The Physics of Polarized Dust Emission

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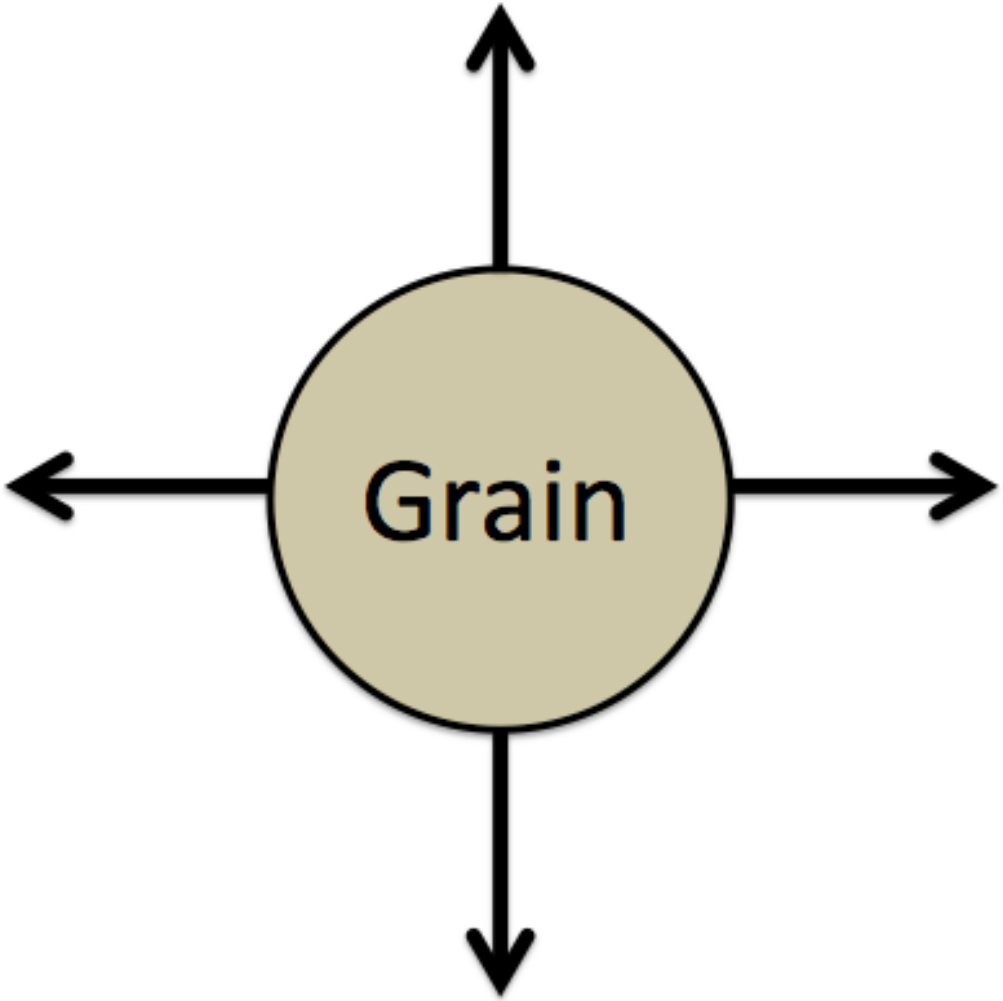
Outline

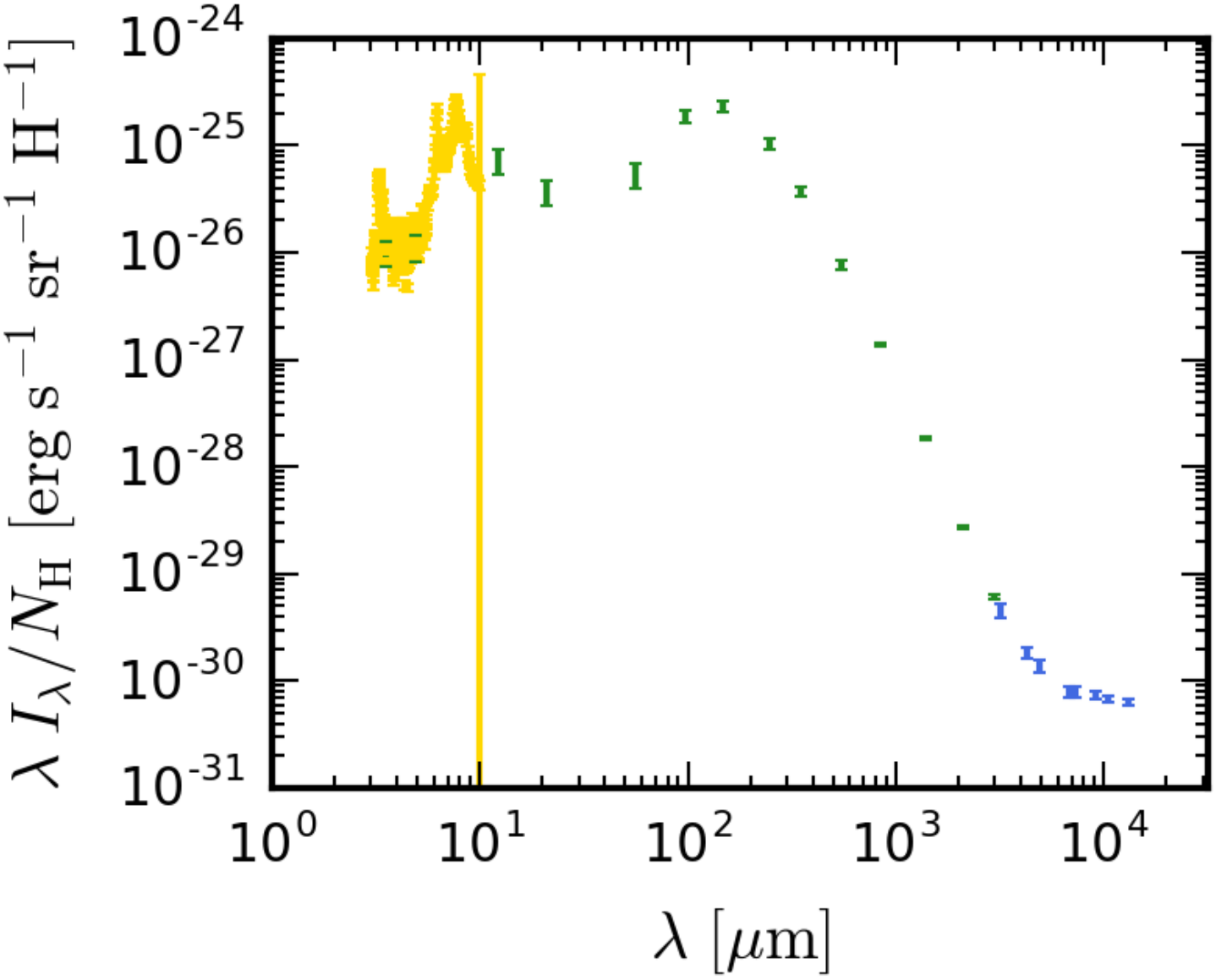
1. What is the physics of dust emission?
2. Why is dust emission polarized?
3. What determines the degree of polarization?
4. What determines the frequency-dependence of the polarized emission?

