ON THE ESTIMATION OF THE LIFETIME OF THE ACCRETION DISK IN THE SEMIDETACHED BINARIES

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ABSTRACT. The results of 3D numerical simulations of mass transfer in semidetached binaries after the mass transfer termination are presented. On the first stage the 3D gasdynamical simulation of mass transfer for the case of constant rate of mass transfer has been conducted up to the steady-state solution. Then the matter outflow was adopted to be terminated and the dependency of the lifetime of residual disk on numerical viscosity has been considered.

Key words: Stars: binary: cataclysmic; stars: accretion disk.

1. Problem setup

The purpose of this work is to investigate the flow structure in a semidetached binary after the mass transfer termination. On the first stage the 3D gasdynamical simulation of the gaseous flows for the case of constant rate of mass transfer has been conducted up to the steady-state solution. Then it was adopted that matter outflow is terminated and the fate of residual disk was considered. It is well known that the evolution of accretion disk is controlled by physical processes responsible for the redistribution of the angular momentum in the disk. To investigate the influence of viscosity we conduct 3 runs for various values of viscosity, these ones corresponding to the following effective values of parameter α in terms of the α-disk (Shakura and Syunyaev 1994): $\alpha \sim 0.08 \div 0.1$, $0.04 \div 0.06$ and $0.01 \div 0.02$.

Let us consider a semidetached binary system and adopt that accretor has the mass M_1, the mass-loosing star has the mass M_2, the separation of the binary system is A, and angular velocity of orbital rotation is Ω. The flows of matter in this system can be described by Euler equations with equation of state for ideal gas $P = (\gamma - 1)\rho\varepsilon$, where P – pressure, ρ – density, ε – specific internal energy, γ – adiabatic index. To mimic the radiative loss of energy we adopt the value of γ close to 1: $\gamma = 1.01$, which corresponds to the near-isothermal case (Bisikalo et al. 1997, Molteni et al. 1991).

To obtain the numerical solution of the system of equations we used the Roe-Osher TVD scheme of a high order of approximation (Roe 1986, Chakravarthy and Osher 1985) with Einfeldt modification (Einfeldt 1988). The original system of equations was written in a dimensionless form. To do this, the spatial variables were normalized to the separation A, the time variables were normalized to the reciprocal angular velocity of the system Ω^{-1}, and the density was normalized to its value in the inner Lagrangian point L_1. The gas flow was simulated over a parallelepipedon $[-{}^1\!/_2A \ldots {}^1\!/_2A] \times [-{}^1\!/_2A \ldots {}^1\!/_2A] \times [0 \ldots {}^1\!/_4A]$ (due to the symmetry of the problem calculations were conducted only in the top half-space). The sphere with a radius of ${}^1\!/_{100}A$ representing the accretor was cut out of the calculation domain.

The boundary and the initial conditions were determined as follows:

- the donor star fills it's Roche lobe;
- we adopted free-outflow conditions at the accretor and at the outer boundary of the calculation domain;
- on the first stage in gridpoint corresponding to L_1 we injected the matter with parameters $\rho = \rho(L_1)$, $V_x = c(L_1)$, $V_y = V_z = 0$, where $c(L_1) = 10^{-1}$– is a gas speed of sound in L_1;
- on the second stage when steady-state regime was reached at the moment of time $t = t_0$ we adopted free-outflow conditions at the accretor and at the outer boundary of the calculation domain.

The initial conditions corresponded to the background gas with the following parameters were used:

$$\rho_0 = 10^{-5}\rho(L_1), \quad P_0 = 10^{-4}\rho(L_1)\, c^2(L_1)/\gamma, \quad \mathbf{V}_0 = 0.$$

2. Estimation of the lifetime of the residual disk for different values of viscosity

To evaluate the influence of the viscosity on the solution, three runs with different spatial resolution were conducted. The Euler equations don't include physical viscosity so we varied the numerical viscosity by virtue of changing of computational grid. Three grids were chosen for the simulation: 31×31×17("A"), 61×61×17("B") 91×91×25("C"). The used grids were uniform for all the runs. In terms of the α-disk the numerical viscosity for runs "A", "B", "C" approximately corresponds to $\alpha \sim 0.08 \div 0.1$, $0.04 \div 0.06$ and $0.01 \div 0.02$.

Prior to simulation of the flow structure with stopped mass transfer the near-steady-state solutions for the case of constant non-zero rate of mass transfer were obtained and used as initial conditions. At the moment of time $t = t_0$, the rate of mass transfer was decreased in five order of magnitude, which corresponds to the termination of the mass transfer.

