CPHDUST2018

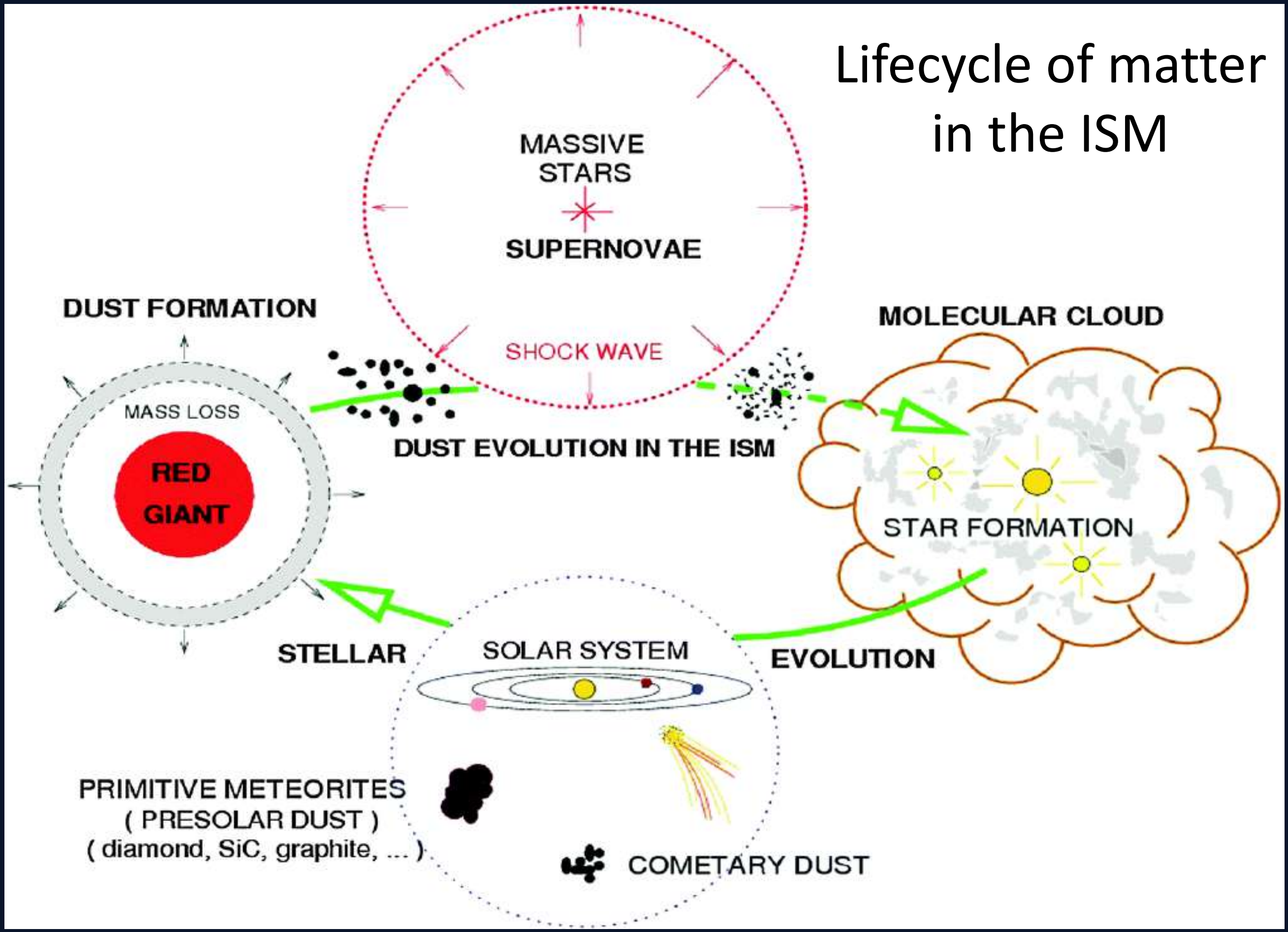
The properties of interstellar dust in the Milky Way and in nearby galaxies

Maud Galametz, CEA Saclay

DUST : A TRACER OF GALAXY EVOLUTION

A strong diagnostic tool

- Role in the ISM chemistry, heating and cooling
- Tracer of the gas reservoirs
- Tracer of the SFR



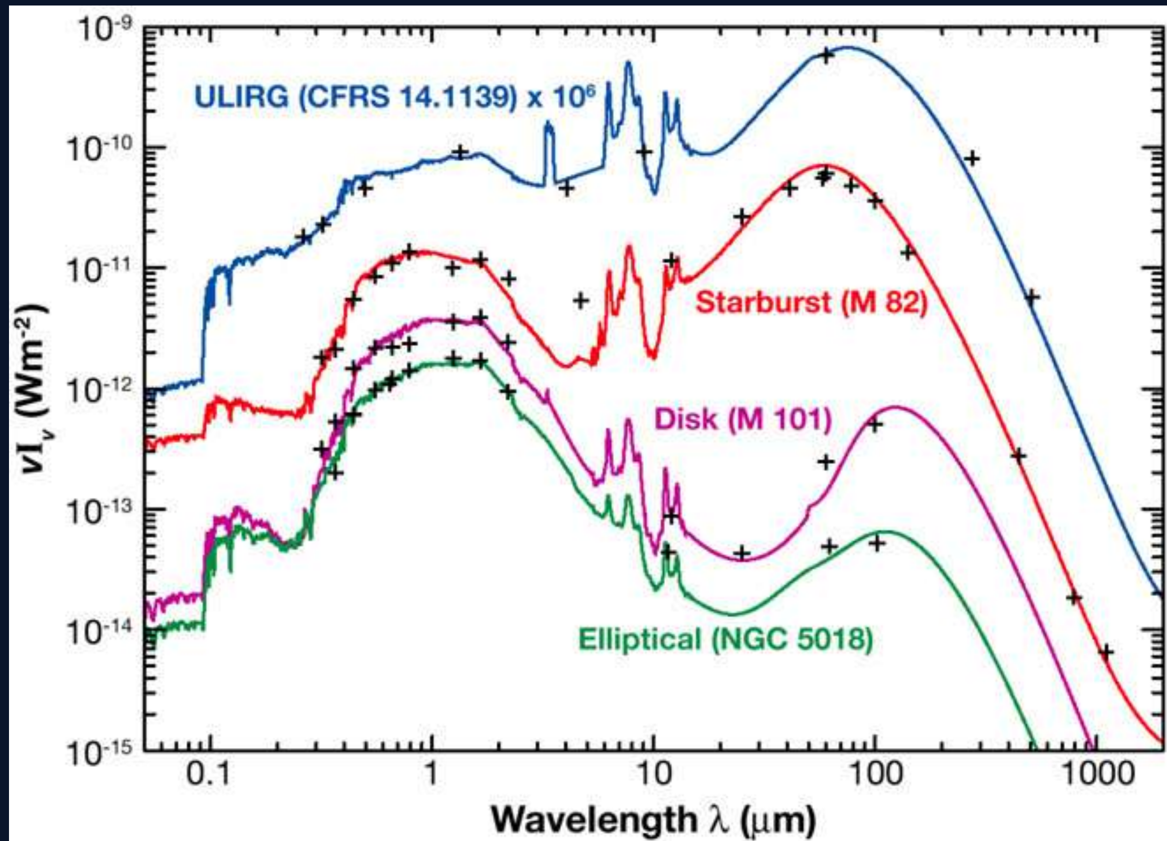
From Jones et al 2004

DUST : A TRACER OF GALAXY EVOLUTION

Nearby galaxies: different laboratories to understand dust properties

Effects of dust evolution on the SED itself

- Reemit from 30% to 90% of the stellar power



Galliano et al 2004

CONTENT OF THIS TALK

1- Dust composition and distribution

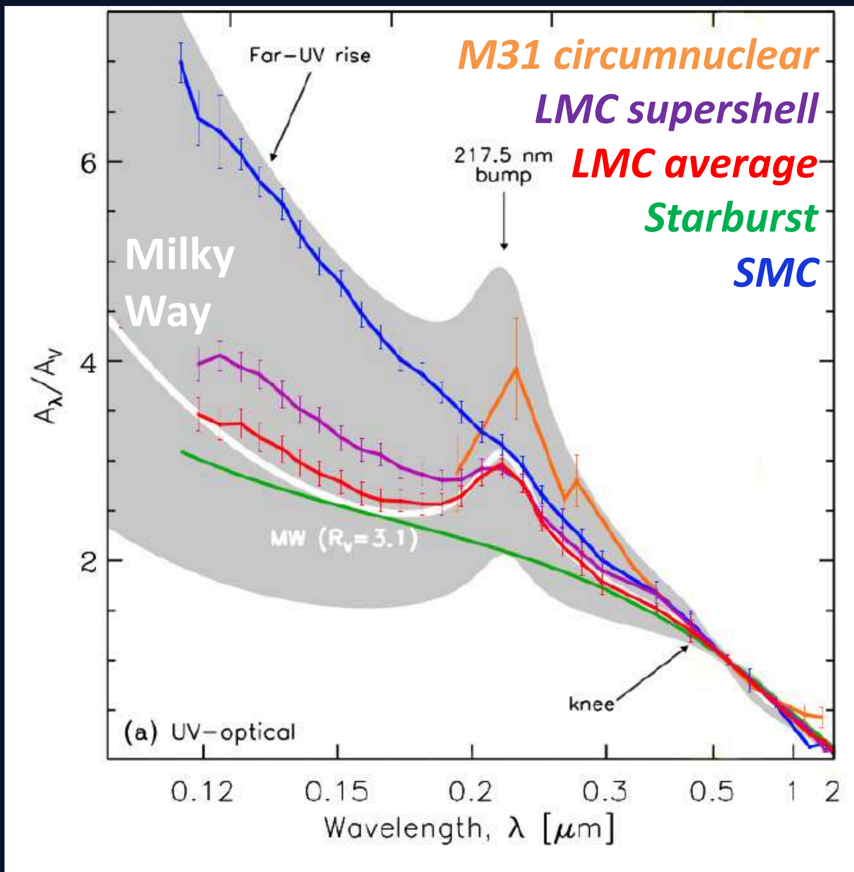
2- Dust modelling and current revisions

3- Evolution in the ISM

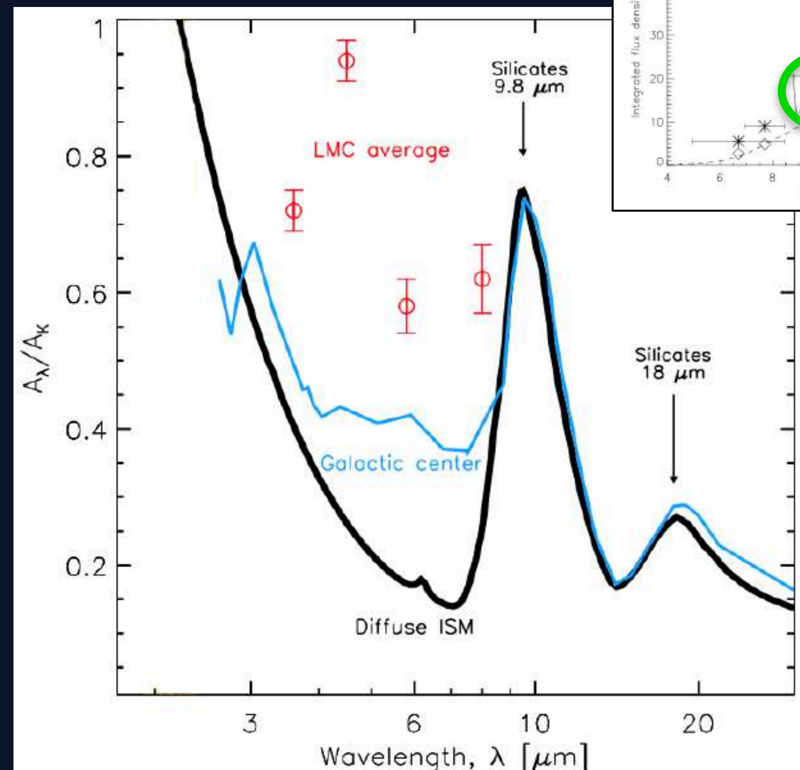
4- Dust polarisation

DUST COMPOSITION

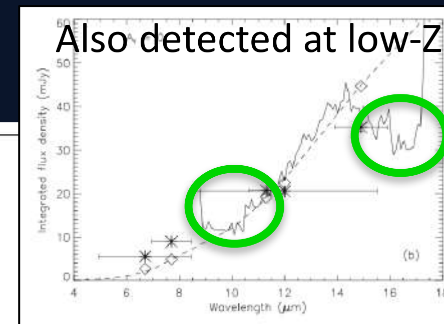
The extinction curves provides us with clues on the dust composition



