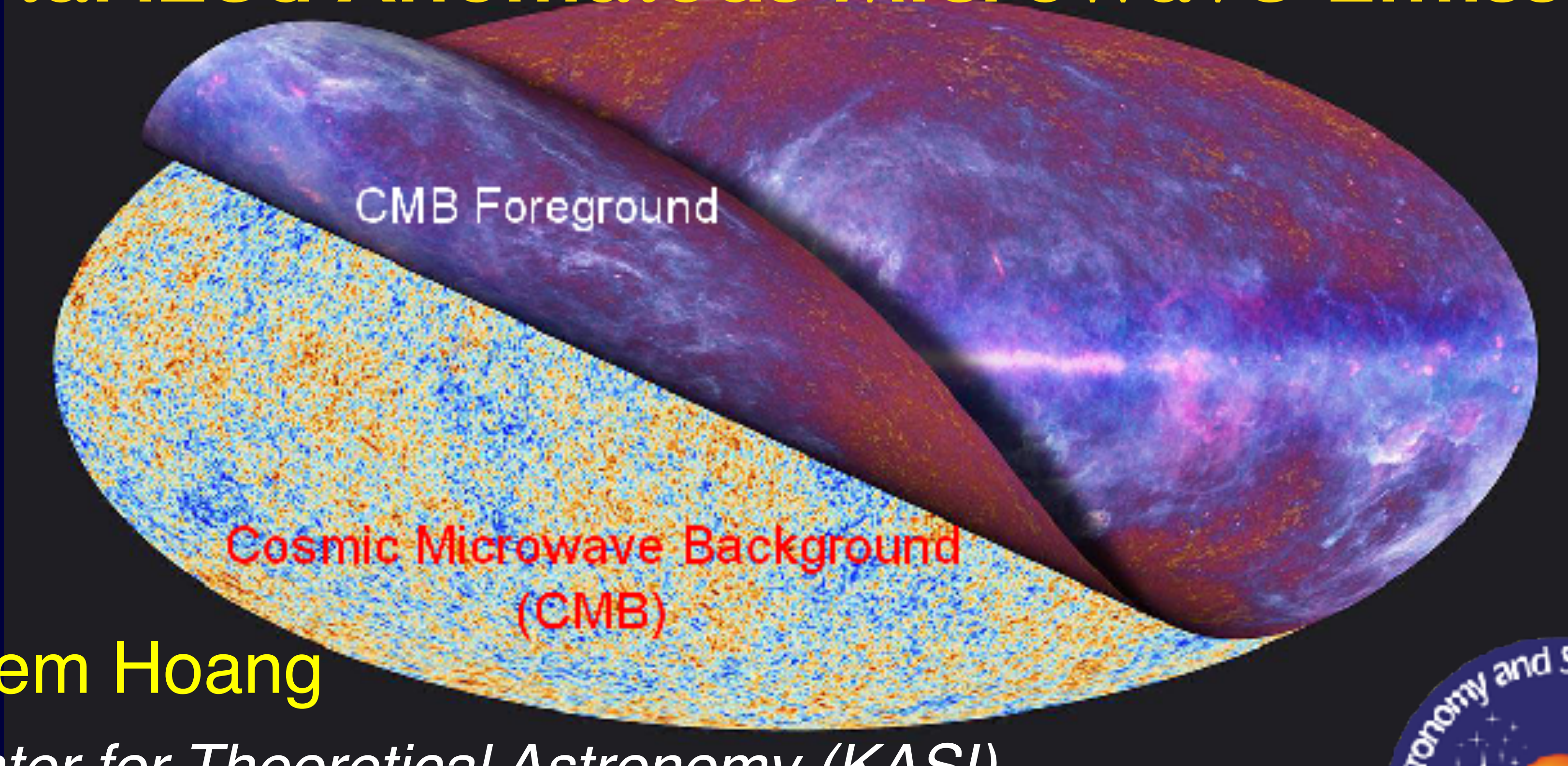
Tiny Dust Particles Challenge Big Quest for CMB B-modes:

Polarized Anomalous Microwave Emission



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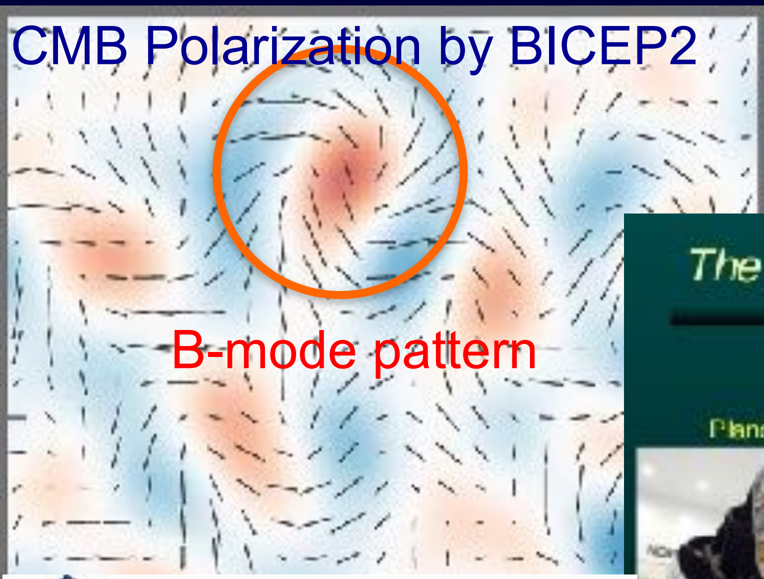
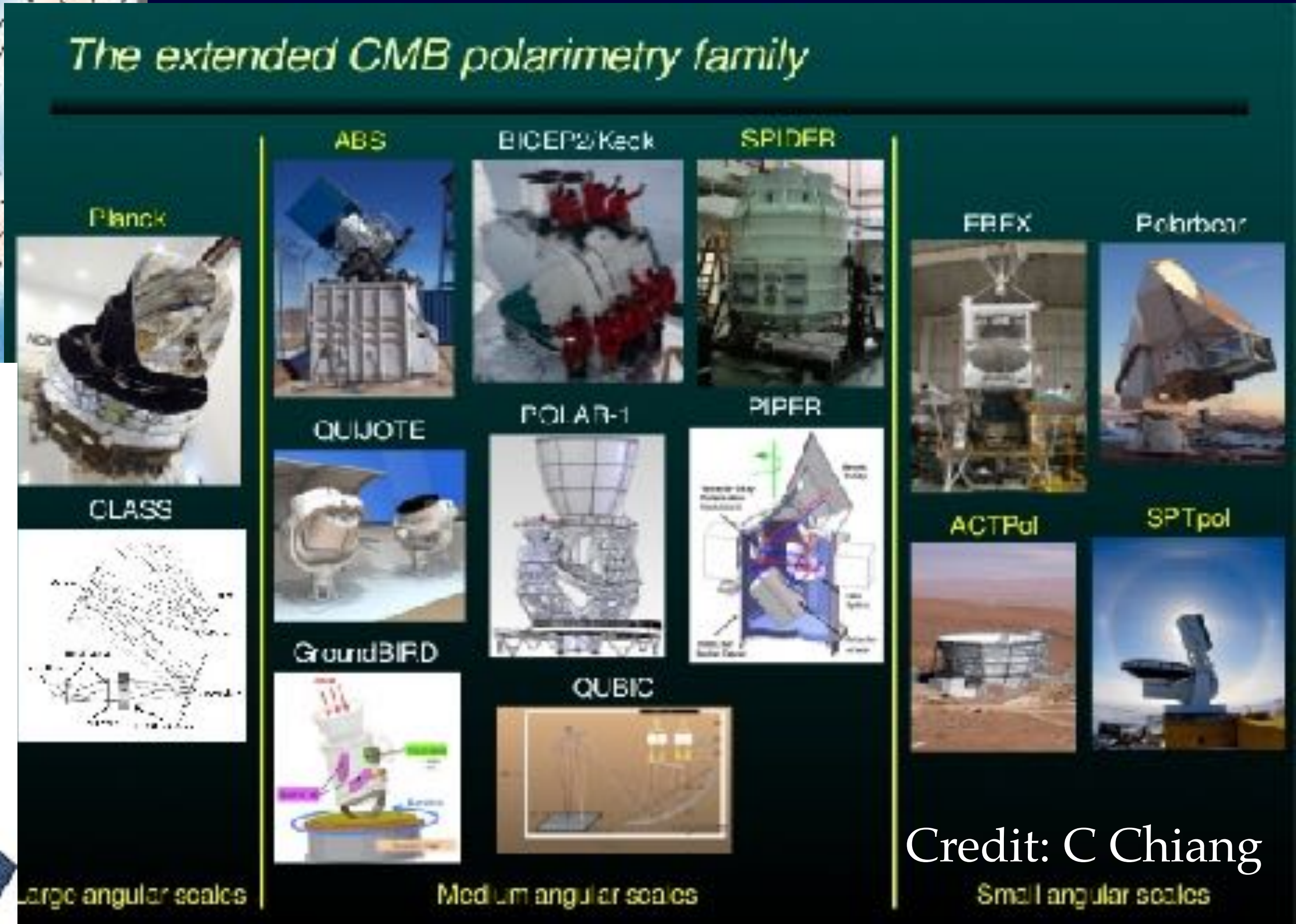
Special thanks to: Alex Lazarian, Bruce Draine, Peter Martin

