^{-3}$ is formed; interaction of the stellar wind from the accretor's polar areas with the envelope above the disc results in generating jet like structures, where gas moves from the accretor with the velocities close to the accretor's stellar wind velocity. The densest part of the structure locates at co-ordinate y=-0.15 with the particles concentration $10^{12} \div 10^{14} cm^{-3}$ and

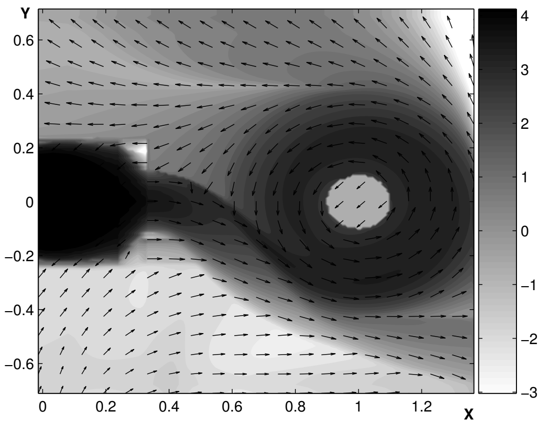

Fig.1a Isolines of equal density and current lines at the orbital plane (variant 1-1).

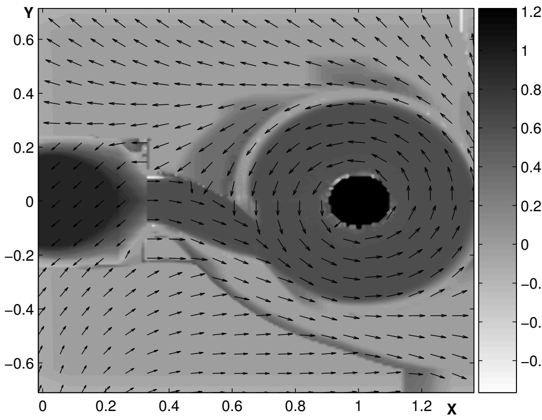

Fig.1b Isolines of equal temperature at the orbital plane (variant 1-1).

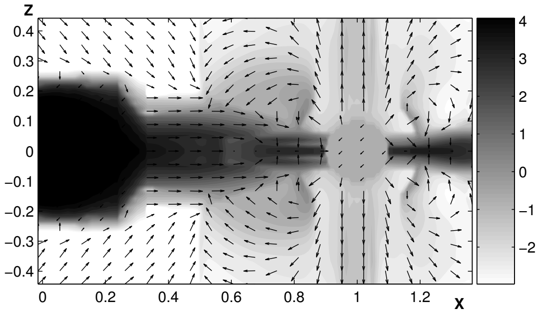

Fig.2a Isolines of equal density and velocity field at area z-x (variant 1-1).

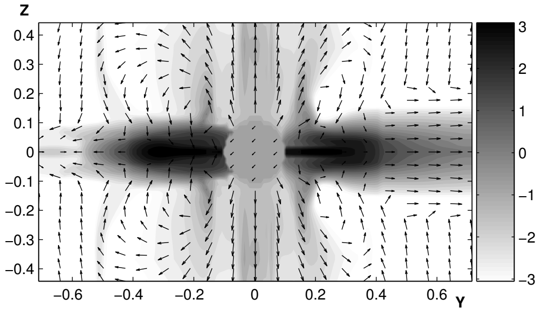

Fig.2b Isolines of equal density and velocity field at area z-y (variant 1-1).

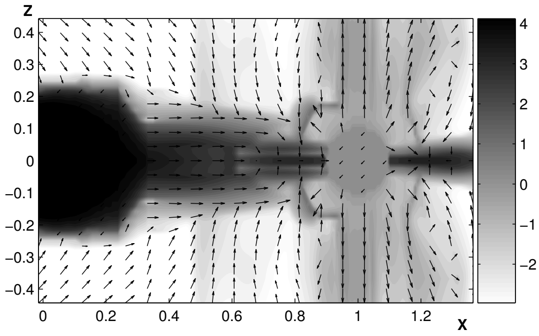

Fig.3a Isolines of equal density and velocity field at area z-x (variant 1-10).

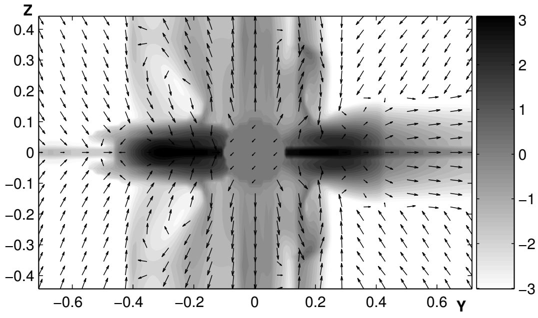

Fig.3b Isolines of equal density and velocity field at area z-y (variant 1-10).

