MODELLING DUST EVOLUTION WITH THEMIS

Dust properties from diffuse to dense ISM

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Outline

Observed variations in dust properties

Diffuse ISM
Dense ISM

The Heterogeneous dust Evolution Model for Interstellar Solids

Dust components
A core/mantle dust model

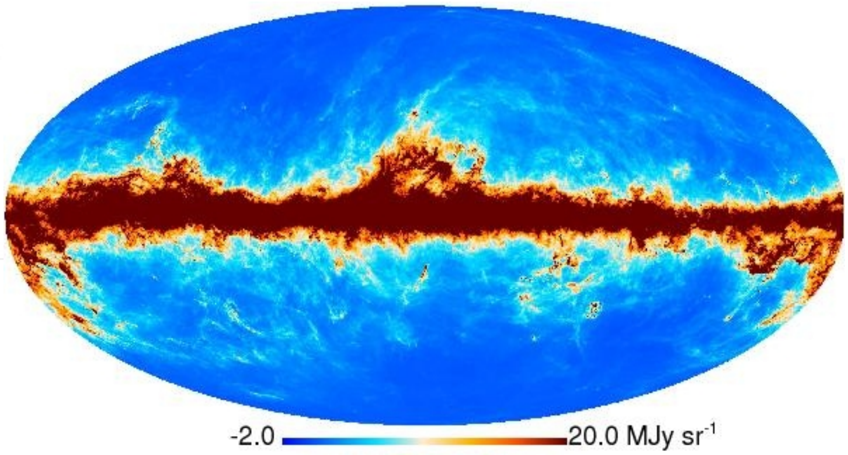
THEMIS: comparison with observations

$\left.\begin{array}{l}\text{Diffuse ISM}\\\text{Dense ISM}\end{array}\right\}$ emission + scattering

Observed variations in dust properties

Diffuse ISM observations

All-diffuse-sky variations in the dust opacity Planck Collaboration XI (2014): $N_H < 3\times10^{20}$ H/cm^2



IRAS - 100 µm
Planck-HFI - 350 µm
- 550 µm
- 850 µm

- Fit of each pixel of the sky

$$I_\nu = N_H\, \sigma_{\nu 0}\, B_\nu(T)\, (\nu/\nu_0)^\beta$$

column density ↗ N_H
opacity ↑ $\sigma_{\nu 0}$
Planck function ↖ $B_\nu(T)$
spectral index ↖ β

- Additional parameters

$L_H = \int I_\nu \, d\nu / N_H$ ← luminosity
$\tau_{\nu 0} = N_H\, \sigma_{\nu 0}$ ← optical depth

- Comparison with extinction

$$E(B\text{-}V) = A_B - A_V$$

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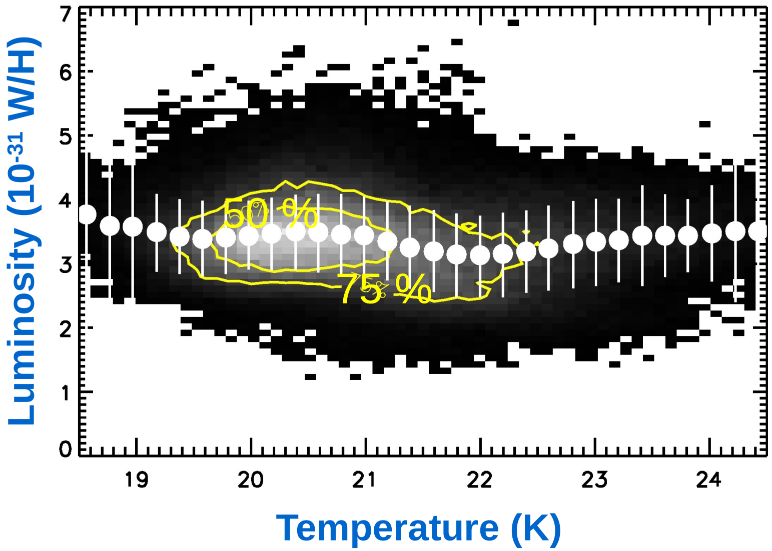

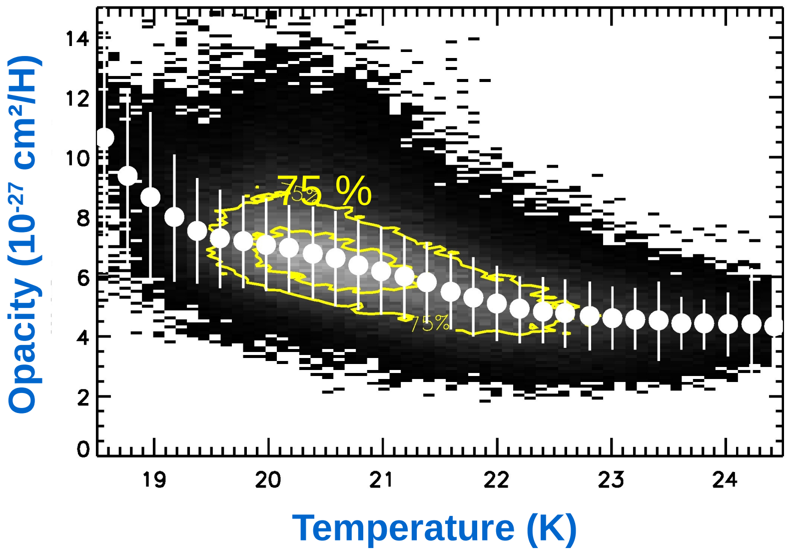

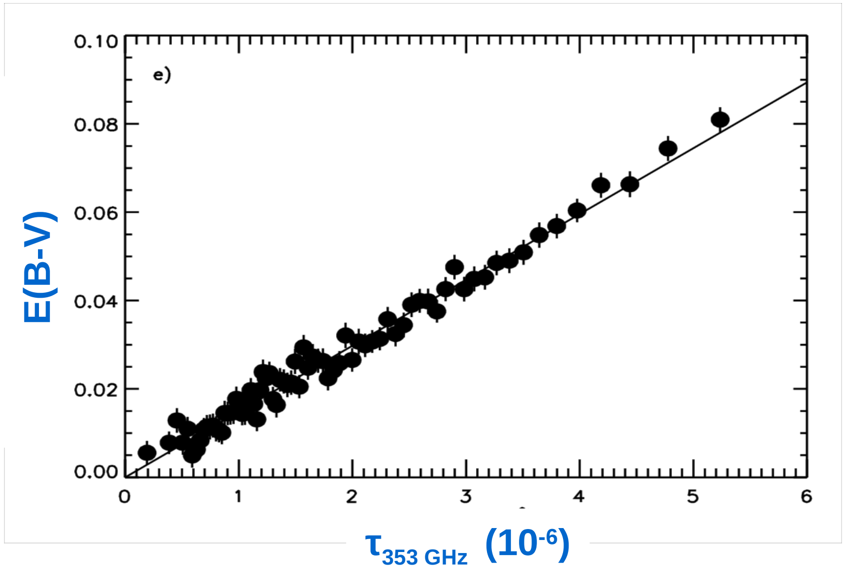

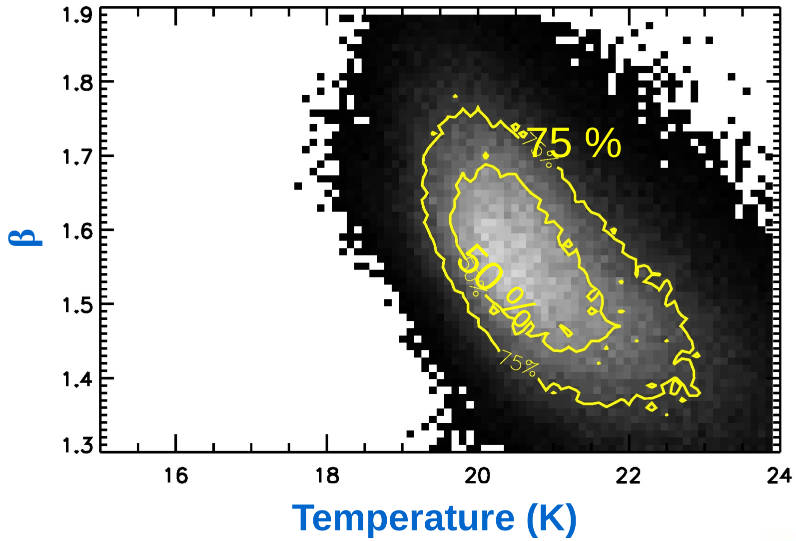

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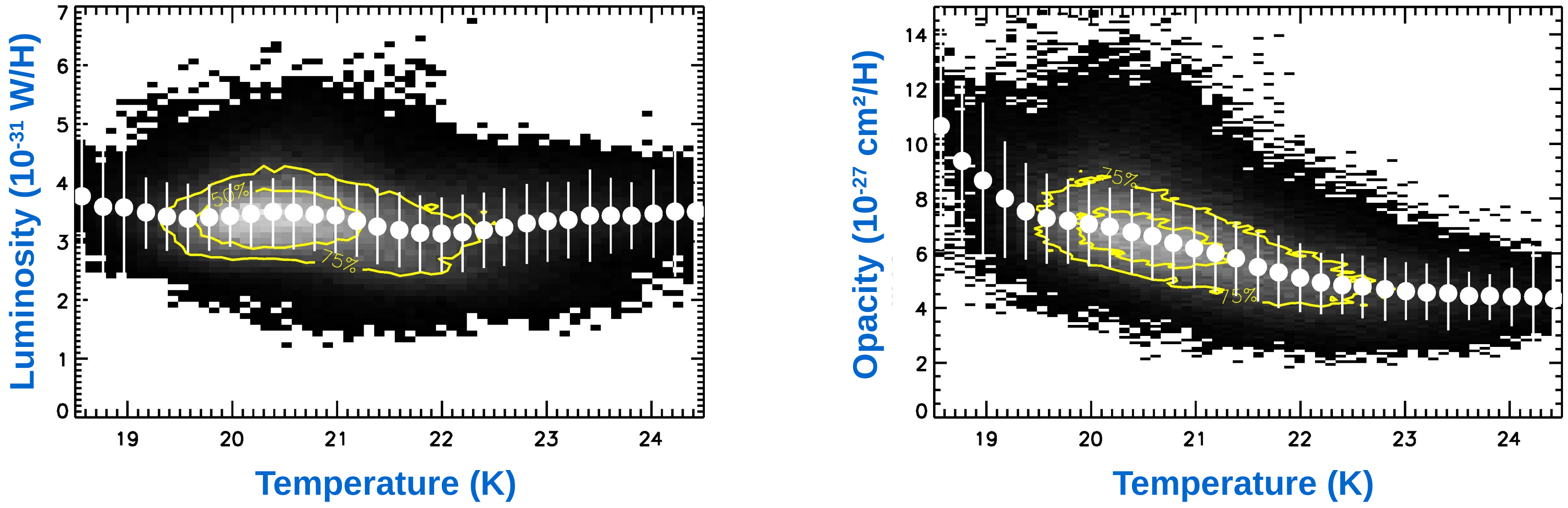


- $N_H < 3\times10^{20}$ H/cm^2

- E(B-V) from SDSS data towards quasars

- Observational results
  - → β-T variations
  - → luminosity independent of T
  - → hotter grains = less emissive grains