Some Specs of Dust

- Typical size of $\sim 0.1\mu$m, but extends down to big atoms and up to $\sim 0.5\mu$m
- Made of carbon, silicon, oxygen, magnesium, iron (mostly)
- Appears to come in two distinct types: carbonaceous and silicate

Imagine a Spherical Grain...




10^{-24}
10^{-25}
10^{-26}
10^{-27}
10^{-28}
10^{-29}
10^{-30}
10^{-31}
$\lambda\, I_\lambda / N_{\rm H}$ [erg s^{-1} sr^{-1} H^{-1}]
10^0
10^1
10^2
10^3
10^4
λ [μm]

Simple Parametric Model

Dust heated to temperature T_d emits as a modified blackbody

$$I_\nu^{\mathrm{dust}} = A \left(\frac{\nu}{\nu_0} \right)^\beta B_\nu \left(T_d \right)$$

A = How much dust?
T_d = How hot is the dust?
β = What is the dust made of?

Is this model adequate?

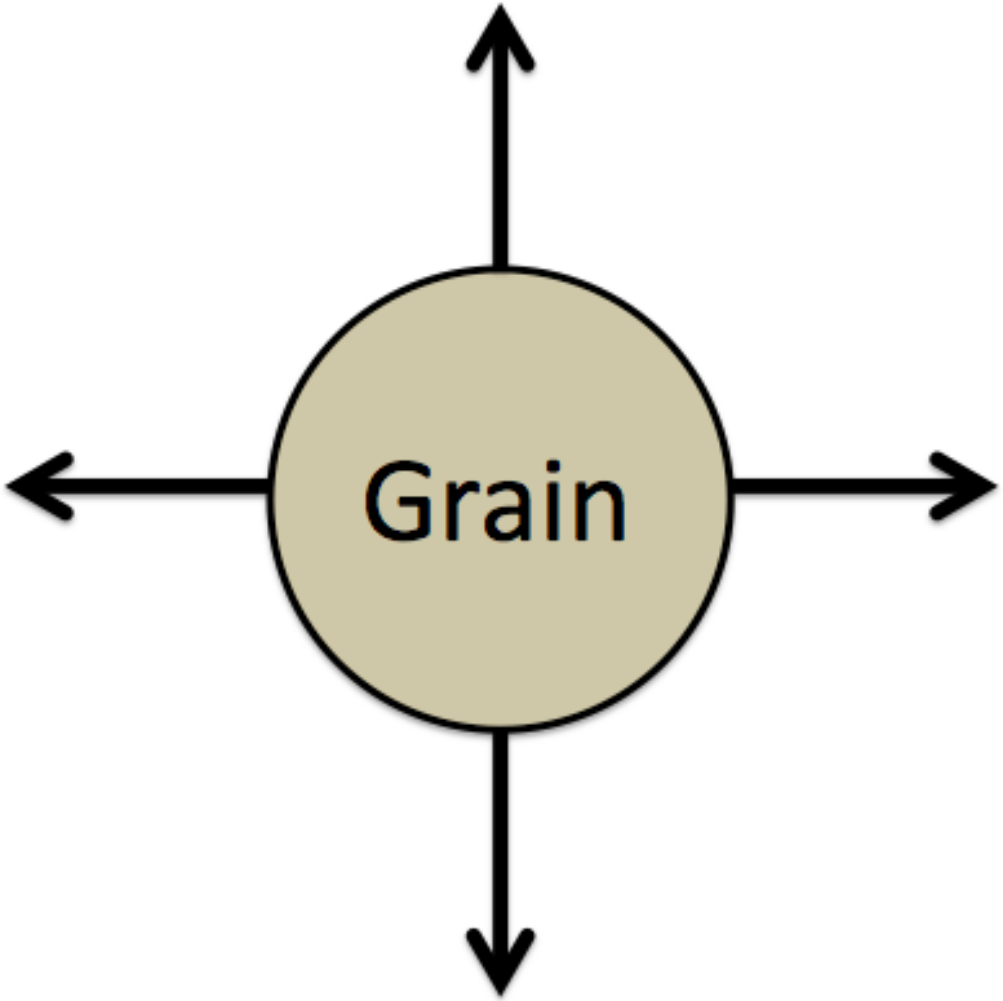
1. β may be too simple description of material properties of grains
2. More than one kind of dust, each with its own β and T_d
3. Line of sight samples many environments with different radiation fields and different T_d
4. Grains of different size are heated to different T_d

Why is Dust Emission Polarized?

