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THE DEPENDENCE OF ON- AND OFF-STATE GENERATIONS IN CLASSICAL MICROQUASARS FROM THE DISK DENSITY. 3-D NUMERICAL HYDRODYNAMICAL SIMULATIONS OF THE HIGH AND LOW MASS ACCRETION RATE IN ACCRETION DISK IN MICROQUASAR CYG X-1

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ABSTRACT. In the present work we have computed and have compared the on- and off- generations in low and high mass accretion rate accretion disks. The comparison shows that in the case of low mass accretion rate in disk (10^{-10} solar mass per year) the ON-state time interval is very short, order of $0.2 \div 0.4$ of precession period; in the case of high mass accretion rate in disk (10^{-9} solar mass per year) the ON-state time interval is relatively long, order of $0.7 \div 0.9$ of precession period. This shows that in the case more dense disk ON-states are relatively very long time interval because of high mass accretion rate in disk. This result is natural for classical microquasar (CYG X-1) in which the on-states are corresponding high mass accretion rates. For comparison we may also write that the time intervals of OFF-states in the present calculations are order of $1.3 \div 1.5$ of precession periods. The calculations also show that in OFF-states the accretion disk have the low specific viscosity and on contrary have the high specific angular momentum. In ON-states the disk have to contrary to OFF-states the high specific viscosity and low specific angular momentum. It shows that in OFF-states the disk is very rapidly rotating with low viscosity. In ON-states the situation is on contrary. Such the disk time-behaviour is true for both low and high mass accretion rate. The calculations also show that in ON-states the disk radius is very small, order of 0.08 of the orbital separations and on contrary in OFF-states the disk radius is relatively large, order of 0.25 of the orbital separations. The stated above shows that the disk is strong transformed from ON- to OFF-states.

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

АБСТРАКТ. В представленій роботі ми виконали обчислення та порівняння включених та виключених станів з низькою та високою швидкостями акреції в диску. Порівняння показують, що у випадку низької швидкості акреції в диску (10^{-10} Сонячних мас на рік) часовий інтервал включеного стану є дуже коротким, близько $0.2 \div 0.4$ прецесійного періоду, тоді як у випадку високої швидкості акреції в диску (10^{-9} Сонячних мас на рік) часовий інтервал включеного стану відносно довший, близько $0.7 \div 0.9$ прецесійного періоду. Це показує, що у випадку більш густого диску включені стани відносно довші завдяки високій швидкості акреції в диску. Такий результат є природнім для класичного мікрокваазара (CYG X-1), у якого включені стани відповідають високій швидкості акреції в диску. Для порівняння ми можемо також відзначити, що часові інтервали виключених станів в представлених обчисленнях складають $1.3 \div 1.5$ прецесійних періодів. Обчислення також показують, що у виключених станах акреційний диск має низьку питому в'язкість в протилежність високому питомому кутовому моменту. У включених станах диск має в протилежність виключених станів високу питому в'язкість та низький питомий кутовий момент. Це показує, що у виключених станах диск швидко обертається з низькою в'язкістю. У включених станах ситуація є протилежною. Така часова поведінка диску виконується як для високих, так і для низьких швидкостей акреції в диску. Обчислення також показують, що у випадку включених станів радіус диску становить дуже невелику величину, близько 0.08 орбітальних розділень, тоді як у випадку виключених станів радіус диску відносно більший та складає величину близько 0.25 орбітальних розділень. Заявлене вище показує, що диск дуже трансформується під час переходу між включеними та виключеними станами.

Ключові слова: зорі; подвійні зорі; джети; методи: числовий; гідродинаміка.

1. Introduction

In the present research we have continued to simulate the ON- and OFF-states generations on the base of microquasar Cyg X-1 by the methods of 3-D numerical hydrodynamics (Nazarenko & Nazarenko, 2014, 2015, 2016, 2017). The present work is devoted to low and high mass accretion rates (low and high mass transfer rates via one-point respectively) in accretion disk simulations on the base of classical microquasar Cyg X-1. The goal of the present research is to compute the donor's wind, one-point-stream formation, its motion in Roche lobe of accretor, accretion disk formation and it's slaved precession for two cases: low accretion rate in disk (order of 10^{-10} solar mass per year) and high mass accretion rate (order of 10^{-9} solar mass per year).

2. The numerical algorithm

The description of the numerical algorithm in use in details is given in our previous works (Nazarenko & Nazarenko, 2014, 2015, 2016, 2017). Shortly, this algorithm is as follows: to resolve the non-stationary Euler's hydrodynamical equations we have used the astrophysical variant of "large-particles" code by Belotserkovsky and Davydov (Belotserkovskii & Davydov, 1982); to simulate one-point-stream we use the donor's atmosphere model that in turn is constructed on the base Kurucz's grid (Kurucz, 1979) with the donor's parameters; we use the free-flow boundary conditions allowing to a gas to flow freely via the calculation area boundaries; to calculate mass flow real temperature we use the radiation cooling explicitly (Cox & Daltabuit, 1971). In the present calculation we use the rectangular coordinate system centred on the donor's centre. We have adopted the donor's mass to be equal to 40 solar mass and the accretor's mass to be equal to 10 solar mass. The precession period in the present simulations is about of 4 orbital periods. Hereafter all the distances will be given in units of the orbital separations; the average volume disk specific viscosity and the average volume disk specific angular momentum will be given in units of $V_0 A$, where V_0 is the orbital speed and A – the orbital separation.

