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# Influence of Magnetic Geometry in Be-Star Disk Formation due to Rotation in Line Driven Stellar Winds

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**Abstract.** Line driven wind theory has been improved including non-spherical expansion in order to study its influence upon disk formation in early–type stars. Assuming that magnetic field controls the flow geometry, the plasma must flow downstream through open magnetic field lines. It is found that in the polar direction rapid flow tube divergence almost does not modify the location of the critical (singular) point and the calculated terminal velocity is incremented about 400 km/sec. On the other hand in the equatorial direction, for a fast rotation case, the location of the critical point is unchanged and the terminal velocity shows slightly variations of about 50 km/sec. This conclusion in the polar direction is contrary to previous results, where the finite disk correction has not been taken into account. These results suggest, that *open magnetic field lines do not influence disk formation in Be-stars.*

## 1. Hydrodynamic formulation

The model for radiation driven stellar winds of Castor et al. (1975) and its improvements (Kudritzki et al. 1989, hereafter KPPA) considers one component fluid in a stationary regime with spherical symmetry, neglecting the effect of viscosity, heat conduction and magnetic field. The continuity equation is $4\pi v \rho A(r) = \dot{M}$ and the momentum equation in the radial direction is given by

$$v\frac{dv}{dr} = -\frac{1}{\rho}\frac{dp}{dr} - \frac{GM(1-\Gamma)}{r^2} + \frac{v_\phi^2}{r} + g^{line}(\rho, v, v', n_E)$$

here $v$ is the fluid velocity, $v' = dv/dr$ is the velocity gradient, $\rho$ is the mass density, $\dot{M}$ is the mass loss rate, $p$ is the fluid pressure, $v_\phi(r) = v_{rot}R*/r$, where $v_{rot}$ is the equatorial rotational velocity, $\Gamma$ is the the radiative acceleration caused by Thomson scattering in terms of gravitational acceleration. The acceleration due to the lines is given by $g^{line}(\rho, v, v', n_E)$ where $n_E$ is the electron number density and $A(r)$ represents the flow tube area (see below). The standard form of the line force is:

$$g^{line} = \frac{C}{r^2}\, CF(r, v, \frac{dv}{dr}) \left(r^2 v \frac{dv}{dr}\right)^{\alpha} \left(\frac{n_E}{W(r)}\right)^{\delta}$$



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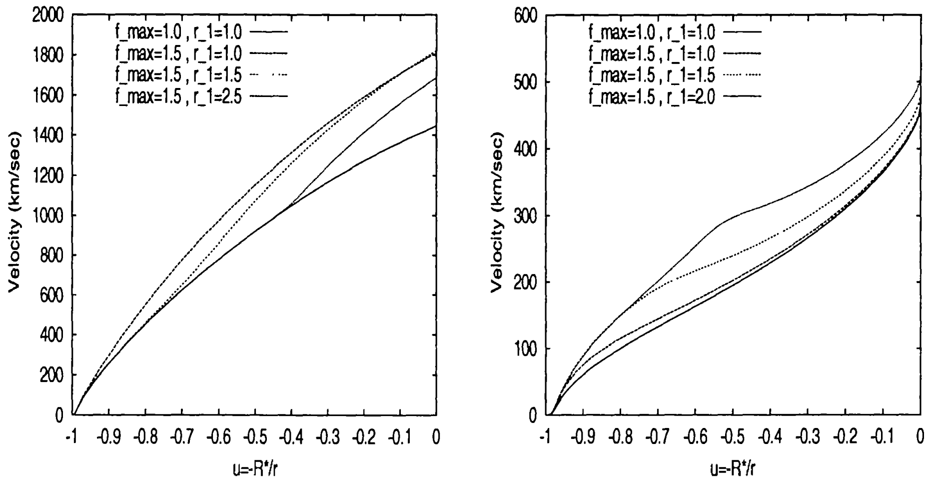


Figure 1. Velocity profile in the polar (left) and equatorial (right) directions.

