Dust formation in Asymptotic Giant Branch stars

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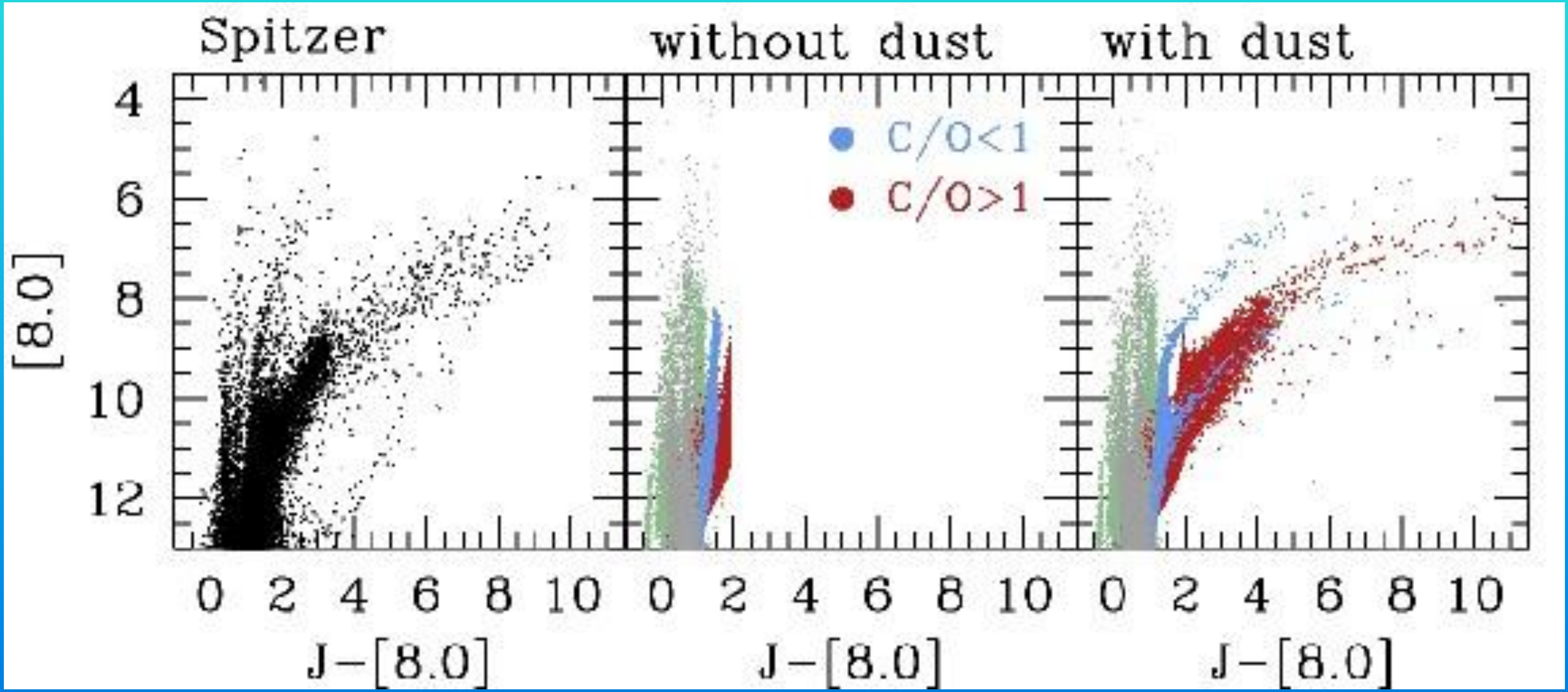
Introduction

- **AGB Stars considered to account for ~50-60% (Gehrz 89) ISM dust in the local Universe**
- **Important for analysis of evolved phases in Mid Infrared HR diagrams**
- **Relevant for dust production at high redshifts (Valiante et al. 09; Marchenko 05; Dwek & Cherchneff10)**

Dust formation in AGBs studied by many authors:
Bowen & Willson 91**;** ***Fleischer et al. 91; Gail & Sedlmayr 1999 (GS99); Lodders & Fegley 1999; Cherchneff 00; Willson 00; Elitzur & Ivezic 01; Jeong et al. 03; Winters et al. 03; Ferrarotti & Gail 06 (FG06); Hoefner 08; Ventura et al. 12***

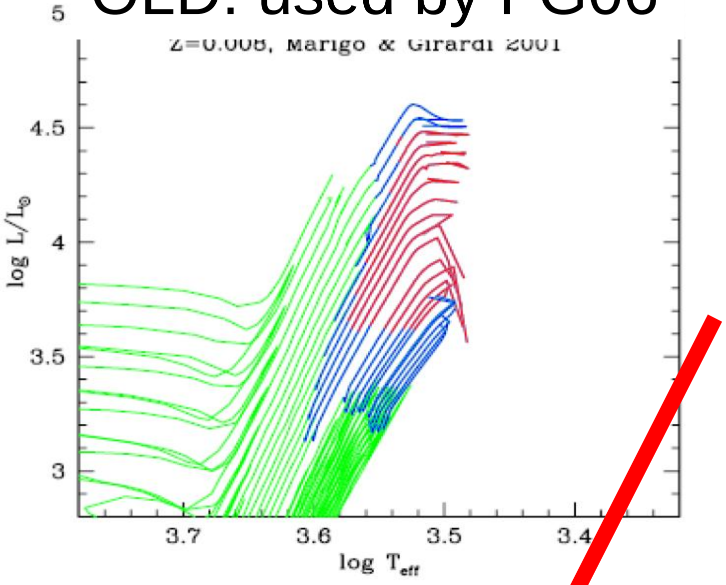
FG06 (and GS99) provide basic set of equations of dust growth coupled with a stationary wind

