Constraining dust properties in C-stars in the SMC: optical constants and grain size of carbon dust

Part of the ERC project STARKEY (PI Paola Marigo)

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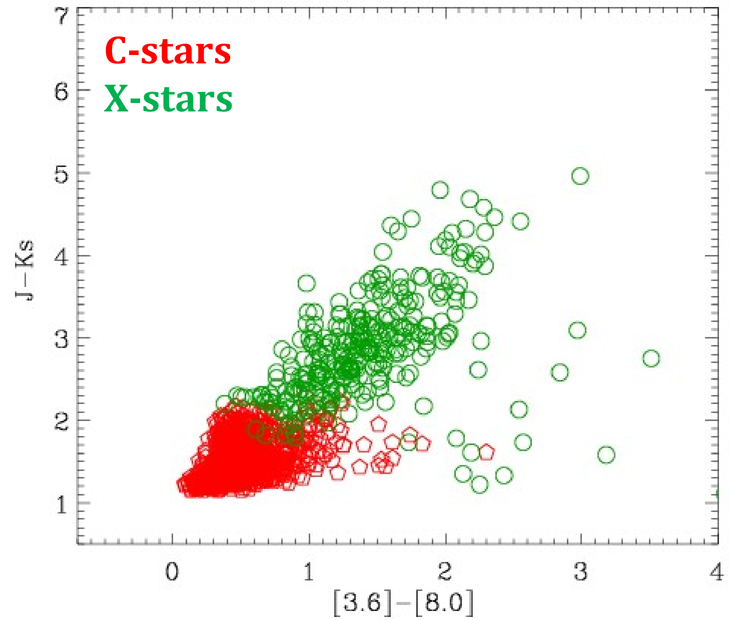
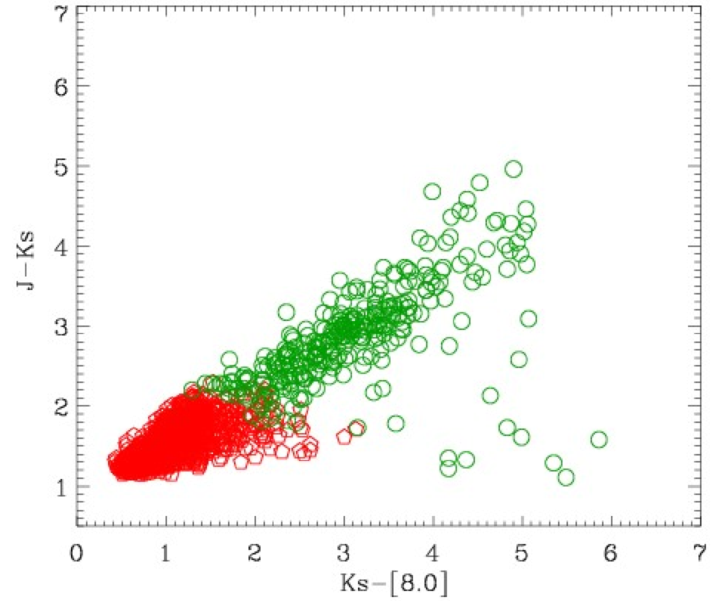
Goals

- **STARKEY: to reproduce and interpret the observations of resolved stellar populations (CCDs, CMDs) $\rightarrow$ simulated with the TRILEGAL code (Girardi et al. 05)**

- **First step (this talk): to reproduce several colors *simultaneously* employing stellar tracks $\rightarrow$ *constraints on carbon dust* (Nanni et al. 16)**

Observations available for AGB stars in the SMC in the NIR and MIR (2MASS, *Spitzer*)





Boyer et al. 2011

X-stars are mostly carbon rich (van Loon et al. 08b; Matsuura et al. 09)

Dust in C-stars: SiC, carbon, MgS

Method

- **Compute dust growth+ radiative transfer in CSEs along the TP-AGB tracks**
- **Compare with the observations in the NIR & MIR colors for a large number of stars**

