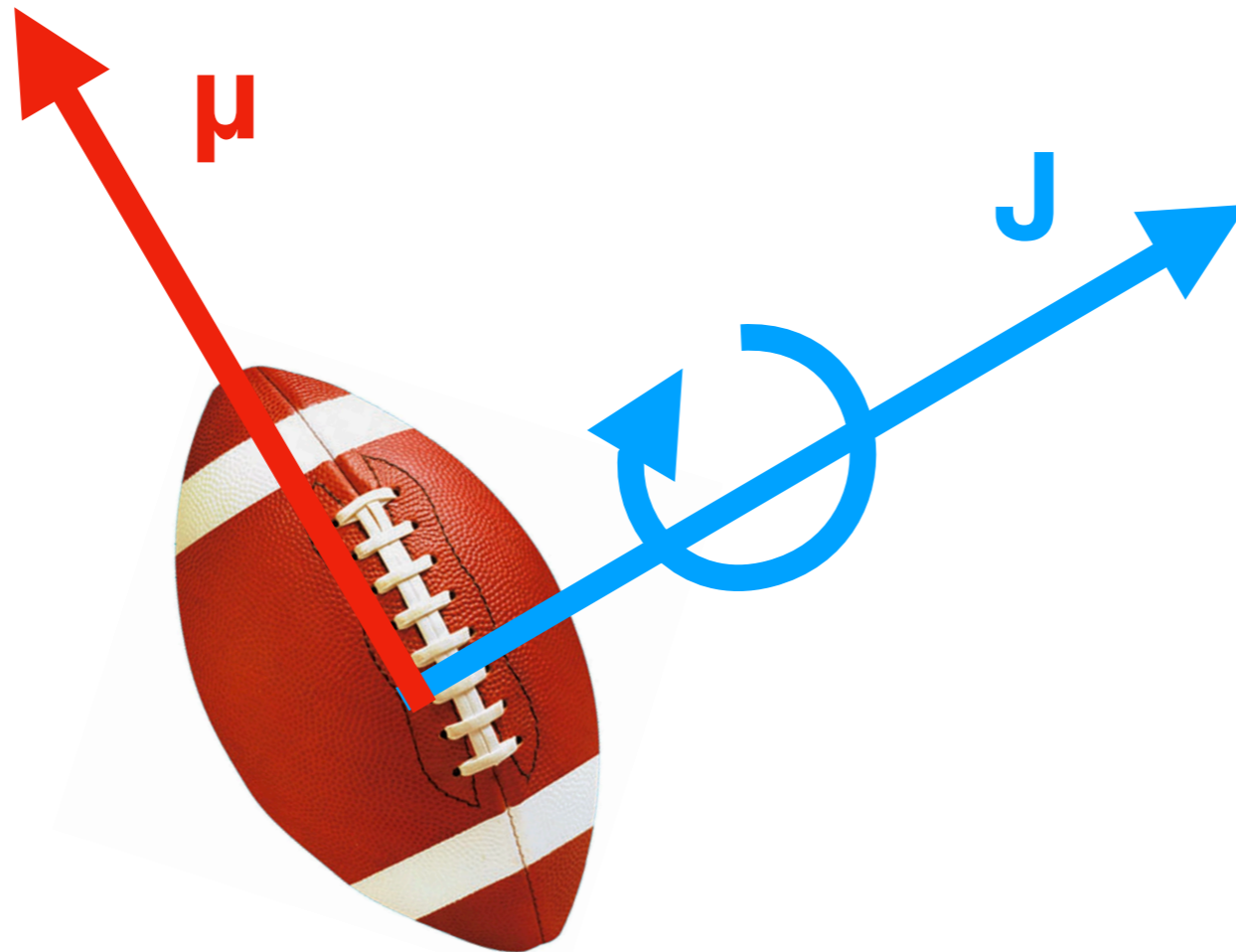


Modeling the Anomalous Microwave Emission



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CMB Foregrounds for B-Mode Studies

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The State-of-Play of Anomalous Microwave Emission (AME) research

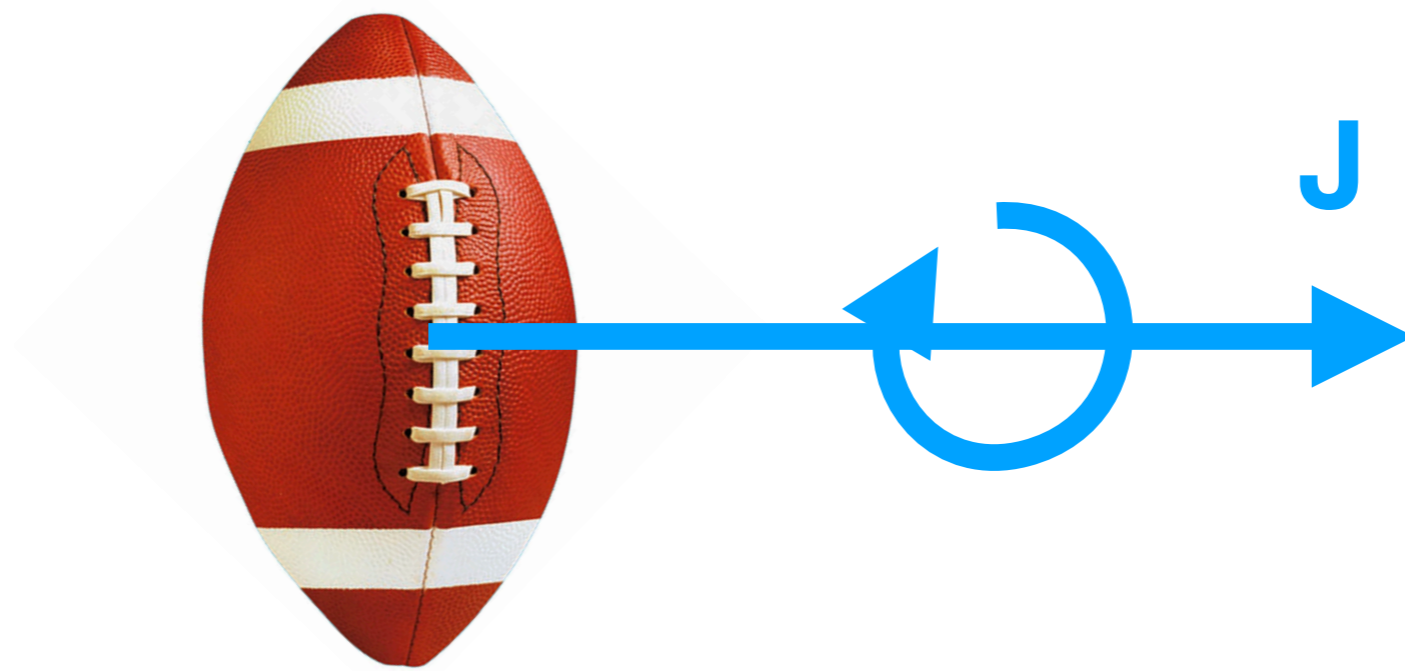
Clive Dickinson ^a✉, Y. Ali-Haïmoud ^b, A. Barr ^a, E.S. Battistelli ^c, A. Bell ^d, L. Bernstein ^e, S. Casassus ^f, K. Cleary ^g, B.T. Draine ^h, R. Génova-Santos ^{i, j}, S.E. Harper ^a, B. Hensley ^{g, k}, J. Hill-Valler ^l, Thiem Hoang ^m, F.P. Israel ⁿ, L. Jew ^l, A. Lazarian ^o, J.P. Leahy ^a, J. Leech ^l, C.H. López-Caraballo ^p, I. McDonald ^a, E.J. Murphy ^q, T. Onaka ^d, R. Paladini ^r, M.W. Peel ^{s, a}, Y. Perrott ^t, F. Poidevin ^{i, j}, A.C.S. Readhead ^g, J.-A. Rubiño-Martín ^{i, j}, A.C. Taylor ^l, C.T. Tibbs ^u, M. Todorović ^v, Matias Vidal ^f

