Active OB stars: structure, evolution, mass loss, and critical limits
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Mass and angular momentum loss of fast rotating stars via decretion disks

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Abstract. The spinup of massive stars induced by evolution of the stellar interior can bring the star to near-critical rotation. In critically rotating stars the decrease of the stellar moment of inertia must be balanced by a net loss of angular momentum through an equatorial decretion disk. We examine the nature and role of mass loss via such disks. In contrast to the usual stellar wind mass loss set by exterior driving from the stellar luminosity, such decretion-disk mass loss stems from the angular momentum loss needed to keep the star near and below critical rotation, given the interior evolution and decline in the star's moment of inertia. Because the specific angular momentum in a Keplerian disk increases with the square root of the radius, the decretion mass loss associated with a required level of angular momentum loss critically depends on the outer radius for viscous coupling of the disk, and can be significantly less than the spherical, wind-like mass loss commonly assumed in evolutionary calculations.

Keywords. stars: mass loss, stars: rotation, stars: evolution

1. Angular momentum loss at the critical limit

Evolutionary models of massive stars show that the stellar rotation can increase with age on the main sequence (Meynet *et al.* 2006). In stars with moderately rapid initial rotation, and with only moderate angular momentum loss from a stellar wind, this spinup from internal evolution can even bring the star to critical rotation. Since any further increase in rotation rate is not dynamically allowed, the further contraction of the interior must then be balanced by a net loss of angular momentum through an induced mass loss.

We examine the scenario that such mass loss occurs through an equatorial, viscous decretion disk.

2. Analytic estimate

Let us assume rigid body rotation of the star. In this case the norm of the total stellar angular momentum J is given by the product of the stellar moment of inertia I and the rotation angular frequency Ω, $J = I\Omega$. The change of the moment of inertia during stellar evolution is $\dot{J} = \dot{I}\Omega + I\dot{\Omega}$. Once the star reaches the critical rotation frequency, $\Omega = \Omega_{\rm crit}$, the spin-up ends ($\dot{\Omega} = 0$), requiring a shedding of angular momentum given by $\dot{J} = \dot{I}\Omega_{\rm crit}$. Assuming this occurs via mass loss at a rate $\dot{M}$ through a Keplerian decretion disk, the angular momentum loss is set by the outer disk radius $R_{\rm out}$, given by $\dot{J}_{\rm K}(R_{\rm out}) = \dot{M} v_{\rm K}(R_{\rm out}) R_{\rm out}$, where the Keplerian velocity is $v_{\rm K}(r) = \sqrt{GM/r}$, and M is the stellar mass. Setting $\dot{J}_{\rm K}(R_{\rm out})$ equal to the above $\dot{J}$ required by a momentum of

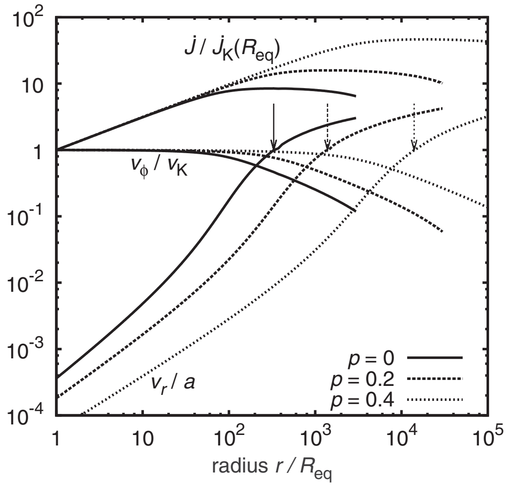

Figure 1. The dependence of the radial (v_r) and longitudinal (v_ϕ) velocities, and the angular momentum loss rate ($\dot{J}$) in units of equator release angular momentum loss rate $\dot{J}_K(R_{eq})$ on the radius in a viscous disk (a is the sound speed). Calculated for $T_{eff} = 30\,000\,K$, $M = 50\,M_\odot$, $R = 30\,R_\odot$ and different disk temperature laws $T = T_0(R_{eq}/r)^p$. Close to the star the anomalous viscosity keeps the matter in the disk in orbits which are nearly Keplerian ($v_\phi/v_K \approx 1$).

inertia change $\dot{I}$, we find the required mass loss rate is (R_{eq} is the equatorial radius)

$$\dot{M} = \frac{\dot{I}}{R_{eq}^2}\sqrt{\frac{R_{eq}}{R_{out}}}, \qquad (2.1)$$

As R_{out} gets larger the required mass loss rate is smaller.

3. Numerical disk models

To obtain a disc structure, we solve stationary hydrodynamic equations in cylindrical coordinates assuming axial symmetry. In analogy with the Shakura & Sunyaev (1973) accretion disks, we model an outward angular momentum transfer via anomalous viscosity. A maximum disk angular momentum loss is obtained in the case when the disk has its outer edge at the radius where $\dot{J}$ is maximum (see Fig. 1). An analytic approximation of the maximum angular momentum loss can be obtained (Krtička *et al.*, in preparation).

4. Radiative ablation

As the radiative force may drive large amount of mass out of the hot stars via line-driven wind it may also effectively set the outer disk radius. As the outer disk radius gets lower, the radiative ablation may decrease the efficiency of the disk angular momentum loss (Krtička *et al.*, in preparation).

Acknowledgements

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References

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