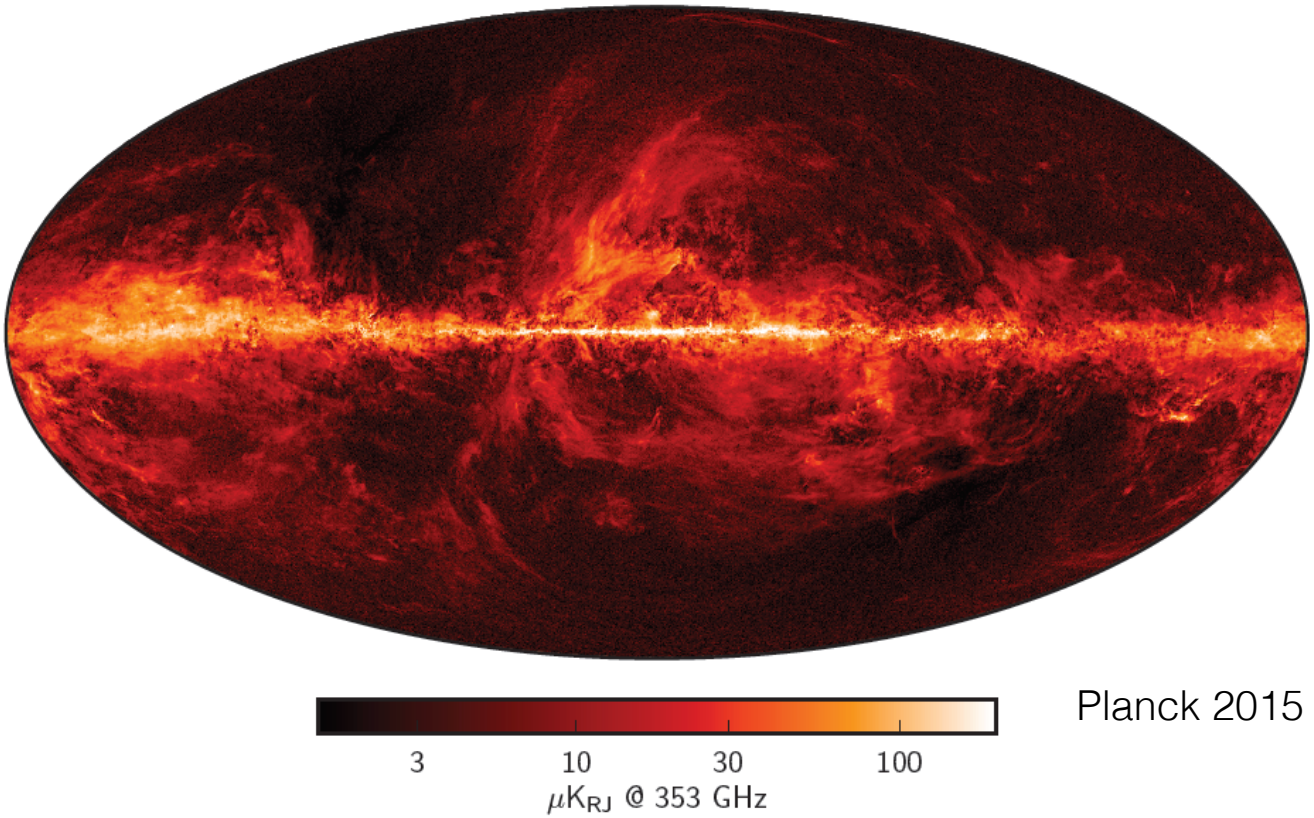
Understanding Interstellar Dust from Polarization Observations

François Boulanger (Ecole Normale Supérieure) &
Vincent Guillet (Institut d'Astrophysique Spatiale)

Outline

- Introduction to polarization of interstellar dust
- Key results from Planck all-sky survey for dust
- New perspective on the nature of large interstellar dust grains

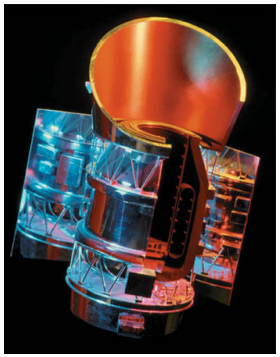
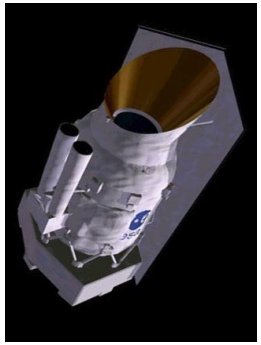
Intensity of dust polarized emission