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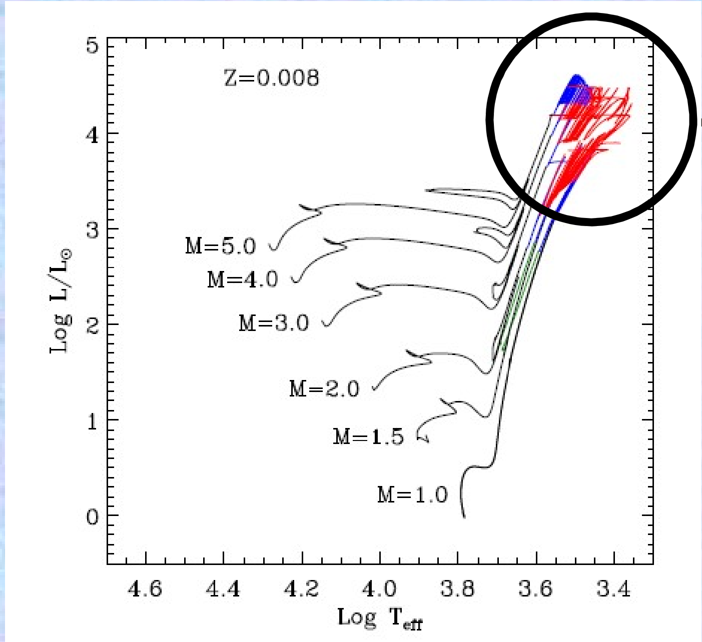
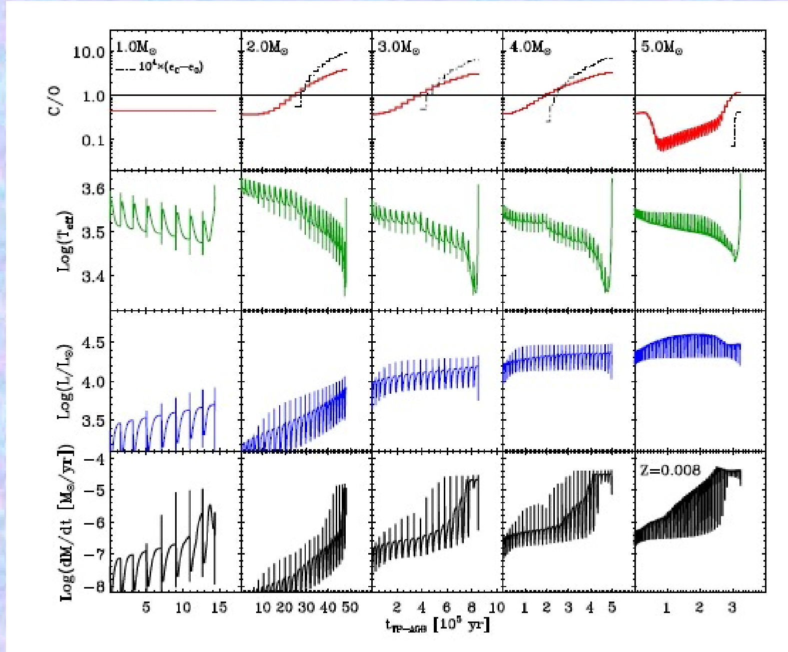
Novelty: dust constraint employing TP-AGB tracks + consistent dust formation model
(Andersen et al. 99 employed dynamical models)

Model

Stellar tracks

(PARSEC + COLIBRI codes)



