STRUCTURE AND TIME-DEPENDENT BEHAVIOR OF BE-STAR DISKS IN BE/X-RAY BINARIES

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We consider the structure and time dependent behavior of the outflow in disks of Be stars in Be/X-ray binaries, based on the viscous decretion disk scenario (Lee et al. 1991). In this scenario, the matter ejected from the star with the Keplerian velocity at the equatorial surface of the star drifts outward because of the effects of viscosity, and forms the disk.

In the present study, we adopt the Shakura-Sunyaev's α-viscosity prescription, and assume the disk to be isothermal. The disk radius is fixed to be $3^{-2/3}$ times the mean binary separation, because in a Be/X-ray binary the disk of the Be star is likely truncated at the radius where the tidally-induced eccentric instability occurs.

Figure 1(a) illustrates a typical structure of viscous decretion disks around Be stars in Be/X-ray binaries: The outflow velocity increases as r, the surface density decreases as r^{-2}, and the angular velocity of the disk decreases as $r^{-1/2}$.

In general, the viscous decretion discs are overstable for $m = 1$ perturbations. The growth rate is of the order $\alpha(H/r)^2\Omega$, where H is the scale-height of the disk and Ω is the angular frequency of disk rotation. Figure 1(b) shows the $m = 1$ overstable mode in the decretion disk shown in panel (a). We note that the perturbation pattern is of the leading, one-armed spiral. We also note also that the characteristics of the one-armed spiral modes are in agreement with the periodicity and the profile variability of the V/R variations of Balmer lines observed for some Be/X-ray binaries.

Finally, we discuss the orbital modulations of X-ray lightcurves observed for Be/X-ray binaries A0535+26 and 4U0115+63. Type I outbursts from A0535+26 occur close to the periastron passages of the neutron star, while those from 4U0115+63 are seen close to orbital phase of ~ 0.3 (Negueruella et al. 1997). The present model is consistent with these features. For small amplitude $m = 1$ perturbations, the eccentricity of the disk is negligible.

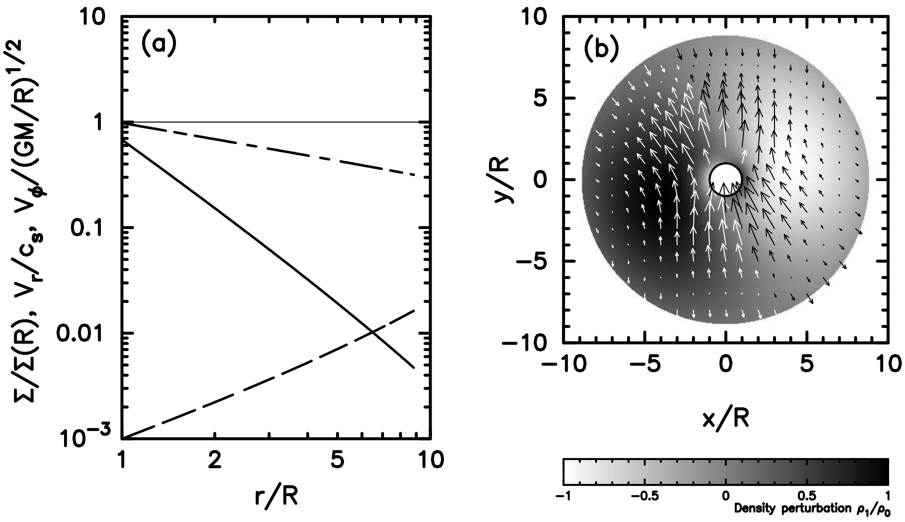

Figure 1. (a) Structure of an unperturbed, viscous decretion disk for a Be/X-ray binary A0535+26. Solid, dashed, and dash-dotted lines denote $V_r/c_{\rm s}$, $V_\phi/(GM/R)^{1/2}$, and $\Sigma/\Sigma(R)$, respectively, where M and R are the mass and radius of the Be star, respectively, V_r and V_ϕ are the radial and azimuthal components of the vertically averaged velocity, respectively, $c_{\rm s}$ is the isothermal sound speed, and Σ is the surface density. We adopt $V_r/c_{\rm s}(R) = 10^{-3}$ and $\alpha = 0.1$. The radiative force in the form of $\eta(r/R)^\epsilon \times GM/r^2$ with $(\eta, \epsilon) = (0.2, 0.1)$ is included. (b) Linear, one-armed fundamental mode in the disk shown in panel (a). The period of this mode is 1.9 yr and the growth time is 8.8 yr. The disk rotates counterclockwise. A gray-scale representation denotes the density perturbation, while arrows denote the perturbed velocity vectors.

Then, the Type I outbursts will occur close to the periastron passages of the neutron star. However, when the amplitude of the $m = 1$ perturbation is large enough to make the disk highly eccentric, the phase of the Type I outburst will also depend on the phase of the $m = 1$ mode which does not necessarily coincide with the periastron pasage of the neutron star.

In conclusion, the viscous decretion disk model for Be stars in Be/X-ray binaries agrees well with long-term V/R variations of Balmer lines and is consistent with the orbital modulations observed for some Be/X-ray binaries.

References

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