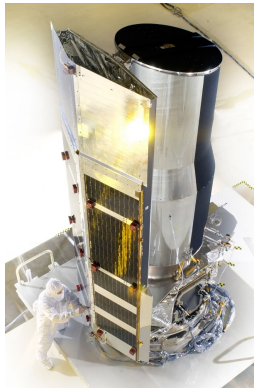


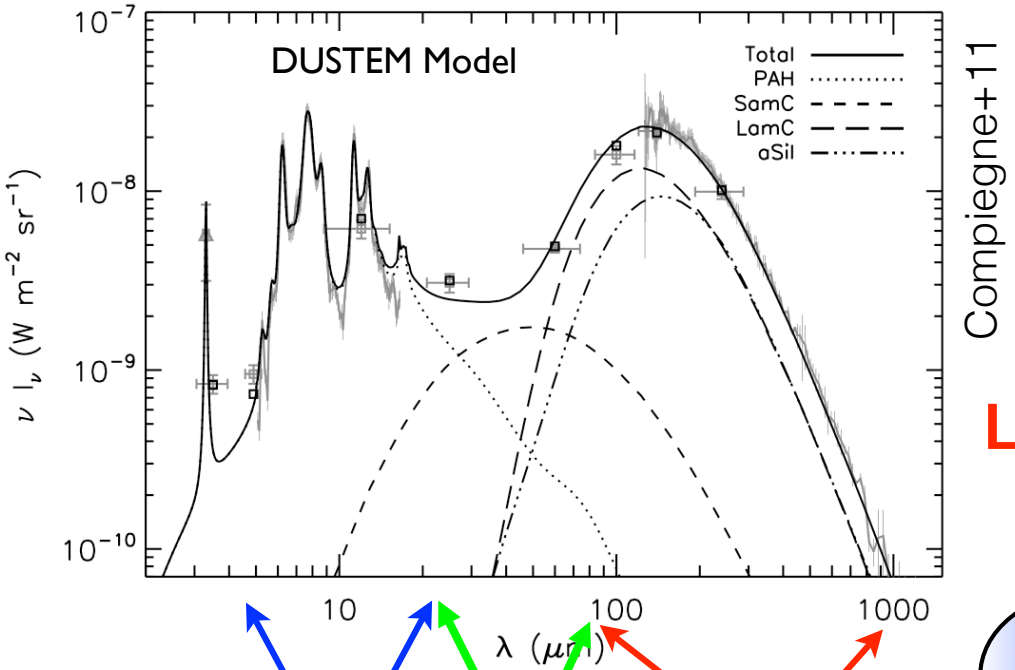
Planck 2015 results X

Dust Emission

IRAS **ISO** **COBE** **Spitzer** **Akari** **Herschel** **Planck**

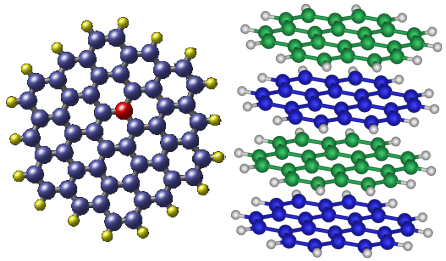





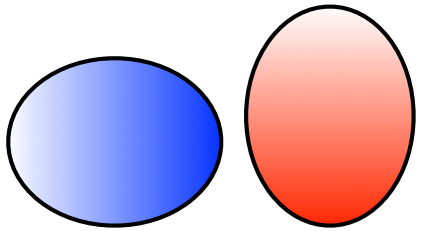



Compiegne+11

PAHs



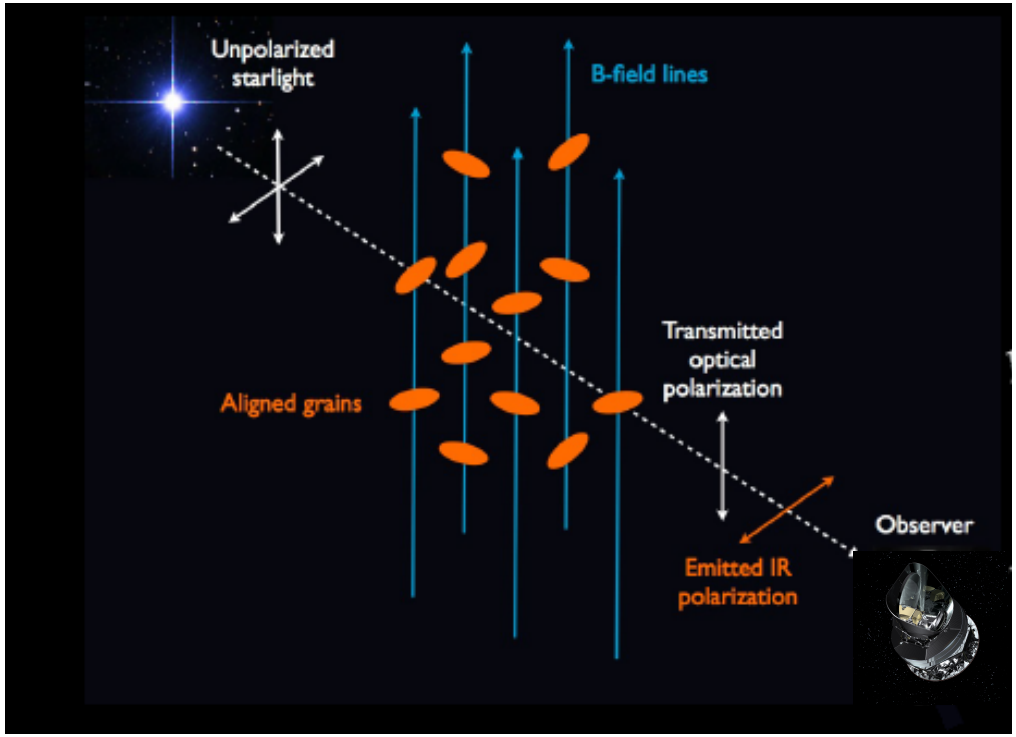
Large Grains > 10 nm



VSGs (nano carbon grains)

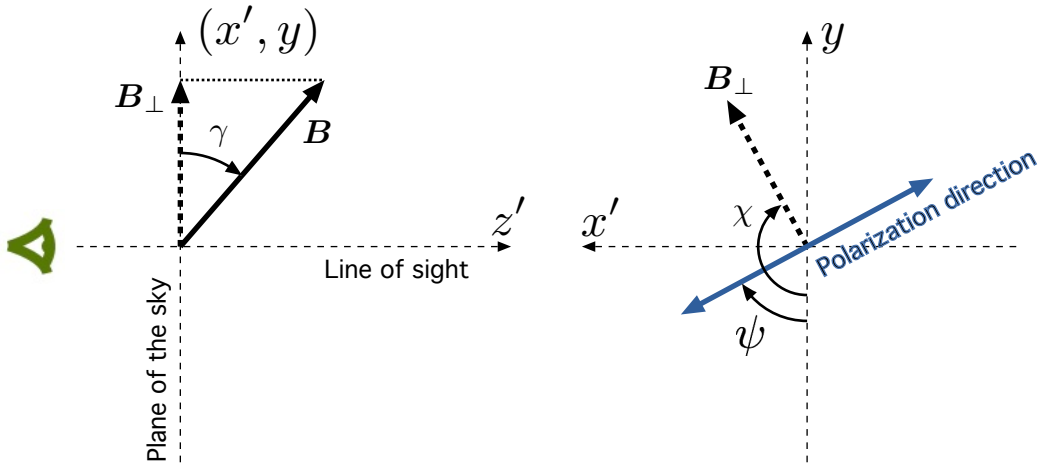
Carbon + Silicates

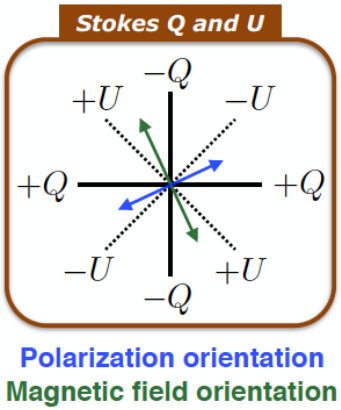
Dust Polarization



- Dust grains are anisotropic
- They align (statistically) with their long axis perpendicular to the magnetic field orientation
- Dust emission (extinction) is perpendicular (parallel) to the magnetic field line

What are we measuring?





Stokes parameters

$$Q = \int p_{\max} R \cos(2\psi) \cos^2\gamma \, dI$$

$$U = -\int p_{\max} R \sin(2\psi) \cos^2\gamma \, dI$$

Polarization angle

$$\psi = 0.5 \arctan(-U, Q)$$

Polarization fraction

$$p = p_{\max} R F \cos^2\gamma$$

$$R \text{ and } F \leq 1$$

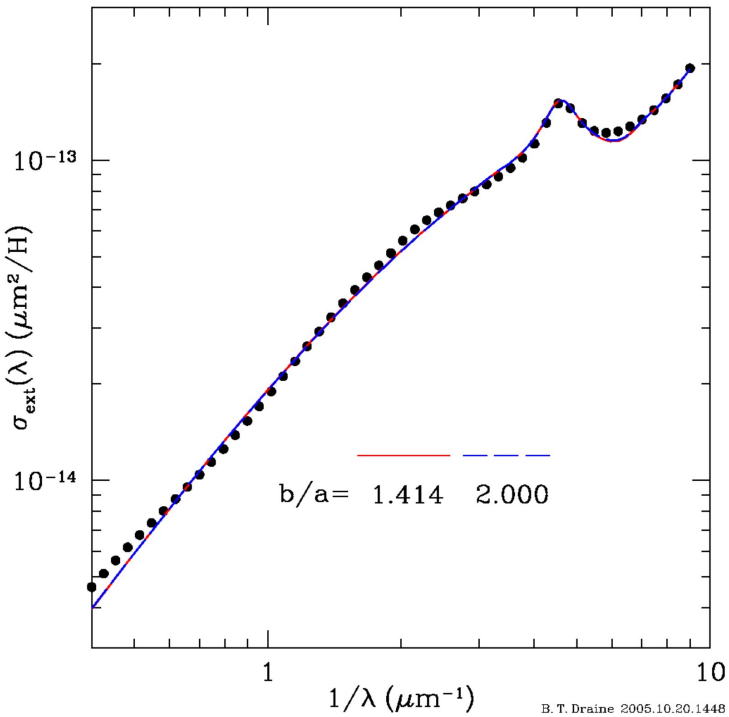
- p_{max}: Intrinsic polarization of dust emission
- R: Rayleigh reduction factor (efficiency of grain alignment)
- F: Depolarization factor (change of B orientation within the beam)

