THE NUMERICAL THREE-DIMENSIONAL HYDRODYNAMIC SIMULATION OF COLLIDING STELLAR WINDS IN A CLOSE BINARY SYSTEM

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ABSTRACT. In the present numerical study the stellar winds from both supergiant-components of a detached close binary system (CBS) are simulated applying methods of the three-dimensional numerical hydrodynamics. The simulated winds collide in the space between the components, forming a stationary shock wave. That shock wave has geometrically intricate shape that consists of several separate filamentary structures. The temperature in the shock wave is about 10^5K, and the temperature in the space adjacent to the shock wave is around $10^4 - 1.5 \cdot 10^4$K. Away from the line-of-centres the shock wave is curved due to the effect of the Coriolis forces and greatly expands under the gas pressure at that. At a distance of about two orbital separations from the line-of-centres the shock wave expands so much that it is practically smearing out in space.

Key words: Stars: close binary system; hydrodynamics; colliding winds.

1. Introduction

The phenomenon of colliding winds (CW) pertains to massive detached CBS consisting of supergiant stars of O and B spectral classes, which generate radiation stellar winds onto each other, forming a strong shock wave that can be a high-flux X-ray source in the space between the binary components. The CW phenomenon was first reported by Prilutskii & Usov (1976) and Cerepashchuk (1976). The observational confirmation of the CW phenomenon was made by Pollock (1987).

The numerical three-dimensional hydrodynamic model of colliding winds accounting for the Coriolis forces was presented in (Lemaster et al., 2007). In that study the geometry of the shock wave, formed in the space between the CBS components, was obtained; and it was shown that the stationary shock wave is significantly curved in space due to the effect of the Coriolis forces, being slightly expanded at that. The only disadvantage of the above-mentioned study was that the radiative cooling was not factored in, and therefore, the temperature in the shock wave and in its surrounding space could be greatly overestimated. To correct the indicated fault, in the present study we simulate the colliding wind phenomenon accounting for the Coriolis forces and explicit radiative cooling applying the methods of numerical three-dimensional hydrodynamics.

2. Numerical methods

In this study the gas flow in the CBS was computed by the relaxation method, i.e. applying the non-stationary Euler equations, integration of which had been performed until the physical quantities within the numerical domain practically ceased to change in time. The equations of motion were integrated by the astrophysical version of the large-particle method by Belotserkovskiy and Davydov. The model of the winds from both components of the binary, as well as the algorithm, which was applied to simulate those winds, is presented in studies (Nazarenko, 2005; 2006; 2008). The indicated algorithm consists of the following: at first, a stellar atmosphere model from the Kurucz atlas (1979) is chosen according to the donor stars parameters; then, the atmosphere of the donor star is created; subsequently, the wind acceleration is introduced in each point of the atmosphere. In so doing, the absolute value of the wind acceleration should be selected to provide the required velocity in the wind. And the direction of the wind acceleration coincides with the normal to the donor stars Roche lobe. The wind, created with such an algorithm, gives the radial velocity profile similar to the model by Castor, Abbott & Klein (1975).

The gravity for the CBS components was computed according to the Roche model, in so doing, it was assumed that the components rotation was synchronized

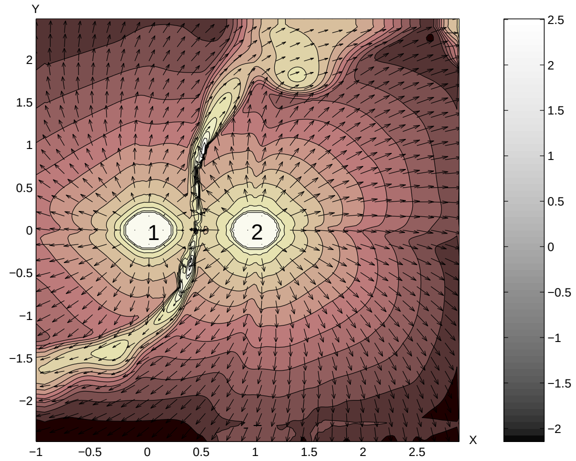

Figure 1: Concentration distribution in the orbital plane on low grid.

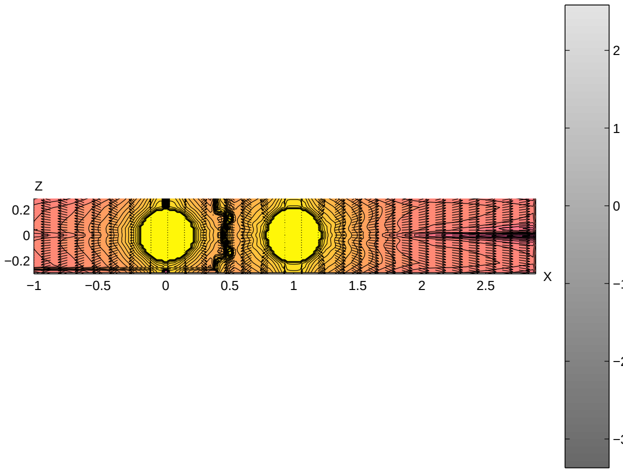

Figure 2: Concentration distribution in Z-X plane on low grid.

with their orbiting. The masses of the components are taken to be equal to $4M_{\odot}$, and the orbital period is assumed to be 15 days.

