GRADUAL FE-ENRICHMENT OF SILICATE DUST IN AGB STAR WINDS

UPPSALA UNIVERSITET

SUSANNE HÖFNER[1], SARA BLADH[1], BERNHARD ARINGER[2] & KJELL ERIKSSON[1]

INTRODUCTION AND SUMMARY

The massive winds observed around AGB stars are generally assumed to be driven by radiation pressure on dust, which is formed in the extended dynamical atmospheres of these long-period variables (see, e.g., Höfner & Olofsson 2018, A&A Rev. 26, 1). Magnesium-iron silicates are good candidates for driving the winds of M-type AGB stars, considering the abundances of relevant elements (Si, Mg, Fe, O) and the prominent mid-IR silicate features observed in circumstellar dust shells. Earlier DARWIN models of winds driven by photon scattering on large Fe-free silicate grains produce realistic mass-loss rates and wind velocities, and the resulting visual-to-near-IR spectra compare well with observations (Höfner 2008, A&A 491, L1; Bladh et al. 2015, A&A 575, A105; Höfner et al. 2016, A&A 594, A108). However, their synthetic spectra show no mid-IR silicate features due to low grain temperatures.

Here we present new DARWIN models that allow for the growth of silicate grains with a variable Fe/Mg ratio, which is set by a self-regulating feedback between grain composition and corresponding radiative heating (Höfner et al., in prep.). The resulting values of Fe/Mg are low, typically a few percent. Nevertheless, the new models show distinct silicate features around 10 and 18 microns. The gradual Fe-enrichment of silicate grains in the inner wind region should produce observable signatures in mid-IR spectro-interferometrical measurements. It is important to note that the enrichment of the silicate dust with Fe is a secondary process, taking place in the stellar wind, on the surface of large Fe-free grains that have initiated the outflow. Therefore, the mass-loss rates are basically unaffected, and existing grids of DARWIN models (Bladh et al. 2019, A&A 626, A100) can be applied to stellar evolution models.