➡ Constraints on dust polarization properties come from the value of p_{max} and its dependence versus frequency ν

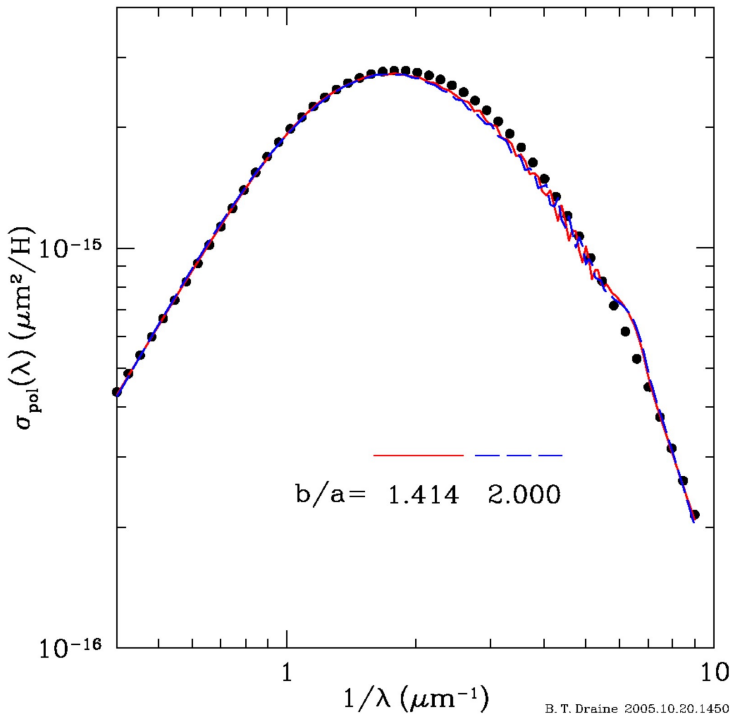
Stellar observations

Draine & Allaf-Akbari 2006

Extinction curve



Polarization curve



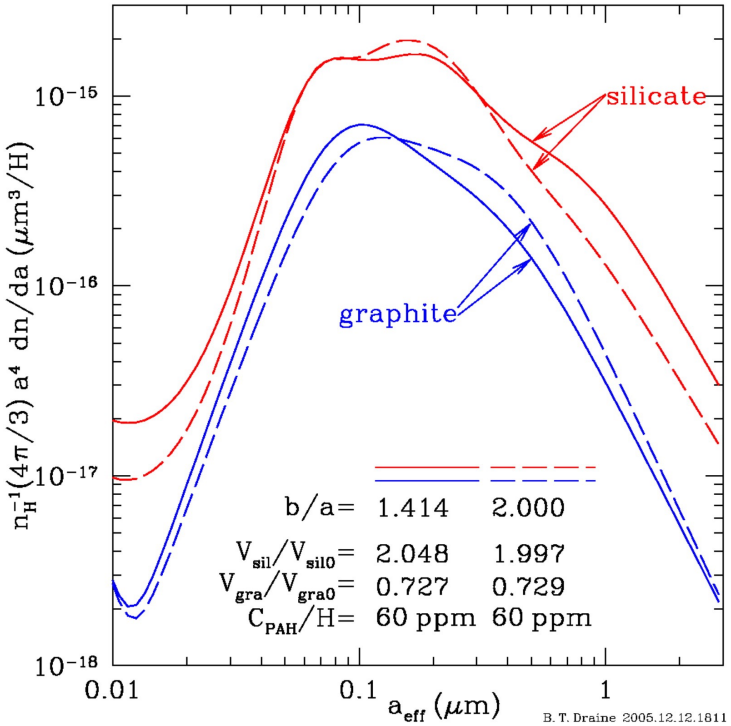
$$p_{\max} \lesssim 0.09 E(B-V)\ \mathrm{mag}^{-1}$$ Serkowsky+ 1975

➡ The difference between the extinction and polarization curves show that polarization arises mainly from large grains

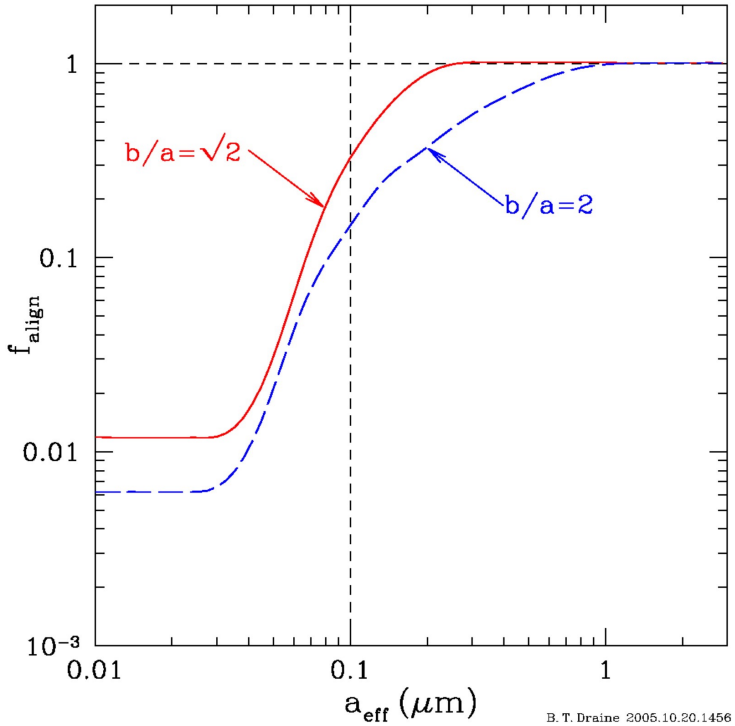
Modelling stellar polarization data

Mass per log size bin

Size distribution



Grain alignment parameter



Perfect

Alignment

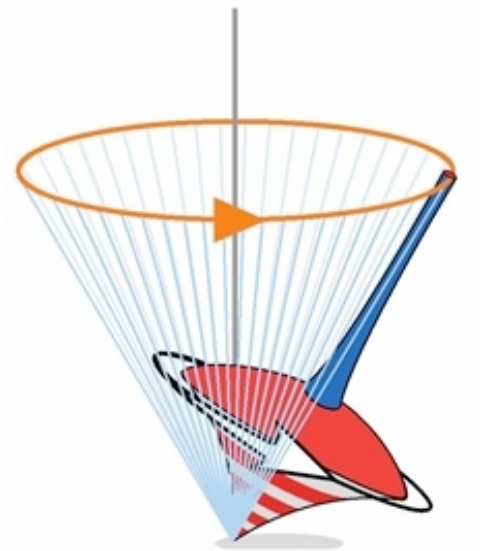
Low

Draine & Allaf-Akbari 2006

- Silicates modeled as oblate spheroids 
- Small grains (size < 100nm) have no or low alignment
- In this model, Carbon grains are not aligned

