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Headwind: Modelling Mass Loss of AGB Stars, Against All Odds

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Abstract. The intricate interplay of atmospheric shock waves and a complex, variable radiation field with non-equilibrium dust formation presents a considerable challenge to self-consistent modelling of atmospheres and winds of AGB stars. Nevertheless it is clear that realistic models predicting mass loss rates and synthetic spectra are crucial for our understanding of this important phase of stellar evolution. While a number of questions are still open, significant progress has been achieved in recent years. In particular, self-consistent models for atmospheres and winds of C-stars have reached a level of sophistication which allows direct quantitative comparison with observations. In the case of stars with C/O < 1, however, recent work points to serious problems with the dust-driven wind scenario. This contribution analyzes the basic ingredients of this scenario with analytical estimates, focusing on dust formation, non-grey effects, and differences between C-rich and O-rich environments, as well as discussing the status of detailed dynamical wind models and current trends in this field.

1. Introduction

Mass loss is one of the most pronounced features of AGB stars, influencing both their evolution and their observable properties in a decisive way. The most commonly accepted scenario is that of a pulsation-enhanced dust-driven wind: stellar pulsation causes atmospheric shock waves which intermittently lift gas above the stellar surface, creating dense, cool layers where solid particles form. The dust is accelerated away from the star by radiation pressure, dragging the gas along. The composition of the grains is determined by the relative elemental abundances in the atmosphere, with C-rich stars forming mostly amorphous carbon grains, and O-rich objects producing silicate dust.

Current knowledge suggests that winds of C-rich AGB stars are rather well understood. For their numerous O-rich counterparts, however, recent work demonstrates that the opacities of silicate grains are insufficient for driving winds (Woitke 2006a and this volume), contrary to previous expectations. This problem becomes apparent with the introduction of frequency-dependent radiative transfer in time-dependent models with a detailed description of dust formation. Ironically, this important step towards more realistic models which brought C-rich models into good agreement with observations, causes serious problems with the wind mechanism in O-rich stars.

The core of this issue can be understood with comparatively simple analytical arguments. A significant part of this review is devoted to isolating the crucial ingredients and analyzing them with simplified analytical descriptions, in particular non-equilibrium dust formation, with special attention to the influence of non-grey effects and differences between C-rich and O-rich stars. These simple estimates are compared to the results of existing numerical models, rounding up with an overview of the present status of such detailed models, and current trends.

Detailed comparisons of the input physics of various numerical models and summaries of the historical developments in this field can be found in earlier reviews, e.g., by Willson (2000), Woitke (2003) and Höfner (2005).

2. Basic ingredients and characteristic numbers

Dust grains forming in the extended atmospheres of AGB stars condense under non-equilibrium conditions with temperature acting as a threshold, prevailing densities and abundances determining the efficiency of grain growth, and pulsation and shock waves setting the time scales. In other words, condensation will usually be incomplete, and the dust-to-gas ratio is not a simple function of abundances.

2.1. Grain temperature and condensation radius

A prerequisite for condensation or survival of existing grains are temperatures below the stability limit of a specific condensate. In principle, a distinction between the respective temperatures of ambient gas and grains has to be made. In practice, however, gas temperatures tend to be lower than grain temperatures at a given point, and therefore the limit will usually be defined by the grain temperatures which, in turn, are given by radiative equilibrium, i.e.

$$\int_0^\infty \kappa_\lambda B_\lambda(T_d)\, d\lambda = \int_0^\infty \kappa_\lambda J_\lambda\, d\lambda \tag{1}$$

