Planck Observations of Dust Polarization

Planck Collaboration
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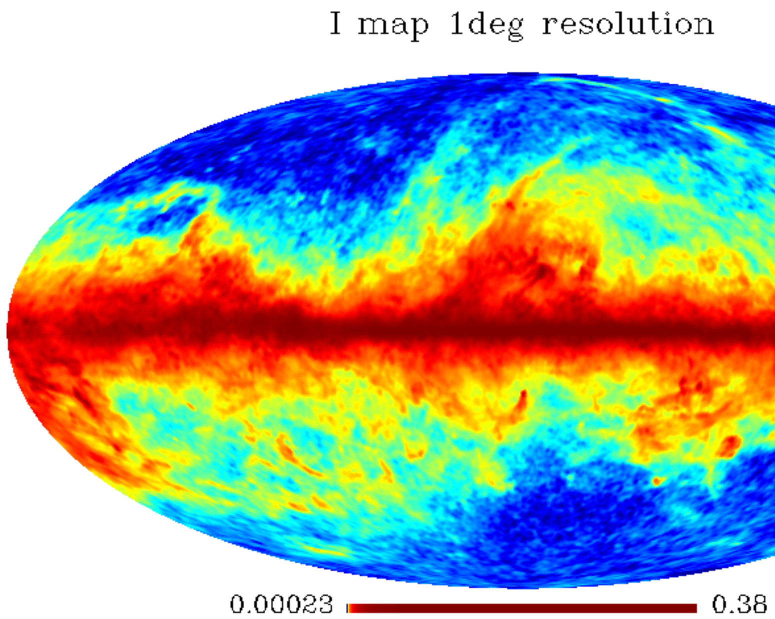
Outline

- The dust polarization sky as seen by the Planck high frequency instrument (HFI, 100-353 GHz)
  - Maps of Stokes parameters
  - Data analysis
  - First Planck papers on Galactic Polarization

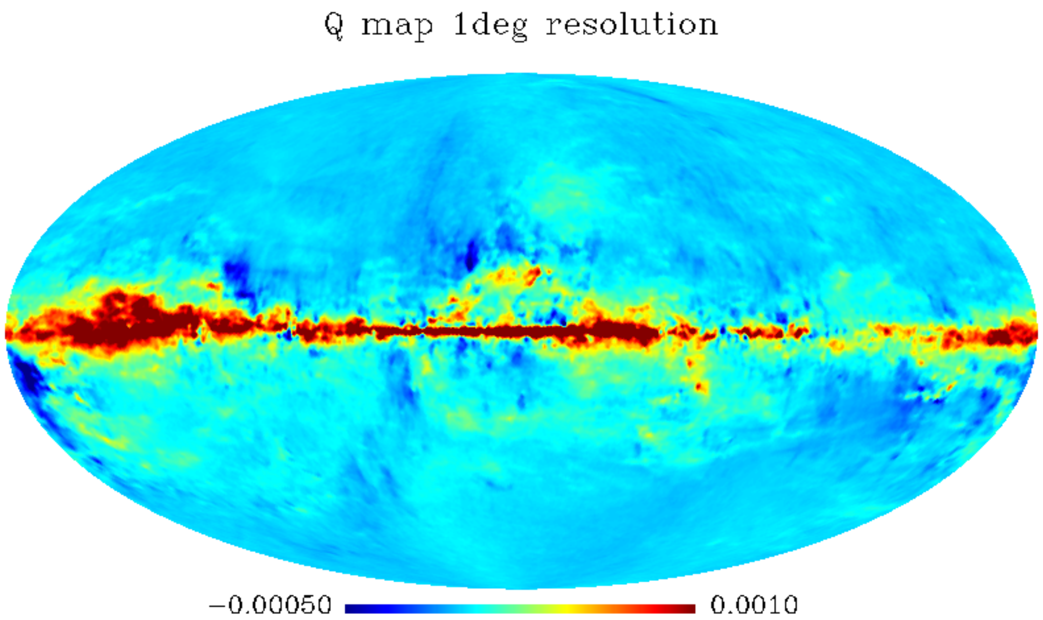
- Context and Planck highlights from three complementary perspectives on the data:
  - Dust polarization and the structure of the Galactic magnetic field
  - Dust polarization properties: constraints on existing models
  - Power spectra analysis for component separation

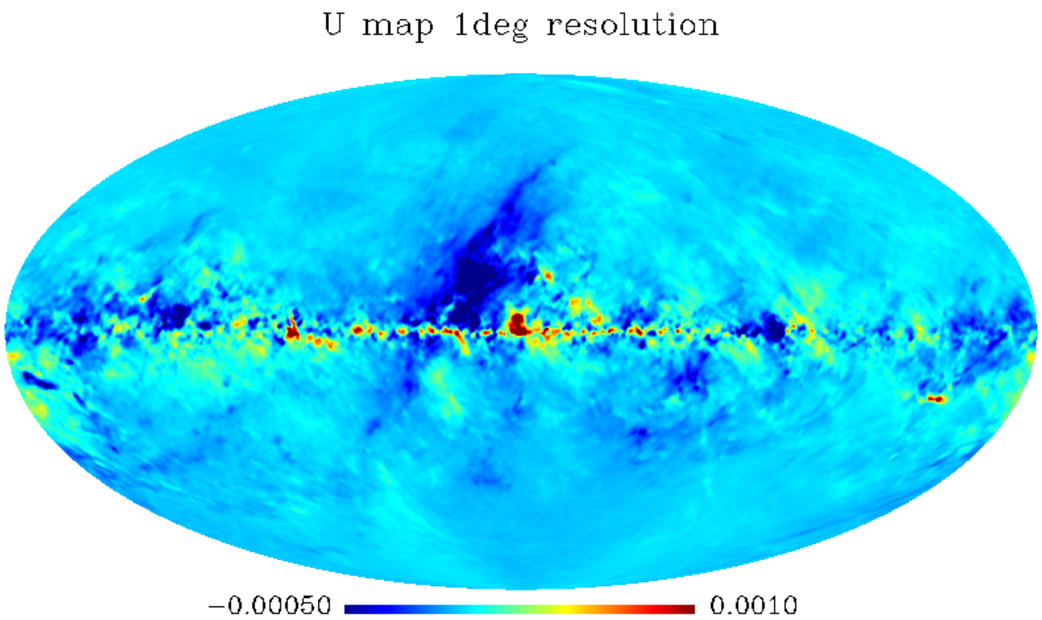
Introduction and review of detailed results presented in posters and talks tomorrow