Grain Alignment

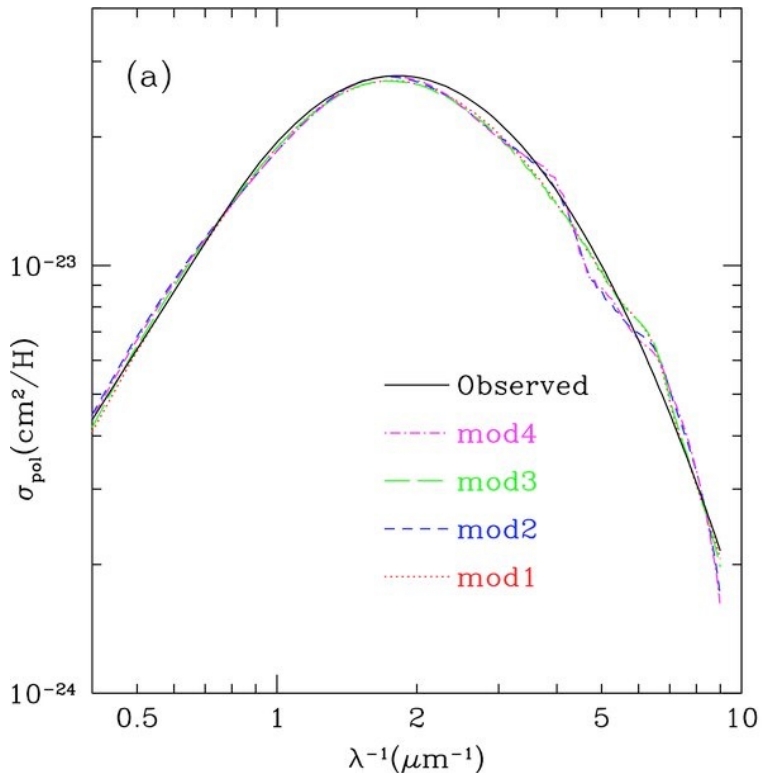
- Interstellar grains spin like tops around their axis of maximal inertia. Their rotation axis precesses around the magnetic field lines.
- Alignment of interstellar grains is thought to result from the combined action of radiative torques (RATs, e.g. Hoang and Lazarian 2016). Alignment with respect to the magnetic field is most effective for grains comprising magnetic inclusions (high magnetic susceptibility).
- Alignment by RATs is effective for grains sizes a > λ/2, which naturally accounts for the alignment threshold ~ 100 nm inferred from the polarization curve.
- We know that silicate grains are aligned. The alignment of carbon grains is an open question.



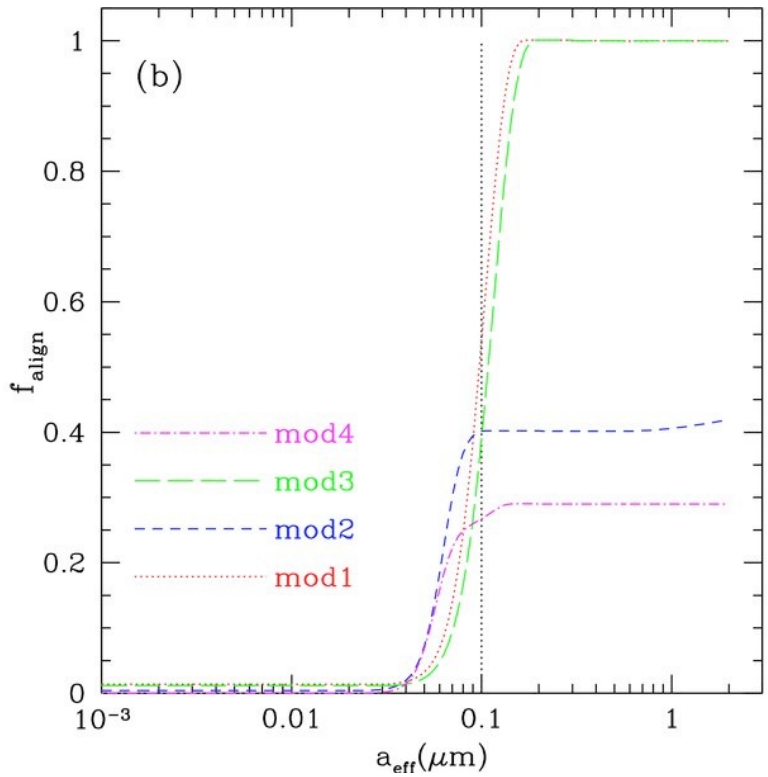
Model of dust polarization in emission

Draine & Fraisse (2009)

