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THREE-COMPONENT MODELING OF C-RICH AGB STAR WINDS

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RESUMEN

Las estrellas AGB son sistemas complejos con procesos interactuantes de radiación, gas y polvo que un modelo preciso debe describir adecuadamente. Nuestro modelo de viento se basa en una hidrodinámica radiativa dependiente del tiempo combinada con un componente de polvo de carbono representado por las llamadas ecuaciones de momento. El modelo hace posible estudiar las propiedades de un viento estelar incluyendo el desplazamiento entre las fases de gas y polvo. Presentamos los resultados actuales de nuestros cálculos de tres componentes y discutimos las consecuencias para la estructura del viento y la pérdida de masa.

ABSTRACT

The AGB stars are complex systems with interacting radiation, gas and dust processes, all of which an accurate model has to describe properly. Our wind model is based on time-dependent radiation-hydrodynamics combined with a carbon dust component represented by so-called moment equations. The model makes it possible to study the properties of a stellar wind including drift between the gas and dust phases. We present current results of our three-component calculations and discuss the consequences for the wind structure and the mass loss.

Key Words: **HYDRODYNAMICS — INSTABILITIES — RADIATIVE TRANSFER — STARS: AGB AND POST-AGB — STARS: MASS-LOSS**

1. INTRODUCTION

When low- to intermediate-mass stars ascend the asymptotic giant branch (AGB) they pass through a violent period characterized by complex interacting processes between e.g., pulsations, shock formation, dust formation and heavy mass loss. This phase does not end before the star has lost most of its envelope and has affected not only its neighborhood but also (in the long-term perspective) the interstellar medium and the galactic chemical evolution; hence the importance of understanding the consequences of the interactions.

Due to the complexity of AGB stars, it is currently not possible to make a theoretical model of the full star, but one has to pinpoint the most important aspects. In the case of dust-driven wind models these are normally assumed to be the dust formation, pulsations and the dynamic evolution of the wind, cf. Figure 1. An aspect which is often discussed in this context is the importance of drift, i.e., the gas and the dust are allowed to move relative to each other. In this article we present new models where drift is self-consistently included in the calculations. Before we compare the results of a drift model with a non-drift model in § 3 we briefly summarize the physical assumptions we use in § 2. The conclusions are presented in § 4.

2. PHYSICS OF THE WIND DRIVING MECHANISM

The physics discussed here presents only a glimpse of the complete AGB wind model. For a detailed discussion of physical assumptions, the numerical method and the modeling method we refer to Sandin & Höfner (2003a).

We consider three physical components in our dust-driven AGB star wind model: the gas, the radiation field, and the dust. The dust is assumed to be a collisionless medium composed of spherical dust grains in the form of amorphous carbon. Furthermore, the average dust properties are given by moments of the dust-size distribution function. In the description of the dust formation, the processes of nucleation, growth, evaporation and chemical sputtering (by gas particles) are taken into account. A time-dependent treatment of the dust formation is important since the corresponding timescales are comparable to, or longer than, the relevant dynamical and thermodynamical timescales in the wind.

Physical interactions couple the gas, radiation field and dust components; Figure 2 shows a schematic of the transfer of mass, momentum, and energy involved in the wind. The most important process in the wind formation is the transfer of momentum from the radiation field via the dust to the

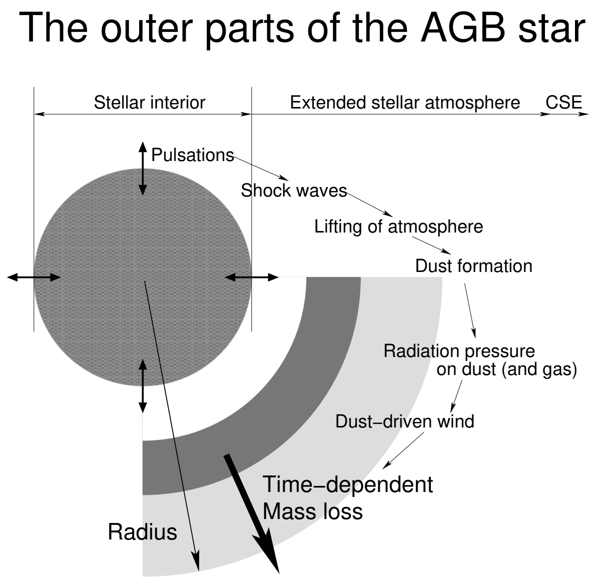

Fig. 1. A sketch of the AGB star showing the processes that form the dust-driven stellar wind. The modeled region, extending out to about $30\,R_*$, is a part of the extended stellar atmosphere and contains both the photosphere and the dust formation region.