Talk Outline

- Spinning Dust: Theory and Predictions
- Alternative Models

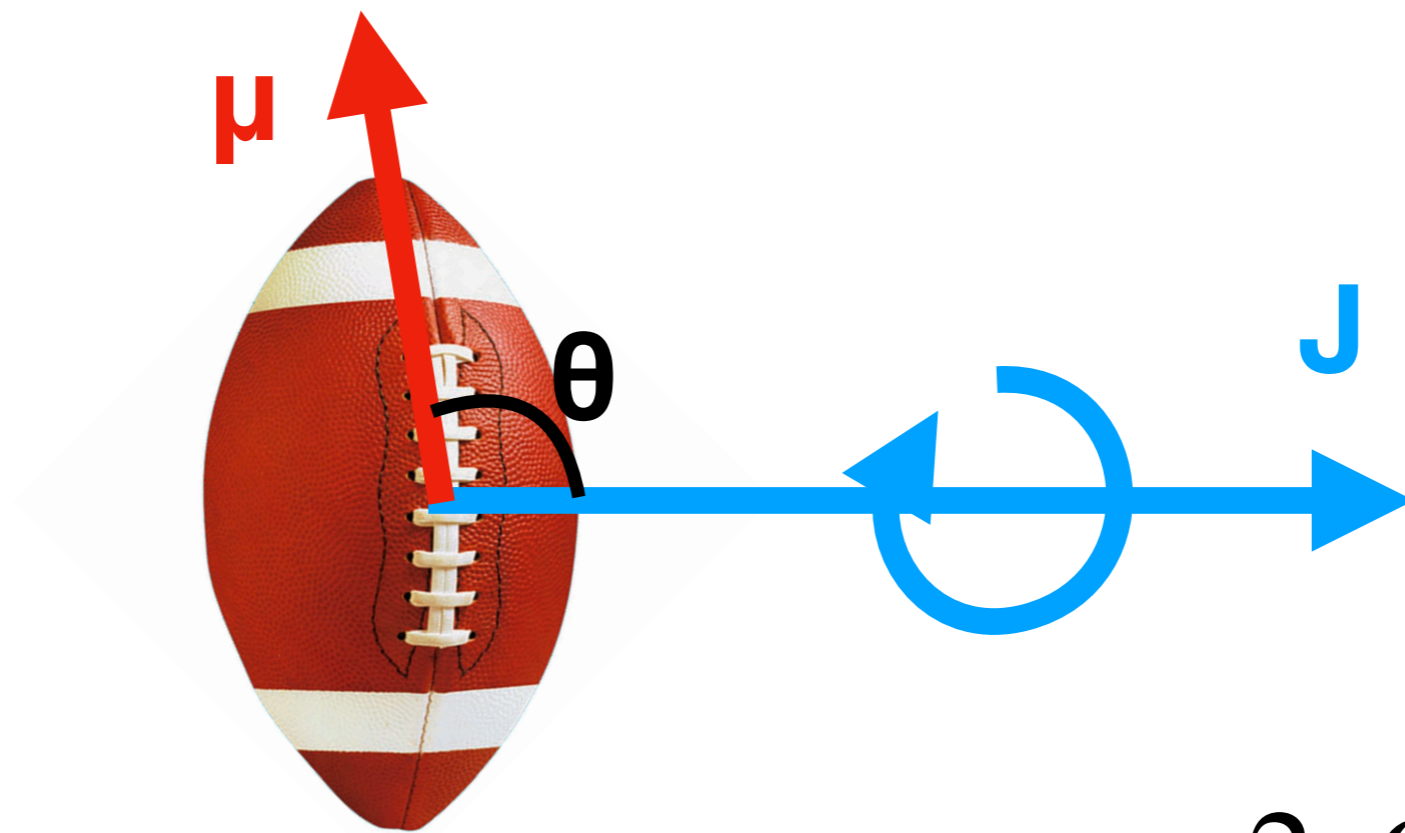
Dust Is Spinning

Generically, grains will be spinning in the ISM due to collisions with gas atoms and other processes



Spinning Dipoles Radiate

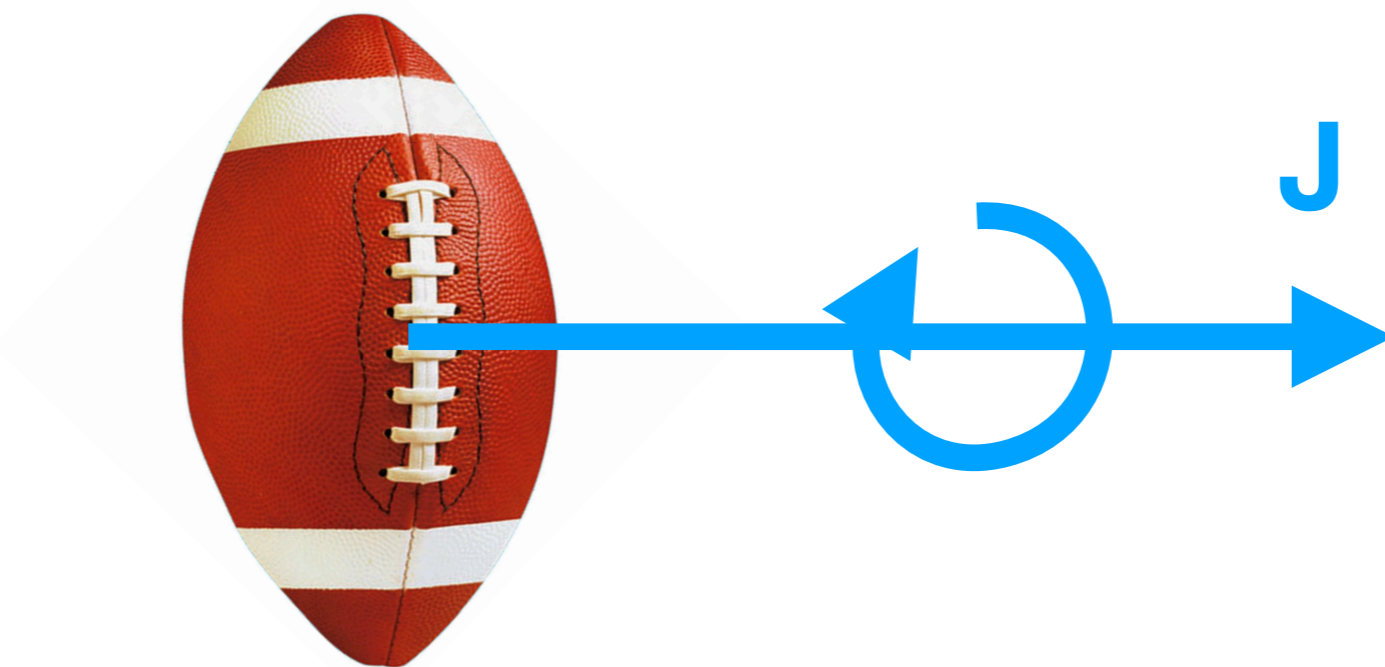
If the grain has an electric (or magnetic!) dipole moment, it will radiate as it spins



$$P = \frac{2}{3} \frac{\omega^4 \mu^2 \sin^2 \theta}{c^3}$$

How Fast Dust Is Spinning?

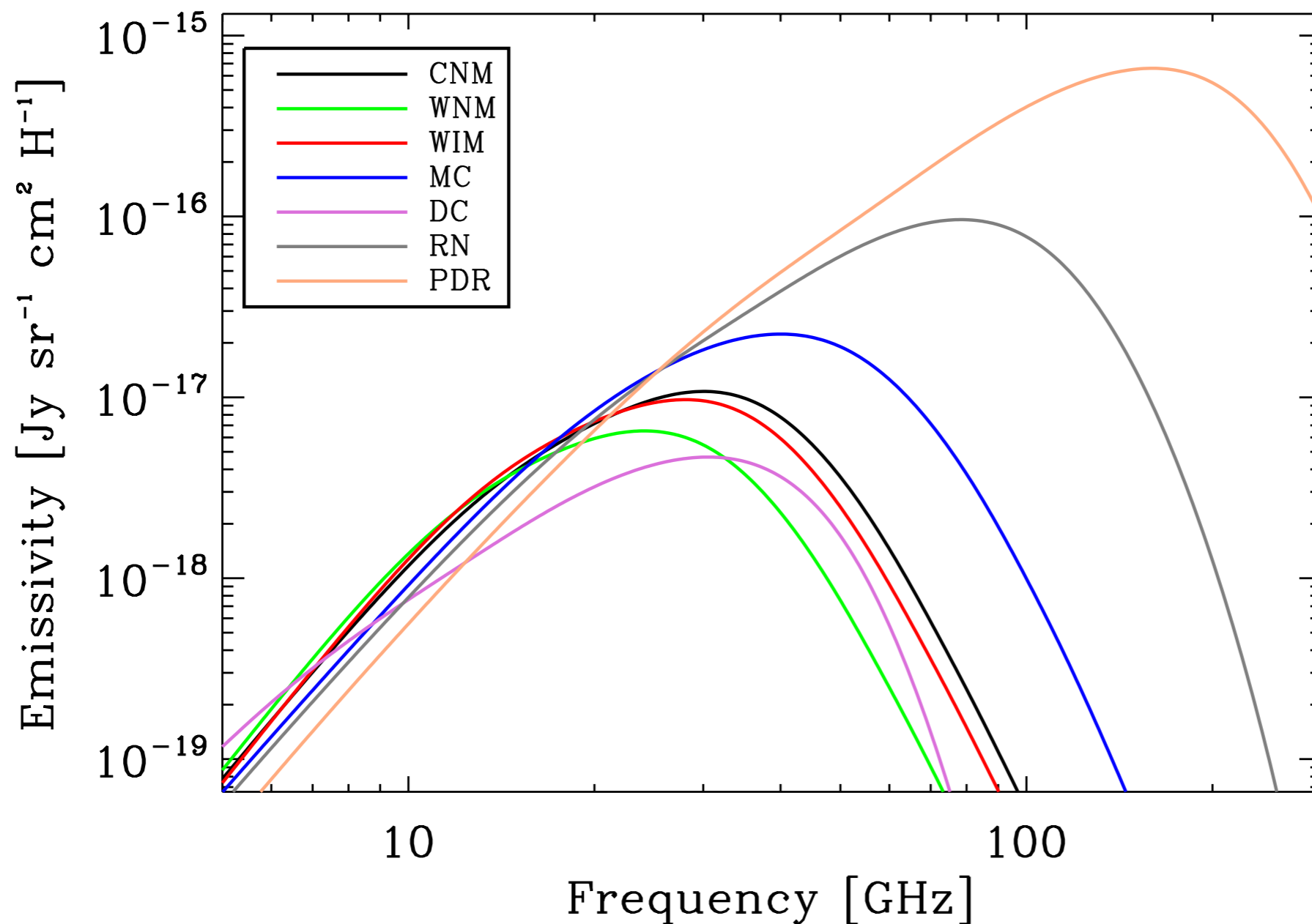
$$\nu = 21 \text{ GHz} \left(\frac{T}{100 \text{ K}} \right)^{1/2} \left(\frac{\rho}{3 \text{ g cm}^{-3}} \right)^{-1/2} \left(\frac{a}{5 \text{ \AA}} \right)^{-5/2}$$