Polarization curve



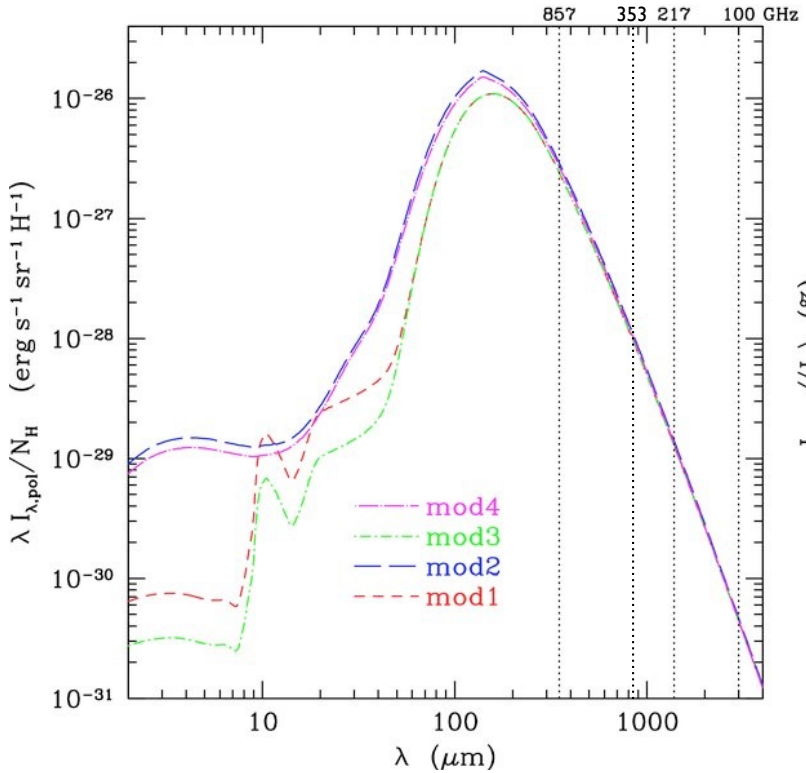
Alignment vs grain size



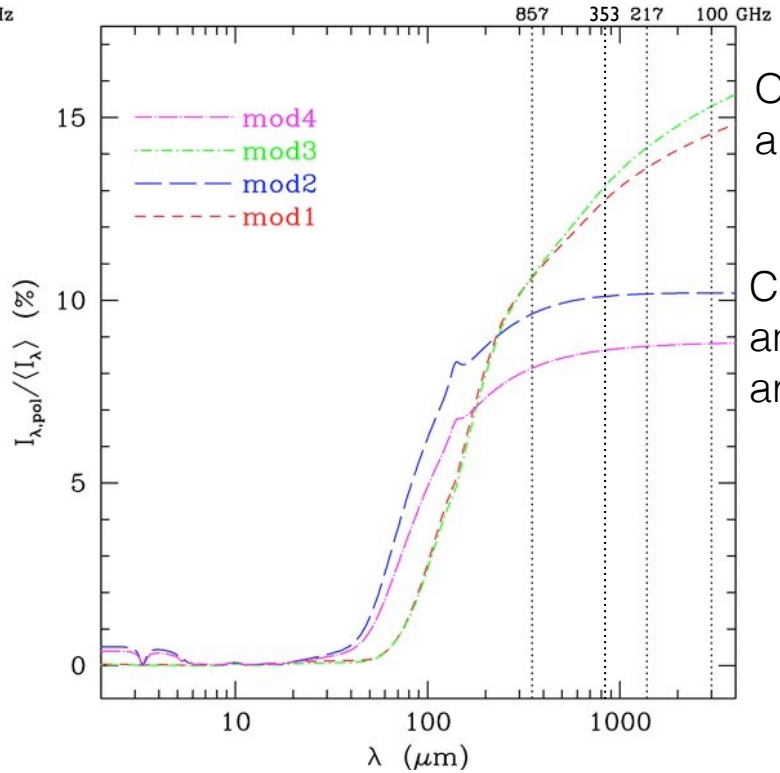
- Models 1 and 3: only silicate grains are aligned
- Models 2 and 4: both carbon and silicate grains are aligned
- All models produce the same polarization opacity in the visible and near-IR, but distinct values of P/I in the sub-millimeter

Dust polarization in emission

Polarized dust emission



Polarization fraction



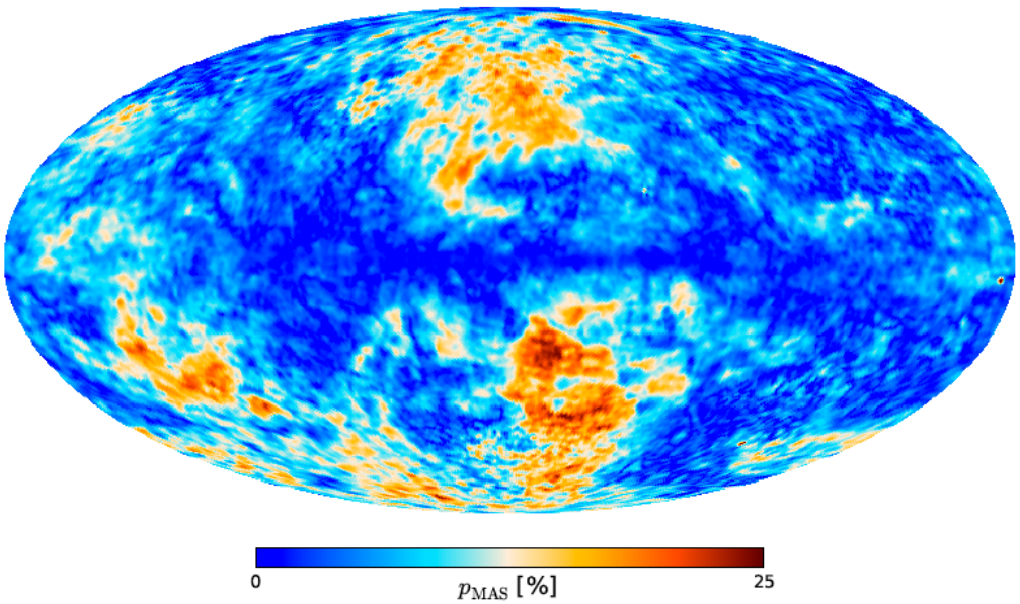
Only silicates are aligned

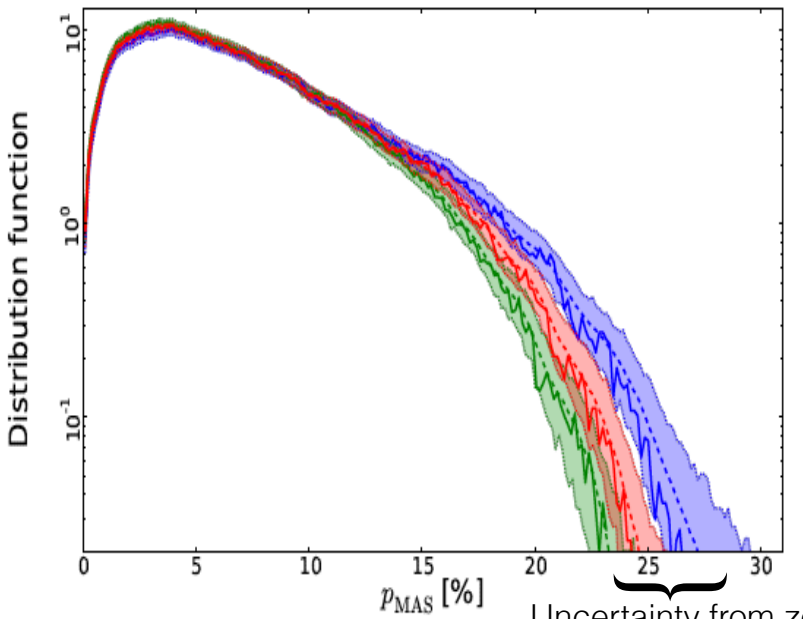
Carbon grains and silicates are aligned

➡ Models 1 and 3 produce a higher degree of polarization at Planck frequencies that increases towards 100 GHz