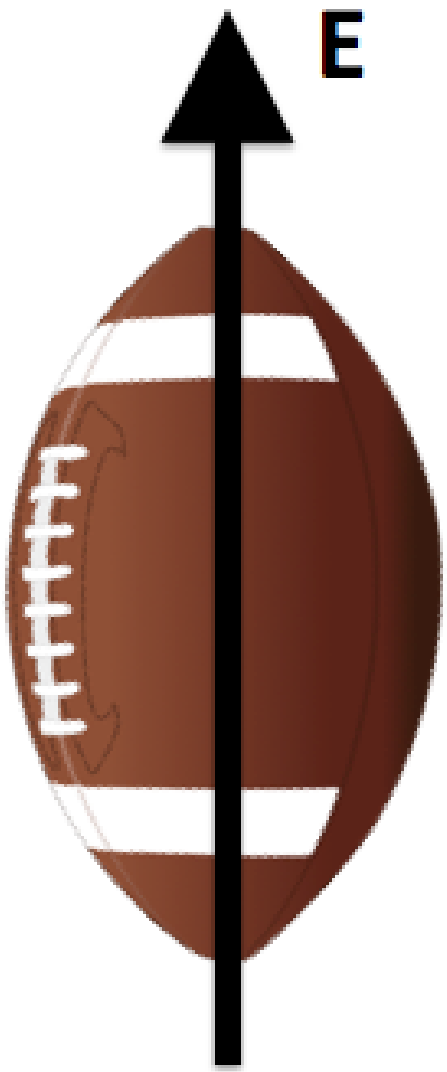
Two ingredients required:

1. Grains must be aspherical
2. Grains must be aligned

Grain Shape

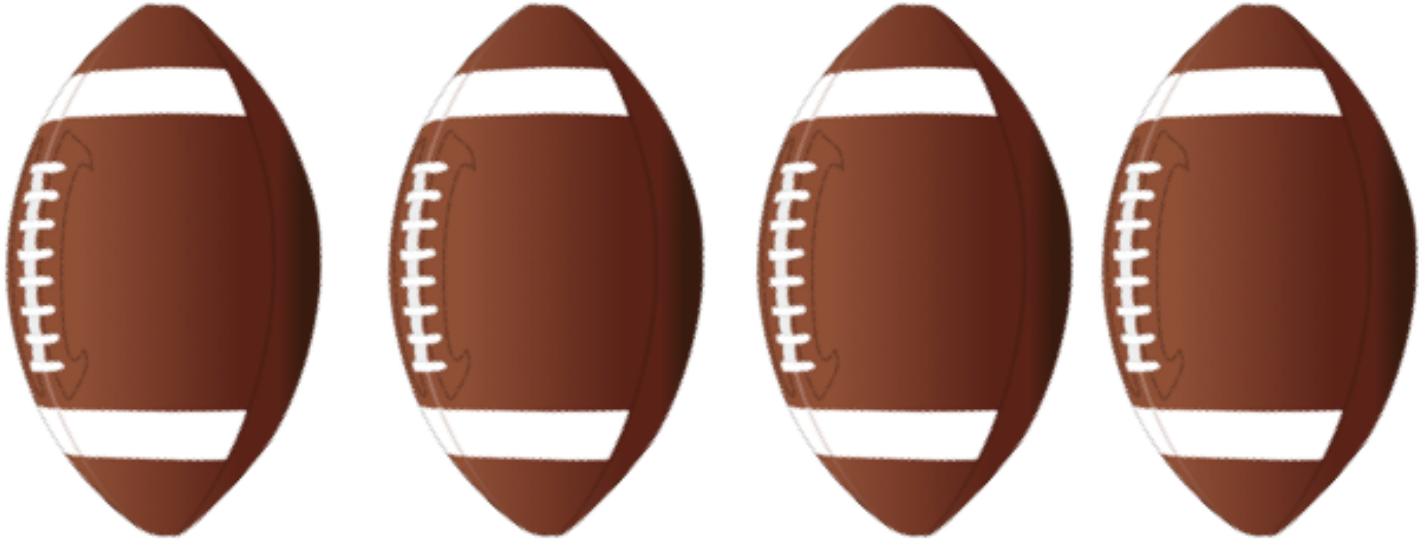


Grain Shape



Grain Alignment

Grain Alignment



Grain Alignment

Grain spins about $\vec{\mathbf{J}}$
$\vec{\mathbf{J}}$ systematically aligns with $\vec{\mathbf{B}}$

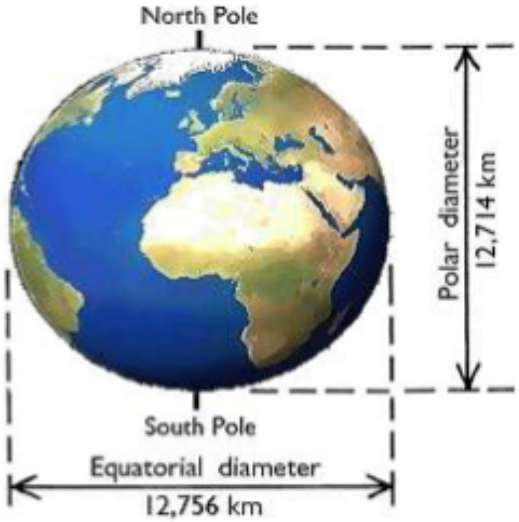
Outline

✓ Why is dust emission polarized?