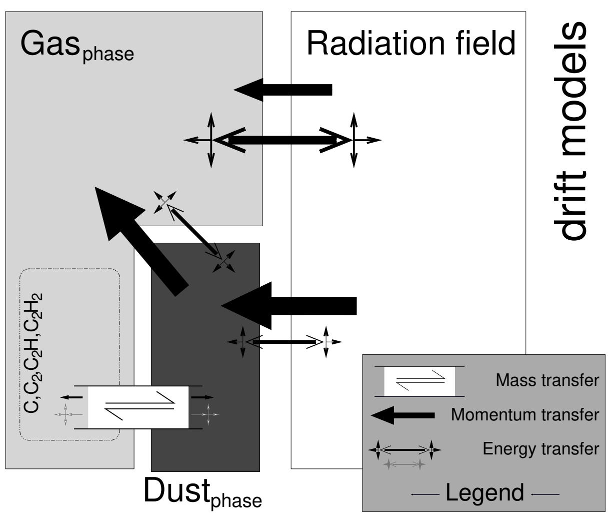

Fig. 2. Transfer of mass, momentum and energy between the three wind components of gas, dust and radiation field in the cool dust-driven stellar wind.

gas. In drift models the momentum transfer between the gas and the dust is determined in a coupling of the radiative pressure on the dust grains and the drag force between dust grains and gas particles. In non-drift models all the dust momentum is immediately transferred to the gas and the dust and gas are assumed to move at the same velocity.

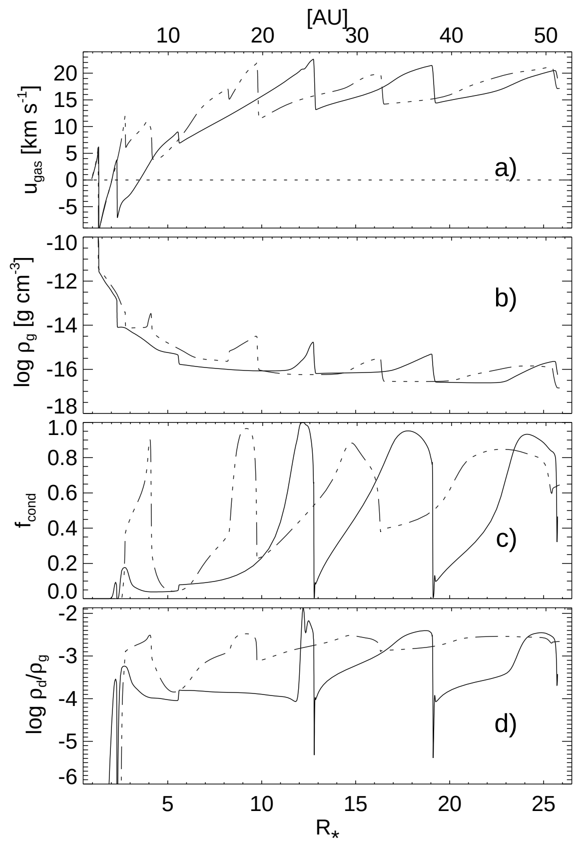

Fig. 3. Radial structure plot showing an instant of model R10FU2C16 (see text). The drift model is represented by the solid line and the non-drift model by the dash-dot-dotted line. (a) the gas velocity $u_{\rm gas}$; (b) the gas density $\rho_{\rm g}$; (c) the degree of condensation $f_{\rm cond}$; (d) the dust/gas density ratio $\rho_{\rm d}/\rho_{\rm g}$. The accumulation of dust in the region behind gas shocks in drift models is seen together with the larger variations of the drift model in the lowermost panel showing the dust/gas density ratio.

3. DRIFT MODELS VS. NON-DRIFT MODELS

The consequences of permitting drift between the gas and the dust become evident when drift models and non-drift models are compared. In Figure 3 we show a radial plot at one instant of both a drift model and a non-drift model. Compared to the drift models presented in Sandin & Höfner (2003a), the current drift model is computed using an improved numerical scheme (adopting a second order advection). The model (R10FU2C16) is computed with the stellar parameters: $L_* = 1\times10^4\,L_\odot$, $M_* = 1.0\,M_\odot$, $T_* = 2790\,{\rm K}$. In addition, the carbon/oxygen abundance ratio is specified as $\varepsilon_{\rm C}/\varepsilon_{\rm O} = 1.6$. Stellar pulsations are simulated using a piston with the period $P = 525$ days and amplitude $\Delta u_{\rm p} = 2\,{\rm km\,s^{-1}}$. The same

