Modeling the Frequency Dependence of Polarized Dust Foregrounds

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Hensley & Bull arXiv:1709.07897

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Frequency Dependence of Dust Emission

1. What dust properties are likely to vary from sightline to sightline?
2. How do these properties affect the dust SED?
3. SED variations $\rightarrow$ frequency decorrelation

Simple Parametric Model

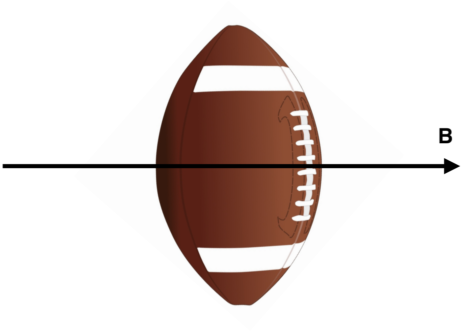
Dust heated to temperature T_d emits as a modified blackbody

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

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

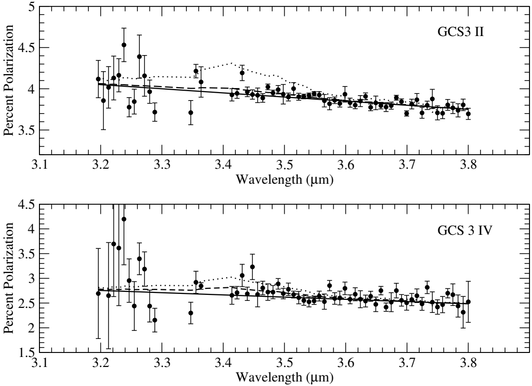
Polarization Primer

- Grains are **aspherical** and preferentially **aligned** with the local magnetic field
- Polarize starlight through absorption, re-radiate as polarized light in the IR



Polarization Primer

- Grains are of different composition appear to have different polarization properties
- Silicate Features– Polarization detected
- Carbonaceous Features– Unpolarized



Chiar et al 2006

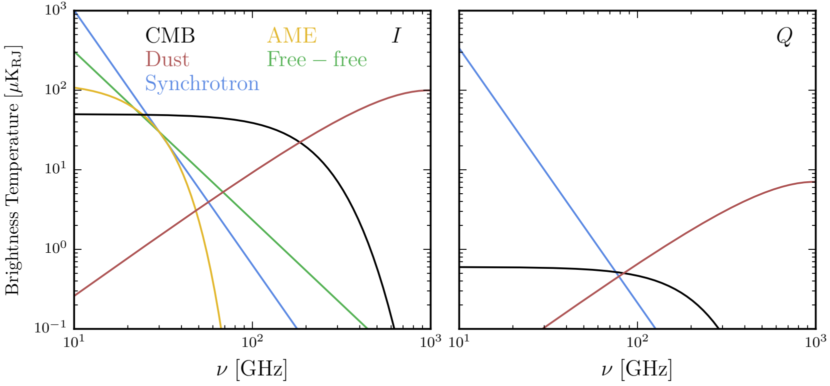
Key Questions

- Are modified blackbody parameterizations robust enough for realistic dust complexity?
- What dust complexities are most difficult for analysis and how can they be best mitigated?

Single Pixel Paradigm

1. Work with one realization of all non-dust components in the microwave sky, set to representative amplitudes and SEDs

The Microwave Sky in Intensity and Polarization



Emission Components

Synchrotron

$$I_\nu = A_1 \left(\frac{\nu}{\nu_0}\right)^{\beta}$$

Free-free

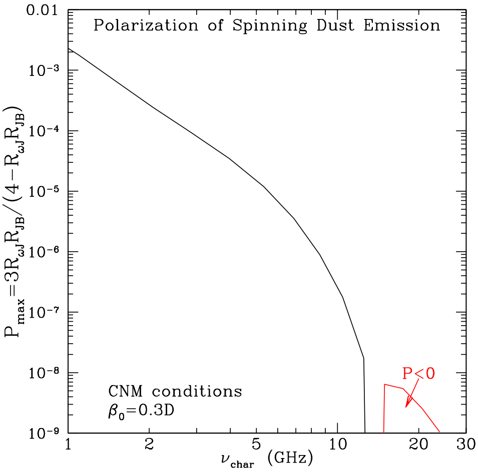
$$I_\nu = A_2 \left(\frac{\nu}{\nu_0}\right)^{-0.12}$$