KIAS, Oct 31- Nov 3, 2016

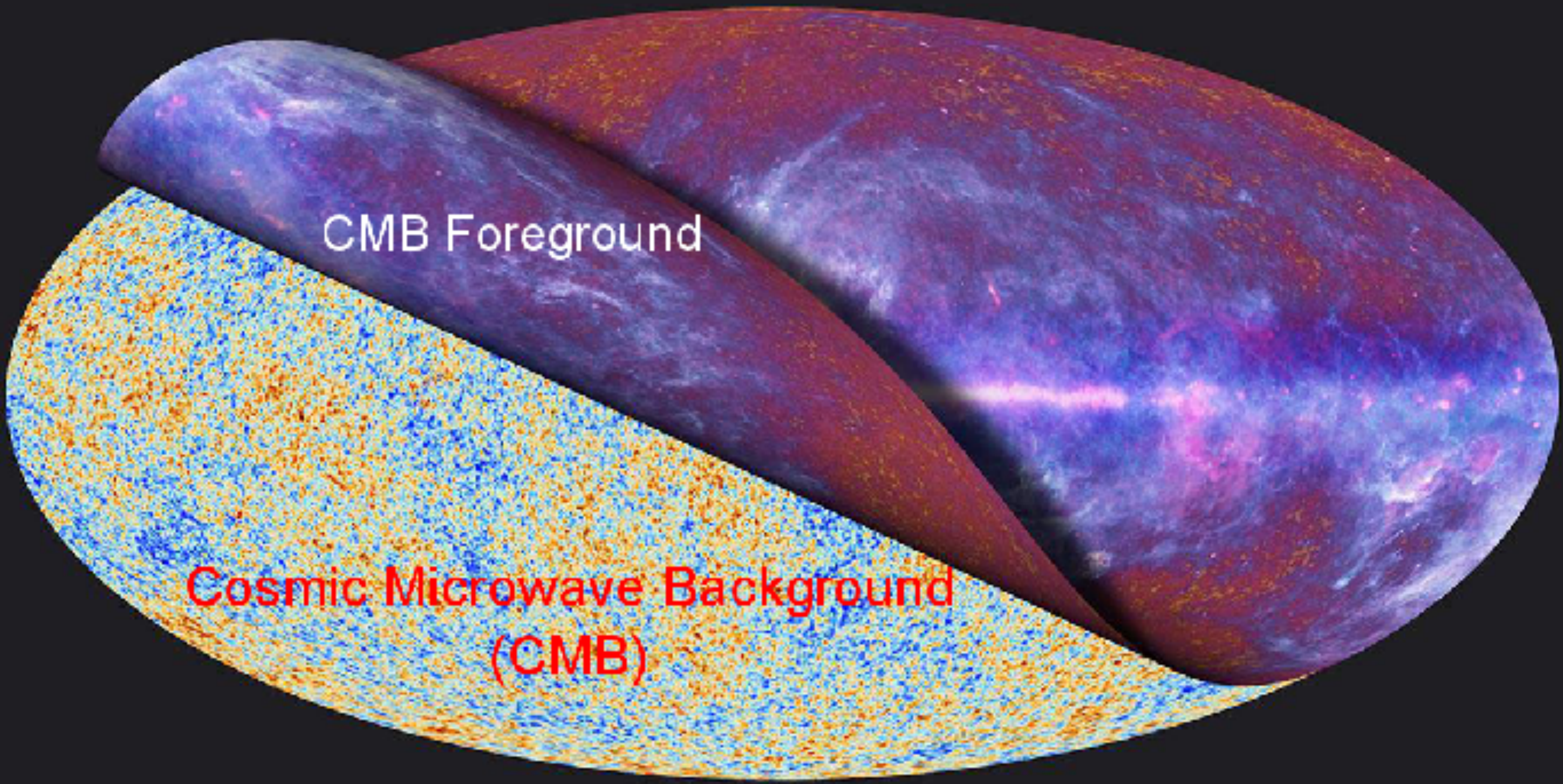
Golden Age of CMB Polarimetry: Gravitational Waves with CMB B-Mode



