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Dust from AGBs: from carbon to silicates

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To better understand the role of Asymptotic Giant Branch stars as dust polluters in the Universe, we calculate the dust formed around AGBs in the metallicity range $0.05 \leq Z/Z_{\odot} \leq 0.4$, following the complete evolution of models with masses in the range $1\ M_{\odot} \leq M \leq 8\ M_{\odot}$. We assume that dust forms via condensation of molecules within a wind expanding isotropically from the stellar surface. The dust formed is extremely sensitive to the initial mass of the star: carbonaceous grains are prevalent around lower mass objects, whereas high mass models produce silicates and alumina dust, because of the strong Hot Bottom Burning experienced. The transition between the two regimes occurs around $3M_{\odot}$, partly depending on the metallicity assumed. Dust production in low-mass stars is almost independent of Z, whereas in high-mass objects the rate of silicate production increases with metallicity, because of the higher abundance of silicon in the envelope.

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1. Introduction

Stars with an initial mass in the range 1 $M_\odot \leq M \leq 8\ M_\odot$, after the exhaustion of helium in the core, evolve through the Asymptotic Giant Branch (AGB). During this phase, the stars experience a considerable change in the surface chemical abundances and lose the whole envelope via stellar winds. These processes, together with the low surface temperature of these sources, make AGB stars a suitable place where gas condenses into dust grains which are accelerated by the radiation pressure. For this reason, AGBs earned an increasing interest in the astronomical community, owing to their central role played as dust polluters in the interstellar medium at the present days, as well as in the early Universe [1].

Many efforts have been done so far to model the dust formation process, starting from the pioneering works of the Heidelberg group [2],[3],[4]. A step forward was made by Ventura et al. [5],[6],[7], and Di Criscienzo et al. [8], where the scheme introduced by Ferrarotti & Gail [4] is coupled with a complete and self-consistent set of models of the entire AGB phase .

During the Thermal Pulses phase (TP), AGBs experience a deep convective process, the Third Dredge Up (TDU), which brings up carbon produced by He-burning to the surface, eventually leading to a surface $C/O > 1$ in stars with $M < 3-4\ M_\odot$. In these objects, called carbon stars, the great abundance of C favors the production of solid carbon and silicon carbide dust grains. Stars with $M \geq 3-4\ M_\odot$ experience the ignition of a proton capture nucleosynthesis at the base of the convective envelope, called Hot Bottom Burning (HBB). In these stars, the large surface abundances of oxygen and silicon favors the production of silicates as main dust compound. Thanks to the Mg-Al cycle, which enhances the surface aluminum available, Al_2O_3 is also formed.

We have calculated the dust produced by models of initial mass 1 $M_\odot \leq M \leq 8\ M_\odot$ and metallicity in the range $0.05 \leq Z/Z_\odot \leq 0.4$. We focus on the relative effects of the TDU and HBB.

2. The model

The stellar evolution models are calculated by means of the ATON code [9], which allows to follow the evolution of the chemical and physical properties of the star from the pre-main-sequence to the entire AGB phase. The convective instability is treated according to the Full Spectrum of Turbulence (FST) description, [10]. Mass loss for M-stars is described according to [11], while for C-stars we use the treatment by [12]. We consider the presence of some extra-mixing from convective borders with the aim of reproducing the observed luminosity function of the carbon stars in the Large Magellanic Cloud.

Starting from the outputs of the stellar evolution (M, L, T, mass loss rate and the surface chemical composition), we describe the dust production following the model by Ferrarotti & Gail [3]. The wind is assumed to expand with constant velocity (v_0=1kms^{-1}) until the temperatures become sufficiently low to allow condensation of gas particles into dust. The dust production increases the opacity of the wind, allowing the radiation pressure from the central object on the grains to accelerate the wind and disperse the dust in the surrounding medium.

3. Results and discussion

The dust yields from AGBs can be distinguished in two classes: lower mass stars, which

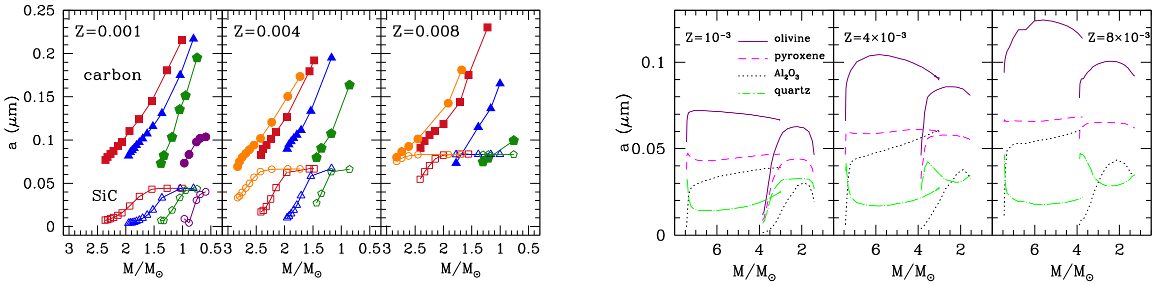

Figure 1: Left panel: the variation of the size of dust grains of carbon (full points) and SiC (open) during the AGB evolution of models of initial mass 1 $M_{\odot}$ and 3 $M_{\odot}$ of metallicity $Z = 10^{-3}$, $Z = 4\times10^{-3}$ and $Z = 8\times10^{-3}$ (right). Right panel: the variation of the mean grain size of olivine (violet, solid lines), pyroxene (magenta, dashed), quartz (green, dot-dashed) and alumina (black, dotted) in models of initial mass 4 $M_{\odot}$ and 7.5 $M_{\odot}$ with the same metallicities of the left panel.