From 0.1 to 2 μm



From 1 to 25 μm



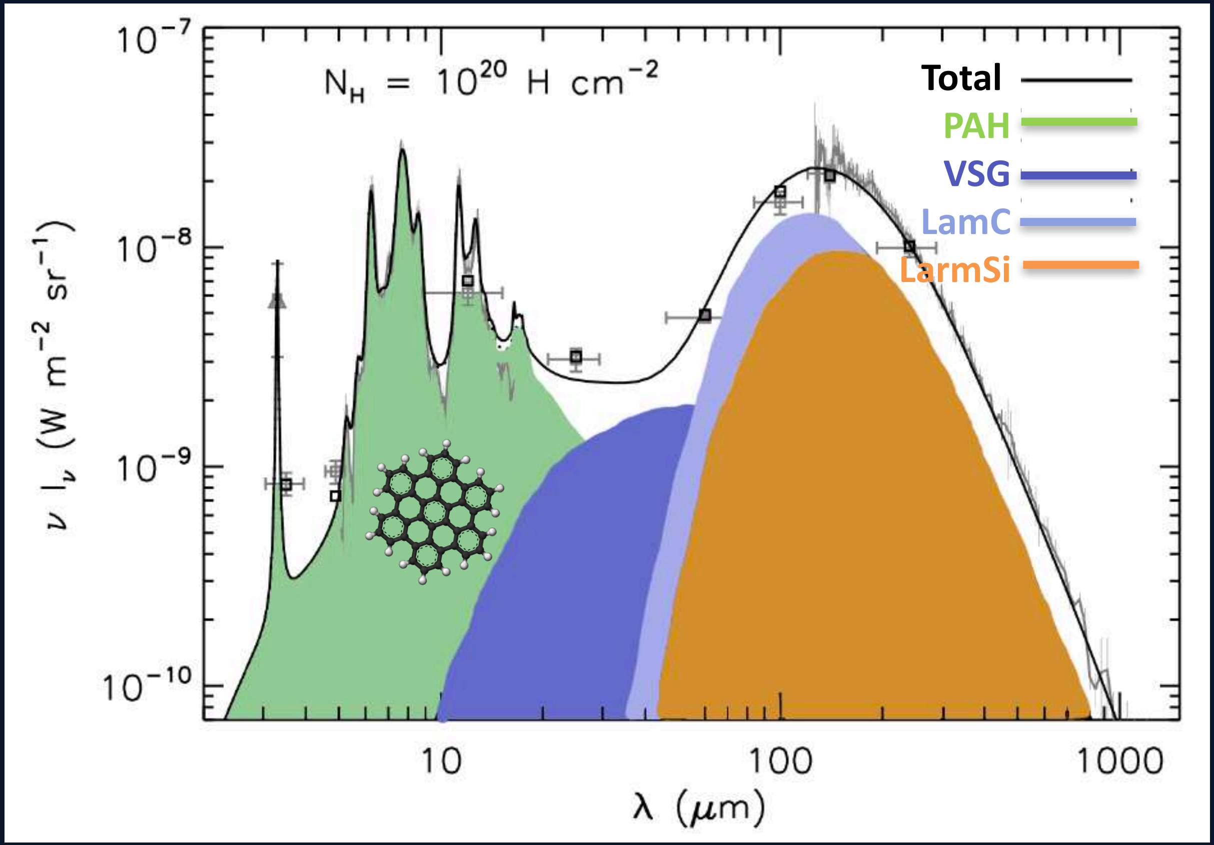
Thuan et al 1999

From Galliano, Galametz & Jones et al 2017

DUST COMPOSITION

PAHs

Their emission varies with their ionization, size …



Compiègne et al 2011

Very small grains
Small grains

Sizes < 20nm
Can vary significantly

Large grains

Carbonaceous grains
and
Amorphous silicates

Grains at thermal
equilibrium

MACROSCOPIC DISTRIBUTION

A few spatial scales relevant for the heating of the dust

- Scale lengths:

  MIR often compact – FIR larger than stellar scale-length

- Scale heights :

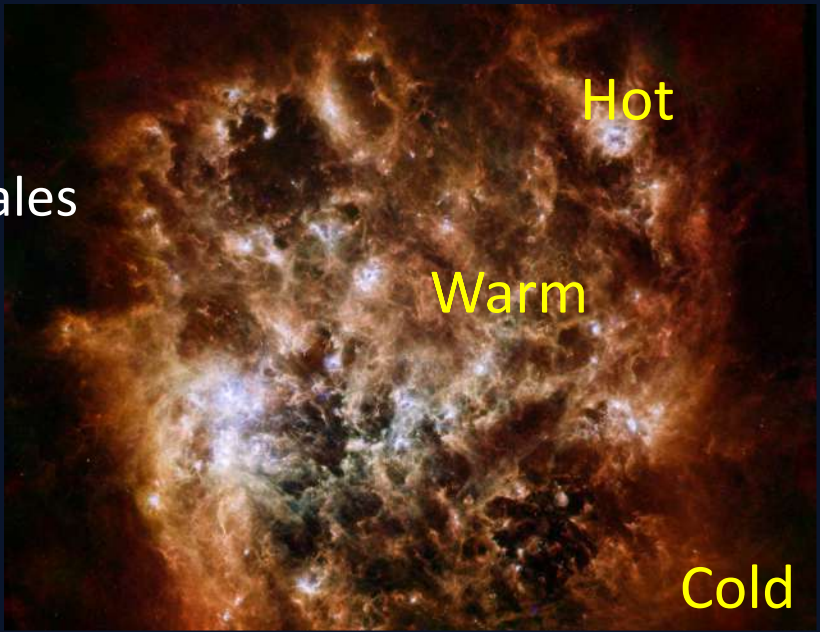
  100 - 200 pc in the FIR

  cold dust could extend to even larger scales

- Mean free path $l_V \propto$ density

  l_V ~ 60 pc when n_H ~ 10 cm-3

  ~ 0.06 pc when n_H ~ 10^4 cm-3

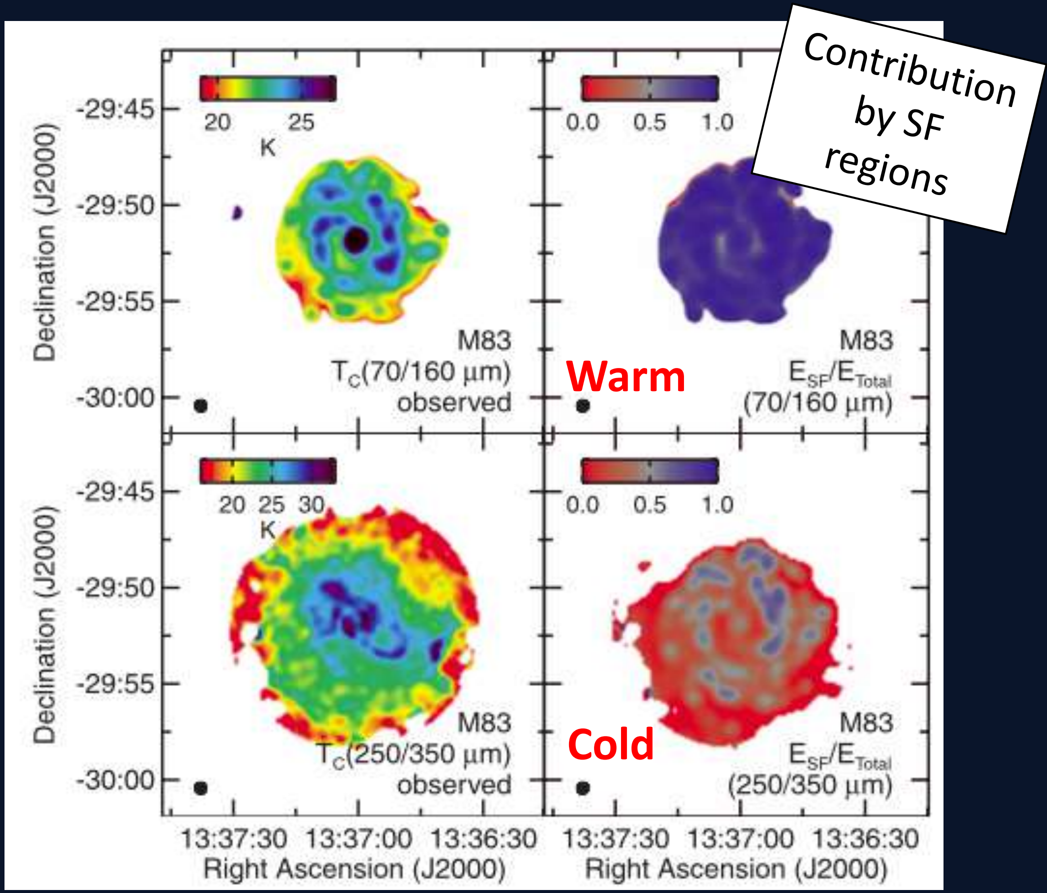


The LMC observed with Herschel

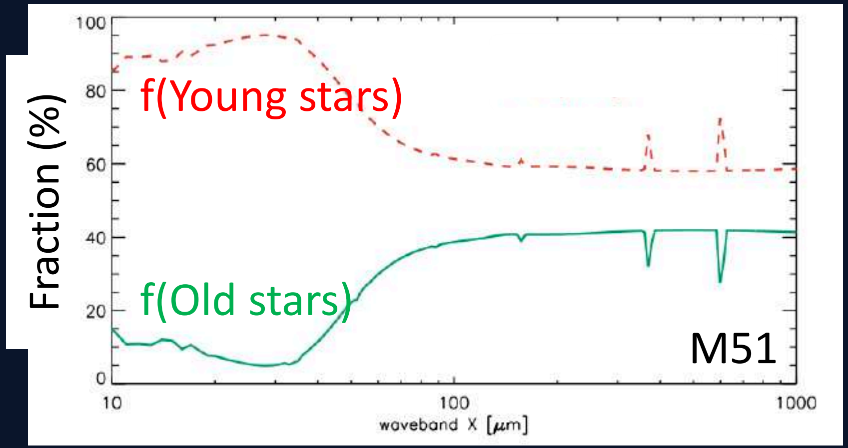
MACROSCOPIC DISTRIBUTION

Studying the **heating sources** with IR colours or radiative transfer models

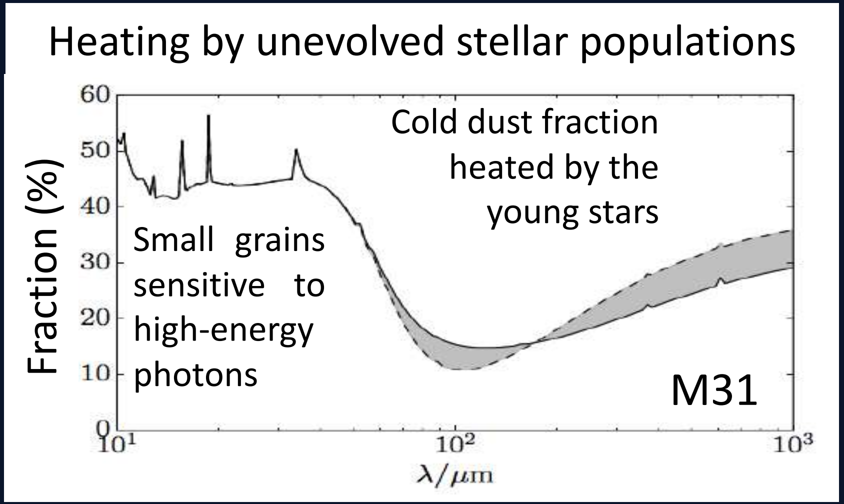
- Heating of the cold dust by lower-mass stars
- Variation with the galaxy evolutionary stage



Bendo et al 2012



De Looze et al 2014



Viaene et al 2016

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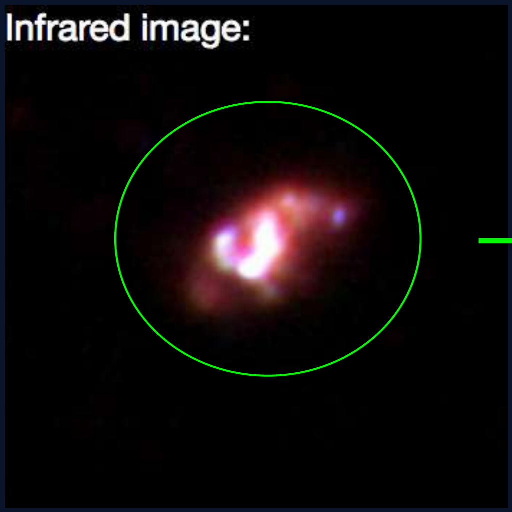
A CLASSICAL PRESCRIPTION

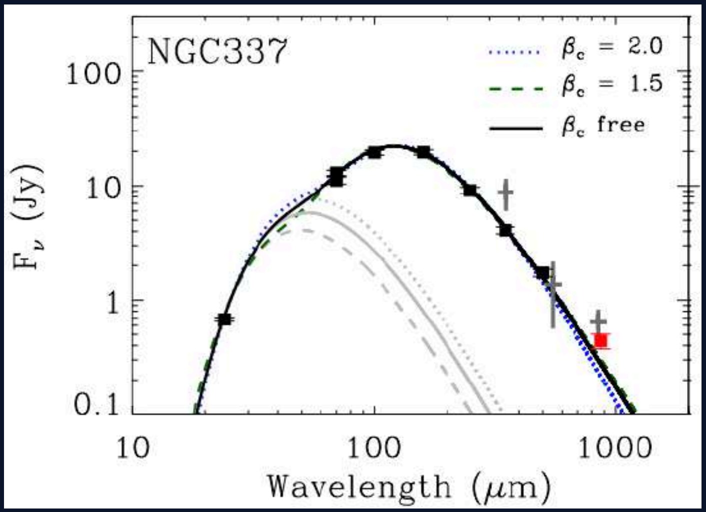
Modified blackbody model

Emissivity index

$$L_\nu(\lambda) = M_{dust} \, . \; \kappa(\lambda_0)\,(\lambda_0/\lambda)^\beta \, . \; 4\pi\, B_\nu(\lambda, T_{dust})$$