The dust polarization sky at 353 GHz



- First all sky maps of dust polarization.
- The data provides the sensitivity to image the polarization of dust emission over the whole sky
- Complementary to observations of stellar polarization which provide detailed information on smaller angular scales





Data analysis

- The dust polarization holds information on dust polarization properties, grain alignment process(es) and the Galactic magnetic field:
  - Which dust components contribute to polarization?
  - Where in the ISM are grains aligned with the magnetic field and with what efficiency?
  - What is the interplay between the structure of the Galactic magnetic field and that of interstellar matter?
- The data analysis aims at disentangling these three facets of Galactic microwave polarization.
- Two complementary approaches: statistical and analysis of maps (I, Q, U and derived quantities: polarized emission P, polarization degree P/I and angle).
- Spectral/calibration mismatch corrected using sky observations. Data redundancy used to check for residual systematics.
- 3D MHD simulations used to guide the data analysis and test the robustness of science results

First Planck papers on Galactic polarization

- **The Planck dust polarization sky** (Talk J.P Bernard)
  - Introduction to the dust polarized sky as seen by Planck HFI.
- **Dust polarization in molecular clouds** (Poster F. Levrier)
  - Statistics on P/I and polarization angles observed towards nearby molecular clouds. Comparison with MHD simulations.
- **Spectral characterization of Galactic polarization** (Poster T. Ghosh)
  - The frequency dependence of polarized emission spatially correlated with dust polarization at 353 GHz. Comparison of results with predictions of existing models.
- **Dust polarization properties** (Talk V. Guillet)
  - Dust polarization extinction vs sub-mm emission. Comparison of results with predictions of existing models.
- **Power spectra of dust polarization maps** (Talk J. Aumont)
  - The structure of the dust polarization sky for component separation

Dust Polarization and the Galactic magnetic field

Observations of the Galactic magnetic field

- **Synchrotron emission** traces the field over the whole volume of the Galaxy including the thick disk and Galactic halo. The volume emissivity scales as $n_{cr} \times B_{\perp}^2$.

- **Faraday rotation** traces the amplitude of $B_{//}$ in ionized gas. The rotation measure scales as $\int n_e \times B_{//}\, ds$.

- **Dust polarisation** traces the magnetic field over the thin disk where matter is concentrated. The volume emissivity scales as n_H. The contribution from dust in the thick Galactic disk is minor. Observed polarization is the sum of two contributions:

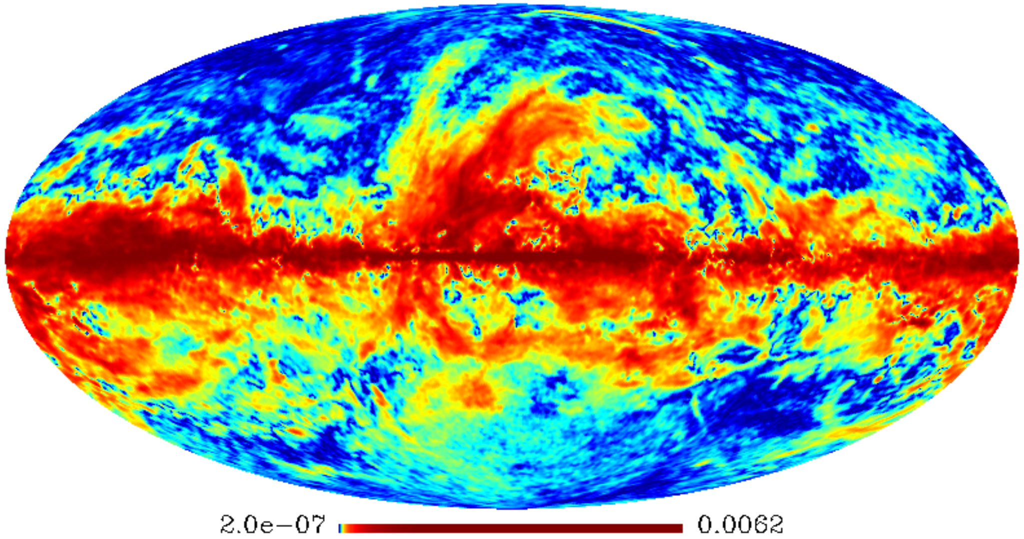
    - The warm medium (WNM/WIM) with a significant volume filling factor ($f_{WNM/WIM} \gtrsim 0.2$). This contribution traces the mean direction/structure of the field averaged along the line of sight.

    - The cold medium (CNM) with a small volume filling factor ($f_{CNM} \lesssim 0.01$). This contribution traces the direction/structure of the field within localized clouds.