Dust polarization fraction

Polarization fraction





Uncertainty from zero-level of dust emission

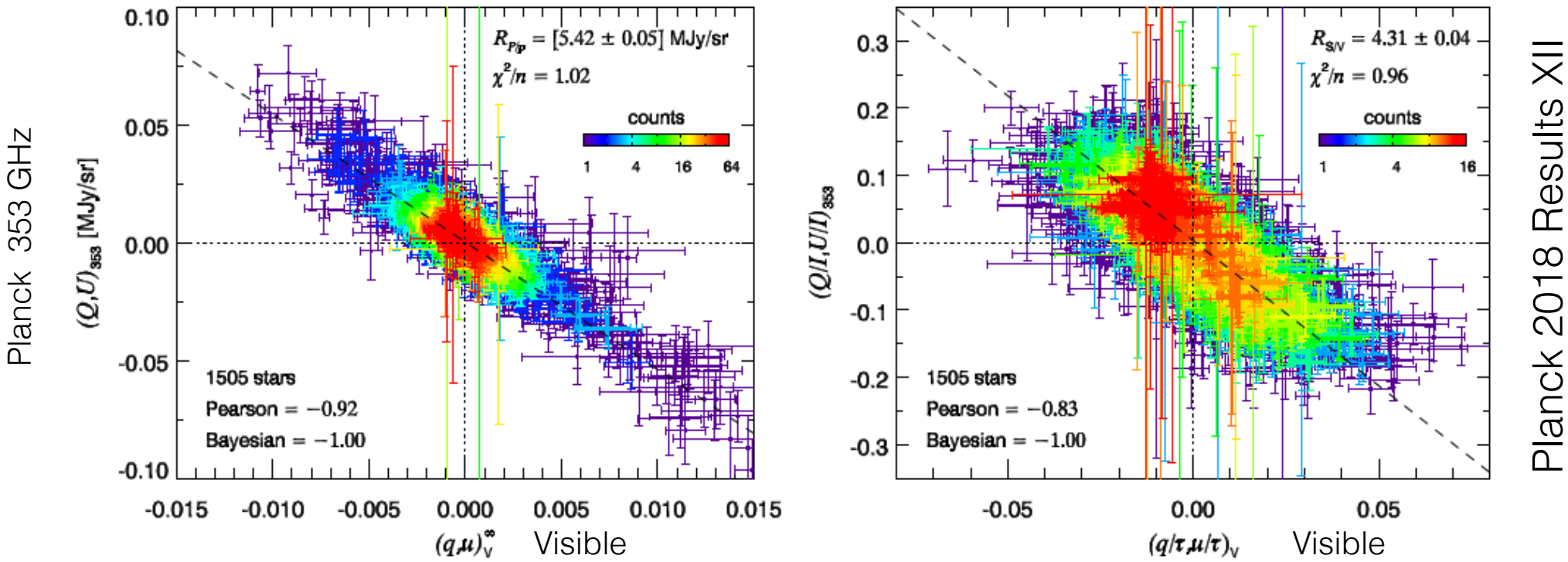
- The maximal polarization fraction is larger (>20%) than expected. It is a challenge for dust models to explain such high values (Guillet+ 2018)
- Variable degree of depolarization from the superposition of a small number of ISM *clouds* along the line of sight with distinct polarization

Planck 2018 Results XII

Polarization extinction vs emission

Stokes parameters

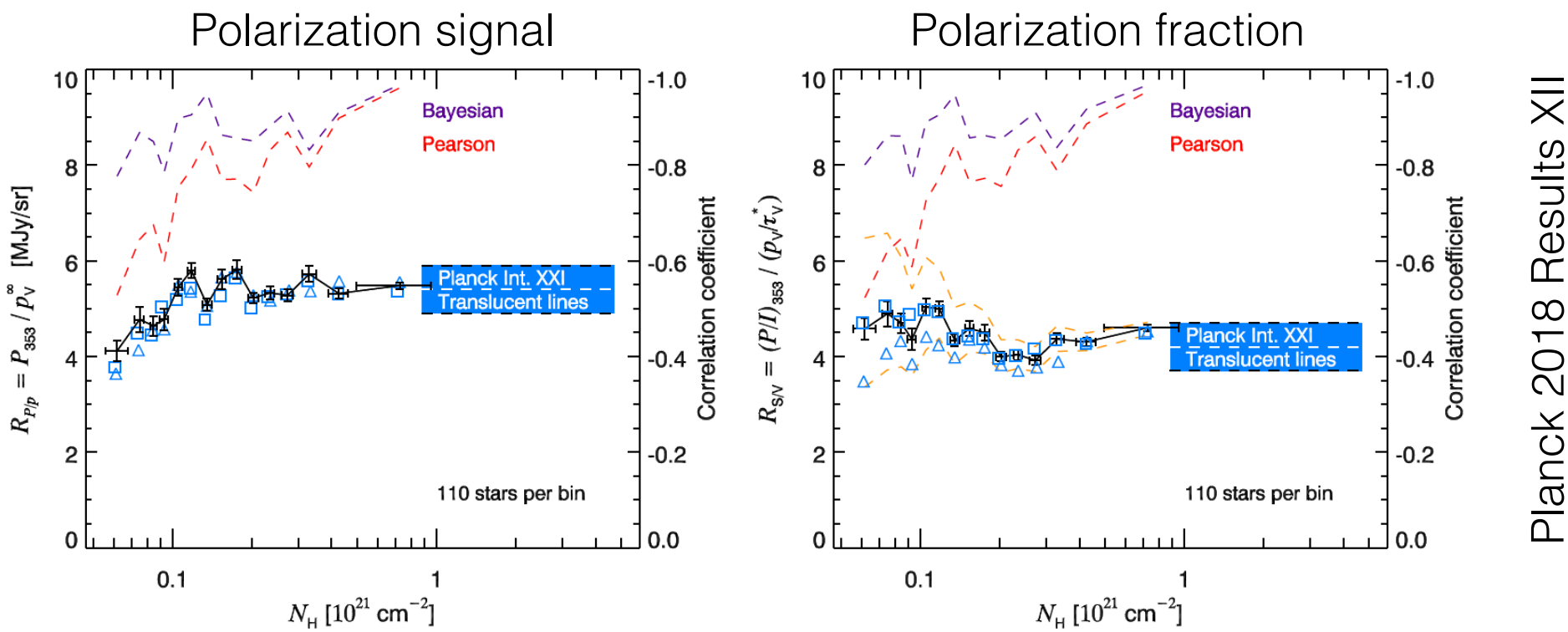
Polarization degree



➡ Good correlation between Planck and stellar polarization

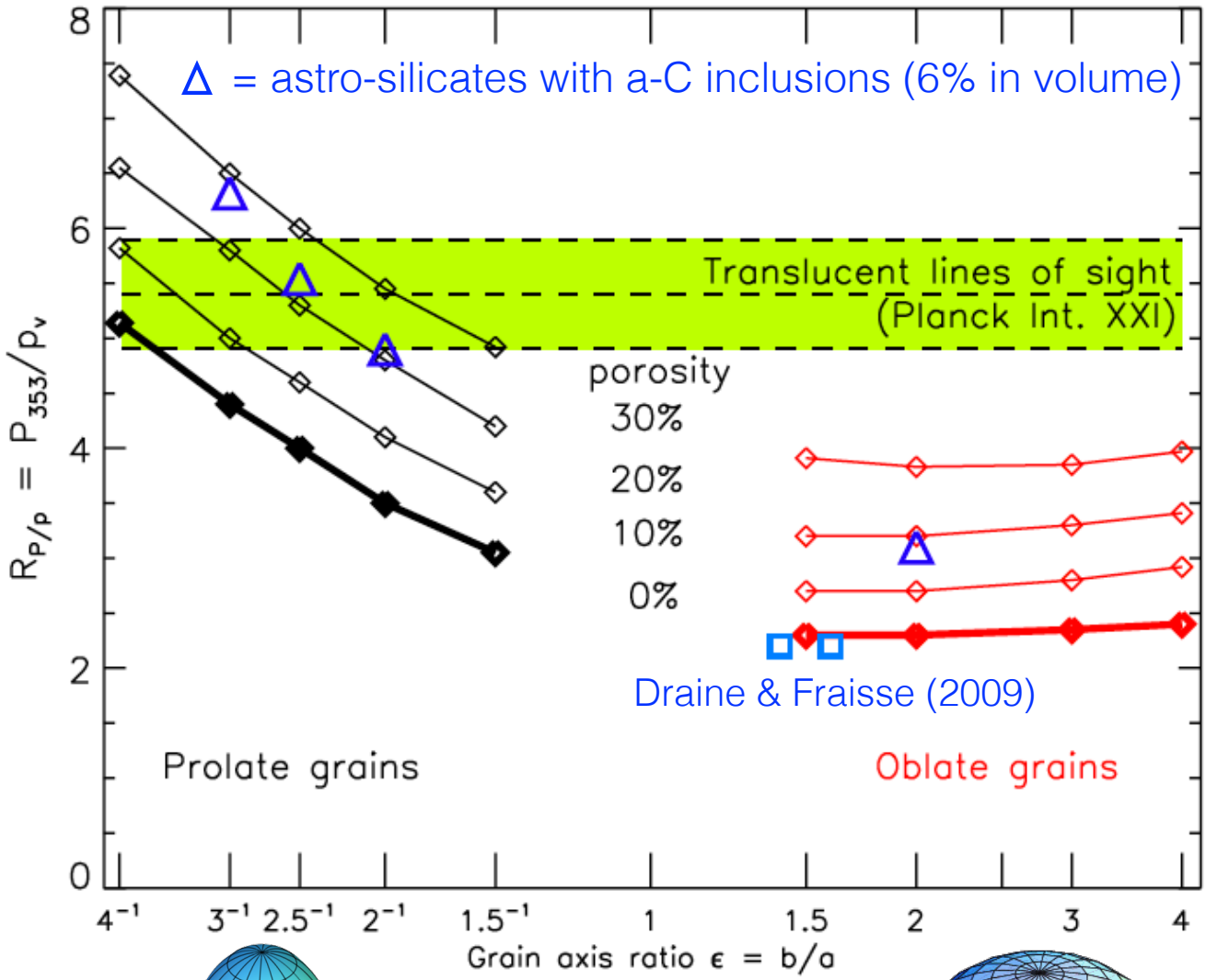
➡ The measured ratios between Stokes parameters and polarization fraction constrain dust models