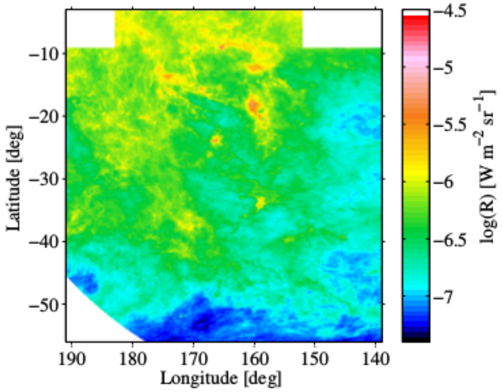
- Recent studies about variations in the DISM
  - → Reach et al. (2015, 2017)
  - → Murray et al. (2018)
  - → Nguyen et al. (2018)

- Possible explanations
  - → gas-to-dust mass ratio
  - → C depletion in grains
  - → dust properties

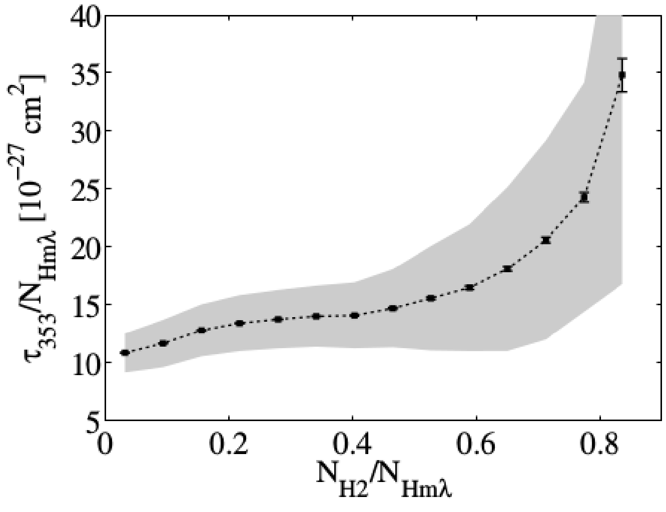
➡ **dust evolves in the diffuse ISM**

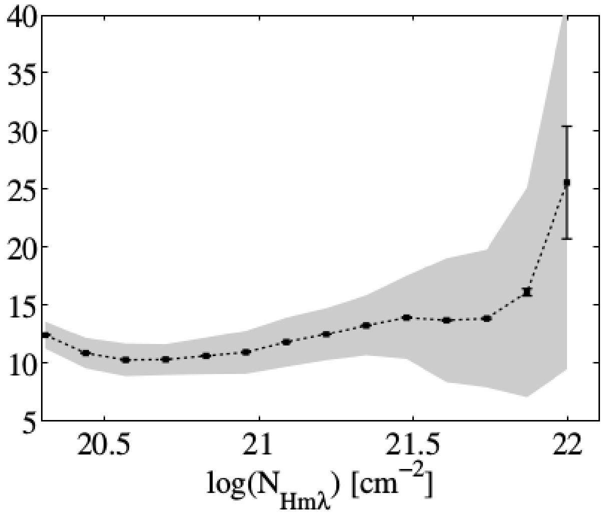
Dense ISM observations

Far-IR/submm opacity increase & temperature decrease & (β, T) relation
Rémy et al. (2017, 2018): 6 nearby anti-centre clouds



- Observations towards Cetus, Taurus, Perseus and California regions
- Usual behaviour of dense clouds
  - T_{dust} ↘
  - $\tau_{submm/FIR}$ and β ↗
- Gradual evolution across all phases
  - significant in DNM
  - stronger in CO





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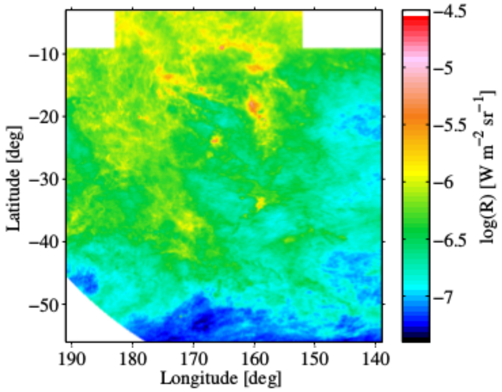

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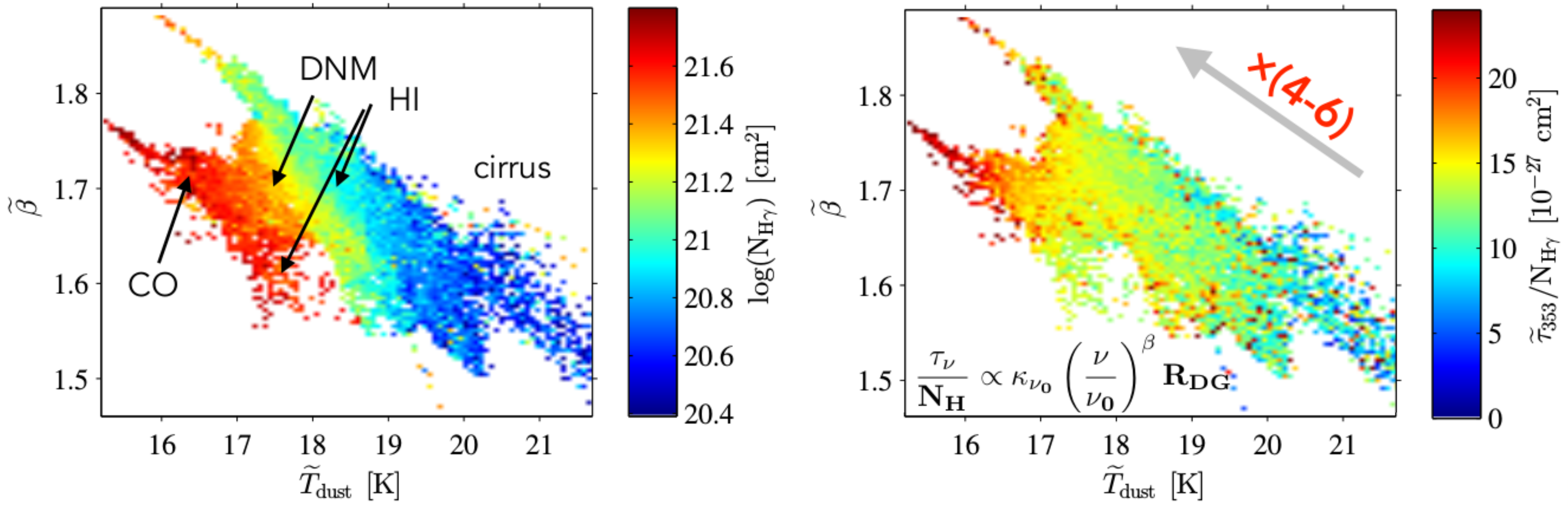


THEMIS
→ The Heterogeneous dust Evolution Model for Interstellar Solids

What dust components are included ?

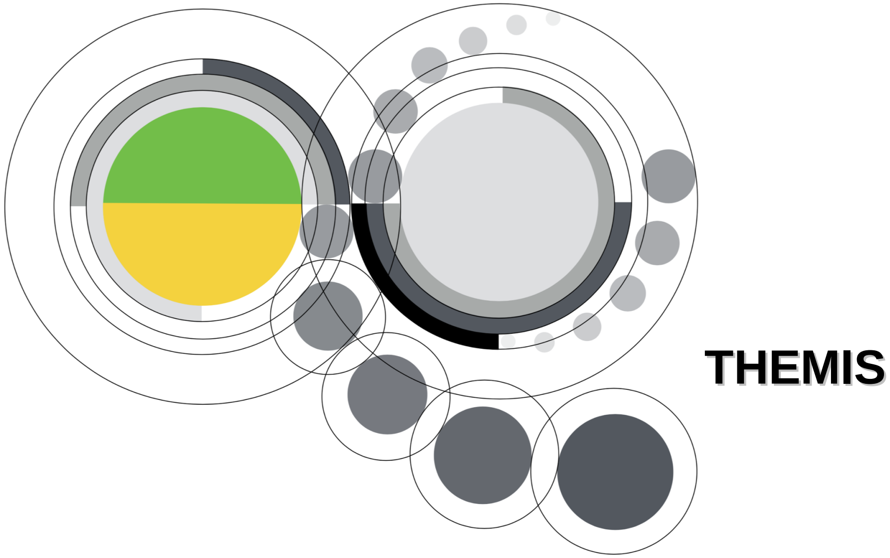
- Use optical properties based on laboratory data

  Dartois et al. (2004, 2005), Jena group's DDOP , Menella et al. (1995),
  Ordal et al. (1985, 1988), Pollack et al. (1994), Rouleau & Martin (1991),
  Scott & Duley (1996), Smith (1984), Zubko et al. (1996)
  and very soon Demyk et al. (2017)