2 What determines the degree of polarization?

3 Could the polarization fraction be frequency-dependent?

Grain Shape


North Pole
Polar diameter
12,714 km
South Pole
Equatorial diameter
12,756 km

Alignment Efficiency

$\vec{\mathbf{J}}$ and $\vec{\mathbf{B}}$ may be misaligned

Composition

Grains are of different composition appear to have different polarization properties

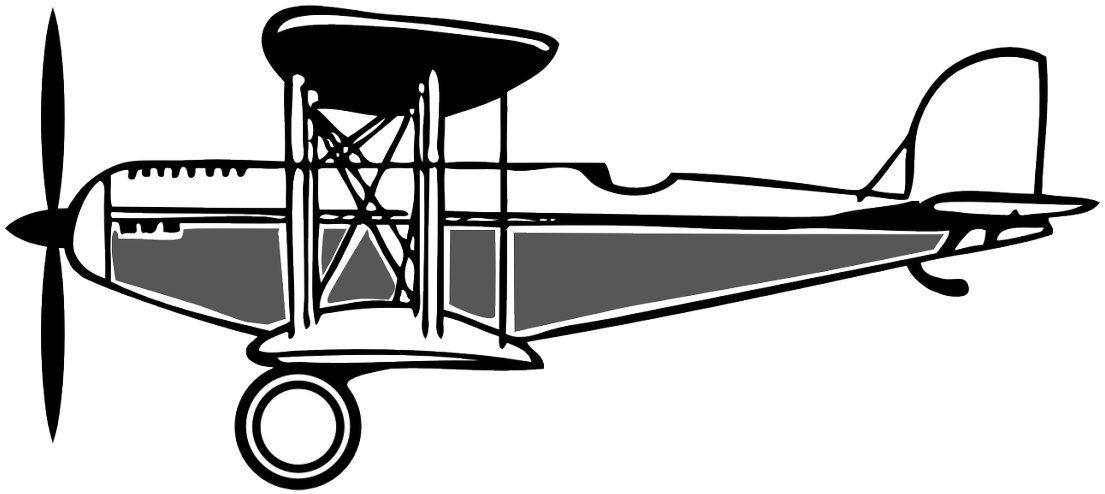
- Silicate Features– Polarization detected
- Carbonaceous Features– Unpolarized

Viewing Angle

If magnetic field is aligned with the line of sight, then minimal polarization

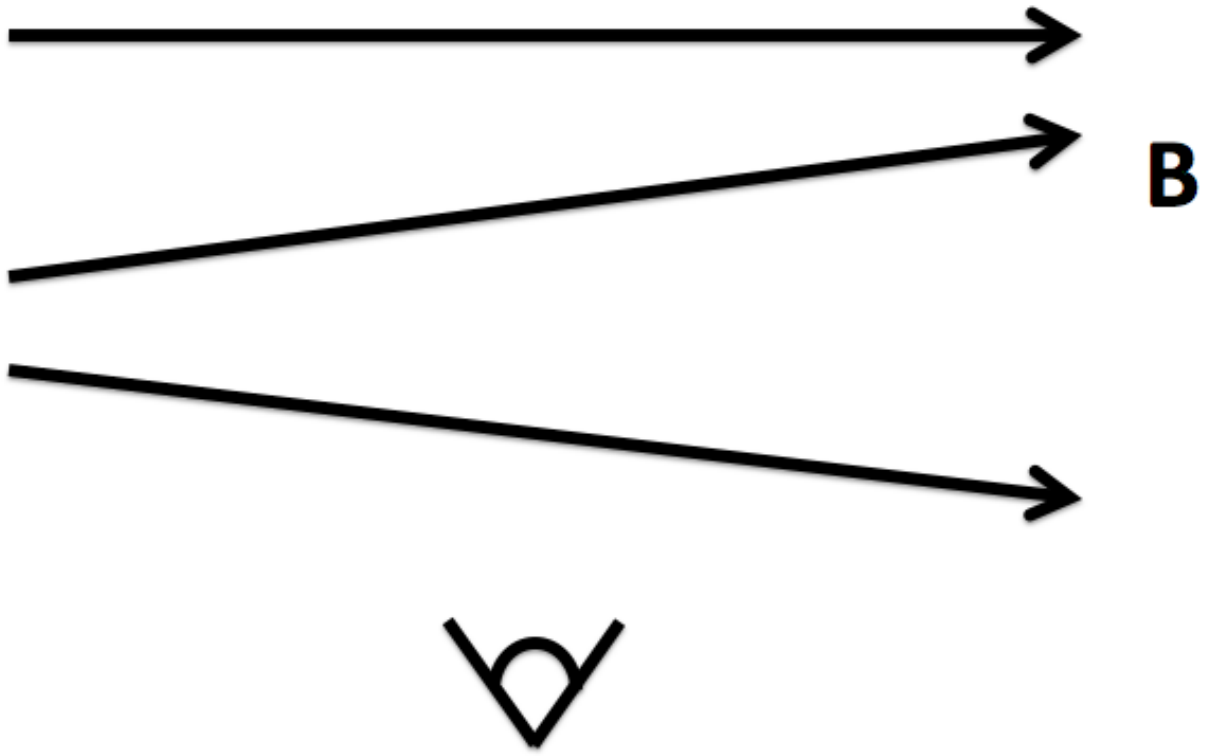
Viewing Angle

If magnetic field is in the plane of the sky, maximal polarization



Field Geometry

Tangling of the magnetic field along the line of sight reduces polarization



Summary

1. Dust grains produce polarization because they are aspherical and aligned

2. Degree of polarization depends on viewing angle, magnetic field geometry, and grain properties like:
   - Alignment efficiency
   - Composition
   - Shape

Outline

✓ Why is dust emission polarized?

✓ What determines the degree of polarization?

3 Could the polarization fraction be frequency-dependent?

Simple Parametric Model

Can extrapolate to polarization

$$I_\nu^{\mathrm{pol,dust}} = Ap\left(\frac{\nu}{\nu_0}\right)^\beta B_\nu\left(T_d\right)\sin^2\gamma$$