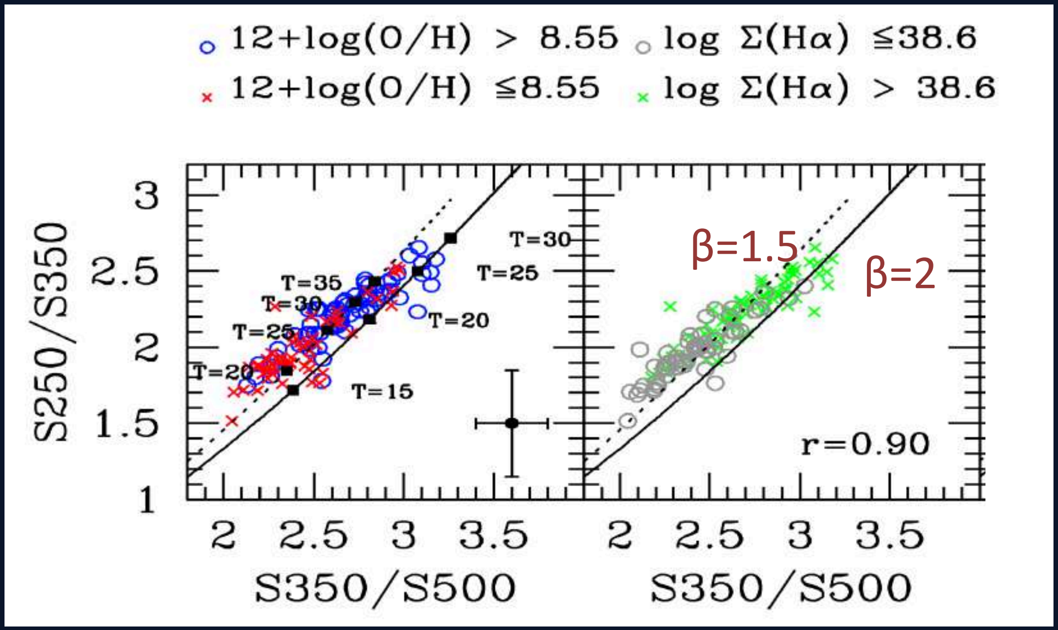


~ kpc scale resolution
@ 10Mpc with SPIRE



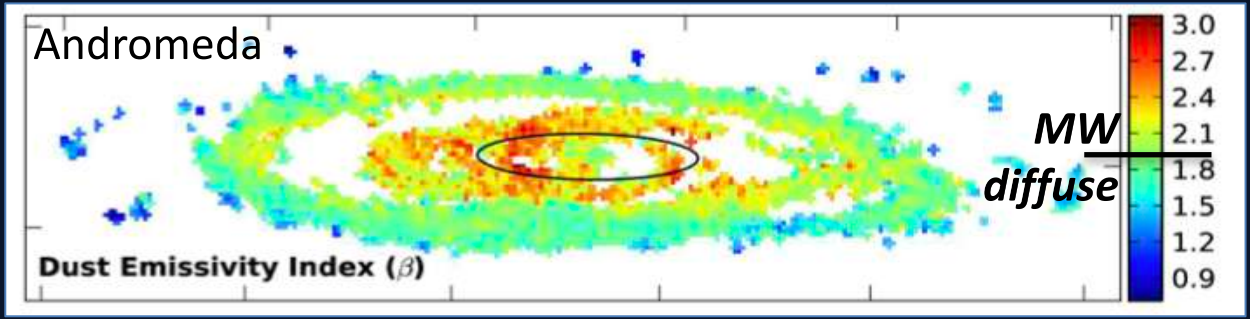
Galametz et al 2014

VARIATION OF BETA IN NEARBY GALAXIES

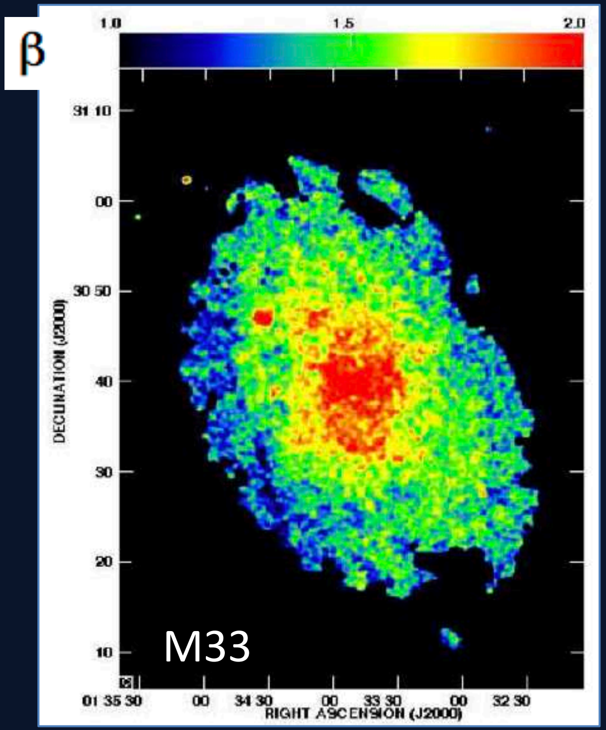


Boselli et al 2012

- Investigations using color ratios
  - β = 2 or unique not appropriate



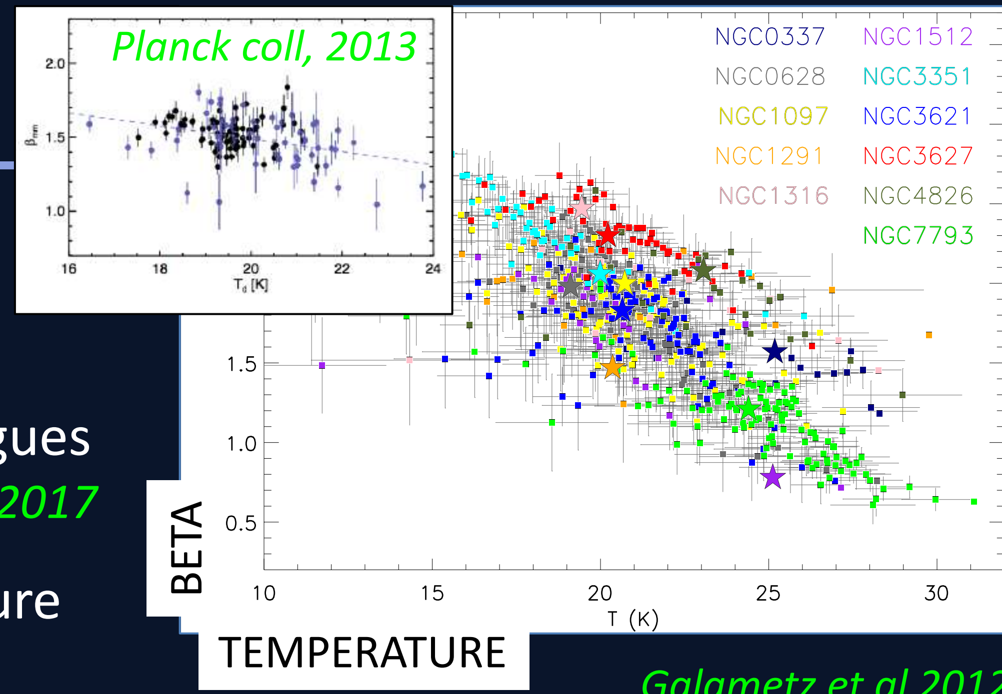
Smith et al, 2012



Tabatabaei et al, 2013

BUT difficult to study due to the numerous degeneracies…

BETA-T ANTI-CORRELATION



Galametz et al 2012

Explanations:

- Laboratory experiments on dust analogues

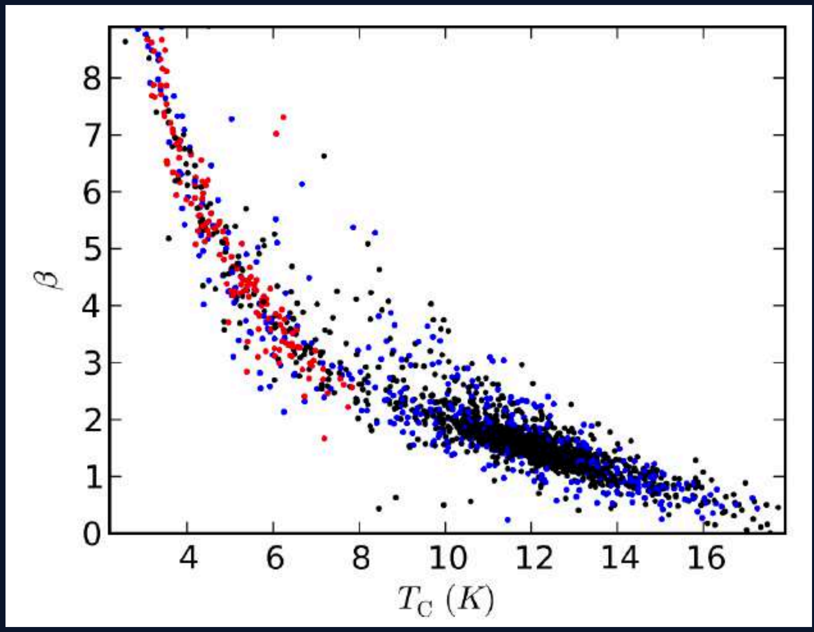
Coupeaud et al. 2011; Demyk et al.2017

- changes in the composition and structure of silicate or carbon dust

Meny et al. 2007; Jones et al 2013

BUT

Degeneracies between the dust colour temperature and the observed spectral index



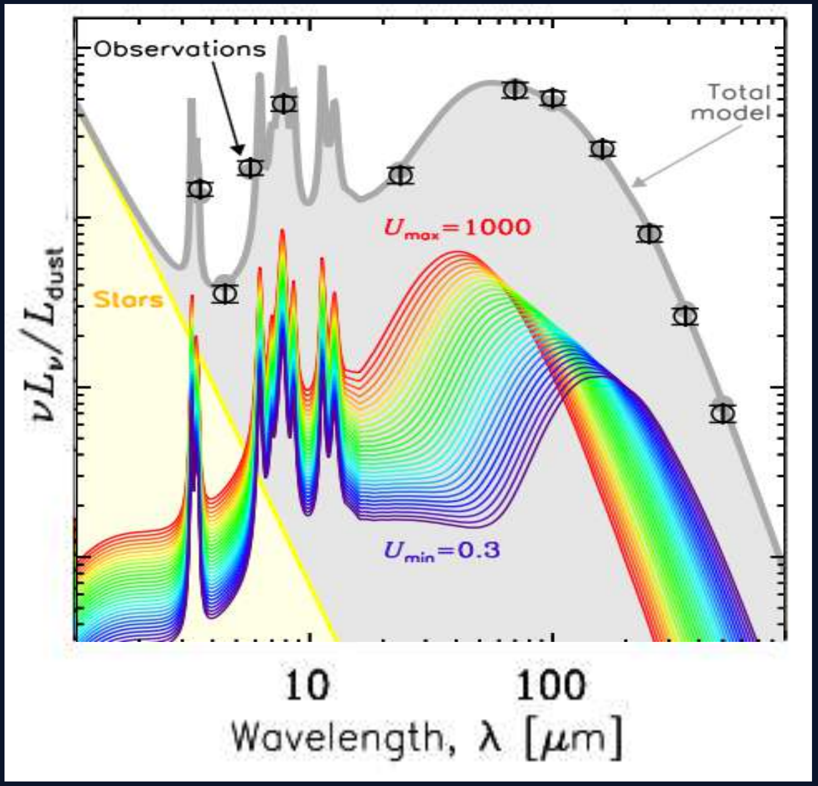
Juvela & Ysard 2012

ANOTHER CLASSICAL PRESCRIPTION

Dust mixing with various temperatures

Prescription from Dale et al. 2001:

$$dM_{dust} \propto U^{-\alpha}\, dU \text{ with } U_{min} < U < U_{max}$$



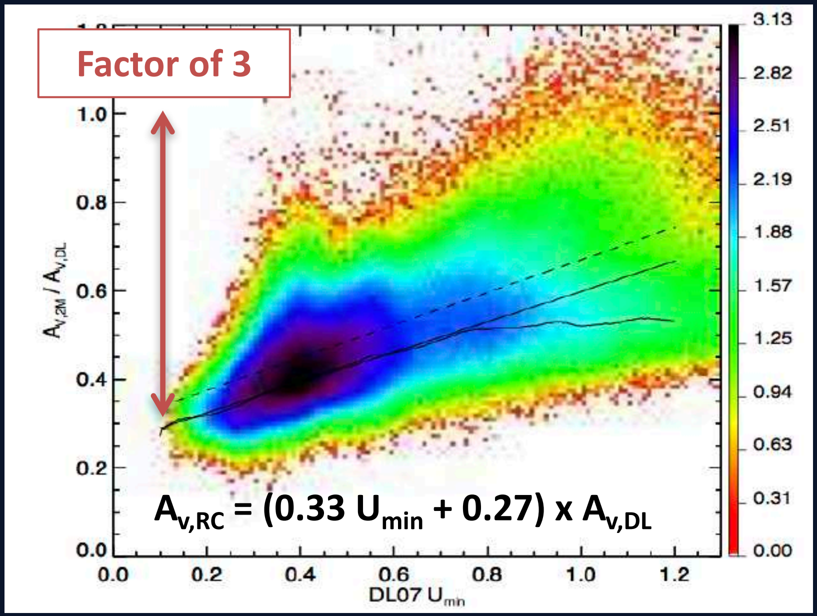
BUT

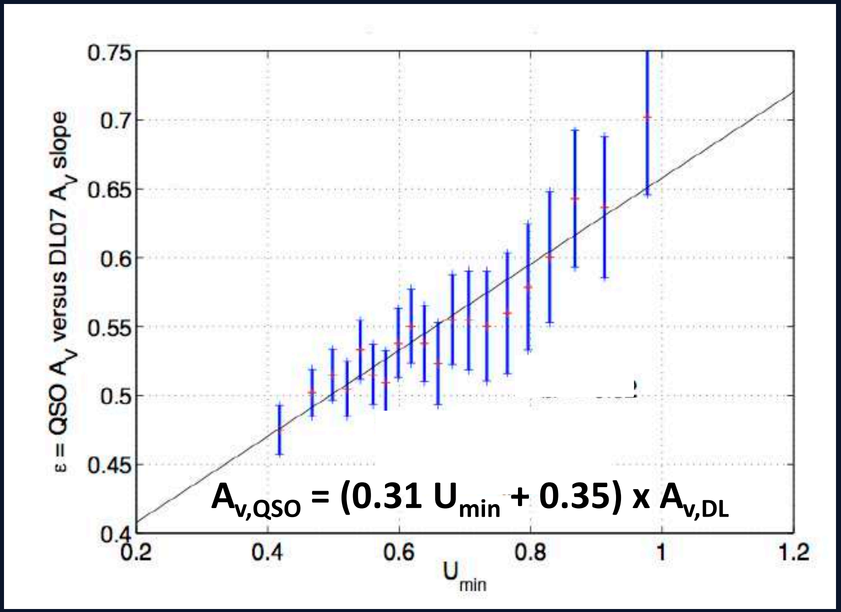
- Similar noise-induced anti-correlations