- Size- and surface-dependent a-C(:H) optical properties

- Mg-rich amorphous silicates with metallic nano-inclusions

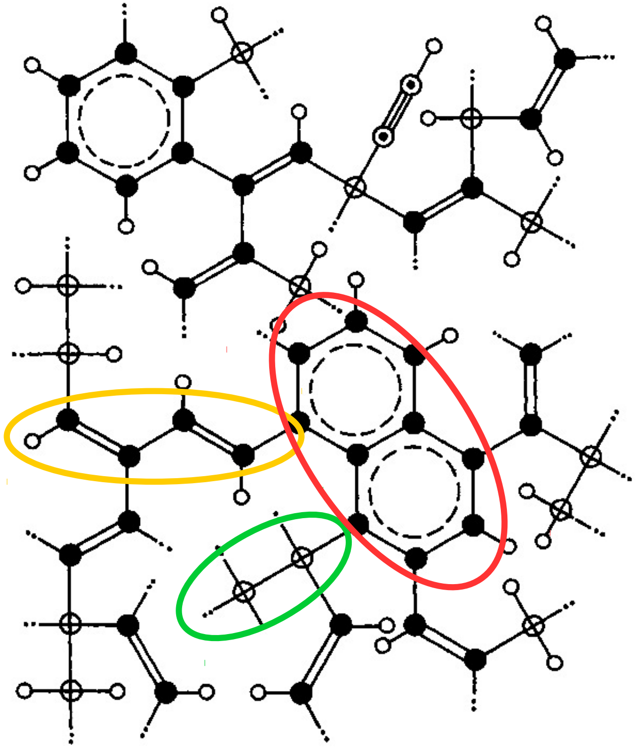
- Core-mantle particles CM



Dust components

a-C(:H) materials { a-C:H ↔ a-C }

aliphatic	C-C sp^3 C atoms
olefinic	C=C sp^2 C atoms
aromatic	C=C sp^2 C atoms



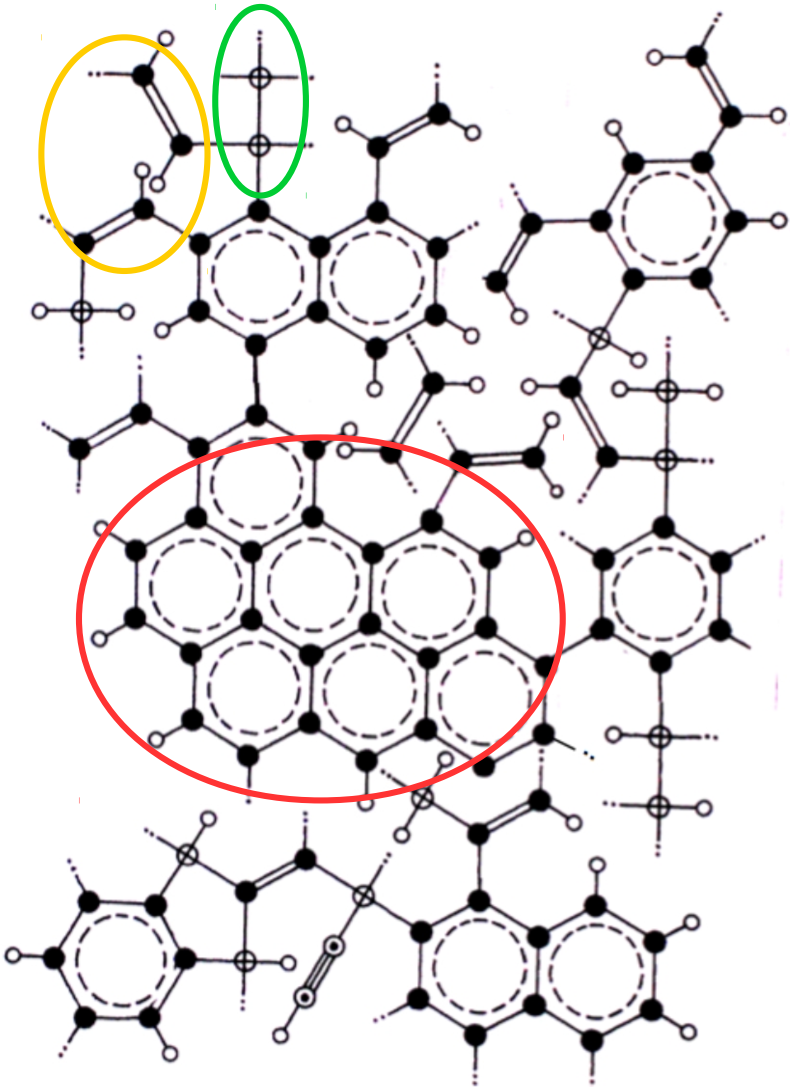
EUV photolysis

ion irradiation

heat

increase in aromatic domain size

H atom loss from structure & smaller band gap

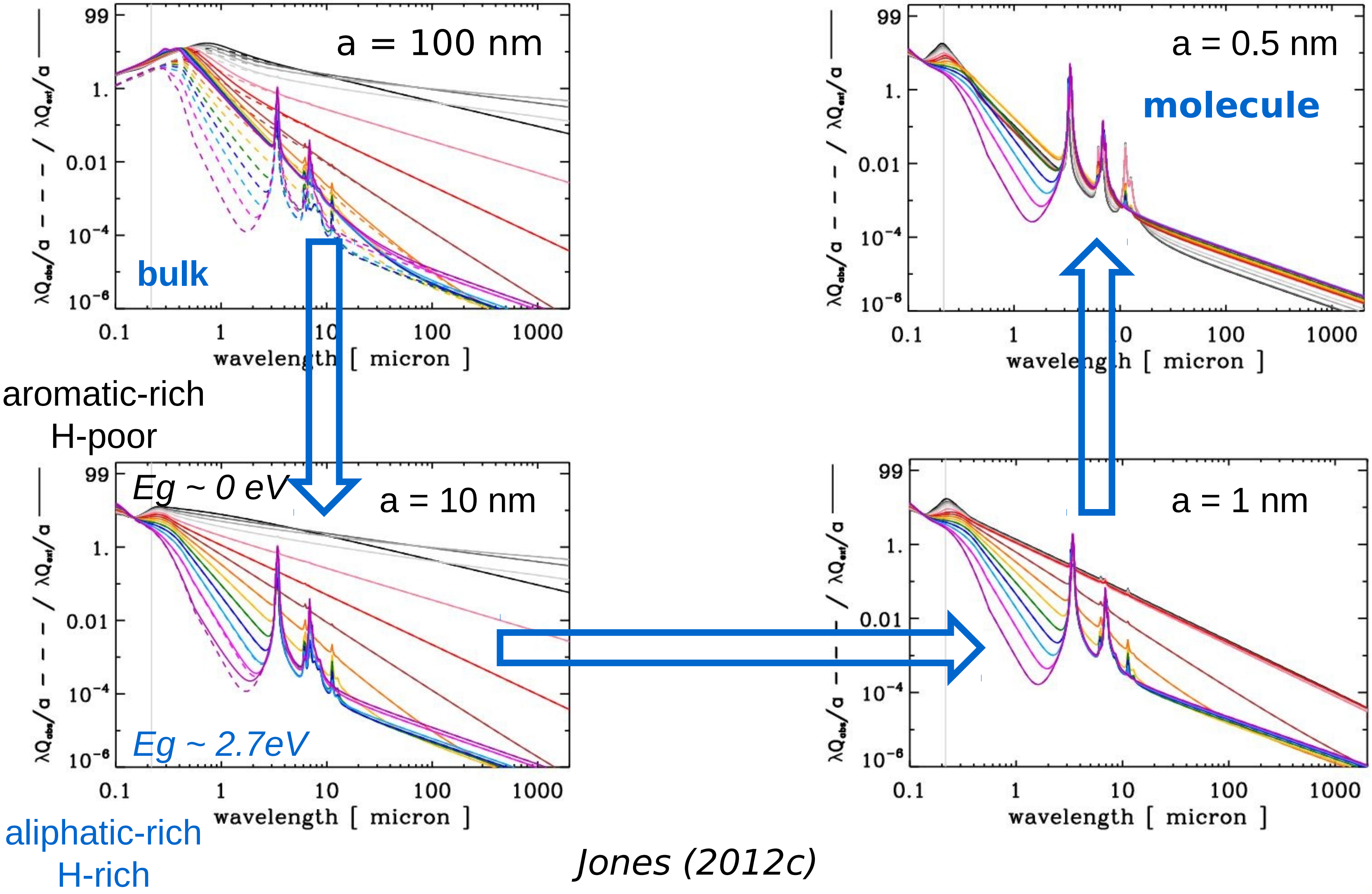


Jones, Williams & Duley (1990)
Micelotta et al. (2012)
Jones (1990, 2012abc)
Jones et al. (2013)

Dust components

a-C(:H) materials { a-C:H ↔ a-C }

$\lambda Q_{ext}/a$ from ‘’n’’ and ‘’k’’ calibrated on laboratory data



Jones (2012c)

Dust components

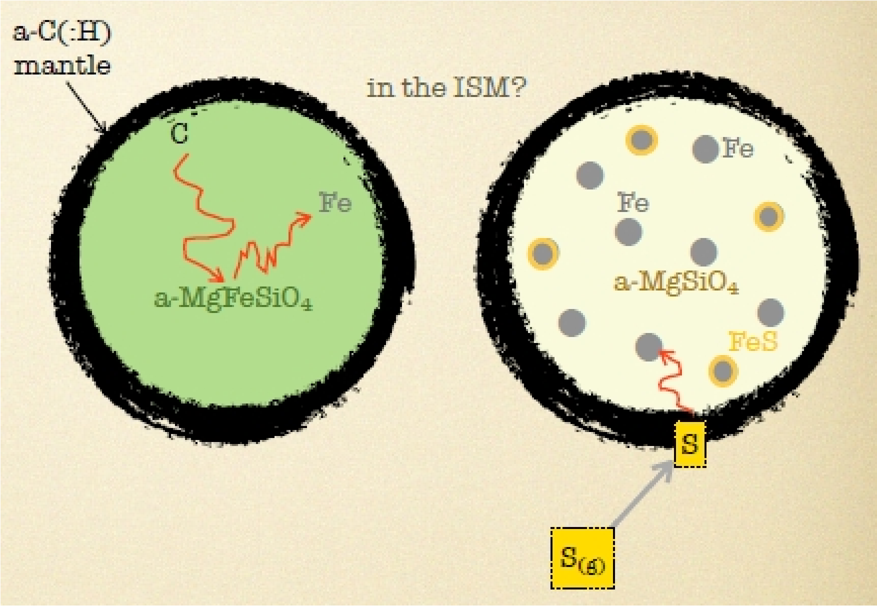
Amorphous silicates

- 50%-50% olivine & pyroxene normative compositions
  → optical properties based on lab data

- Aromatic-rich/H-poor amorphous carbon mantle around the silicate core

- Amorphous silicate annealed in the presence of carbon
  → reduction of Fe & formation of Fe nano-particles
  → FeS inclusions

Davoisne et al. (2006), Djouadi et al. (2007)



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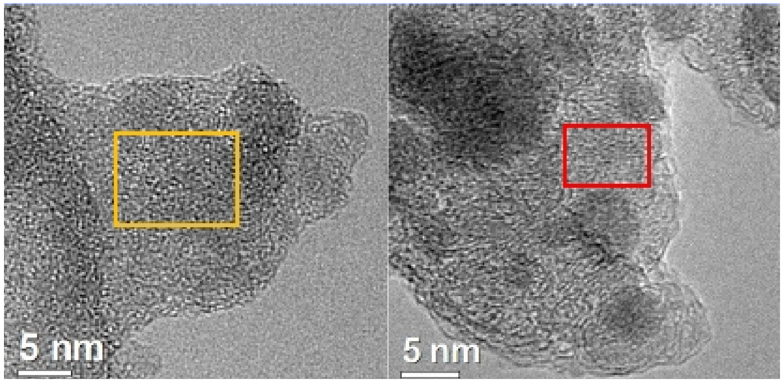
Davoisne et al. (2006), Djouadi et al. (2007)