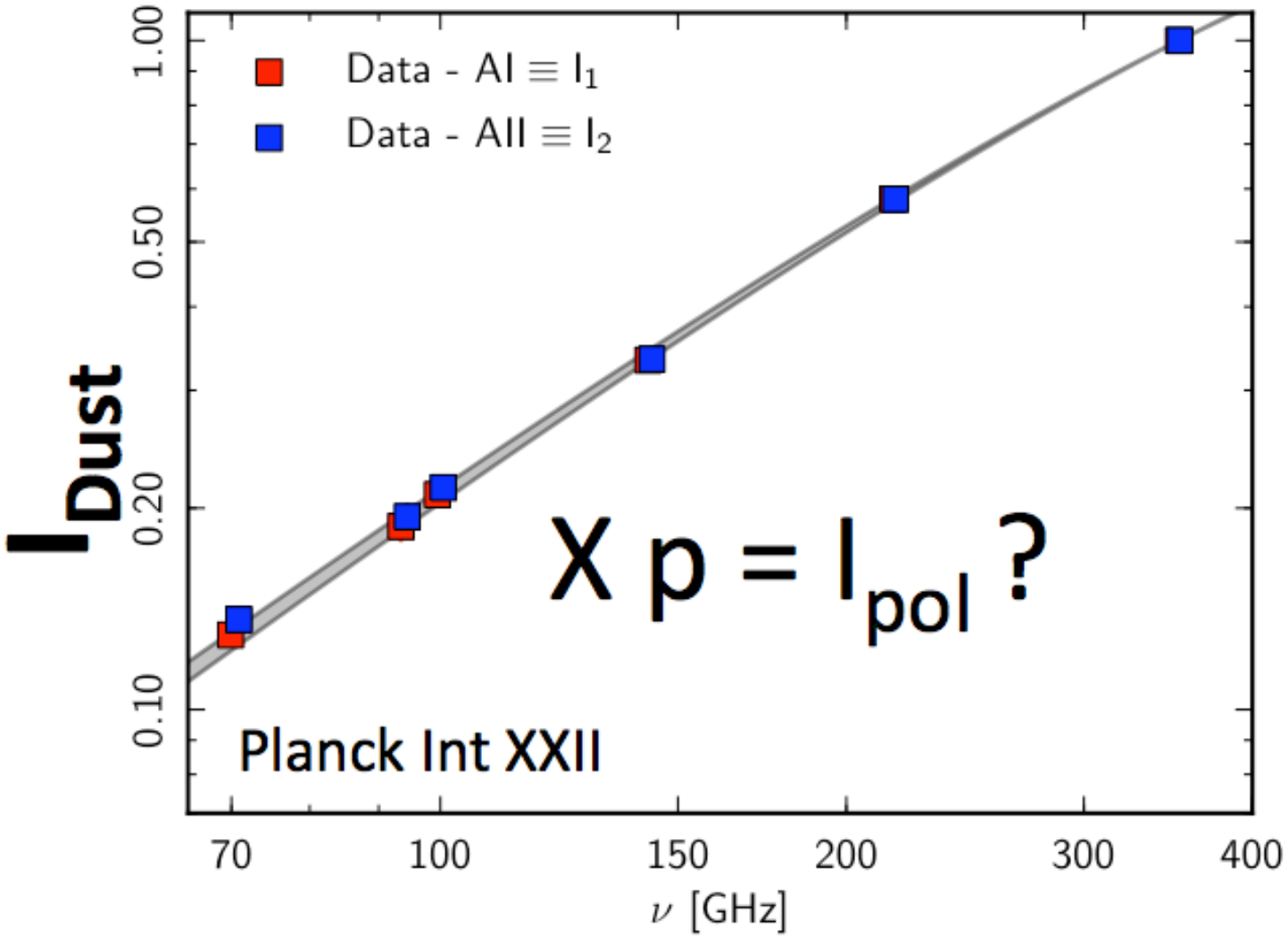
Scalar parameter p encapsulates effects of grain shape and magnetic field disorder

Simple Parametric Model

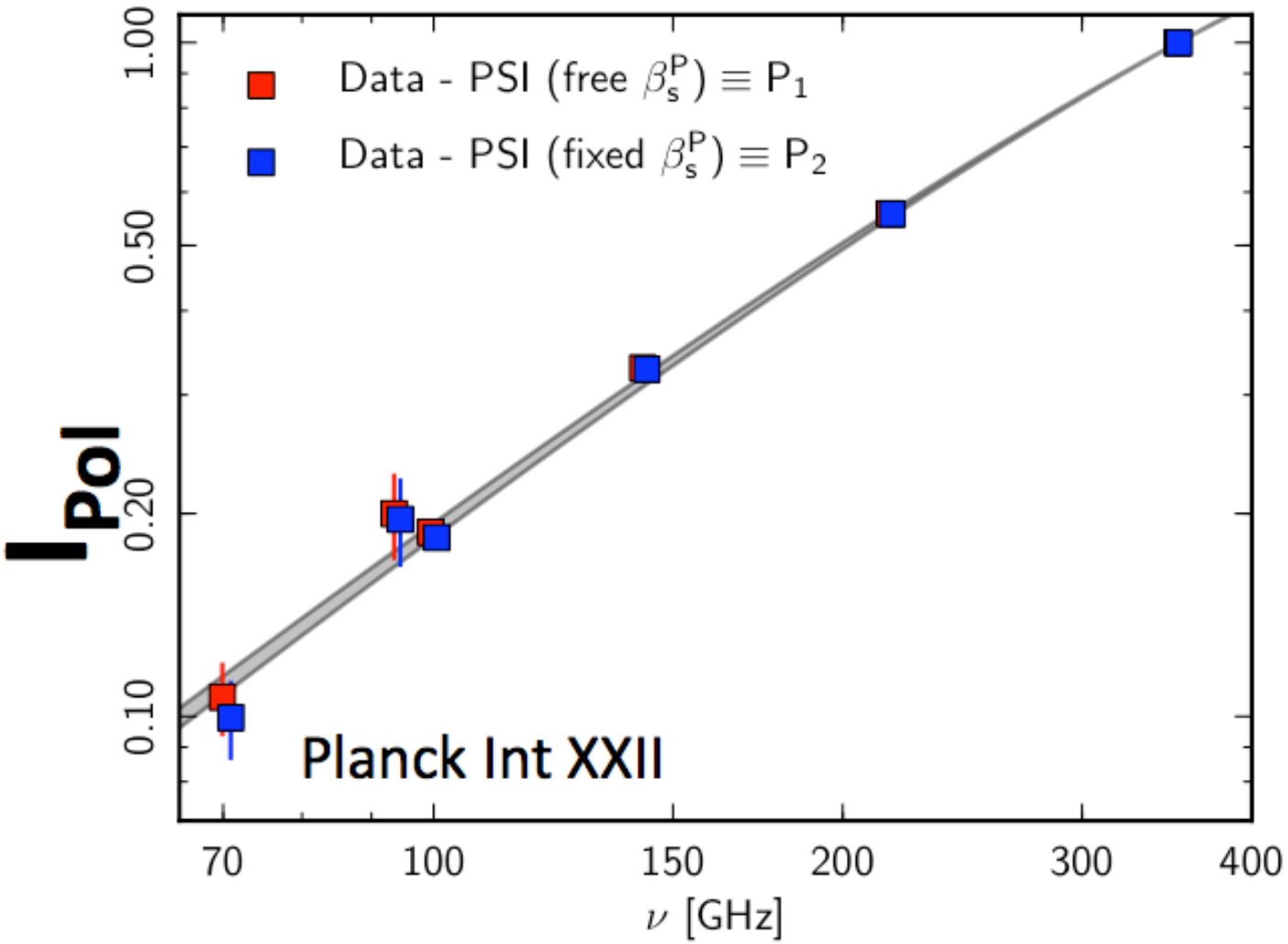
What if dust is more complicated than this?