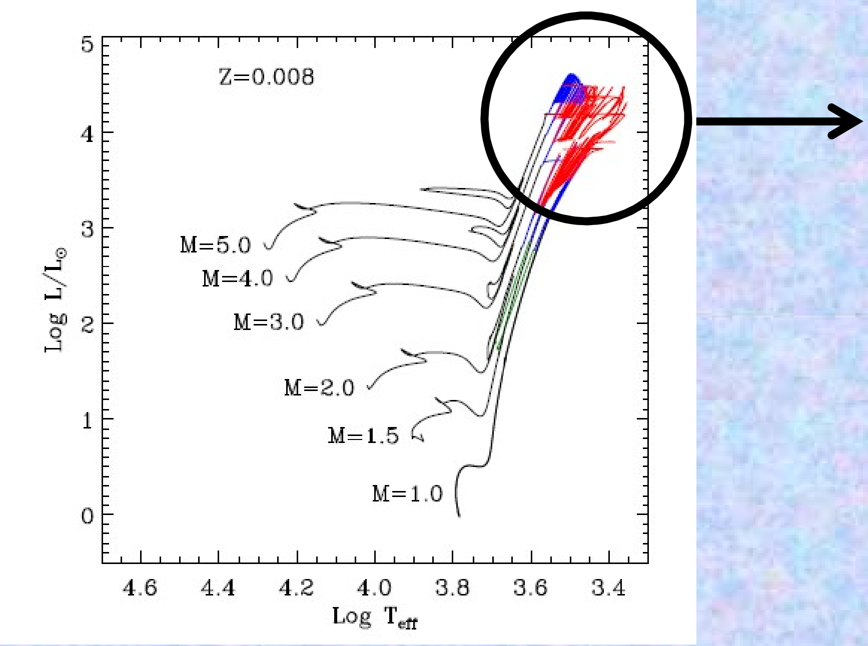


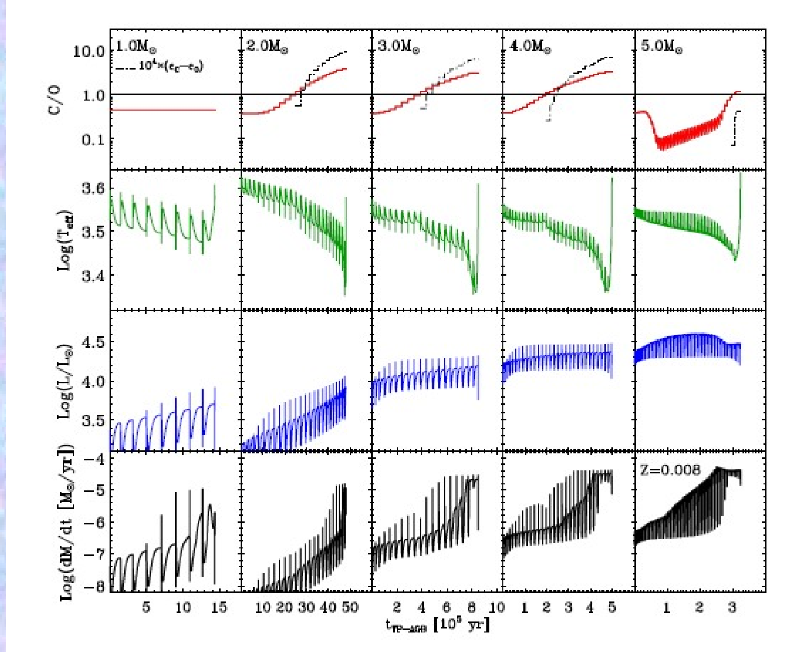
Bressan et al. 12; Marigo et al. 13

TP-AGB models (Marigo et al. 2013):

- on-the-fly computation of detailed molecular chemistry (800 species) and opacities
- 3° dredge-up and mass loss : parameterized description
- HBB: complete nuclear network (CNO, NeNa, MgAl cycles) coupled to a diffusive description of convection (MLT)
- HBB nucleosynthesis and energetics fully accounted (no synthetic formalism)

Stellar tracks
(PARSEC + COLIBRI codes)





Bressan et al. 12; Marigo et al. 13

M [$M_\odot$]=1.4, 1.6, 2.0 with Z=0.002
M [$M_\odot$]=2, 2.4 with Z=0.004
M [$M_\odot$]=3.0 with Z=0.006

INPUT of the DUST FORMATION MODEL

Nanni et al. 13, 14 (revised version of Ferrarotti & Gail 06 - FG06)

Input model ingredients (TP-AGB tracks - Bressan et al. 12, Marigo et al.13)

- actual star mass
- effective temperature (and spectrum)
- stellar luminosity
- **mass-loss** (prescriptions in TP-AGB models)
- elements abundances in the atmosphere (including C/O)

Output: circumstellar envelope (Nanni et al. 13-14)

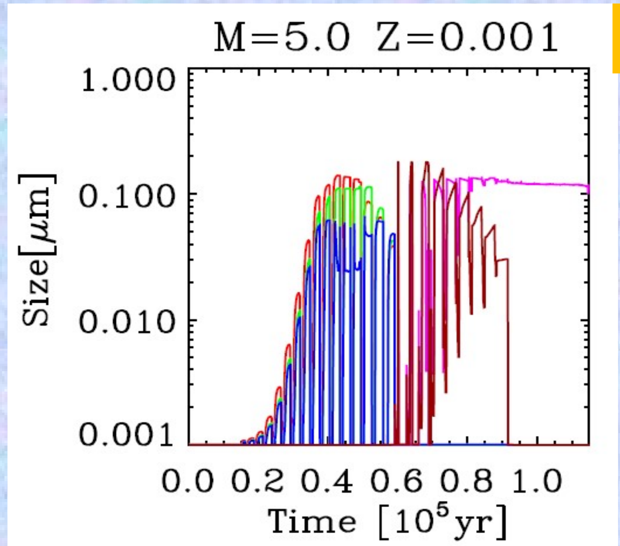
- **dust composition** (we include **several dust species**)
- **mass-loss in dust**
- **outflow velocity**
- **grain sizes**
- fraction of elements locked in dust grains
- **dust ejecta**
- **dust-to-gas ratios**

(Nanni et al.16)

(+radiative transfer code)

