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SPH Simulations of Accretion Flow via Roche Lobe Overflow and via Mass Transfer from Be Disk

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Abstract. We compare the accretion flow onto the neutron star induced by Roche lobe overflow with that by the overflow from the Be disk, in a zero eccentricity, short period binary with the same mass transfer rate, performing three-dimensional Smoothed Particle Hydrodynamics simulations. We find that a persistent accretion disk is formed around the neutron star in both cases. The circularization radius of the material transferred via Roche lobe overflow is larger than that of the material transferred from the Be disk. Thus, the growth of the accretion disk in the former case becomes significantly slower than in the latter case. In both cases, the mass accretion rate is very small and varies little with orbital phase, which is consistent with the observed X-ray behavior of Be/X-ray binaries with circular orbits (e.g. XTE J1543-568).

1. Introduction

Most of binaries, which exhibit the X-ray activity, have a circular orbit around the common center of mass, in which an accretion disk is mainly formed via the Roche lobe overflow from a mass-donor star. On the other hand, in Be/X-ray binaries which consist of a neutron star and a Be star, an accretion disk is formed around the neutron star via the mass transfer from the circumstellar disk of the Be star (Hayasaki & Okazaki 2004) Little work has been so far done on the accretion flow around the neutron star with an attention to the difference between the overflow from the circumstellar disk around the Be star (model A) and the Roche lobe overflow from the Be star (model B). In this paper, we study how the material accretes onto the neutron star in both cases, performing three dimensional (3D) Smoothed Particle Hydrodynamics (SPH) simulations.

2. Formation and Evolution of the Accretion Disk

We carried out the simulations by using the same 3D SPH code as in Hayasaki & Okazaki (2004, 2005a,b) (see also Okazaki et al. 2002; Bate et al. 1995) In order to investigate the accretion flow around the neutron star, two simulations have the same parameters as Hayasaki & Okazaki (2005b) except for the eccentricity $e = 0.0$, the mass transfer rate $\dot{M}_T \sim 1.24 \times 10^{-11} M_{\odot} yr^{-1}$ and the inner boundary radius $r_{\rm in} = 6.0 \times 10^{-3}a$, where a is the semi-major axis of the binary. In model B, the Roche lobe overflow is modeled by launching the gas particles at the inner Lagrange point L_1, in which we add 1000 SPH particles per orbit with an initial speed $v_{inj} = 0.1a\Omega_{\rm orb}$, in a direction 0.387 rad prograde of the binary axis (Lubow & Shu 1975). In what follows, the units of time is $P_{\rm orb} = 24.3\,d$.

Fig.1 shows the orbital-phase dependence of the circularization radius (the left panel) and the viscous time-scale in units of $P_{\rm orb}$ (the right panel). In each panel, the solid line and the dotted line denote the circularization radius and the viscous time-scale of model A and model B, respectively. As shown in Fig.1, it is likely that the disk growth of model A is faster than that of model B.

Fig.2 gives snapshots of the accretion flow around the neutron star at $t =$ 35. Each panel shows the logarithm of the surface density, where the solid curve denotes the inner Roche lobe. As seen in Fig.2, we note that a persistent accretion disk is formed around the neutron star in both cases.

Fig.3 shows the evolution of mass-accretion rate. The solid line and the dotted line show the mass-accretion rate of model A and model B, respectively. We note from the figure that the mass accretion rate of model A is much higher than that of model B.

