

THREE-DIMENSIONAL NUMERICAL HYDRODYNAMICAL SIMULATION OF LOW/HARD AND HIGH/SOFT STATES IN ACCRETION DISCS OF MICROQUASARS AND QUASARS ON BASE OF UNDEFINED PRECESSION

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ABSTRACT. In this study, the models of slaved precession of accretion disc and donors radiation-driven wind were performed using three-dimensional numerical astrophysical methods by the example of microquasar Cyg X-1. As is shown, in the course of precession of the accretion disc blown by the donor's wind the states with high and low temperature (low and high mass accretion rate, respectively) start being generated in the centre of disc. Our computations of disc precession performed on base of undefined precession that means each point of rotation axis of accretion disc makes unclosed difficult curve instead of a circle as it is in case of definite precession. In this case, the transition between states of high and low temperature takes place irregularly and not depend on precession period. The duration of transition between these both states is less than intervals of states on several orders of magnitudes.

Key words: Stars: close binary system; microquasars; quasars.

1. Introduction

In present work we continue to simulate high/soft and low/hard (ON- OFF-: active and passive) states in accretion discs of microquasars and quasars. Our idea consists in that in precession accretion disc having been blown by the donor's wind begins to generate the states of low and high temperature in the disc centre. Since these states are unti correlated with mass accretion rate we interpreted them as ON- and OFF-states in accretion discs of microquasars. In the previous our work (Nazarenko, 2014) we had simulated ON- and OFF-states on the base of defined precession. The result of it was the transition between ON- and OFF-states was every precession period. But it occurs irregularly in real microquasars and not depends from precession period. By such the way to improve the results of previous work in the present

one we simulate ON- and OFF-states on the base of undefined precession. It means that each point of rotation axis of accretion disc makes unclosed curve. Thus our goal in the present research is to make the change between both ON- and OFF-states to be irregular and don't depended from precession period.

2. The numerical approach

To obtain the goal stated above we use special numerical technique. This one is as follows: to simulate 3D mass flow in the calculation area from initial time to stationary state we use non-stationary Euler's hydrodynamical equations. We resolve these equations by astrophysical variant of 'Big-particles' code by Belotserkovsky and Davydov (Nazarenko, 2014). This astrophysical variant is distinct to the standard 'Big-particles' code (Belotserkovskii et al., 1982) that in this one the internal energy on first time substep is used (in standard code the total energy on first time substep is used). To decrease the effects of numerical viscosity attributing the cold in use we use the special technique to decrease radial velocity in accretion disc and do the temperature in calculation area to the real one. We use rectangular numerical grid and also the rectangular Cartesian coordinate system that is connected hardly with the donor. To simulate the precession of accretion disc we use the slaved precession. In the chosen coordinate system the accretor makes the unclosed curve.

To decrease large computer expenses and order to run our calculation over long time we use the accretion disc precession period equal to orbital one. In the present calculation we use the following dimensionless units: the velocities are given in units of the orbital speed; the temperatures are given in units 10^4K ; the numerical time units are such that 2π is corresponding to the orbital period; mass accretion rate is given in units of solar mass per year in logarithmic scale. We cut the space around the accretor with the radius of

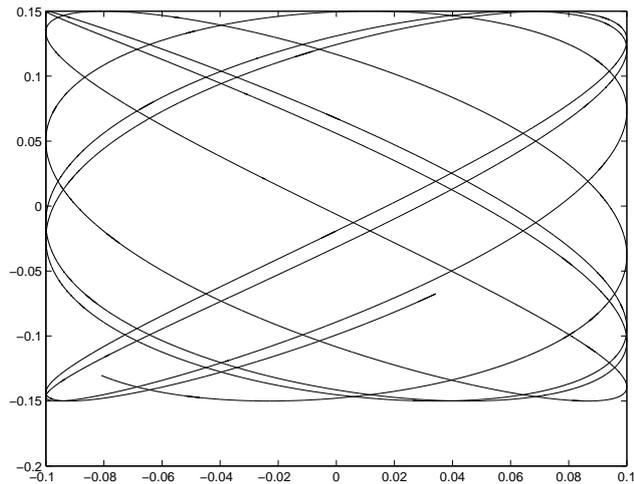


Figure 1: The time change of the accretor's coordinates in z-y plane.

0.025 (10% of the outer disc radius) to avoid singularity. This space has the size of 5000 Schwarzschild radii and it means that our simulations are running far away from accretor.