CMB: Cosmic Microwave Background



Precision Cosmology Requires Accurate CMB Foreground Model

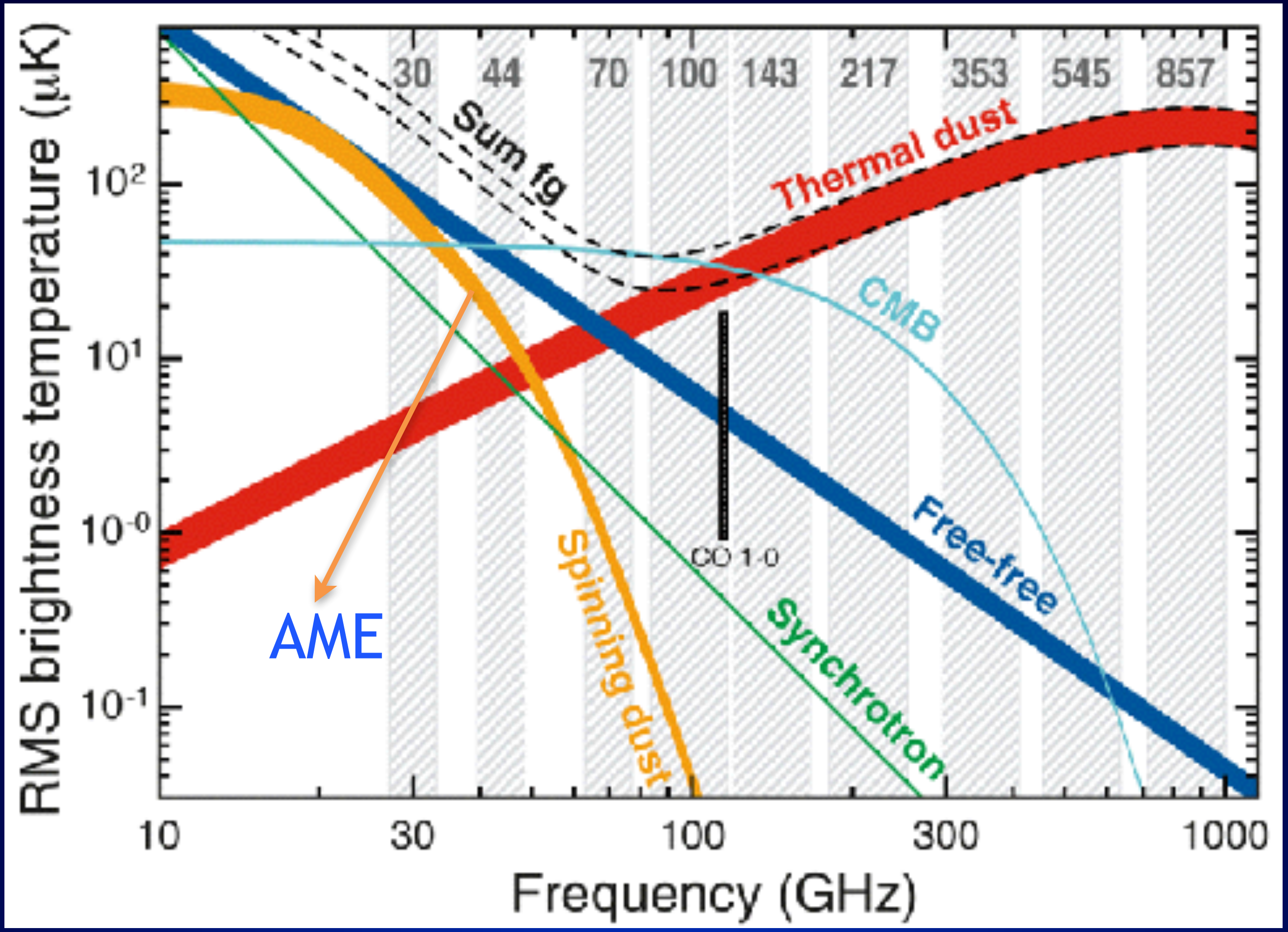


Planck Collaboration

From BICEP2: we cannot ignore CMB foreground polarization

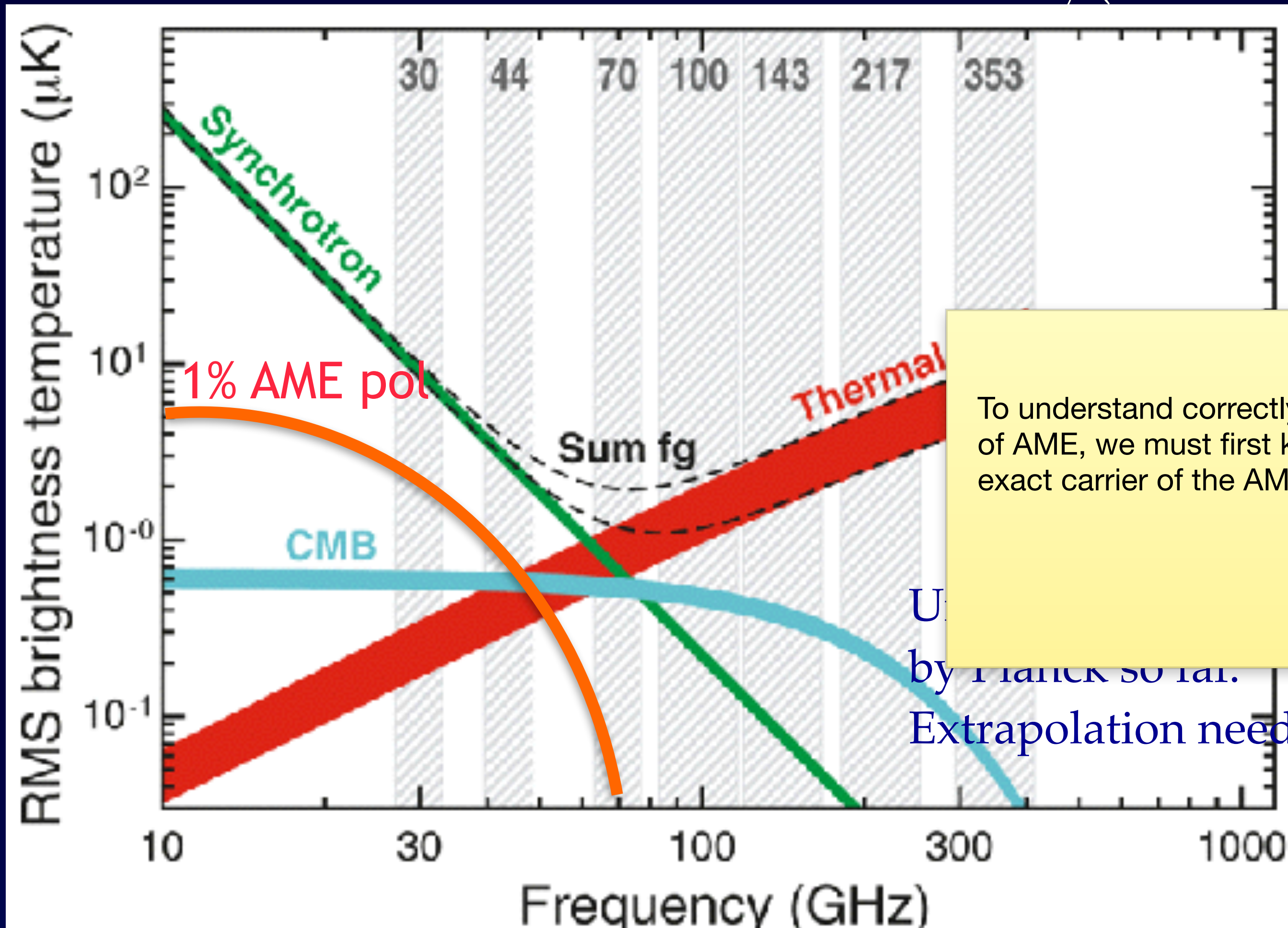
Anomalous Microwave Emission (AME) as an important CMB foreground

Total intensity (Planck et al. 2015)



How does polarized AME affect B-modes?

Polarized intensity (Planck et al. 2015)



To understand correctly the polarization of AME, we must first know what is the exact carrier of the AME.

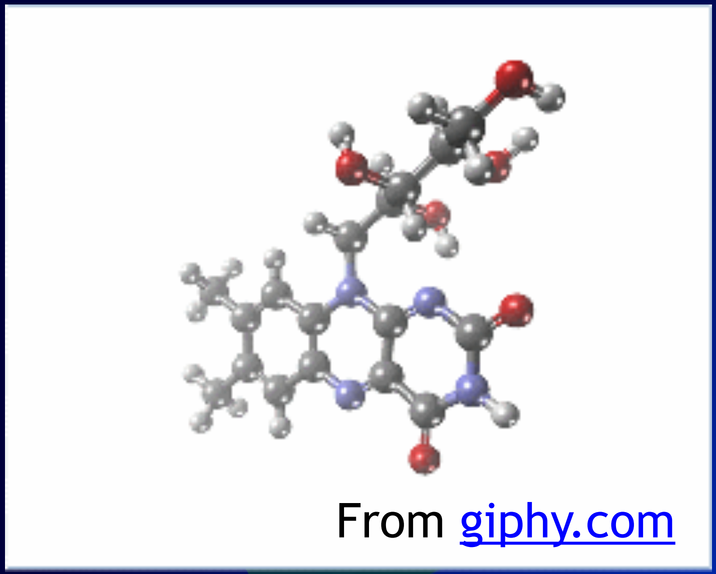
ratio by more than 1σ. For sensitive CMB experiments, omitting in the foreground modelling a 1% polarized spinning dust component may induce a non-negligible bias in the estimated tensor-to-scalar ratio.

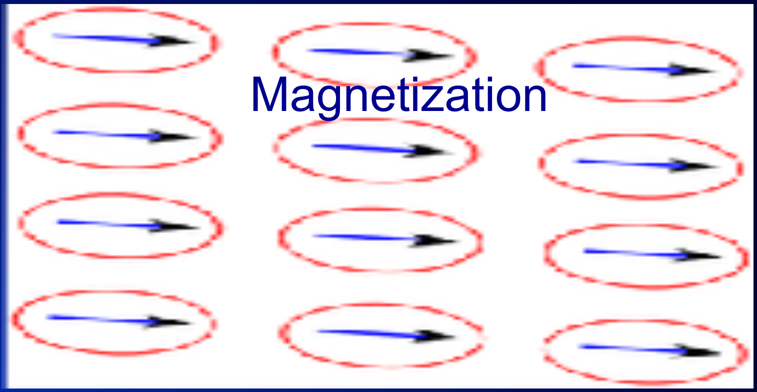
Simulations by Dickinson's group

A Brief History of Anomalous Microwave Emission (AME)

- 1996 (COBE) Kogut et al. found emission excess at 31 GHz
- 1997 Leitch et al. found *emission excess at 14.5 and 32 GHz*

- 1998 Draine and Lazarian: *electric dipole emission from spinning ultrasmall grains*
- 1999 Draine and Lazarian: *magnetic dipole emission from iron nanoparticles*





A lot of great work, galactic and extragalactic studies, many different objects support spinning dust emission

- Instruments used to study spinning dust: OVRO, COBE-DMR, Tenerife, Saskatoon, Green Bank,VCA, CBI WMAP etc (A de Oliveira Costa, D Finkbeiner)
- Measured in diffuse and molecular gas, HII regions etc (Dickinson+13, Tibbs + 13)
- Measured in extragalactic environments (e.g. Murphy et al. 2010, Scaife et al. 2010, Hensley et al. 2014)
- WMAP, Planck found convincing evidence of spinning dust
- Discussed as means of study ISM and dust properties (Tibbs et al.)

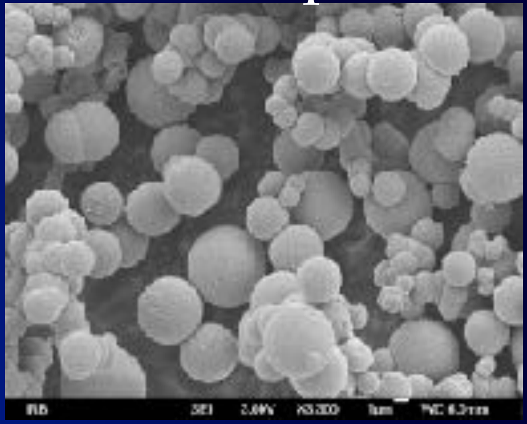
Possible Origins of the AME

1. Rotational emission (i.e., spinning dust emission):
    1. spinning PAH molecules (Draine & Lazarian 1998)
    2. spinning silicate nanoparticles (Hoang et al. 2016)
    3. spinning iron nanoparticles (Hoang & Lazarian 2016)
2. Magnetic Dipole Emission from iron particles