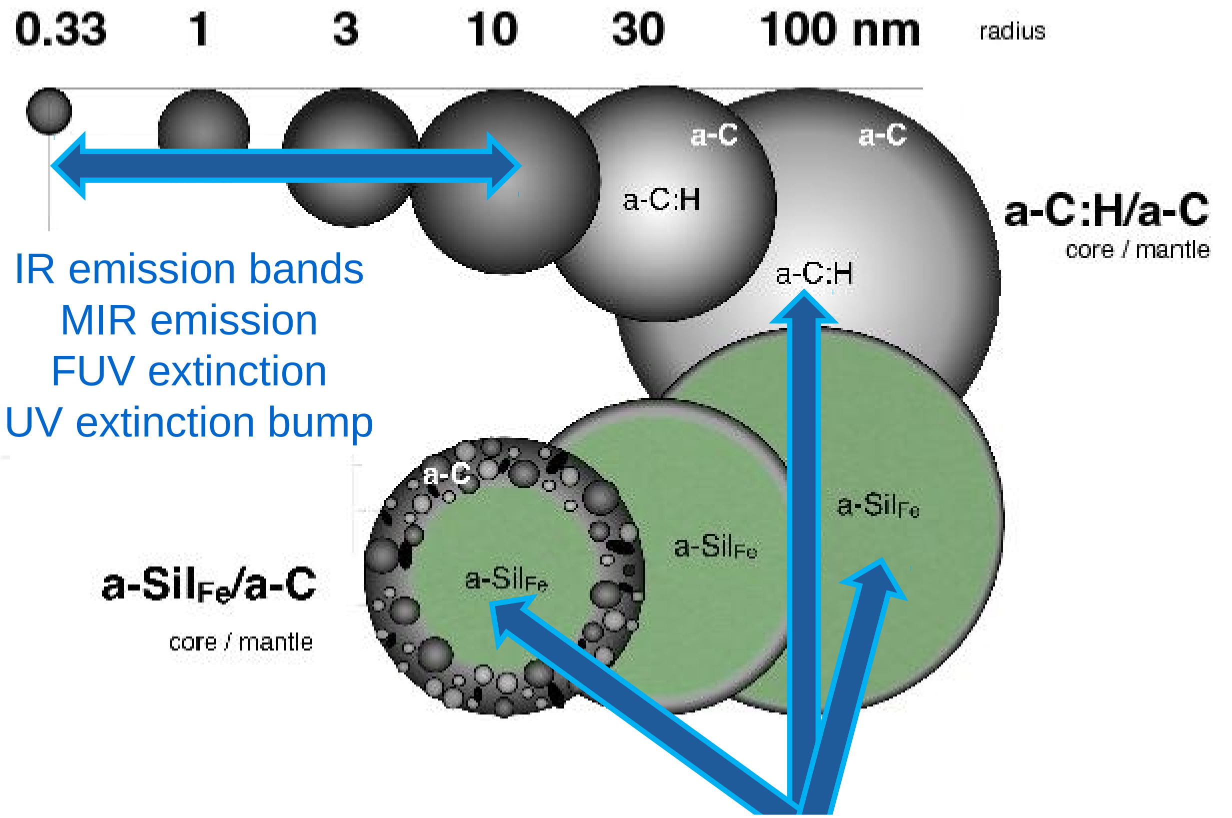
- H^+ bombardment of amorphous silicates with Fe in the matrix
  → selective oxygen sputtering
  → reduction of Fe^{2+} to metallic Fe

Jäger et al. (2016)



THEMIS for the diffuse ISM

Core-mantle dust model → CM



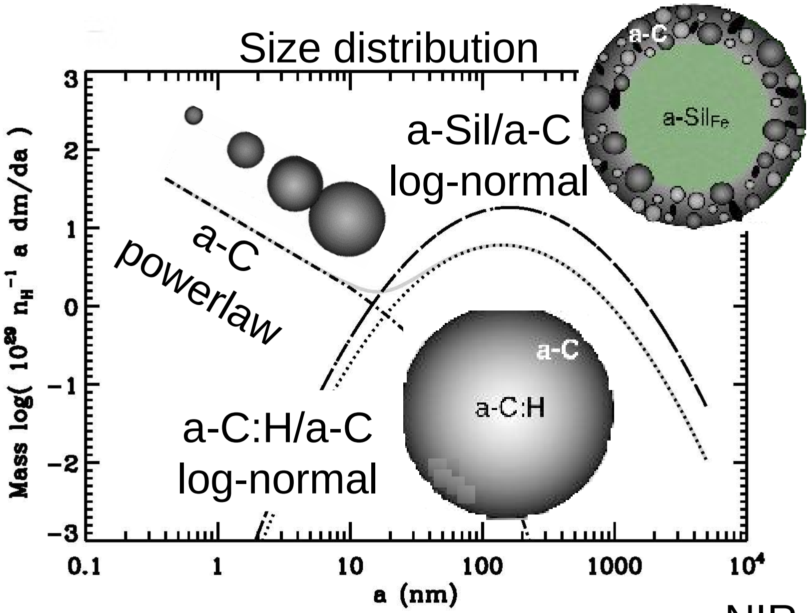
IR emission bands
MIR emission
FUV extinction
UV extinction bump

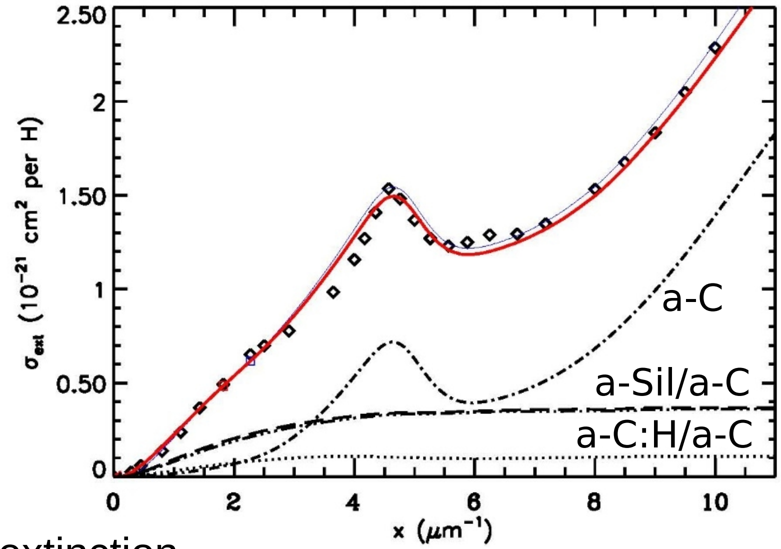
IR absorption bands
visible/MIR extinction
FIR/submm emission

Jones et al. (2013)
Köhler, Jones & Ysard (2014)
Jones, Köhler, Ysard et al. (2017)

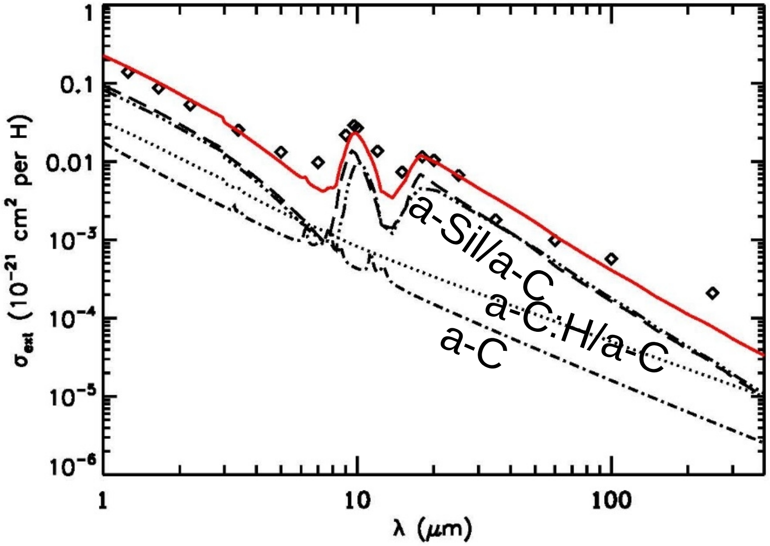
THEMIS for the diffuse ISM

Core-mantle dust model → CM


Size distribution


IR-vis-UV extinction

NIR-FIR extinction

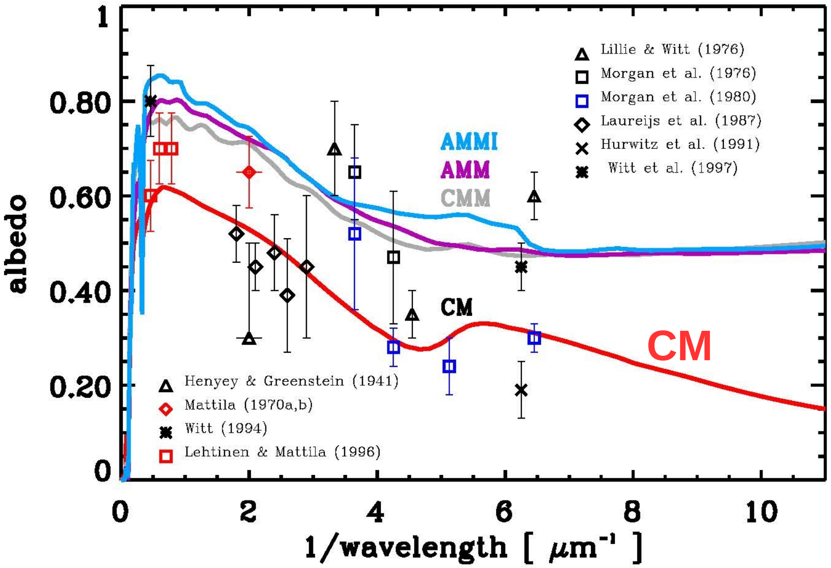


Jones et al. (2013)
Köhler, Jones & Ysard (2014)
Jones, Köhler, Ysard et al. (2017)