Using the assumption of a Planckian radiation field (with stellar surface temperature T_* at R_*), geometrically diluted according to distance from the stellar surface

$$J_\lambda = W(r)\, B_\lambda(T_*) \qquad W(r) = \frac{1}{2}\left(1 - \sqrt{1 - \left(\frac{R_*}{r}\right)^2}\right) \tag{2}$$

in the equation of radiative equilibrium, the grain temperature T_d as a function of distance from the star can be estimated if the wavelength-dependent opacity of the dust particles κ_λ is known. The latter can often be approximated in the critical wavelength region around the stellar flux maximum by $\kappa_\lambda \propto \lambda^{-p}$ where the exponent p is characteristic of the grain material, leading to

$$W(r) = \frac{\int_0^\infty \kappa_\lambda B_\lambda(T_d)\, d\lambda}{\int_0^\infty \kappa_\lambda B_\lambda(T_*)\, d\lambda} = \left(\frac{T_d}{T_*}\right)^4 \frac{\kappa_\lambda^{\rm Planck}(T_d)}{\kappa_\lambda^{\rm Planck}(T_*)} = \left(\frac{T_d}{T_*}\right)^{4+p} \tag{3}$$

where the superscript 'Planck' denotes a Planck mean of the opacity (see, e.g., Lamers & Cassinelli 1999 for details). The condensation radius r_c, defined as the point where the grain temperature T_d is equal to the condensation temperature

T_c (stability limit) of the respective grain material, is therefore given by

$$\frac{r_c}{R_*} = \frac{1}{2}\left(\frac{T_c}{T_*}\right)^{-\frac{4+p}{2}} \tag{4}$$

where we have used the approximation $W(r) \approx (R_*/2r)^2$ for $r \gg R_*$.

Therefore, to determine the location where condensation may start for a particular material, we need to know its condensation temperature and the dependence of the opacity on wavelength around the flux maximum. For amorphous carbon grains we have $T_c \approx 1500\,\mathrm{K}$ and $p \approx 1$. Assuming a stellar surface temperature of $T_* \approx 3000\,\mathrm{K}$ we obtain $r_c/R_* \approx 3$ which is in good agreement with detailed frequency-dependent models where dust usually forms at $2-3\,R_*$.

For silicate grains the picture is more complicated. To illustrate the problem, we consider olivine, i.e. a material with the composition $\mathrm{Mg}_{2x}\mathrm{Fe}_{2(1-x)}\mathrm{SiO}_4$ ($0 \leq x \leq 1$) and a condensation temperature of $T_c \approx 1000\,\mathrm{K}$ in the relevant density range. On the one hand, the lower value of $T_d/T_* \approx 1/3$ (compared to $\approx 1/2$ for carbon grains) leads to a stronger dependence of r_c/R_* on p (see Fig. 1). On the other hand, the value of p varies strongly with the relative Fe-content (x) of the material, with larger (more positive) values of p for iron-rich grains. For forsterite ($\mathrm{MgSiO_4}$), representing one end of the chemical spectrum, lab data indicates $p \approx -1$ in the relevant wavelength rage (see Fig. 2 in Andersen, this volume). For $\mathrm{MgFeSiO_4}$ (with equal amounts of Mg and Fe, corresponding roughly to solar composition) the value is closer to $p \approx 2$. Therefore forsterite may condense at a distance of $\approx 3\,R_*$ while $\mathrm{MgFeSiO_4}$ will probably not form closer to the star than $\approx 14\,R_*$. Already these first estimates lead us to expect that silicate grains forming in AGB stars will tend to be iron-poor, a conclusion which is supported by other arguments and detailed modelling (see below).[1]

2.2. Dust opacity, shock waves and wind regimes

Assuming for the moment that a certain dust species will actually form beyond its condensation radius, will the grains significantly contribute to driving a wind? This is, of course, a matter of the corresponding opacity produced by the grains. If we can assume that gravity and radiation pressure are the only relevant forces beyond r_c, the (co-moving) equation of motion for a matter element can be written as

$$\frac{du}{dt} = -g_0\left(\frac{r_0}{r}\right)^2 (1-\Gamma) \qquad \text{with} \qquad \Gamma = \frac{\kappa_H L_*}{4\pi c G M_*} \tag{5}$$

where r is the distance from the stellar center, u the velocity, $g_0 = GM_*/r_0$ denotes the gravitational acceleration at the (arbitrary) point r_0, κ_H the flux mean opacity, and M_* and L_* are the stellar mass and luminosity, respectively (all constants have their usual meaning). The material properties (and relative abundances) of the dust species determine the value of Γ which, in turn, determines the further dynamics of the matter element. Several special cases are immediately apparent:

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[1] Similar arguments hold for pyroxenes, another possibly abundant grain material, with a composition $\mathrm{Mg}_x\mathrm{Fe}_{(1-x)}\mathrm{SiO}_3$ ($0 \leq x \leq 1$).

