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The slow winds of A-type supergiants

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Abstract. The line driven- and rotation modulated-wind theory predicts an alternative *slow* solution, besides from the standard m-CAK solution, when the rotational velocity is close to the critical velocity. We study the behaviour of the winds of A-type supergiants (Asg) and show that under particular conditions, e.g., when the δ line-force parameter is about 0.25, the slow solution could exist over the whole star, even for the cases when the rotational speed is slow or zero. We discuss density and velocity profiles as well as possible observational conterparts.

Keywords. stars: supergiants, stars: winds, outflows, stars: mass loss

1. Introduction

The theory of radiation driven winds (CAK, Castor *et al.* 1975) and later m-CAK (Pauldrach *et al.* 1986) succeeded in describing terminal velocities (V_∞) and mass losses ($\dot{M}$) of hot stars apart from predicting the wind momentum luminosity (WML) relationship. This relationship was empirically found for the most of luminous O-type stars (Puls *et al.* 1996) and extended to lower luminosity objects by Kudritzki *et al.* (1999), who found that it depends on the spectral type. Particularly, Asg show V_∞ values a factor 3 lower than theoretical ones (Achmad *et al.* 1997) and V_∞ decreases when increasing the escape velocity (V_{esc}) (Verdugo *et al.* 1998a), in clear contradiction with the CAK theory (fast solution). Moreover, Kudritzki *et al.* (1999) found that Hα profile of these stars can be modeled with β velocity laws, for $\beta > 1$. These observational discrepancies with CAK and m-CAK theories could be related to a change in the parameter α along the wind due either to a change in the ionization of the wind or to a decoupling of the line-driven ions in the wind from the ambient gas (Achmad *et al.* 1997). In 2004, Curé (2004) revisited the theory of steady fast-rotating line-driven winds and found that for $\omega = V/V_{crit} > 70\%$ there exists another hydrodynamical or *slow* solution, which is denser and slower than the standard m-CAK solution. For B-type stars he obtained velocity distributions, as well as the critical point and $\dot{M}$, that can be matched by a velocity law with $\beta > 1$. Therefore, we propose here that the winds of Asg could be related to the *slow*

Table 1. Stellar and Wind Parameters

Mod	Teff [K]	log g	R [$R_\odot$]	ω	α	k	δ	α_{eff}	$V\infty_{pol}$ [km s^{-1}]	$F_{m,pol}$ [$M_\odot$/(yr sr)]	$V\infty_{eq}$ [km s^{-1}]	$F_{m,eq}$ [$M_\odot$/(yr sr)]	$\dot{M}$ [$M_\odot$/yr]
1 (s)	13000	1.73	68	0.4	0.51	0.03	0.23	0.28	160	4.78×10^{-5}	142	5.78×10^{-5}	6.41×10^{-4}
2 (f)	10000	2.0	60	0.4	0.49	0.07	0.15	0.34	350	1.14×10^{-5}	291	1.54×10^{-5}	1.59×10^{-4}
3 (s)	10000	2.0	60	0.4	0.49	0.07	0.26	0.23	207	9.79×10^{-8}	181	1.21×10^{-7}	1.32×10^{-6}
4 (s)	9500	1.7	80	0.4	0.49	0.07	0.26	0.23	168	5.94×10^{-7}	149	7.40×10^{-7}	8.04×10^{-6}
5 (s)	9000	1.7	100	0.4	0.49	0.07	0.26	0.23	188	3.08×10^{-7}	165	3.84×10^{-7}	4.18×10^{-6}
6 (s)	9000	1.7	120	0.4	0.49	0.07	0.26	0.23	206	3.57×10^{-7}	178	4.49×10^{-7}	4.87×10^{-6}

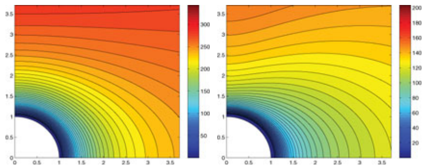

Figure 1. Wind velocity distributions. Left: Model 2 (Fast). Right: Model 3 (Slow).

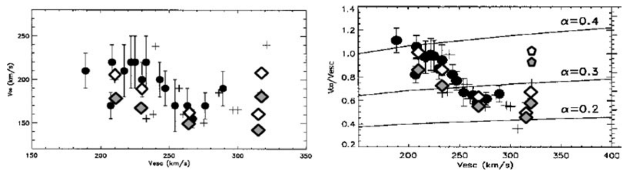

Figure 2. The white/grey romboids (penthagons) correspond to equator/pole slow (fast) solutions, black symbols correspond to Figs. 2 and 3 of Verdugo et al. (1998b).

hydrodynamical solutions described by Curé (2004). We demonstrate numerically that for Asg, given a particular set of wind parameters, k, α and δ, there exists a *slow solution* at all latitudes for low rotational velocities ($\omega < 0.4$), and even for the non-rotating case.

2. Results and Conclusions

We calculated numerically wind solutions for different rotational velocities and different stellar and wind parameters. Table 1 lists some of the models we computed for low values of ω: those marked with an "s" in the first column present a slow solution at all latitudes, while the remaining corresponds to the fast solution at all latitudes ("f"). Figure 1 displays the behaviour of the fast and slow solutions as a function of latitude for models with the same stellar and wind parameters, except δ. $\dot{M}$ and V_∞ obtained with models 1, 3, 4, 5 and 6 are in good agreement with those observed in Asg (Verdugo *et al.* 1998a; Kudritzki *et al.* 1999). Instead, the fast solution leads to higher $\dot{M}$ and V_∞. We find that the solutions for slow winds (see Figure 2, in white/grey romboids) match observational data of some Asg stars (black symbols, Verdugo *et al.* 1998b).

By solving the 1-D hydrodynamic equation of rotating line-driven winds of Asg for different sets of line force parameters, we found a slow wind regime over all latitudes when increasing the parameter δ, which describes changes in the ionization stage of the wind. These slow solutions trace the observational trends found by Verdugo *et al.* (1998a). Our result supports these authors' hypothesis, stating that the negative slope of V_∞/V_{esc} vs. V_{esc} could be related to the degree of ionization and wind density.

References

Achmad, L., Lamers, H. J. G. L. M., & Pasquini, L. 1997, *A&A*, 320, 196

Castor, J. I., Abbott, D. C., & Klein, R. I. 1975, *ApJ*, 195, 157

Curé, M. 2004, *ApJ*, 614, 929

Kudritzki, R. P., Puls, J., Lennon, D. J., Venn, K. A. *et al.* 1999, *A&A*, 350, 970

Pauldrach, A., Puls, J., & Kudritzki, R. P. 1986, *A&A*, 164, 86

Puls, J., Kudritzki, R.-P., Herrero, A., Pauldrach, A. W. A. *et al.* 1996, *A&A*, 305, 171

Verdugo, E., Talavera, A., & Gmez de Castro, A. I. 1998a, *Ap&SS*, 263, 263

Verdugo, E., Talavera, A., & Gmez de Castro, A. I. 1998b, in: W. Wamsteker, R. Gonzalez Riestra & B. Harris (eds.), *Ultraviolet Astrophysics Beyond the IUE Final Archive*, ESA-SP 413, p. 293