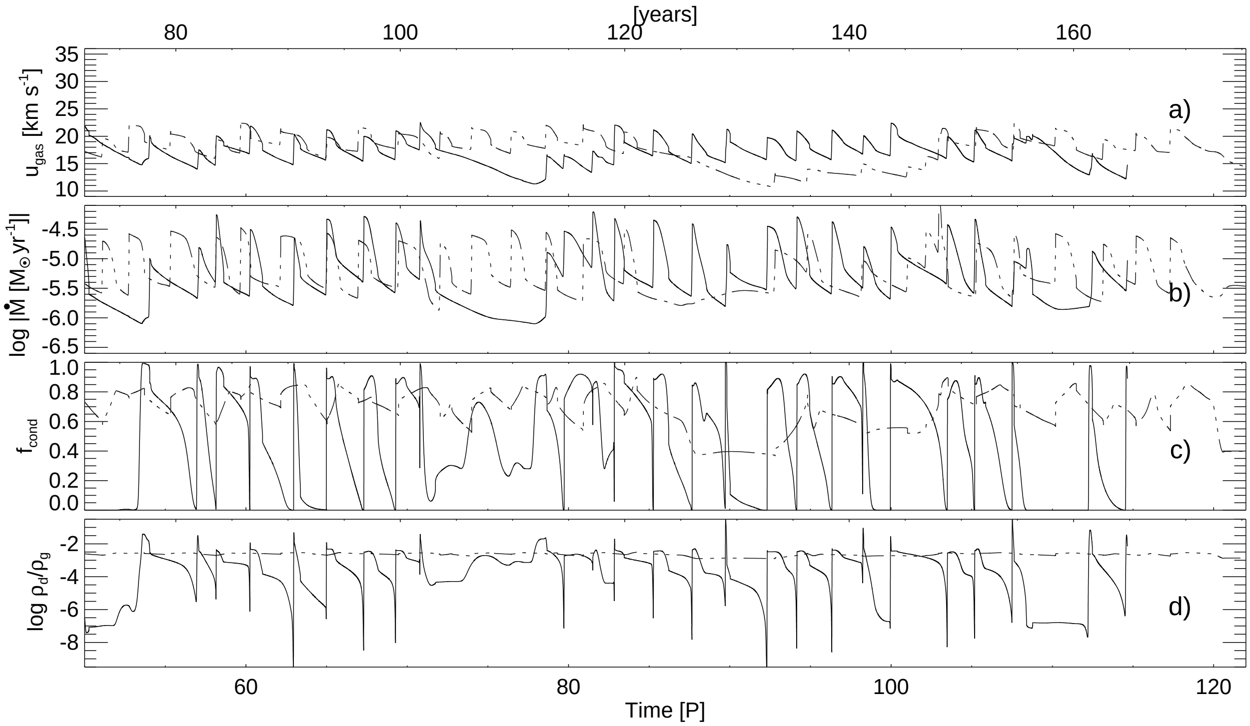

Fig. 4. Temporal structure plot of model R10FU2C16 (see text) at the outer boundary. The drift model is shown with a solid line and the non-drift model with a dash-dot-dotted line: (*a*) the terminal velocity u_∞; (*b*) the mass loss rate $\dot{M}$; (*c*) the degree of condensation $f_{\rm cond}$; and (*d*) the dust/gas density ratio $\rho_{\rm d}/\rho_{\rm g}$. Note the larger variations of the drift model in the average properties in the two lower panels, also see the corresponding panels in Fig. 3.

parameters were used in the non-drift model R10C16 in Höfner & Dorfi (1997).

In drift models the individual dust grain tends to move to regions where the interaction with the gas is strong. A consequence of this is that the dust is accumulated in the dense regions behind shocks, see the plots of the degree of condensation and dust/gas density ratio in Figs. 3*c* and *d*. Note that the regions between the shocks are more clearly depleted of dust in the drift model. Differences are not evident in the plots of the gas velocity and the gas density.

The effects of the accumulation can also be seen in the temporal evolution at the outer boundary (Figure 4). The drift model shows much larger variations throughout the full time-period shown in the dust properties (two lowermost panels). For the current model parameters the larger variations result in average outflow quantities that are lower than the corresponding non-drift model quantities (not easily seen in the figure).

For a detailed discussion of these results we refer to Sandin & Höfner (2003b).

4. CONCLUSIONS

We have looked at the influence of drift between gas and dust in a dust-driven AGB star wind model. The computation of a wind model allowing drift requires both a proper physical and numerical description of the gas-dust interaction terms.

When drift is taken into account, the dust tends to move to dense regions in the wind where the gas-dust interaction is strong, i.e., the dust accumulates in regions behind shocks. The consequence of the redistribution of the dust is a larger temporal variation in the wind properties, in particular in those describing the dust. The influence of drift on the wind models is intricate and no simple rules can be given to convert the results of models without drift to include these effects.

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