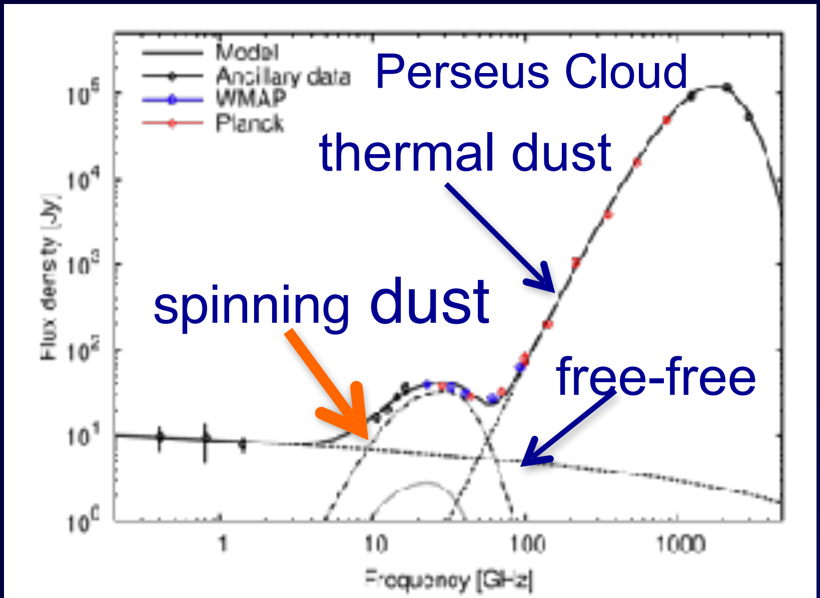
PAH molecule

Nanosilicate

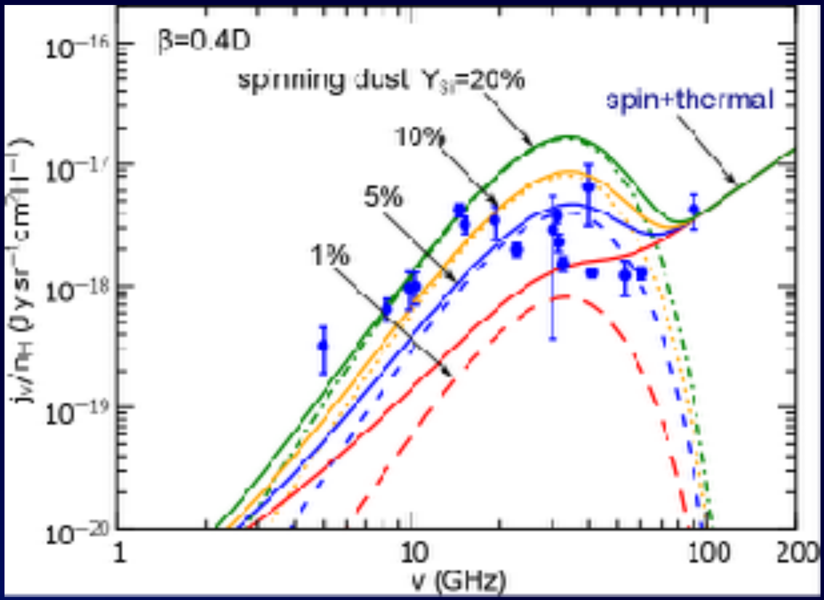
Iron Nanoparticle



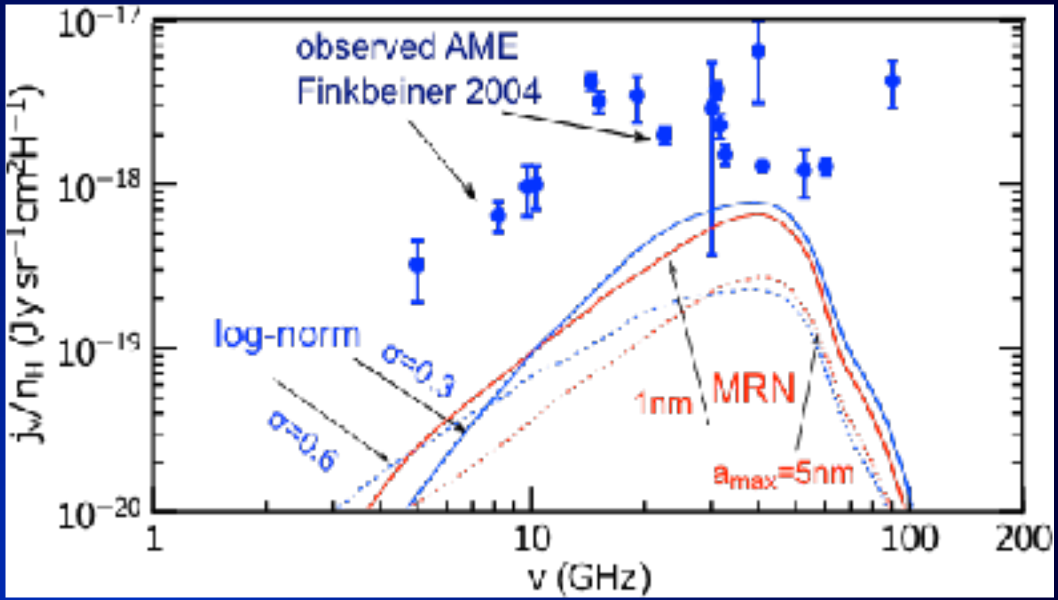
spinning PAH (Planck collaboration 2011)



spinning nanosilicates (Hoang et al. 2016)



spinning iron nanoparticle (Hoang & Lazarian 2016)

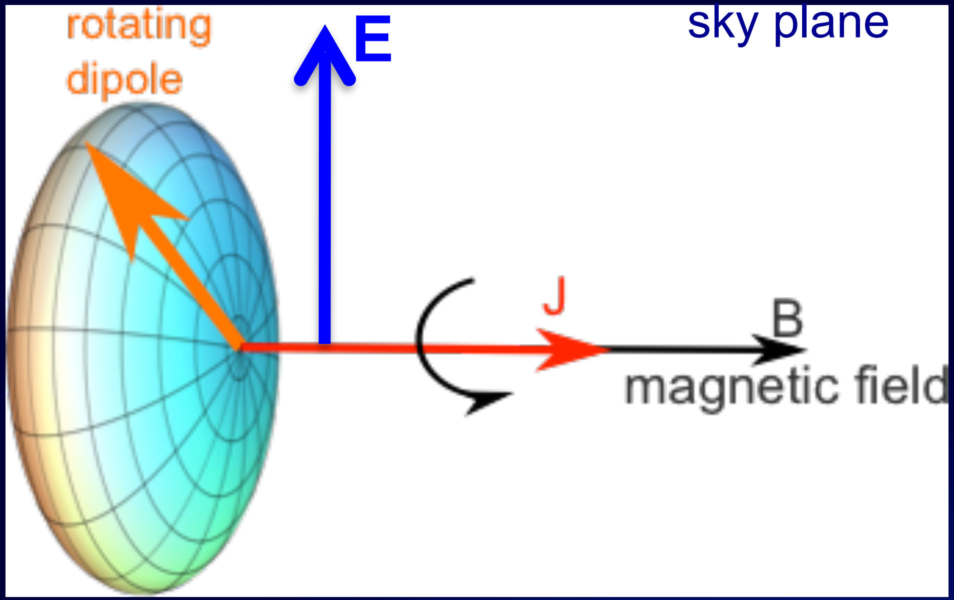


Polarization of the Anomalous Microwave Emission

Unknown carrier of the AME results in uncertainty in the expected polarization of the AME!