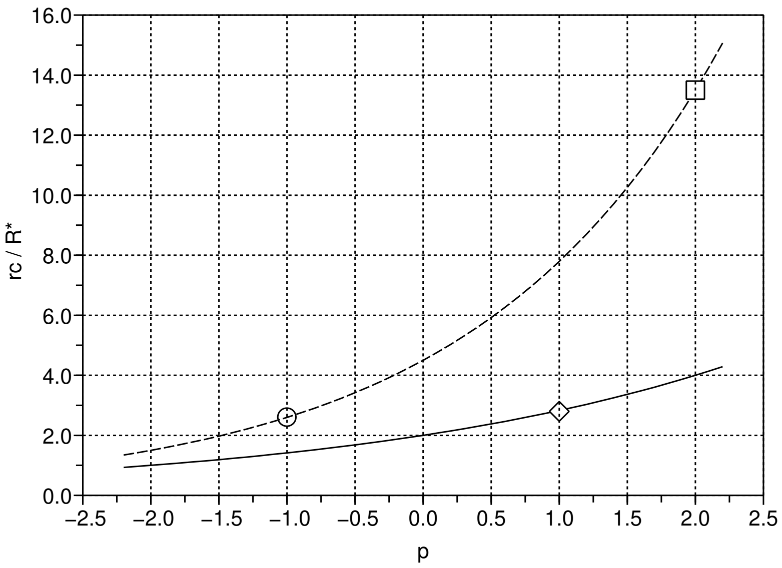

Figure 1. Condensation radius (in units of stellar radius) as a function of p. The lower curve corresponds to $T_c/T_* = 1/2$ (representative of carbon grains; full line) and the upper curve to $T_c/T_* = 1/3$ (characteristic of silicates; dashed). The symbols show the approximate location of various materials in this diagram (diamond: amorphous carbon; circle: Mg_2SiO_4; square: $MgFeSiO_4$). Models with grey radiative transfer (or grey dust opacities) correspond to $p = 0$.

- If no (or very little) dust is forming, Γ will be (close to) zero. The matter element will follow a ballistic trajectory, according to its initial velocity,[2] reaching a maximum distance $r_{\max}$ of

$$\frac{r_0}{r_{\max}} = 1 - \left(\frac{u_0}{u_{\rm esc}}\right)^2 \qquad \text{where} \qquad u_{\rm esc} = \sqrt{\frac{2GM_*}{r_0}} \tag{6}$$

  and then falling back towards the stellar surface.

- If $\Gamma = 1$, the r.h.s of the equation of motion vanishes. The matter element continues to move at a constant velocity.

- If $\Gamma > 1$, du/dt is positive, the matter is accelerated away from the star.

- If $0 < \Gamma < 1$, the final fate of the matter element (escape or fall-back) depends on the velocity at which it is moving when it reaches r_c.

The dynamical behavior in the regime $0 < \Gamma < 1$ can be investigated with the following simplified model: if we assume that Γ is constant outside r_c (and

[2]In the discussion here we always assume that the velocity before reaching the dust condensation radius is below the escape velocity. Otherwise it would be misleading to talk about a dust-driven wind.

zero inside), the factor $(1-\Gamma)$ is a constant that can be multiplied with g_0, resulting in an equation of motion

$$\frac{du}{dt} = -g_\Gamma \left(\frac{r_0}{r}\right)^2 \qquad \text{with} \qquad g_\Gamma = g_0\,(1-\Gamma) \tag{7}$$

which formally looks like the ballistic equation of motion for $\Gamma = 0$, but with a re-scaled gravitational acceleration g_Γ, and therefore a re-scaled (lower) escape velocity $u_{\rm esc}^\Gamma = \sqrt{2GM_*(1-\Gamma)/r}$. Consequently, the actual velocity of the matter element when reaching r_c may be above $u_{\rm esc}^\Gamma$ (while still being below the escape velocity without dust), resulting in a wind.