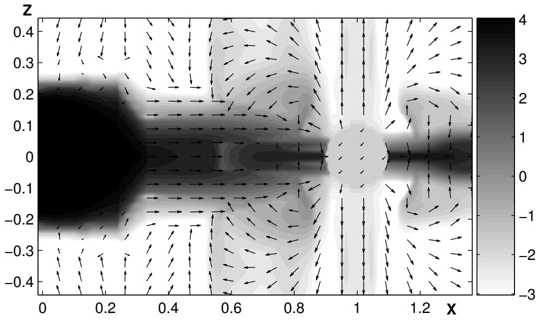

Fig.4a Isolines of equal density and velocity field at area z-x (variant 1-0.1).

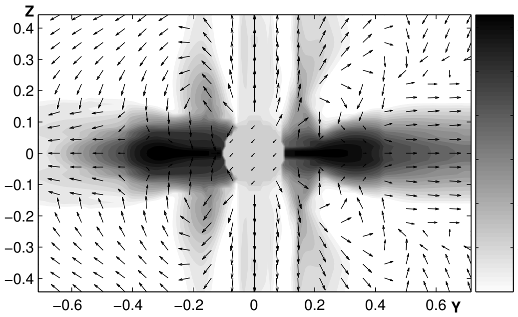

Fig.4b Isolines of equal density and velocity field at area z-y (variant 1-0.1).

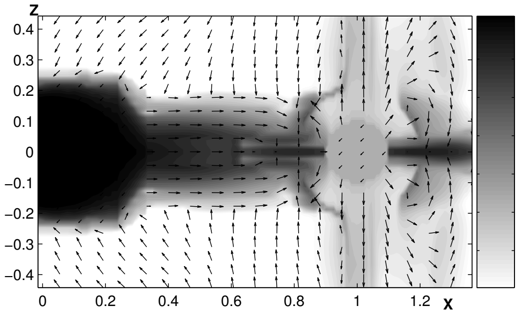

Fig.5a Isolines of equal density and velocity field at area z-x (variant 10-0.1)

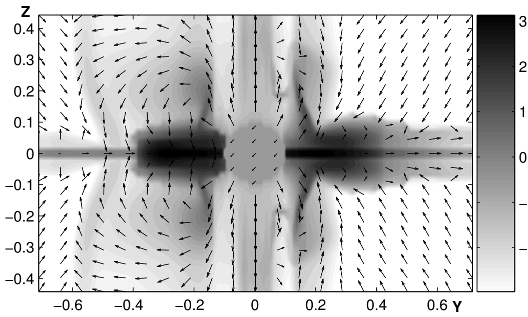

Fig.5b Isolines of equal density and velocity field at area z-x (variant 10-0.1)

temperature of $35000 \div 45000$ K; interaction of jet like structure and the disc evokes a strong shock wave, in which observation emission lines of the system can be generated; the mass transfer in the binary becomes non conservative - $50L_1$ ($\dot{M}_{L1}$) out of the system. Thus, in the present model we succeeded in getting the observing jet like structures with gas velocity about 700 km/sec; however, such disc parameters as R_d and h_d turned to be much less than the observing ones.

2. Features of three-dimensional hydrodynamical modelling of of mass transfer with an accretor wind.

Our approach to calculation of mass transfer in system β Lyrae, both initial boundary conditions and model of binary system are similar to the first part of article (Nazarenko, Glazunova 2006 I). The parameters of binary system and a degree of the overflow by the donor of its Roche-lobe is the same to the article I. We also resolve the nonstationary Euler hydrodynamics equations using the same version of the large-particle method by Belotserkovskii and Davydov 1982 in the same variant, as in the first article.

The area of calculations in the given work is limited accretors Poche-lobe with the sizes of a numerical grid 160*160*70. In the present work to reduce numerical viscosity we apply the method of regularization of the velocity field, using the procedure of division on physical processes, admissible for the numerical method of large particles (Nazarenko 2007). The viscosity for our computations equals to 0.01 in units of a standard *alpha*-disc viscosity. The model of the accretor's radiating wind, used in this paper, was built as follows. To simulate the stellar wind from the accretor initially we build the accretor's atmosphere, which is to be steady for the whole computation period. Then we

Table 1:

ρ_w/ρ_{aw} Par gas str	1-1	1-10	1-0.1	10-1	0.1-1	10-0.1	Observ par
$R_d(R_\odot)$	30	23	26	23	25	15-17	30
$H_d(R_\odot)$	6-8	4-6	3-5	4-6	4-6	3-4	8-12
$\rho_{jet}1^{11}sm^{-3}$	0.1-1	1	0.01	0.1	0.01-0.1	0.01	1
form	tor	cyli	tor	cylin	cylin	cylin	cylin
$h_{shell}1011sm^{-3}$	18	18	12	15	10	18	14
$\rho_{shell}10^{11}sm{-}3$	0.1-1	0.1-1	0.1	1-10	0.1	1-10	1
v_{zsh} km/c (0.8,0.3)	75	-250	-19	-310	240	78	700

define its radiating pressure in approximation of optically thin layer ($P_r = \alpha\sigma T^4$/c ,where α is the Thompson scattering coefficient,σ is the constant of Stephan-Boltsmann, and c is the speed of light) and of optically thick layer ($P_r = 4\pi\sigma T^4$ /c). On practice we select the smaller radiating pressure of two to make the calculations steadier for the whole computation period. To avoid unreal high accelerations for low densities we equate radiating acceleration to zero for the density less than $4 \times 10^8 cm^{-3}$.

Gas acceleration in the upper layer of the accretor's atmosphere is determined by the forces balance: gravitational force, Coriolis force, radiant pressure in continuous spectrum and in the lines of Layman series. Gas acceleration is given for the field between 1 and 2 star's radii. As a result we obtain the velocity profile close to the profile of the stellar wind model by Castor et al. (1975). To make the mechanism of wind displacement by the stream out of the orbital plane more correct and to select such parameters, which ensure the disc's form to be similar to its observational characteristics, when jet like structures are generating, we input two free parameters ρ_w: if the density in the set cell is higher than that signature, the wind velocity linearly falls to zero, and ρ_{aw} is initial density of the stellar wind.

As it is shown in our previous calculations (Nazarenko, Glazunova 2006 II) to form jet like structures with observational velocity 700 km/sec, we must set the same signature of accretor's stellar wind velocity. That is why in the present paper the wind velocity at infinity is to be equal 700 km/sec, although such velocity is a bit low for the stellar wind of the dwarf of B0 spectral class, which might be the accretor.

3. Results of calculations.

The general results of computations are presented on Fig. 1-5 and Table 1. Main differences of those computations from the results of article I are the following: a round disc with low numerical viscosity, as well as correct calculation of the stellar wind displacement out of the orbital plane let us receive a cylindrical thicker disc. Such disc is more common to the disc, obtained by analysis of the light curves (Linnell 2000).

Fig. 1 shows density and temperature division in the orbital plane for the signatures of parameters ρ_w and ρ_{aw} 1-1. The radius of a disk is 25 $R_\odot$, density is of $10^{12} \div 10^{14} sm^{-3}$, temperature is 20000-40000 K. Density and temperature signatures for the disc remain the same for all variants of our computations, but radius and heights of the disc vary. Fig. 2-5 presents density division at areas z-x and z-y for different signatures of parameters ρ_w and ρ_{aw}. Table 1 show signatures of the main parameters of the disc and different types of envelopes for all variants ρ_w and ρ_{aw}. From all figures and table it is clear that signatures 1-1 and 0.1-1 are the closest to the observational parameters of the disc. For displacement density $10^{11} cm^{-3}$ and initial density of a star wind of $10^{10} sm^{-3}$ (the variant 1-1) the sizes and height of a disk are maximal and are close to observable, however, the disc form is close to torus and the envelope expands $18 R_\odot$ high, that contradicts the observations. Among all variants with the disc form close to cylindrical variant 0.1-1 is the closest to the observational disc parameters.

References

Harmanec P, Morand F., Bonneua D., Jiang Y., Yang S., Guinan E.F., Hall D.S., Mourrd D., Hadrava D., Bozie H., Sterken C., Tallon-Bose I., Walker G.AH., McCook G.P., Vakili F., Stee Ph., Le Contel J.M.: 1996,*Astron. and Astrophys.,* **312**, 877.

Linnell A.: 2000, *MNRAS,* **319**, 255.

Linnell A.: 2003, *MNRAS,* **332**, 21.

Nazarenko V.V., Glazunava L.V.: I 2006, *Astron. Rep.,* **50**, 380.

Castor J., Abbott D., Klein R.: 1975, *Astrophys. J.,* **195**, 157.

Belotserkoskii O.M., Davydov Yu.M.: 1982, *The big particles code in gas dynamics*, Moskaw, Scientist.

Nazarenko V.V., Glazunava L.V.: II 2006, *Astron. Rep.,* **50**, 369.

Nazarenko V.V.: 2007, *in print.*