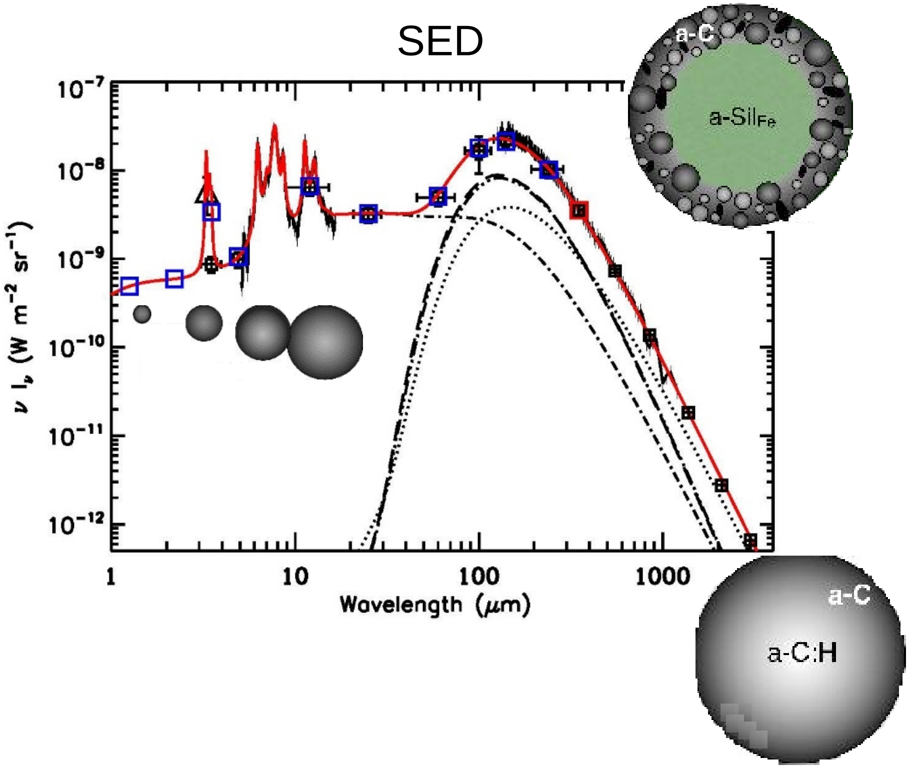
THEMIS for the diffuse ISM

Core-mantle dust model → CM

Albedo



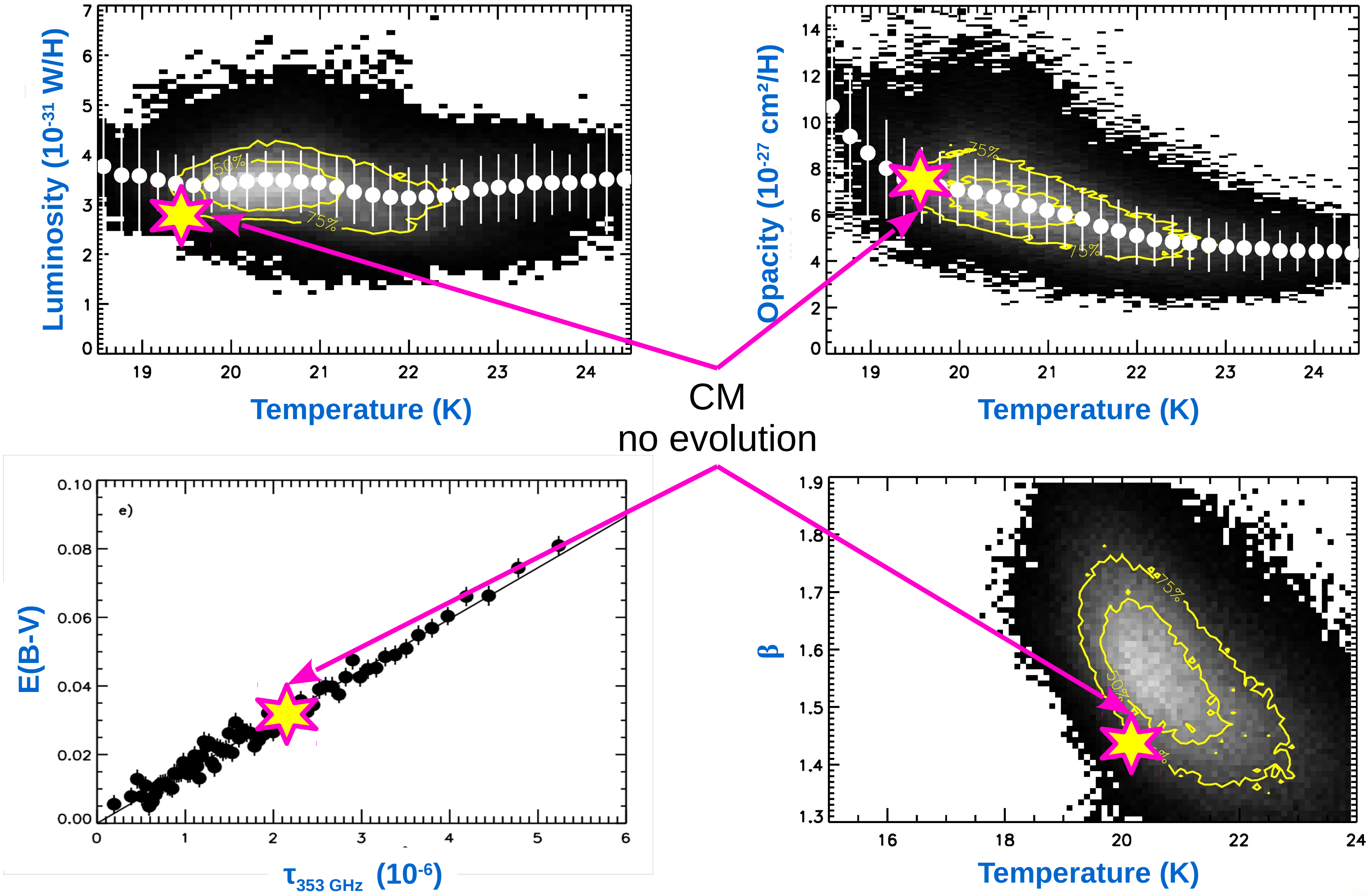
SED



Jones et al. (2013)
Köhler, Jones & Ysard (2014)
Jones, Köhler, Ysard et al. (2016, 2017)

THEMIS
→ Dust evolution in the diffuse ISM

Comparison with Planck Collaboration XI (2014)

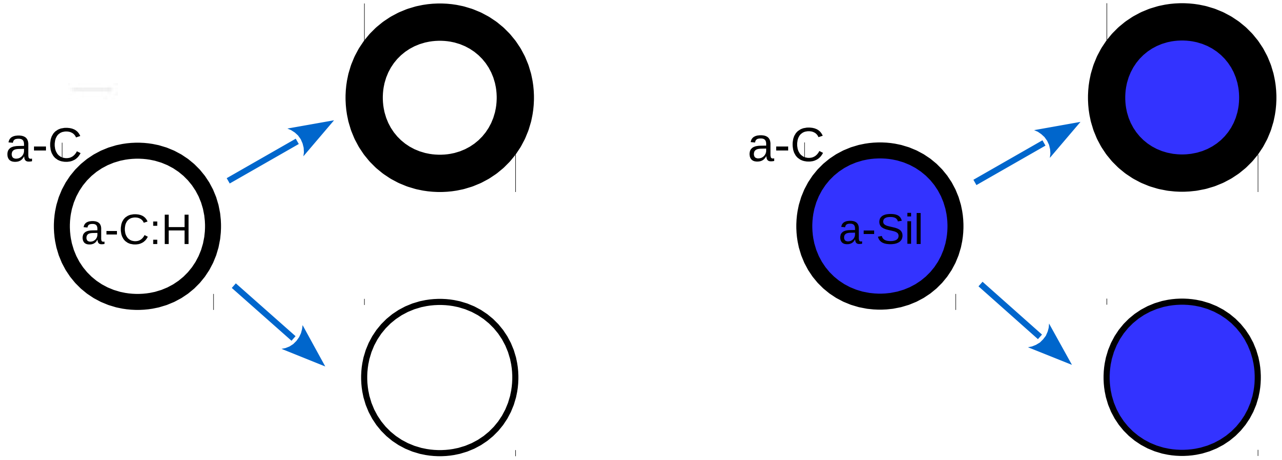


CM
no evolution

Ysard, Köhler & Jones (2015)

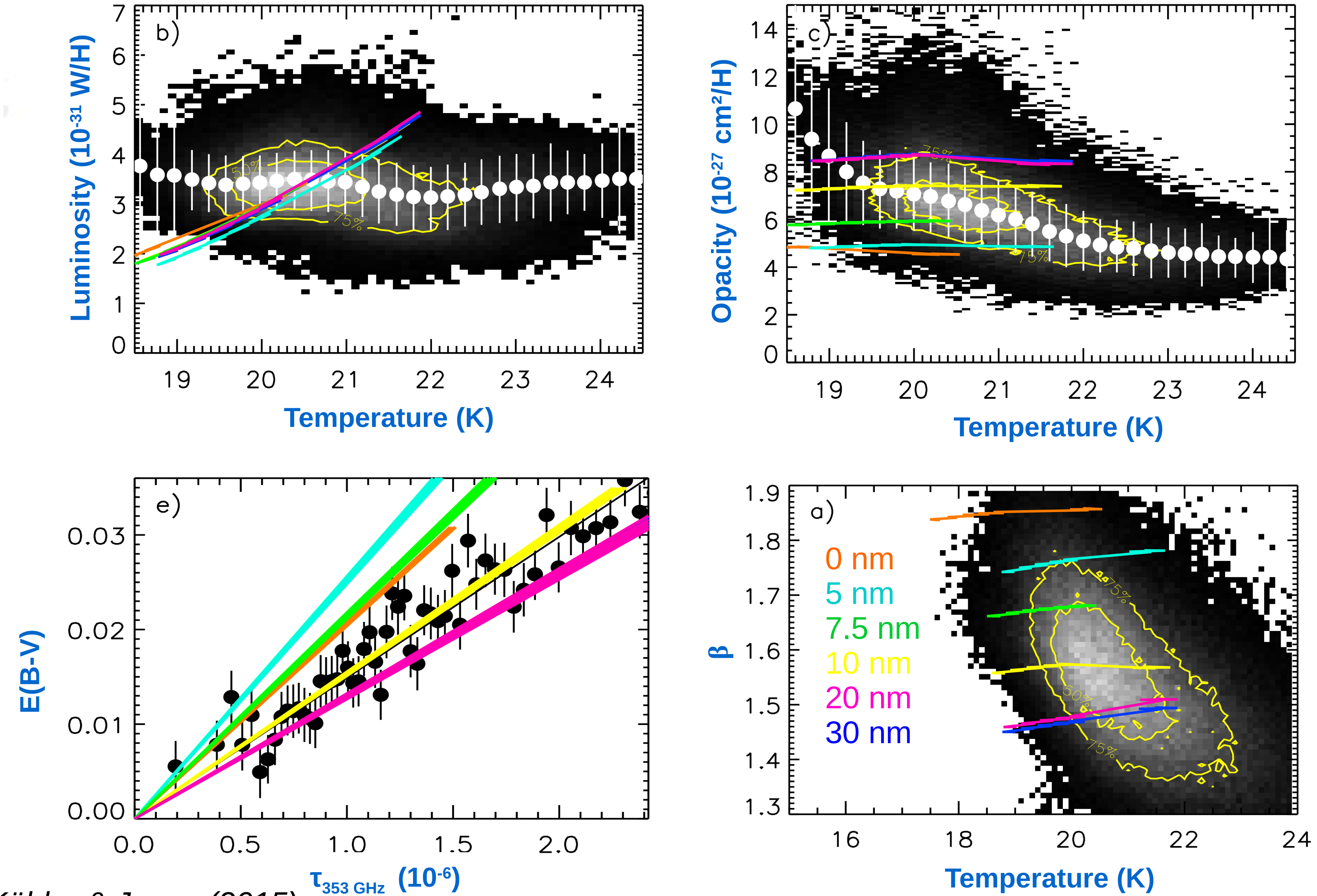
What do we expect to vary in the diffuse ISM ?

- Radiation field
- Grain size distribution
- Fe and FeS inclusions
- Carbon mantle thickness
- Total abundance of C in dust