3. Numerical results

The computations commence with simulating of the winds from both components, which are subsequently distributed over the whole numerical domain. It takes about 1/6 of the first orbital period to form the winds from the components. As a result of interaction between the winds from both components, a stationary shock wave is formed in the space between the components, and the duration of its formation equals to approximately one orbital period. To trace the shock waves distribution in space away from the line-of-centres, the computations were made on two numerical grids.

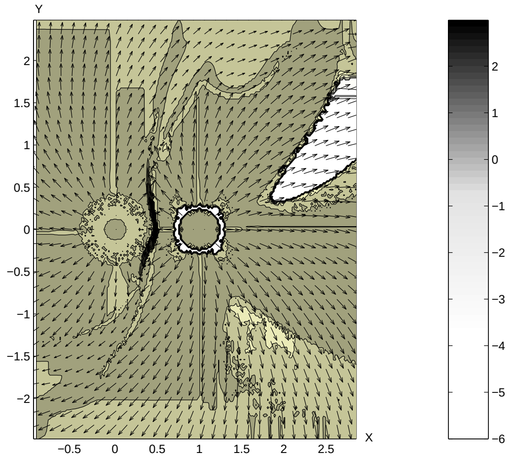

Figure 3: Temperature distribution in the orbital plane on low grid.

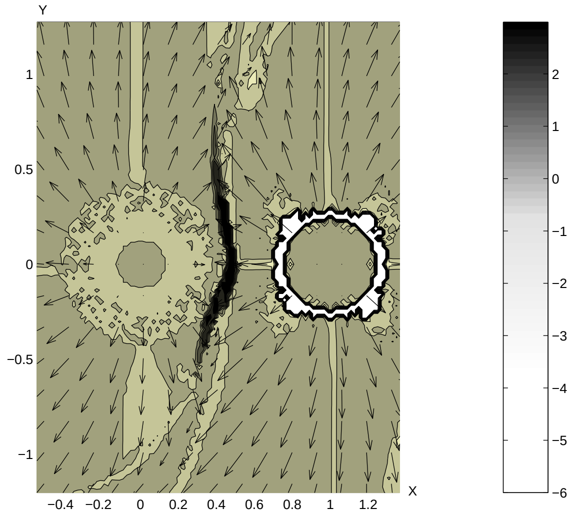

Figure 4: Temperature distribution in the orbital plane in the vicinity of shock on low grid.

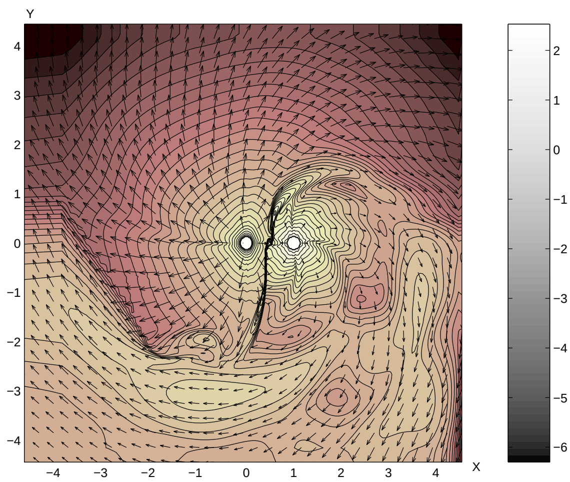

Figure 5: Concentration distribution in the orbital plane on low extended grid.

The first grid size was 1.5 x 2.5 units of the orbital separation, and the second grid dimensions were 4.5 x 4.5 (in the orbital plane). The numerical results for the first numerical grid are presented in Figure 1a-b where the distribution of the matter concentration is given in 10^{11} units of particles per cm^3 in the orbital plane and in the plane, which is perpendicular to the orbital plane and passes through the line-of-centres. As is evident from Figure 1a where the gas flow in the orbital plane is shown, the stationary shock wave, formed in the space between both components, has a rather intricate shape; and as that shock wave moves away from the line-of-centres, it is significantly curved due to the effect of the Coriolis forces and simultaneously begins to greatly expand, being rapidly mixed with the winds from both components. As is seen in Figure 1b, the indicated stationary shock wave is vertically cylindrical-symmetric and propagating quite far away from the orbital plane up to the altitude of 0.6-0.8 units of the orbital separation above or below the orbital plane.

The temperature distribution of the gas flowing in the orbital plane is presented in Figure 2a-b in 10^4K units for the coarse numerical grid. It follows from the figures that the stationary shock wave takes the shape of a cord, elongated in a direction perpendicular to the line-of-centres at the distance of up to 0.5 from the line-of-centres. The temperature in that cord is about $2 \cdot 10^7$K.

In Figure 3 the distribution of the matter concentration in the orbital plane is shown for the wide spatial numerical grid. As is seen in that figure, the gas from the stationary shock wave is twisted due to the effect of the Coriolis forces at a distance of approximately one unit of the orbital separation from the line-of-centres, and it is gradually mixed with the winds from both components (at a distance of about two units of the orbital separation from the line-of-centres), forming a wide band that spirals outwards the CBS.

4. Conclusions

A stationary shock wave, resulted from the collision of the winds from two components of a massive CBS, was simulated in the presented computations. The computations demonstrated that the indicated stationary shock wave takes the shape of a cord with the width of about 0.02-0.03 units of the orbital separation and the length of 0.5 from the line-of-centres in the perpendicular direction. The temperature in the stationary shock wave is about $2 \cdot 10^7$K. The concentration of matter in the stationary shock wave is about 10^{11} particles per cm^3. The above-listed parameters of the stationary shock wave indicate that the shock wave can be a high-flux X-ray source.

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