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MASS-CAPTURE RATE BY THE NEUTRON STAR IN Be/X-RAY BINARIES

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RESUMEN

Estudiamos la interacción entre el disco de estrellas Be y la estrella de neutrones en binarias Be/rayos X mediante simulaciones en tres dimensiones SPH. Encontramos que el truncamiento resonante del disco de la estrella Be opera bien excepto para sistemas con excentricidad orbital extremadamente alta o grandes ángulos de desalineación entre el disco Be y el plano orbital. Debido al truncamiento, la tasa de captura de masa por la estrella de neutrones es sensible tanto a la excentricidad orbital como al ángulo de desalineación. Posee un solo pico en sistemas coplanares y en sistemas con ángulos de desalineación pequeños, mientras que llega a tener dos picos en sistemas con grandes ángulos de desalineación.

ABSTRACT

We study the interaction between the Be-star disk and the neutron star in Be/X-ray binaries by three dimensional SPH simulations. We find that the resonant truncation of the Be disk works except for systems with extremely high orbital eccentricity or large misalignment angles between the Be disk and the orbital plane. Owing to the truncation, the mass-capture rate by the neutron star is sensitive both to the orbital eccentricity and to the angle of misalignment. It is single-peaked in coplanar systems and in systems with small misalignment angles, whereas it becomes double-peaked in systems with large misalignment angles.

Key Words: **ACCRETION, ACCRETION DISKS — BINARIES: CLOSE — HYDRODYNAMICS — STARS: EMISSION-LINE, BE — X-RAYS: STARS**

1. INTRODUCTION

The Be/X-ray binaries, the dominant subclass of high mass X-ray binaries, consist of a Be star (i.e., a B-type star with an equatorial disk) and a neutron star. The orbit is wide (several tens of days $\lesssim P_{\rm orb} \lesssim$ several hundred days) and mostly eccentric ($e \gtrsim 0.3$). Most of the Be/X-ray binaries exhibit only transient X-ray activity due to the transient accretion of matter on to the neutron star from the Be-star disk.

Although there is no widely-accepted model for Be-star disks, the viscous decretion disk model (Lee et al. 1991; Porter 1999; Okazaki 2001) naturally explains many of the observed features and thus seems promising. The model assumes that the star can eject gaseous particles with the Keplerian velocity at the stellar equator. The ejected particles then drift outward by viscosity and form a disk.

Recent semi-analytical studies (Negueruela & Okazaki 2001; Okazaki & Negueruela 2001) showed that the Be disk in coplanar Be/X-ray binaries is truncated at a radius smaller than the periastron distance, as long as $\alpha_{\rm SS} \ll 1$, where $\alpha_{\rm SS}$ is the Shakura-Sunyaev viscosity parameter. The result agrees with the observations (Reig et al. 1997; Zamanov et al. 2001) and has been confirmed by numerical simulations (Okazaki et al. 2002).

On the other hand, no study has been done about the interaction between the Be disk and the neutron star in systems in which the Be disk is misaligned from the binary orbital plane. One of the main purposes of this paper is to study the effect of the misalignment on the interaction between the Be disk and the neutron star, using a three dimensional Smoothed Particle Hydrodynamics (3D SPH) code.

2. NUMERICAL MODEL

We use a 3D SPH code in which the Be disk is modeled by an ensemble of gas particles of negligible masses and the Be star and the neutron star by two sink particles with corresponding masses (see Okazaki et al. 2002; see also Bate et al. 1995). For simplicity, we assume that the disk is isothermal at the temperature of half the effective temperature of the Be star and has the viscosity parameter $\alpha_{\rm SS} = 0.1$. We also assume that the neutron star has a variable accretion radius of $0.9r_{\rm L}$, where $r_{\rm L}$ is the Roche-lobe radius for a circular binary. The mass ejection mechanism from the Be star is modeled by constantly injecting gas particles at a radius just outside the equatorial surface.