To get 20-30 GHz spinning dust emission, grains have to be *very small*, < 1 nm

The Spinning Dust SED

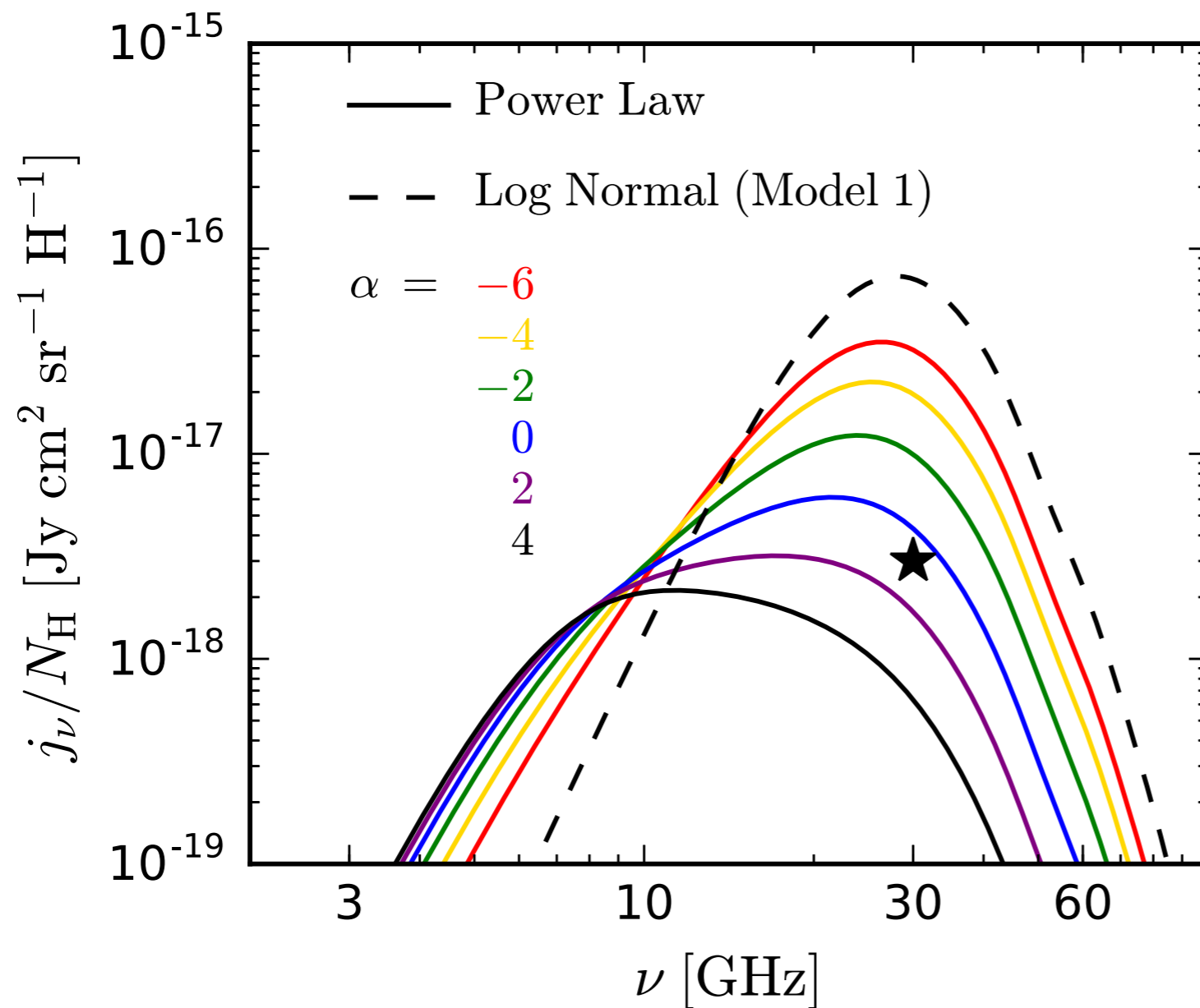
The SED is expected to vary with environment...



Dickinson+ 2018

The Spinning Dust SED

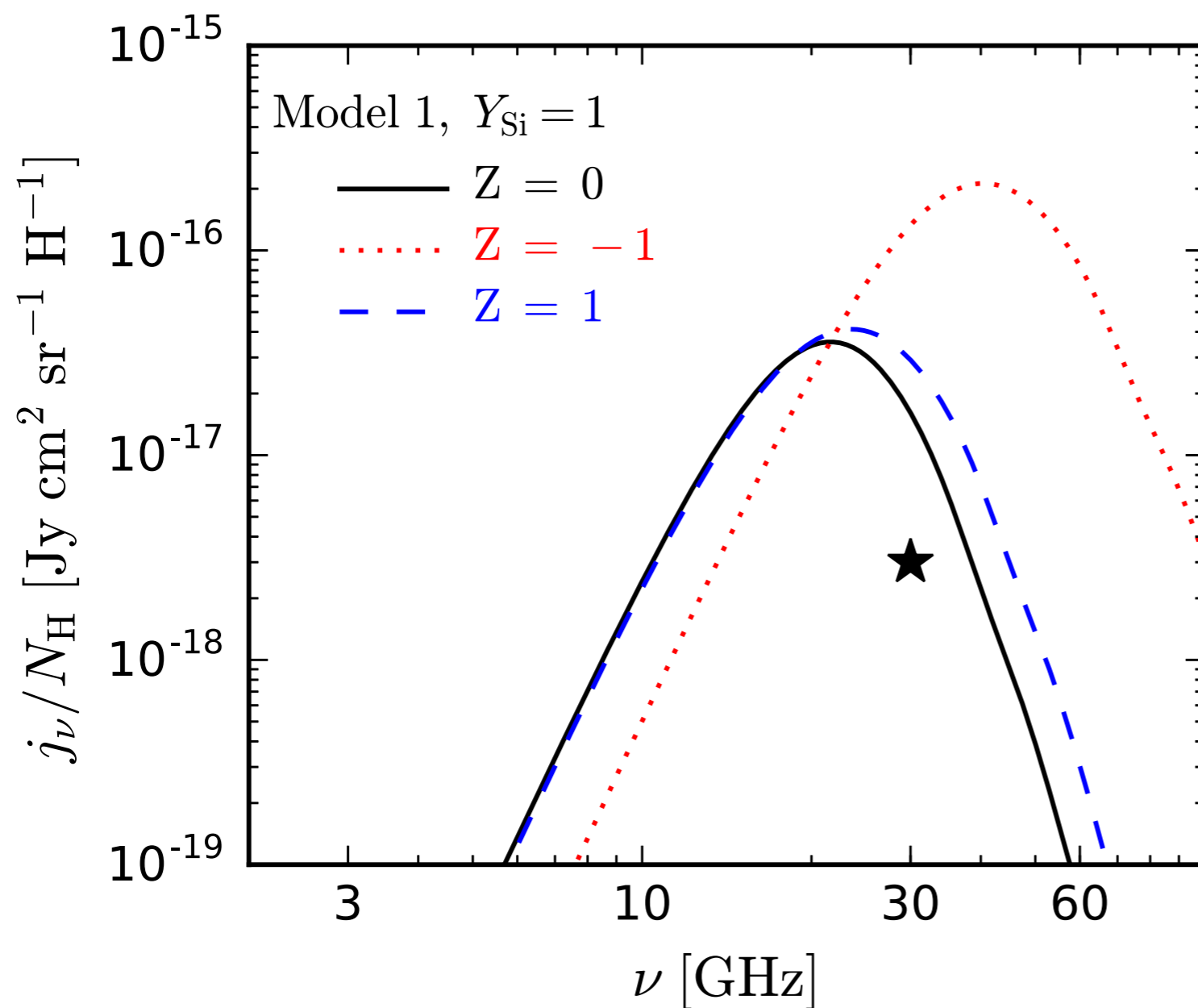
...and nanoparticle sizes...



