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S. Štefl, S. P. Owocki and A. T. Okazaki

Long-Term Evolution of Accretion Disks around Neutron Stars in Be/X-ray Binaries

K. Hayasaki[1,2] and A. T. Okazaki[3]

[1]*Department of Applied Physics, Graduate School of Engineering, Hokkaido University, Kitaku N13W8, Sapporo 060-8628, Japan*

[2]*Centre for Astrophysics and Supercomputing, Swinburne University of Technology, Hawthorn Victoria 3122 Australia*

[3]*Faculty of Engineering, Hokkai-Gakuen University, Toyohira-ku, Sapporo 062-8605, Japan*

Abstract. We study the long-term evolution of the accretion disk around the neutron star in Be/X-ray binaries. We confirm the earlier result by Hayasaki & Okazaki (2004) that the disk evolves via a two-stage process, which consists of the initial developing stage and the later developed stage. The peak mass-accretion rate is distributed around apastron after the disk is fully developed. This indicates that the modulation of the mass accretion rate is essentially caused by an inward propagation of the one-armed spiral wave. The X-ray luminosity peak around the apastron could provide circumstantial evidence for an persistent disk around the neutron star in Be/X-ray binaries.

1. Introduction

Most Be/X-ray binaries show only temporal X-ray activity, i.e., regular periodic outbursts at periastron (Type I) and/or giant outbursts (Type II) with no orbital modulation. X-ray outbursts are considered to be caused by the mass-accretion onto the neutron star through the mass transfer from the Be-star disk (Okazaki et al. 2002). Recently, Hayasaki & Okazaki (2004) (hereafter, paper I) studied the accretion flow around the neutron star in a Be/X-ray binary with a short period ($P_{\rm orb} = 24.3$ days) and moderate eccentricity ($e = 0.34$), using a three-dimensional (3D) Smoothed Particle Hydrodynamics (SPH) code. They showed that a time-dependent accretion disk is formed around the neutron star. Hayasaki & Okazaki (2005) (hereafter, paper II) further showed that the disk has a one-armed spiral structure induced by a phase-dependent mass transfer from the Be disk. These are, however, the results from simulations run over a period shorter than the viscous time-scale of the disk, and it was not known how the accretion disk evolves over a period longer than the viscous time-scale. In this paper, we study the long-period evolution of accretion disk around the neutron star in Be/X-ray binaries, performing the 3D SPH simulations.

2. Long-Term Evolution of Accretion Disk

Our simulations were performed by using the same 3D SPH code as in paper I, which was based on a version originally developed by Benz (Benz 1990; Benz et al. 1990) and later by Bate, Bonnell & Price (1995). For the comparison purpose, we run the simulations with the same parameters of model 1 in paper I, except that the number of injected particles per orbit is the three times less than that of model 1 in paper I. The orbital period $P_{\rm orb}$ is 24.3 d, the eccentricity e is 0.34, and the Be disc is coplanar with the orbital plane. The inner radius of the simulation region $r_{\rm in}$ is $3.0 \times 10^{-3}a$, where a is the semi-major axis of the binary. The polytropic equation of state with the exponent $\Gamma = 1.2$ is adopted. The Shakura-Sunyaev viscosity parameter $\alpha_{\rm SS} = 0.1$ throughout the disc. In what follows, the units of time is $P_{\rm orb}$.

Figure 1 shows the evolution of several non-axisymmetric modes with an improved definition of the mode strength in paper II. The solid-thin, dotted and solid-thick lines denote the strengths of $m = 1$, $m = 2$ and $m = 3$ modes, respectively. From Figure 1, we note that the $m = 1$ component dominates the other components throughout the run.

The top panel of Figure 2 shows the evolution of the mass-accretion rate and the corresponding X-ray luminosity, whereas the bottom and the middle panel shows orbital-phase dependence of the peak of mass-accretion rate and its frequency distribution, respectively. It is noted from these figures that the mass-accretion rate has double peaks per orbit at an initial developing stage ($0 \leq t \lesssim 10$). While the first peak is due to the direct accretion of particles with the low specific angular momentum, the second one is mainly caused by an inward propagation of $m = 1$ mode. After the disk is fully developed ($t \gtrsim 10$), the mass accretion rate has a single peak per orbit only due to the wave induced accretion.

