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Acceleration of winds of red supergiant stars

G. R. Cunha Sampaio[1], Y. F. Tamburus[1], N. F. S. Andrade[1], & V. Jatenco-Pereira[1]

[1] Instituto de Astronomia, Geofísica e Ciências Atmosféricas, São Paulo, SP
e-mail: guilhermerenato@usp.br, ytamburus@usp.br, natalia.fernanda.andrade@usp.br, vera.jatenco@iag.usp.br

Abstract. In the present work, we studied the influence of resonant damping of an Alfvén wave flux on accelerating the wind of red supergiant stars. We conclude that this mechanism satisfactorily matches observations, such that the final wind velocity is approximately half the escape velocity.

Resumo. Neste trabalho estudamos a influência do amortecimento ressonante de um fluxo de ondas Alfvén como mecanismo de aceleração do vento de estrelas supergigantes vermelhas. Concluímos que este mecanismo se adequa de forma satisfatória às observações de modo a velocidade final do vento ser da ordem da metade da velocidade de escape.

Keywords. winds – supergiants – plasmas

1. Introduction

Several studies in the literature deal not only with the diagnosis of mass loss but also with the construction of models to explain it. Jatenco-Pereira & Opher (1989) (JPO from now on) proposed a model for mass loss in red supergiant stars where the damping of an Alfvén wave flow, created in the turbulent region of the star acts as the principal wind acceleration mechanism.

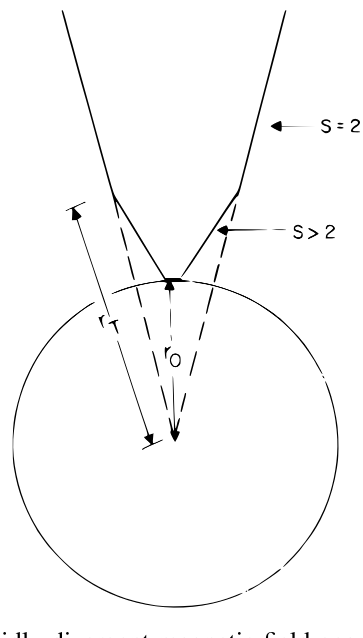

Figure 1. Rapidly divergent magnetic field geometry, where r_T defines the transition radius from divergent geometry $S > 2$ to radial $S = 2$, from JPO.

The proposed model is based on the geometry of the Sun's coronal holes, which, when observed in X-rays, reveal a rapidly diverging structure, as shown in Figure 1. Just like the work done in JPO, we used an Alfvén wave flux localized at the base of the stellar wind, propagating out of the star along the magnetic field lines. This waves are damped with damping length, L, transferring momentum for the plasma, accelerating it. Thus, the velocity profile is given by:

$$\frac{1}{u}\frac{du}{dr}\left[u^2 - V_T^2 - \frac{1}{4}\left[\frac{1+3M_A}{1+M_A}\right]\langle\delta v^2\rangle\right] = \frac{Z}{r}\left[V_T^2 + \frac{1}{4}\left[\frac{1+3M_A}{1+M_A}\right]\langle\delta v^2\rangle + \frac{1}{4}\frac{r}{L}\langle\delta v^2\rangle - \frac{1}{2Z}v_e^2\right], \quad (1)$$

where u is the velocity of the wind, V_T, thermal speed, M_A is the Alfvén Mach number given by $M_A = \frac{u}{V_A}$ (where V_A is the Alfvén velocity) and lastly, Z is a constant that takes the values for the divergent geometry as a function of the radius, as illustrated in Figure 1 whose dynamics are governed by the Equation 2:

$$Z = \begin{cases} S, & \text{for } r \leq r_T \\ 2, & \text{for } r > r_T. \end{cases} \quad (2)$$

Therefore, it was necessary to construct a numerical code to obtain the wind velocity profile provided by Equation 1.

2. Methodology and Procedures

Still following JPO, an isothermal wind model was used with the same objective: to reproduce the low terminal wind velocity of cold supergiant stars.

For the wave damping, we considered the resonant absorption of surface Alfvén waves (Lee & Roberts 1986), where within an inhomogeneity, such as a divergent geometry of an open magnetic field, there exists an Alfvén wave with frequency ω_2, and outside the inhomogeneity, an Alfvén wave with frequency ω_1, which is lower than ω_2, so assuming a linear variation of the wave frequency $\omega_A^2 = k^2 v_A^2(x)$, we have:

$$\omega_A^2 = \bar{\omega}^2 + \left(\omega_2^2 - \omega_1^2\right)\left(\frac{x}{2a}\right), \quad (3)$$

where $\bar{\omega}$ is given by:

$$\bar{\omega}^2 = \frac{\left(\omega_2^2 - \omega_1^2\right)}{2}, \quad (4)$$

and x is the distance along the inhomogeneity,which has width a. This implies the concentration of surface wave energy within a thin resonant layer, where we assume the energy is dissipated locally as heat over a damping length L.