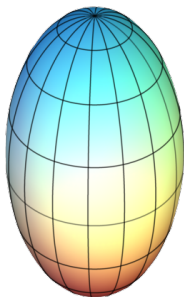
Polarization ratios extinction vs emission



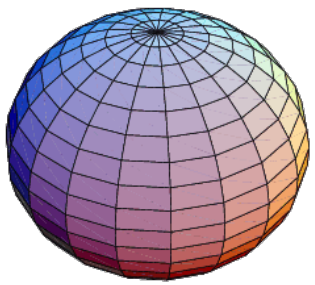
- ➡ The ratios first determined in translucent lines of sight apply to the diffuse interstellar medium
- ➡ We observe no signature of dust evolution

The nature of silicate grains





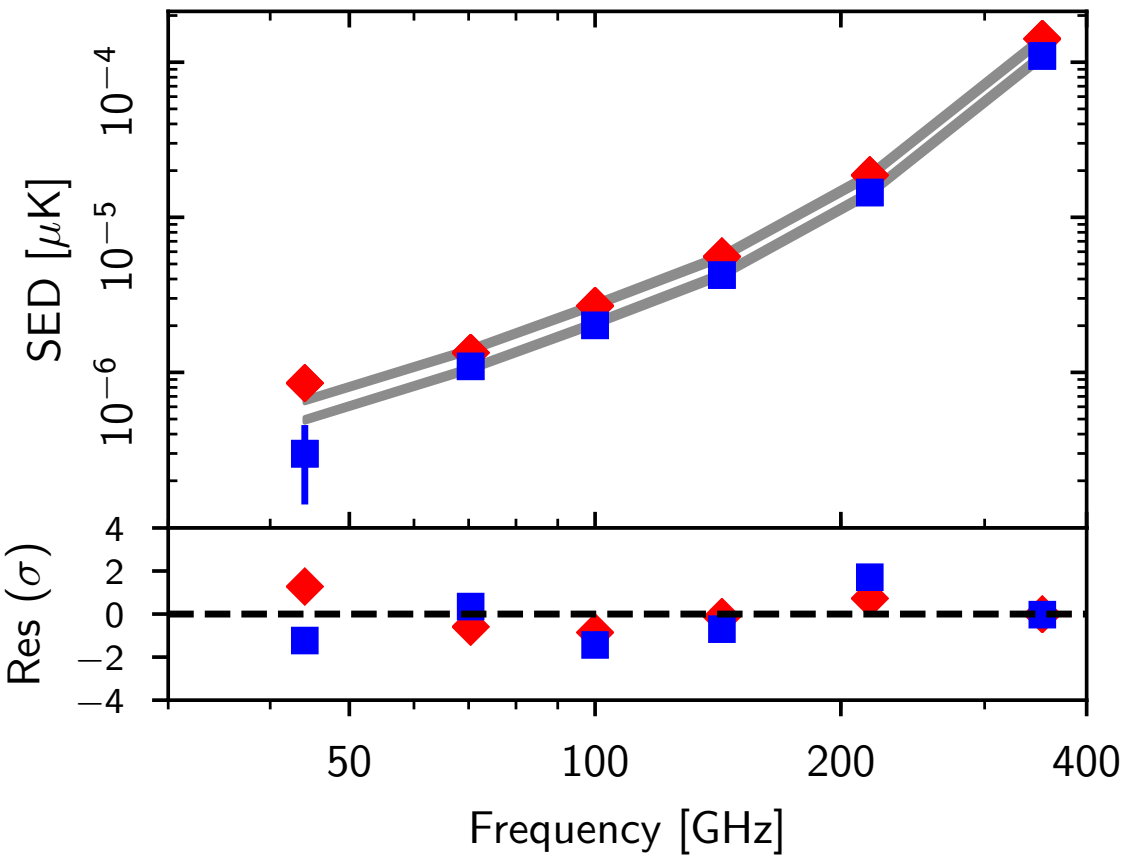
Ratio between sizes perpendicular to and along symmetry axis



➡ Ratio between sub-mm and visible polarization is matched for prolate astro-silicate grains, which are porous, or with a-C inclusions