The time changes of the accretor's coordinates are given below.

$$\begin{aligned} x_{ac1} &= 1.0, & \text{if } t < 0 \\ y_{ac1} &= 0.0, & \text{if } t < -0.25 \\ z_{ac1} &= 0.0, & \text{if } t < 0 \end{aligned}$$

$$\begin{aligned} x_{ac1} &= 1.0 + A \sin\left(2\pi \frac{t}{P_x}\right), & \text{if } t > 0 \\ y_{ac1} &= 0.0 + B \cos\left(2\pi \frac{t}{P_y}\right) \cdot N_{prec}, & \text{if } t > -0.25 \\ z_{ac1} &= 0.0 + C \sin\left(2\pi \frac{t}{P_z}\right), & \text{if } t > 0 \end{aligned}$$

where $A = B = C = 0.15$, $N_{prec} = -1$ for retrograde precession, $N_{prec} = 1$ for prograde precession and P_x, P_y, P_z are precession periods for appropriate accretor's coordinates. The time is given in units of precession period.

3. The numerical results

The unclosed curve made by the accretor over on the time of calculation is shown in Fig. 1. The evolution of the accretion disc central temperature in time is shown in Fig. 2. The dependance of mass accretion rate of our accretion disc model versus time is shown in Fig. 3. The mass accretion rate is negative since it is accretion process. As it is led from Fig. 2 we run our calculation over long time as large as 17th precession period. It shows that the essential physical values are strong conserved in our present simulation in code in use. First we see in Fig. 2 it is the high temperature interval is from 4 to 13.5 precession period. The interval of low temperature in Fig. 2 is on 13.75-14.50 precession pe-

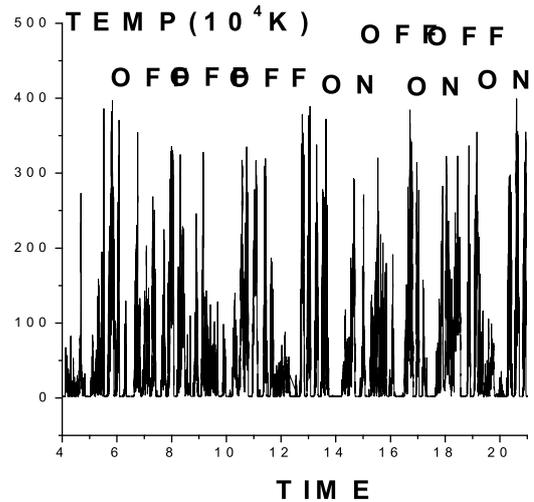


Figure 2: The dependance of the temperature in the disk's centre versus time.

riod. This interval is over 0.75 precession period. We have interpreted these intervals of low and high temperature as generation low/hard and high/soft states in our accretion disc model. We have make such the interpretation since the both time intervals of temperature stated above are unti correlated with mass accretion rate in our accretion disc model (see Fig. 2 and Fig. 3). Accordingly mentioned above we may say that the change between both low/hard and high/soft states is not making every precession period in our present calculation and is strong irregular. As we think such the fine result occurs due to the using undefined precession in the present work. To show the time structure of low/hard and high/soft states in more details we have plotted partially low/hard state (Fig. 4) and high/soft one (Fig. 5). As it is good seen from these figures, the time characteristics of low/hard state in first turn are strong discrete i.e. it is in the view of partial peaks. The amplitudes of these peaks are in the interval from 2 to 400 (maximal values). By the other words, the central disc temperature is changing in time in 200 times. As it is led from Fig. 4 and Fig. 5, the relation between both low/hard and high/soft states time intervals is order of 10. This magnitude is in good accordance with the corresponding value in real Cyg X-1 in which the low/hard states are over several years and the high/soft states are over several months (Lachowicz et al., 2006). In order to see in more details the transition between both low/hard and high/soft states on time of 13.75 (see Fig. 2) we are plotted the vicinity of this time on high resolution scale (see Fig. 6). As it is led from these figures, the time interval of the transition stated above is order of 0.005 of precession period or 40 minutes of orbital time.

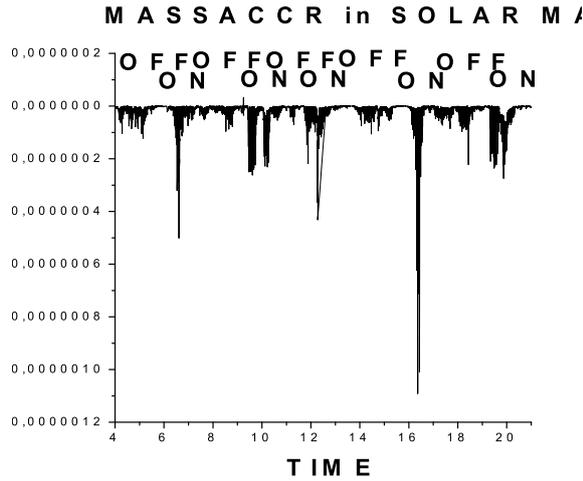


Figure 3: The dependance of the mass accretion rate in the disk's centre versus time.