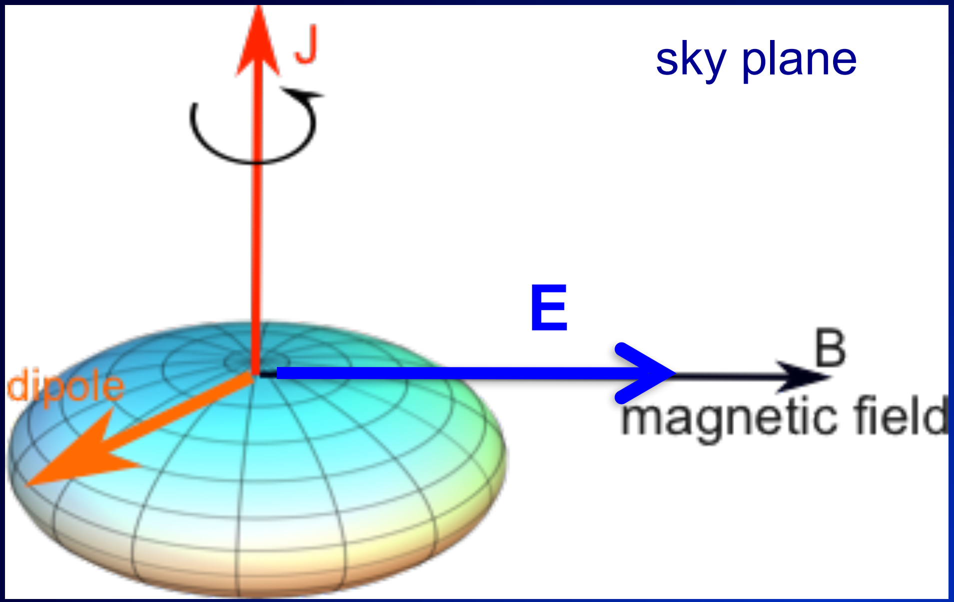
PAH

Physics: nanoparticles must be aligned to produce polarization



E perpendicular to B

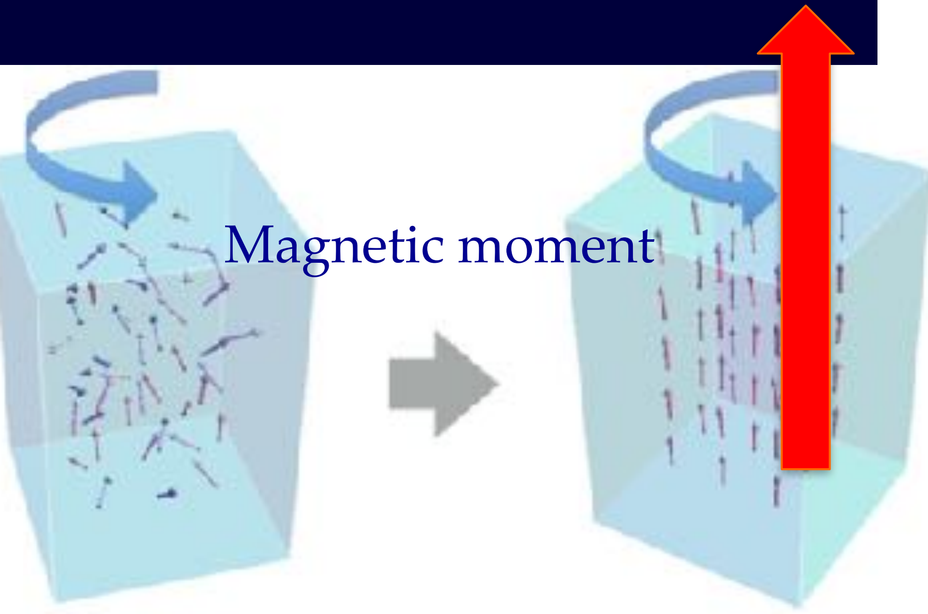
100% right polarization

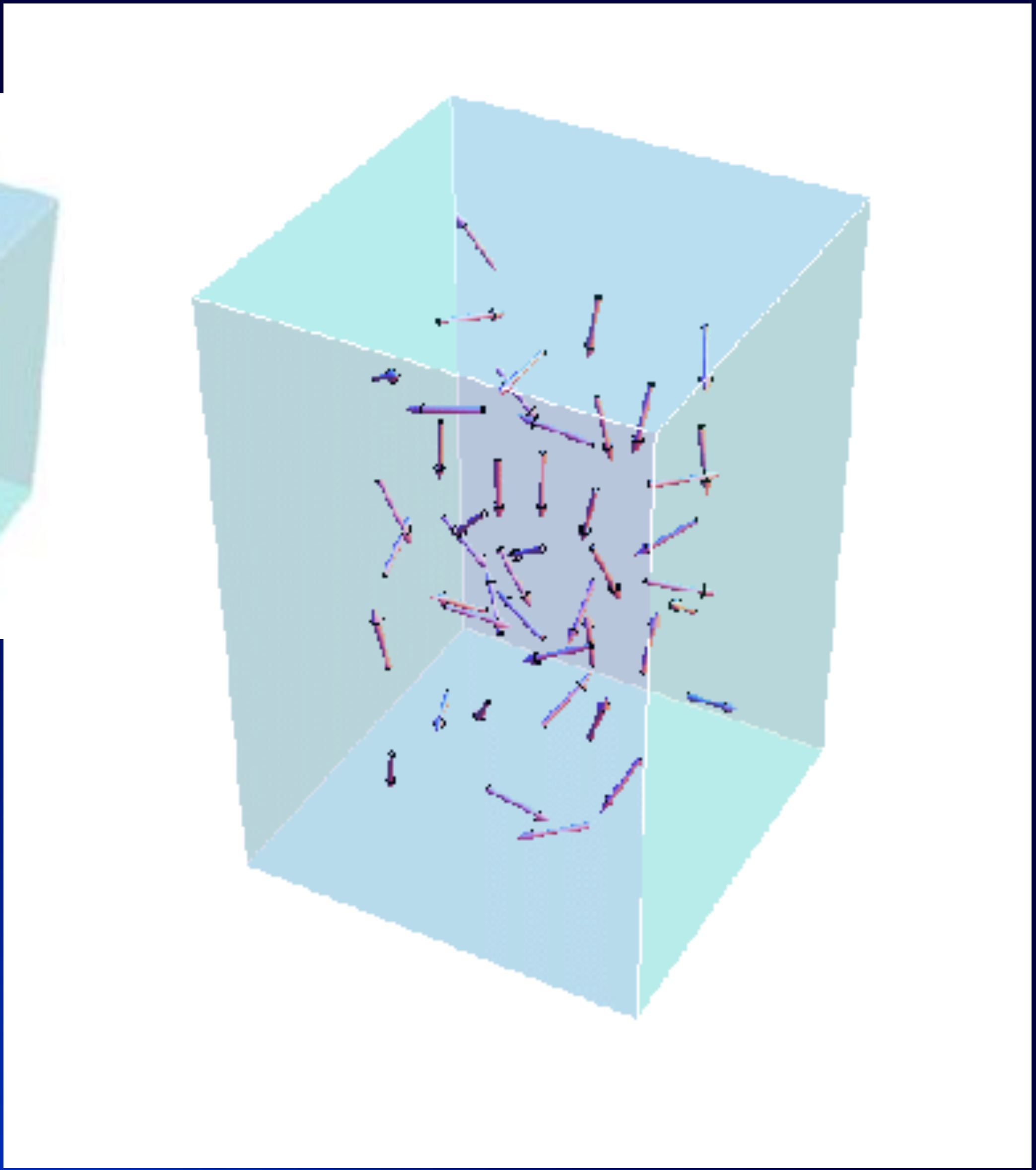


E parallel to B

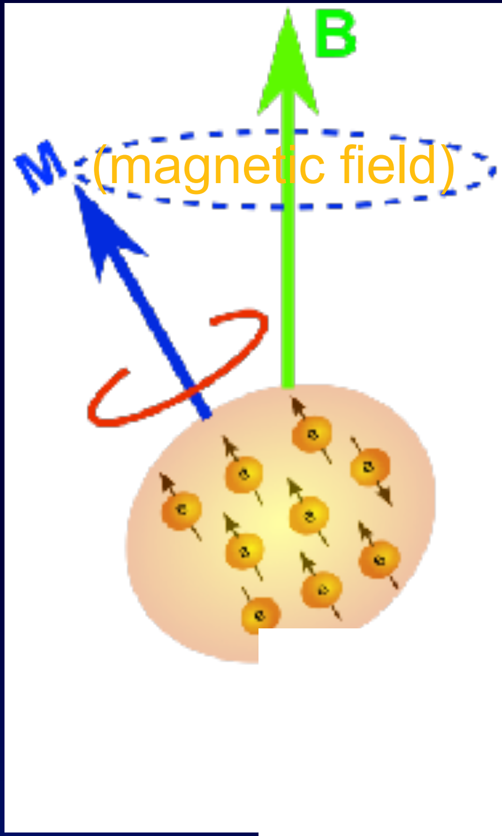
100% wrong polarization

Grains get magnetic moment via spinning: Barnett effect

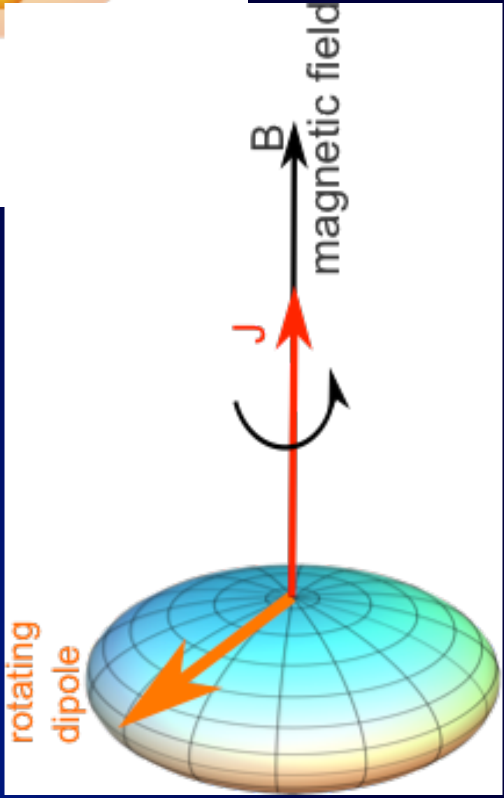




The grain coupled to B-field via Larmor precession



Small grains aligned by Paramagnetic Relaxation

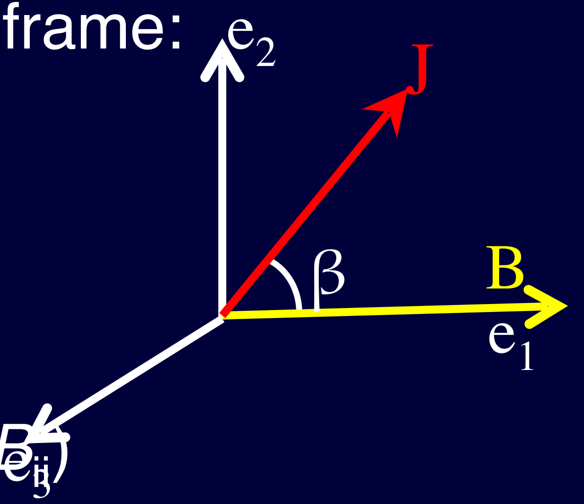


Calculations of paramagnetic alignment

- Evolution of angular momentum **J** in the lab frame:

$$dJ_i = A_i dt + \sqrt{B_{ii}} dq_i, \ i = 1-3$$

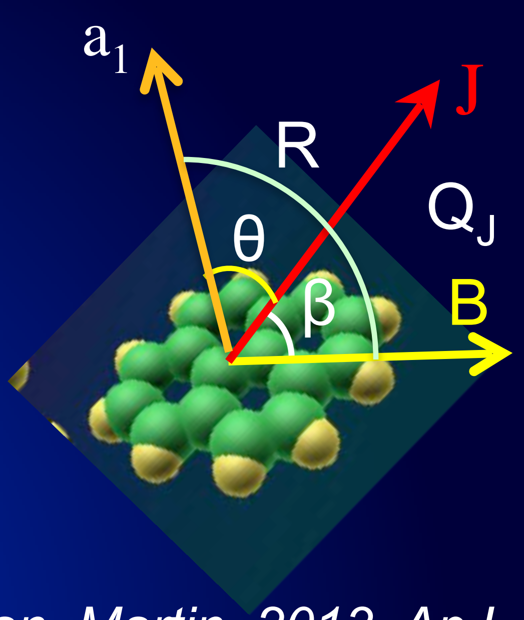
$$A_i = \sum_k \left\langle \frac{\Delta J_i^k}{\Delta t} \right\rangle, B_{ii} = \sum_k \left\langle \frac{(\Delta J_i^k)^2}{\Delta t} \right\rangle, \langle dq^2 \rangle = dt$$



- Damping and excitation coefficients (A_i and B_{ii})
  - paramagnetic relaxation
  - grain-neutral collision
  - grain-ion collisions
  - infrared emission
  - plasma drag by passing ions
- Degrees of alignment:

$Q_J(J,B) = \langle G_J \rangle$, $Q_X(a_1,J) = \langle G_X \rangle$, $R = \langle G_X * G_J \rangle$

with $G_J = [3\cos^2\beta - 1]/2$, $G_X = [3\cos^2\theta - 1]/2$

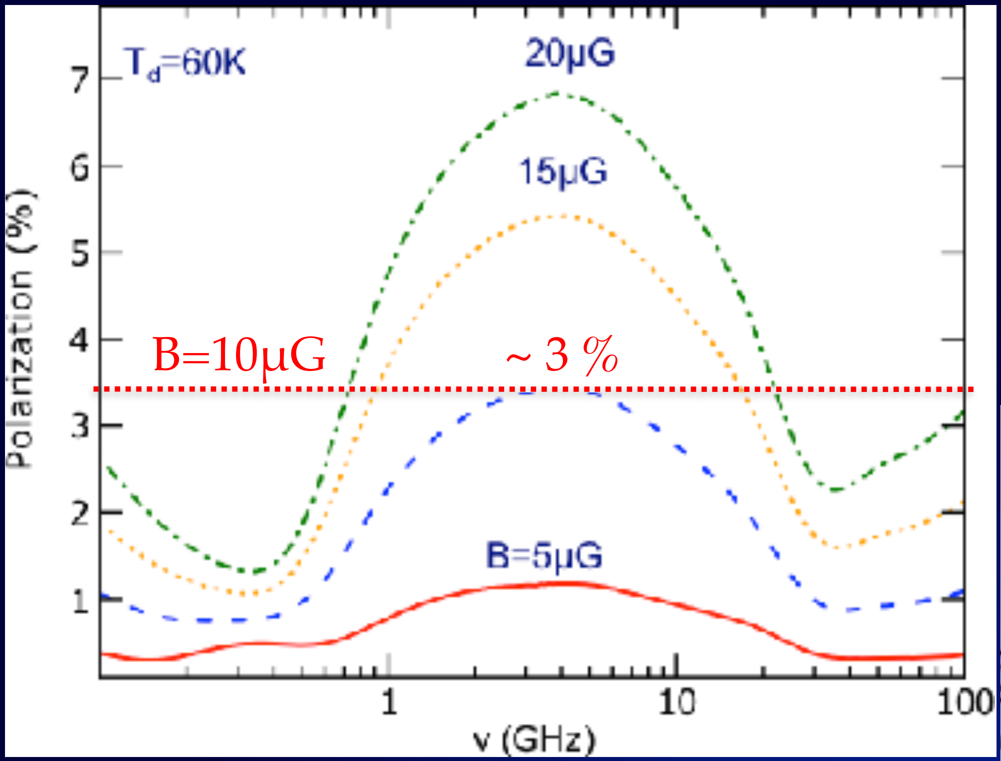


- Polarization Level ~ R, Q_X, Q_J

Hoang, Lazarian, Martin, 2013, ApJ

Polarization of spinning PAHs

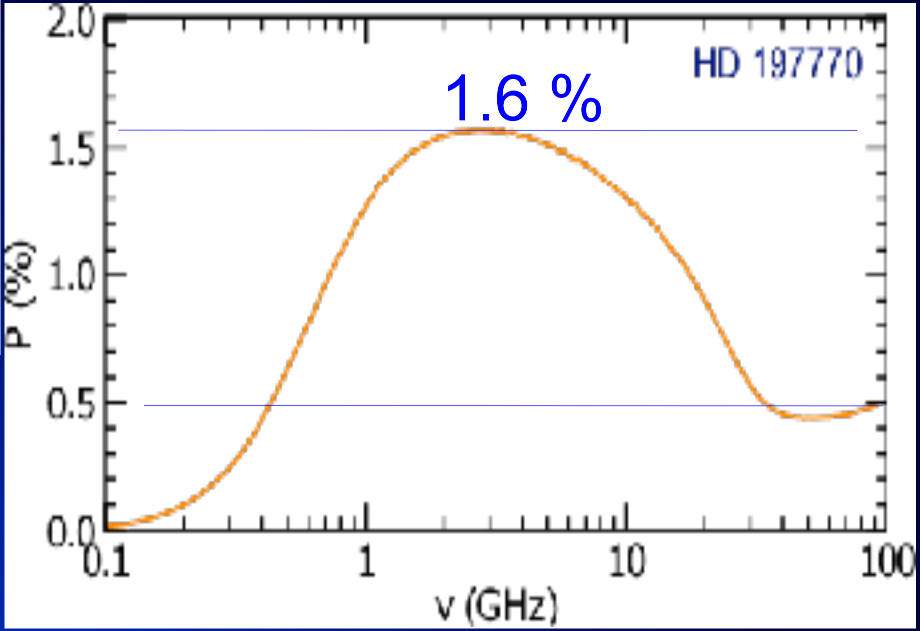
Theory: maximum polarization ~ 3 %



Polarization:

$P \sim Q_J$

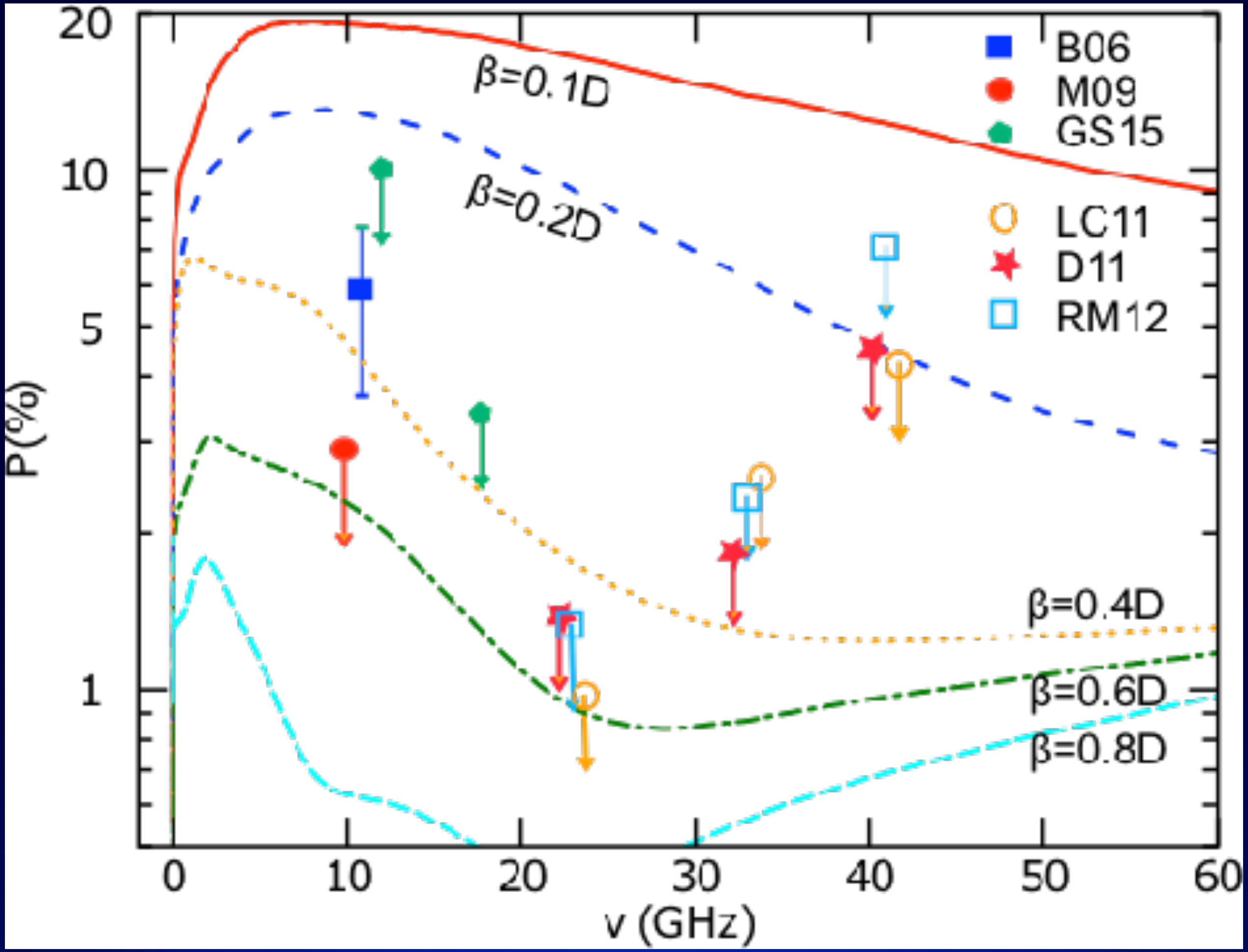
Inverse Modeling using UV pol bump of starlight