To find the critical case that divides fall-back from outflow, we assume that the velocity prior to condensation is only due to the pulsation-induced shocks propagating through the atmosphere. We use the simplified picture that a shock passing through the matter element under consideration can be treated as an instantaneous acceleration to a velocity u_0 at the point r_0 (which will in practice be close to R_*), followed by a ballistic movement of the shocked gas. We consider the solution of the ballistic equation of motion ($\Gamma = 0$) for $r \leq r_c$, requiring that the velocity at the point r_c matches $u_{\rm esc}^\Gamma$, i.e.,

$$u_0^2 - u^2(r_c) = -2GM_* \left(\frac{1}{r_c} - \frac{1}{r_0}\right) \qquad \text{and} \qquad u^2(r_c) = \frac{2GM_*}{r_c}\,(1-\Gamma)\ . \tag{8}$$

For $0 < \Gamma < 1$ we can therefore distinguish two cases:

- a pulsation-supported dust-driven wind regime for

$$1 > \Gamma > \frac{r_c}{r_0}\left(1 - \left(\frac{u_0}{u_{\rm esc}}\right)^2\right) \qquad \text{or} \qquad 1 > \frac{u_0}{u_{\rm esc}} > \sqrt{1 - \Gamma\left(\frac{r_0}{r_c}\right)} \tag{9}$$

- a 'parachute regime' (decelerated fall-back) for

$$\frac{r_c}{r_0}\left(1 - \left(\frac{u_0}{u_{\rm esc}}\right)^2\right) > \Gamma > 0 \qquad \text{or} \qquad \sqrt{1 - \Gamma\left(\frac{r_0}{r_c}\right)} > \frac{u_0}{u_{\rm esc}} > 0 \tag{10}$$

Assuming that $r_0 \approx R_*$ and, consequently, $u_0/u_{\rm esc} \approx (u_{\rm shock}/u_{\rm esc})_{\rm r=R_*}$ the condition for a pulsation-supported dust-driven outflow can be reformulated in the more convenient form

$$\left(\frac{u_{\rm shock}}{u_{\rm esc}}\right)_{\rm r=R_*} > \sqrt{1 - \Gamma\left(\frac{R_*}{r_c}\right)} \qquad (0 < \Gamma < 1) \tag{11}$$

where $u_{\rm shock}$ denotes the velocity of the shocked gas (not to be confused with the shock amplitude).

In order to determine the value of Γ for various grain materials, we first need to calculate the corresponding (flux mean) opacities. For simplicity, we assume that κ_H can be approximated with the small particle limit opacity of spherical grains at $\lambda_{\rm max} \approx 1\mu$m (flux maximum of the star). Therefore, we have

$$\kappa_H \approx \frac{1}{\rho}\int_0^\infty a^2\pi\, Q_{\rm ext}(\lambda_{\rm max})\ n(a)\,da = \frac{\pi}{\rho}\, Q'_{\rm ext}(\lambda_{\rm max}) \int_0^\infty a^3\, n(a)\,da \tag{12}$$

where a denotes the grain radius, $n(a)$ the number density of grains and $Q_{\rm ext}$ is the extinction efficiency. For grains small compared to the wavelength, the quantity $Q'_{\rm ext} = Q_{\rm ext}/a$ becomes independent of the grain radius and can therefore be taken out of the integral. The last integral represents the fraction of a given volume which is occupied by the grains, apart from a factor $4\pi/3$, and it can be rewritten in terms of the space occupied by a monomer (basic building block) in the condensed material times the number of monomers found in a certain volume,