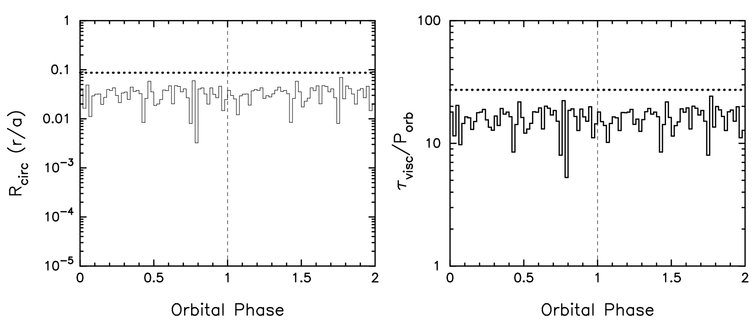

Figure 1. Orbital dependence of the circularization radius (the left panel) and the ratio of the viscous time-scale to the orbital period (the right panel). The solid line and the dotted line show the circularization radius and the viscous time-scale of the model A and model B, respectively.

3. Summary

We have performed 3D SPH simulations in order to compare the accretion flow onto the neutron star induced by Roche lobe overflow with that by the overflow from the Be disk in a zero eccentricity, short period binary with the same mass-transfer rate. We have found that a persistent accretion disk is formed around the neutron star in both cases, as seen in Fig.2. The mass accretion rate in model A is much higher than that in model B because of the smaller circularization radius in model A, as shown in Fig.1 and 3. This indicates that the disk growth is faster as the specific angular momentum of gas particles is lower. In either case, the tiny mass-accretion rate is consistent with the observed X-ray behavior of Be/X-ray binaries with circular orbits (e.g. XTE J1543-568).

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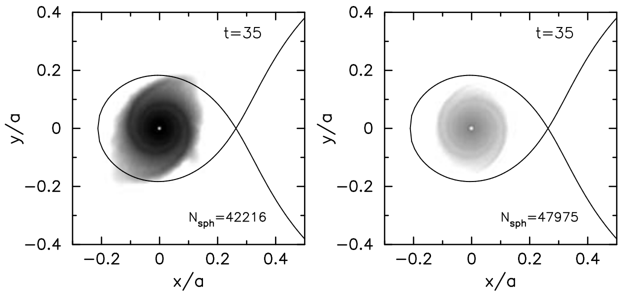

Figure 2. Snapshots of the accretion disk formation in a Be/X-ray binary with $P_{\rm orb} = 23.4$ and $e = 0.0$ at $t = 35.0$ in model A (the left panel) and model B (the right panel), respectively. Each panel shows the surface density in a range of three orders of magnitude in the logarithmic scale. Annotated in each panel are the simulation time and the number of SPH particles. The solid curve denotes the inner Roche lobe in each panel.

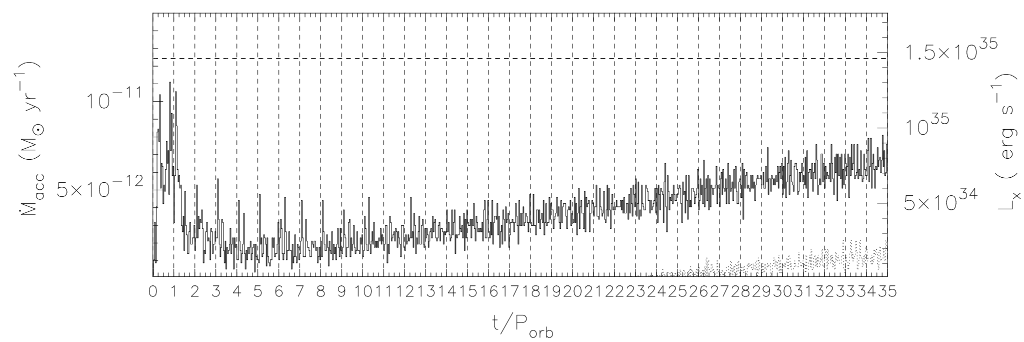

Figure 3. Evolution of the mass-accretion rate for $0 \leq t \leq 35$. The solid and dotted lines denote the mass-accretion rate of model A and model B, respectively. The dashed line shows the mean mass-transfer rate $\sim 1.24 \times 10^{-11}\ M_\odot/yr$ from the Be star. The right axis denote the X-ray luminosity corresponding to the mass-accretion rate.

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