Hoang and Lazarian 2015

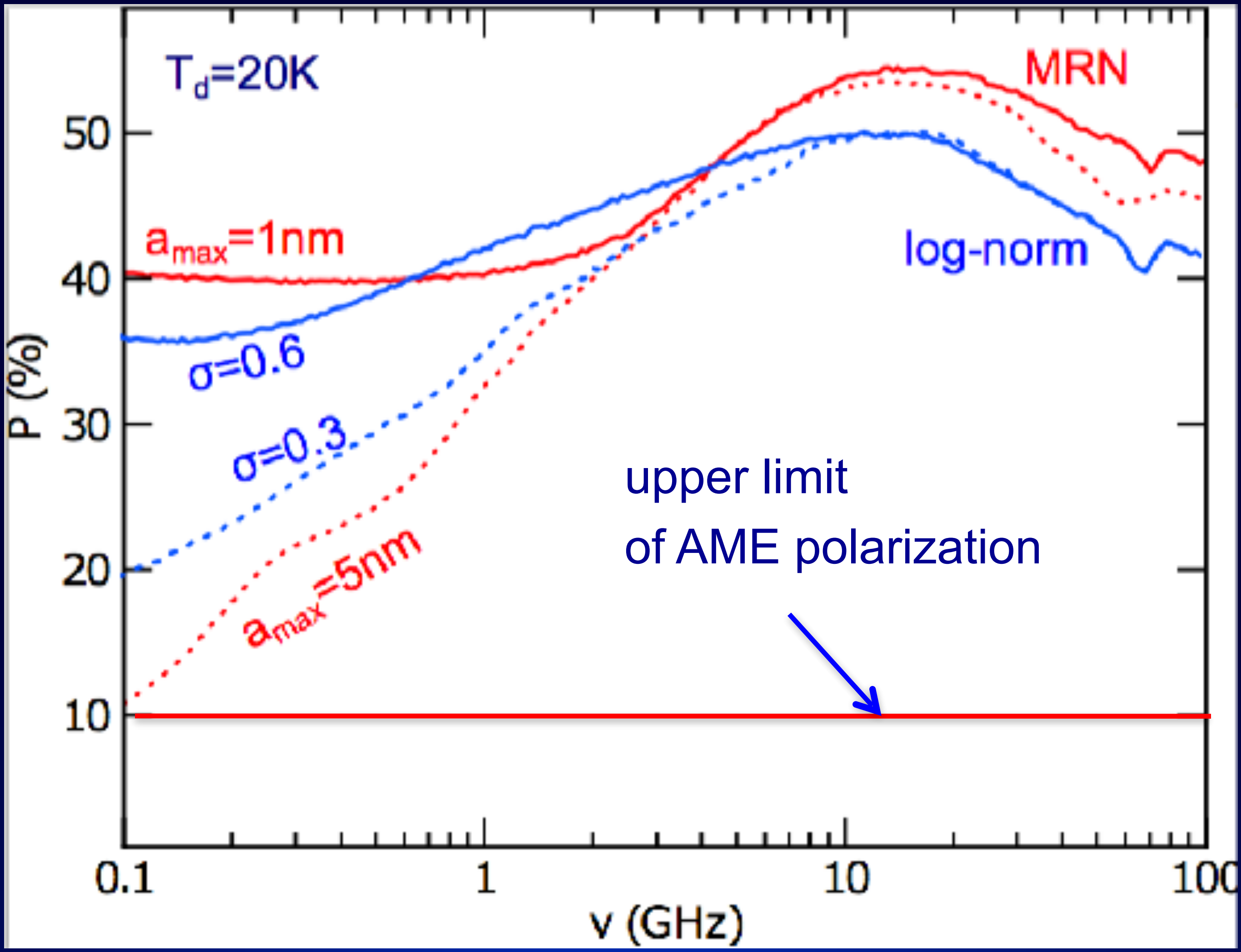
Hoang, Lazarian, Martin, 2013, ApJ

Spinning silicate nanoparticles



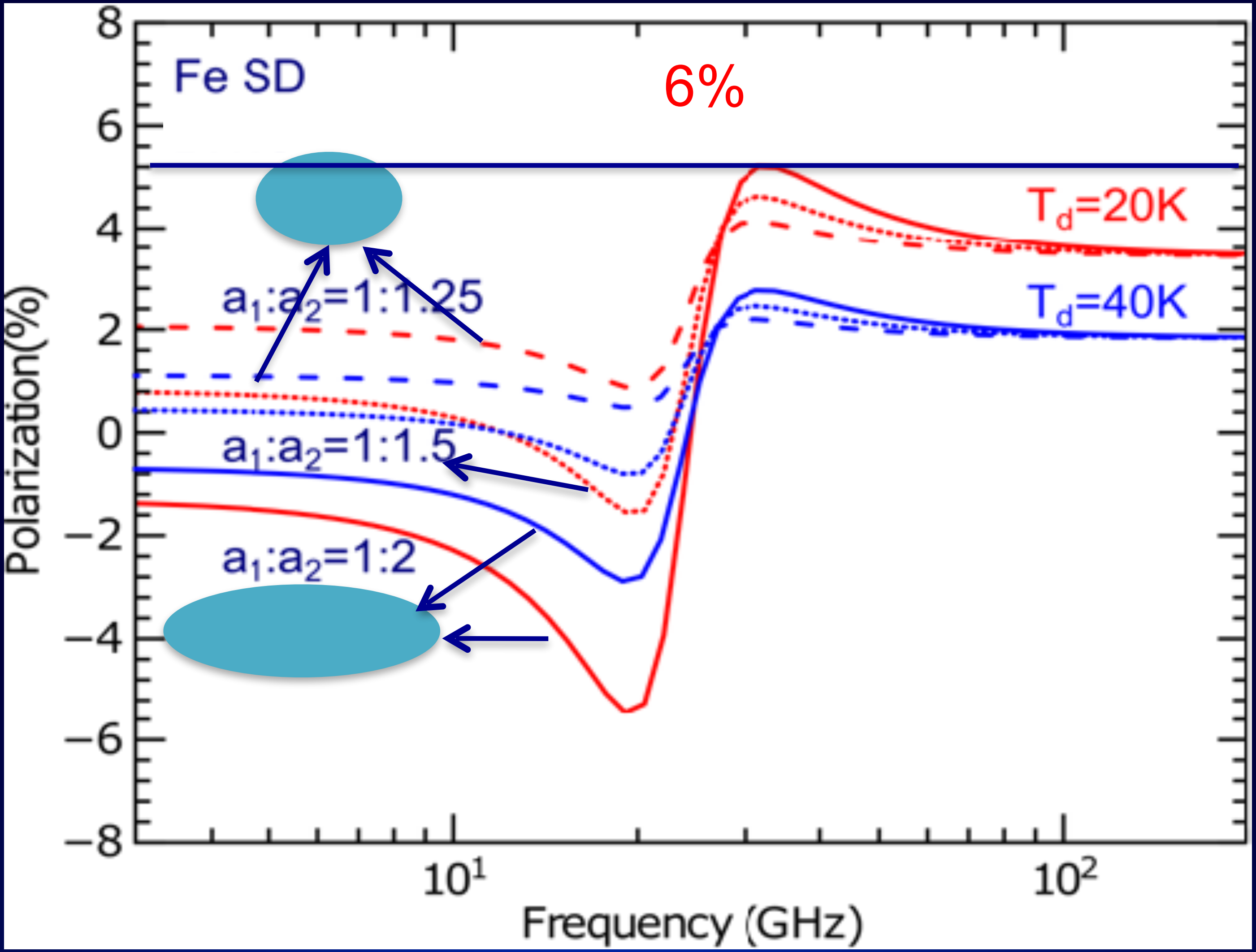
Hoang, Vinh, & Lan 2016, ApJ, 824,18

Spinning iron nanoparticles



Hoang & Lazarian 2016, ApJ, 821,91

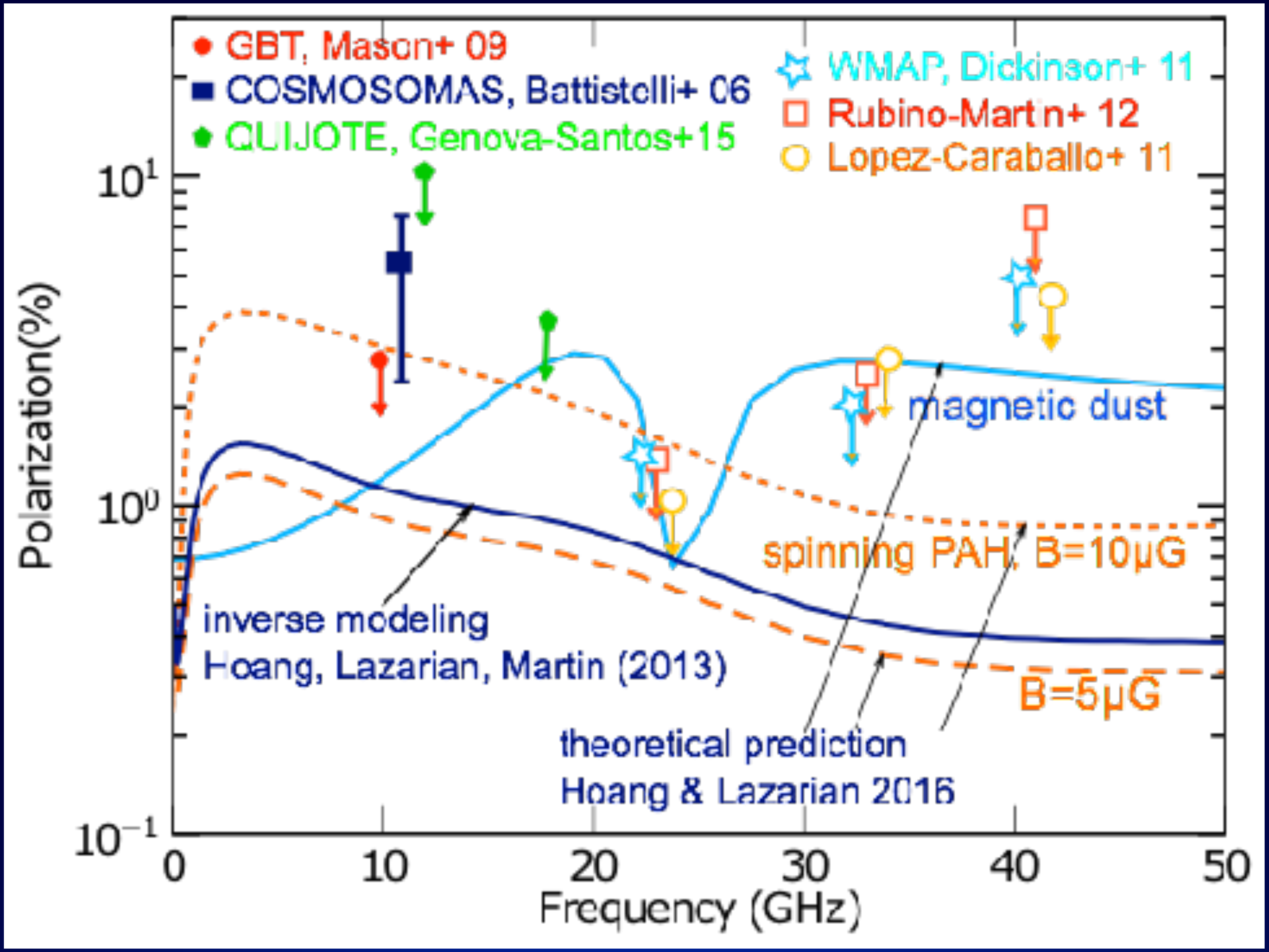
Magnetic dipole emission is <5%



Polarization by ensemble of iron nanoparticles with a power law size distribution

Hoang & Lazarian 2016, ApJ, 821, 91

Theory vs. Observations



ratio by more than 1σ. For sensitive CMB experiments, omitting in the foreground modelling a 1% polarized spinning dust component may induce a non-negligible bias in the estimated tensor-to-scalar ratio.

