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3D NUMERICAL HYDRODYNAMICAL MODELS OF THE PRECESSING THICK ACCRETION DISK AND ON- AND OFF-STATE GENERATIONS IN MICROQUASARS

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ABSTRACT. The thick accretion disk and donor's wind on the example of CYG X-1 are computed. The main aim of the present simulations is to calculate the precessing thick accretion disk and ON- and OFF-state generation by the methods of 3D numerical hydrodynamics. The main task of the present research is to investigate the dependencies of the central disk temperature and mass accretion rate versus time. Non-stationary Euler's hydrodynamical equations are resolved by astrophysical variant of large-particle method by Belotserkovskii & Davydov. The ON- and OFF-state generation for the precessing thick accretion disk was setting. The correlation between radio flux and X-ray was setting. Our present calculations also show that in the cases of the thick accretion disk the jet velocities will be close to 0.24 -0.26 of light speed (see for instance SS433) and on contrary in the cases of a thin accretion disk jet velocities will be close to 0.98 -0.99 of light speed (see for instance CYG X-1).

Keywords: Stars: binaries – stars: jets – methods: numerical – hydrodynamics.

1. Introduction

In the present report we have continued to simulate ON- and OFF-states in microquasars. In our previous works we have modelled ON- and OFF-states on the base of thin accretion disk and microquasar CYG X-1. In these works the simulation of ON- and OFF-states on the base of long precession Nazarenko & Nazarenko (2014), the simulation of low/hard and high/soft states in accretion discs of microquasars and quasars on base of undefined precession Nazarenko & Nazarenko (2015) and the simulations of a radiation-driven jet launch and disappearing over low/hard state Nazarenko & Nazarenko (2016) were made.

In our present work we will simulate the thick accretion disk (the disk with the radiation pressure) and on this base the ON- and OFF-states will br simulated on the example of microquasar CYG X-1. For this purpose we have modelled the slaved precession of accretion disk and the donor's wind. We hope that in the precession thick accretion disk having been blown by the donor's wind two states in the disk's centre will begin to be generated – with the high and low density and temperature.

2. The numerical algorithm

To compute the thick accretion disk models, we have calculated the mass flow from the initial state to a steady one. To this end, we have used non-stationary Euler equations of hydrodynamics which are solved using the astrophysical variant of the large-particle method by Belotserkovskii & Davydov (1982). The distinction between astrophysical and standard applications of the large-particle method consists in the use of the internal energy at the first time substep in the astrophysical variant of the code.

In the computations, we have used a Cartesian coordinate system in which the X-axis lies on the line of centres. In this coordinate system, the donor position is 0.0, 0.0, 0.0, and that of accretor is 1.0, 0.0, 0.0. In the computations, we have factored in the gravity force and gas pressure of the binary components, as well as the Coriolis and centrifugal forces of the orbital motion. We calculated the gravity of the binary components in the approximation of the Roche model. We set the orbits of the binary components to be circular. To make an accretion disk to be thick one we have calculated radiation pressure z-component, $F_{rad,z}$, in the disk volume. Here we explicitly imply that the radiation pressure is differently from zero in the disk volume along z-axis only.

$$F_{rad,z} = \frac{\alpha \cdot H_z}{c} \quad , \qquad (1)$$

where α is the coefficient of Thomson scattering, H_z is radiation flux along z-axis and c is light speed.

In this work and in the presented computations, we have employed the following dimensionless units. The density is expressed in units of 10^{11} particles per cm^{-3}; all distances are given in units of the orbital separation;

the temperature is given in units of eV. In the computations, the velocities are expressed in units of V_{orb} while in the figures presented in this paper, we have employed km s^{-1} as the velocity units. The time is expressed in such units that the orbital period is equal to 2π.

The code in use in the present paper is belonging to so-called methods of 'through account'. The last means that all the features of flow (shock, shock front, discontinuities and et cetera) are calculated through the single algorithm.

For the simulations presented in this work, RC has been calculated accordingly to the model for the radiative cooling of a low-density plasma with cosmic abundances in the ionisation equilibrium described in Cox & Daltabuit (1971).

The description of the used numerical algorithm in details one may see in Nazarenko & Nazarenko (2014, 2015, 2016).

In the present research the space resolution of the numerical grid in use was about of 5000 $\div$ 6000 Schwarzcshild radii. In the real microquasars the hot disk corona and jets are produced on the highness the hot disk corona and jets are produced on the highness order of 50 $\div$ 100 Schwarzcshild radii. It means that our space resolution is very low to produce hot corona really from quantitative point of view. But from quality point of view our present simulation may be very real since we can not to make the space resolution to be as in the real microquasars because of the very large computer expenses (we must cover all the disk space by one numerical grid).

The computations have been performed using FORTRAN 9.1. We have also employed the double-precision operations in the calculations.

