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Stellar Winds of Classical T Tauri Stars

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Abstract. We present calculations of the structure of magnetized winds of classical T Tauri stars (TTSs) in an axisymmetric, stationary, polytropic approximation in a given magnetosphere (i.e. we do not self-consistently take into account the influence of the flow dynamics on the structure of the underlying magnetosphere). According to the widely accepted model of CTTSs the magnetosphere is dominated by a strong stellar magnetic field ($B_* \simeq 1$ kG) which may be of dipolar type. The behaviour of the magnetic flux-tube function yields valuable constraints on the wind solutions.

1. Introduction

T Tauri Stars are low-mass pre-main sequence stars (Appenzeller & Mundt 1989). Classical T Tauri stars (CTTSs) are often surrounded by an accretion disk and in many cases show highly collimated bipolar outflows which reach velocities of several hundred km/s. It is meanwhile widely accepted that CTTS magnetospheres are dominated by the stellar magnetic field with strengths of several kG. By means of this field the star couples to the surrounding disk. A wind is driven by the magnetic properties of the underlying star and disk. This model, which was first developed by Camenzind (1990), allows to simultaneously describe outflow and accretion phenomena and reconciles the observed low rotation rates of CTTSs with accretion activities.

2. Magnetized Winds

In the limit of ideal magnetohydrodynamics (MHD) the wind plasma is coupled to the magnetic field lines. The wind-magnetosphere structure is therefore mathematically determined by the wind equation and the Grad-Schlüter-Shafranov (GSS) equation for the magnetic flux tubes Ψ. We do not solve these two equations simultaneously but solve the wind equation along fixed magnetic flux tubes for a wind originating from the stellar surface. In our approximation the magnetosphere is built up by a strong stellar magnetic dipole field (of the order of kilo-Gauss), which is squeezed by a surrounding accretion disk. Analytic expressions for magnetic fields of this type have been given by Riffert (1980). The magnetic flux-tube functions decrease as a dipole in the innermost region and become constant at a distance of a few stellar radii (Paatz & Camenzind 1996). The behaviour of the flux function in this region poses constraints on the wind

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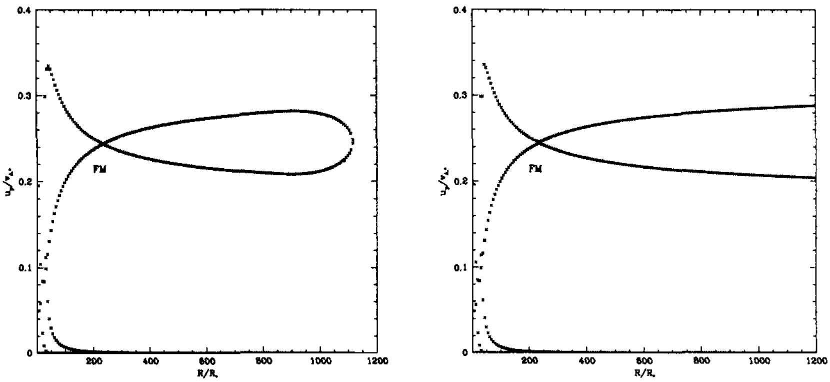

Figure 1. Poloidal velocity u_p (normalized to the Alvfén velocity on the star) of stellar winds as a function of the radius R (normalized to the foot point cylindrical radius). If the mass flux per magnetic flux tube η is too low (i.e. almost force-free solutions) the wind solution breaks down and does not reach the jet region (Fig. 1.a). Higher values of η allow the existence of asymptotic wind solutions (Fig. 1.b). FM denotes the fast magnetosonic point

parameters. Wind solutions only reach the collimation region at $\simeq$ 100 AU if they obey

$$\frac{4\pi\eta}{\Omega^{F^2}}\sqrt{\left(\frac{2E}{3}\right)^3} > \Psi_\infty\,, \tag{1}$$

where η denotes the mass flux per magnetic flux tube, Ω^F the angular velocity of the flux tube, E the total energy of the flow and Ψ_∞ the magnetic flux at large distances. Relation (1) can be derived from the energy equation of a polytropic flow (Paatz & Camenzind 1996). Eq. (1) shows that for higher Ω^F (as is perhaps the case in very early stellar phases) the mass loss rate has to be correspondingly higher to allow for wind solutions. Such winds can play an important role in the spin-down history of CTTSs (Paatz & Camenzind 1997).

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