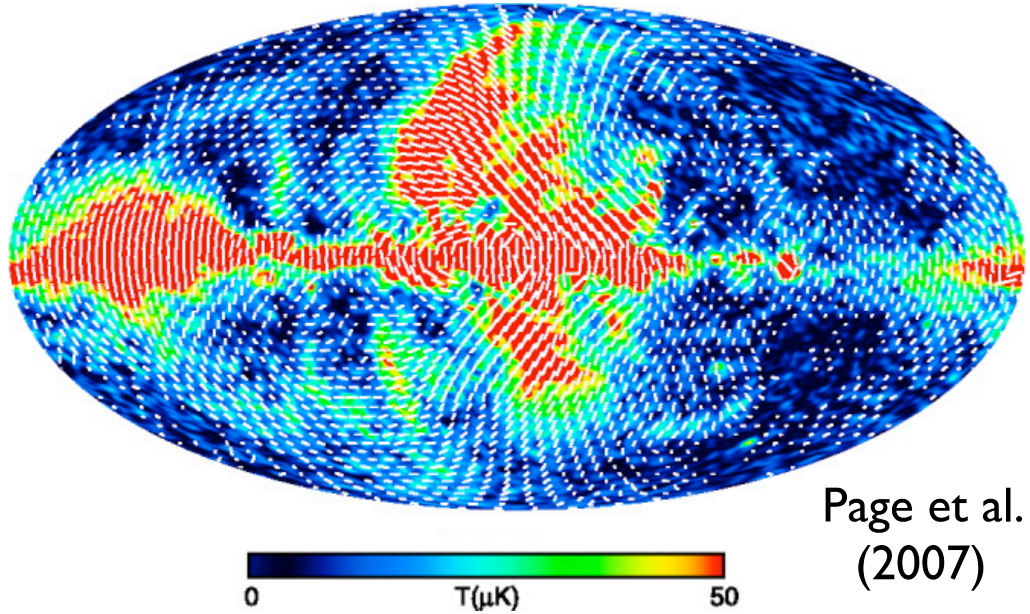
➡ **Dust polarization is best suited to characterize the interplay between the structure of the Galactic magnetic field and that of interstellar matter**

Planck Polarization maps in context

P from Planck 353 GHz at 1° resolution

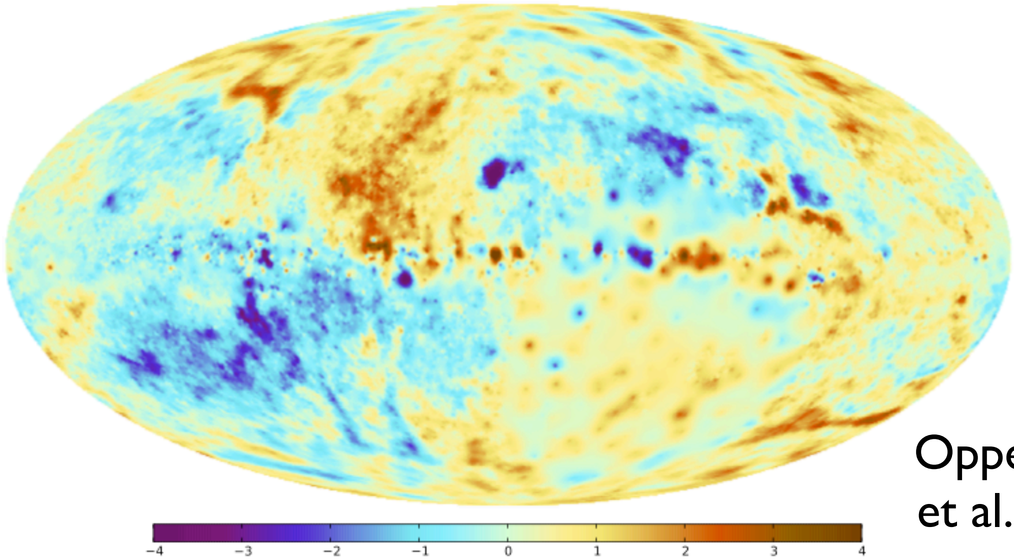


P from WMAP 23 GHz



Page et al. (2007)

Map of Faraday rotation measure normalized by Galactic latitude profile

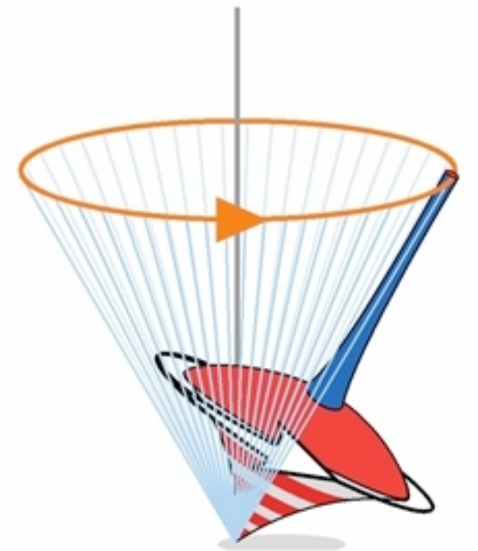


Oppermann et al. (2012)

How well does the Planck map trace the field structure?