for details see, e.g., KPPA. The function $A(r)$, in the continuity equation corresponds to the function from Kopp & Holzer (1976, hereafter KH) (see also MacGregor 1988) namely:

$$A(r) = A_* \left(\frac{r}{R_*}\right)^2 f_{KH}(r)$$

where $A_*$ is the area of the stellar surface and the function $f_{KH}(r)$ accounts for the rapid diverging geometry (faster than $r^2$) from KH:

$$f_{KH} = \frac{f_{max}\, e^{(r-r_1)/\sigma} + f_1}{e^{(r-r_1)/\sigma} + 1}$$

with $f_1 = 1 - (f_{max} - 1)\, exp((R_* - r_1)/\sigma)$. The parameter $r_1$ means the point where the spatial rate of change of $f$ is maximum; $\sigma$ represents the length scale reference of $r_1$ where most of the change of $f$ takes place and $f_{max}$ is the net non-spherical divergence. The case when the geometry is not influenced by a magnetic flux tube corresponds to $f_{max} = 1$.

## 2. Numerical results

The inclusion of the $f_{KH}$ certainly modifies the topology of the problem. The parameters of the KH function are relative small. Thus the standard solution analysis of singular points is not substantially modified. We select a typical main sequence Be star with the following parameters: $T_{eff} = 25000K$, $\log g = 4.03$ and $R/R_\odot = 5.3$. The line-force parameters used are: $\alpha = 0.5$, $k = 0.3$ and $\delta = 0.1$. From the results (see Figure 1 and Table 1) it is evident that the location of the critical (singular) point is slightly affected by this magnetic geometry. This is because the singular point lays close to the stellar surface and the parameter $r_1$ takes values larger than $r_{singular}$. On the other hand, the terminal velocity increases about 300 - 400 km/sec when compared to the case where $f_{max} = 1$. The reason for this is an increase in the line-force, due to its non-linear dependency in the velocity gradient, in the *region of most rapid flow tube divergency.* In a previous investigation, Curé (2001) showed that when

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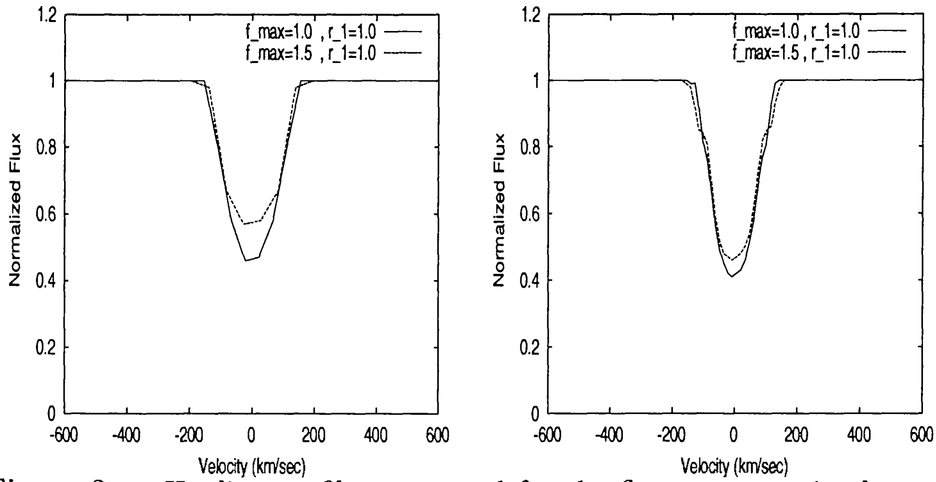


Figure 2. Hα line profiles computed for the flow structure in the polar (left) and equatorial (right) directions.

rotation is included in the wind dynamics, there exist more than one singular point depending on the rotational velocity. For the fast rotational case, i.e., $v_{rot} \geq 0.8\, v_{crit}$ where $v_{crit}$ is the break-up velocity, there is one singular point, and in this case the terminal velocity, is much lower than in the non–rotational case. The results from Table 1 and Figure 1 show that the magnetic geometry have no influence in the location of the critical (singular) point. For this type of solution the singular point lays very far away from the stellar surface and the parameter $r_1$ takes values much lesser than $r_{singular}$. Here the increase in the terminal velocity is almost negligible, about 50 km/sec compared to the case where $f_{max} = 1$. The reason for this is an increase in the line-force, this is again due to its non-linear dependency in the velocity gradient, but here the velocity as well as its gradient grow very slowly, therefore the impact in the *region of most rapid flow tube divergency* is not as much as in the polar case.