become carbon stars owing to TDU, produce solid carbon, silicon carbide and iron dust grains; conversely, more massive stars, owing to the effect of HBB, are the leading sources for silicates, iron and alumina dust.

In the left panel of Fig. 1, we show the mean grain size of solid carbon and silicon carbide during the AGB phase. The size of solid carbon grains increases during the AGB phase, as a consequence of the gradual increase in the surface carbon. The maximum dimension reached is $a_C \sim 0.25$ μm, independently of metallicity. On the other hand , SiC grains grow until a certain value, dependent on Z. The SiC production is correlated to the abundance of silicon and is limited by the sulphur molecule: this element causes the exhaustion of the gaseous silicon available, forming SiS. In the right panel of Fig. 1, we show the evolution of the mean size of dust grains formed around massive stars: silicates are the most abundant products and their dust grain dimension increases with metallicity and initial stellar mass. Olivine is the dominant species, with grain sizes in the range 0.05μm<$a_{ol} < 0.13\mu$m. Pyroxene and quartz are formed in smaller dimension. Owing to the Mg-Al cycle active in the HBB nucleosynthesis, Al is abundant enough to condense into Al_2O_3. Its grain size increases with stellar mass and metallicity and it reaches the maximum dimension of 0.07μm, saturating all the gaseous aluminum available.

In Fig. 2, we report the mass of dust produced during the whole AGB phase for models with different initial mass and metallicity. In C-stars (left panel) the dominant species (80-90%) is solid carbon ($10^{-4}M_{\odot} < M_C < 10^{-2}M_{\odot}$). The highest production is reached by models with mass 2-2.5$M_{\odot}$; these results are practically independent of metallicity. SiC is also produced in smaller quantities ($10^{-4}M_{\odot} < M_{SiC} < 10^{-3}M_{\odot}$); the amount of SiC formed increases with mass and metallicity. In O-rich stars, dust formation is driven by HBB, which determines higher luminosities and mass loss rates, thus favoring gas condensation. Silicates are the dominant species ($\sim 80\%$) with dust masses in the range $10^{-3}M_{\odot} < M_{sil} < 10^{-2}M_{\odot}$ for metallicities $Z > 10^{-3}$. At $Z = 10^{-3}$ less silicates form, owing to the scarcity of silicon in the envelope and to the strong HBB, that destroys the surface oxygen. Al_2O_3 is also formed in minor quantities ($M_{Al_2O_3} < 10^{-3}M_{\odot}$).

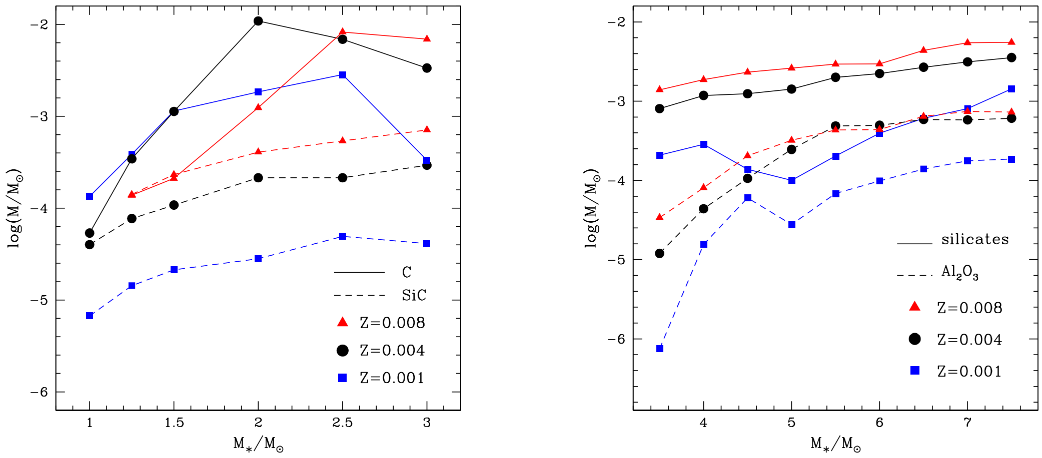

Figure 2: Left panel: the mass of solid carbon (solid line) and silicon carbide (dashed line) produced as a function of the initial mass for the metallicities $Z = 8\times10^{-3}$ (red triangles), $Z = 4\times10^{-3}$ (black circles) and $Z = 10^{-3}$ (blue squares). Right panel: The mass of silicates (solid line) and alumina (dashed line) produced as a function of the initial mass, with the same metallicities representation of the left panel.

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