3. The results

The plan of our present calculations is such that initially up to 36.5 precession period we were simulated the thin precession accretion disk (with the slaved precession) and after it, beginning with 36.5 precession period we start to calculate radiation pressure (Z-component only) into accretion disk. By this reason the disk become thick one very rapidly (on dynamic time scale) and after it we continue our calculation up to 41.5 precession period in order to see the disk properties over sufficiently long time.

To show the disk plane and vertical structure of the calculated thick accretion disk we are plotted the cross-section of the calculation area by X-Y plane lying on the disk plane (see Fig.1, Fig.2) and by the Z-X plane lying on the line of centres (see Fig.3, Fig.4) for times of 37.01 (Fig.1, Fig.3) when the temperature is high in the disk's centre and for times of 38.61 (Fig.2, Fig.4) when the temperature is low in the disk's centre). As one can see from these pictures the vertical size of disk is practically equal to the orbital disk size. By the other words we really see the thick disk on Fig.3, Fig.4. These figures also show that some features are present in the disk – here we have in mind in first turn the presence of funnel along the disk rotation axis, placed in the direction to contrary of the disk rotation vector. As we may see from the Fig.3, Fig.4 the present disk have approximately the cylindrical symmetry and the symmetry axis is the disk rotation one. These figures also show that the disk plane is always parallel to the donor's plane and it means that the slaved precession is working absolutely exactly.

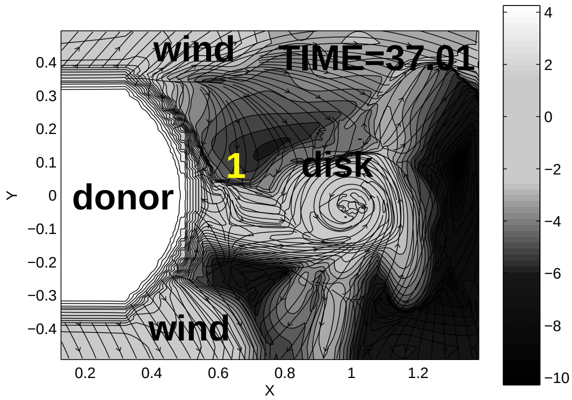

Figure 1: The disk plane structure on time of 37.01.

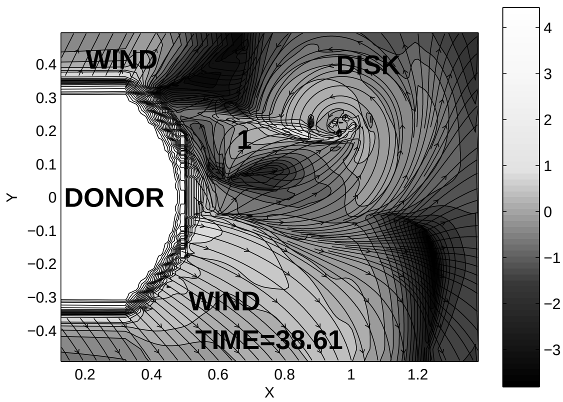

Figure 2: The disk plane structure on time of 38.61.

The essential parameters of a disk in the present calculation are the central disk's temperature and mass accretion rate. As easy to see the most interest is presented the dependencies of these values versus time. We show these dependencies in Fig.5 and Fig.6 in which

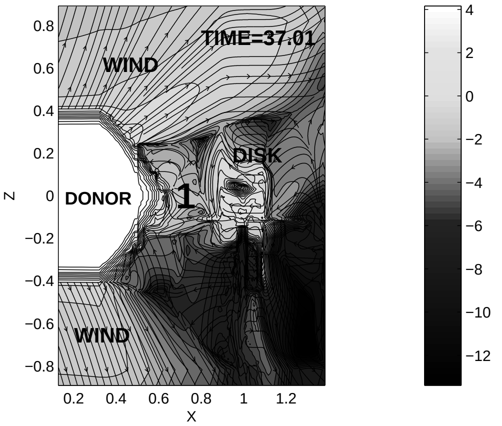

Figure 3: The vertical disk structure on time of 37.01.

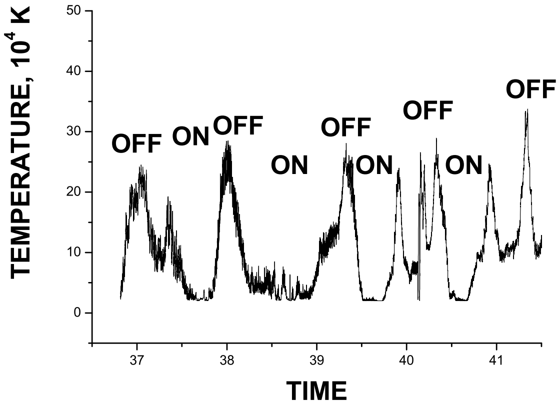

Figure 5: The central disk temperature versus time.