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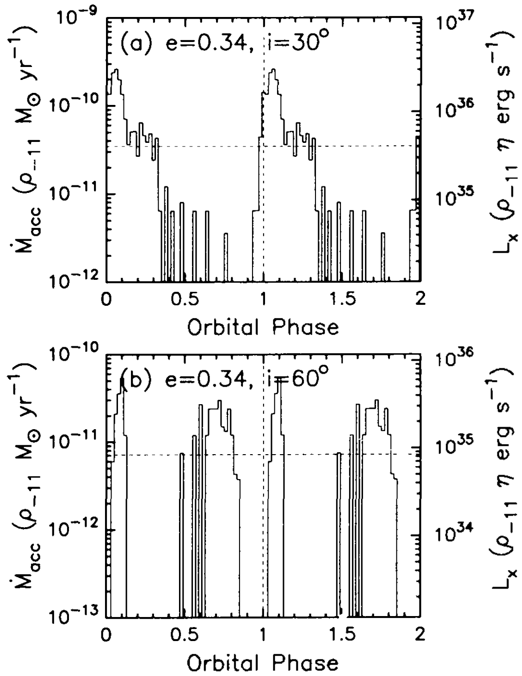

Fig. 1. Phase dependence of the mass-capture rate $\dot{M}_{\rm acc}$ by the neutron star: (a) $i = 30°$ and (b) $i = 60°$. The data are folded on the orbital period over $40P_{\rm orb} \leq t \leq 50P_{\rm orb}$. The horizontal dashed line in each panel denotes the mass-capture rate averaged over this period. The right axis shows the X-ray luminosity corresponding to $\dot{M}_{\rm acc}$, which is defined by $L_{\rm X} = \eta G M_{\rm X} \dot{M}_{\rm acc}/R_{\rm X}$ with $M_{\rm X} = 1.4 M_\odot$ and $R_{\rm X} = 10^6$ cm.

As the Be star, we take a B0V star of $M_* = 18M_\odot$, $R_* = 8R_\odot$, and $T_{\rm eff} = 26,000$ K with the equatorial plane tilted from the binary orbital plane by the angle i. The neutron star of $1.4M_\odot$ orbits about the Be star with the orbital period $P_{\rm orb}$ and the eccentricity e. In this paper, $P_{\rm orb}$ is set to 24.3 d and the azimuth of the tilt is set toward the periastron. We run each simulation for $50P_{\rm orb}$ (~ 3.3 yr). In all simulations, the number of SPH particles at the end of the simulation is about 2×10^4.

3. INTERACTION IN COPLANAR SYSTEMS

We have found that the Be disk is resonantly truncated except for systems with extremely high orbital eccentricity ($e \gtrsim 0.8$). The mass-capture rate $\dot{M}_{\rm acc}$ by the neutron star has a peak slightly after periastron passage and decreases monotonically afterwards. $\dot{M}_{\rm acc}$ is higher and has stronger phase dependence for higher e.

4. INTERACTION IN MISALIGNED SYSTEMS

We have found that the Be disk in misaligned Be/X-ray binaries with moderate eccentricity is also resonantly truncated as in coplanar binaries, unless the angle of misalignment $i \gtrsim 60°$. The disk structure and evolution are also similar to those in coplanar systems: The disk is nearly Keplerian and the radial velocity is highly subsonic. Owing to the truncation, the disk density increases more rapidly than in isolated Be stars and the mass-capture rate by the neutron star is reduced to a level much lower than the mass-ejection rate of the Be star.

Figure 1 shows phase dependence of the mass-capture rate $\dot{M}_{\rm acc}$ for (a) $i = 30°$ and (b) $i = 60°$. From the figure, we note that $\dot{M}_{\rm acc}$ decreases with increasing i. We also note that the mass-capture rate in misaligned systems has a secondary peak, unlike in coplanar systems. For small inclination angles ($i \lesssim 30°$), the secondary peak is much weaker than the primary peak, making a hump in the mass-capture rate profile. However, for large inclination angles ($i \gtrsim 45°$), it is comparable to the primary peak. This feature may explain systems that show two X-ray outbursts per orbit. The mass-capture rate by the neutron star gives useful information on the interaction in Be/X-ray binaries. As shown by Hayasaki & Okazaki (2004), however, the mass-accretion rate is much lower than the mass-capture rate. Much more work should be done on the accretion flow around the neutron star to understand the X-ray behavior of these systems.

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