Alignment of dust grains

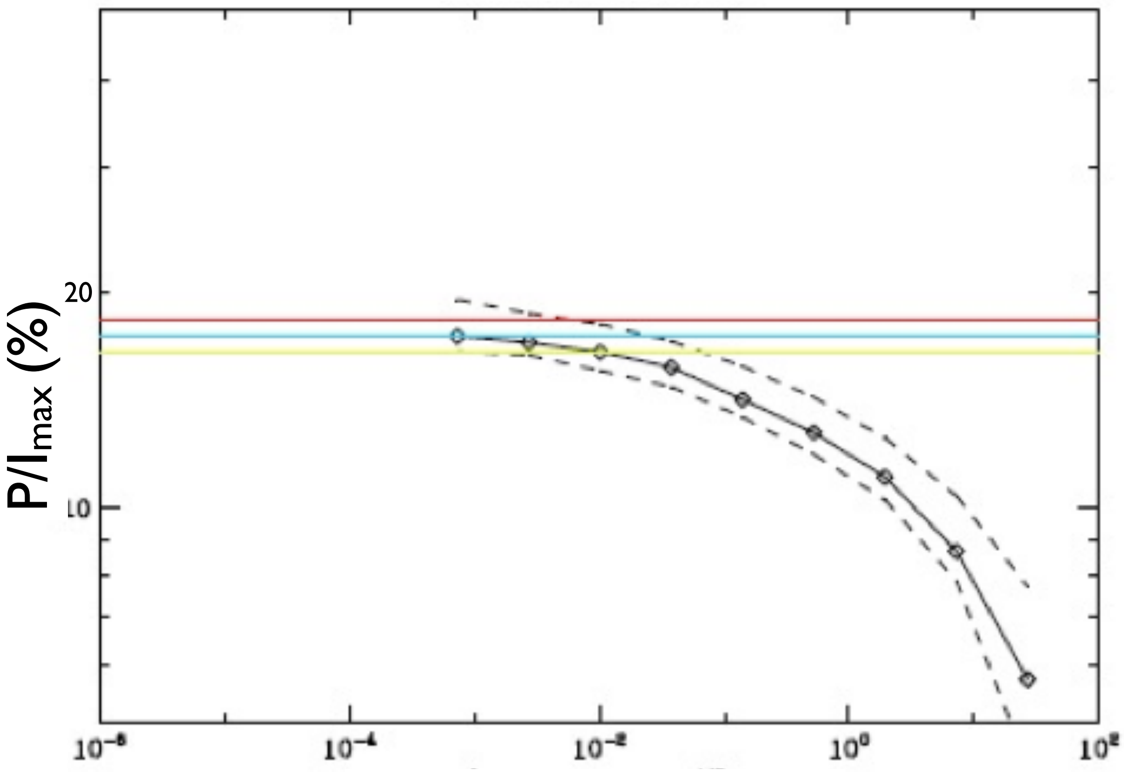
- Interstellar grains spin like tops around their axis of maximal inertia.
- Their rotation axis precesses around the magnetic field lines.
- Dissipation of precession energy leads to alignment with the field. Alignment may be associated with paramagnetic dissipation (Davis-Greenstein 1951) or radiative torques (Lazarian & Hoang 2007).
- Alignment mechanisms are opposed by grain-gas collisions.



Where in the ISM and with what efficiency are the grains aligned ?

High polarization degree

Cumulative Histogram of P/I ratio
353 GHz and 1° resolution



Sky upper percentile

- The observed degree of polarization $(P/I)_{obs}$ is up to 18%.

➡**The intrinsic degree of dust polarization** ($(P/I)_{dust} \geq (P/I)_{obs}$) **is high**

- This result is consistent with earlier results from the Archeops experiment (Benoit et al. 2004).

- $(P/I)_{dust}$ is likely to vary across the sky. Theory says alignment depends on the grain size distribution, the spectrum of the radiation field, and its orientation with respect to the B field. H_2 formation can also locally enhance $(P/I)_{dust}$ (Hoang & Lazarian 2008).

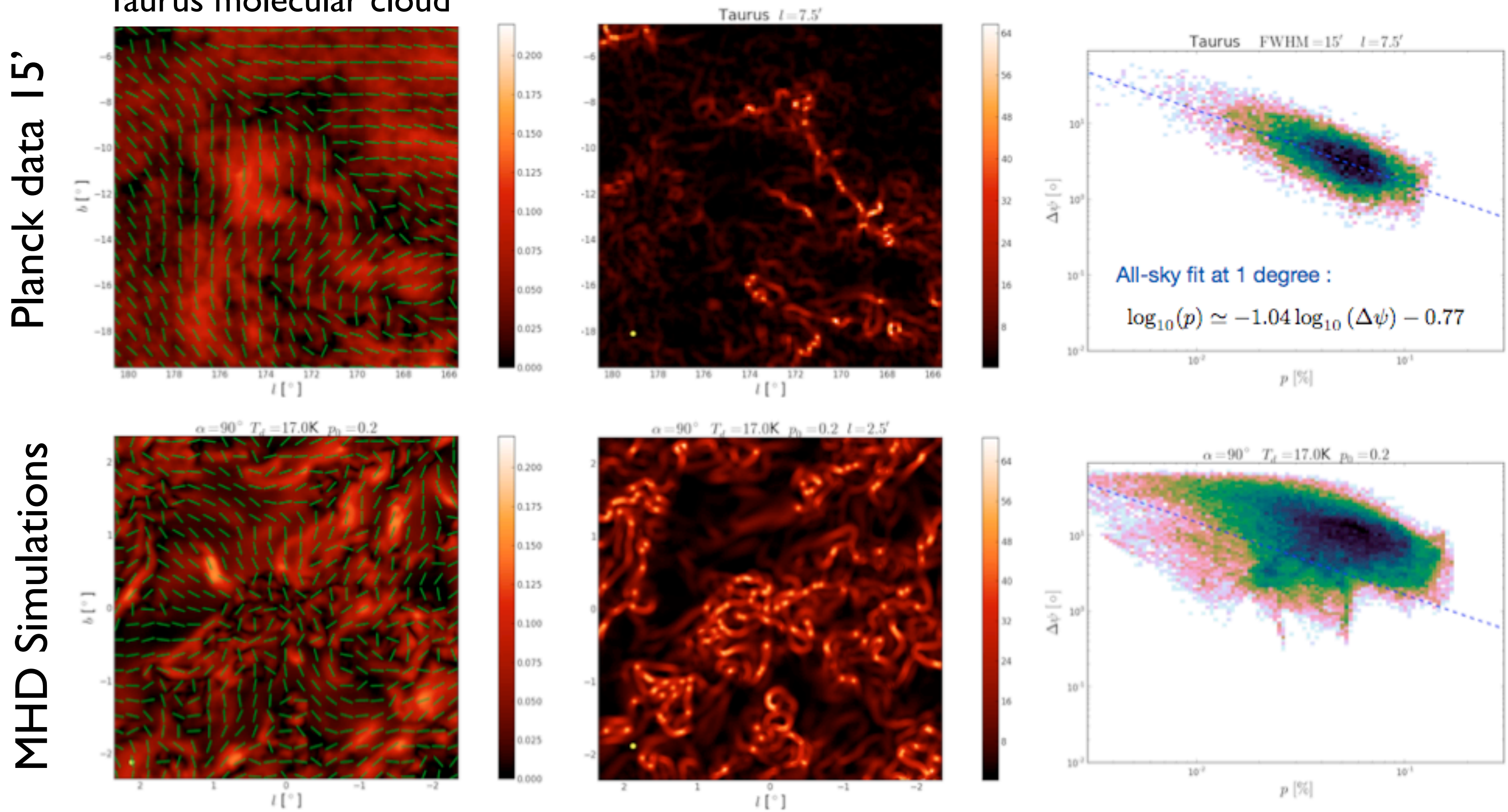
➡Talk J.P. Bernard on Galactic science session on thursday