$$I_\nu^{\mathrm{pol,dust}} = Ap\left(\frac{\nu}{\nu_0}\right)^\beta B_\nu\left(T_d\right)\sin^2\gamma$$

Ideal Picture

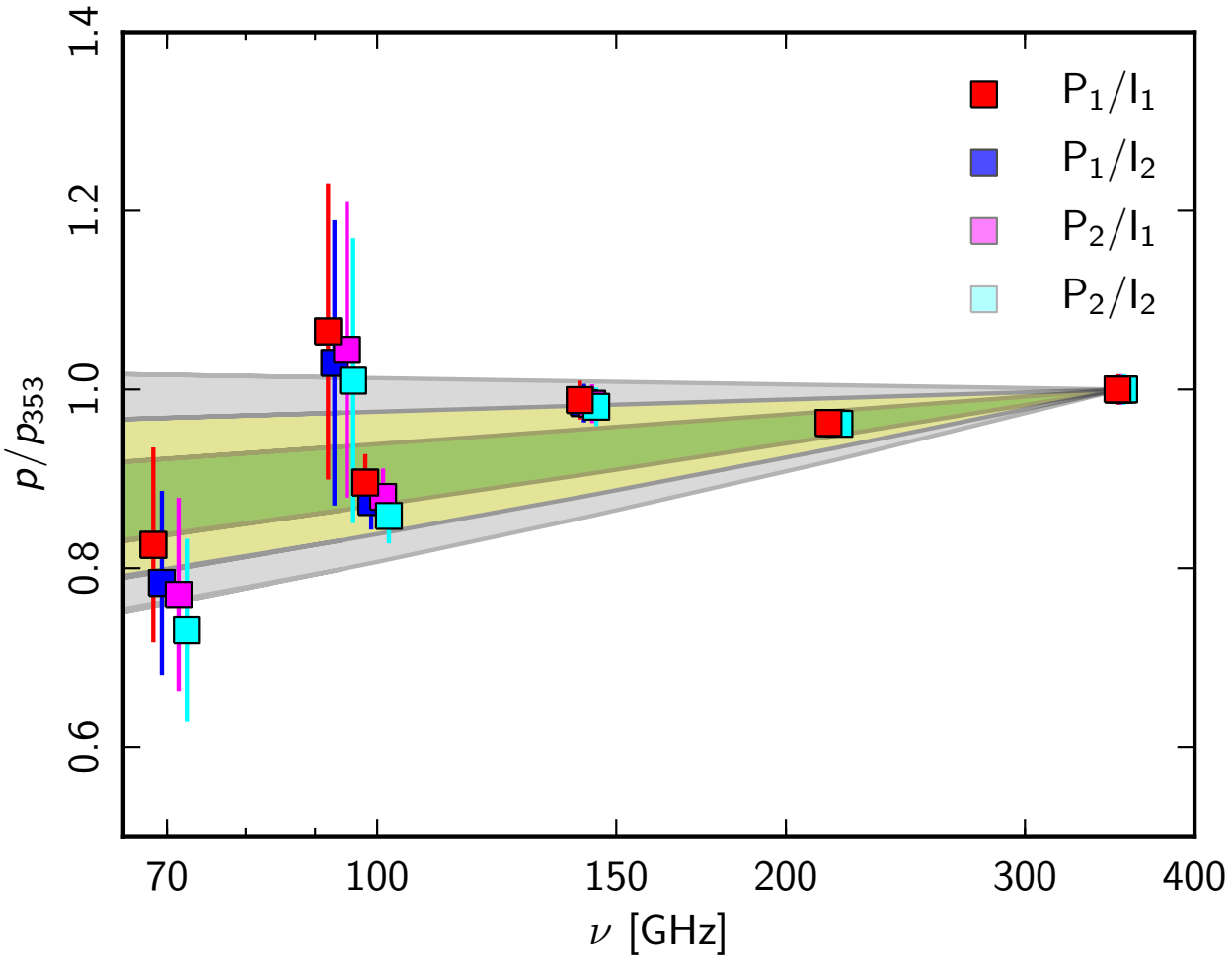


Ideal Picture



Planck Results

We know this isn't entirely the case... Why?