- Still usually assumes that the dust composition and size distribution does not change

CONSTRAINTS ON THE DUST OPACITY

- Model the Galactic IR/submm emission (Planck, IRAS, WISE)
- Compare $A_{v,DL}$ with
  - stellar observations in molecular clouds
  - optical estimates from QSOs in the diffuse ISM



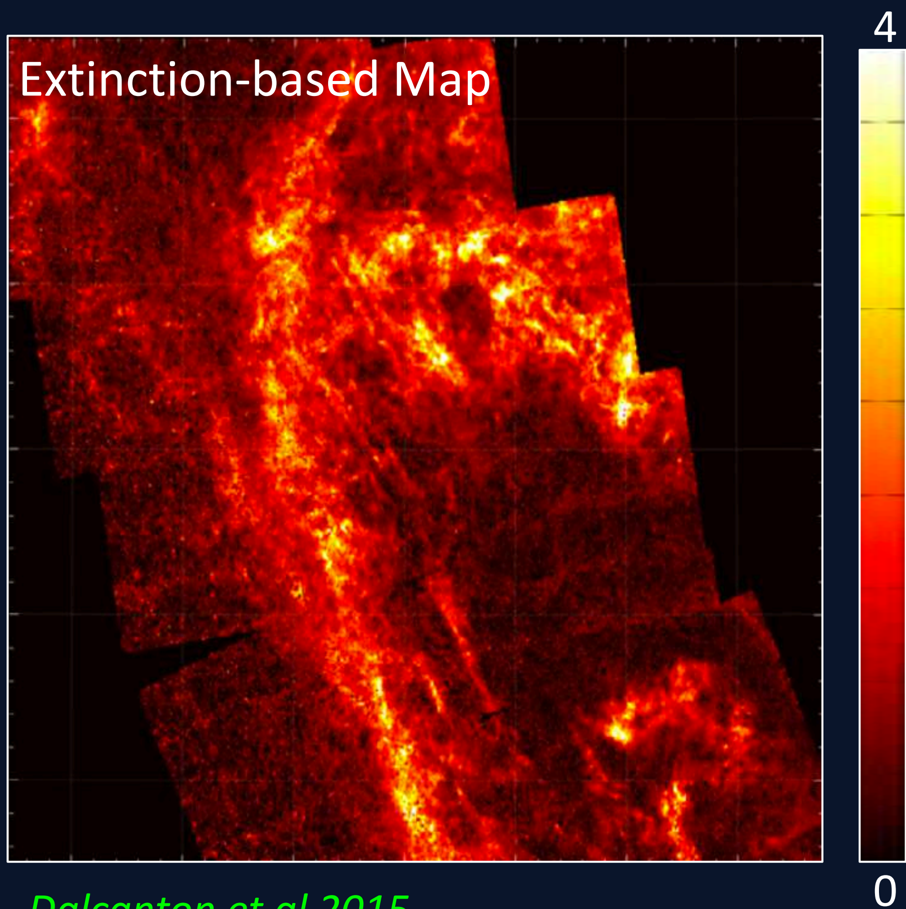


Planck Collaboration 2014 (Paper XXIX)

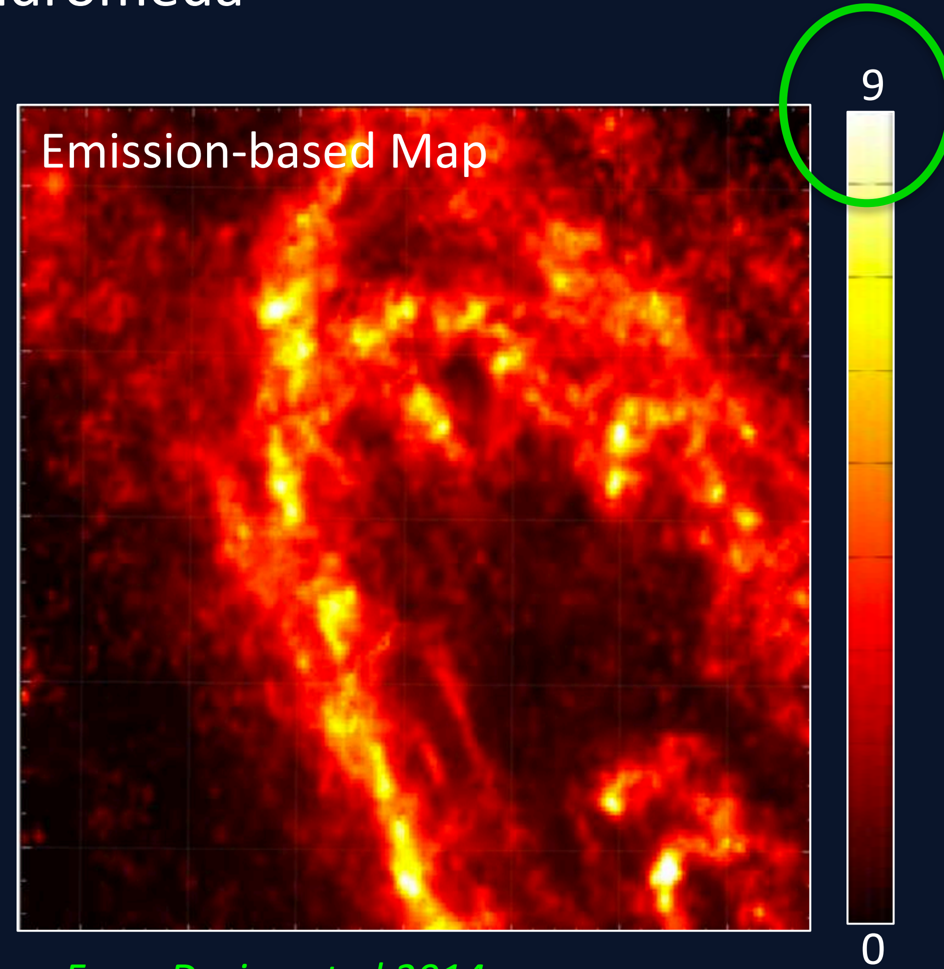
→ Not the right far-IR opacity of dust grains, even in the diffuse ISM

CONSTRAINTS ON THE DUST OPACITY

The same discrepancy is observed in Andromeda



Dalcanton et al 2015



From Draine et al 2014

→ Revision of the physical properties of current models

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DUST EVOLUTION PROCESSES

Grain Formation

- Grain condensation (Sne ejecta, AGB stars)
- Accretion of atoms and molecules (growth, mantle, ice) in the ISM

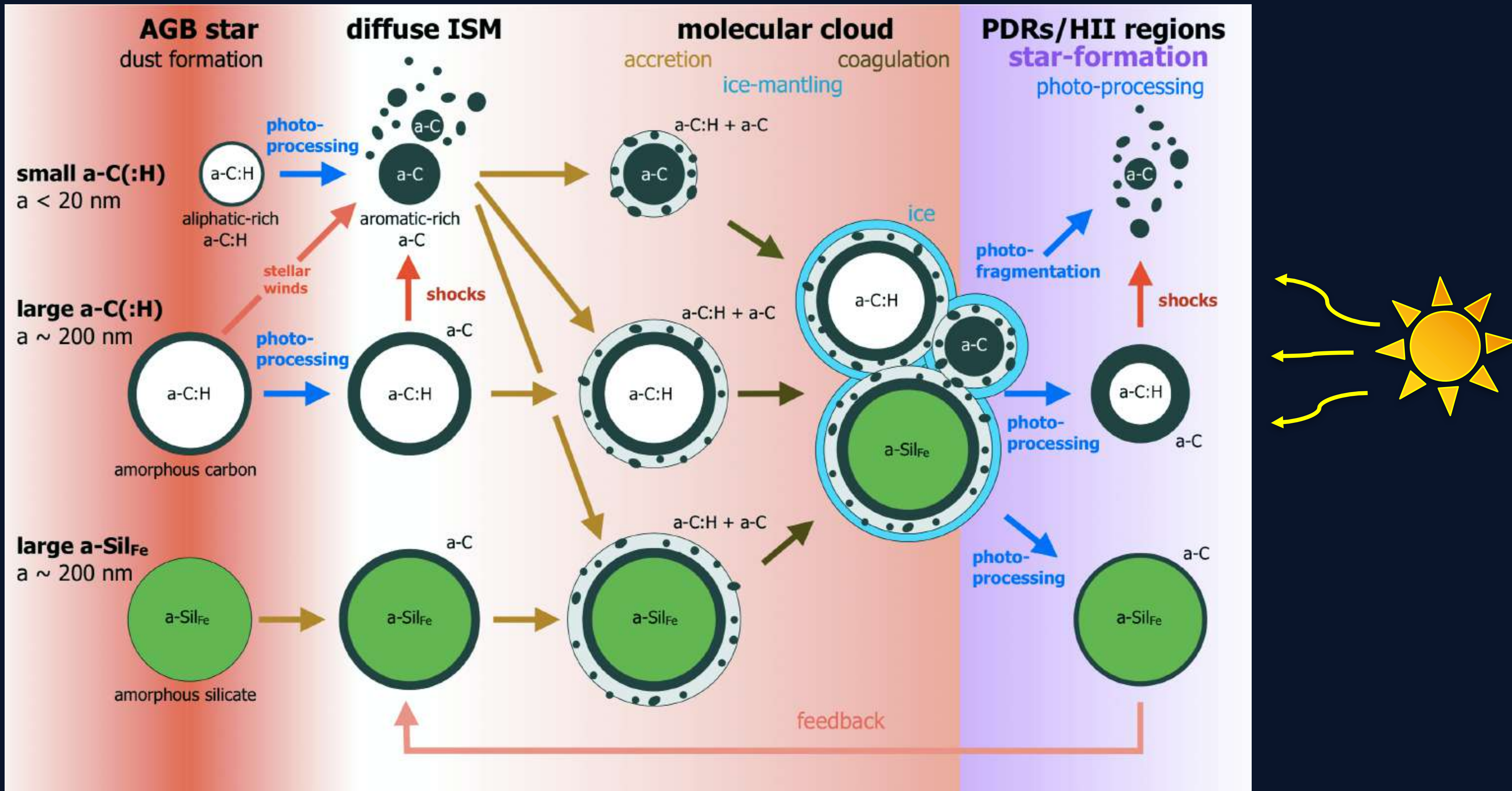
Grain Processing

- Shattering, fragmentation by grain-grain collisions
- Structural modifications (high energy photons, cosmic rays)
- Coagulation

Grain Destruction

- Erosion and evaporation (thermal or kinetic sputtering)
- Photo-desorption of atoms and molecules
- Thermal evaporation
- Astration (incorporation into stars)

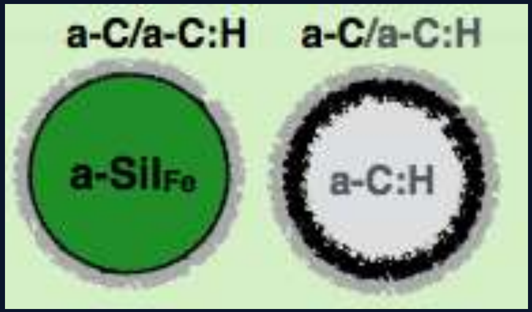
DUST EVOLUTION PROCESSES



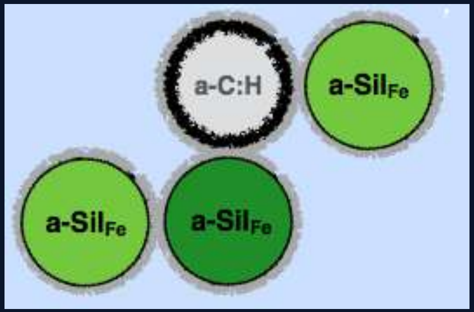
From Jones et al 2013; schematic diagram of the THEMIS model