Statistical studies of polarization maps

P/I and polarization angle
Taurus molecular cloud

Local dispersion of ψ

$$\Delta\psi^2(l) = \frac{1}{N}\sum_{i=1}^{N}\left[\psi(\mathbf{r}) - \psi(\mathbf{r}+\mathbf{l}_i)\right]^2$$



- P/I and $\Delta\psi$ are anti-correlated as in MHD simulations (Poster F. Levrier)

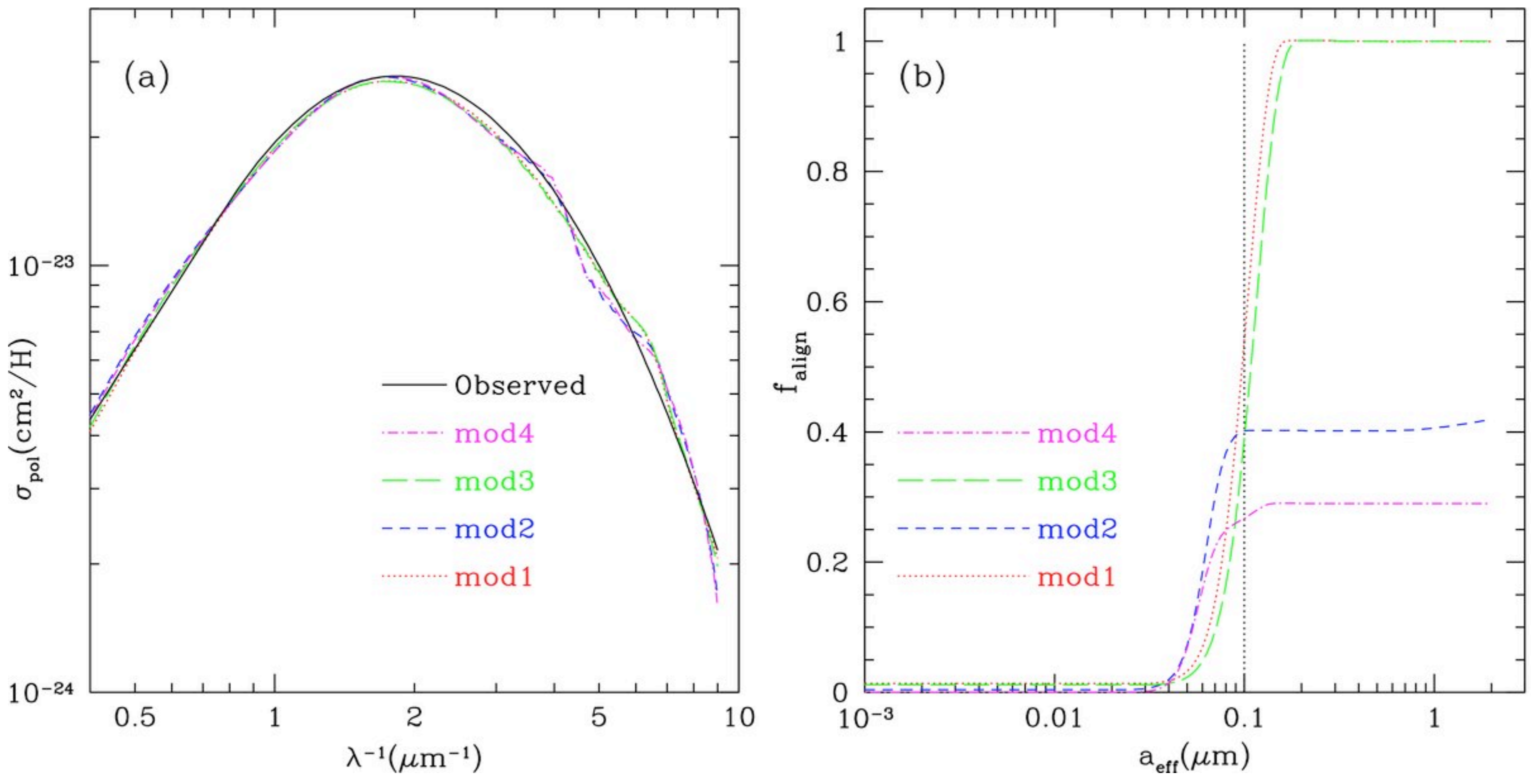
➡**Over the diffuse ISM, the structure in polarization maps traces the structure of the magnetic field**. Changes in alignment efficiency only affect P/I

Dust polarization properties

Model of dust polarization

Polarization modeling in Draine & Fraisse (2009)