TP-AGB calibration:
e.g. Models vs LMC Observations



Dust/Gas assumed in these models

OLD: used by FG06

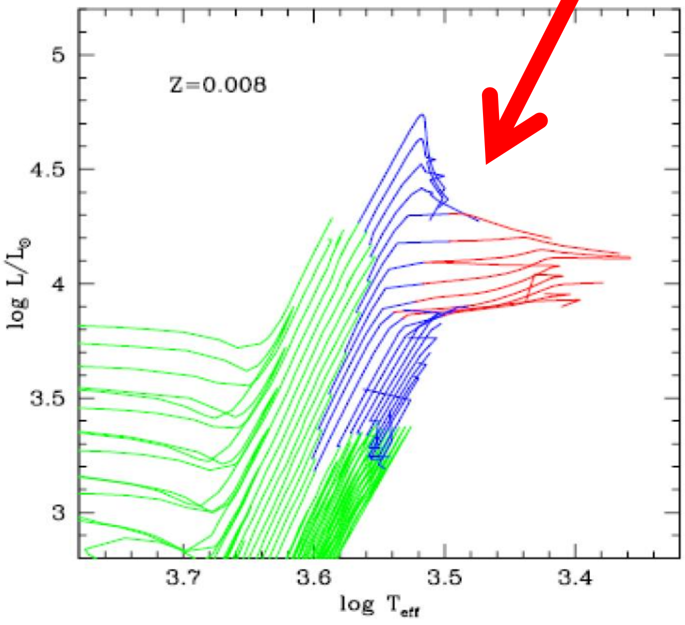


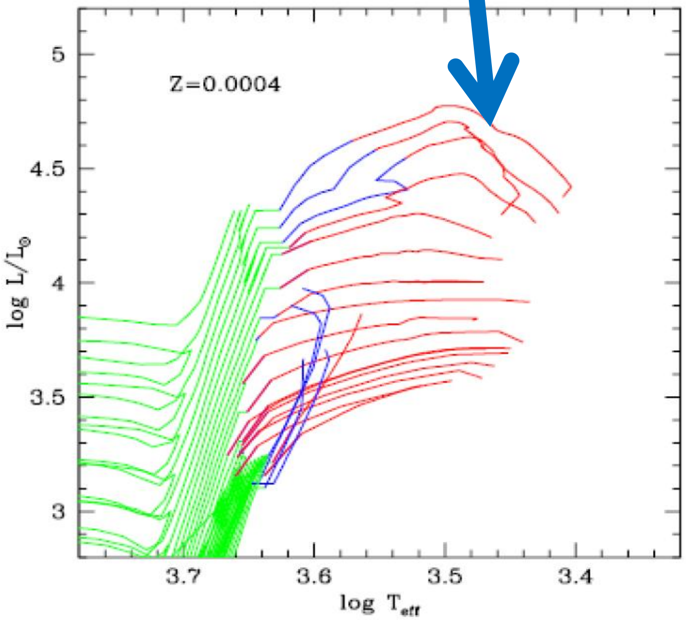
We follow the FG06 scheme with new AGB tracks by Marigo et al. 2012

Main Characteristics

After Marigo et al (2008), AGB phase reaches lower effective temperatures (opacity): important for the dust formation process

Low effective temperatures also at low Z





Marigo et al. 2012 based on new tracks (Bressan et al. 2012) update input physics & different metal partitions

Dust formation & chemistry

1) When a **dense gas cools down** (expanding envelope) a temperature is reached where **large molecules aggregates** form (a few tens to hundreds of atoms) -> **seeds nucleation process**

2) Dust may grow on **seeds** by **addiction of other molecules** or **atoms** -> **accretion processes**

3) Dust Chemistry dictated mainly by **C/O ratio**:
(***III Dredge UP*** + ***Hot Bottom Burning***, see e.g. Hoefner 2009)