We built a numerical code to solve the equation of motion and thus obtain the wind velocity profile. First, as a test, we applied the model to a $K5$ supergiant star with parameters proposed by Holzer, Fla & Leer (1983) and reproduced the velocity profile obtained by JPO. Then, we applied the model to the star *Alpha Orionis*, with parameters from Schuller et al. (2004), where according to observations, the terminal wind velocity, u, should be lower than the escape velocity, v_e, (Weymann 1962), with the results shown below.

3. Results

For Alpha Orionis, the physical parameters of the star are given in Table 1 .

Table 1. Initial physical parameters of *Alpha Orionis* from Schuller et al. (2004).

Parameter	Value	Unit
Radius	608.3 $R_\odot$	cm
Mass	10 $M_\odot$	g
Temperature	3640	K
ρ	6×10^{-13}	$g\ cm^{-3}$
B	10	G
L_0	0.2	r_0
ϕ	3×10^6	$erg\ cm^{-2}\ s^{-1}$
v_e	79.2	km/s

Using the parameters given in Table 1 , we show in Figure 2 the wind velocity profile for $S = 4.8$ and we obtained a terminal wind velocity $u_\infty = 51.3\ km\ s^{-1}$ satisfying the condition $u_\infty < v_e$.

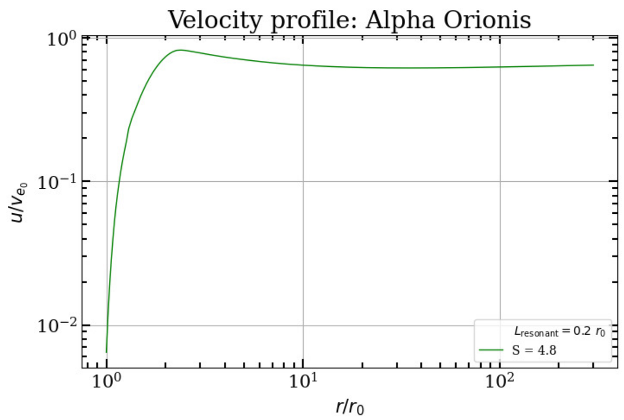

Figure 2. Wind velocity (u) profile of *Alpha Orionis* star accelerated by an Alfvén wave flux.

Finally, we obtained the stellar wind velocity profiles for the same L_0, but using a different parameters for the geometry opening S, for demonstrating the importance of rapidly divergent geometry for the wind final velocity, resulting in a terminal velocity of: 68.98 $km\ s^{-1}$, still following the physical condition $u_\infty < v_e$, as shown in Figure 3.

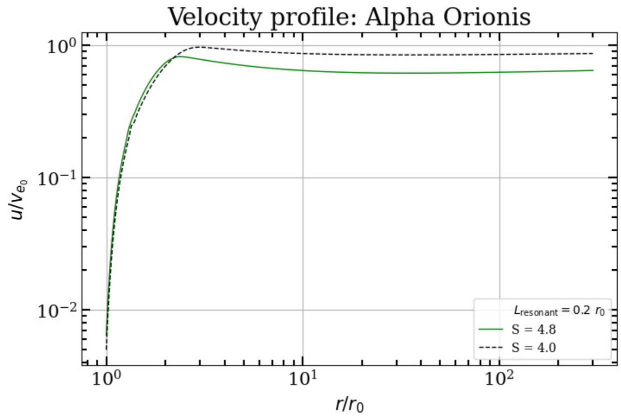

Figure 3. Wind velocity (u) profile of *Alpha Orionis* star for $S = 4.0$ (dashed line) and S=4.8 (solid line).

4. Conclusions

We applied the model of stellar wind acceleration by an Alfvén wave flux to the star *Alpha Orionis*. The model uses a divergent geometry for the magnetic field, as observed in the Sun, and resonant damping of surface Alfvén waves as the acceleration mechanism. The results are consistent with the observations $u_\infty < v_e$. We also show the importance of the divergent field geometry for the terminal wind velocity, by decreasing it, we obtain an increasingly higher final velocity.

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