3. The results

Before a starting precession we run our simulations over 5 precession periods to show a stationary state in disk over long time. The precession starting is on time equal to zero. After a precession starting we run our simulation over $5 \div 6$ precession periods. This time interval is containing two ON-states and two OFF-states. The essential parameters of a disk before a starting of precession are as follows: the number density in one-point is equal to $3.0 \cdot 10^{10}$ cm^{-3}, the average volume number density in a disk is order of $2.0 \cdot 10^{12}$ cm^{-3}, the mass accretion rate and mass transfer rate via one-point are equal to $2.5 \cdot 10^{-10}$ solar mass per year for low mass accretion rate case; the number density in one-point is equal to $3.0 \cdot 10^{11}$ cm^{-3}, the average volume number density in a disk is order of $2.0 \cdot 10^{13}$ cm^{-3}, the mass accretion rate and mass transfer rate via one-point are equal to $2.5 \cdot 10^{-9}$ solar mass per year for high mass accretion rate case. The key parameter in our present simulations is the time behaviour of the disk mass accretion rate. This behaviour is showing for low and high mass accretion rate cases in Fig. 1 and Fig. 2. As it is seen from these figures ON-states are about of 2,0 and 5,0 precession periods and OFF-states are in the time intervals from 0 to 2 and from 2 to 4 precession periods. The comparison of both Fig.1 and Fig. 2 shows that in the low mass accretion rate case the time intervals of ON-states are more short relatively the high mass accretion rate case. It show that Fig. 1 more corresponds to observational data of Cyg X-1 (Lachowicz et al., 2006). To illustrate the present computations in more details we are plotted in Fig. 3 and Fig. 4 the time dependencies of the averaged volume disk specific viscosity and the averaged volume disk specific angular momentum for low mass accretion rate case. As it is led from these figures, the disk have the high specific viscosity and low specific angular momentum over ON-states and on contrary, the disk have the low specific viscosity and high specific angular momentum over OFF-states. By the other words, the disk is very rapidly rotating with small viscosity over OFF-states and the situation is contrary over ON-states. To show the geometrical disk structure over ON- and OFF-states we are plotted the cross-sections of the calculation area by the disk plane and by the z-x plane for ON- state (Fig. 5 and Fig. 6) and for OFF-state (Fig. 7 and Fig. 8) for high mass accretion rate case. In these Figures the numbers 1 and 2 are marking the disk and the vicinity of one-point and one-point-stream respectively. As it is easy seen from these figures in the case of ON-state the disk have very small radius (by the other words is very compact), is very dense and is having the very power and dense one-point-stream. In the case of OFF-state the disk is very large with the radius of 0.35 approximately, is having relatively small density and is having the very small size in the vertical direction.

4. Summary and conclusions

The present calculations show that over OFf-state our numerical disk model have relatively large radius

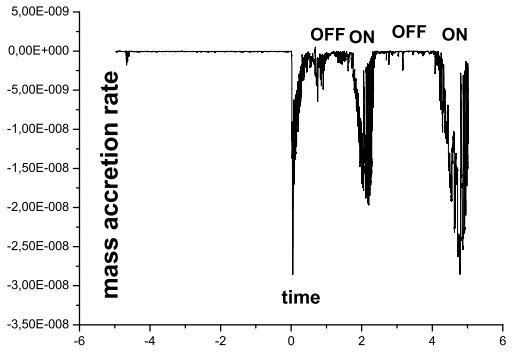

Figure 1: The mass accretion rate versus time for low mass accretion rate.

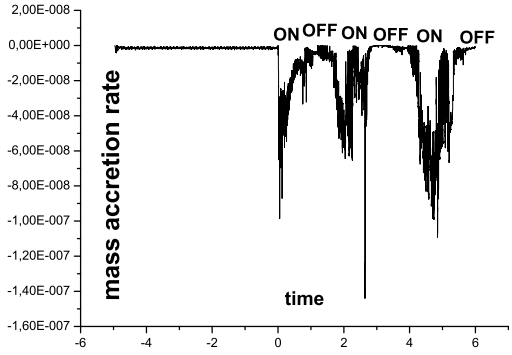

Figure 2: The mass accretion rate versus time for high mass accretion rate.

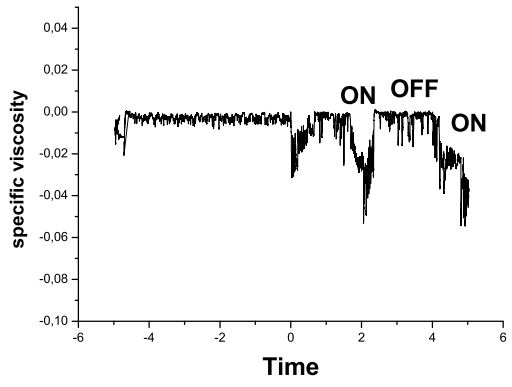

Figure 3: The disk average volume specific viscosity versus time for low mass accretion rate.