FE/MG IN SILICATES: SELF-REGULATION VIA GRAIN TEMPERATURE

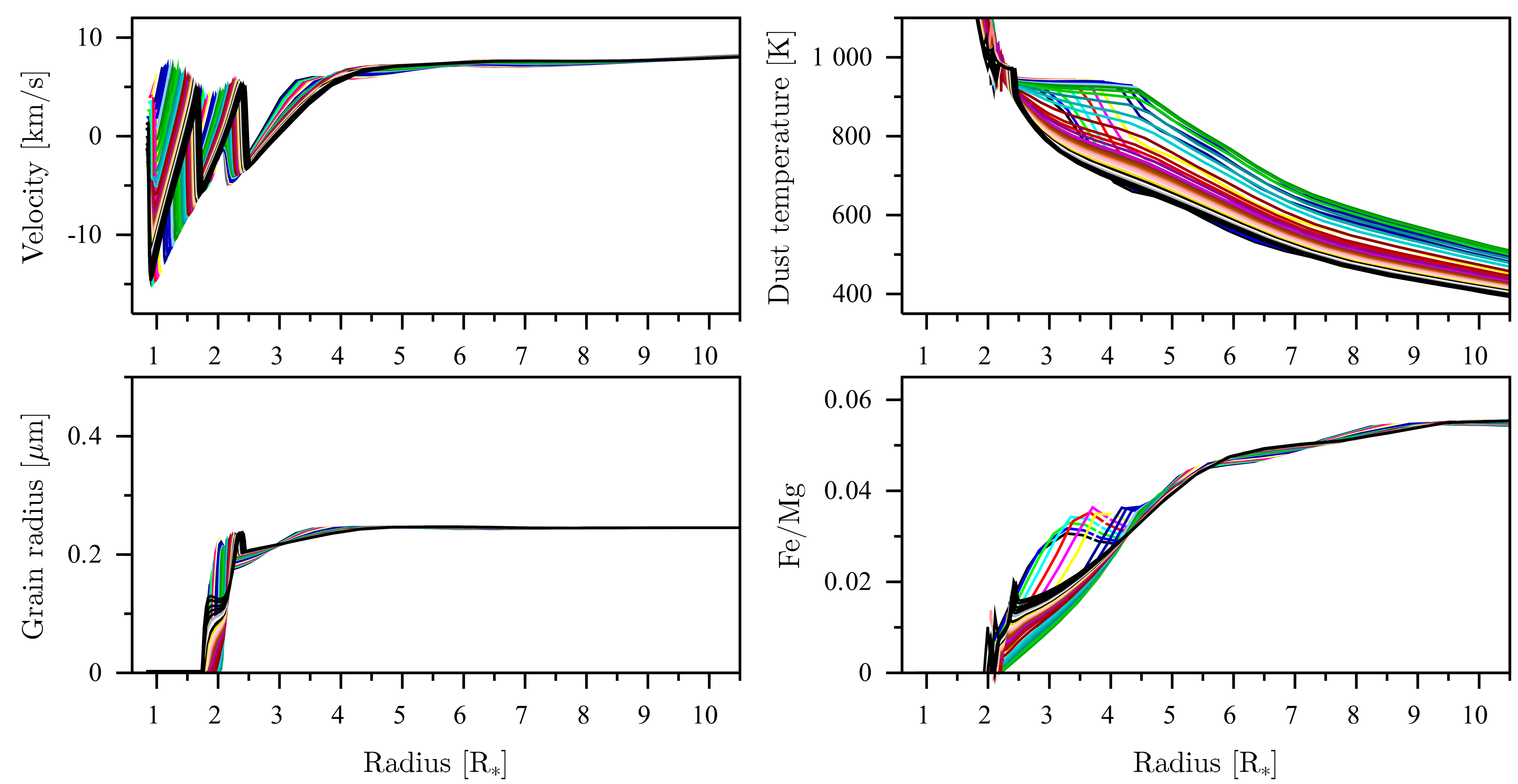

Figure 1: Time-dependent radial structure of a typical model ($M_* = 1\,M_\odot$, $L_* = 7000\,L_\odot$, $T_* = 2700$ K), $P = 390$ d, $\Delta M_{\rm bol} = 0.71$), zoomed in on the dust formation region (snapshots of 40 pulsation phases).

Figure 1 shows the time-dependent radial structure of a typical model. The inner part of the atmosphere (below $\approx 2R_*$) is dominated by pulsation-induced shock waves, which are visible as steep changes in velocity (top left panel). Around $2R_*$ dust condensation starts, and the grains grow rapidly in size (bottom left). Initially, the grains are Fe-free and very transparent at visual and near-IR wavelengths. When they reach the critical size regime where photon scattering becomes efficient, radiation pressure triggers an outflow (positive values of the velocities, top left). Grain growth slows down critically in the outflow due to rapidly falling densities as the material is driven away from the star.

In the wind, where the stellar flux and the resulting radiative heating of the dust grains decrease with distance from the star, dust particles can be more opaque without getting destroyed by heating. As shown in the bottom right panel of Fig. 1, the Fe/Mg ratio in the grains increases as they move away from the star. However, the Fe-enrichment is limited: even a small amount of Fe leads to substantial heating by absorption of stellar photons. Fe/Mg values of a few percent make the composite grains about $200-400$ K warmer than their Fe-free counterparts. The top values are close to the sublimation temperature of the grains, apparent as a plateau in the top right panel, showing grain temperatures.