$$\int_0^\infty a^3\, n(a)\, da = \frac{3}{4\pi}\, V_{\rm mon}\, n_{\rm mon} = \frac{3}{4\pi}\, \frac{A_{\rm mon} m_p}{\rho_{\rm grain}}\, f_c\, \varepsilon_c\, n_{\rm H} \tag{13}$$

where we have expressed the monomer volume $V_{\rm mon}$ in terms of the atomic weight of the monomer $A_{\rm mon}$ and the density of the grain material $\rho_{\rm grain}$, and the number of monomers in a volume $n_{\rm mon}$ by the abundance of the key element of the condensate ε_c, the degree of condensation of this key element f_c, and the total number density of H atoms $n_{\rm H}$ (m_p = proton mass). Using $n_{\rm H} = \rho/(1{+}4\,\varepsilon_{\rm He})\, m_p$, we finally obtain

$$\kappa_H \approx 0.5\, \frac{A_{\rm mon}}{\rho_{\rm grain}}\, Q'_{\rm ext}(\lambda_{\rm max})\;\; f_c\, \varepsilon_c\,. \tag{14}$$

Below, we list the properties of different grain materials and the corresponding Γ, assuming $L/M = 5000\, L_\odot/M_\odot$ and a degree of condensation of the key element $f_c = 1$ (note that the value of Γ scales linearly with each of these two factors). The abundance of the key element ε_c corresponds to either all C not bound in CO for carbon grains (C/O = 1.5), or to Si for silicates. The data for $Q'_{\rm ext}$ is taken from Rouleau & Martin (1991, amorphous carbon) and Jäger et al. (2003, silicates; cf. Figs. 1 and 2 in Andersen, this volume).

material	$A_{\rm mon}$	$\rho_{\rm grain}$ [g/cm^3]	$Q'_{\rm ext}$ [1/cm]	ε_c	$\Gamma^{f_c=1}_{L/M=5000}$
amorphous carbon	12	1.85	$2\cdot10^4$	$3.3\cdot10^{-4}$	10
Mg_2SiO_4	140	3.27	$2\cdot10^1$	$3.6\cdot10^{-5}$	$6\cdot10^{-3}$
$MgFeSiO_4$	172	3.71	$7\cdot10^3$	$3.6\cdot10^{-5}$	2

As expected, the value of Γ for amorphous carbon grains is well above the threshold for a dust-driven wind, even for a degree of condensation $f_c \approx 0.3-0.5$ as typically found in detailed models. For silicate grains, the picture is, again, more complex: for forsterite (Mg_2SiO_4), on the one hand, Γ is so far below the critical value that even the scenario of a pulsation-supported dust-driven outflow as discussed above is unrealistic, since it would require $(u_{\rm shock}/u_{\rm esc})_{\rm r=R_*}$ close to unity. Silicate grains containing equal amounts of Mg and Fe, on the other hand, could result in a sufficiently high Γ, but as we saw above they will not form sufficiently close to the star to drive a wind.

At this point one might wonder about alternatives to the ballistic one-shock scenario for the trajectory prior to dust condensation. It might be possible that a matter element gets hit by several shocks at increasing distance from the star if the fall-back is slow enough ('parachute regime', see above), gradually driving the gas out to a considerable distance (see, e.g., Bowen 1988). One could even think about replacing the first step(s) on the way with other mechanisms which on their own may not be sufficient to drive an outflow (just like the shock waves alone will hardly do the trick, at least not within observed constraints as known today). Several such possibilities have been discussed in the literature earlier, e.g., Alfvén waves (e.g., Hartmann & MacGregor 1980), sound waves (e.g., Pijpers & Hearn 1989), or high thermal gas pressure due to heating by shock waves ('calorisphere', Willson & Bowen 1998). However, each of these alternatives faces the same question: will densities and dynamical timescales allow for efficient grain condensation at a certain distance from the star?