BH & Draine 2017

The Spinning Dust SED

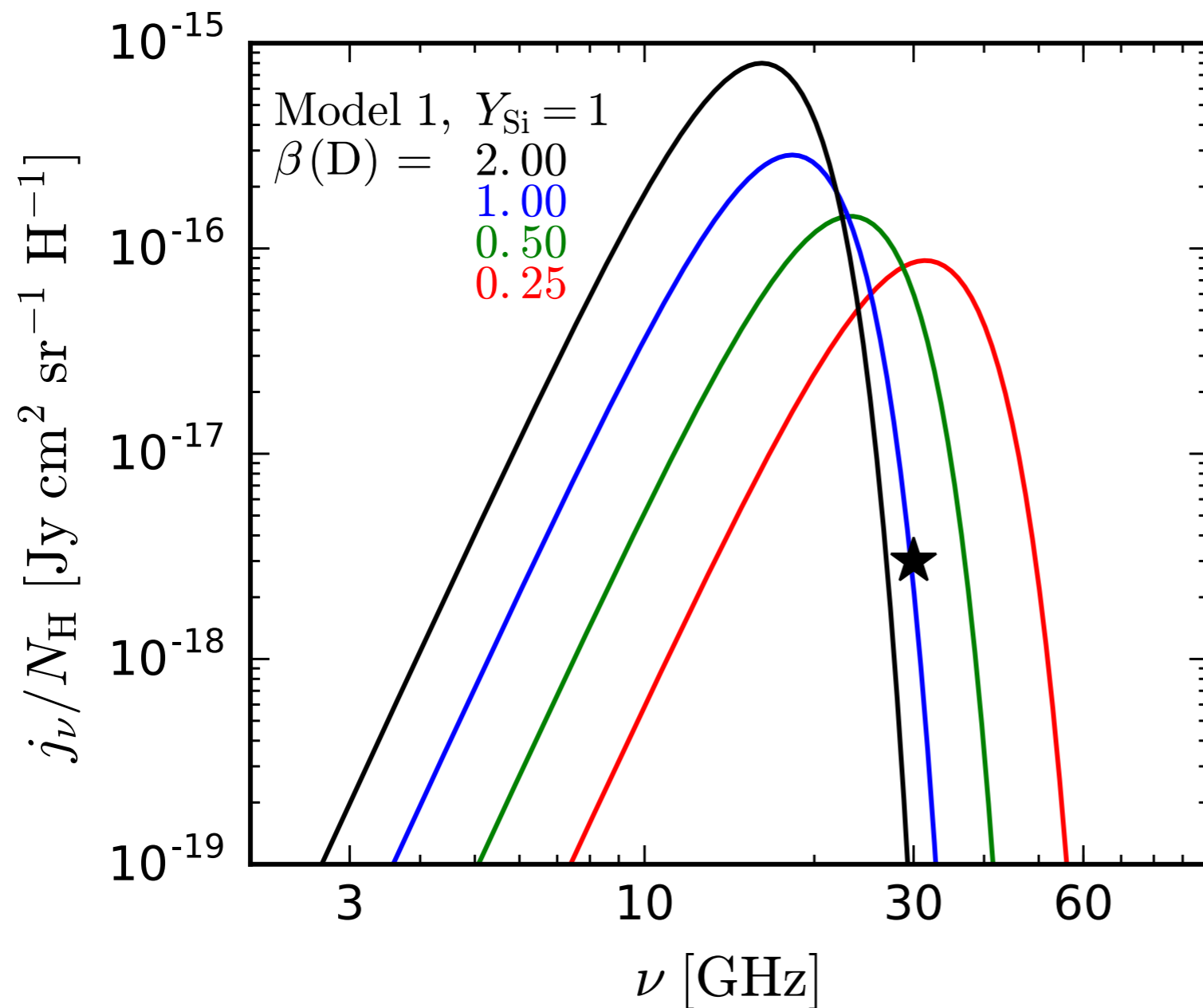
...and charge states...



BH & Draine 2017

The Spinning Dust SED

...and dipole moments...



BH & Draine 2017

The Spinning Dust SED

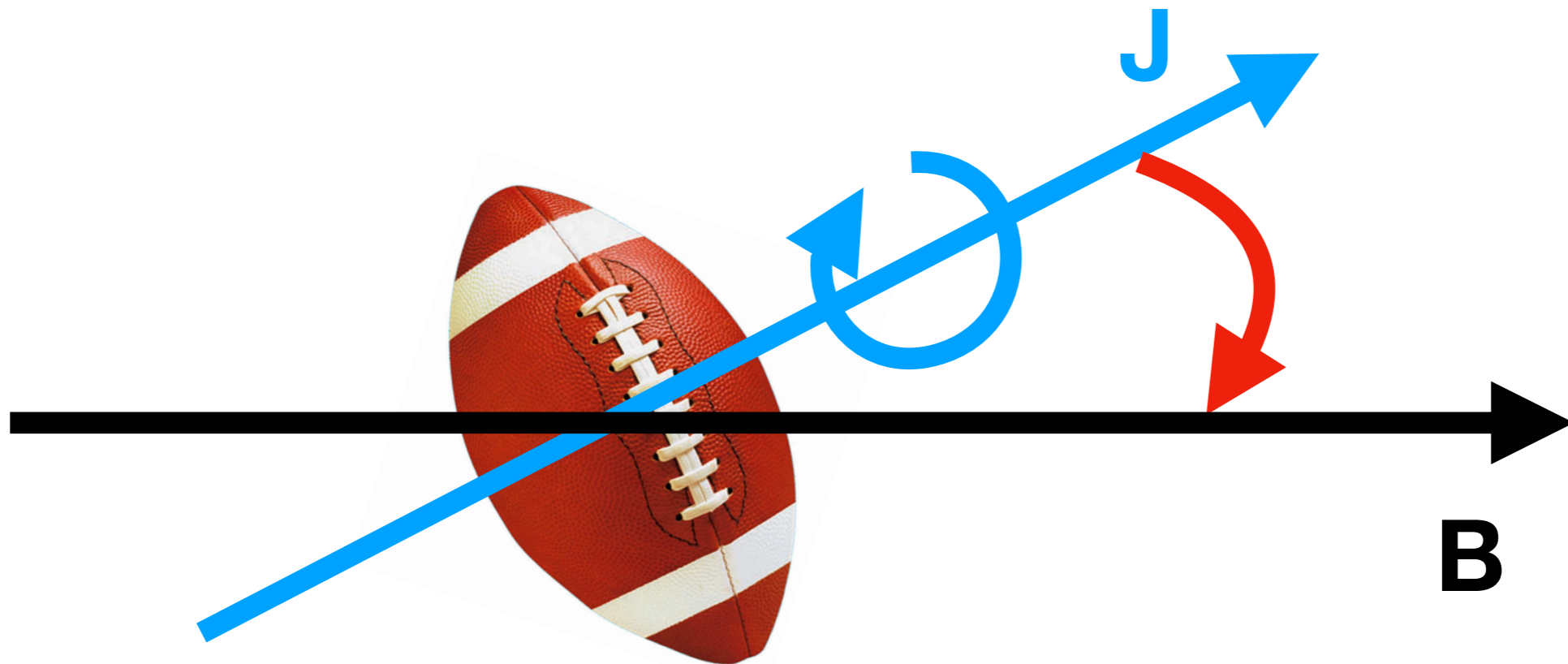
- We have little *a priori* knowledge of how the properties of nanoparticles vary spatially
- Observational windows into the smallest dust grains are few and far between
- Will be useful to try to measure and understand SED variations in specific regions