Planck Int XXII

Composition

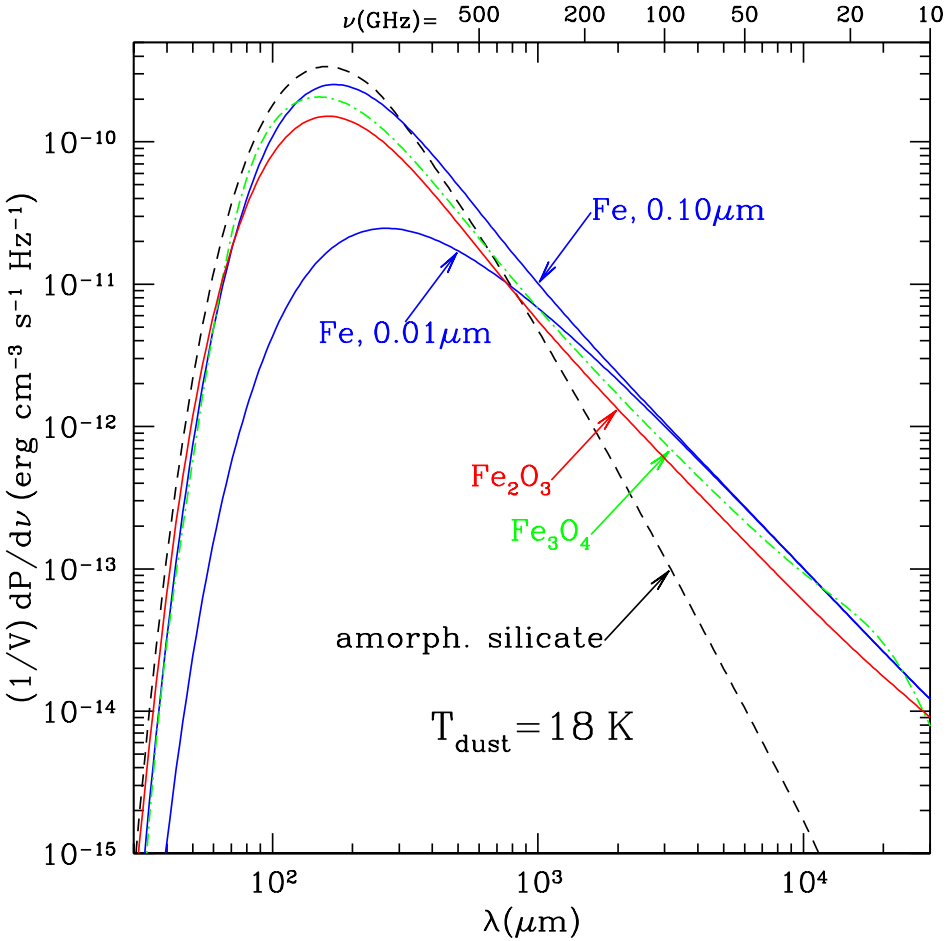
- Dust of different composition seems to have different polarization properties

- If they have different SEDs, polarization fraction will evolve

$$p(\nu) = \frac{I_{\mathrm{pol}}^{\mathrm{sil}} + I_{\mathrm{pol}}^{\mathrm{car}} + I_{\mathrm{pol}}^{??}}{I_{\mathrm{tot}}}$$

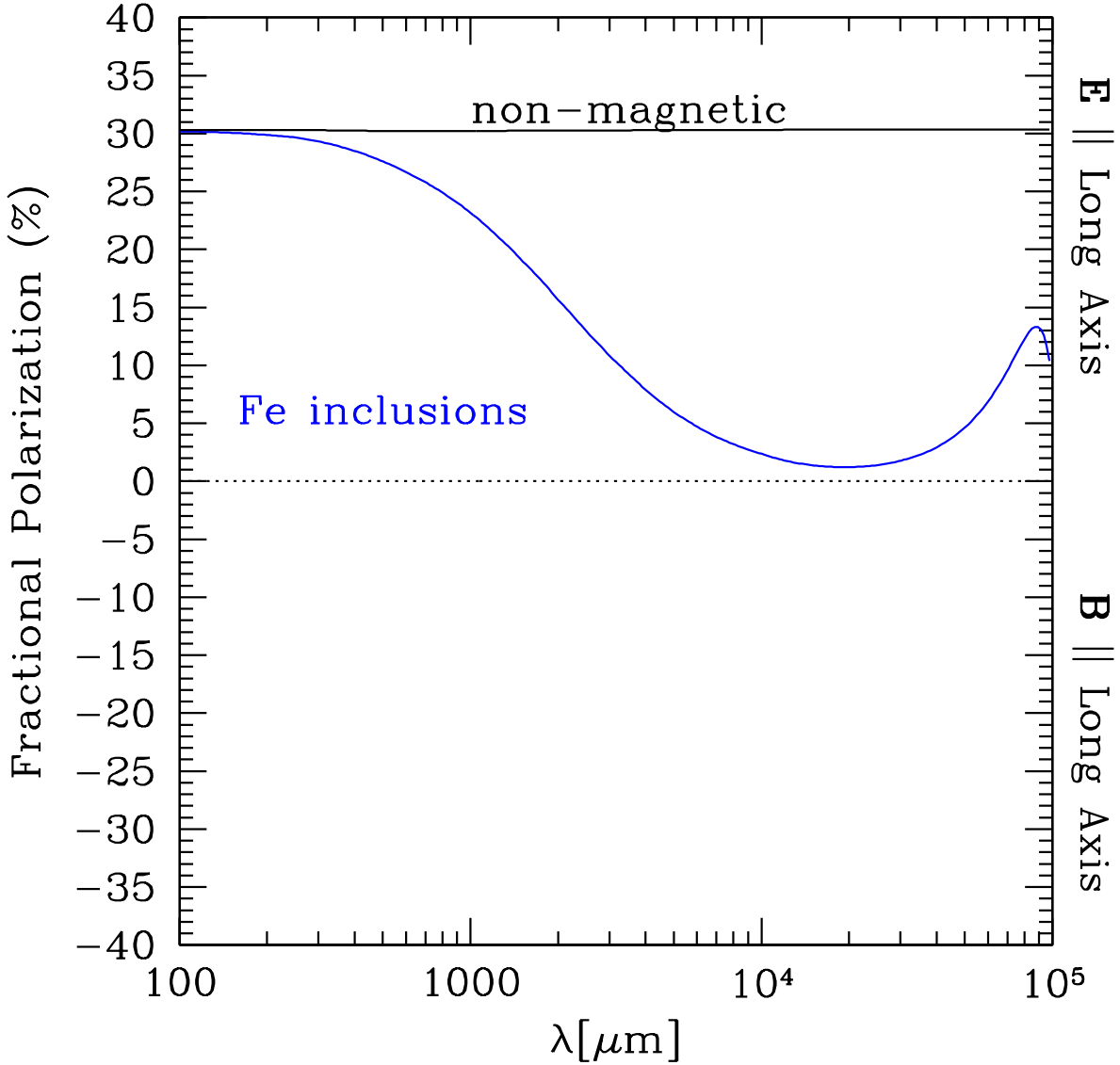
Magnetic Nanoparticles

- **Emissivity per unit volume** of 0.01μm grains heated to 18K
- Emissivity in mm and sub-mm much stronger than amorphous silicate grains