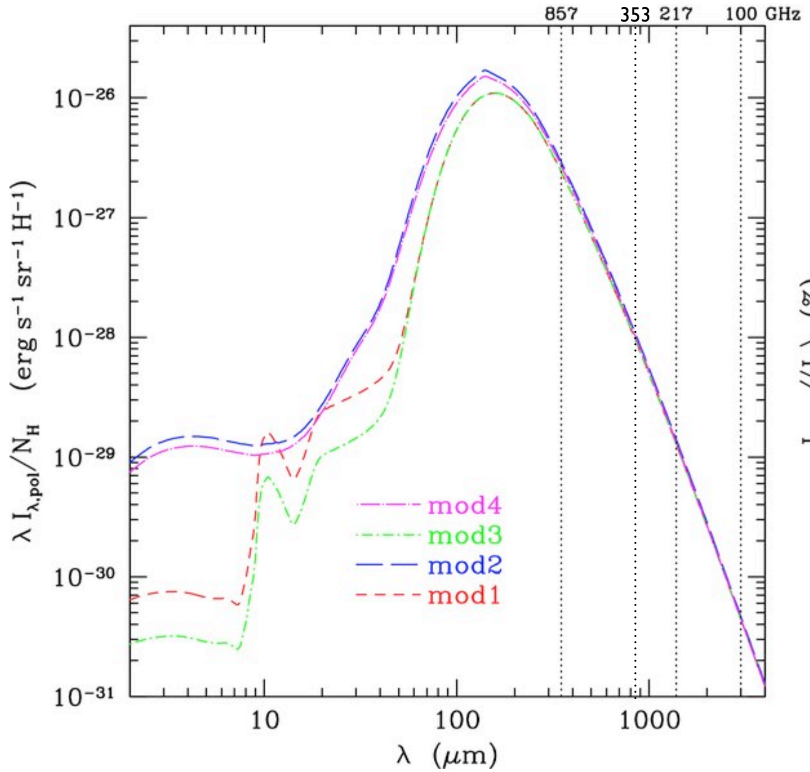
Polarization opacity **Alignment vs grain size**



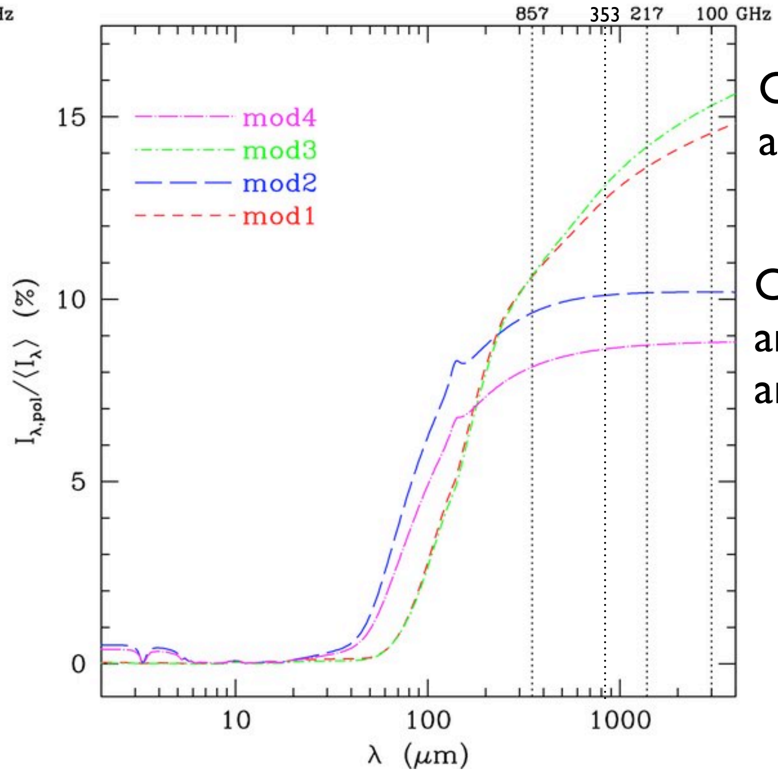
- Models 1 and 3 only silicate grains are aligned
- Models 2 and 4 both carbon and silicate grains are aligned
- All models produce the same polarization opacity in the visible and near-IR, $(P_{ext}/\tau_{ext})_{dust}$ = 3%, but distinct values of P/I in the sub-millimeter