The work of the mechanism to produce low/hard and high/soft states is very simple in the present paper. In the precession accretion disk having been blown by the donor's wind to states of low and high densities in the centre of disk is formed. When the densities in the disk centre are low, the radiation cooling is not efficient and instantly due to the action of the disk viscosity the kinetic energy of the disk rotation are transformed in thermal one. In this case the temperature in the disk centre is high. When the densities in the disk centre are high, the radiation cooling is strong effective and temperature in the disk centre is low.

4. Summary and discuss

Analyzing the numerical results described above we may say that the goal stated introduction is obtained and we have simulated low/hard and high/soft states and the change between both states is irregularly and is not depending from precession period. We may to mark also that the essential microquasar properties were have simulated in our present work. First of all, we show that the relation between both states is the factor of 10; the changes of central disc temperature and mass accretion rate in both states are order of 200 and 100 respectively; the transition between both states is order of 40 minutes of orbital time; the time structure of low/hard state has discrete character in the present simulation. All four properties of low/hard and high/soft states are qualitatively and quantitatively in a good accordance with observations (Lachowicz et al., 2006; Fender et al., 2003; 2004). The evolution of our calculation in the future works we see to run jet produc-

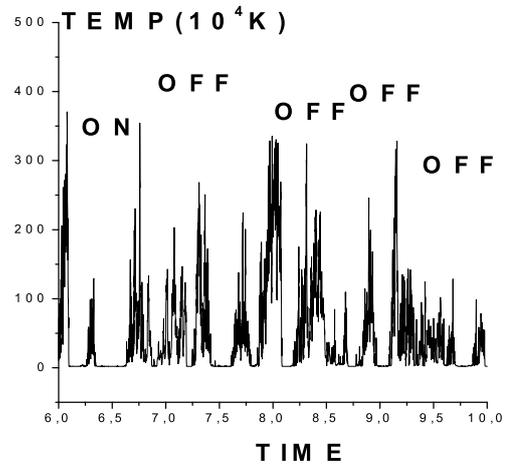


Figure 4: The dependance of the temperature in the disk's centre versus time over the interval of 6-10 precession periods.

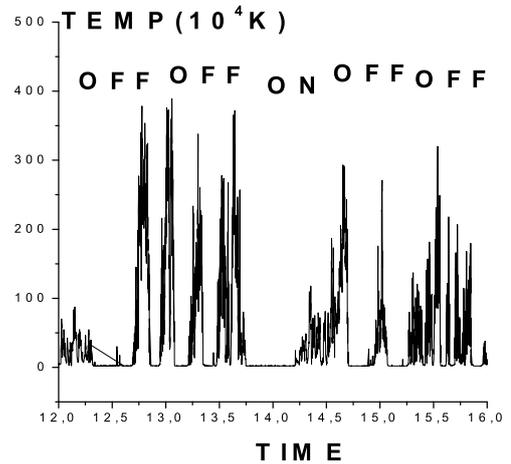


Figure 5: The dependance of the temperature in the disk's centre versus time over the interval of 12-16 precession periods.

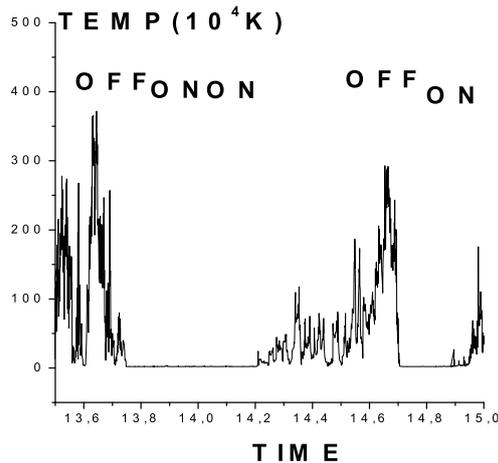


Figure 6: The dependance of the temperature in the disk's centre versus time on the high time scale over the interval of 13.6-15.0 precession periods.

tion and also its appearance and disappearance in simulated low/hard and high/soft states by us. We have planned to simulate radiation-driven jets since with our point of view such the jets may easy explained the microquasar phenomenon. Such the conclusion is based on three points on our opinion:

1) In low/hard state the temperature near the accretor in disc hot corona is increased by factor of 10 (from 10-20 KeV to 100 KeV, Fender et al., 2003; 2004). The last means that in these terms the radiation pressure will be rather able to produce jets.

2) The luminosities of microquasars are close to super critical one by factor of 0.3 - 0.7 (Fender et al., 2003; 2004).

3) The formation of radiation-driven jets in the view of narrow stream may be easy explained by radiation flux configuration on the bottom of the funnel of disc hot corona: this flux is distance from zero only in the direction in parallel to the disc rotation axis, since namely in this direction the disc central source radiation may freely leave a funnel.

In the last conclusion we implicitly imply that funnels are exist in all the microquasars.

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