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Thresholds for the Dust Driven Mass Loss from C-rich AGB Stars

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Abstract. It is well established that mass loss from AGB stars due to dust driven winds cannot be arbitrarily low. We model the mass loss from carbon rich AGB stars using detailed frequency-dependent radiation hydrodynamics including dust formation. We present a study of the thresholds for the mass loss rate as a function of stellar parameters based on a subset of a larger grid of such models and compare these results to previous theoretical work. Furthermore, we demonstrate the impact of the pulsation mechanism and dust formation for the creation of a stellar wind and how it affects these thresholds and briefly discuss the consequences for stellar evolution.

Keywords. stars: AGB and post-AGB, atmospheres, mass loss

1. Why a Mass Loss Threshold?

As shown by, e.g., Gail & Sedlmayr (1987), Dominik *et al.* (1990) and appearent in the detailed models by Höfner *et al.* (2003) as well, a dust-driven stellar wind cannot be maintained down to arbitrarily small ratio of radiative to graviational acceleration $\Gamma_{\rm d}$. For a "polytropic wind" one may derive an analytical expression for the terminal wind velocity,

$$v_\infty^2 \approx \frac{1}{2}\Delta v_{\rm p}^2 + \left(\frac{2}{\gamma-1}\right)\bar{c}_s^2(R_{\rm in}) + \bar{v}_{\rm esc}^2(R_{\rm c})\left[\bar{\Gamma}_{\rm d} - \frac{R_{\rm c}}{R_{\rm in}}\right], \tag{1.1}$$

where γ is the polytropic index, $R_{\rm c}$ is the characteristic radius at which dust starts to condense, $\bar{v}_{\rm esc}^2(R_{\rm c})$ is the average escape velocity at $R_{\rm c}$, $\bar{c}_s^2(R_{\rm in})$ is the average sound speed at the inner boundary of the model (located at $R_{\rm in} \sim R_\star$) and $\Delta v_{\rm p}$ is the "piston amplitude", i.e. the strength of the pulsations (Mattsson 2006). The equation above captures the general trend of v_∞ with $\Gamma_{\rm d}$ and predicts a threshold at $\Gamma_{\rm d} \approx 0.8$ for reasonable values of the model parameters (see Fig. 1, left panel).

We have used our RHD code for dynamic stellar atmospheres of carbon-rich AGB stars (described in Höfner *et al.* 2003, Mattsson 2006), including frequency-dependent radiative transfer and dust formation, to explore the relations between basic stellar parameters and a dust-driven stellar wind. Here we present results from the computation of a grid of wind models at solar metallicity. An associated library of dynamic spectra is under development (see the poster by Wahlin *et al.*).

A mass loss threshold appears as one would expect from Eq. (1.1) and we find that below a critical C/O and/or above a critical $T_{\rm eff}$ no dust driven wind can be formed. All other stellar parameters were kept fixed in these models. We also see a rather strong dependence on C/O for both the wind velocity and the mass loss rate, which is quite interesting in comparison with previous studies of this kind. Arndt *et al.* (1997) as well as Wachter *et al.* (2002) find a weak dependence on C/O, which stands in sharp contrast to the results presented here. However, our findings here (as well as in Höfner *et al.* 2003) are, qualitatively speaking, hardly a new discovery. Höfner and Dorfi (1997) and Winters

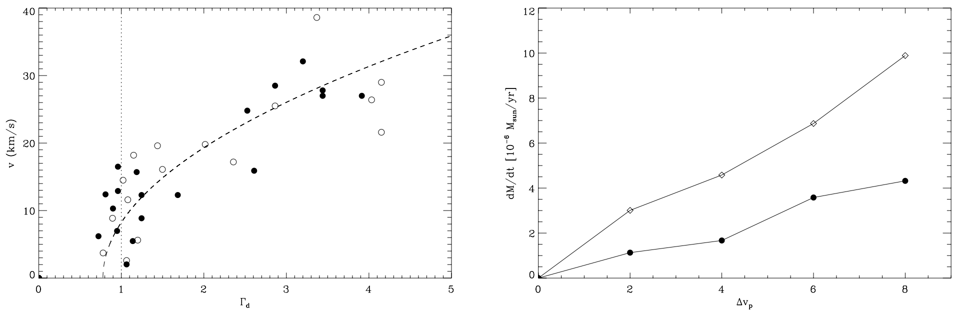

Figure 1. Left: Wind velocity (in km s^{-1}) as function of the acceleration parameter $\Gamma_{\rm d}$ for all models of the sub-grid calculated with $M_\star = 1M_\odot$, $Z = Z_\odot$ and $\Delta v_{\rm p} = 4.0$ km s^{-1}. Black dots represent models with $\Delta v_{\rm p} = 4.0$ km s^{-1} and circles represent models with $\Delta v_{\rm p} = 6.0$ km s^{-1}. The dashed curve shows an analytical model with $\gamma = 7/6$, $M_\star = 1M_\odot$, $R_\star = 3.5 \cdot 10^{13}$ cm, $R_{\rm in}(0) = 0.9R_\star$, $R_{\rm c} = 2.5R_\star$ and $c_s(R_{\rm in}) = 7.0$ $\rm kms^{-1}$. Right: The mass loss rate as a function of the piston amplitude. Black dots represents the case where $L_\star = 7100L_\odot$ and diamonds represents $L_\star = 10000L_\odot$.

et al. (2000) have already pointed out the strong C/O-dependence, especially in the critical wind regime, although this has not been widely recognised. Furthermore, there is a linear dependence of the mass loss rate on the piston amplitude, i.e. $\dot{M} \propto \Delta v_{\rm p}$ (see Fig. 1, right panel). The trend is strong enough to make $\Delta v_{\rm p}$ significant in parametric prescriptions of the mass loss rate.

2. Conclusions

The results from our new detailed grid of wind models at solar metallicity suggests that C-stars with strong winds may actually be a rare species. How would this affect models of stellar evolution, nucleosynthesis and, consequently, models of chemical evolution of galaxies? We want to make the following points:

• The strength of the pulsations and the C/O-ratio are *not* redundant parameters in a mass loss prescription.

• It may be dangerous to use parametric mass loss formulae including too few stellar parameters and extrapolate beyond the range of stellar parameters used obtain the formula.

• The mass loss rate depends strongly on the efficiency of dust formation, which cannot simply be parameterised in terms of the basic stellar parameters: mass, luminosity and temperature, only.

• **There exists a threshold for dust-driven winds which has previously been neglected in mass loss prescriptions and thus not included in models of stellar evolution!**

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