The Carrier of Spinning Dust Emission

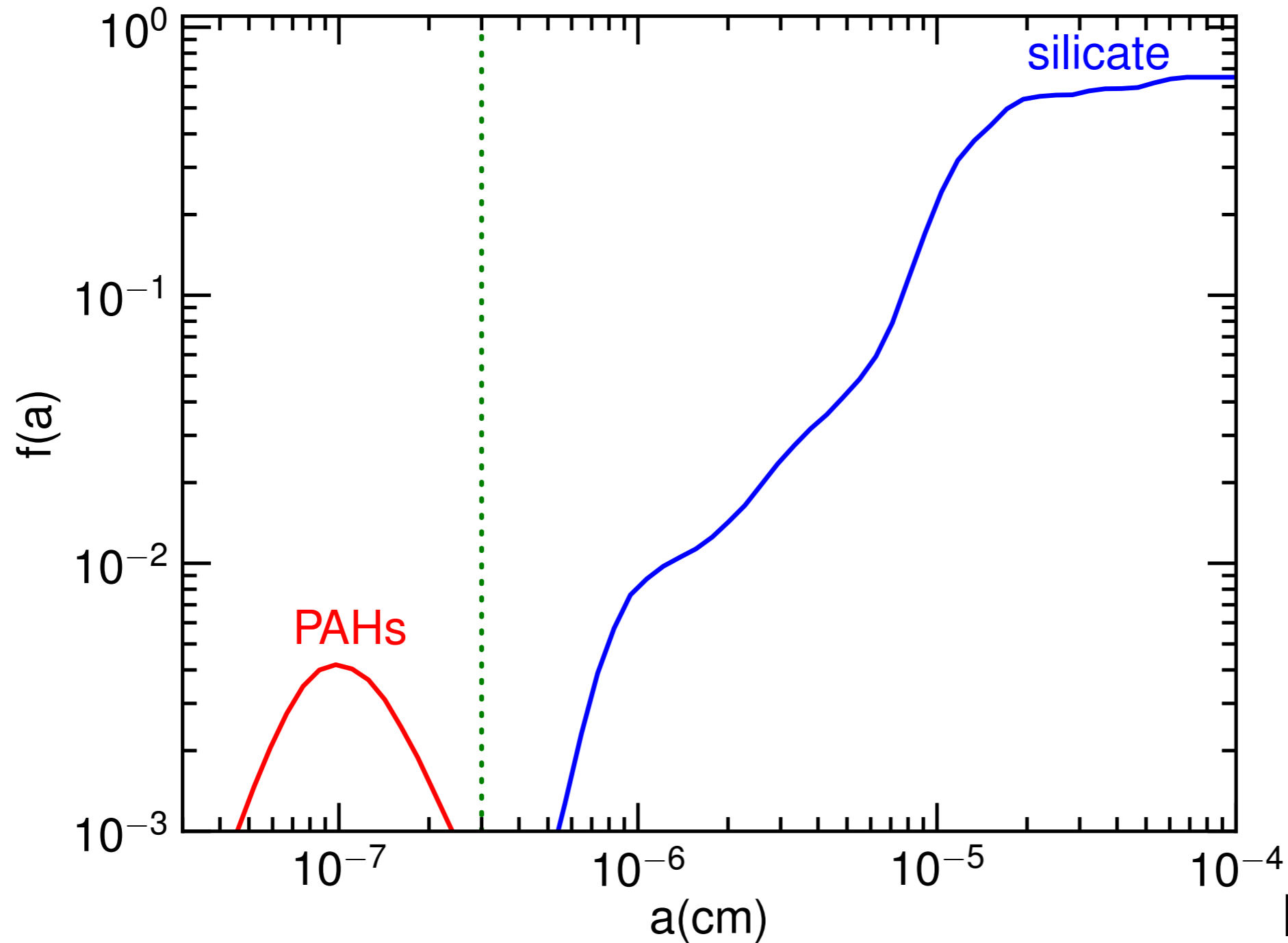
- Was first thought to be PAHs due to their ubiquity and clear abundance, but studies in **specific Galactic regions** (Tibbs+ 2011, Vidal+ 2011, Battistelli+ 2015), with **full-sky maps** (BH+ 2016), and even **protoplanetary disks** (Greaves+ 2018) didn't support an AME-PAH connection
- Fortunately, any small enough, abundant enough grain will do, such as nanosilicates (Hoang+ 2016, BH & Draine 2017)

Spinning Dust Polarization

- Emission 100% polarized with perfect grain alignment
- In big grains, dissipative processes bring \mathbf{J} into alignment with \mathbf{B}