Guillet et al. 2018

Dust spectral energy distribution in polarization



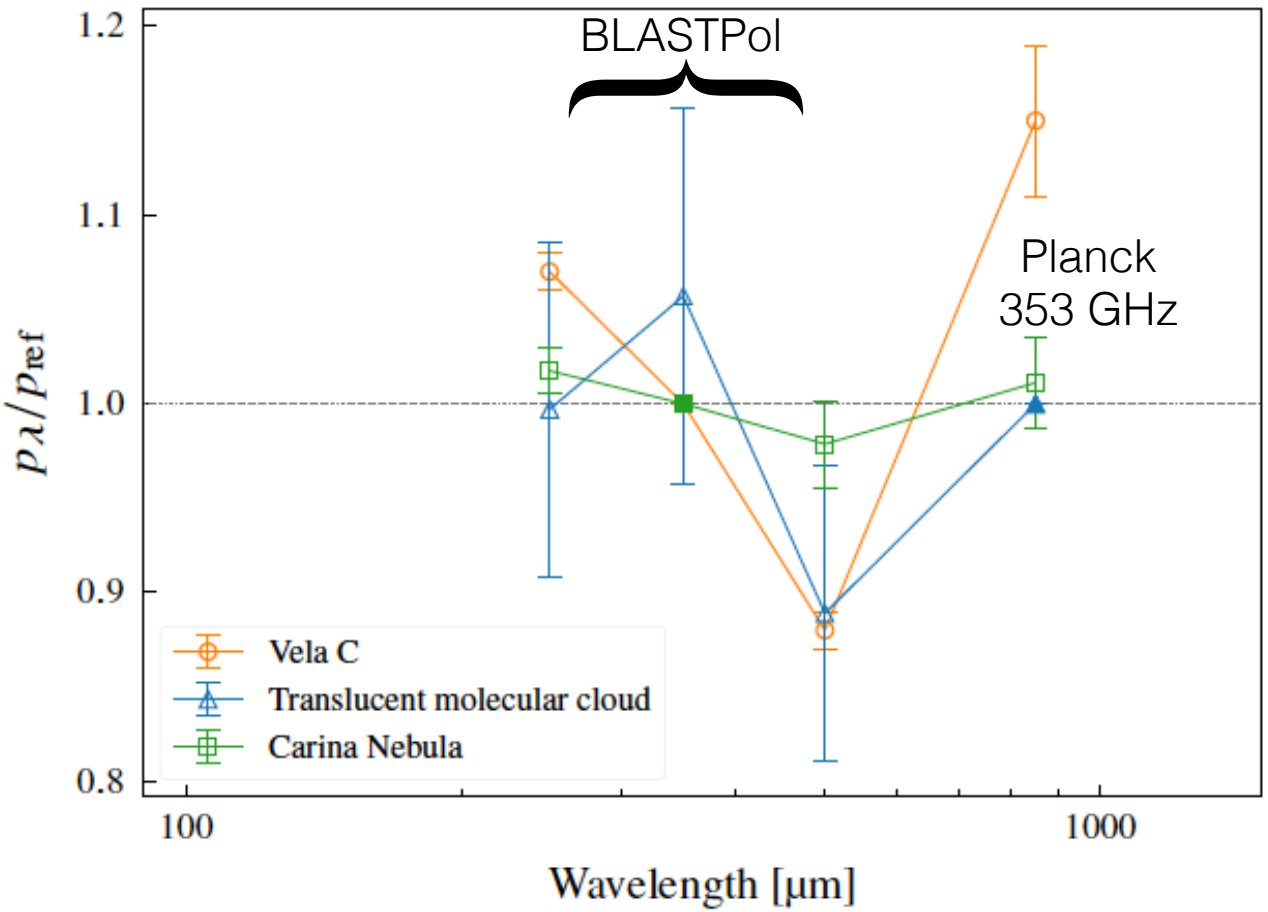
Data points E & B-modes with modified black body fits

- The dust SED in polarization from blind component separation is remarkably well fit by a single temperature modified black-body emission law from 353 to 44 GHz

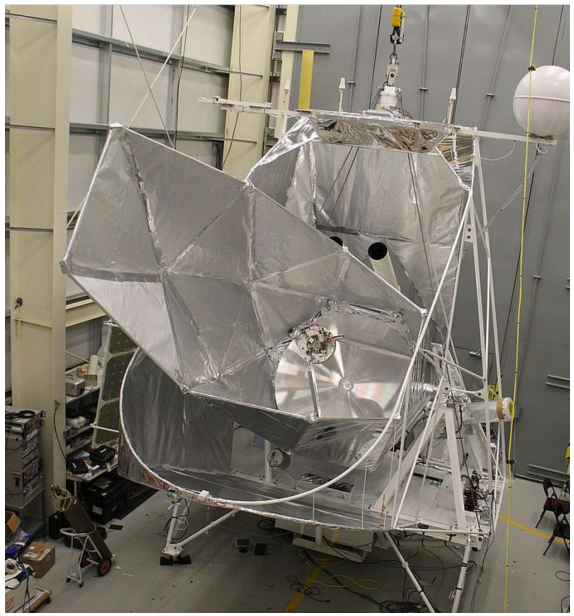
➡ This unexpected result constrains dust models involving multiple dust components

- Separate carbon and silicate grains with distinct SEDs
- Magnetic dipole emission at microwave frequencies (Draine & Hensley 2013)
- Two level systems (Meny+ 2017)

Spectral energy distribution polarization fraction



BLASTPol

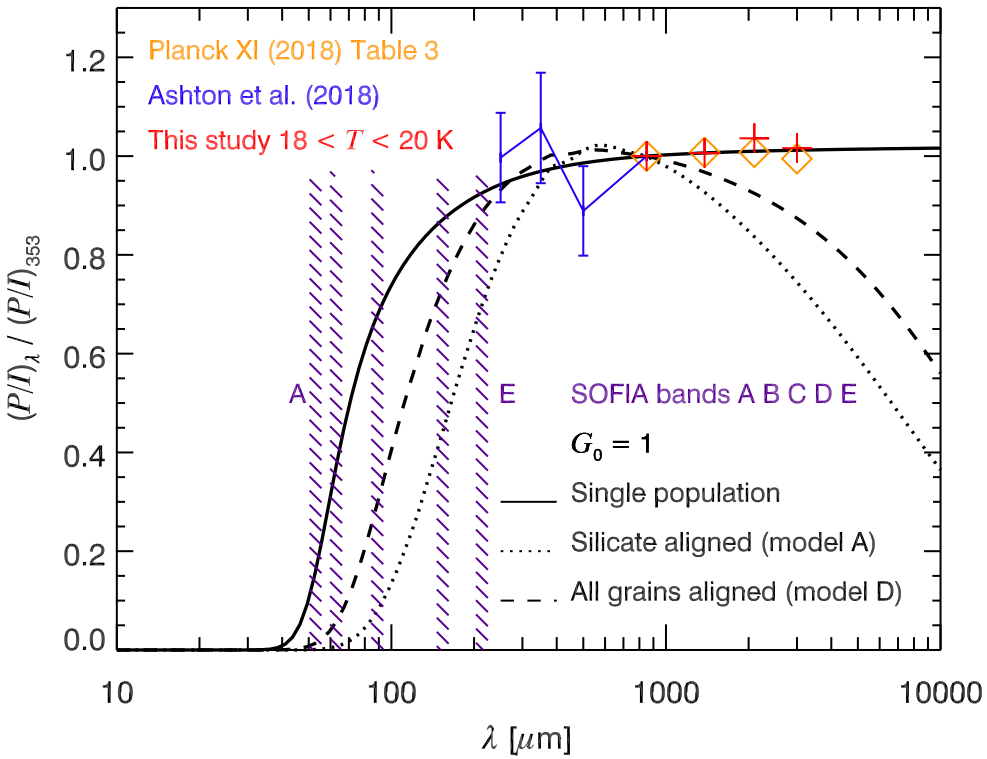


Data from Gandilo+ 2016, Ashton+ 2018 & Shariff+ 2019

➡ The SED is remarkably flat. This is also true at Planck frequencies

➡ This result suggests that we are observing a single grain type in both total intensity and polarization

A single population of large dust grains



➡ Hypothesis to be tested with HAWC+ on board of SOFIA

Dust polarimetry from ground-based telescopes at sub-mm/mm wavelengths

CMB experiments Atacama & South Pole

NIKA2 Pol IRAM 30m

+ Far-IR dust polarimetry from balloon-borne experiments (PILOT, BLASTPol) and B-BOP on SPICA

Summary

- Polarization observations in emission from far-IR to mm wavelengths are providing new constraints on the nature of large interstellar dust grains
- Planck and BLASTPol results are more straightforwardly interpreted if we assume that we are observing a single type of large grains in both total intensity and polarization
- This hypothesis can be further tested with existing observing facilities

Thank you