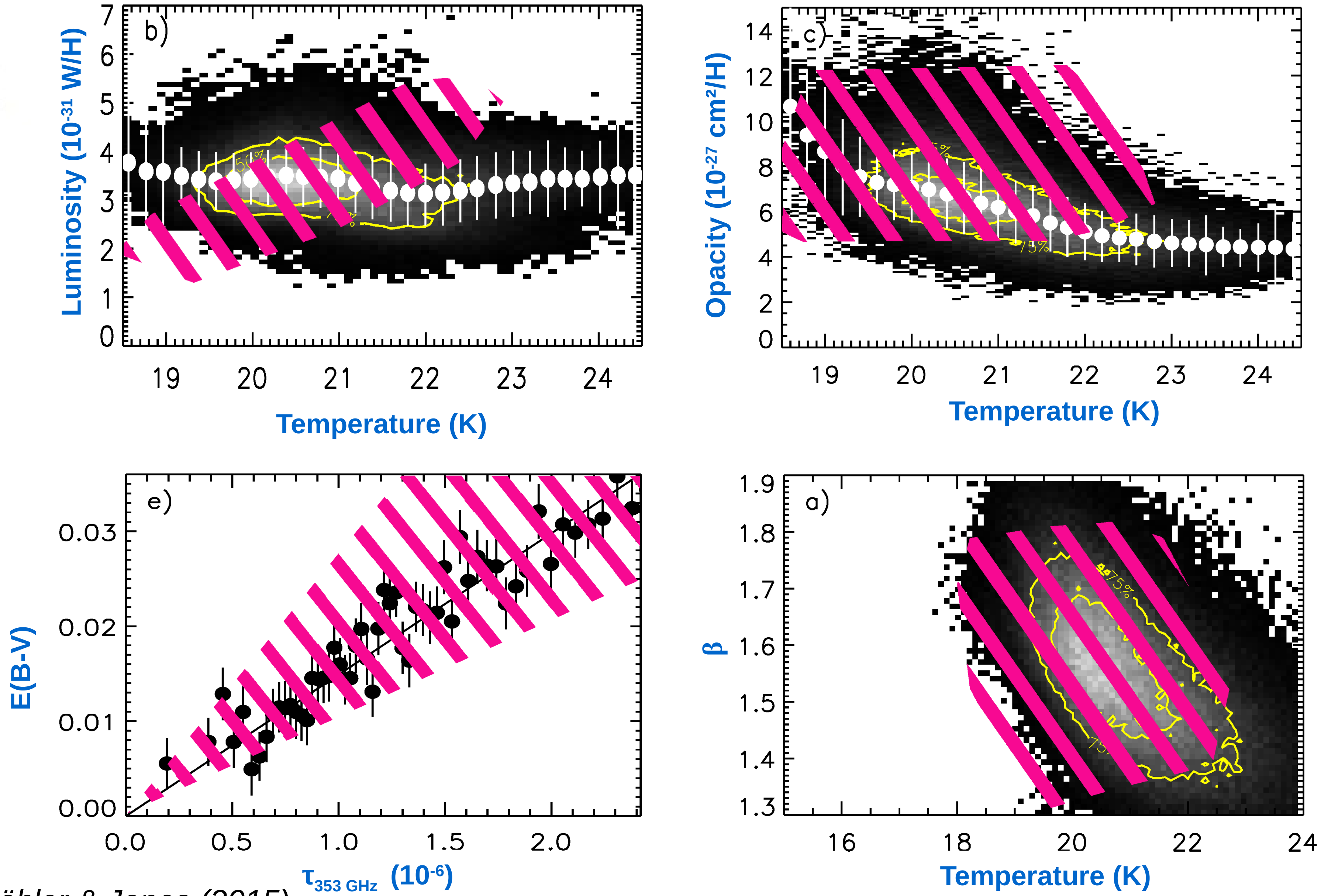
Ysard, Köhler & Jones (2015)

Example : variations in the a-C:H/a-C mantle thickness



Ysard, Köhler & Jones (2015)

And varying (almost) everything

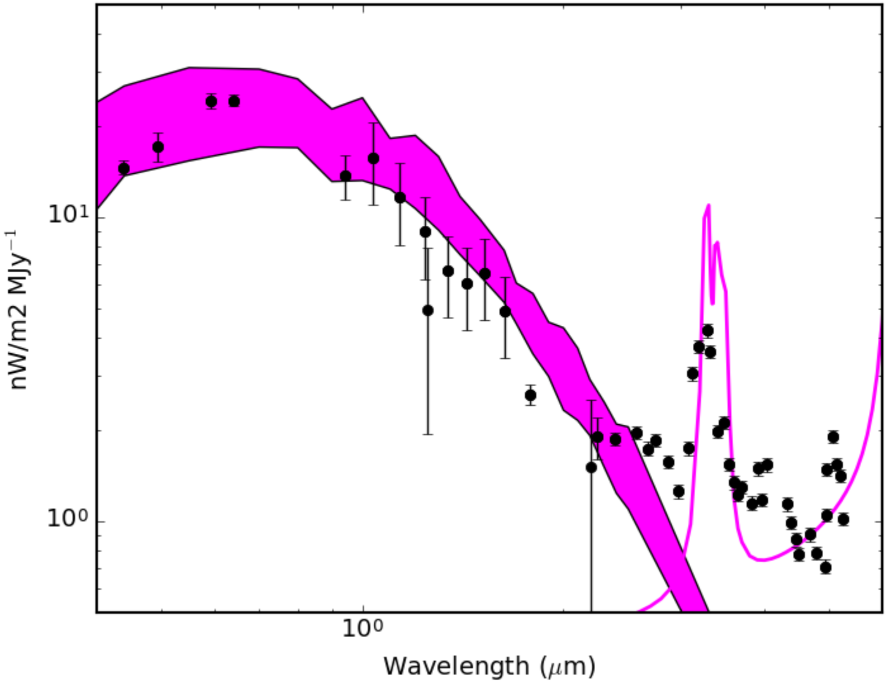


Ysard, Köhler & Jones (2015)

Diffuse Galactic Light

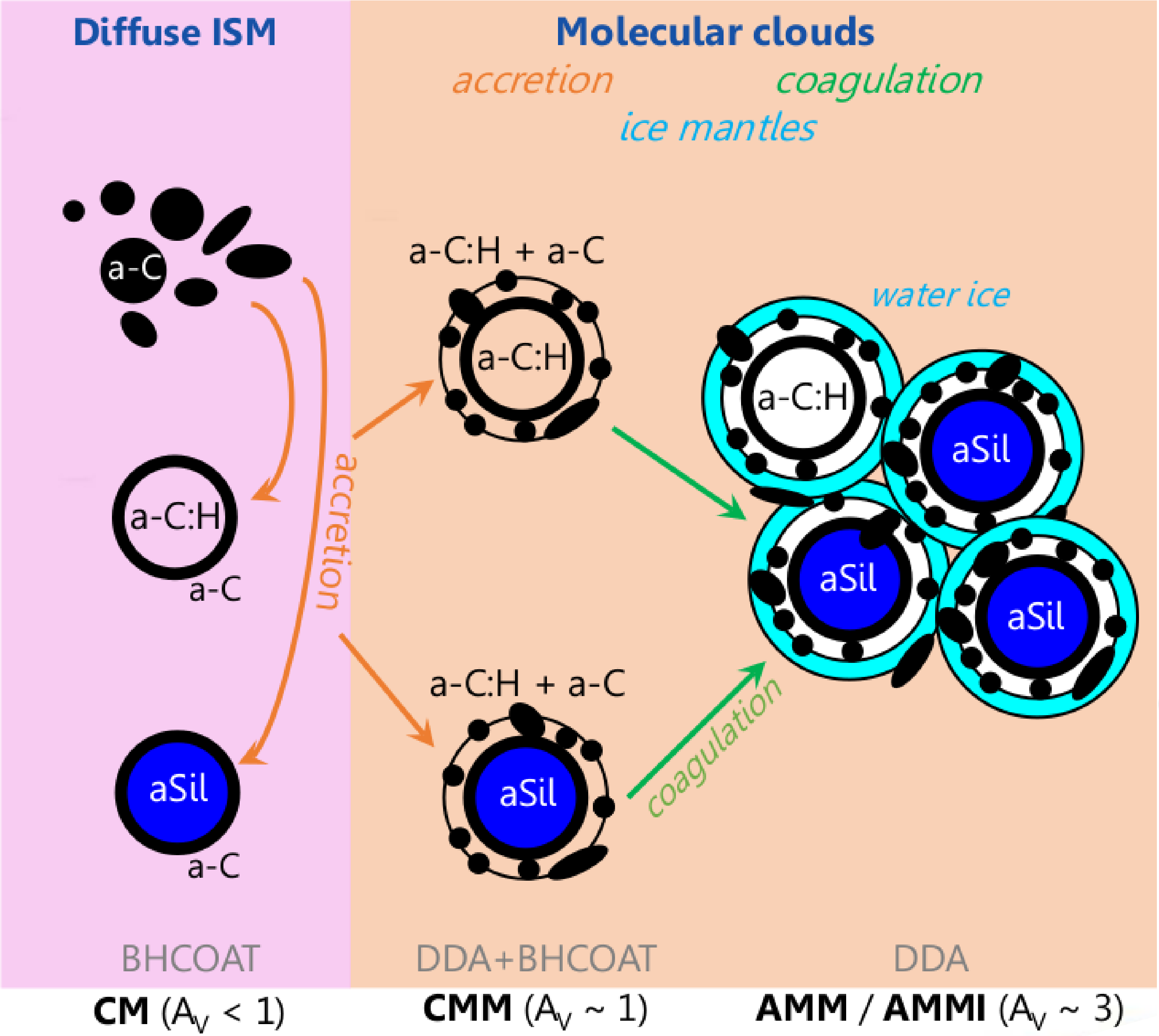
- DGL data points from Sano et al. (2015) and references therein
- Variable mantle thickness on both carbonaceous and silicate grains
- Dust property variations required to explain Planck data consistent with DGL observations

near-IR / 100 µm



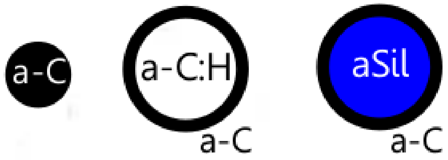
THEMIS
→ Dust evolution in the dense ISM

THEMIS from diffuse to dense ISM



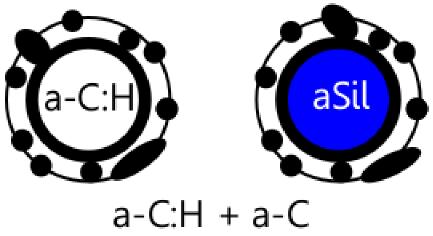
Köhler, Ysard & Jones (2015)