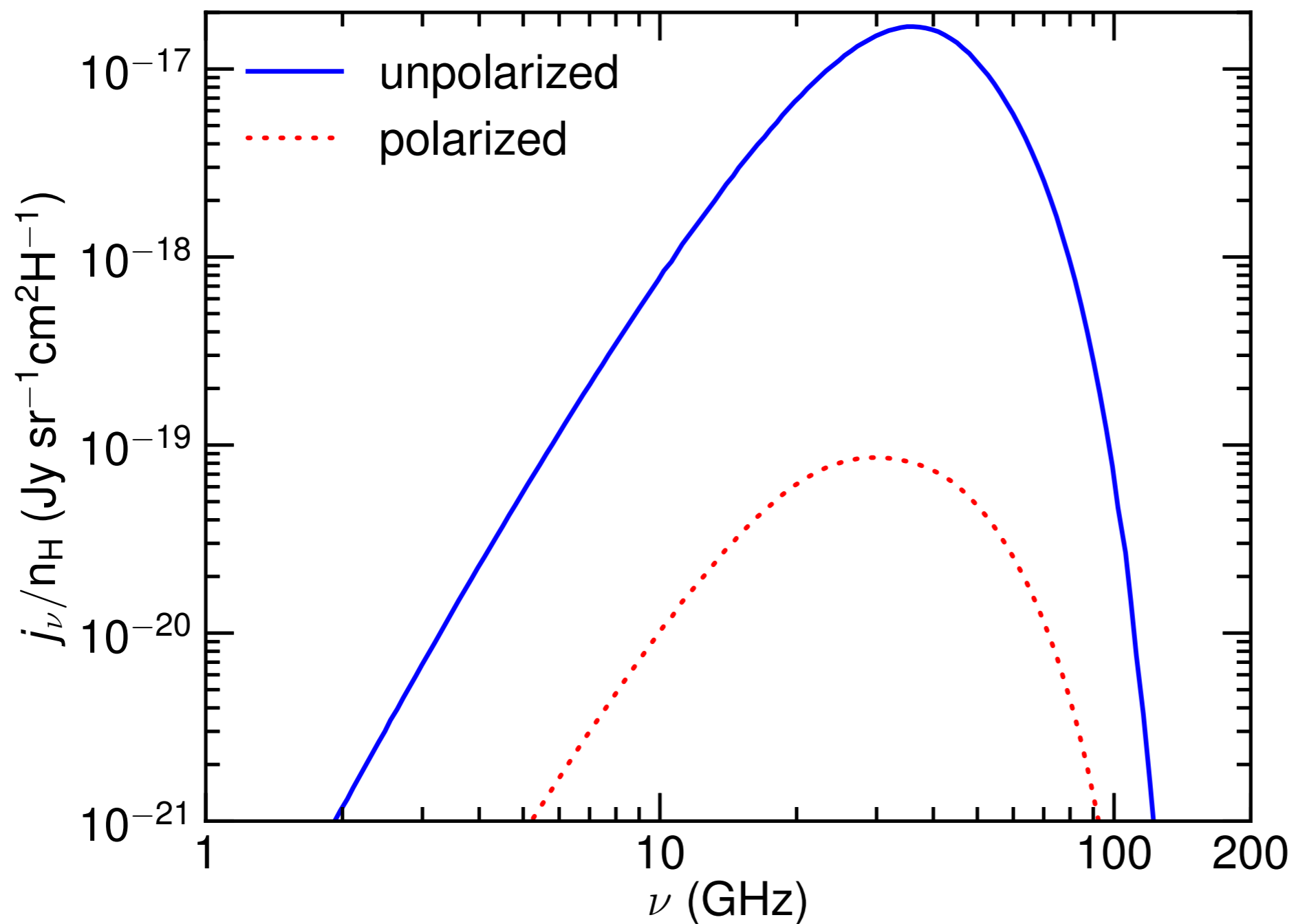


Spinning Dust Polarization



Hoang+ 2013

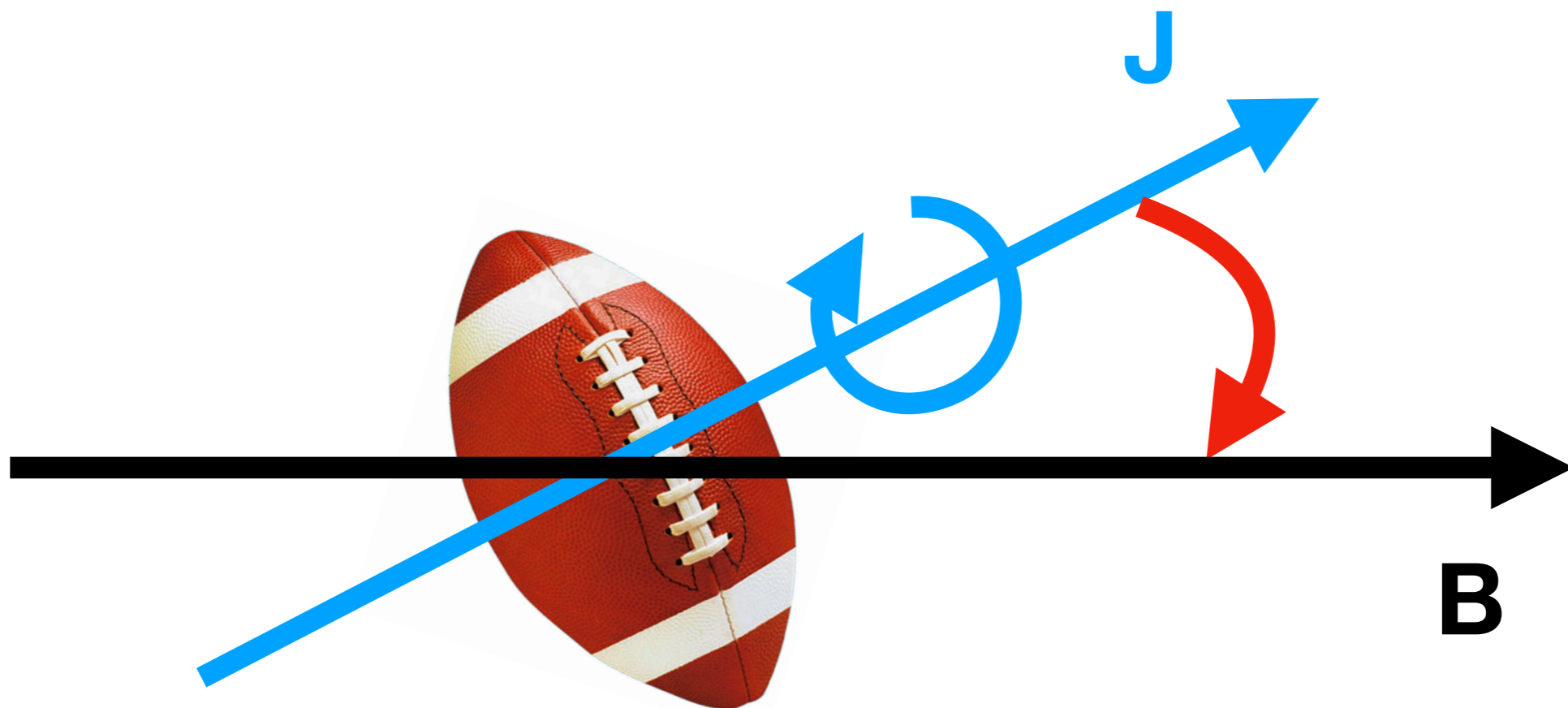
Spinning Dust Polarization



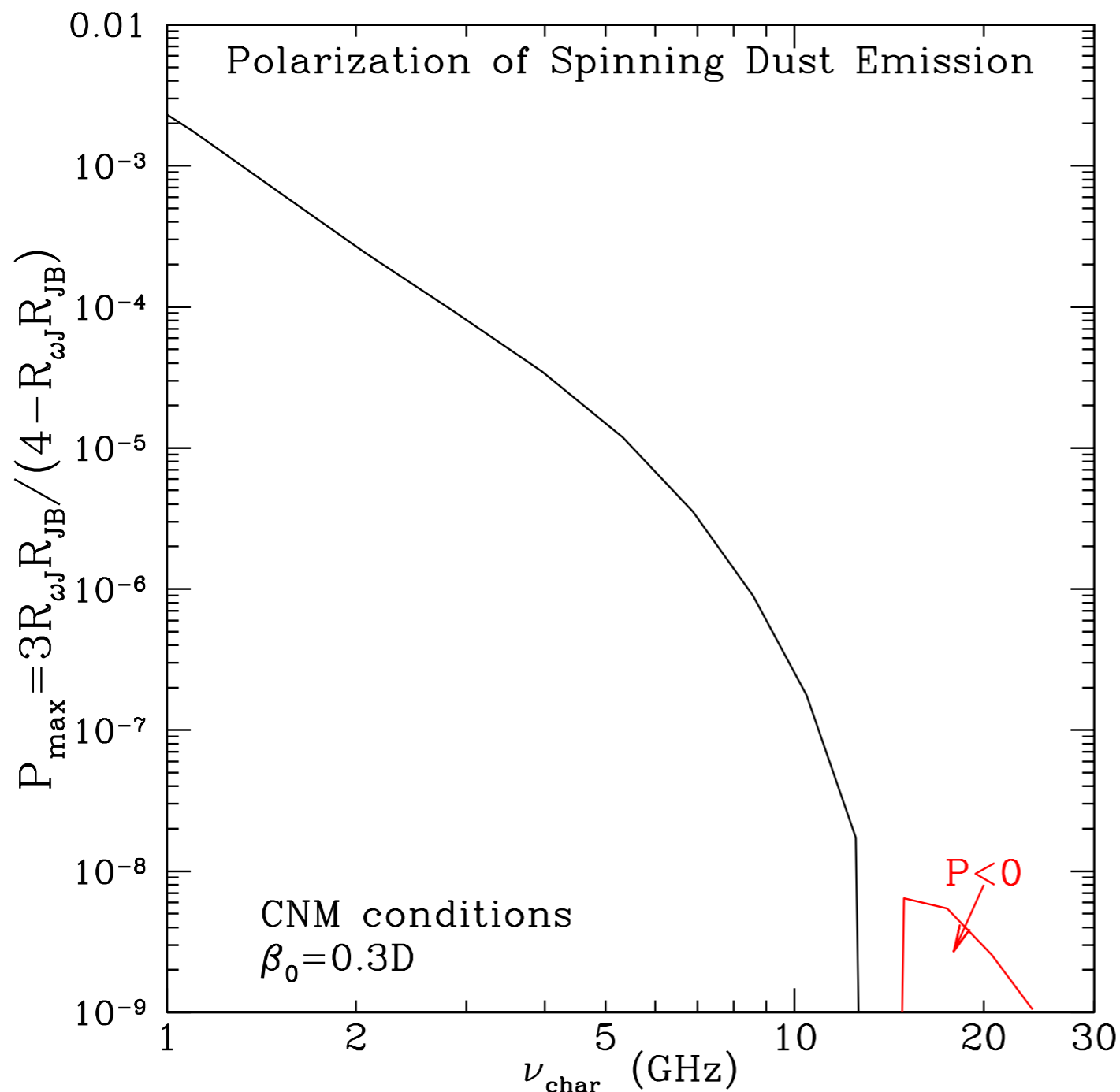
Hoang+ 2013

Spinning Dust Polarization

- Recall grains must be *very small* so need to be thought of quantum mechanically
- Alignment requires converting rotational kinetic energy to heat, but rotational and vibrational energy states are quantized



Spinning Dust Polarization



Prediction:

No polarization at any significant level

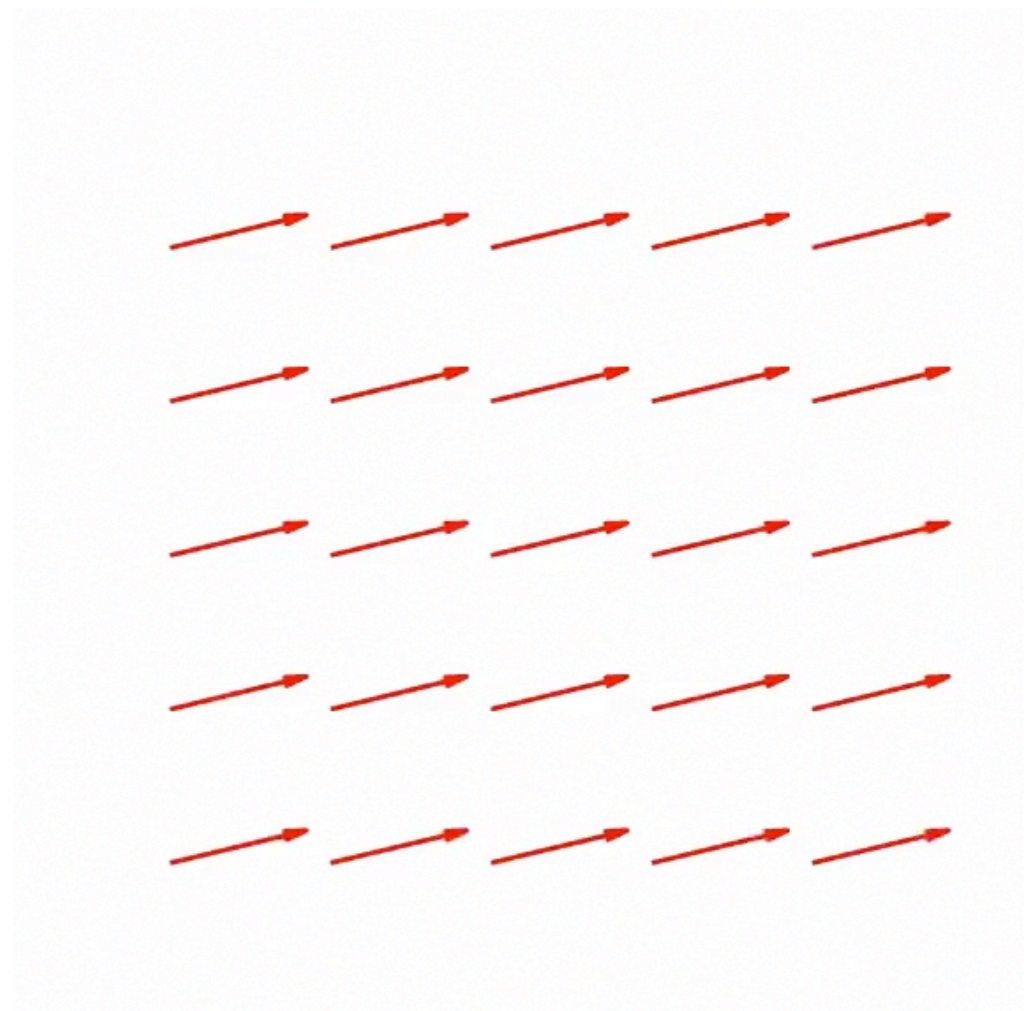
Draine & BH 2016

Alternative Models

- Magnetic Dust
- Other thermal emission mechanisms

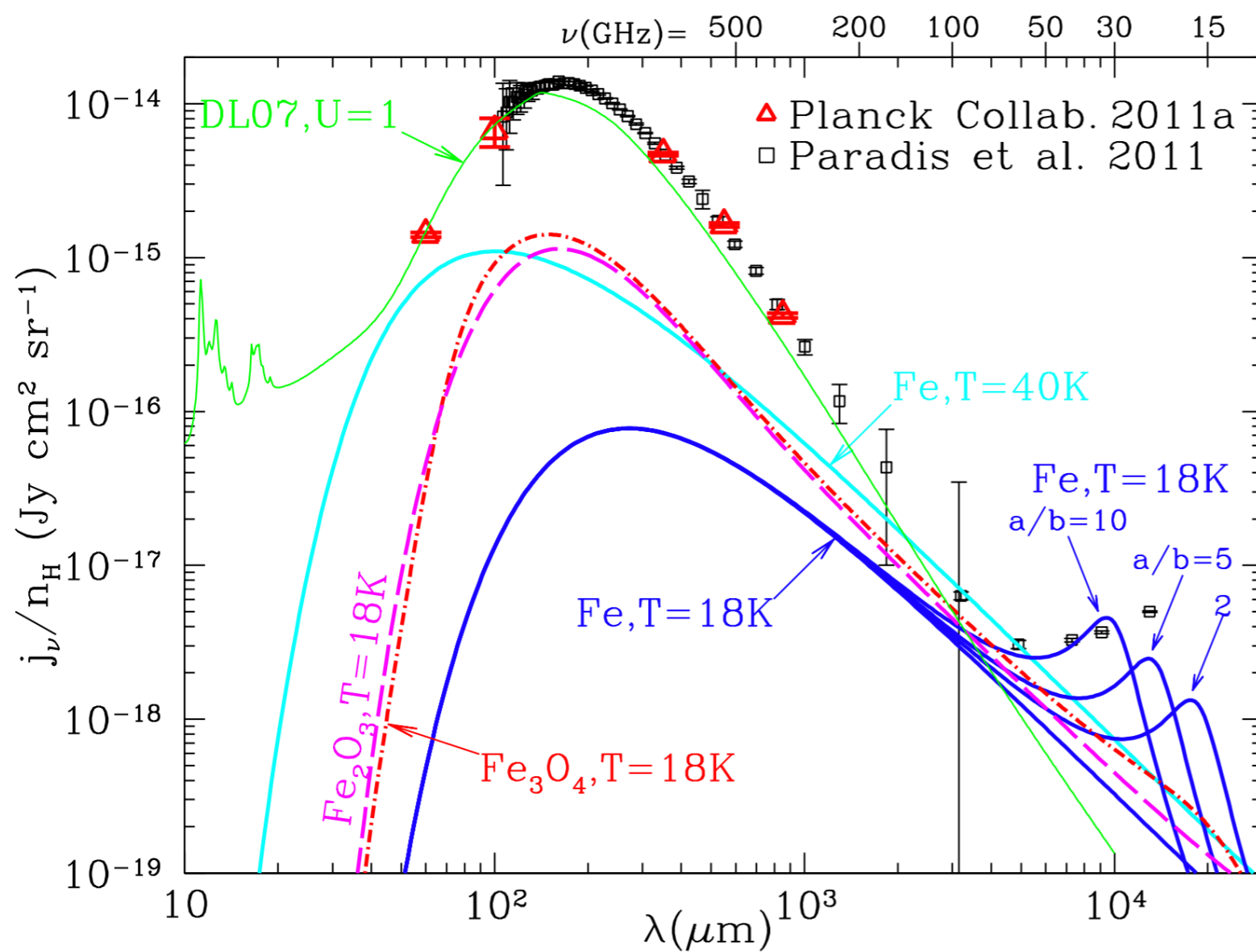
Magnetic Dust

- Nearly all of the interstellar Fe is in dust
- Some might be in the form of ferromagnetic inclusions



Magnetic Dust

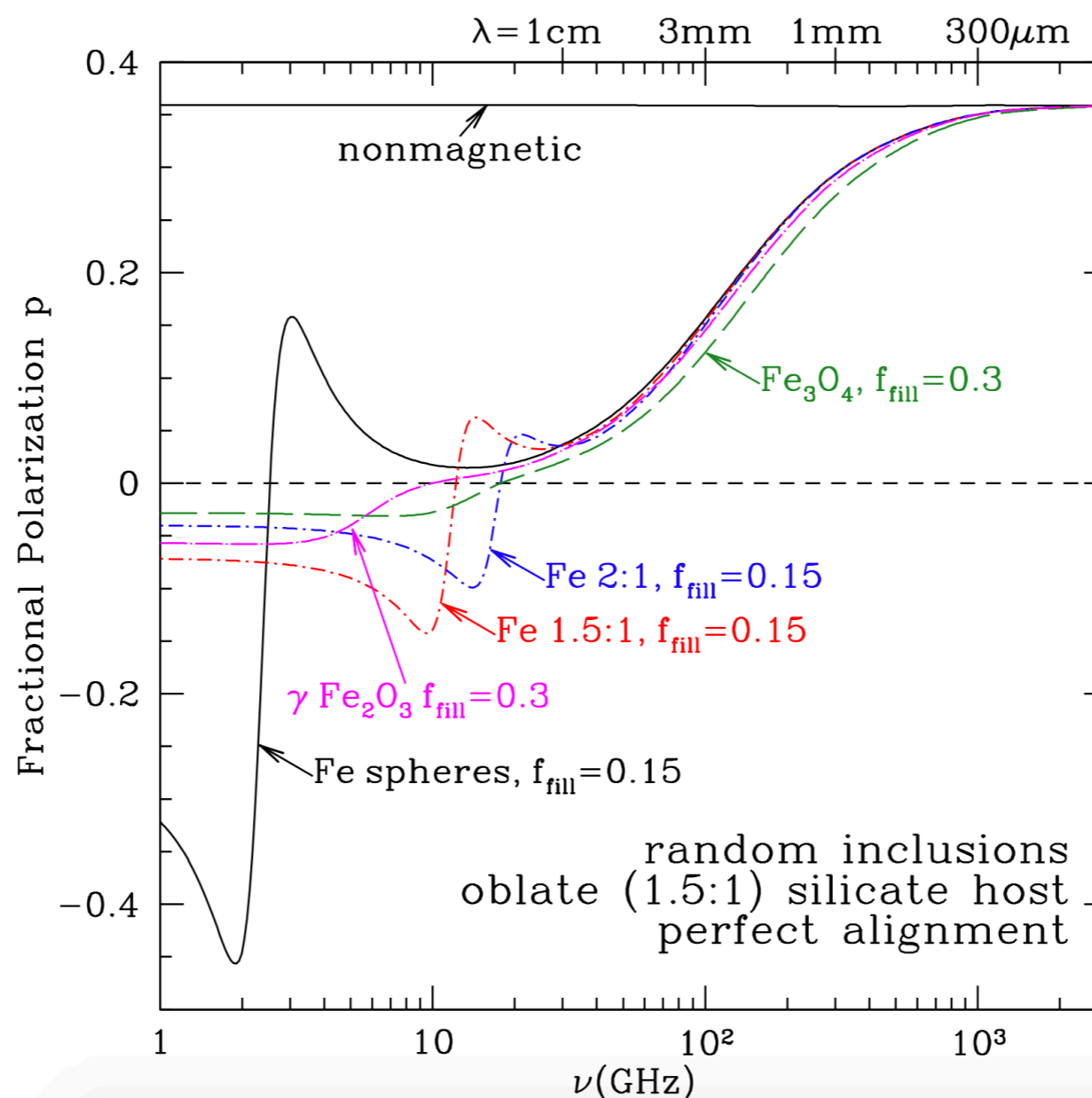
Strong millimeter emission and possible resonances in the radio