Calculations of runs "A" and "B" were lasted until the density of gas becomes less than the background density $\rho_0 = 10^{-5}\rho(L_1)$. This corresponds to the full vanishing of matter due to accretion and outflow through outer boundary. The durations of these two runs correspond to $5P_{orb}$ and $12P_{orb}$ after the moment of time t_0. Run "C" has the best resolution and the minimal numerical viscosity. Nevertheless, this run was conducted to $10P_{orb}$ only, since this run is very computer-time-consuming while the time when disk vanishes can be estimated as $\sim 50P_{orb}$. We extrapolated the results of calculation of run "C" for $t > 10P_{orb}$.

To evaluate the lifetime of the residual disk we used the estimation of the gas mass change $m = \iiint \rho dxdydz$, which is shown on Figures 1 and 2. In Fig. 1 the time variation of the total mass of the calculation domain is presented. Fig. 2 demonstrates the change of the mass of the accretion disk zone versus time. The accretion disk sizes change from runs to runs; therefore, for the sake of comparison of results of different runs we calculate not the exact mass changes in the accretion disk but the mass changes in the domain $r < 0.1, h < 0.05$, which is rather close to the accretion disk sizes for all the three runs. The lower limit of the density of gas is the background density ρ_0, therefore the mass of the uniform matter with $\rho{=}\rho_0$ calculated for the whole computation domain and for the disk zone are asymptotic lines for graphs $m(t)$. These lines are shown in the corresponding figures by dashed lines.

The analysis of the data presented in the figures shows that the lifetime of the residual disk is increased with the decrease of the numerical viscosity: for the run "A" ($\alpha \approx 0.1$) $\tau_{disk} \approx 5P_{orb}$; for the run "B" ($\alpha \approx 0.05$) $\tau_{disk} \approx 12P_{orb}$; for the run "C" ($\alpha \approx 0.01$) he extrapolation of the result of simulation shows that the lifetime of the residual disk exceeds 50 orbital periods. It is pertinent to note that the value $\alpha \approx 0.01$ is typical for observable accretion disks (Lynden-Bell and Pringle 1974, Meyer-Hofmeister and Ritter 1993, Tout 1996, Armitage and Livio 1996). Consequently, we can expect the lifetime of residual disk after the termination of mass is of order 50 orbital periods (near a week) for typical dwarf novae.

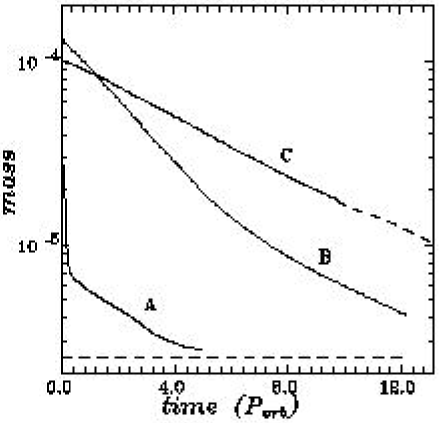

Figure 1: Time evolution of the total mass of the calculation domain for "A"($\alpha \approx 0.1$), "B" ($\alpha \approx 0.05$), and "C" ($\alpha \approx 0.01$) runs. The mass of the uniform matter corresponding to the backgrownd density $\rho = \rho_0$ is shown by the dashed line.

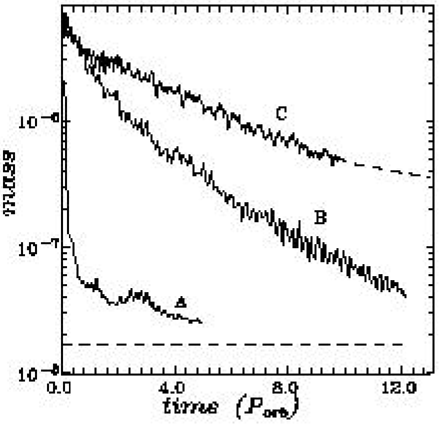

Figure 2: Time evolution of the mass of the accretion disk zone for "A"($\alpha \approx 0.1$), "B" ($\alpha \approx 0.05$), and "C" ($\alpha \approx 0.01$) runs. The mass of the uniform matter corresponding to the background density$\rho = \rho_0$ is shown by the dashed line.

3. Conclusions

The 3D numerical simulations of structure of the accretion disk after the mass transfer termination reveals an essential increase of its lifetime with the decrease of viscosity. For effective $\alpha \sim 0.05$ the lifetime of the residual disk exceeds 12 orbital periods and for $\alpha \sim 0.01$ (that is typical for observable accretion disks) the lifetime of the residual disk is as much as 50 orbital periods.

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