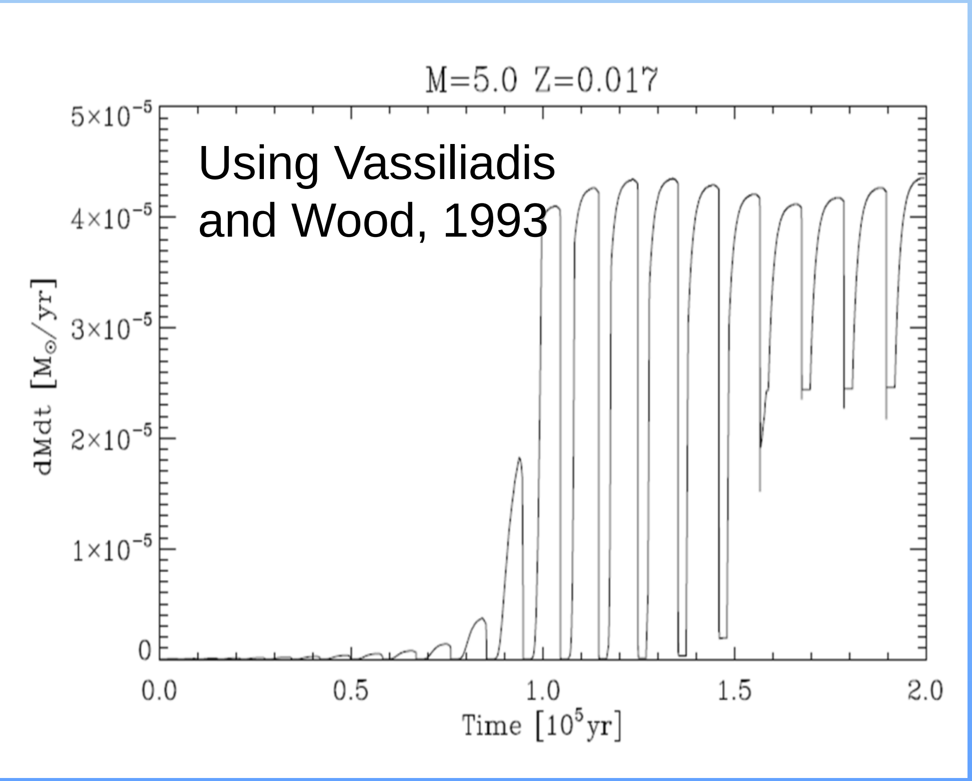
Small solid particles (10^{-3} μm<a<0.1-0.2 μm) of different composition:

- Corundum (Al_2O_3) & Silicates (Mg_2SiO_4, $MgSiO_3$, SiO_2) in **M stars** (C/O<1)
- Amorphous carbon dust, Silicon Carbide (SiC) in **C stars** (C/O>1)
- SiC, Silicates, FeSi in **S stars** (C/O~1)

Dust evolution (growth and/or destruction) may continue in the ISM

Input model ingredients:

- actual star mass
- effective temperature
- stellar luminosity
- mass loss (Vassiliadis & Wood, 1993)
- elements abundances in the atmosphere (including C/O)



Using Vassiliadis and Wood, 1993

Output: circumstellar envelope

- dust composition
- condensation radius
- **terminal wind velocity**
- **final dust sizes**
- fraction of elements locked in dust grains
- **dust yields**
- dust/gas ratio