Draine & BH 2013

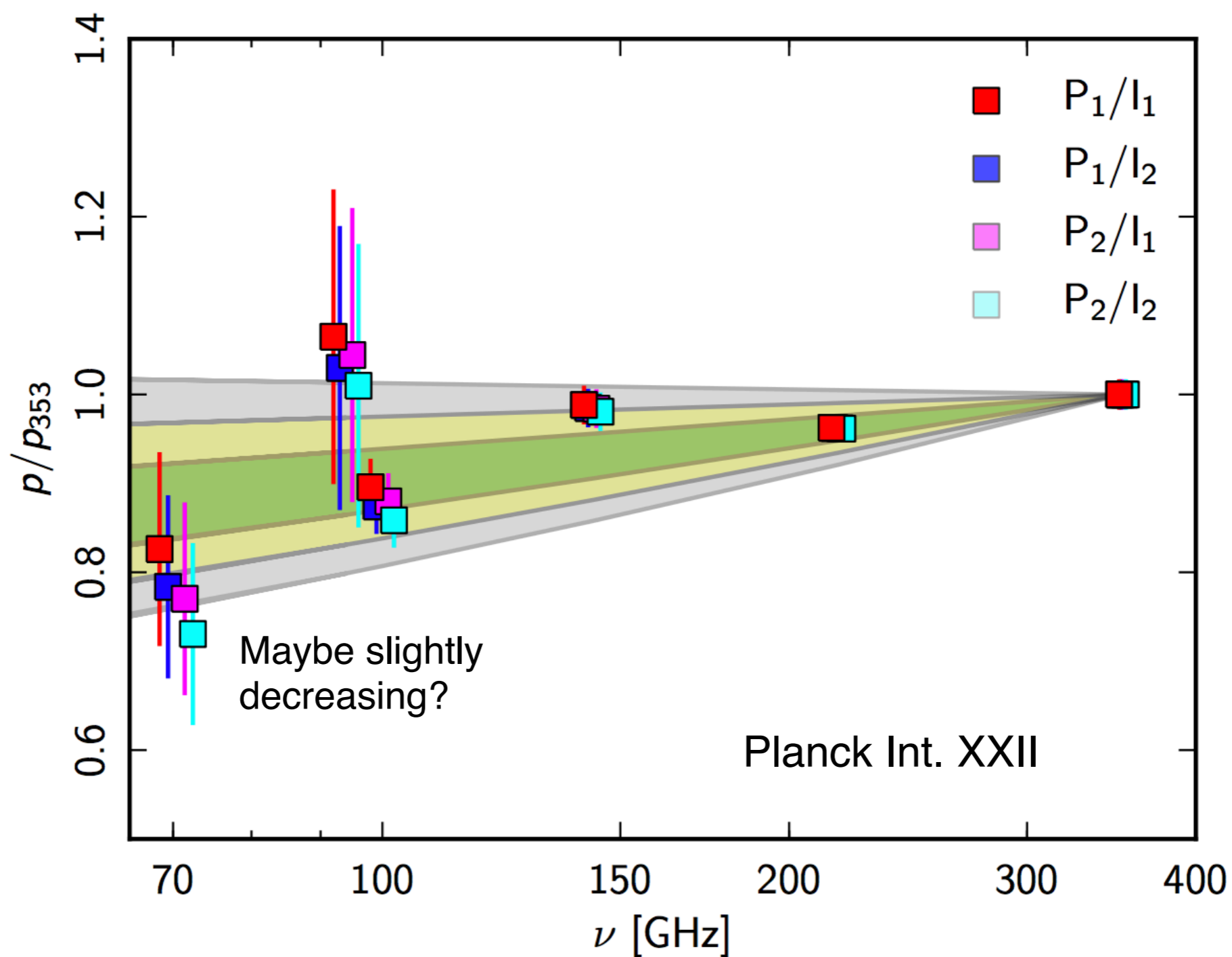
Magnetic Dust

Distinct polarization signature—magnetic dipole emission polarized orthogonally to typical electric dipole emission



Draine & BH 2013

Planck Polarization Fraction

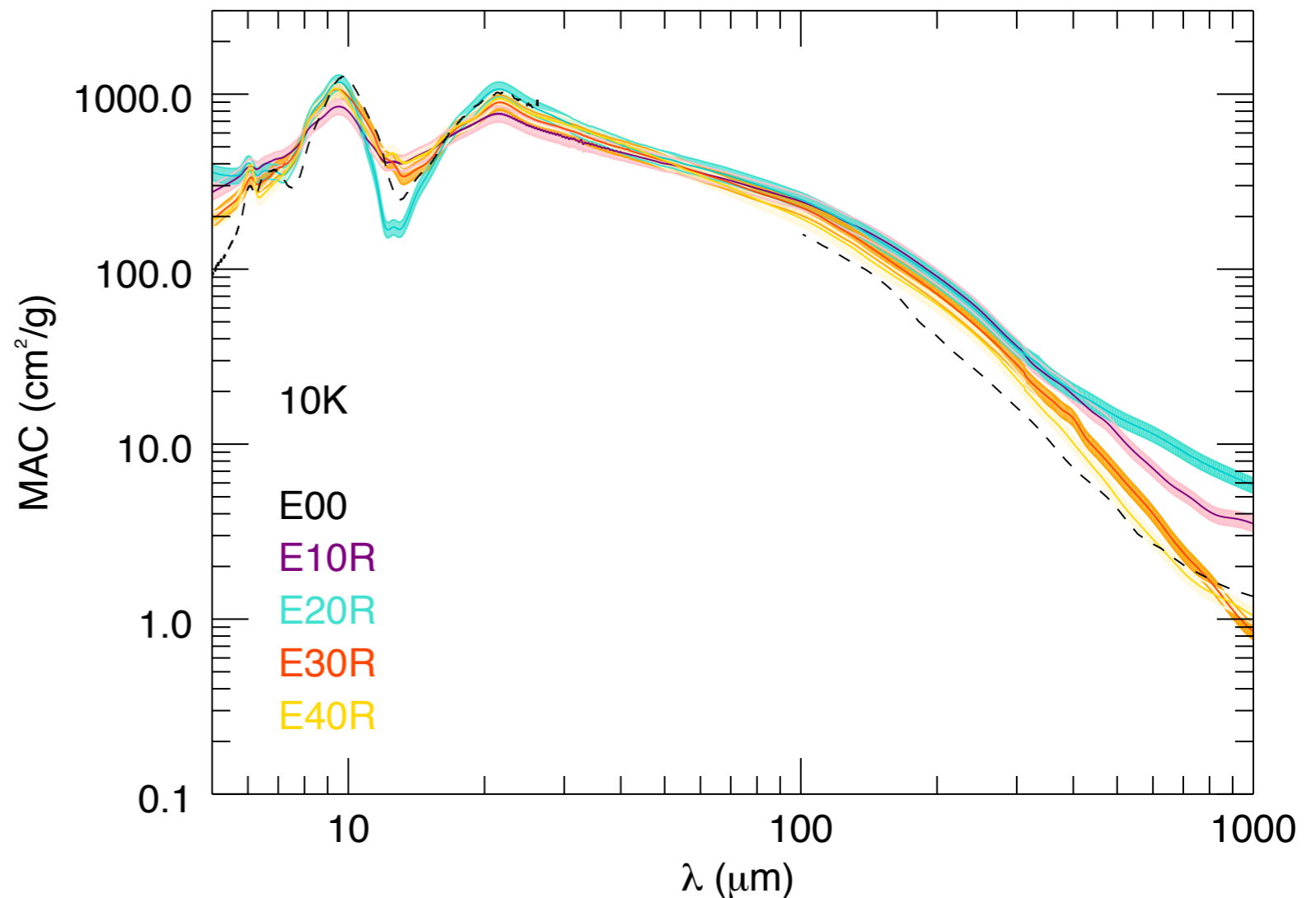


Magnetic Dust as AME?

- Resonance behavior depends on specific shapes of grains, hard to get an AME-like spectrum generically
- Would expect strong polarization, which does not appear to be consistent with observations
- Possible magnetic dipole emission is there as a sub-dominant component of the long wavelength emission, but seems unlikely to give the AME “bump”

Other Thermal Mechanisms?

- Optical properties of grains may just have a feature at these wavelengths
- Two level system models have been suggested as a possible AME explanation (Jones 2009)
- If emission from big grains, we'd expect polarization



Demyk+ 2017

Summary

- Spinning dust still appears to be the most likely explanation for the AME, though other processes may be contributing at a lower level
- The spinning dust SED is expected to be highly variable given its sensitivity to the properties of ultra-small grains
- There are strong theoretical arguments for negligible polarization from spinning dust