Spinning Dust

$$I_\nu = A_3 \left(\frac{\nu}{\nu_0}\right)^{2} \exp\left[1 - (\nu/\nu_{\mathrm{pk}})^2\right]$$

Spinning Dust Polarization

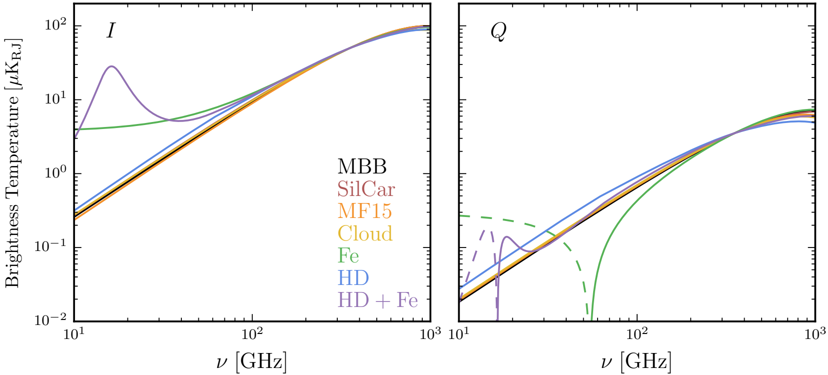
Spinning dust emission effectively unpolarized
Draine and Hensley 2016



Single Pixel Paradigm

1. Work with one realization of all non-dust components in the microwave sky, set to representative amplitudes and SEDs
2. Employ a suite of dust models encompassing a range of dust physics

A Suite of Dust Models



Single Pixel Paradigm

1. Work with one realization of all non-dust components in the microwave sky, set to representative amplitudes and SEDs
2. Employ a suite of dust models encompassing a range of dust physics
3. Employ a suite of mock instruments measuring in seven log-spaced frequency bins

$$\nu_{\rm min} = \{20, 30, 40\}\,{\rm GHz}$$
$$\nu_{\rm max} = \{300, 400, 500, 600, 700, 800\}\,{\rm GHz}$$

Single Pixel Paradigm

1. Work with one realization of all non-dust components in the microwave sky, set to representative amplitudes and SEDs
2. Employ a suite of dust models encompassing a range of dust physics
3. Employ a suite of mock instruments measuring in seven log-spaced frequency bins
4. Add noise based on forecasts for next-generation CMB experiments (100 realizations)
5. Perform component separation

Fitting Functions

One component MBB

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

Two component MBB

$$I_\nu^{\rm dust} = A_1 \left(\frac{\nu}{\nu_0}\right)^{\beta_1} B_\nu\left(T_{d,1}\right) + A_2 \left(\frac{\nu}{\nu_0}\right)^{\beta_2} B_\nu\left(T_{d,2}\right)$$

Component Separation

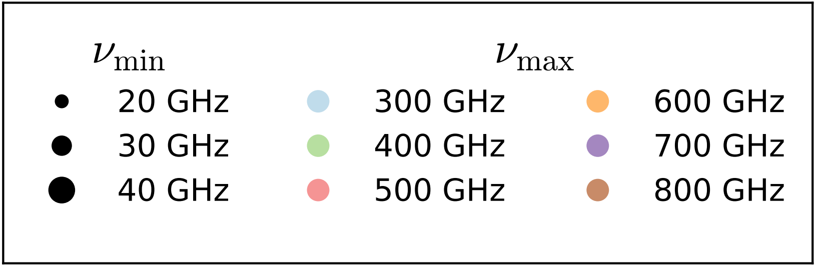
Input: 14 data points (Q and U in seven frequencies)

1. Fit with MBB dust
2. Fit with 2MBB dust

Perform MCMC fit for each band configuration (18), dust input model (7), dust fit model (2), and noise realization (100) (that's over 25,000 MCMCs)