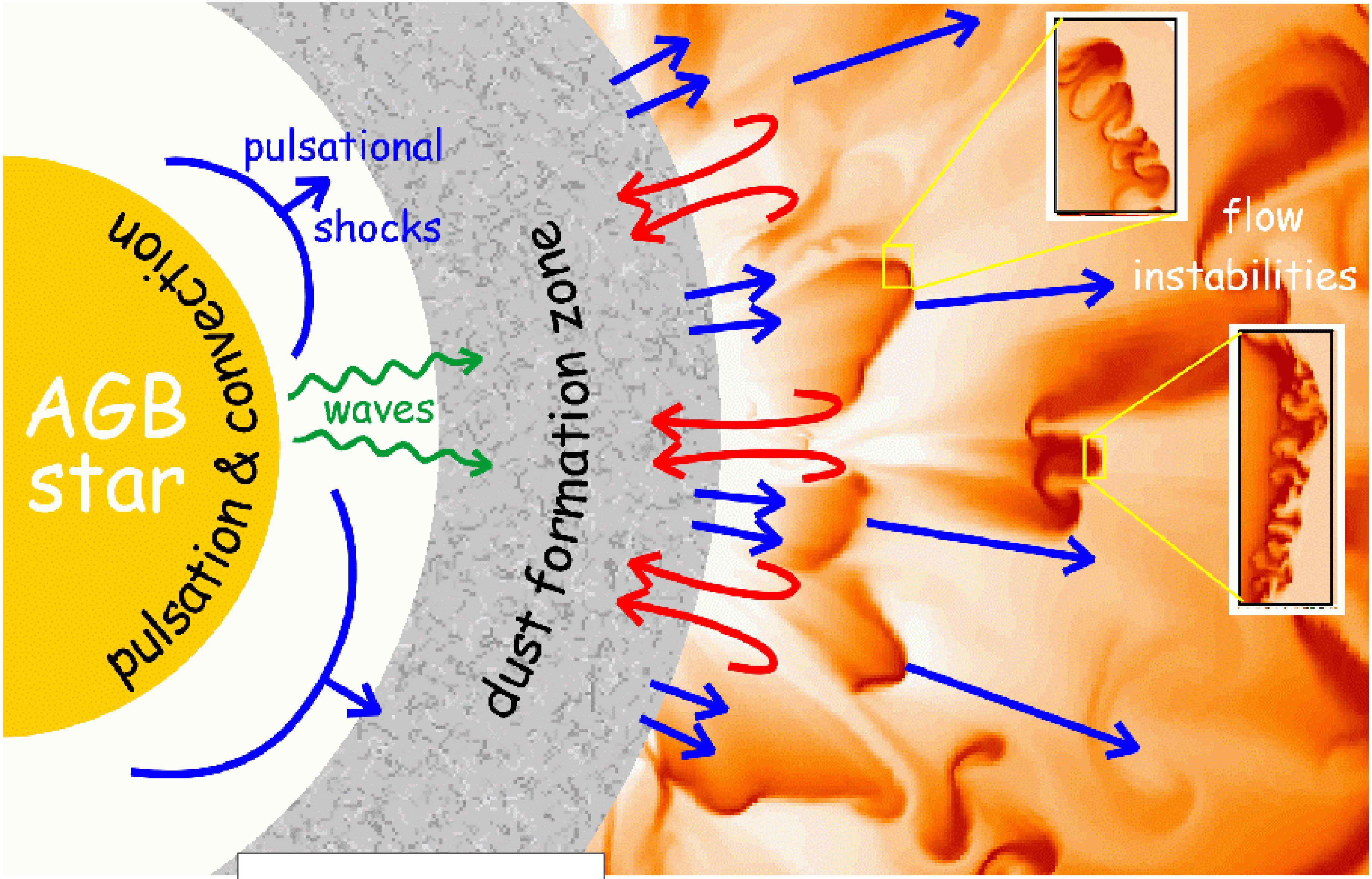
A few differences with respect to FG06

- **Opacities**
- Number of Seeds (parameter)

Opacities & Wind dynamics

$$v\frac{dv}{dr} = -\frac{GM_*}{r^2}(1-\Gamma)$$

$$\Gamma = \frac{L_*}{4\pi c G M_*}k$$



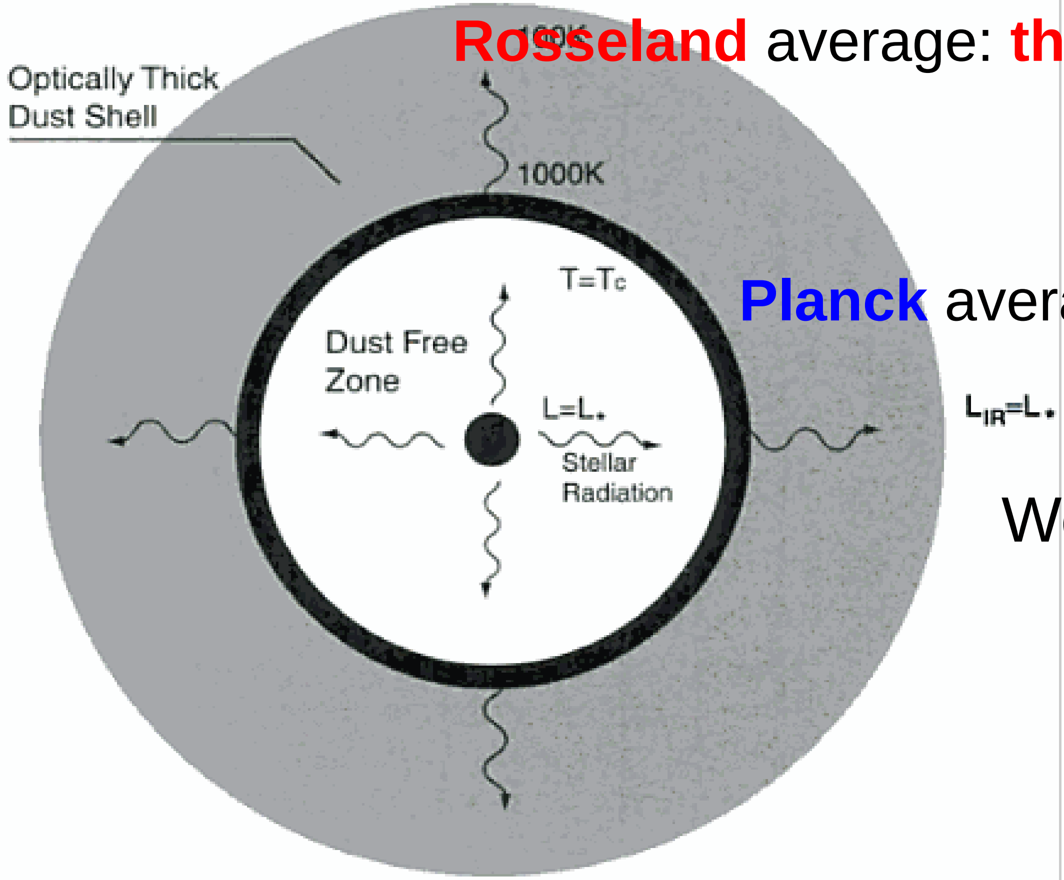
$$k = k_{gas} + \sum_i f_i k_i$$

$$\Gamma > 1$$

Opacities

Scaled with the abundance of the key-element (with Z) for each dust type *i*:

$$k_{i,\lambda} \propto \varepsilon_i \propto Z$$



Rosseland average: **thick** (***local T***)

$$k_{i,r} = \left(\frac{\int_0^\infty \frac{1}{k_{i,\upsilon}} \frac{\partial B_\upsilon(T)}{\partial T} d\upsilon}{\int_0^\infty \frac{\partial B_\upsilon(T)}{\partial T} d\upsilon} \right)^{-1}$$

Planck average: **thin** (**T***)

$$k_{i,p} = \frac{\int_0^\infty k_{i,\upsilon} B_\upsilon(T_*) d\upsilon}{\int_0^\infty B_\upsilon(T_*) d\upsilon}$$