(about of 0.35) and is rotating very rapidly. On contrary over On-state the disk is very dense, have the very dense one-point stream, have the very small radius (about of 0.09) and have also the high specific viscosity. The main conclusion of the present research

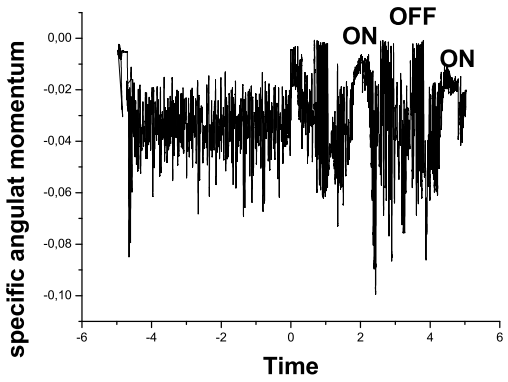

Figure 4: The disk average volume specific angular momentum versus time for low mass accretion rate.

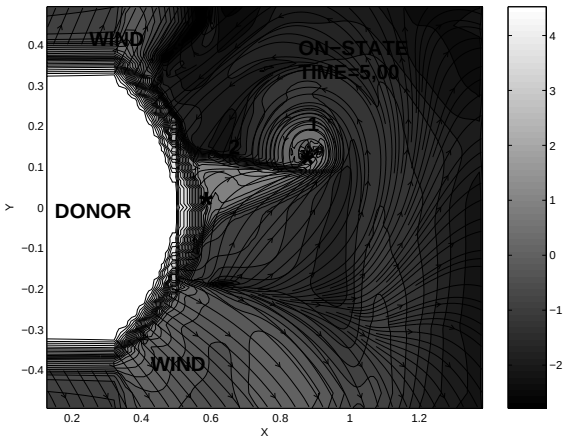

Figure 5: The cross-section of the disk by disk-plane for on-state.

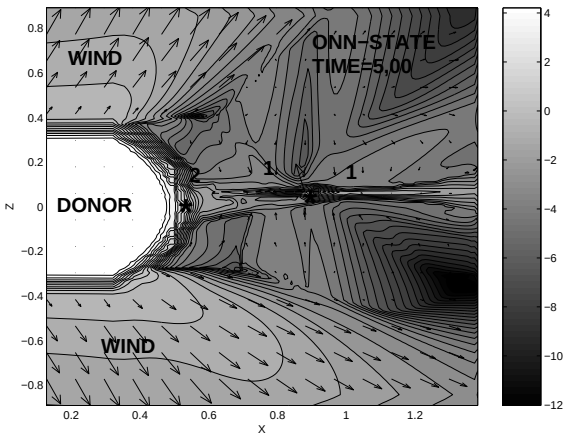

Figure 6: The cross-section of the disk by the z-x plane for on-state.

is that the low accretion rate case is in the very good accordance with observational data of Cyg X-1 (X-ray observations - Lachowicz et al., 2006).

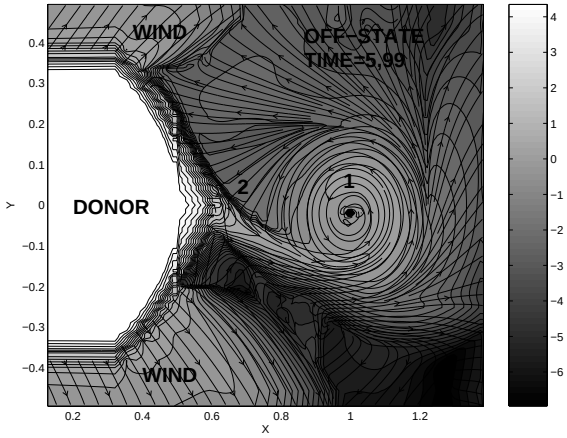

Figure 7: The cross-section of the disk by disk-plane for off-state.

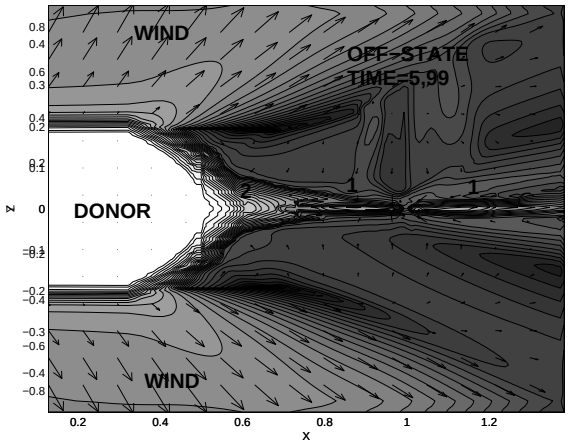

Figure 8: The cross-section of the disk by the z-x plane for off-state.

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