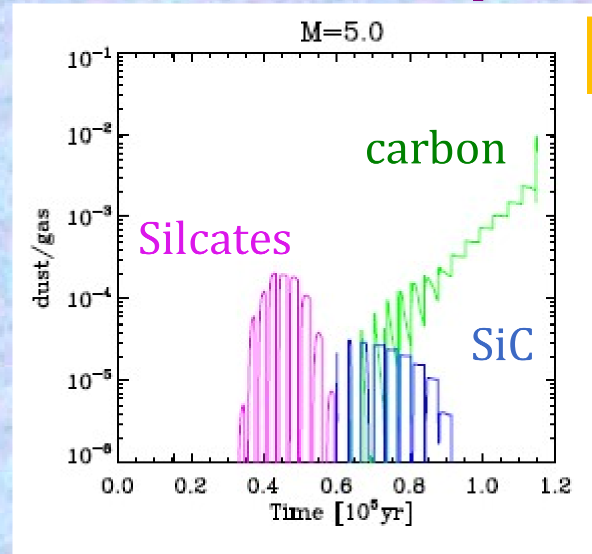
- **NIR and MIR colors**

Dust mineralogy, abundances & spectra



grain size

Olivine
Pyroxene
Periclase
Amorphous C
Silicon Carbide



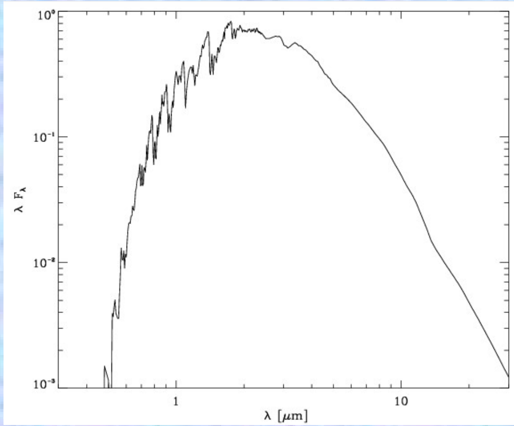
dust/gas

Nanni et al. 13-14

RT code MoD (Groenewegen 12),
based on DUSTY (Ivezic&Elitzur 97)

Stellar spectra: COMARCS grid (Aringer et al. 16)

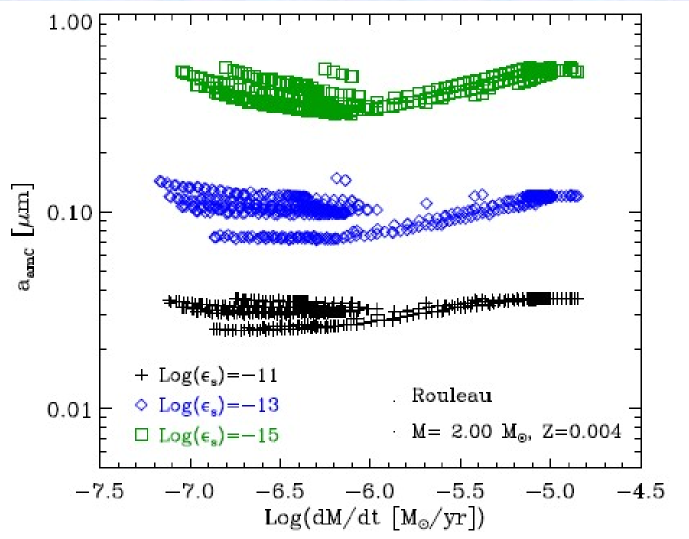
→



Spectra & colors

Other assumptions

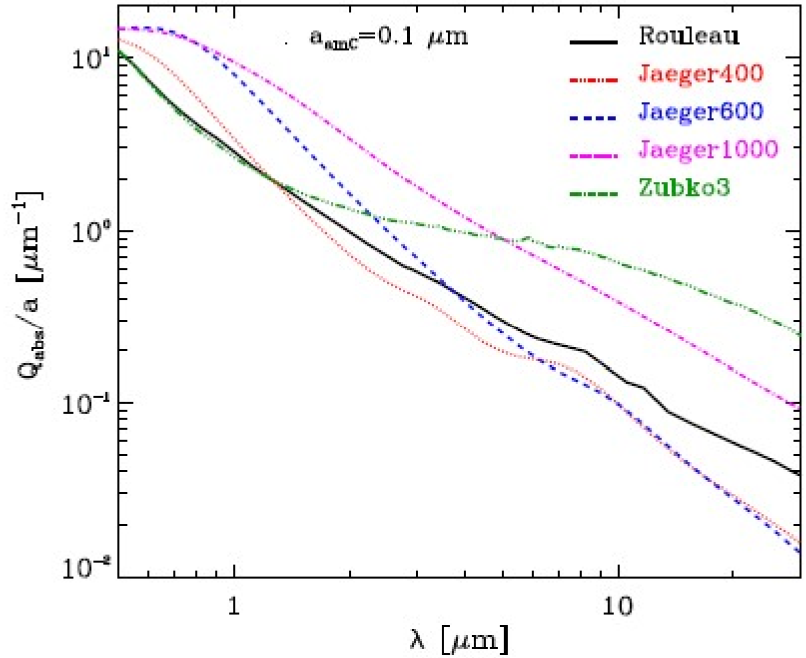
- Spherical grains
- Different carbon optical data sets → need to be tested in order to find the best one to reproduce observations
- Number of initial particles (→ typical grain size) → adjustable parameter, proportional to the carbon-excess
- Typical grain size 0.04<a< 0.7 μm