Results

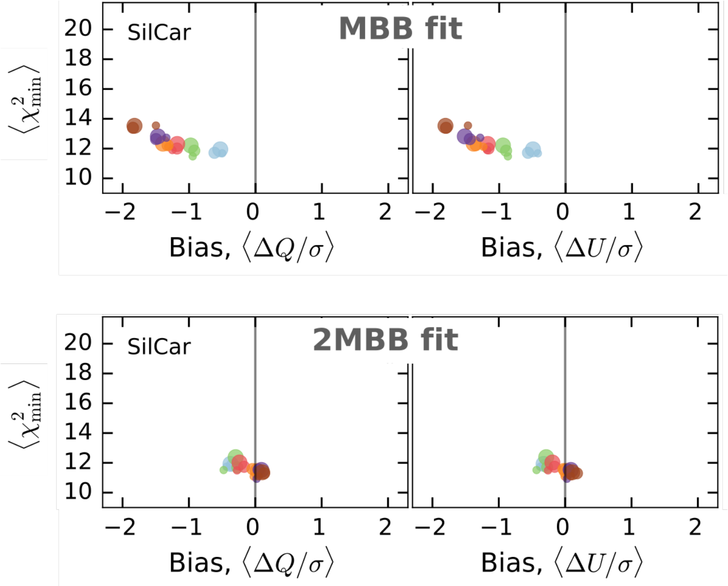
Let's step through the results for each input dust model one by one



Two Kinds of Dust

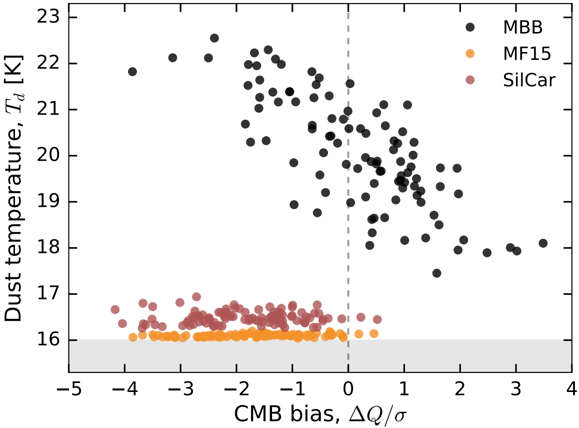
- Dust may not be homogeneous– empirical and physical models suggest (at least) two distinct kinds of dust, silicate and carbonaceous
- Model each component with its own β (1.6 and 1.8) and T (15 and 24 K), one polarized and one not

Fit Results


SilCar
MBB fit
$\langle \chi^2_{\rm min} \rangle$
20
18
16
14
12
10
−2
−1
0
1
2
Bias, $\langle \Delta Q/\sigma \rangle$
Bias, $\langle \Delta U/\sigma \rangle$
SilCar
2MBB fit
$\langle \chi^2_{\rm min} \rangle$
Bias, $\langle \Delta Q/\sigma \rangle$
Bias, $\langle \Delta U/\sigma \rangle$

Beware the Temperature Prior!

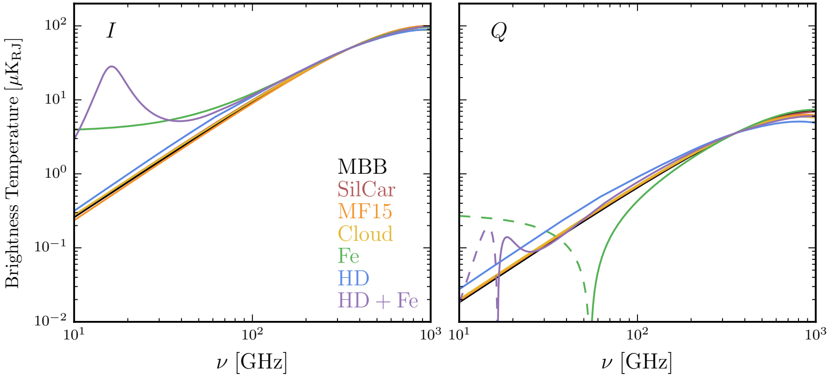
Dust component dominating in total intensity may not be the same as that dominating the polarization