SPECTRA & PHOTOMETRY

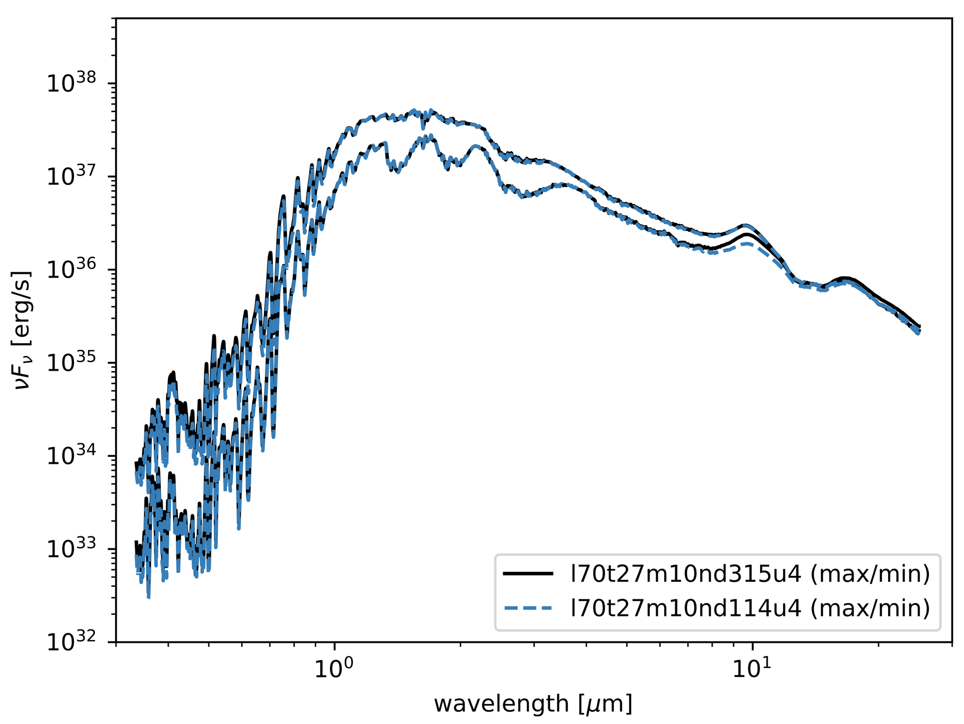

Figure 2: Spectral energy distributions of the model in Fig. 1 (blue dashed lines) and of a version with a lower grain abundance (black lines) at maximum and minimum light. The silicate features around 10 and 18 μm are clearly visible, and vary with phase.

The new models show distinct silicate features around 10 and 18 microns. The effect of the Fe-enrichment on visual and near-IR photometry is moderate, and the new DARWIN models agree well with observations in $(J-K)$ vs. $(V-K)$ and *Spitzer* color-color diagrams.

WIND PROPERTIES

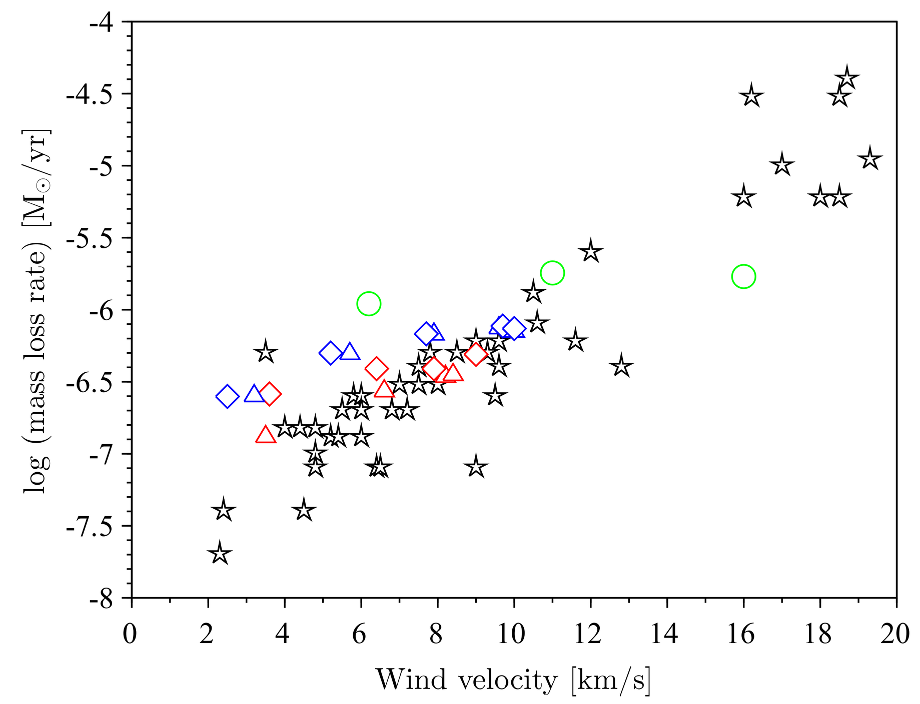

Figure 3: Mass-loss rate versus wind velocity: black symbols indicate observations by Olofsson et al. (2002, A&A 391, 1053) and González Delgado et al. (2003, A&A 411, 123); the red, blue and green symbols represent the new DARWIN models.

AFFILIATIONS & CONTACT

[1] Dept. of Physics & Astronomy, Uppsala Univ.

[2] Department of Astrophysics, Univ. of Vienna

Web https://www.astro.uu.se/exwings/

Email susanne.hoefner@physics.uu.se

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