Understanding Interstellar Dust from Polarization Observations

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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
Dust Emission

IRAS | ISO | COBE | Spitzer | Akari | Herschel | Planck

DUSTEM Model

PAHs

VSGs (nano carbon grains)

Large Grains > 10 nm

Carbon + Silicates
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

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

Polarization angle

\[ \psi = 0.5 \arctan(-U, Q) \]

Polarization fraction

\[ p = p_{\text{max}} R F \cos^2 \gamma \]
\[ R \quad \text{and} \quad F \leq 1 \]

- \( p_{\text{max}} \): 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 \( p_{\text{max}} \) and its dependence versus frequency \( \nu \)
The difference between the extinction and polarization curves show that polarization arises mainly from large grains

\[ p_{\text{max}} \lesssim 0.09E(B - V) \text{ mag}^{-1} \]  
Serkowsky+ 1975
Silicates modeled as oblate spheroids

- Small grains (size < 100nm) have no or low alignment
- In this model, Carbon grains are not aligned
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 $a > \lambda/2$, which naturally accounts for the alignment threshold $\sim 100$ nm inferred from the polarization curve.

We know that silicate grains are aligned. The alignment of carbon grains is an open question.
Models of dust polarization in emission

‣ 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

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

François Boulanger
The Physics and Chemistry of the Interstellar Medium
2/09/2019
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.
Good correlation between Planck and stellar polarization

The measured ratios between Stokes parameters and polarization fraction constrain dust models
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 sub-mm and visible polarization is matched for prolate astro-silicate grains, which are porous, or with a-C inclusions

Draine & Fraisse (2009)

Guillet et al. 2018
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)
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

$\Rightarrow$ 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

**Ongoing and upcoming Atacama CMB experiments (Stage II & III)**

- **CLASS 1.5m x 4**
  - 72 detectors at 30 GHz
  - 512 at 95 GHz
  - 2000 at 147 and 217 GHz

- **Simons Army**
  - (Polarbear 2.5m x 3)
  - 22,764 detectors
  - 90, 150, 220, 280 GHz

- **ACT 6m**
  - AdvACTpol:
    - 88 detectors at 28 & 41 GHz
    - 1712 at 95 GHz
    - 2718 at 150 GHz
    - 1006 at 230 GHz

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