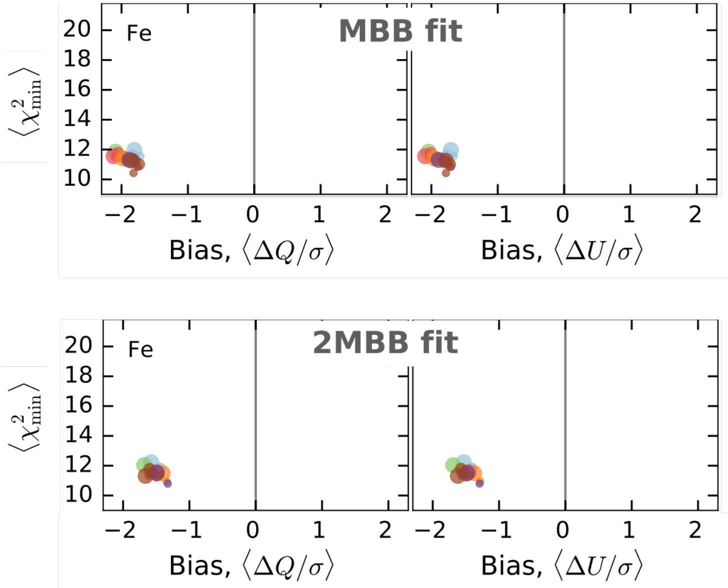
Magnetic Dust

- Interstellar grains found by Stardust and Cassini were amorphous silicate with iron inclusions
- Ferromagnetic iron can be emissive in the microwave due to magnetic effects (Draine & Hensley 2012, 2013)
- Polarized emission from magnetic iron is **orthogonal** to polarized emission from non-magnetic grains, resulting in a unique polarization signature

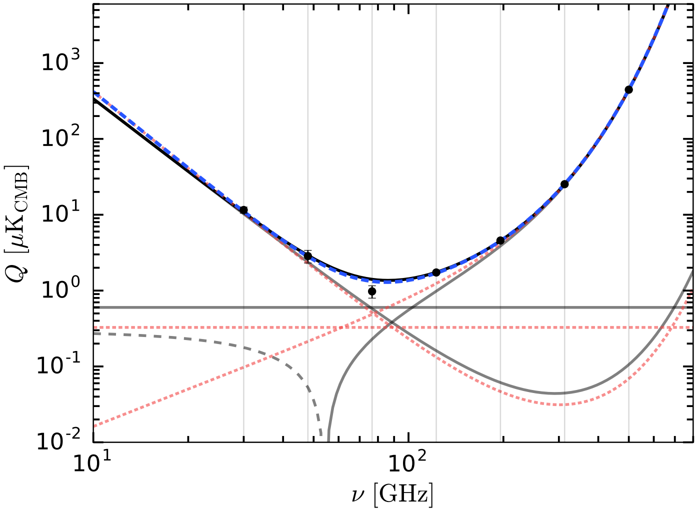
A Suite of Dust Models



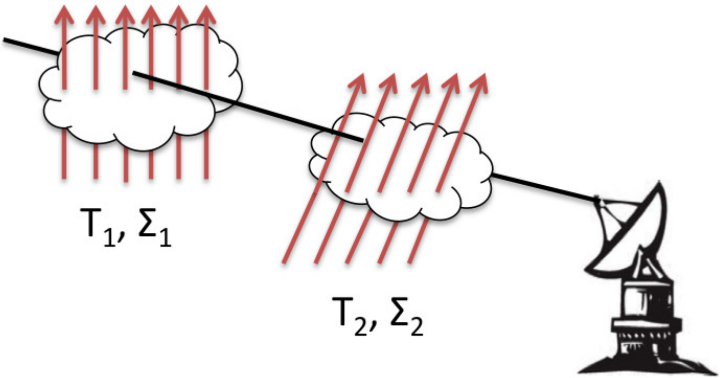
Fit Results


MBB fit
Fe
20
18
16
14
12
10
−2
−1
0
1
2
$\langle \chi^2_{\rm min} \rangle$
Bias, $\langle \Delta Q/\sigma \rangle$
Bias, $\langle \Delta U/\sigma \rangle$
2MBB fit
Fe
$\langle \chi^2_{\rm min} \rangle$
Bias, $\langle \Delta Q/\sigma \rangle$
Bias, $\langle \Delta U/\sigma \rangle$