From Lamers and Cassinelli, 1999

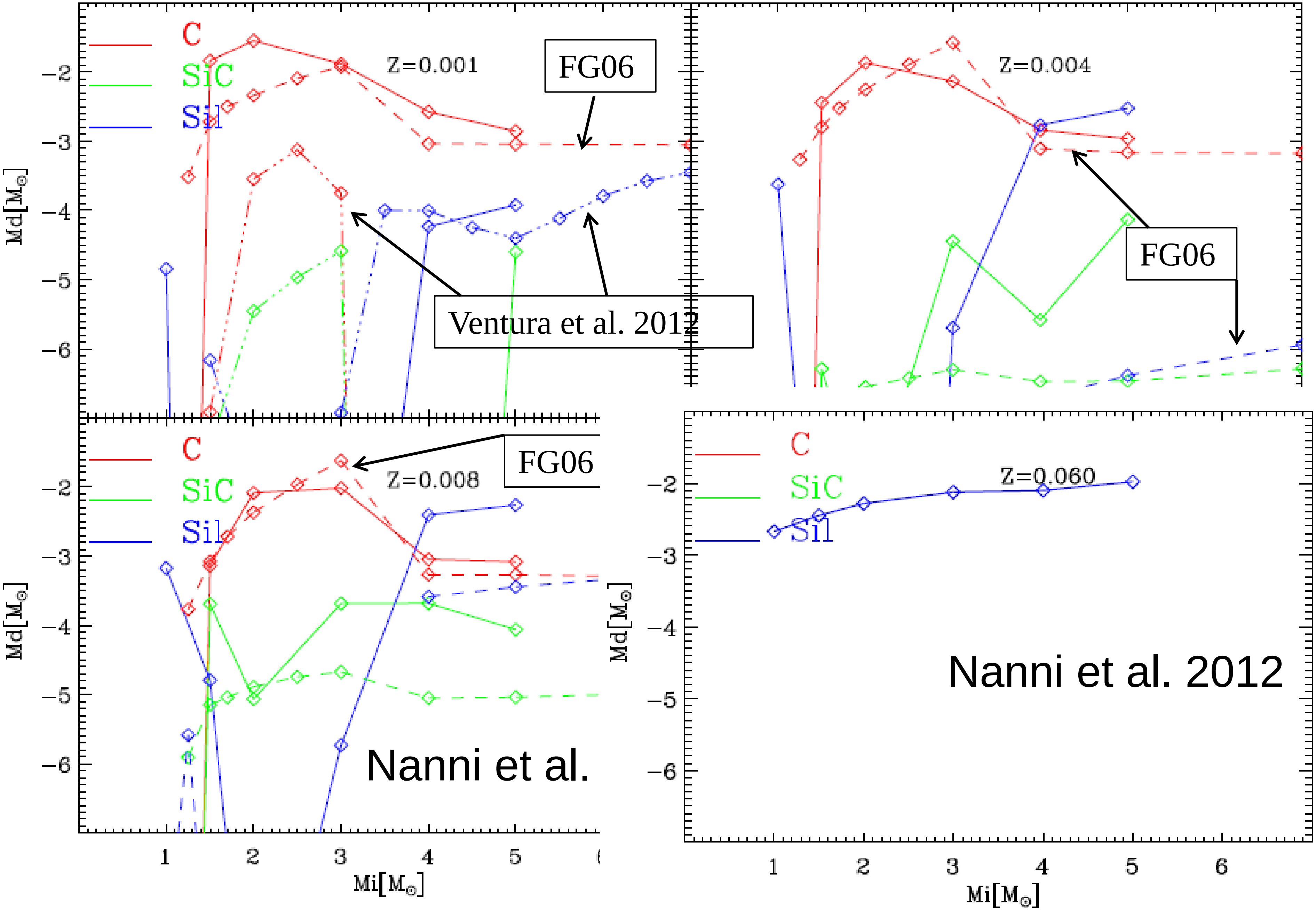
Weighted with the dust optical depth

-> ***k= k***$_{av}$

$$k_{av} = k_p e^{-\tau_d} + k_r(1 - e^{-\tau_d}).$$