EMISSIVITY VARIATIONS

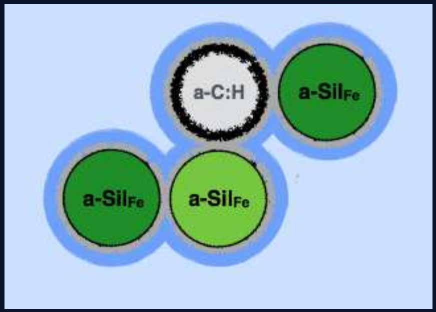
Core-mantle



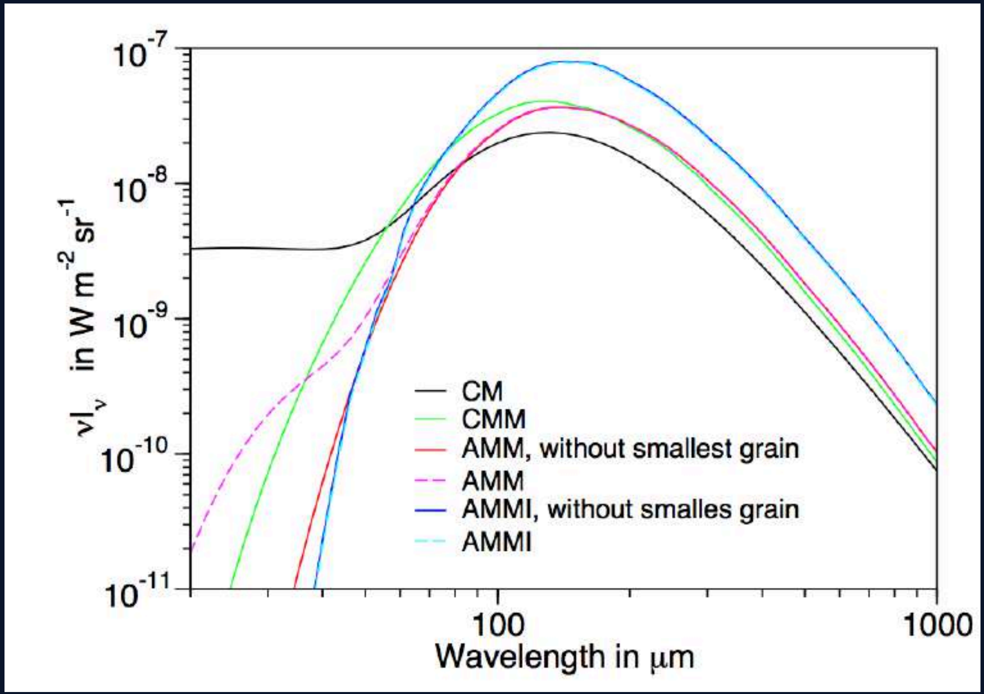
Core-mantle-mantle

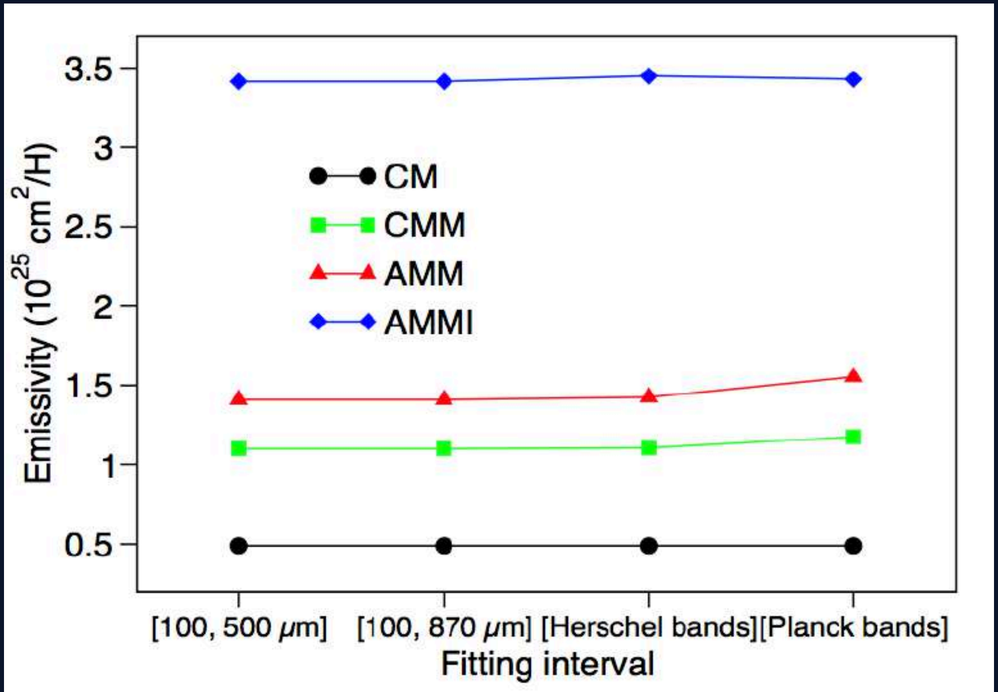


Aggregates



Aggregates with ice mantle

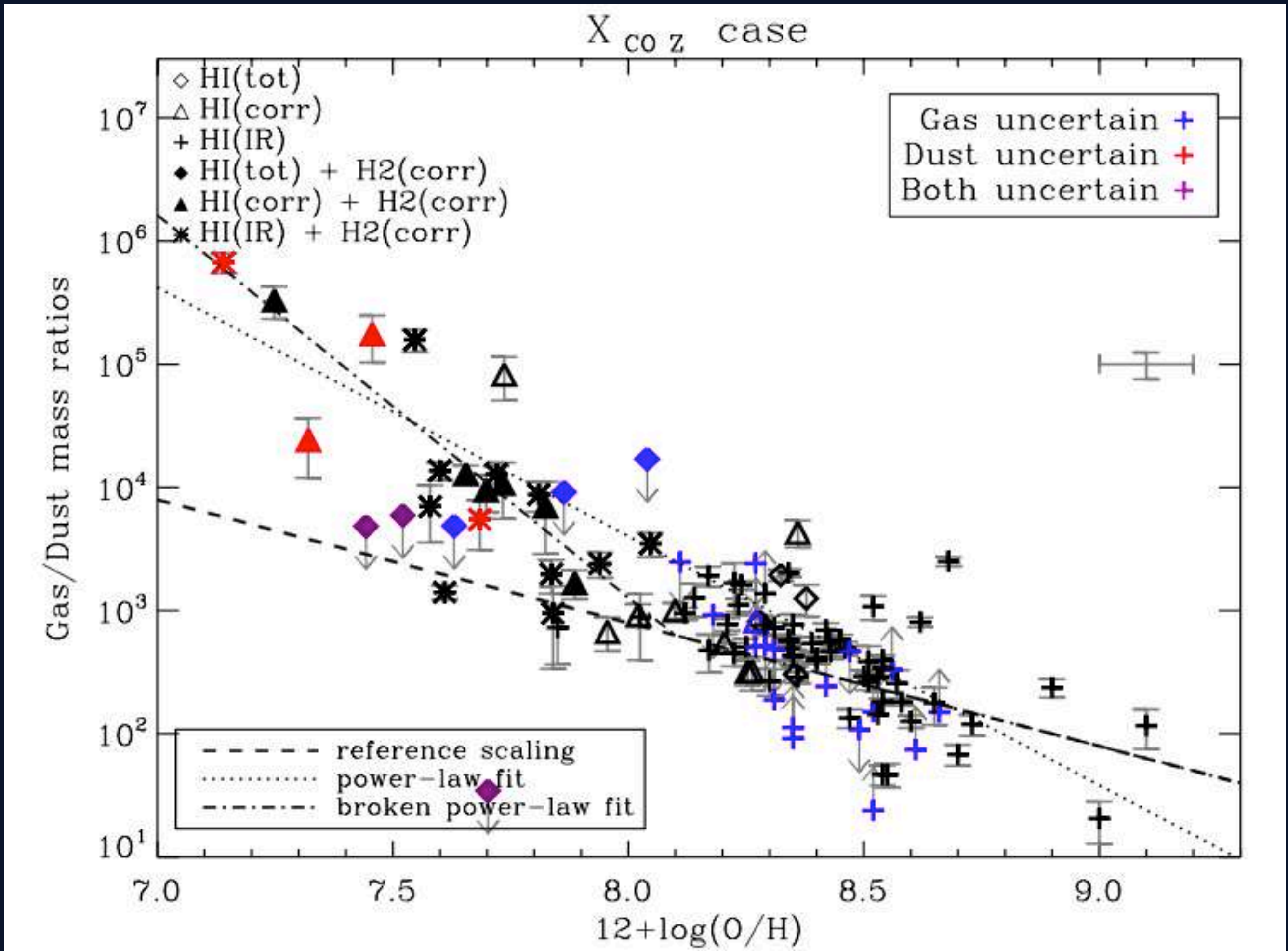




Köhler et al, 2015

GAS-TO-DUST MASS RATIO EVOLUTION

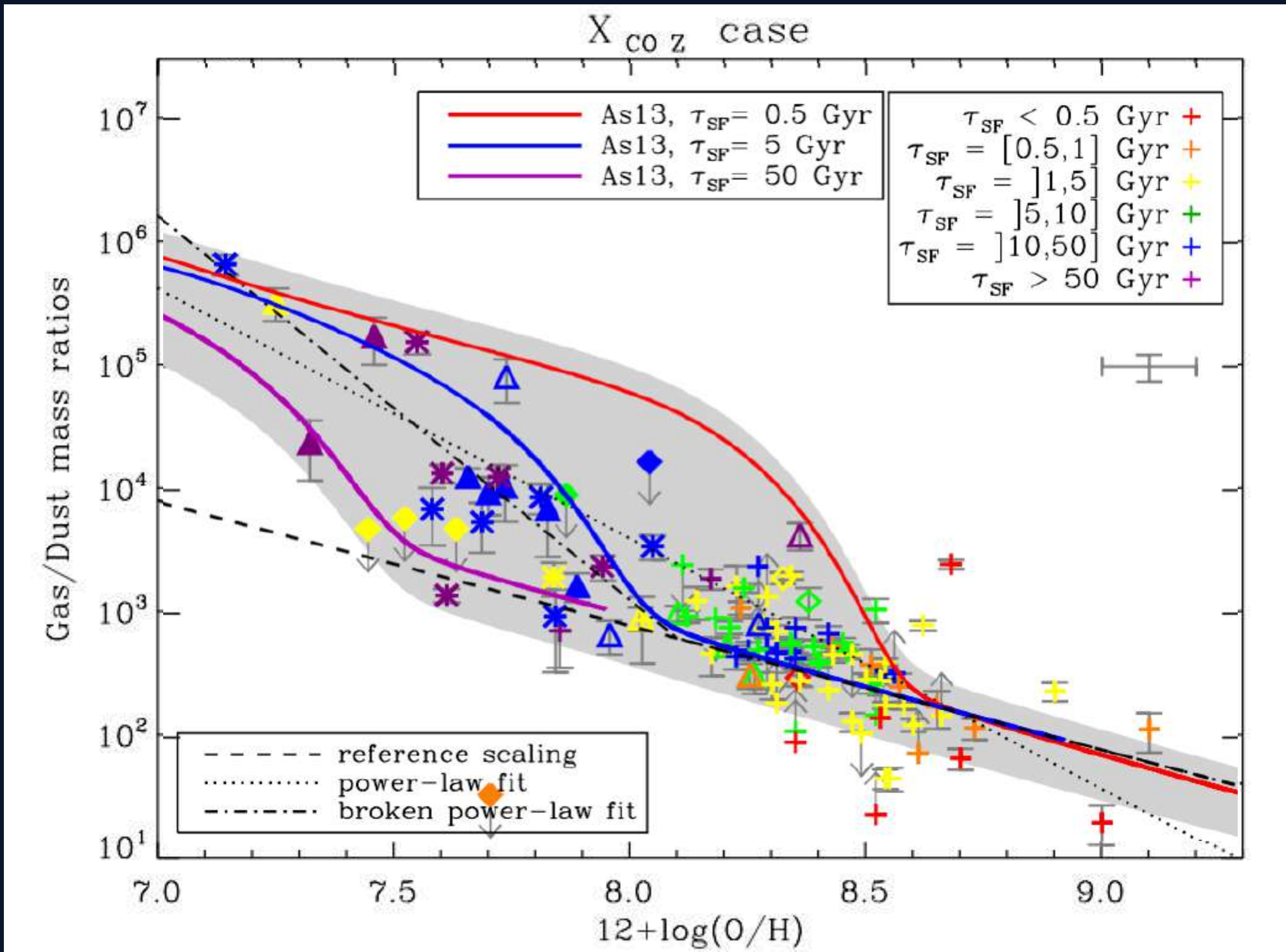
Clear evolution of the ratio with metallicity



Rémy-Ruyer et al, 2014

GAS-TO-DUST MASS RATIO EVOLUTION

Clear evolution of the ratio with metallicity



Chemical Evolution models from Asano et al (2013a)

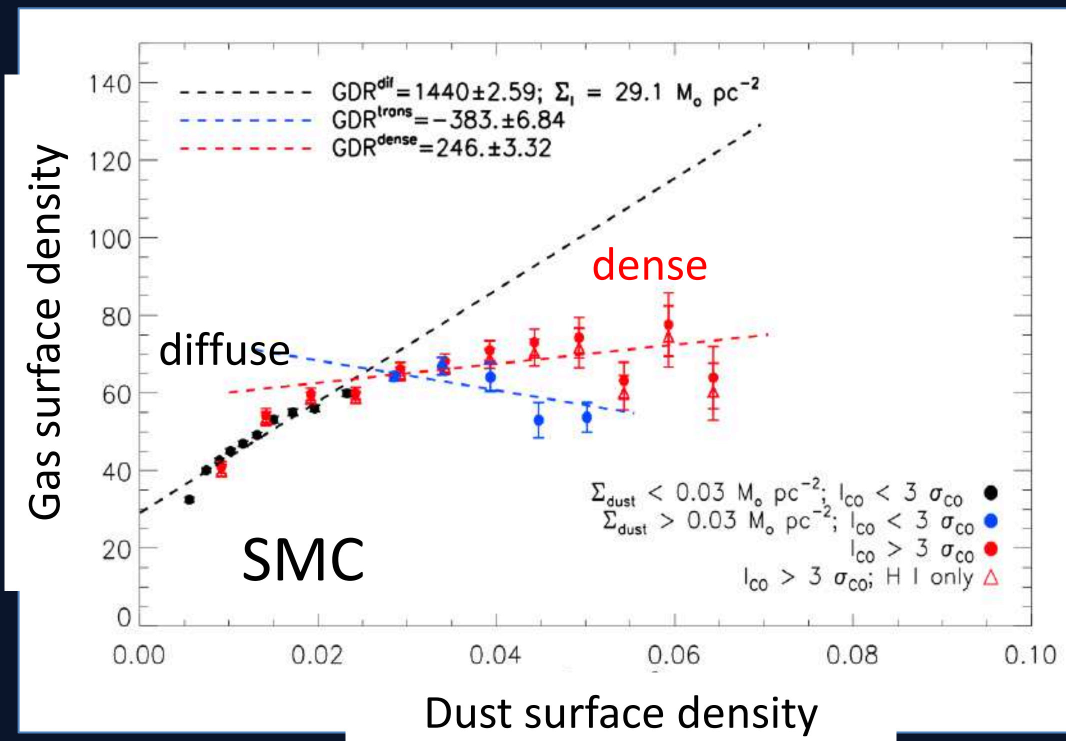
The trend can be explained when **grain growth** in the ISM is taken into account in the dust formation processes.