Dust polarization in emission

Polarized thermal emission



Degree of polarization



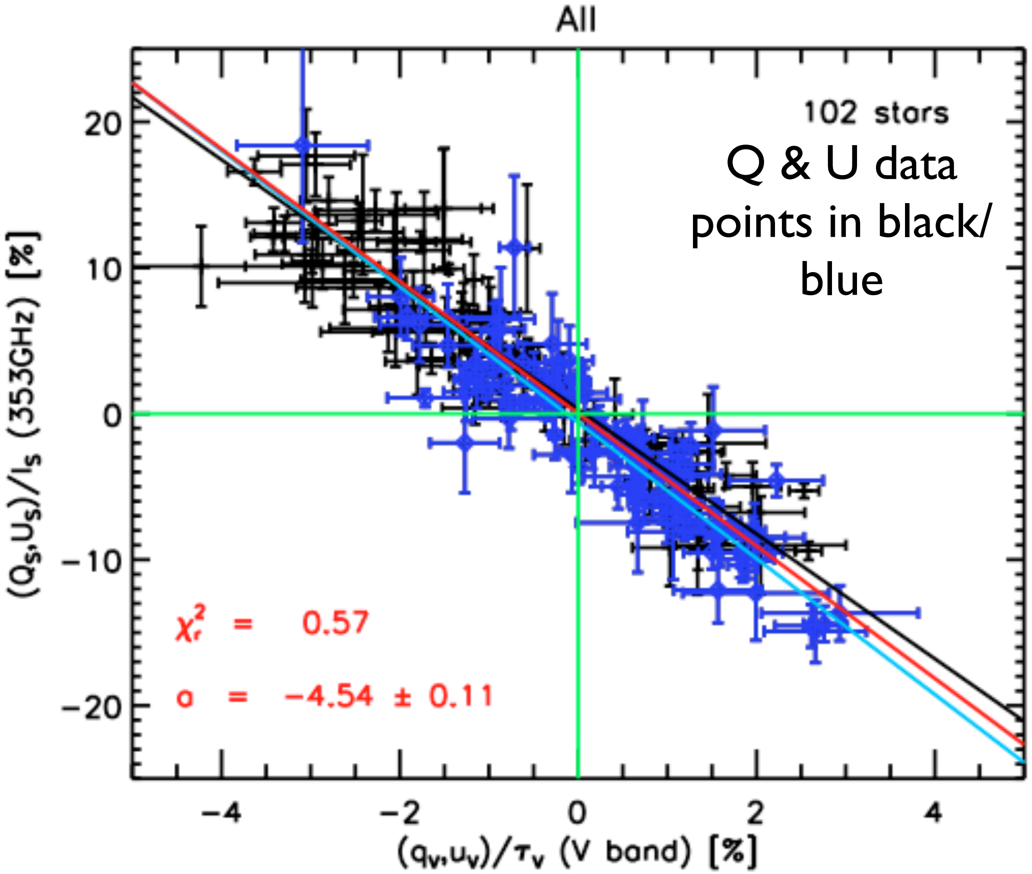
Only silicates are aligned

Carbon grains and silicates are aligned

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

What are Planck data teaching us about polarization at sub-mm and microwave frequencies ?

Comparison with stellar polarization data

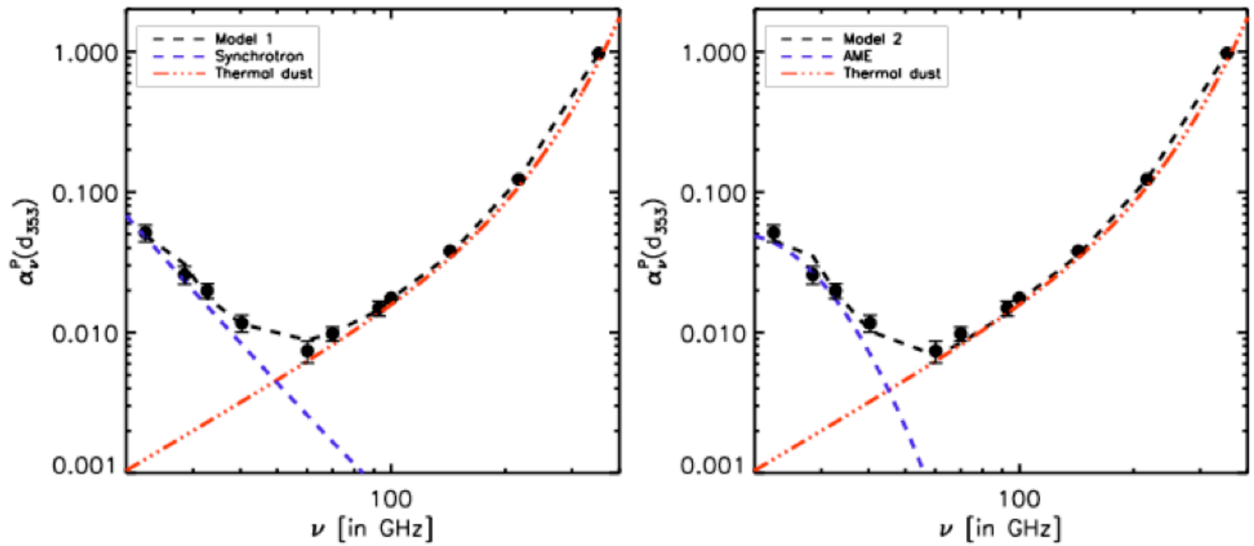


- Data comparison allows us to measure the Polarization ratio R= $(P/I)_{353GHz}/(P_{ext}/\tau_{ext})_V$ that only depends on dust polarization properties
- The measured value, 4.5±0.5, is within the range that may be accounted for by the Draine & Fraisse models with no alignment of carbon grains (Models 1 & 3)
- For $(P/I)_{353GHz}$ of 18%, $(P_{ext}/\tau_{ext})_V$ = 4±0.5%, a value higher than that used to normalize the model.

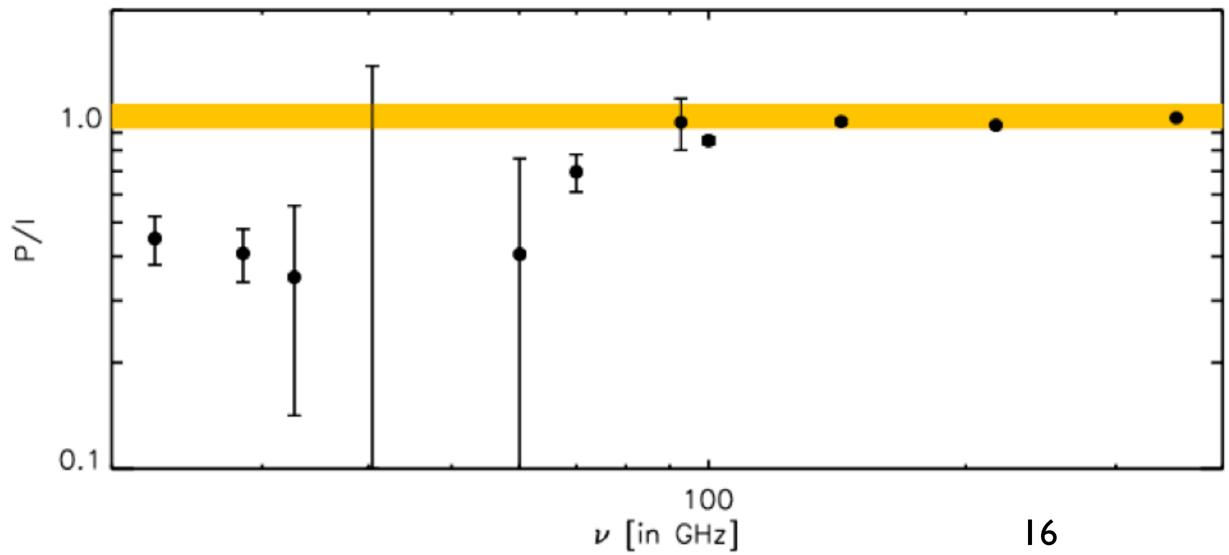
➡Talk V. Guillet on the Galactic Science session on thursday