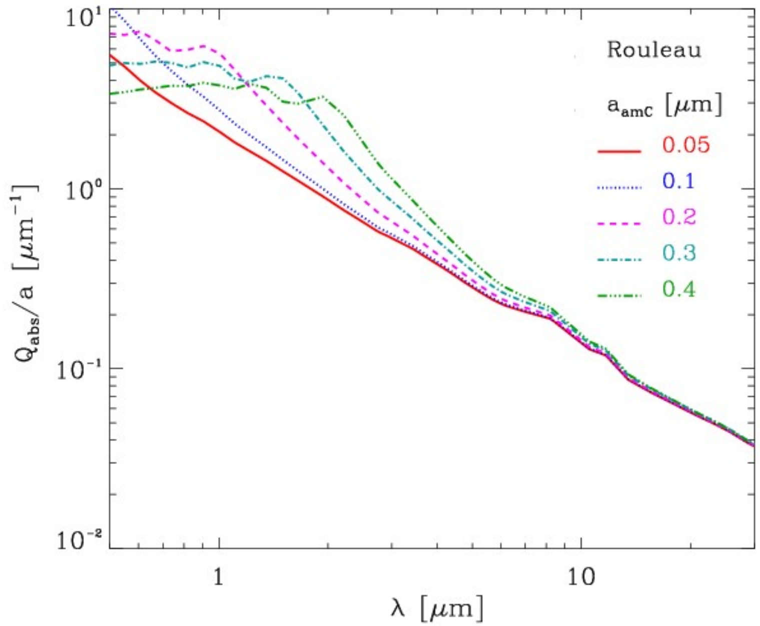


Input: data sets of optical constants

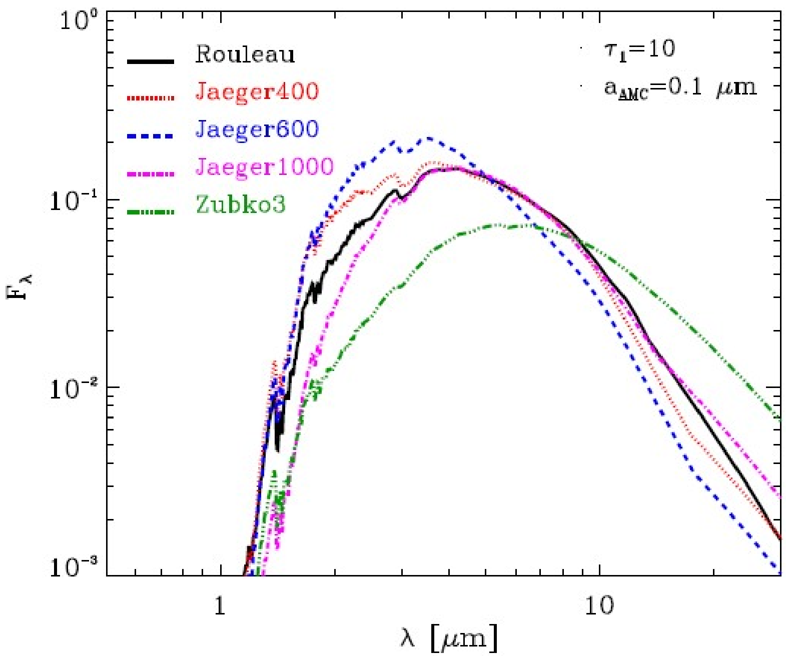
Designation	ρ_d [g/cm^3]	Reference
Jaeger400	1.435	Jager, Mutschke & Henning (1998)
Jaeger600	1.670	Jager, Mutschke & Henning (1998)
Jaeger800	1.843	Jager, Mutschke & Henning (1998)
Jaeger1000	1.988	Jager, Mutschke & Henning (1998)
Zubko1	1.87	Zubko et al. (1996)
Zubko2	1.87	Zubko et al. (1996)
Zubko3	1.87	Zubko et al. (1996)
Rouleau	1.85	Rouleau & Martin (1991)
Hanner	1.85	Hanner (1988)