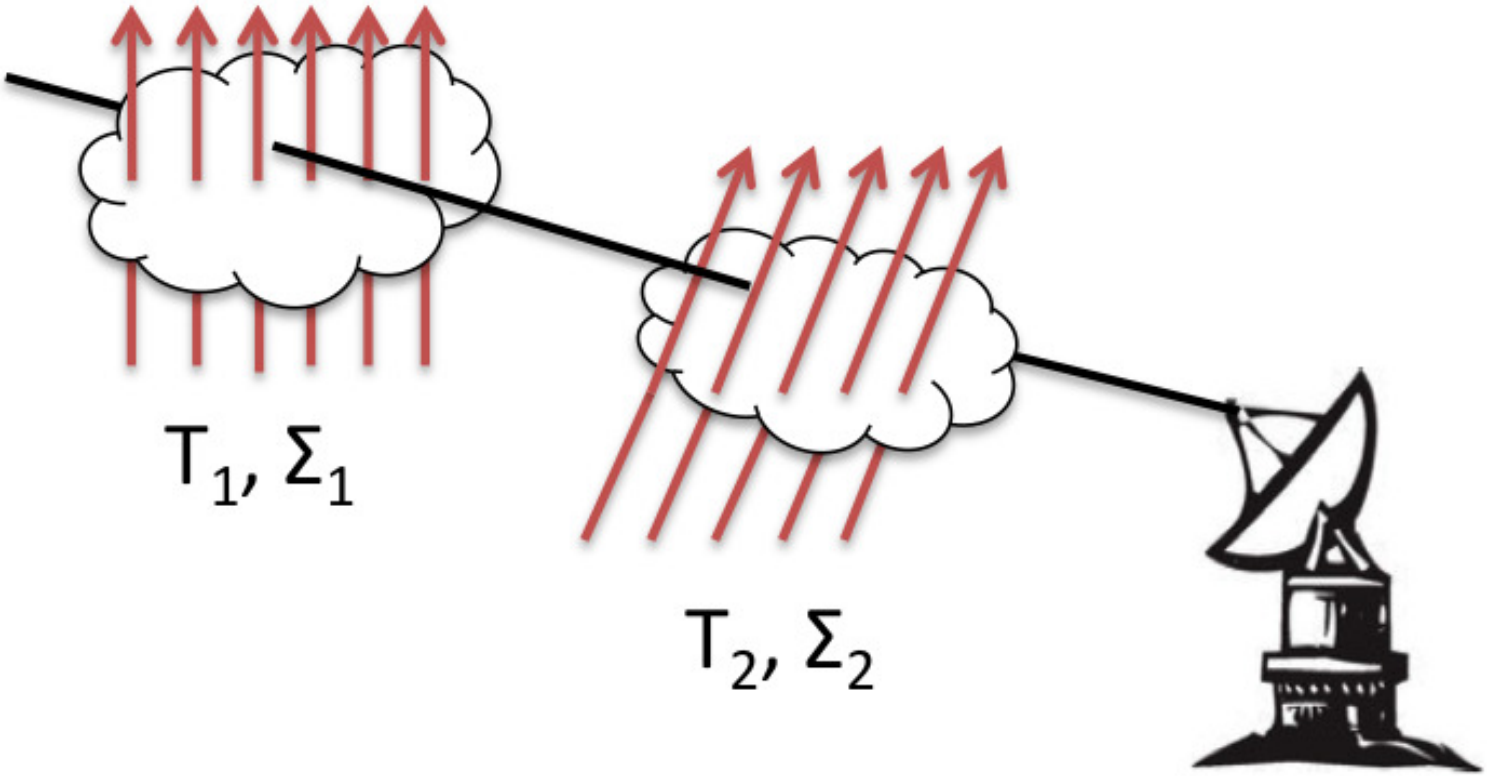


Draine and Hensley 2013

Magnetic Nanoparticles



Depolarization



Tassis & Pavlidou 2015

Summary

The dust SED in polarization may be different than the dust SED in total intensity because:

1. The dust SED is the sum of multiple grain components with different SEDs and polarization properties
2. The dust SED and magnetic field direction may vary along the line of sight

One Way Forward

Physical dust modeling

Big Picture

- Grains producing polarized emission in the IR are **the same grains** that produce polarized extinction in the optical
- Use multi-wavelength data to construct a **physical** model of dust compatible with the observations

Method

Find observations that constrain:

- Abundances
- Extinction (total and polarized)
- Emission (total and polarized)

then build a model that satisfies all constraints simultaneously

A New Model

To construct a new model, we have:

- Updated the material properties of the silicate and carbonaceous grains based on new astronomical observations and laboratory data (Draine & Hensley 2016, in prep)
- Added magnetic nanoparticles as an optional model component
- Using new grain materials, found a best fit size distribution and alignment function

With a Model, We Can...

- Test the model against the *Planck* sky and learn what drives variations in dust properties
- Predict dust properties at all wavelengths given a model fit
- Simulate different realizations of dust properties and the implications for component separation

Testing the Model

- Model parameterized by radiation field strength and amount of dust in each silicate and carbonaceous components
- In progress: full-sky model fitting with *Planck* data
- In development: code interface to models to enable easy SED fitting, simulation construction, etc.