2.3. Condensation efficiency and time scales

Discussions about dust in atmospheres and winds of AGB stars often ignore the fact that a low enough temperature is only a necessary condition for the formation or survival of dust grains, and not a sufficient one. In dynamical atmospheres and winds where timescales are set by pulsation and wind dynamics, the efficiency of dust formation is strongly dependent on prevailing gas densities and abundances. As matter moves away from the star, the temperature decreases, which – at first – favors grain formation. At the same time, however, the growth of grains turns into a race against falling density which slows down the process, and more often than not leads to incomplete condensation.

Simple estimates based on gas kinetics as presented in Gustafsson & Höfner (2004) demonstrate that the timescales for the growth of carbon grains close to the condensation radius (i.e. at about 2-3 stellar radii) are on the order of a year, i.e. comparable with the pulsation period of the star, and increasing outwards with falling density. This is in good agreement with detailed numerical models which tend to show mean degrees of condensation well below unity (typically 0.3-0.5), and a rather limited zone of grain growth.

Iron-poor silicates, which should have a condensation radius similar to amorphous carbon grains (see above), face the problem that the abundance of the key element Si is about an order of magnitude lower than that of C, increasing the estimate for the grain growth time by a corresponding factor (the timescale is inversely proportional to this abundance). This might result in a rather low dust formation efficiency, which, in combination with the low opacity of such grains, makes them a by-product of the wind, not a driver.

Iron-rich silicates, on the other hand, which could in principle contribute to the total opacity, and consequently to driving the wind, will most likely not form in significant amounts, being handicapped by both the low abundance of Si and the much lower densities prevailing at distances corresponding to their large condensation radius. At such distances, the densities will be at least an order of magnitude lower than in the region where carbon or iron-poor silicates may form, adding another factor of ten to the grain growth timescale.

3. Detailed models: status and trends

The development of models for a particular phenomenon – in this case mass loss through dusty winds – often occurs in several steps: first ideas about basic processes lead to order of magnitude estimates, followed by simple (analytical or numerical) models. If the basic principles seem sound the next step is an iterative improvement of numerical models by comparison with observations, leading eventually to detailed, reasonably realistic models which, finally, can be applied to study certain astrophysical phenomena in a wider context (e.g. the role of dusty winds in stellar and galactic evolution, to pick a not-so-random example).

Detailed time-dependent models for winds of AGB stars currently come in three major groups, namely two types of spherically symmetric frequency-dependent models including non-equilibrium dust formation for C-rich and O-rich chemistry, respectively, and 2D/3D models concerned with the effects of giant convection cells and structure formation on atmospheres and mass loss. These three types of models have reached different stages in their development, as will be discussed below.[3]

Early pioneering models in this field, exploring the general effects of pulsations and dust for cool stellar winds (e.g. Wood 1979, Bowen 1988) make hardly a distinction between C-rich and O-rich stars, with the possible exception of choosing appropriate values for certain input parameters. The turning point came with the inclusion of a detailed description of dust formation (e.g., Fleischer et al. 1992, Höfner & Dorfi 1997, Winters et al. 2000, Jeong et al. 2003) in contrast to a parameterized description of the dust opacity, and/or the introduction of frequency-dependent radiative transfer, accounting for the complex opacities of molecules and dust (e.g., Höfner 1999, Woitke 2006a).

The latest generation of models for atmospheres and winds of C-rich AGB stars by Höfner et al. (2003), combining a frequency-dependent treatment of radiative transfer with time-dependent hydrodynamics and a detailed description of dust formation, compares well with various types of observations, such as low-resolution NIR spectra (Gautschy-Loidl et al. 2004) or profiles of CO vibration-rotation lines (Nowotny et al. 2005ab and this volume). With these non-grey dynamical models it is possible for the first time to simultaneously reproduce the time-dependent behavior of fundamental, first and second overtone vibration-rotation lines of CO, features originating in the outflow, dust formation region, and pulsating atmosphere, respectively, probing the dynamics from the photosphere out into the wind. Recently, Mattsson et al. (2007) have applied these models to investigate the formation of detached shells in connection with a He-shell flash. Currently, a large grid of dust-driven wind models for C-rich AGB stars and an accompanying library of variable synthetic spectra are being computed (see Mattsson et al., this volume).