$$\tau_d = \int_{R_*}^{r} \rho k_{av} dr$$

Final dust masses, α-ehnanced models



FG06

Ventura et al. 2012

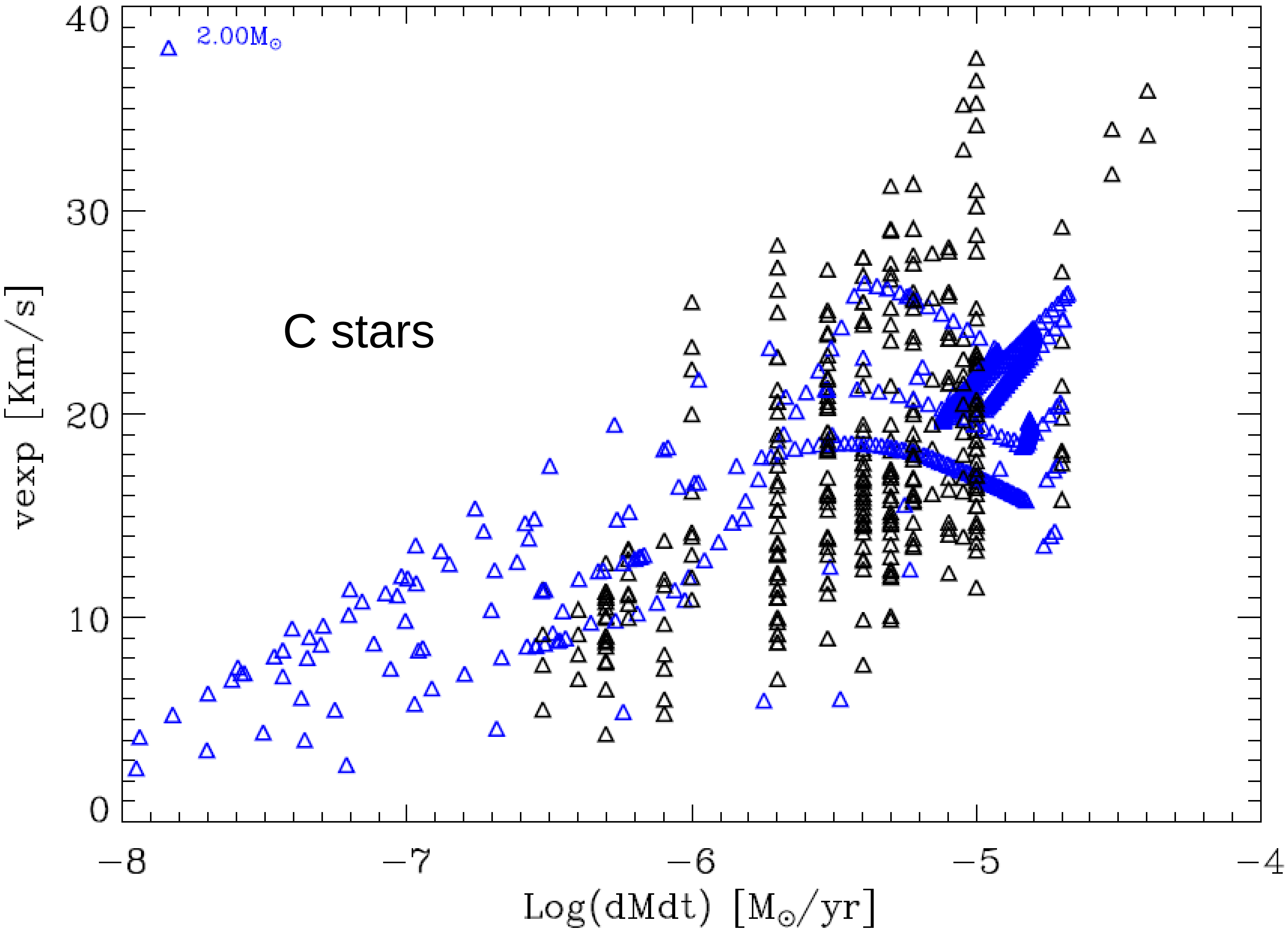
FG06

FG06

Nanni et al.