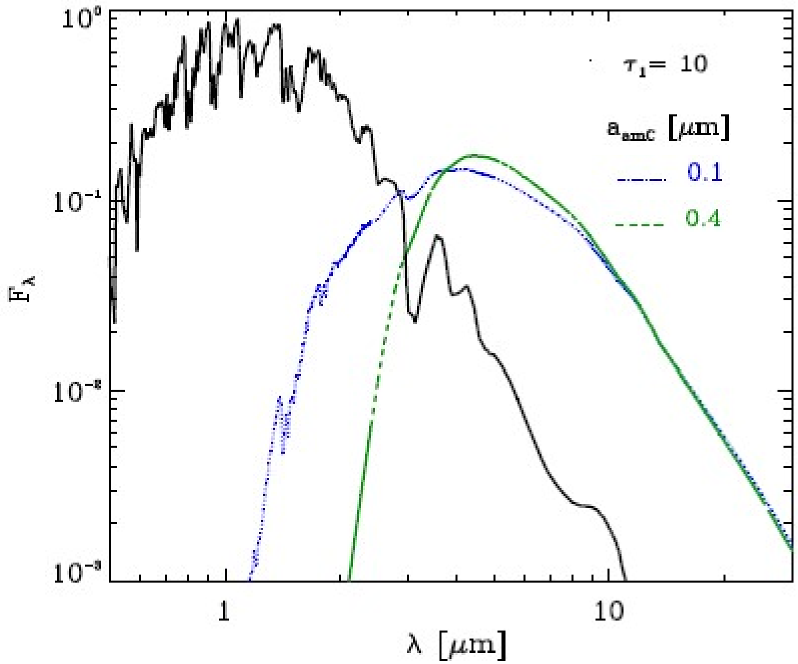
Optical properties of carbon grains



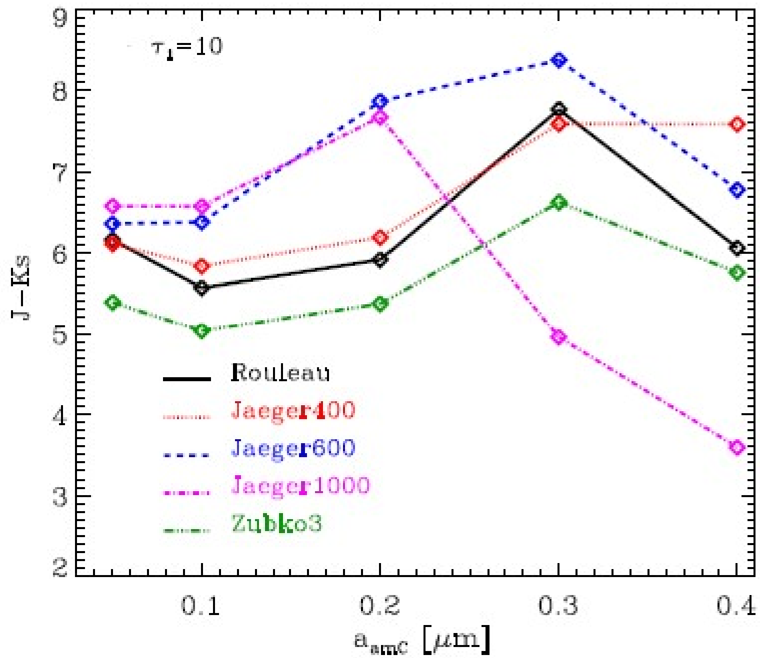


Optical properties of carbon grains



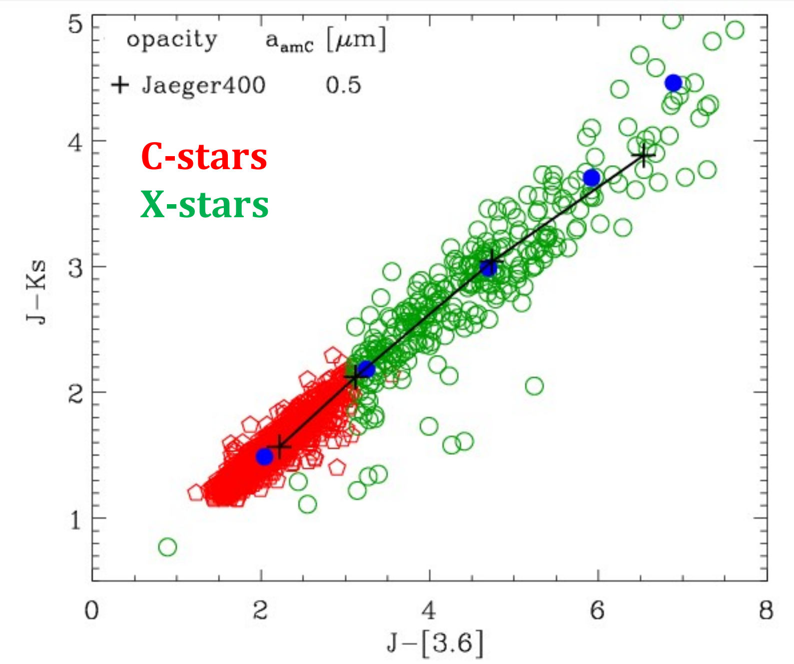


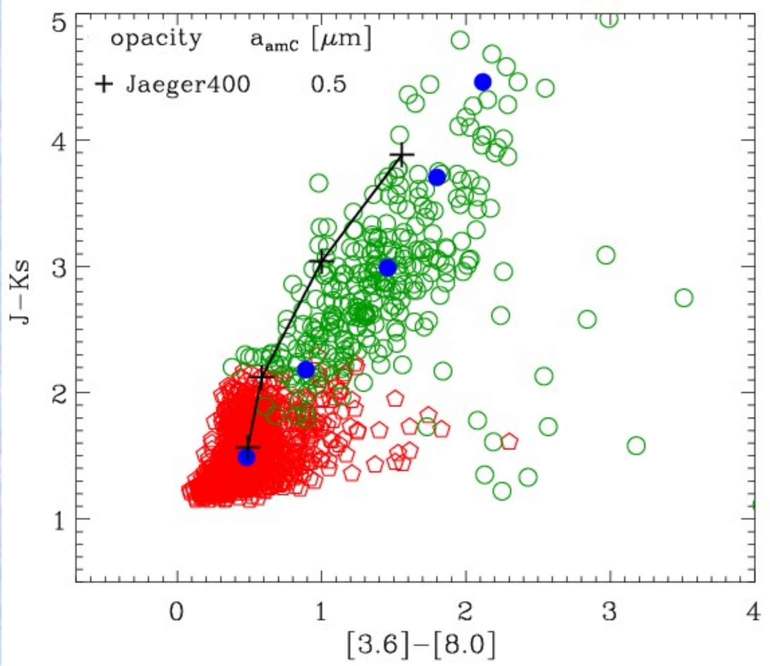
Optical properties of carbon grains



Different optical data sets and grains sizes yield different colors
→ We need to constrain the carbon optical data set and grain sizes

Color-color diagrams





Nanni et al. 16

We should reproduce the observed colors

simultaneously

Calibration

Colors

J-Ks, [3.6]-[8.0], J-[3.6], J-[8.0], Ks-[3.6], Ks-[8.0], [3.6]-[4.5], [5.8]-[8.0]