The development of similar detailed models for winds of O-rich AGB stars has been lagging behind the C-rich case, not the least due to a more complex scenario for dust formation. Jeong et al. (2003) presented wind models for M-type stars, combining a detailed description of dust formation with time-

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[3]Other kinds of models, such as stationary wind models, neglecting pulsation and shocks, or pure dynamical atmosphere models without mass loss (e.g. Bessel et al. 1996, Scholz & Wood 2000, Tej et al. 2003ab), are not included in this discussion. Note also that the recent models by Ferrarotti & Gail (2006) studying dust formation for a wide range of stellar parameters and chemical compositions are not wind models in the strict sense of the word since they have mass loss rates as an input parameter, not as a result.

dependent dynamics and grey radiative transfer. While the stellar parameters of these models are somewhat on the extreme side (high luminosities, low effective temperatures), the resulting wind characteristics are reasonably realistic. In view of the discussion in the previous section, it may be surprising that it is possible to drive winds with silicate grains. This is a direct consequence of the grey radiative transfer used in these models which corresponds to an effective value of $p = 0$ (cf. Fig. 1), resulting in a rather small condensation radius for all types of grains, including iron-rich species. Frequency-dependent models for O-rich AGB stars by Woitke (2006a, and this volume) clearly demonstrate that the iron content of silicate grains has to be very low (large condensation radius for iron-rich silicates, combined with low condensation efficiency, see discussion in previous section), and that the wind – even for quite extreme stellar parameters – will consequently not be driven by silicate grains, in contrast to previous expectations.

During recent years, 2D/3D dynamical atmosphere and wind models for AGB stars have emerged, in addition to the spherically symmetric models discussed above. The computational effort behind such models is considerable, and several simplifications have to be introduced in the description of physical processes. Nevertheless, investigating the effects of intrinsically three-dimensional phenomena like convection or flow instabilities on mass loss, seems a timely project in view of recent interferometric observations which indicate deviations from spherical symmetry. Woitke (2006b) presented 2D (axisymmetric) dust-driven wind models, including time-dependent dust formation and grey radiative transfer. He studied how instabilities in the dust formation process create intricate patterns in the circumstellar envelope, but without taking the pulsation of the central star into consideration. Freytag & Höfner (2003, 2007), on the other hand, investigate the effects of giant convection cells and of the resulting shock waves in the atmosphere on time-dependent dust formation in the framework of 3D RHD 'star-in-a-box' models. The atmospheric patterns created by convective motions are found to be reflected in the circumstellar dust distribution, due to the strong sensitivity of grain formation to temperatures and gas densities, as discussed above.

4. Conclusions

The well-known dichotomy between M-type and C-type AGB stars, as observed in molecular spectra, may have an even more drastic consequence for their mass loss mechanism. While advances in modelling, in particular the introduction of frequency-dependent radiative transfer in time-dependent dynamical models, have improved agreement between models and observations of C-rich AGB stars, the opposite seems to be true for the O-rich case. Recent models of M-type stars combining time-dependent dust formation with frequency-dependent radiative transfer demonstrate that silicate grains forming in such environments will be extremely iron-poor, resulting in too low opacities to drive a wind.

These qualitative differences can be understood with simplified analytical considerations, as discussed here, causing serious doubt about the validity of the dust-driven wind scenario for M-type AGB stars, at least in its most simple form. The mystery is deepened by the fact that the observed wind characteristics for both types of stars are rather similar (see, e.g., Olofsson 2004, Ramstedt et al. 2006), which hints at a common mass loss mechanism. In addition, alternative scenarios discussed in the literature may have serious difficulties explaining the formation of considerable amounts of dust as a by-product in an outflow driven by a different force. Non-equilibrium dust condensation is very sensitive to the prevailing thermodynamical conditions, and restricted to a relatively narrow zone close to the star, putting strong constraints on potential driving forces.

In this situation the role of observers should not be underestimated. Any observations which can narrow down the possible range of conditions in the wind acceleration zone are of great importance for solving this problem.

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