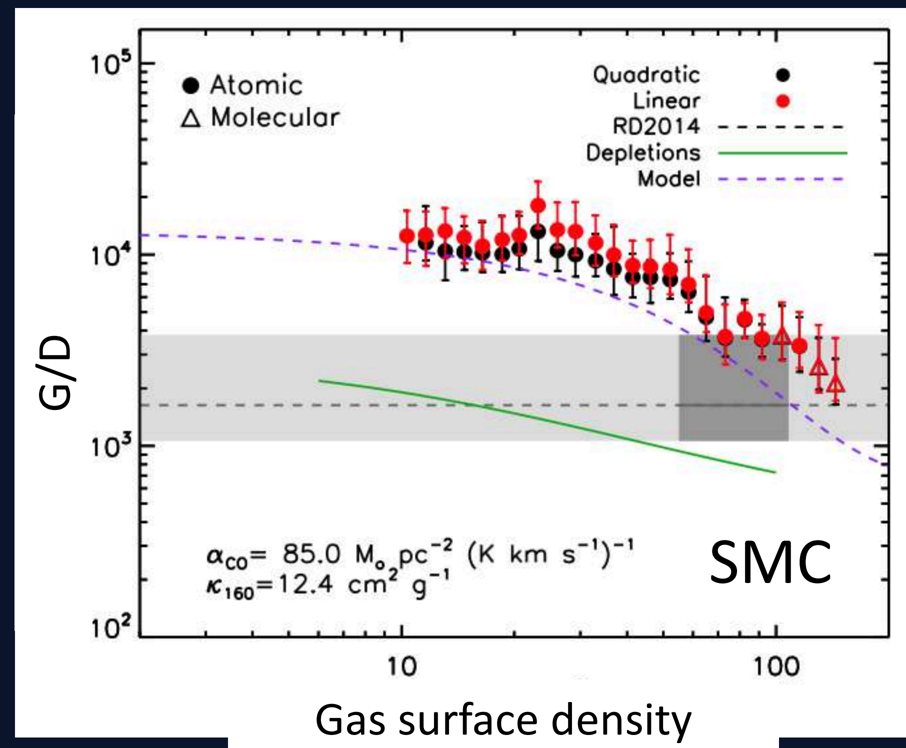
Rémy-Ruyer et al, 2014

SIGNATURES OF DUST EVOLUTION IN THE LMC

Variations in the Gas-to-Dust ratio with the environment

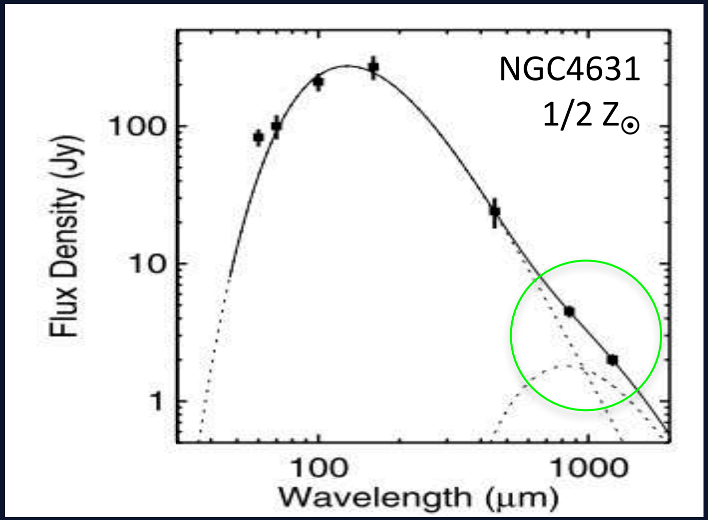
- Decrease of G/D from the diffuse ISM to the dense clouds



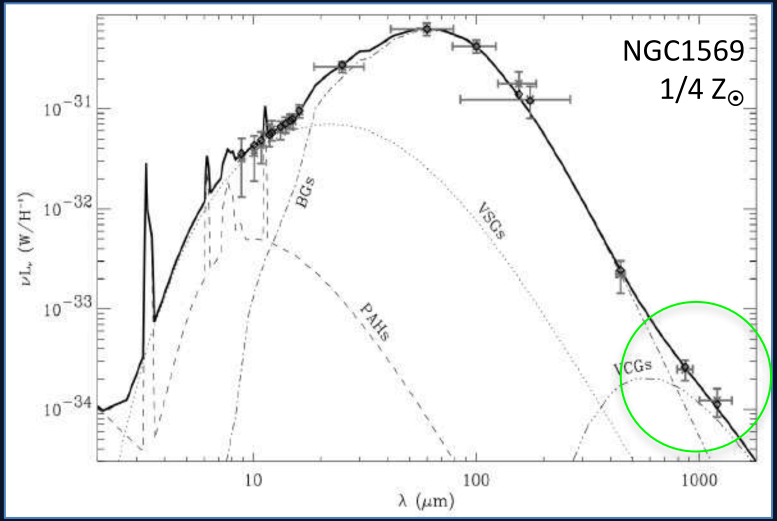


Roman-Duval et al, 2014; 2017

ARE THERE DUST COMPONENTS WE ARE STILL MISSING ?

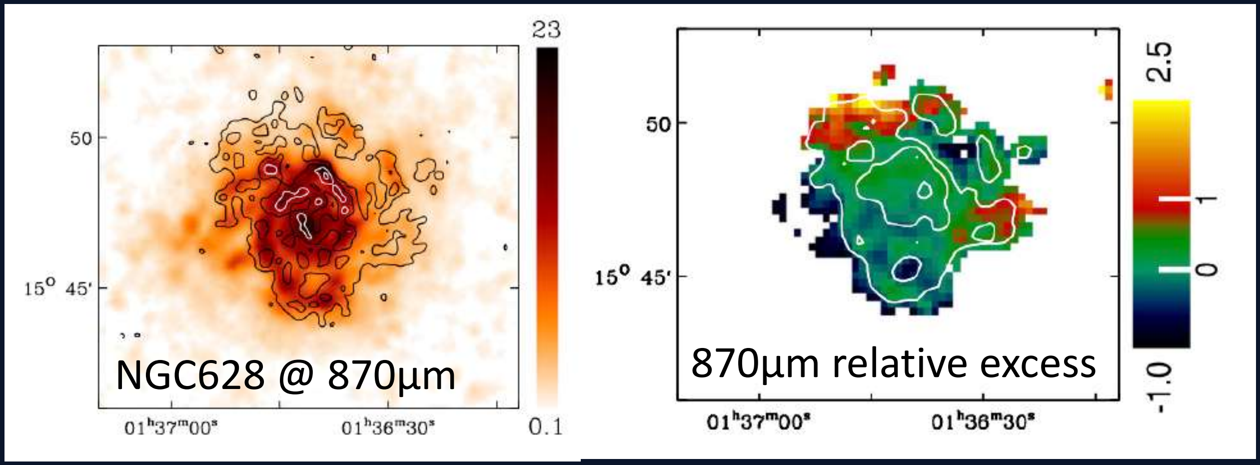


Bendo et al, 2006



Galliano et al, 2003

Detection of a submm excess



Galametz et al, 2014

… among many others:

Bot el al, 2010
Galliano et al, 2005
Zhu et al, 2009

OTHER TYPES OF DUST

Spinning dust

Anomalous Microwave Emission :
i.e. continuum excess

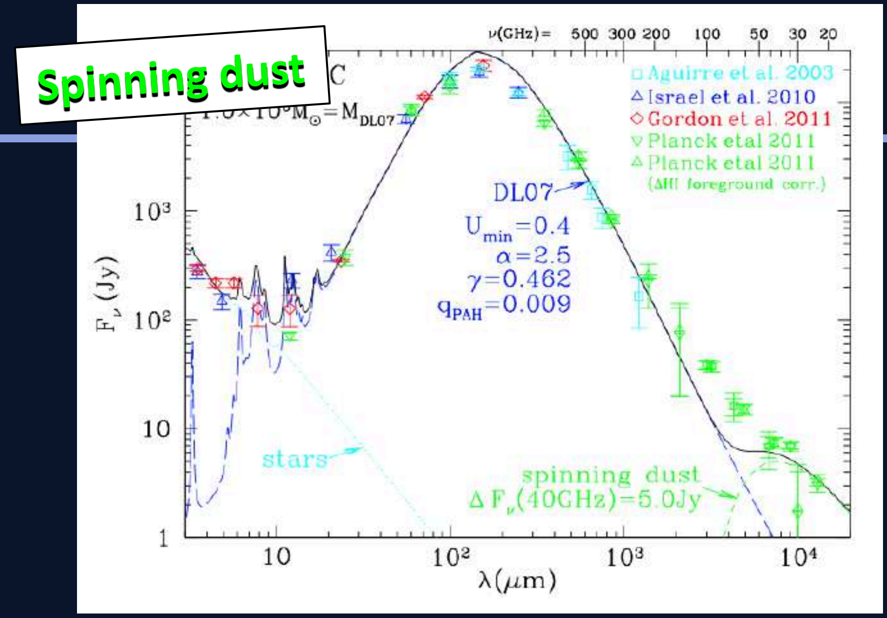
Highly variable in nearby galaxies

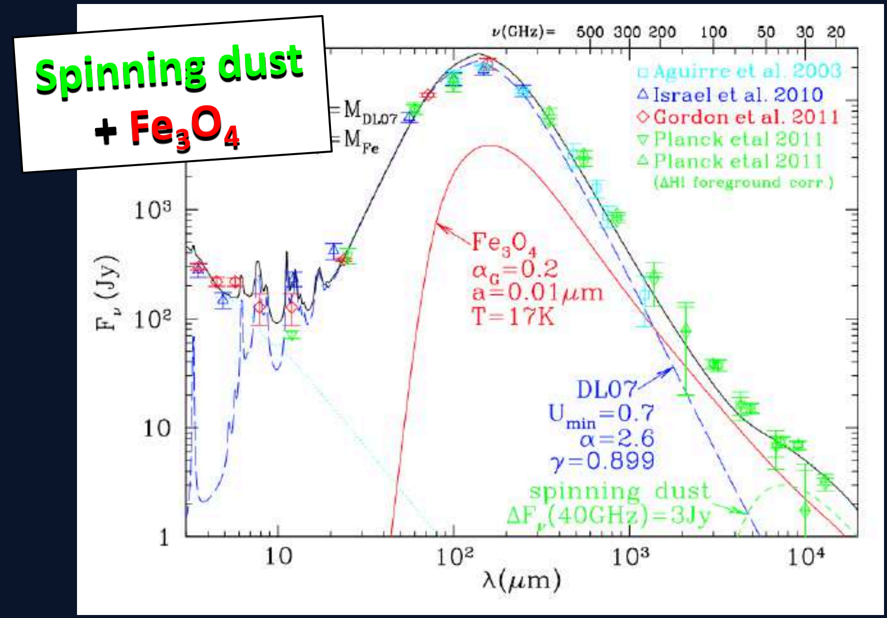
Carriers: PAHs or nano-silicates

Magnetic grains

Magnetic nanoparticles such as
Fe, Fe_3O_4 , γ -Fe_2O_3

The submm excess… an open question…

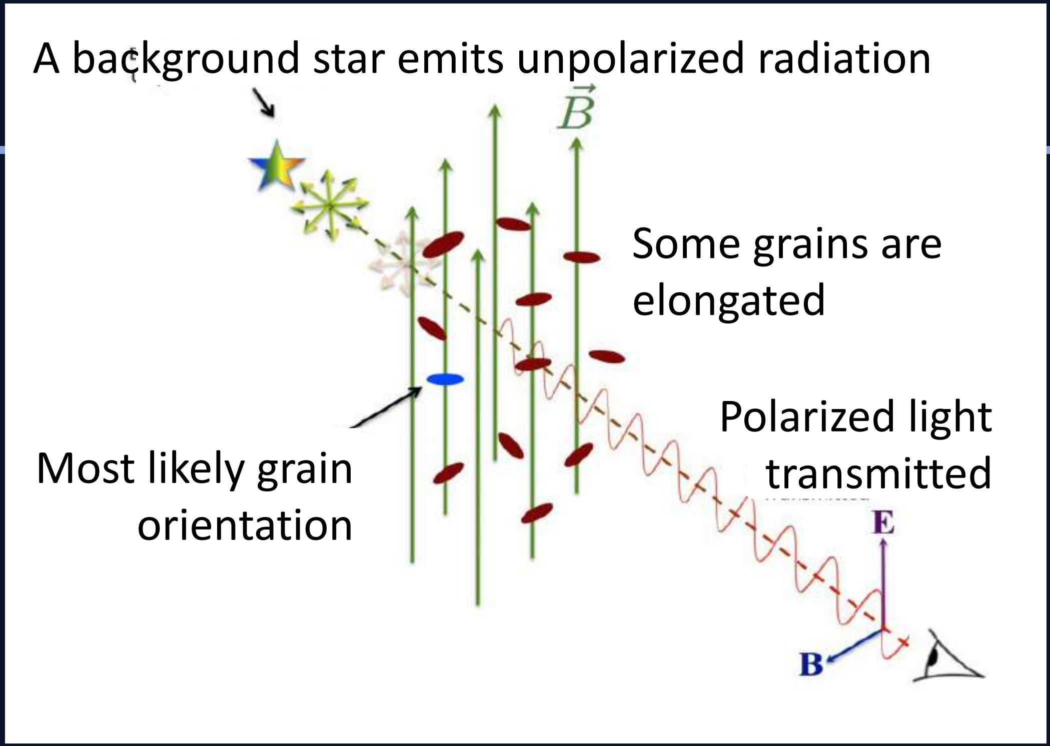




Draine & Hensley (2012)