- An **observed star** occupies a **position** in the space of parameters provided by the **colors**
- The range of J-Ks of the observed data was divided in 5 bins

$$\sigma_c = \sqrt{\frac{\sum_{\rm model} \frac{(x_{\rm model} - x_{\rm av})^2}{\sigma^2_{\rm c,obs}}}{N_{\rm model}}}$$

- For each color "c"
- For each bin in J-Ks

$$\sigma = \frac{\sum_c \sigma_c}{N_c}$$

Including all the colors

$\langle\sigma\rangle$

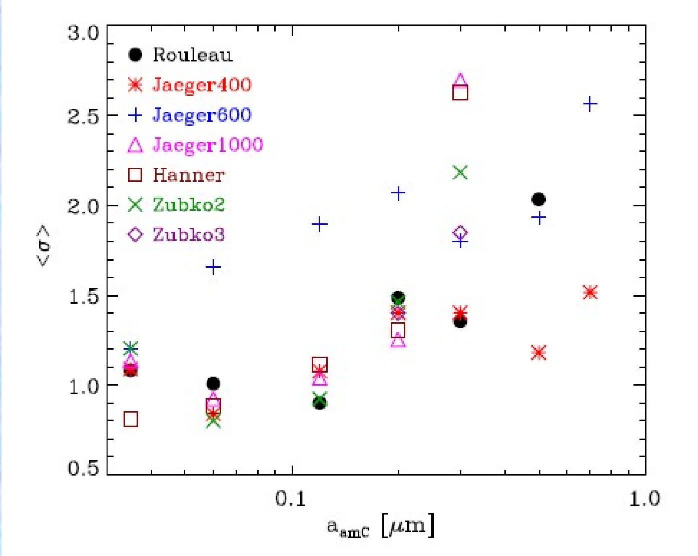
Average over all the bins

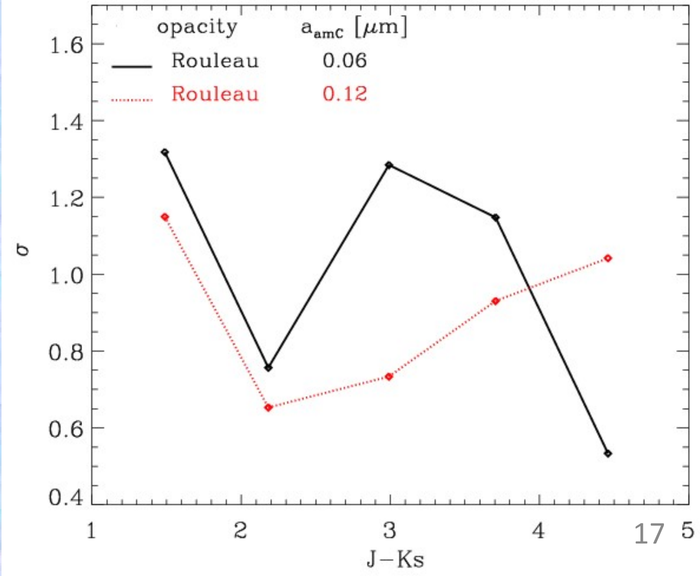
Results

➢**Larger deviations** for increasing grain sizes (**$a_{amC} \geq$ 0.2 μm**)

