STELLAR WINDS AND MASS LOSS OF A ROTATING STAR

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Abstract. The mass loss to be expected from the corona of a rotating F2-star is calculated. The rotation is supposed to be rigid up to a certain distance $s$, as if it were maintained by a strong magnetic field. Dependent on the values of the rotational velocity the mass loss can increase to $26-40\%$ for $v_{\text{rot}}$ up to 200 km s$^{-1}$.

1. Introduction

Since Parker's investigations of the hydrodynamical properties of the solar wind phenomenon (Parker, 1960) much work has been done in this field (Parker, 1969; Mestel and Selley, 1970, and references therein). Part of it considered the influence of a magnetic field on the propagation of solar or stellar wind particles (Ferraro and Bhatia, 1961; Parker, 1963; King and Carovillano, 1966; Pneumann, 1966a, b) or dealt with the problem of the angular momentum involved (Weber and Davis, 1968; Brandt et al., 1969, and references).

Detailed models, including rotation, magnetic fields and anisotropic heat conduction were calculated by Grzedzielski (Grzedzielski, 1968), and recently the non-radial oscillations and the energy transport were examined by the same author (Grzedzielski, 1971). It is not our aim to present here another refined model but instead we wish to develop, near the coronal base where our simplifications will hold, a stellar wind model which will yet enable us to estimate the mass loss to be expected from the corona of rotating F-type stars.

2. Stellar Wind with Inclusion of a Centrifugal Force Term

We consider a rotating star with a strong magnetic field, surrounded by a corona, isothermal up to a certain level $x=b$; from there on we adopt an adiabatic temperature decrease. If the magnetic field is strong enough the stellar wind flow will be forced to move along the field lines up to a certain distance $s$, approximately defined by the equality of the kinetic energy density and the magnetic energy density.

Simplifying, we assume that beyond this point the effect of the magnetic field vanishes and that there is no corotation. From there on the behaviour of the stellar wind is the same as in a non-rotating hydrodynamical model. For the evaluation of the stellar wind velocity the rotation-included solution and the solution without rotation should fit in $s$ in a continuous way.
Since we assume rigid rotation of the corona up to \( r = s \), the angular velocity \( v \) increases with distance
\[
v = \Omega r,
\]
and also the centrifugal force increases with \( r \) till \( r = s \). For \( r > s \) we have for the rotational acceleration
\[
g_r = 0.
\]
For \( r < s \), \( g_r \) decreases from the equator to the poles
\[
g_r = \Omega^2 a \sin \theta,
\]
while the tangential component of \( g_r \) is unimportant since we assume corotation for \( r < s \). Only the radial component \( g'_r \) is of importance:
\[
g'_r = \Omega^2 a \sin^2 \theta.
\]
The average value of \( g'_r \) which we call \( \bar{g}_r \) is then, taking into account a weight function proportional to the surface,
\[
\bar{g}_r (r) = \int_0^{\pi/2} \Omega^2 r \sin^3 \theta \, d\theta = \frac{2\Omega^2 r}{3}
\]
with \( \bar{g}_r = 0 \) for \( r > s \).

The general equation for the conservation of momentum is then
\[
Mmv \frac{dv}{dt} + \frac{GNmM}{r^2} + \frac{d}{dt} \left( 2NkT \right) - \frac{2}{3} Nm \Omega^2 r = 0. \tag{1}
\]
Partly following Parker (1960) we introduce dimensionless parameters
\[
x = r/a; \quad \lambda = \frac{GMm}{akT_0}; \quad \beta = \frac{m \Omega^2 a^2}{3kT_0}; \quad \Psi (x) = \frac{mv^2 (r)}{2kT_0}.
\tag{2}
\]
Equation (1) then reduces to
\[
\frac{d}{dx} \left( 1 - \frac{T}{T_0 \Psi} \right) = 2\beta x - \frac{\lambda}{x^2} - 2x^2 \frac{d}{dx} \left( \frac{T}{x^2 T_0} \right). \tag{3}
\]
As a simplified model we adopt an isothermal corona till a distance \( b \); at larger distances we adopt an adiabatic temperature decrease with a polytropic index \( \alpha \).

For \( r < b \): \( \alpha = 1 \),

\( r > b \): \( \alpha = 5/3 \).

Using the equation of mass conservation and introducing the dimensionless variables defined above, we have
\[
T (x) = T_0 \left( \frac{\Psi (x)}{x^{2(a-1)/2}} \right)^{(a+1)/2}. \tag{4}
\]