Best Fit Model



Cloud Model

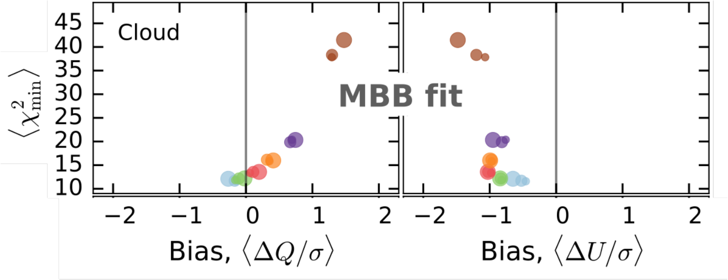


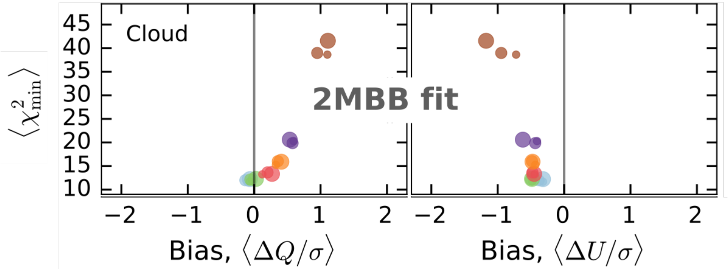
Tassis & Pavlidou 2015

Frequency Decorrelation

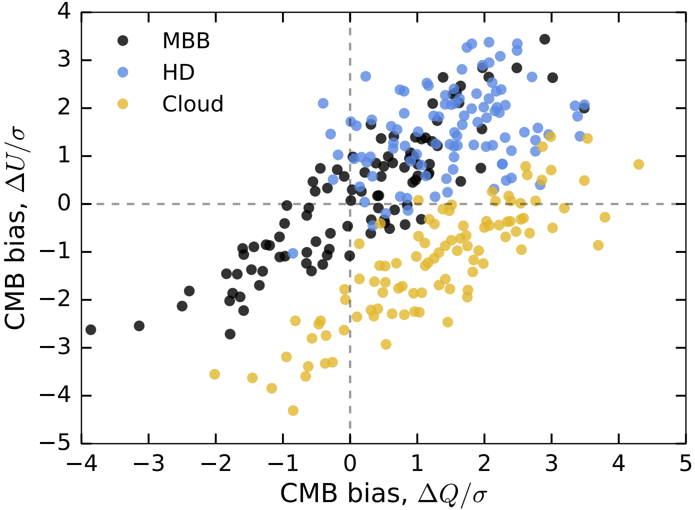
- Even if you know what the dust is doing at one frequency, hard to extrapolate to other frequencies due to the non-trivial way polarizations sum
- Big threat to template-based component separation techniques
- Hints present in the *Planck* data; fully expected from theory, just a matter of what level

Fit Results


Cloud
MBB fit
45
40
35
30
25
20
15
10
$\langle \chi^2_{\min} \rangle$
−2 −1 0 1 2
Bias, $\langle \Delta Q/\sigma \rangle$
Bias, $\langle \Delta U/\sigma \rangle$


Cloud
2MBB fit
45
40
35
30
25
20
15
10
$\langle \chi^2_{\min} \rangle$
−2 −1 0 1 2
Bias, $\langle \Delta Q/\sigma \rangle$
Bias, $\langle \Delta U/\sigma \rangle$

CMB Polarization Angle



Summary

1. Intuition built in temperature does not necessarily carry over to polarization
2. Line of sight effects (decorrelation!) and iron grains are the most pernicious complexities for biasing the fit CMB
3. Biases described here can be mitigated with different analysis techniques and/or ancillary data, but should be demonstrated!