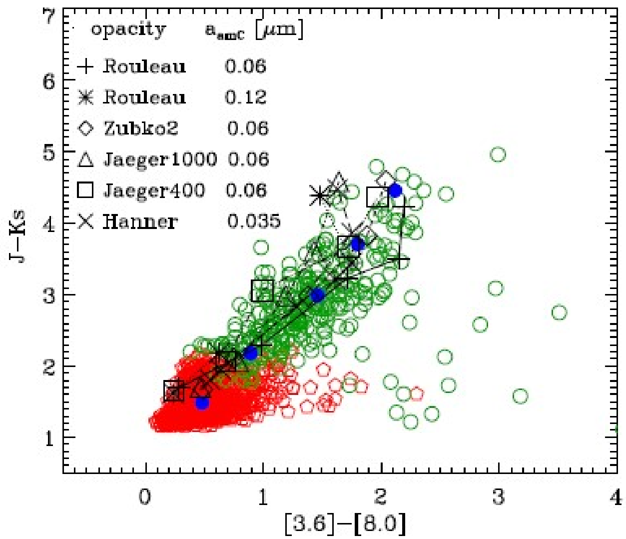
➢Observations are **best reproduced** by **"small" spherical grains** (**0.04 -0.1 microns**)
a_{amC}~0.1 μm from hydrodynamical computations (**Mattsson et al. 10**)

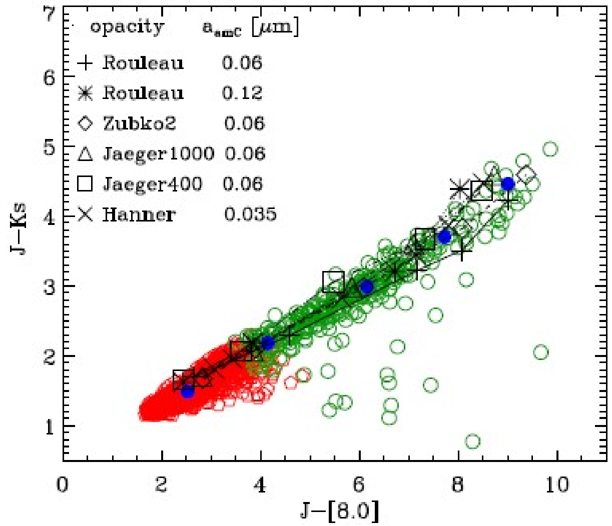
➢Possible trend between **a_{amC} and mass-loss** rate and/or **carbon excess**





Nanni et al. 16


opacity a_{amC} [μm]
Rouleau 0.06
Rouleau 0.12
Zubko2 0.06
Jaeger1000 0.06
Jaeger400 0.06
Hanner 0.035
J−Ks
[3.6]−[8.0]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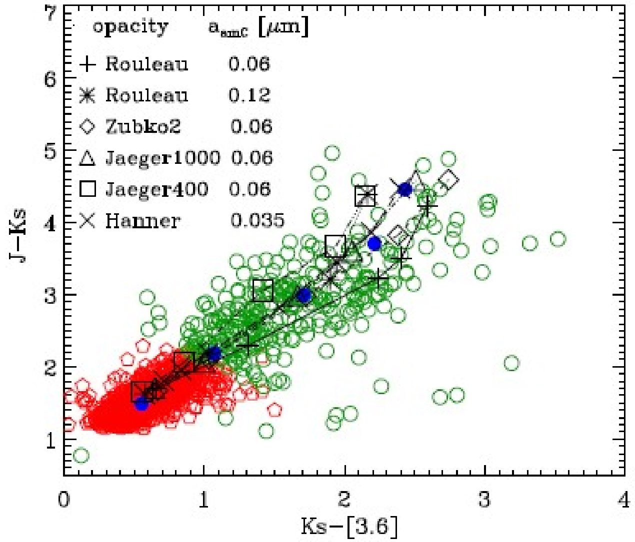
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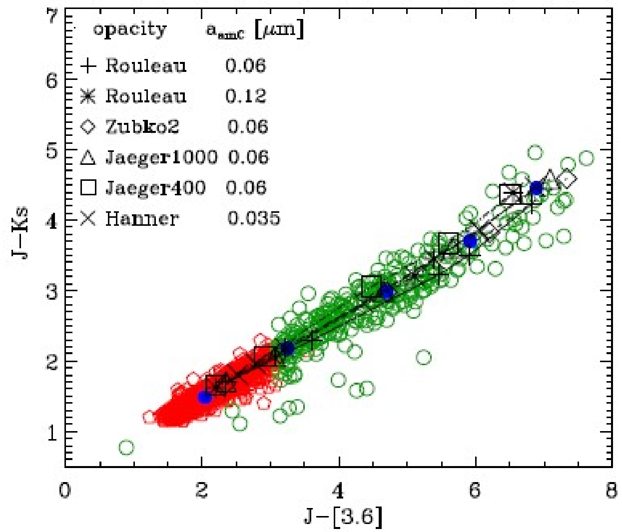
Hanner 0.035
J−Ks
Ks−[3.6]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J−Ks
J−[3.6]

Future work

- **Extend** the calibration to other spectral types (**M-stars**)
- Extend the calibration to **other galaxies** (**different metallicity**)
- Employ the calibrated models for **complete simulations of stellar populations (TRILEGAL)**