Nanni et al. 2012

Loup 1993, models Z=0.017, solar partition



Nanni et al. 2012

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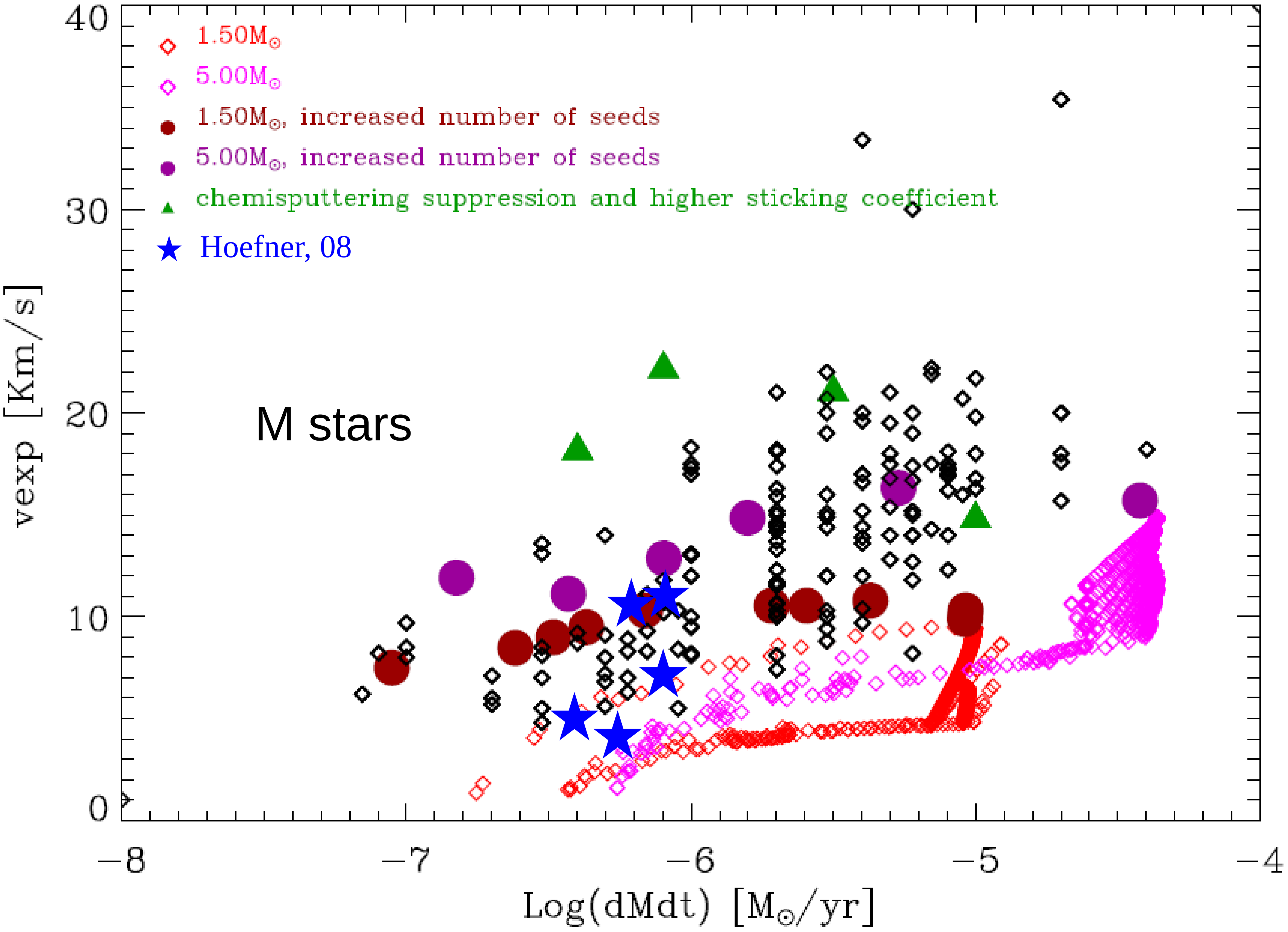
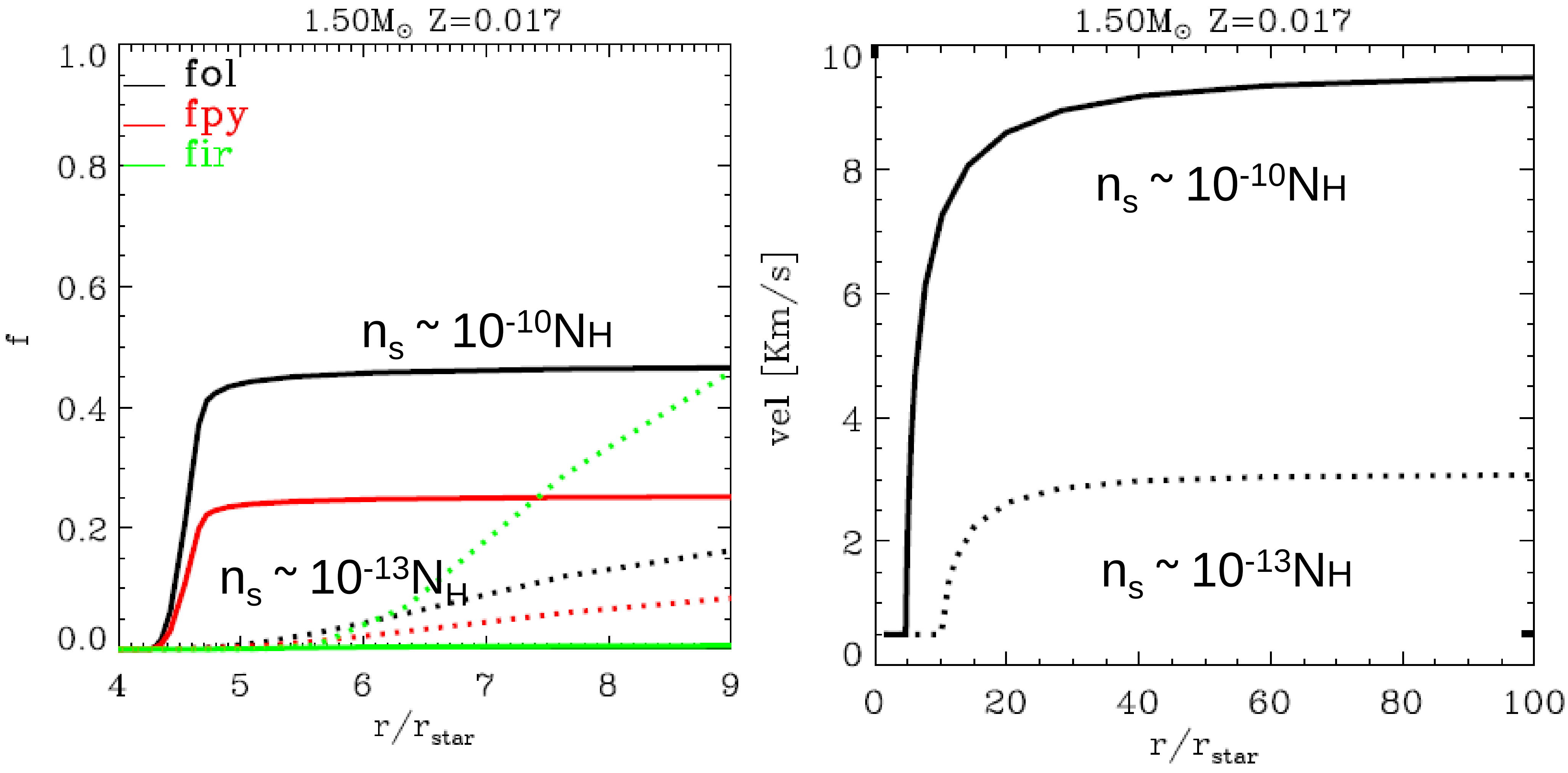


