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WAVES AND INTERACTING FLOWS IN ACCRETION CLOSE BINARY STAR SYSTEMS

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Abstract: *The tidal interaction in binary star systems has been studied, as inflowing matter of donor star contacts with the forming accretion disc and circumdisc halo of the companion star. Numerical methods in the theoretical gas-dynamical calculations have been applied. The results reveal the appearance of wave structures with high density in the disc's area and in the rarefied gas around the accretion disc. The perturbations in the stellar component with disc and the velocity acceleration by the sound value have been estimated. The wave structures have been studied observationally by the method of Doppler Tomography.*

1. Introduction

The tidal shocks in astrophysics may appear in galaxies, proto-planetary and protostellar discs and in the white dwarf's binary star systems. Studying of the disc's structures in the binary stars, by numerical methods, evinces that the gravitational effect of the second component could cause the appearing of spiral shock waves. Sawada, Matsuda & Hachisu [13], have presented these tidally induced shocks as hydrodynamical event. Their research has followed by a number of groups, as Rozyczka & Spruit [12], which found such prominent spiral arms to develop in 2D disc simulations, for various mass ratios. Spiral structures in white dwarfs are also detected by Steeghs et al. in [14]. It is clear from his research in [9] that tidally driven waves can alter the global dynamics and structure of the accretion disc. Such tidally driven spirals could be considered as a transport of angular momentum in accretion discs.

We present here a short report of our study of tidally generated spiral waves that are the result of interaction of the inflow stream with the matter of the disc flow. The gas in the disc is considered to be gas-dynamical and then the examination of the morphology of this interaction requires using the system of gas-dynamical equations, where the radiation heating and cooling are considered, as gravitational Roshe's potential is included. This system allows applying of 3D numerical modeling of structure of the flowing matter. The modeling is performed in non-inertial frame of reference and quadratic 3D set. The boundary conditions are related to the form of the accretor and constant density on the outer edge. According to the work of Boyarchuk et al. [5] the gas-dynamics of the flow in semidetached binary system could be defined by the stream from L_1, quasi-elliptical accretion disc, circumdisc halo and the envelope between two mass components. They classify in this paper the main elements of the flow. The shock interaction area of the circumdisc halo and the stream from L1 is in the outer disc region. The farthest parts of the disc are with low density value and the shock wave, which is caused by their interaction with the flow, is placed at the edge of the stream.

As we noticed, the flow in the disc and in the circumdisc area is considered to be gas-dynamical and it rules by the corresponding equations of mass conservation, Navier-Stokes equations for a viscous flow, energy equation and equation of state. The forms, which are used here, are taken from the papers of Thorn [15] and Frank et al. [7]. Obtaining the solutions of that hydrodynamical system of equations requires applying of numerical methods and they are in accordance to mathematical software, supporting the examinations here.

The method of Runge-Kutta is largely spreading in physical calculations. As we have considered, the explicit part of the method will be working, only. The form of the equations doesn't allow carrying out fully and exact solutions and it is necessary of applying another method in the combination with the Runge-Kutta's. "Alternating direction implicit method" (ADI) is workable for the numerical analysis of partial differential equations. The descriptions of both methods could be found in the papers of Autar & Egwu [1], Chang et al. [6].

To confirm the theoretical examinations of the existence of structures, it is need to perform some observational study of the problem. Until now, directly observation of the spirals and vortices haven't been possible. In this reason, indirectly methods and techniques are used, as the spectra analysis and Tomography. The method of Doppler Tomography is developed by Marsh in [11] and it has applied by many authors as the techniques for the reorganization of the observational data and converts them into the luminosity cart of the two-dimensional velocity space.

2. Results

2.1. Results from the theoretical study.

Following the considerations in the introduction and pointed methods there, we present in this section the results of our study, related to the waves in interacting flows in the accretion binaries.

These tides may cause a development of spiral waves, locally or globally in accretion disc's area. Angular momentum dissipation in the spiral shocks is responsible for the bulk transport of angular momentum outwards and disc materials inwards. This non-local way of transporting angular momentum is possible since the tidal torques of the companion star effectively extract the disc's angular momentum through such tidally generated waves.

The analysis made by Friedman & Bisikalo [8] of the main heating and cooling processes of the matter in the accretion discs in close binary star systems shows that, for the real parameters of the discs, the gas temperature in the outer disc's parts is in the range of $10^4 K \div \sim 10^6 K$. This means that, in the considering binary systems, as well the hot accretion discs as the cold could be formed.

We use perturbed hydrodynamical equations and the numerical method is applied over the variations of matter density and flow velocity. The disc temperatures are chosen to correspond the conditions of Cataclysmic variables accretion discs in a high mass transfer state. In the result, a spiral structure in the disc flow is taking form, which can be seen in the next pictures (figure 1a, 1b). This result is received previously in the paper of Boneva [4].

In the solutions for the high temperature gas, it is observed one-armed spiral wave. In the area, where the second arm has expected to be appeared, the structure of the flow is defined from the stream of L1. This flow is dominated and some kind prevents the formation of the second arm.