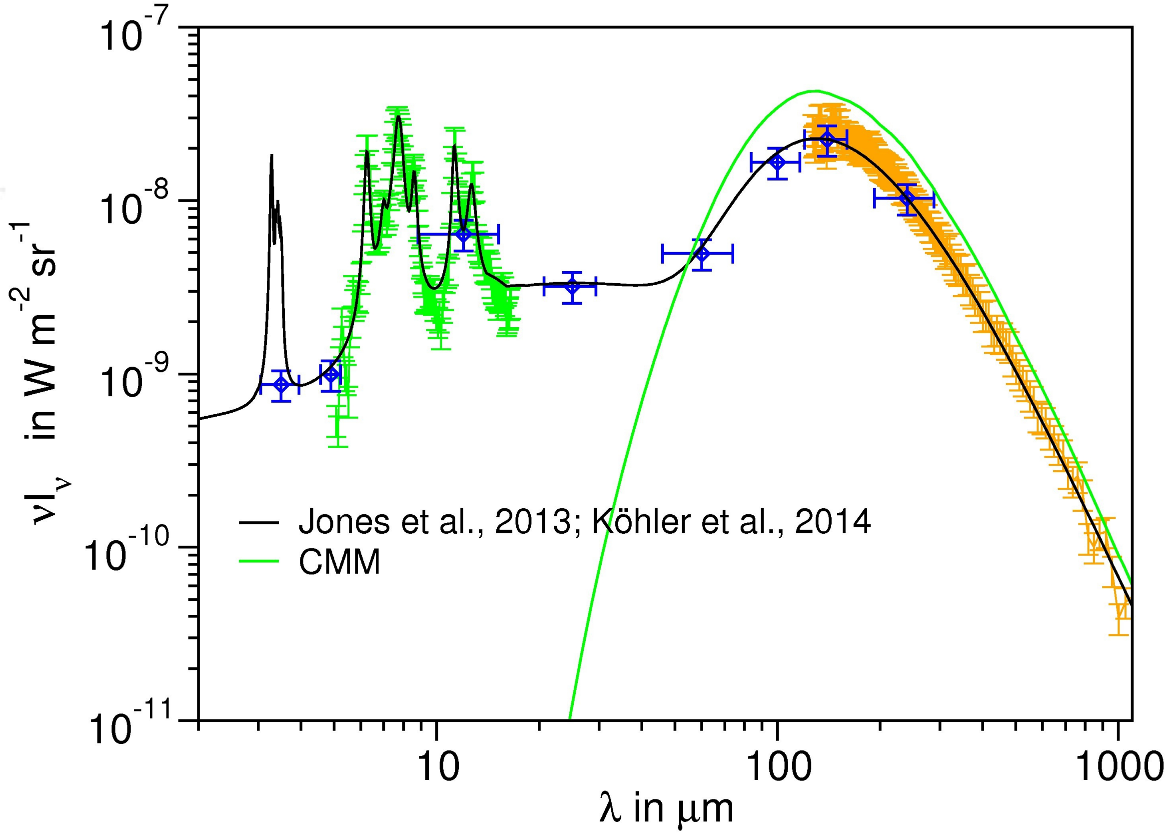
THEMIS SED variations



← **CM**

CMM→

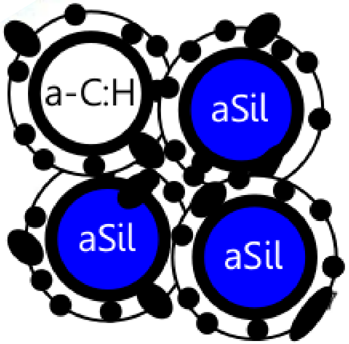


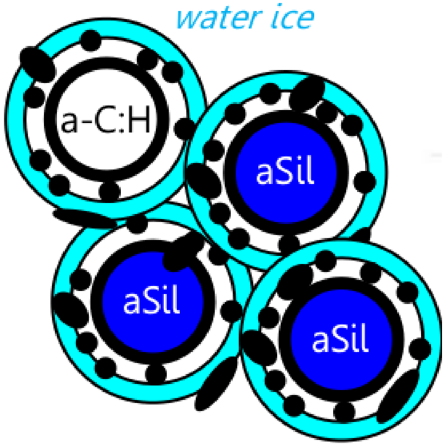


Köhler, Ysard & Jones (2015)

THEMIS from diffuse to dense ISM

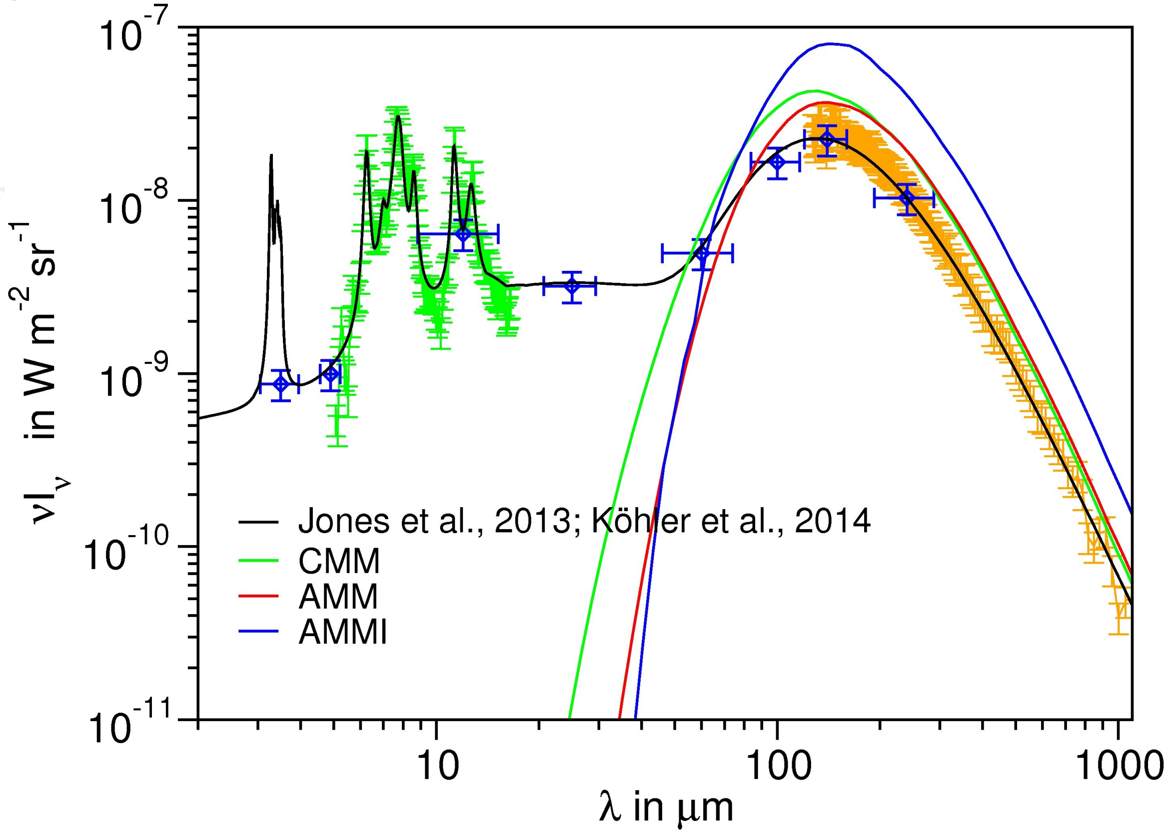
THEMIS SED variations





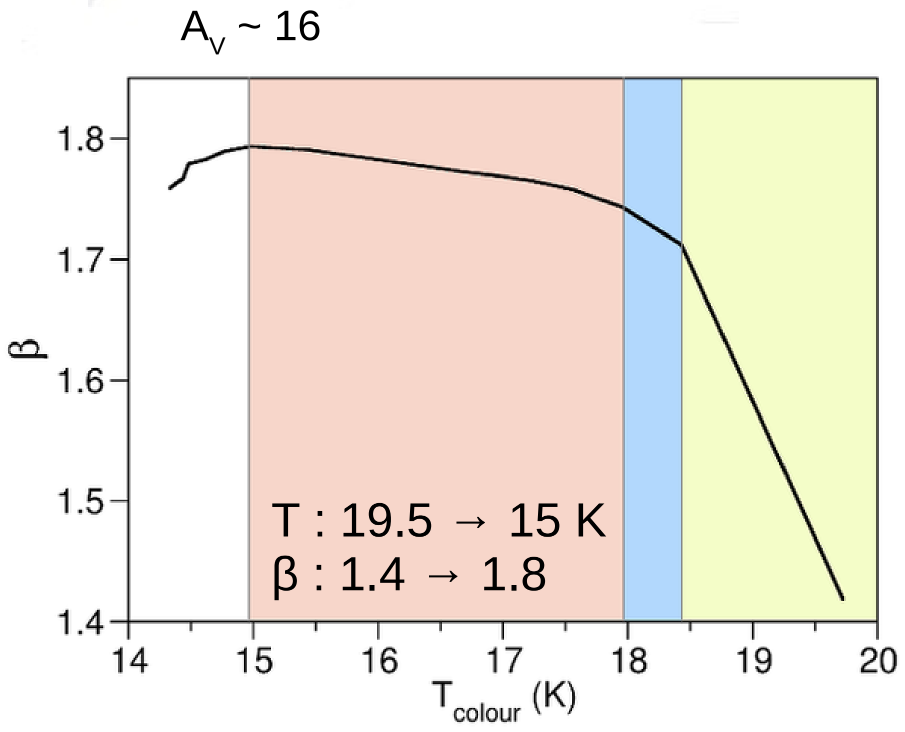
← AMM **AMMI→**

a < 0.25 µm → ~ 50% of mass
0.25 < a < 0.5 µm → ~ 40% of mass
a > 0.5 µm → ~ 10% of mass

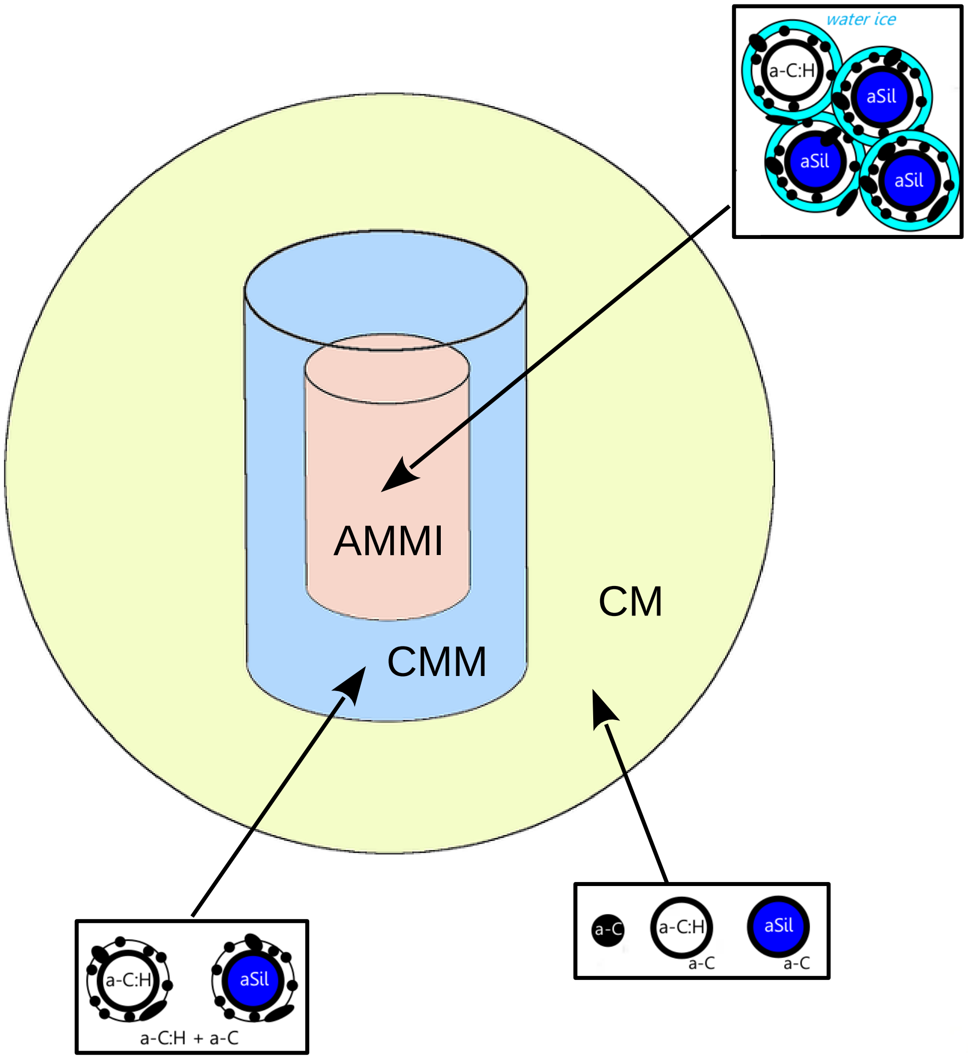


Köhler, Ysard & Jones (2015)