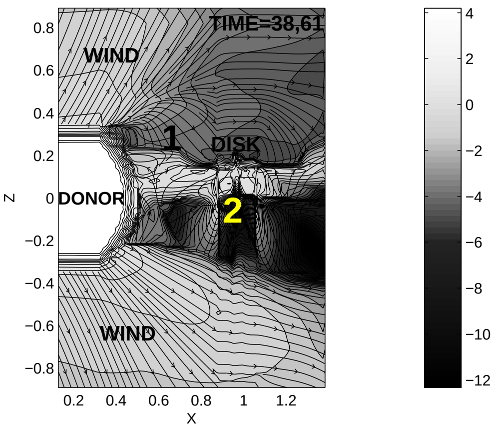

Figure 4: The vertical disk structure on time of 38.61.

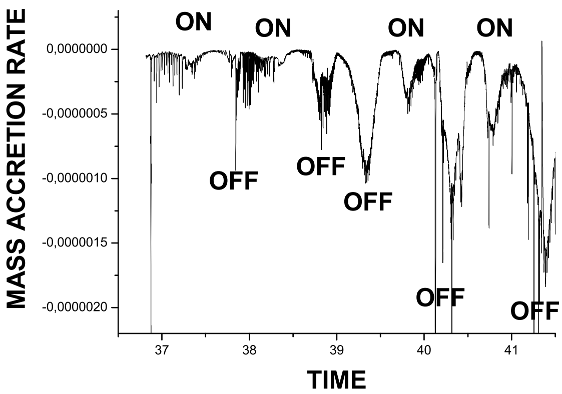

Figure 6: The mass accretion rate versus time.

mass accretion rates are given in units of solar mass in year and times are given in units of precession period which in turn is equal to 2.56 of the orbital period. As we can see from Fig.5 and Fig.6 the temperature and mass accretion rate time behaviours are such that these values have the maximal magnitudes in the view of sharp pics and the region of low magnitudes on the bottom of the dependencies. We have interpreted such the bottoms and sharp pics as ON- and OFF-states production in our calculations. As easy to see temperature and mass accretion rate correlates between a each other. It in turn means that in our calculations radio flux correlates with X-ray flux. Such the correlation coincides with the observed that of in CYG X-3 Fabrika (2004).

As one can see from Fig.5 and Fig.6 the amplitudes of temperature increasing over OFF-states are order of 5 ÷ 7 relatively ON-states. For comparison, in the case of thin disk (see Nazarenko & Nazarenko, 2014; 2015; 2015) these amplitude were equal to 100 ÷ 200. It show that in the case of the thick accretion disk the jet velocities will be much less relatively a thin disk. By the other words, it means that in the case of the thick accretion disk the jet velocities will be close to 0.24 -0.26 of light speed (see for instance SS433).

We may also to see from Fig.1-4 that over OFF-states the disk is strong compressed by the wind and on contrary over ON-states the disk is very extended towards the disk plane. Such the time and space disk behaviours over ON- and OFF-states prompts clear the mechanism to generate ON- and OFF-states that is working in the present research: this mechanism is follows – over the precession of thick disk having been blown by the wind this disk sometimes is strong compressed by the wind and sometimes this compression is very small. By this reason in the first case we see OFF-states generation since in high density disk the region in the disk centre along the disk rotation axis is optically thick and due to this circumstance the temperature in this region becomes to be very high because of the action of the disk viscosity which is transformed the kinetic energy of the disk rotation in the thermal one. In the case when the wind-disk compression is small, the density in a disk is decreased, the region in the disk centre becomes to be relatively optically thin, and due to the action of radiation cooling the temperature in this region is very rapidly decreased. Thus, the mechanism stated above working in terms of optically and geometrically thick accretion disk produced the correlation between central disk temperature and mass accretion rate. This mechanism was also working in our previous works (Nazarenko & Nazarenko, 2014; 2015; 2016) in which the model of optically and geometrically thin accretion disk simulated and in which the anticorrelation between central disk temperature and mass accretion rate occurs.

4. Summary and conclusions

1. The correlation between X-Ray and radio flux calculated in the present research is similar to that of observed in CYG X-3 Fabrika (2004).

2. Our present calculations show that in the cases of the thick accretion disk the jet velocities will be close to 0.24 -0.26 of light speed (see for instance SS433) and on contrary in the cases of thin accretion disk jet velocity will be close to 0.98 -0.99 of light speed (see for instance CYG X-1).

References

Belotserkovskii O.M., Davydov Yu.M.: 1982, *The large particles code in gas dynamics, Moscow, Nauka,* 391.

Cox D. P., Daltabuit E.: 1971, *ApJ*, **167**, 113.

Fabrika, S.: 2004, *Astrophys. and Space Phys. Rev.*, **12**, 1.

Nazarenko V.V., Nazarenko S.V.: 2014, *Odessa Astron. Publ.*, **27**, 137.

Nazarenko V.V., Nazarenko S.V.: 2015, *Odessa Astron. Publ.*, **28**, 171.

Nazarenko V.V., Nazarenko S.V.: 2016, *Odessa Astron. Publ.*, **29**, 82.