CONTENT OF THIS TALK

DUST POLARISATION



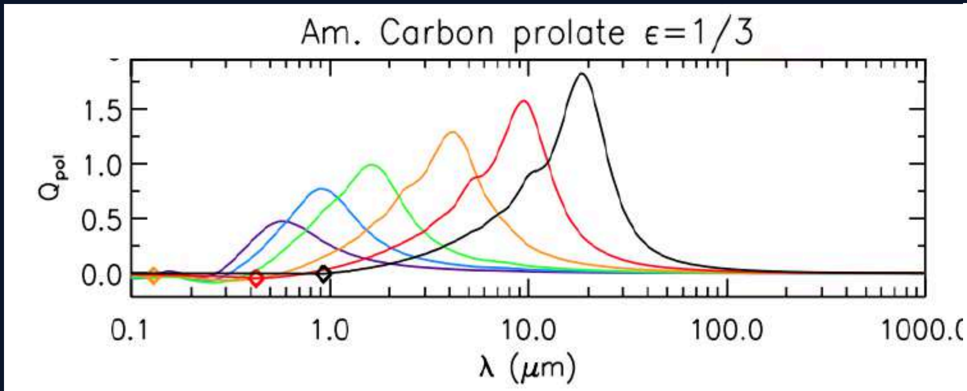
Various potential alignment mechanisms

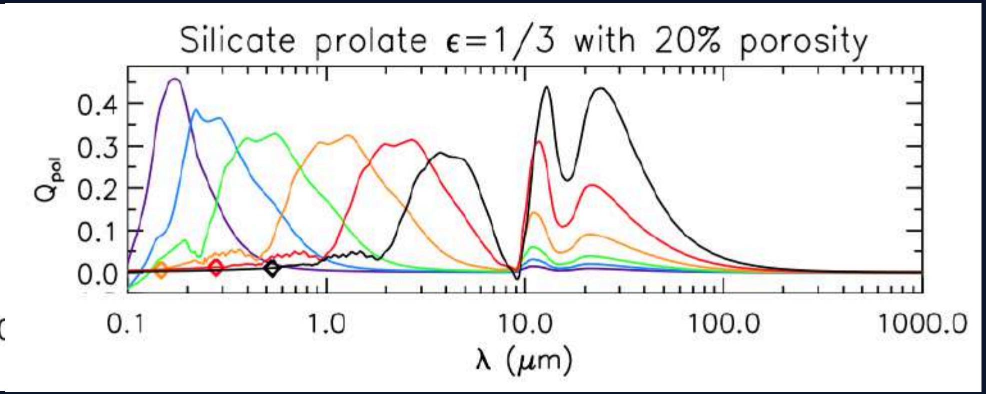
Paramagnetic relaxation

Mechanical alignment

Radiative torques

Polarization depends on the alignment degree and grain structure





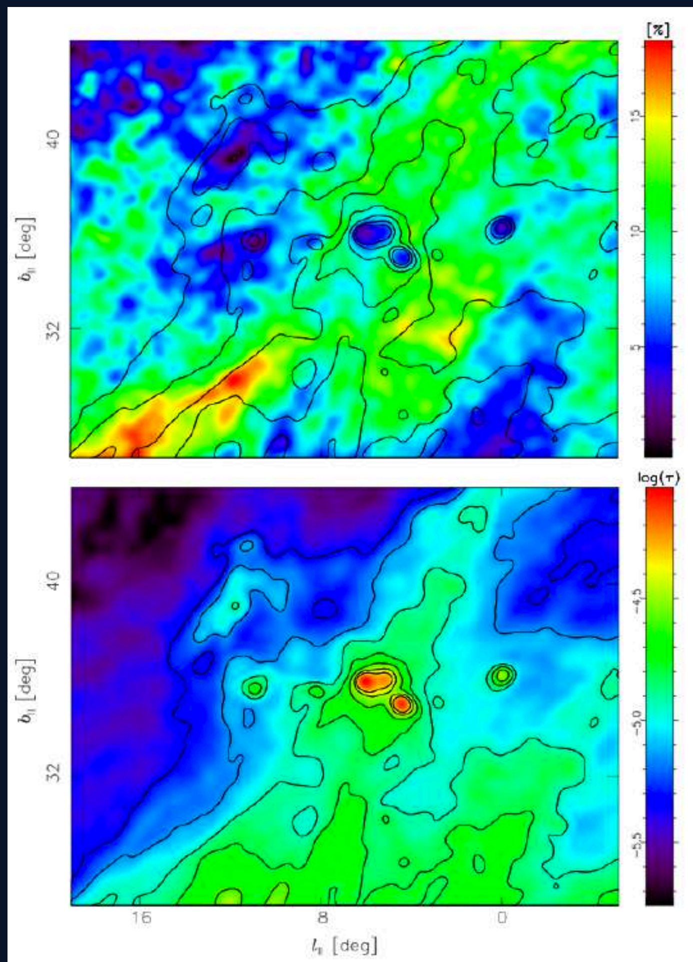
Guillet et al (2017)

DUST POLARISATION IN MW DENSE CLOUDS

Dark molecular cloud L134

Polarization fraction (%)

τ_{353GHz}



Planck Collaboration XIX (2015)

Several possible explanations

Geometrical Effects / mixing along l.o.s. / resolution

Depolarisation due to dampening of radiation field

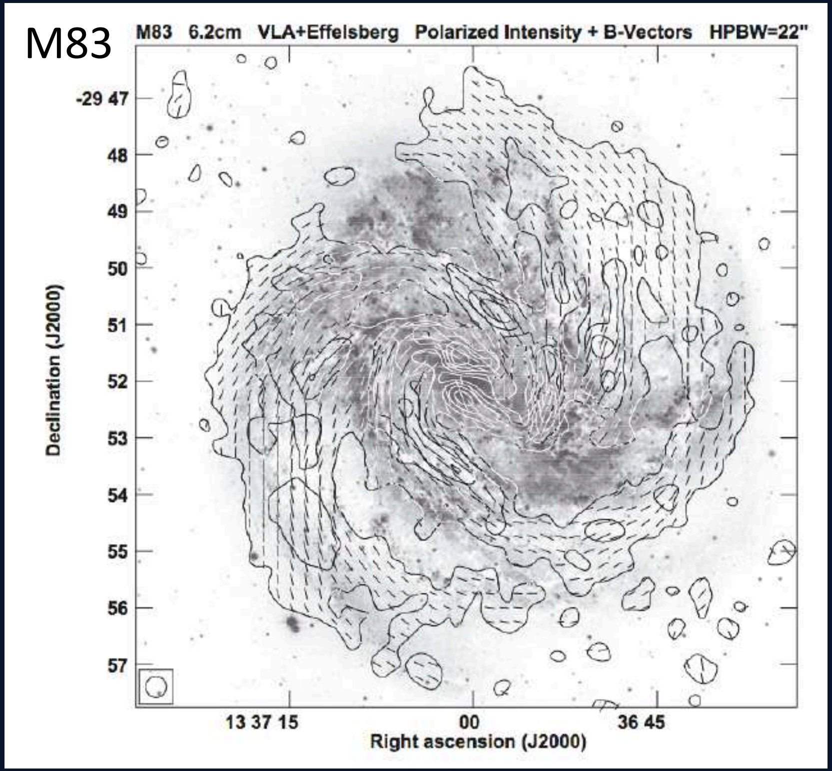
Collisional depolarization

Low grain alignment efficiency at high n

Variation of the grain population

DUST POLARISATION IN NEARBY GALAXIES

Probe the magnetic field structure of nearby galaxies?



Frick et al. 2016

DUST POLARISATION IN NEARBY GALAXIES

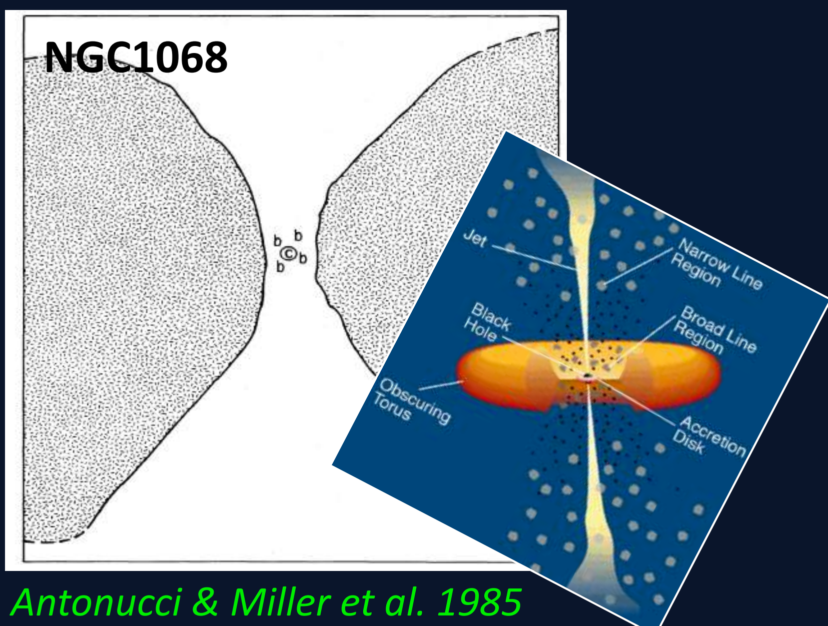
Montgomery et al. 2014

Probe various galaxy components?