After obtaining the velocity and density distributions, we compute the Hα line spectrum that would emerge from a spherically symmetric stellar wind. The stellar atmosphere model consists of a classical photosphere surrounded by an expanding region. The photospheric temperature decreases with radius following the Kurucz's 1979 model for $T_{eff} = 25000K$ and $logg = 4$. Outside the photosphere we consider the presence of a hot region where the temperature increases and reaches a maximum value of $40000K$ at $r = 2R_*$, then the temperature drops down up to a constant value ($T = 8000K$) in the outermost layers (Cidale & Ringuelet 1993).

Table 1. Polar and Equatorial Flows. The radii are in units of $R_*$ and terminal velocity $v_\infty$ is in km sec$^{-1}$.

| Polar Flow | | | | Equatorial Flow with Rotation | | | | |
|---|---|---|---|---|---|---|---|---|
| $f_{max}$ | $r_1$ | $r_{singular}$ | $v_\infty$ | $v_{rot}/v_{crit}$ | $f_{max}$ | $r_1$ | $r_{singular}$ | $v_\infty$ |
| 1.0 | 1.0 | 1.051 | 1450 | 0.8 | 1.0 | 1.0 | 23.11 | 466.7 |
| 1.5 | 1.0 | 1.038 | 1814 | 0.8 | 1.5 | 1.0 | 23.11 | 466.7 |
| 1.5 | 1.5 | 1.051 | 1825 | 0.8 | 1.5 | 1.5 | 23.11 | 485.1 |
| 1.5 | 2.5 | 1.051 | 1609 | 0.8 | 1.5 | 2.0 | 23.11 | 512.6 |

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We performed NLTE line profile calculations assuming that the outflow velocity field presents a spherical distribution which is described by the solution of the hydrodynamic equation in the polar or in the equatorial directions. The radiative transfer and the statistical equilibrium equations for multi level atoms are solved self-consistently in the co-moving frame following Mihalas & Kunasz (1978) scheme. The H atom model consist of 10 levels plus a continuum. The computed H$\alpha$ line profiles are plotted in Figure 2. The velocity structures derived from both polar and equatorial directions yield Balmer lines in absorption. Absorption lines are due to the low velocity gradients that prevail in regions next to the photosphere (Cidale & Ringuelet 1993). In Figure 1 we can note that the velocity structure, for $f_{max} = 1$ and $r_1 = 1$, presents the lowest velocity gradients and then its corresponding H$\alpha$ profile is the deepest. H$\alpha$ line profile is slightly distorted by wind effects when equatorial velocity distributions with larger $f_{max}$ are adopted.

Radiative transfer calculations for a non-spherical configuration could enhance emission features in the line, but these numerical methods are still in progress.

## 3. Conclusions

We have studied numerically the magnetic geometry influence upon radiation driven wind for a Be-star in both, the polar and equatorial directions. Our conclusions are: a) This magnetic geometry has almost no change the location of the singular point neither in the polar nor in the equatorial directions. b) Non-spherical expansion does not modify substantially the wind velocity profile. The magnetic geometry increases the terminal velocity, $v_\infty$ in about 400 $km\,sec^{-1}$ in the polar direction, and *only* 50 $km\ sec^{-1}$ in the equatorial direction, therefore the H$\alpha$ line shows quite insensitive. c) Numerical results for larger values of the $f_{max}$ and $r_1$ parameters suggest the existence of more singular points. Considering these results our main conclusion is that magnetic geometry does not affect the disk formation mechanism in Be-stars.

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