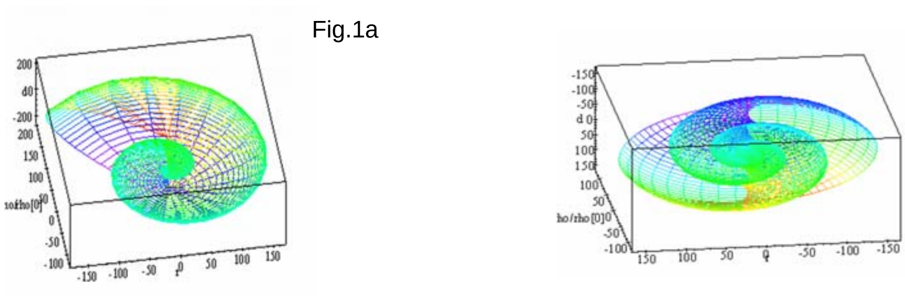

Fig.1a Fig.1b

Fig. 1. Spiral structures in the area of accretion flow. It is shown two cases – in hot disc case the spiral structure arises with one arm (fig.1a). Whereas, at the cold disc it is clearly seen the two arms of the spiral structure (fig.1b) (see [4])

The assumption that the disc is already cold, when the two spiral arms are observed (fig.1b), also means an increased density in the disc. If the disc is cold T~1.4×10^4K, the shock waves are seen as a thickened matter at the density isoclines.

If we take into account the weak effect of flow on the dense inner parts of the disc, and the fact that shock waves are located in the outer parts of the disc, then by a low temperature, we can spend one more element of the structure of the flow, that is: the inner area of the disc. Following analysis of three-dimensional numerical modeling we can assert for the possibility of formation of spiral density wave in the internal parts of the cold disc, as well.

The figures show spiral's formations, as the separated from the whole disc images. In such a way, the form of the wave is more decipherable. Two stages of spiral's development are depicted on the figures.

2.2. Observational results

Gas-dynamical simulation in combination with technique of Doppler Tomography gives the possibility to identify the main elements of the flow. It is studied the CV SS Cyg during outbursts, based on the observations made by Kononov et al. in 2006 in the observatory at the Terskol peak and published in the paper of Kononov et al. [10]. To construct the true cart of image of the obtained data, it is applied the Doppler Tomography. The Method of maximum entropy (MEM) has used to smooth the images from noise and phase shifts. We have derived Hβ and Hγ Doppler tomograms for SS Cyg in its active state from spectral observations of this star (see figures 2a, 2b).

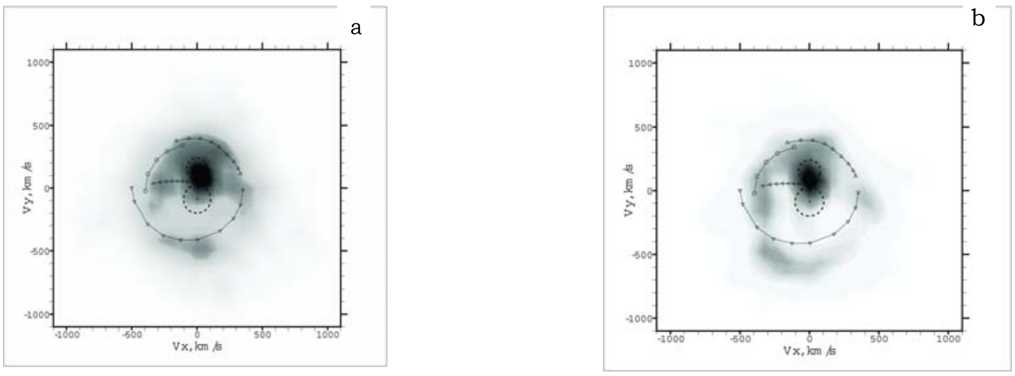

Fig. 2. Doppler Tomograms of the SS Cyg in the Hβ (left) and Hγ (right) lines obtained for the active state from profiles cleaned of broad absorption components. It is also drawn in the pictures the superposition of the flow's elements, obtained by numerical simulations. The dashed curve shows the boundary of the Roche lobe in velocity coordinates (Boneva et all, 2009 [3])

As a result of the comparison are separated following elements: accretion disc, spiral arm of the tidal wave, hotline, shock wave, formed by the interaction of the curcumdisc halo with the flow of inner Lagrange point and the area of the heated material in near the boundary shockwave. It should be noted that the H_γ line in the tomogram is not expressed asymmetry in the vicinity of L_1. In the H_β line there is a slight degree of asymmetry in this area. Distinctive feature that is visible in the tomogram of the active state is essential bulge towards the negative V_y. We can see the main flow elements in the figure above, received in paper of Boneva et al. [3], such as the arms of the tidal spiral streaming from L_1 and the region of interaction of the stream and circum-disk halo (hot line). The superposition of the flow's elements, which is shown at the pictures of the fig.2, is calculated and drawn by using the numerical simulations in the paper [2].

3. Discussion

It is shown in this paper two basically results, as we studied the dynamics of interaction flows in the close binary star system.

It is preformed the numerical macro - analysis of processes in the accretion close binaries. By using the methods of numerical calculations in a combination with the gas-dynamical equations we achieved to the results, which give us a physical explanation of the morphology of the accretion gas flow.

The gas-dynamical simulations show that tidally interaction of the inflow from donor star with the matter of circumdisc halo causes development of spiral density wave, as one-armed model for the hot disc and two-armed model for the cold disc prediction.

The key to discovery of these spiral patterns was the applying of indirect imaging method. Using the technique of Doppler Tomography as the observational method in a combination with the gas-dynamical simulation, we confirmed that the spiral structures in the accretion disc in the white dwarfs close binaries are the main elements of the flow.

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