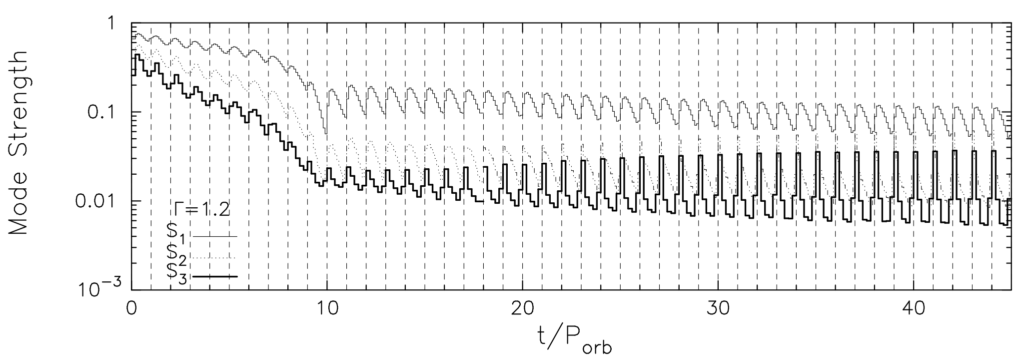

Figure 1. Evolution of several nonaxisymmetric modes for $0 \leq t \leq 45$. The solid-thin, dotted and solid-thick lines denote the strengths of $m = 1$, $m = 2$ and $m = 3$ modes, respectively.

3. Concluding Remarks

We have performed 3D SPH simulations in order to study the long-period evolution of the accretion disk around the neutron star in Be/X-ray binaries. As shown in left panel of Figure 2, the mass-accretion rate gradually increases with the stable material-supply from the Be disk. This strongly suggests the accretion disk finally gets to a quasi-steady state as the third evolutionary stage. On the other hand, the right panel of Figure 2 have shown that after the disk is

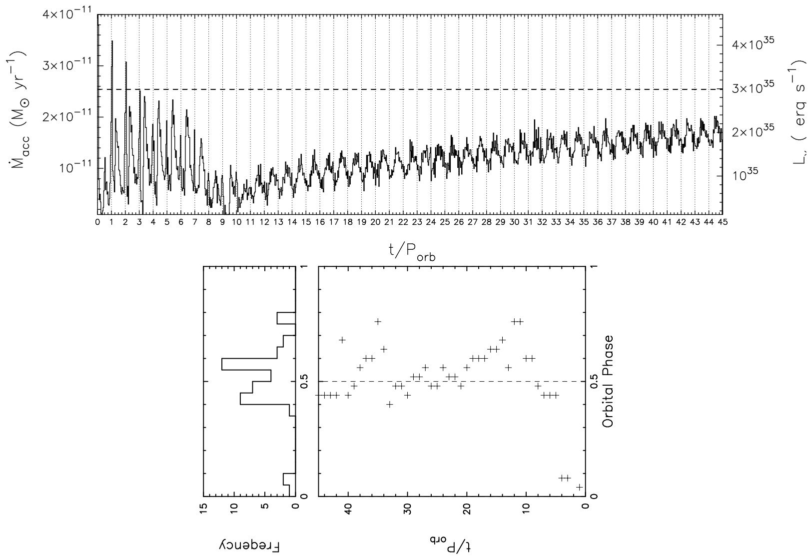

Figure 2. Evolution of the mass-accretion rate $\dot{M}_{acc}$ in units of $M_{\odot}yr^{-1}$ (the top panel) and orbital-phase dependence of the peak of mass-accretion rate (the bottom right panel) and its frequency distribution (the bottom left panel). In the top panel, the right axis is for the X-ray luminosity corresponding to the mass accretion rate. The horizontal dotted line denotes the averaged mass transfer rate from the Be disk. In the bottom panel, the crosses denote the orbital-phase dependence of the X-ray maxima, of which the frequency distribution is shown by the histogram in the bottom left panel.

fully developed, the peak of mass-accretion rate is distributed distinct from the periastron due to an inward propagation of the one-armed spiral wave. This indicates that the X-ray maxima distinct from the periastron could provide circumstantial evidence for an persistent disk around the neutron star in Be/X-ray binaries.

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