Nanni et al. 2012

Possible ways out (1): number of seeds

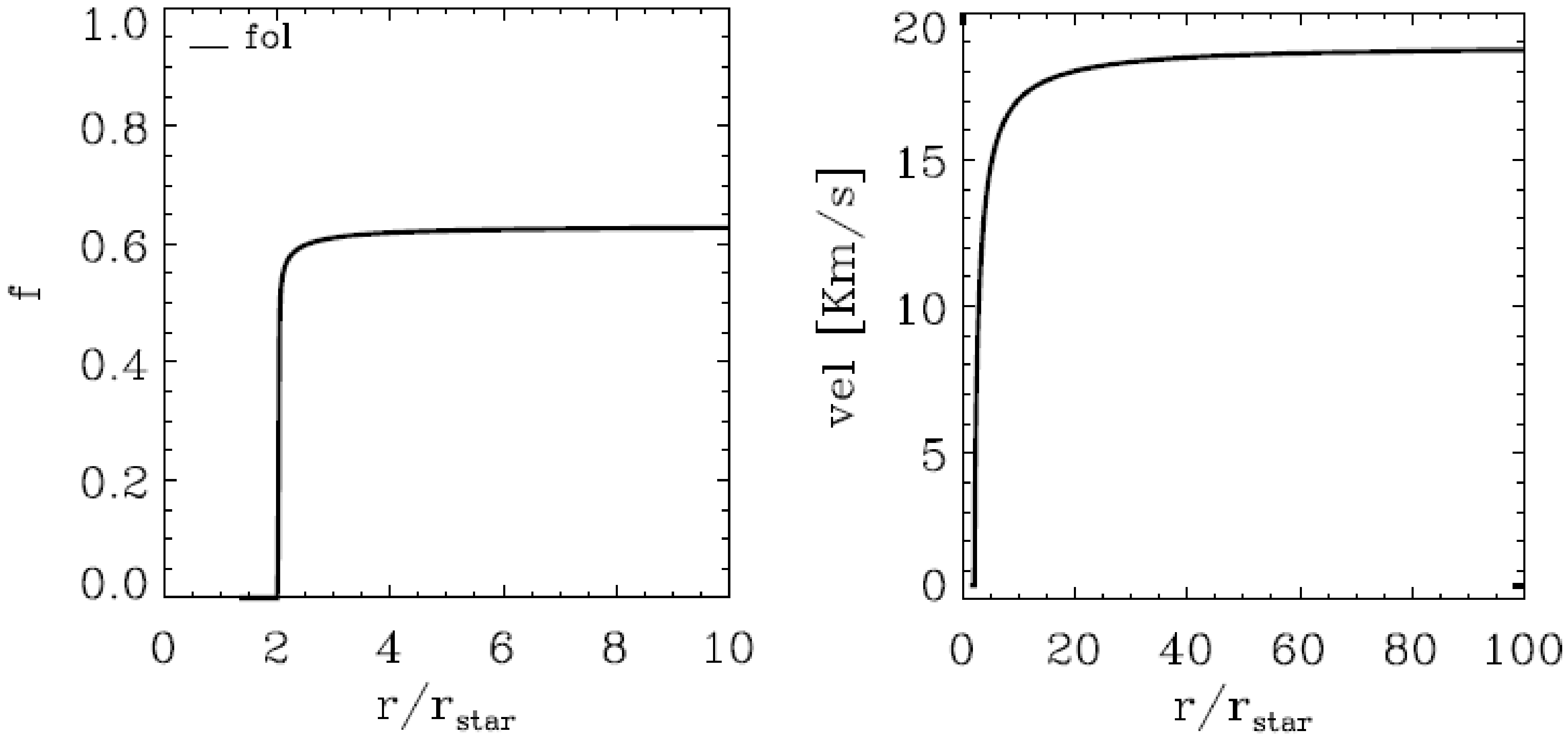
Intermediate Mass Loss : ~4x10^{-7} $M_\odot$/yr



Typical grain size (**0.1 μm**) **not** reproduced (10 times smaller!)

Possible ways out (2): H_2 chemisputtering suppressed + sticking coefficient increased

Intermediate Mass Loss : ~8x10^{-7} $M_\odot$/yr



α=1 for olivine, but from experiments **α~1**

Conclusions

1) The **dust formation model** + **updated stellar AGB tracks** is a fundamental tool to study the contribution of **AGB stars** to the **dusty ISM**.
Applications: star clusters in nearby galaxies (Mid Infrared Colours) and galaxy evolution (evolution of dust)

2) **Observable properties** of the AGB stars in the **local Universe**

a) The properties of **C stars** are nicely reproduced by delaying.

b) **M star** data are not so well reproduced (lower vexp than observed)
Preliminary tests : this point can be solved if the *bulk of condensation happens in an inner part of the stellar envelope*.

3) AGB dust **yields** for a broad range of **metallicities** and **partitions** of heavy elements, both **with** and **without chemisputtering**.

4) The model will soon be coupled with a radiative transfer code to predict the **MIR colours** of these stars, in order to provide a direct consistent observable for the **mass loss rate**.