Dust correlated polarization

Spectral dependence of polarization signal spatially correlated with Q_{353GHz} and U_{353GHz} maps



P/I normalized at 353 GHz



- **Turn-over of SED of polarized emission at ~60GHz like for intensity**
- We think it is due to synchrotron emission that is dust-correlated. (Model 1)
- The required degree of AME polarization to account for the data would be high (half that of the sub-mm dust emission, Model 2)

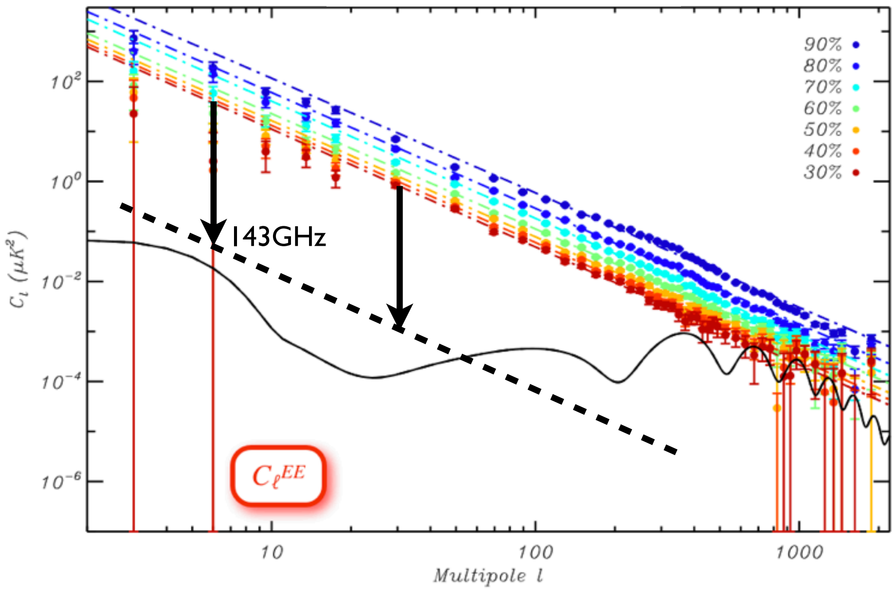
- **P/I is constant from 100 to 353 GHz within a 10% uncertainty**
- No indication of separate grain populations (carbon/silicate grains) or emission mechanisms (thermal/ magnetic dipole emission) with distinct polarization properties

➡Poster T. Ghosh

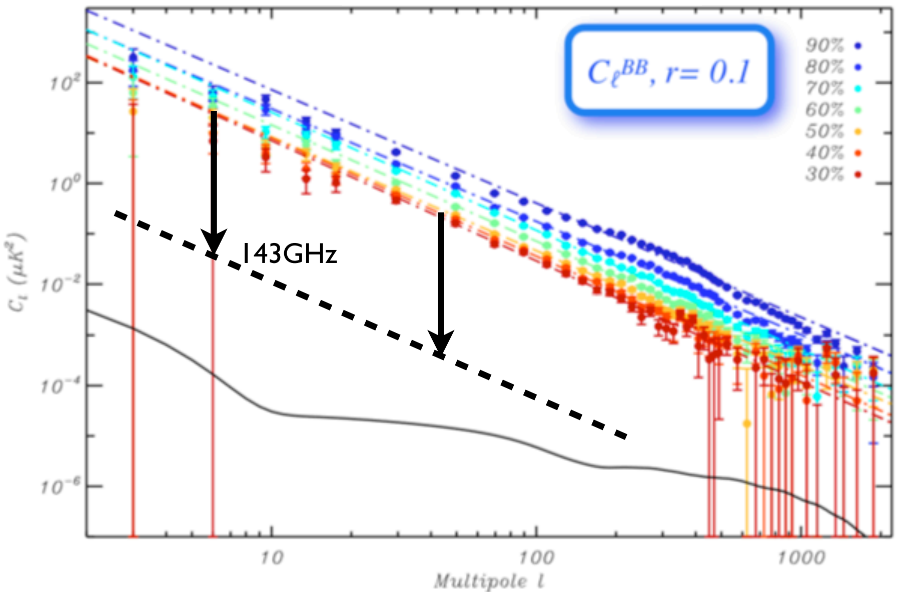
Component Separation

Power spectra

353 GHz EE spectrum



353 GHz BB spectrum



The structure of the dust polarization sky for component separation

- Power spectra for masks covering 30 to 90% of the sky.
- Dependence of spectral index and amplitude of power spectra on frequency and sky fraction
- Comparison with TE, EE and BB CMB spectra

➡Talk J. Aumont on the data processing session on thursday

Summary

- Planck HFI polarization data is opening a new perspective on the Galactic magnetic field. For the first time, we have the data needed to to characterize the interplay between the structure of the Galactic magnetic field and that of interstellar matter in the diffuse ISM and star forming clouds.

- The data analysis also involves the characterization of the polarization properties of dust. Which grains contribute to the observed polarization? Where in the ISM and with what efficiency are they aligned with the B-field?

- First Planck polarization papers and on-going work opens a new research space in Galactic and ISM astrophysics. Results are also key to best separate CMB & dust polarization

- Detailed results to be presented at the Galactic science and data processing sessions on thursday

The scientific results that we present today are a product of the Planck Collaboration, including individuals from more than 100 scientific institutes in Europe, the USA and Canada

Planck is a project of the European Space Agency, with instruments provided by two scientific Consortia funded by ESA member states (in particular the lead countries: France and Italy) with contributions from NASA (USA), and telescope reflectors provided in a collaboration between ESA and a scientific Consortium led and funded by Denmark.