SED variations with radiative transfer effects



Modified blackbody fits in Planck + IRAS bands

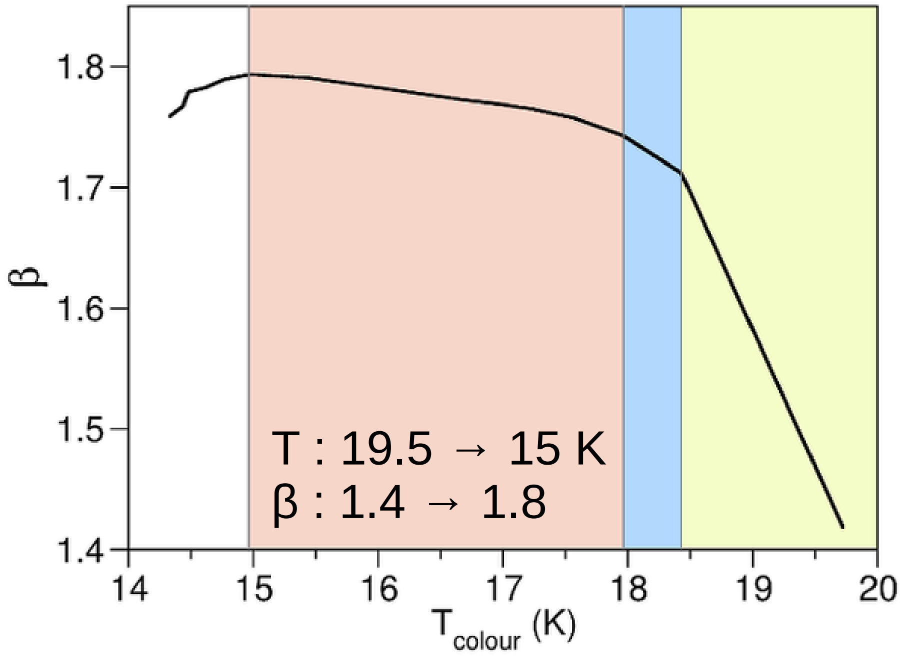


Köhler, Ysard & Jones (2015)

THEMIS + 3D radiative transfer

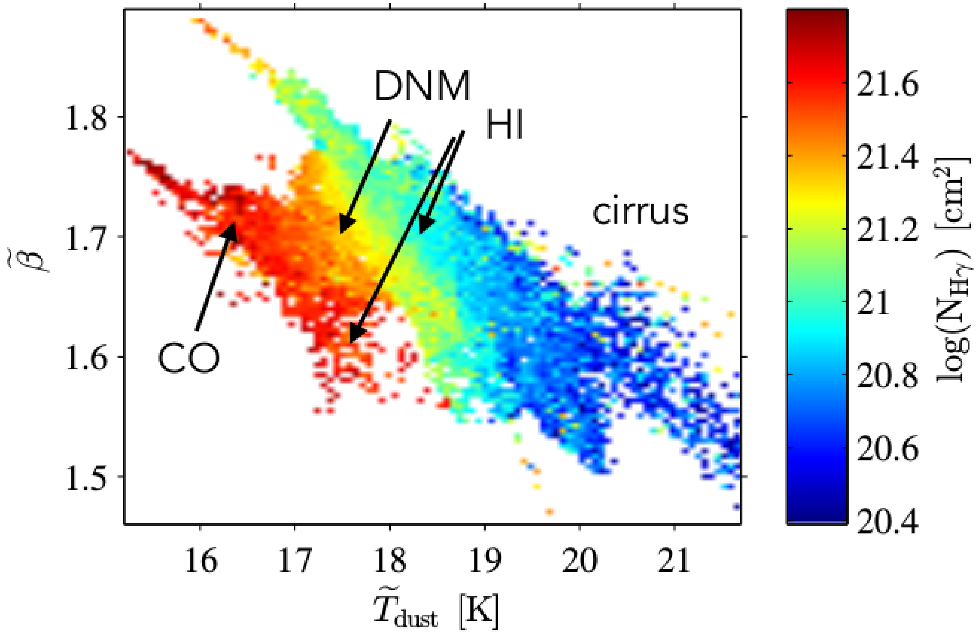
SED variations with radiative transfer effects

A_V ~ 16



Modified blackbody fits in Planck + IRAS bands

Rémy et al. (2017)

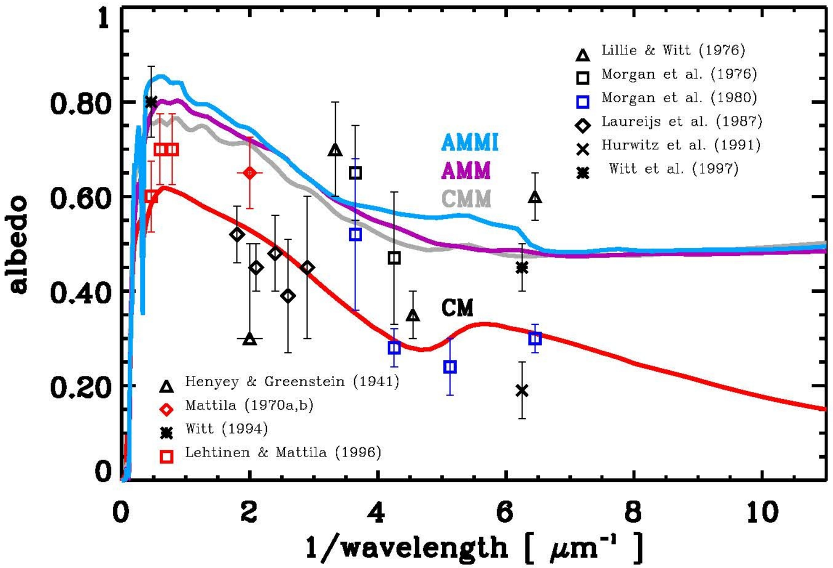


Köhler, Ysard & Jones (2015)

Scattering efficiency : Q_{sca}/Q_{ext}

- In agreement with near-IR albedo and g-factor measurements
  Mattila (1970, 2018), Lehtinen & Mattila (1996)

- Increase in albedo mainly due to a-C:H accretion: Q_{abs} → while Q_{sca} ↗



Jones, Köhler & Ysard (2016)

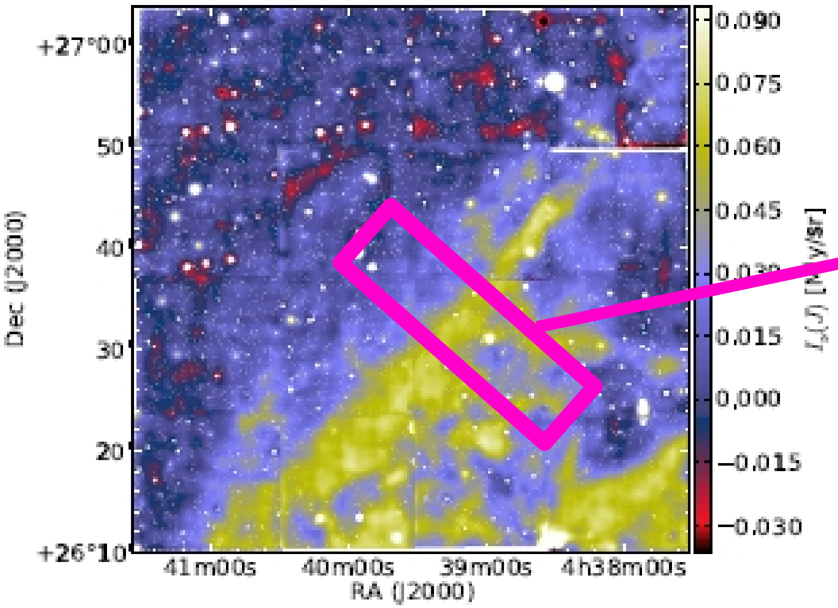
Near-IR scattering: cloudshine

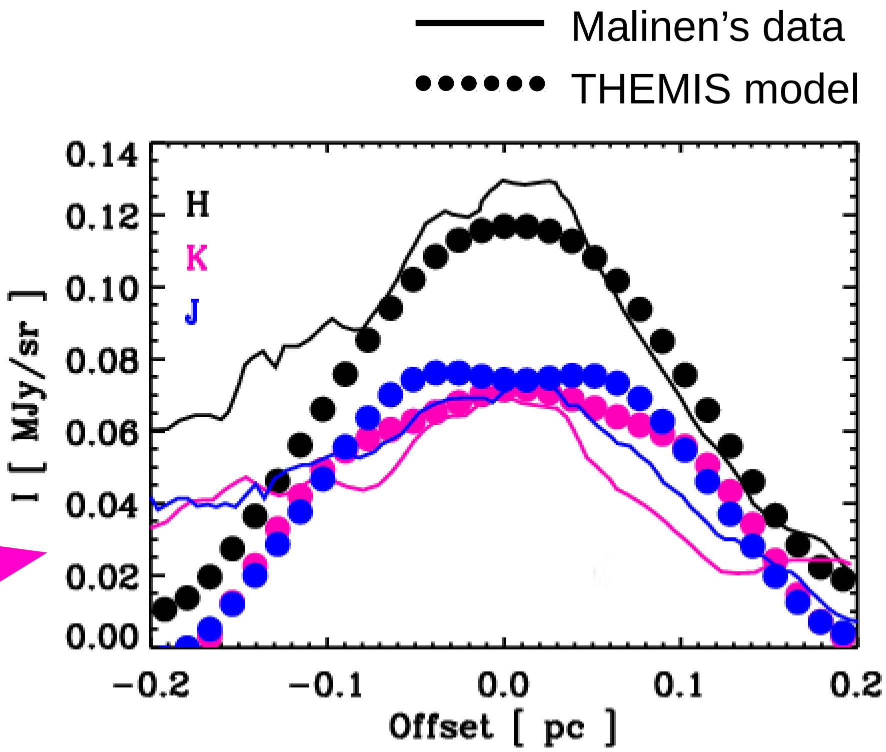
Dense filament in Taurus : Malinen et al. (2013)

→ WFCAM camera on UKIRT
near-IR photometric bands J, H, K

→ Herschel PACS + SPIRE data
model cloud with $\rho_C = 10^4$ H/cm^3, p = 3, and $A_V^{ext} = 1.5$

J map of TMC-1N





Ysard, Köhler & Jones (2016)

Summary

- **Dust evolution as a function of local conditions seems to be the key**

- **What can THEMIS explain ?**
  - ➝ dust SED and its variations in the diffuse ISM
  - ➝ diffuse galactic light peak position and width
  - ➝ general shape and variation trends of the extinction curve
  - ➝ variations in carbon depletion
  - ➝ temperature decrease and opacity increase in dense clouds
  - ➝ β-T variations from diffuse ISM to moderately dense clouds
  - ➝ cloud/coreshine from the visible to mid-IR

- **Current work on THEMIS**
  - ➝ new silicate lab data from Demyk et al. (2017)
  - ➝ non-spherical grains for polarisation
  - ➝ complex aggregates/huge grains (Ysard et al. 2018 + Köhler et al. in prep)
  - ➝ near-IR bands in protoplanetary disks (Boutéraon et al. to be subm.)

- **How to use THEMIS ?**
  - ➝ everything about THEMIS
    https://www.ias.u-psud.fr/themis/
  - ➝ run your own calculations with DustEM
    https://www.ias.u-psud.fr/DUSTEM/