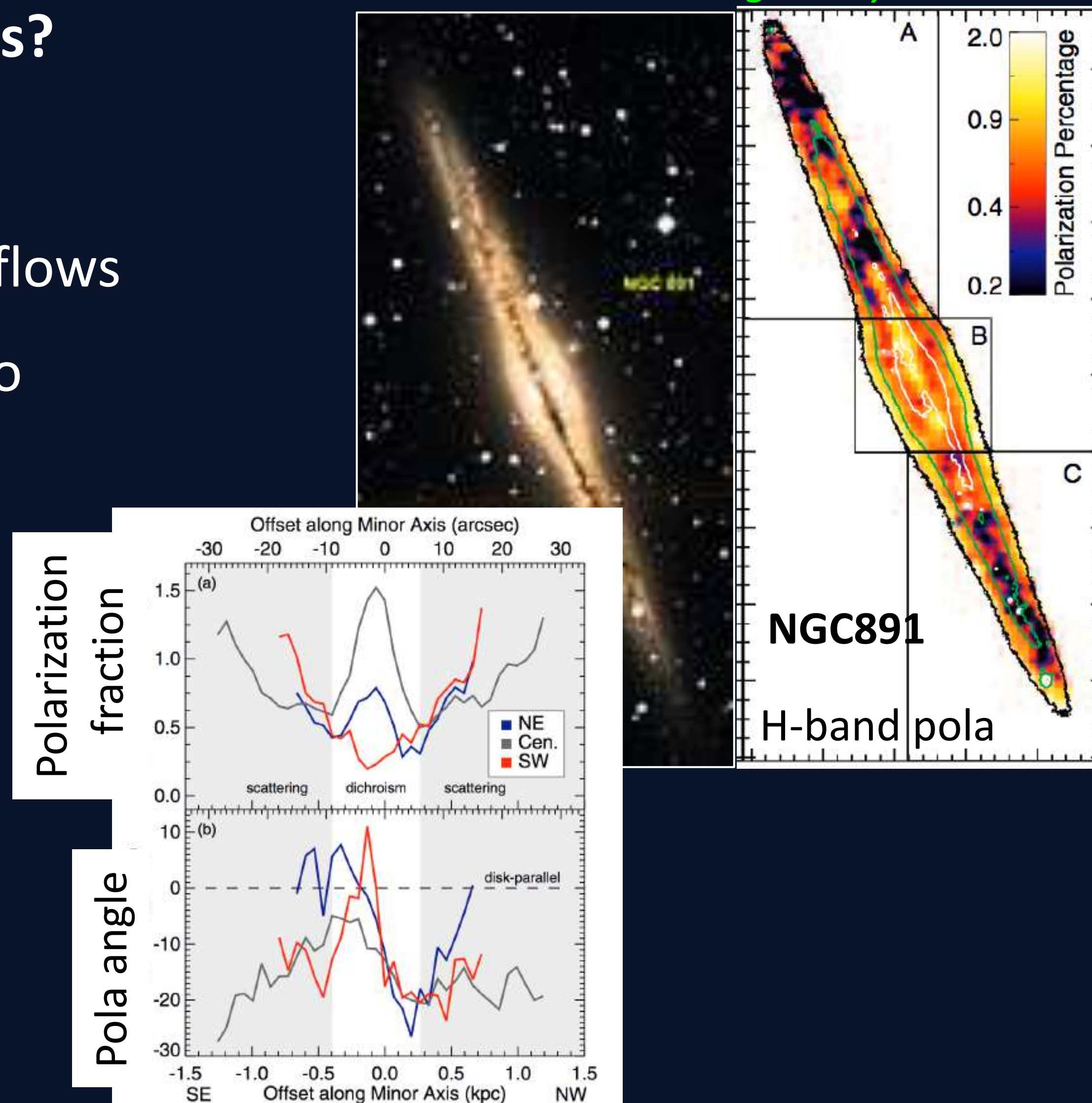
Reveal dusty torii, SF rings

Trace dust blown up by the outflows

Constrain the extend of the halo

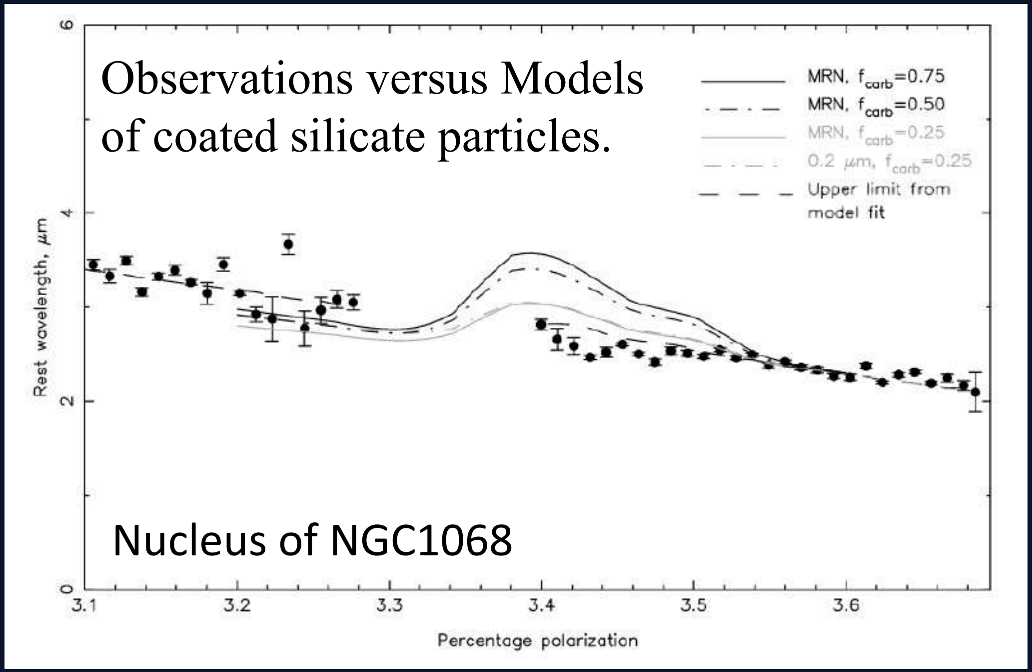


Antonucci & Miller et al. 1985

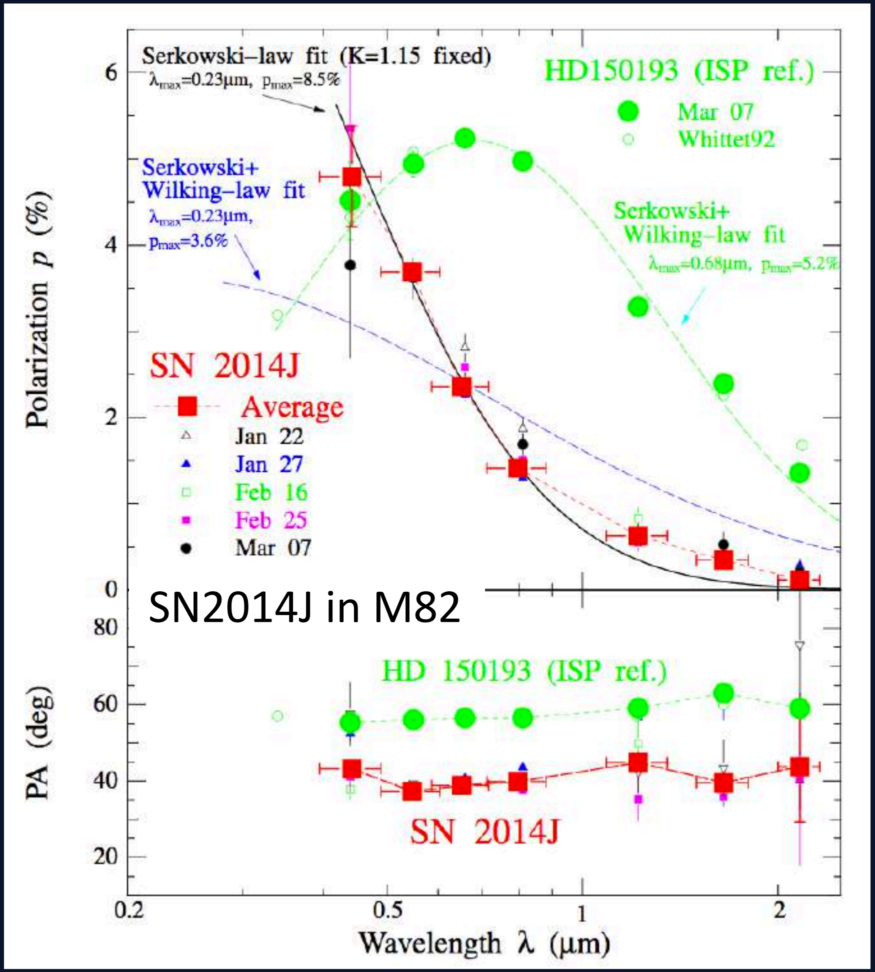


DUST POLARISATION IN NEARBY GALAXIES

Probe the dust composition?



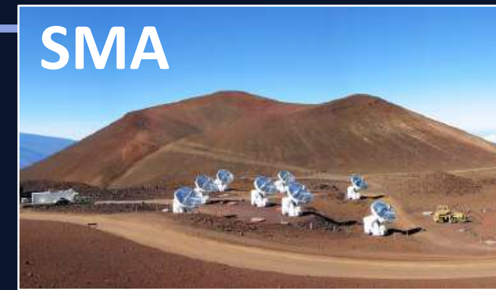
Mason et al 2007

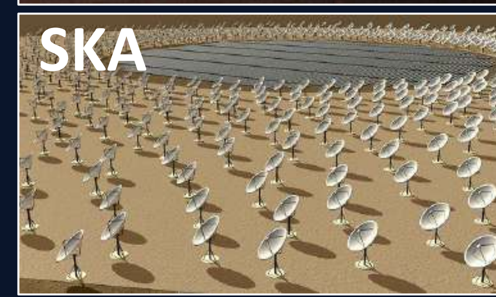


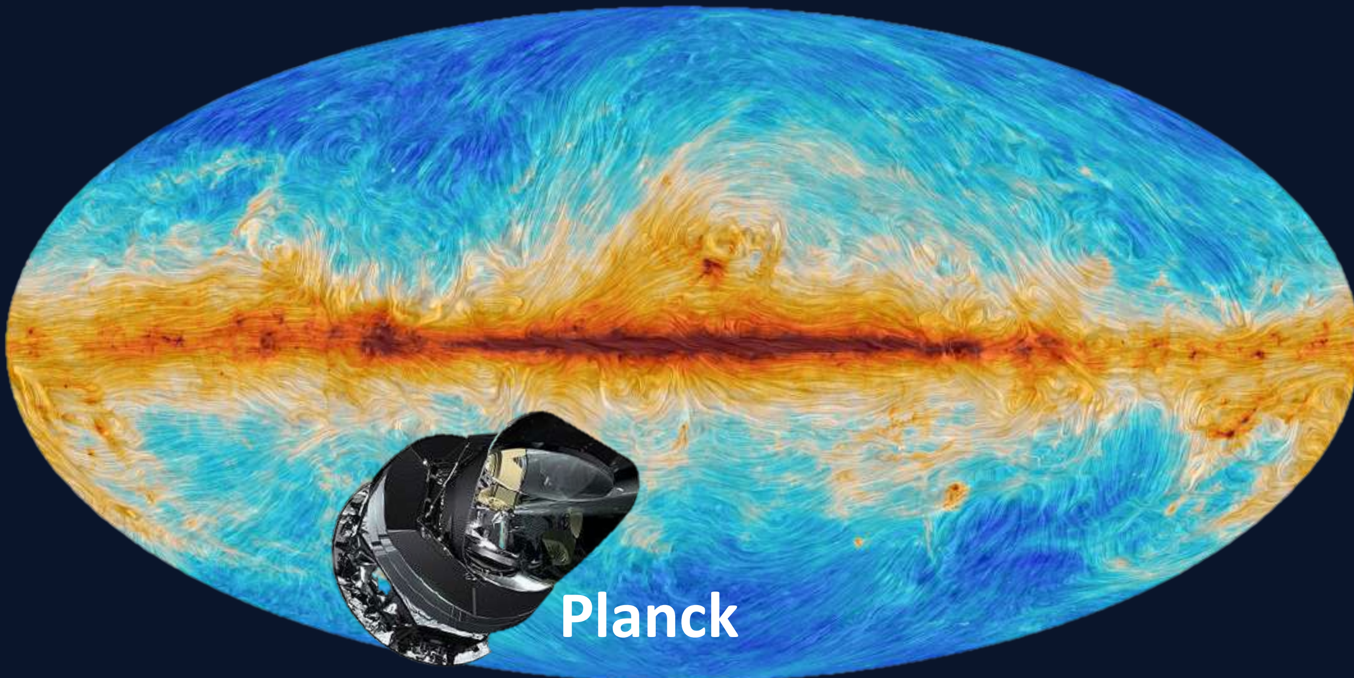
Kawabata et al 2014

A GOLDEN AGE FOR DUST POLARIMETRY

The arrays







Instruments

Baloon exp.

BLASTPol,
PILOT

In space?

POL on SPICA

TAKE-HOME MESSAGES AND FUTURE

Need of refined / rescaled dust properties to fit the submm observations

Signs of dust properties variations from diffuse to dense medium

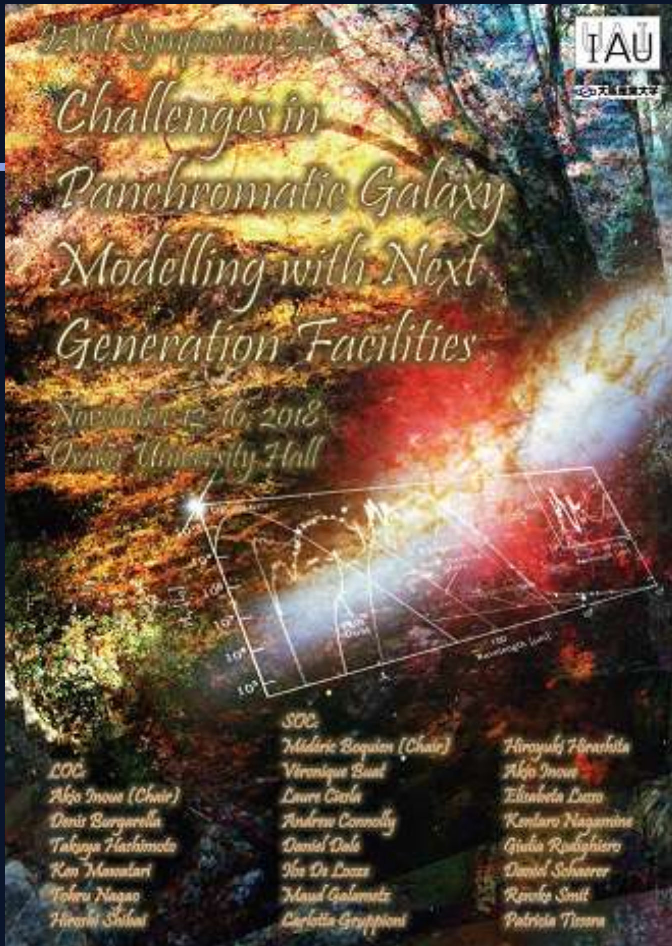
New challenge: model the polarized dust emission

Spatially resolved studies : ALMA, JWST

→ dust heating in dense extragalactic PDRs

FIR spectroscopy / pola: future SPICA

→ better constraint on the shape of the SED
→ IR polarimetry



IAU Symposium 341 - PanModel2018

Challenges in Panchromatic Galaxy Modelling with next Generation Facilities

November 12-16th 2018

Osaka, Japan

https://panmodel2018.sciencesconf.org/

Thank you for your attention!

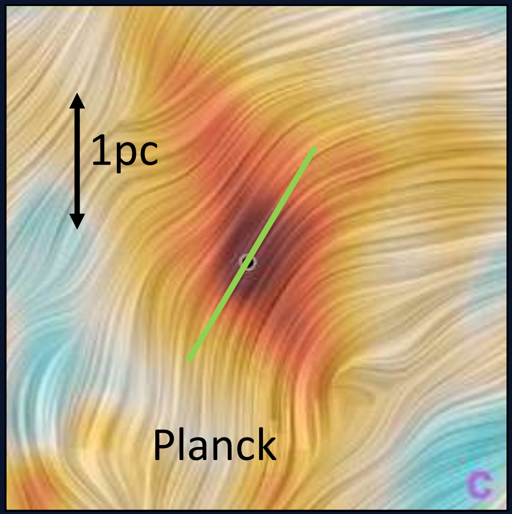
This presentation has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730562 [RADIONET]

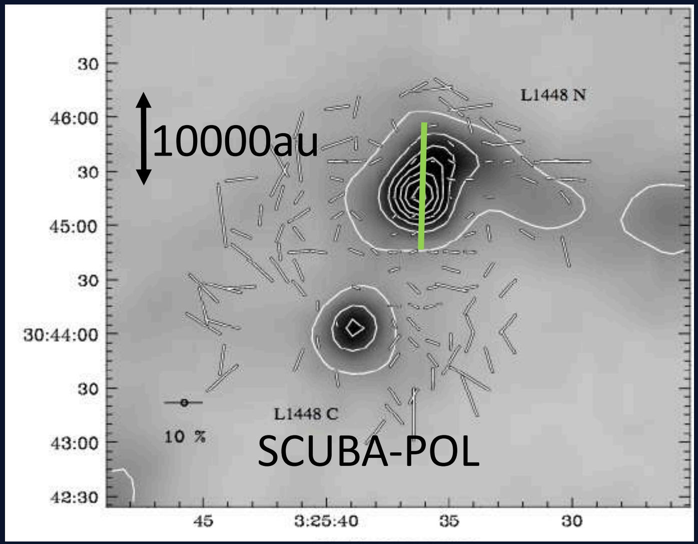
Back-up slides

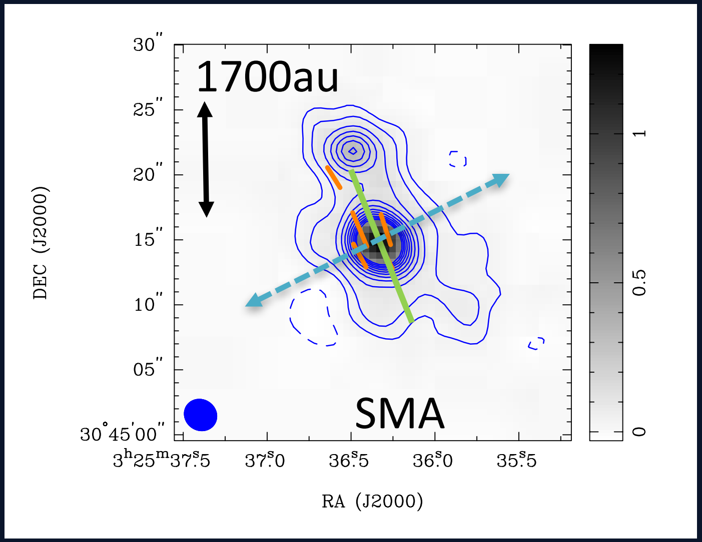
DUST POLARISATION AS A TRACER OF B IN THE MW

L1448N

Matthews et al. 2009 *Galametz et al. 2018*







Cloud scales → Core scales → Envelope scales