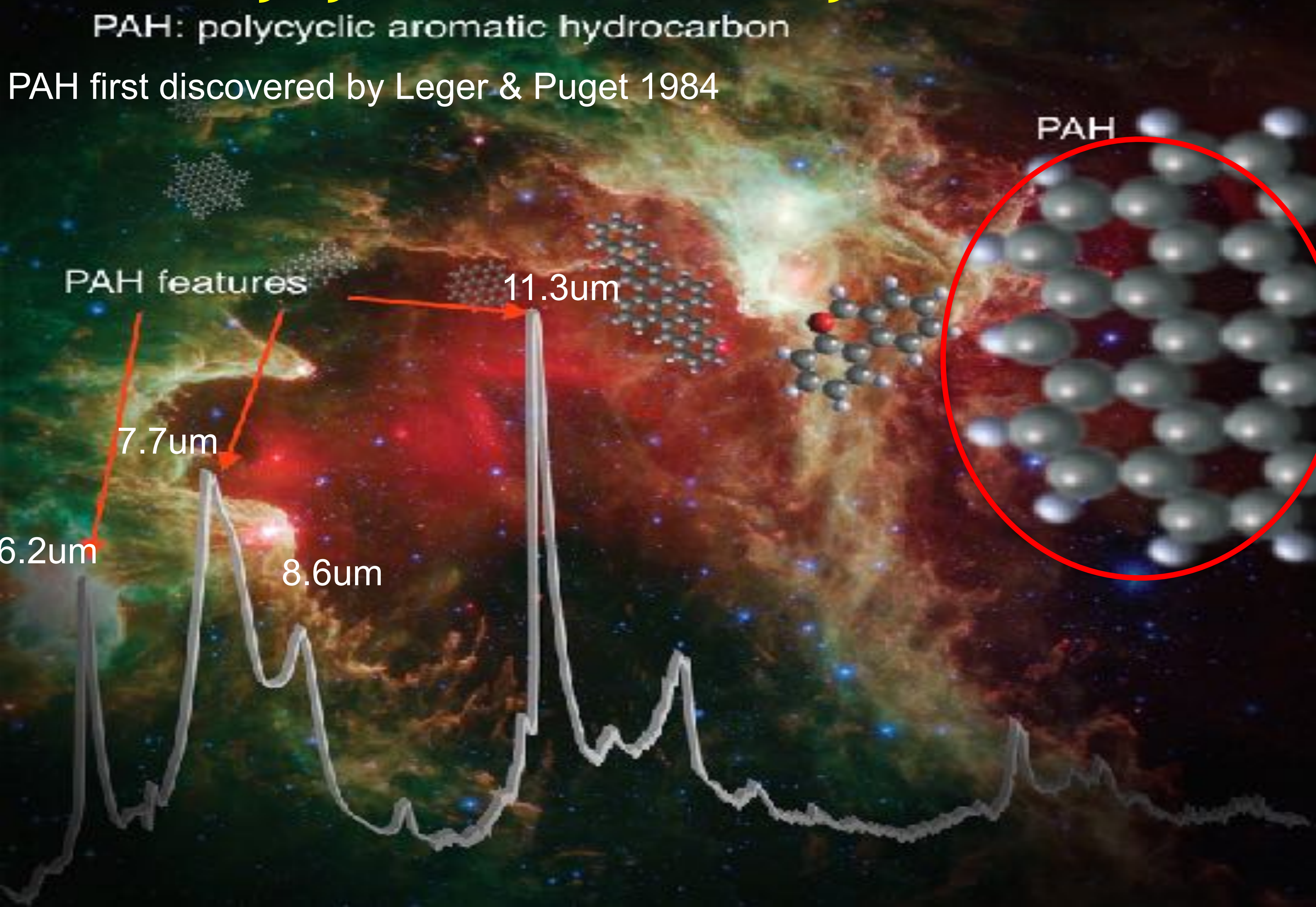
Simulations by Dickinson's

Summary and Future

- B-mode experiments need accurate CMB foreground models.
- The AME is well constrained, but its exact carrier is still mysterious. New population of silicate/iron nanoparticles is perhaps present in the ISM.
- The polarization of AME is uncertain, likely low, but more works need to be done to enable reliable B-mode data analysis
- Future ALMA Band 1 (35-51 GHz), LiteBIRD, are particular useful for the AME polarization study.
- Future SKA mid-frequency (50 MHz-14 GHz) will be of great importance, especially third-phase high-frequency (15-30 GHz).

Thank You Very Much!

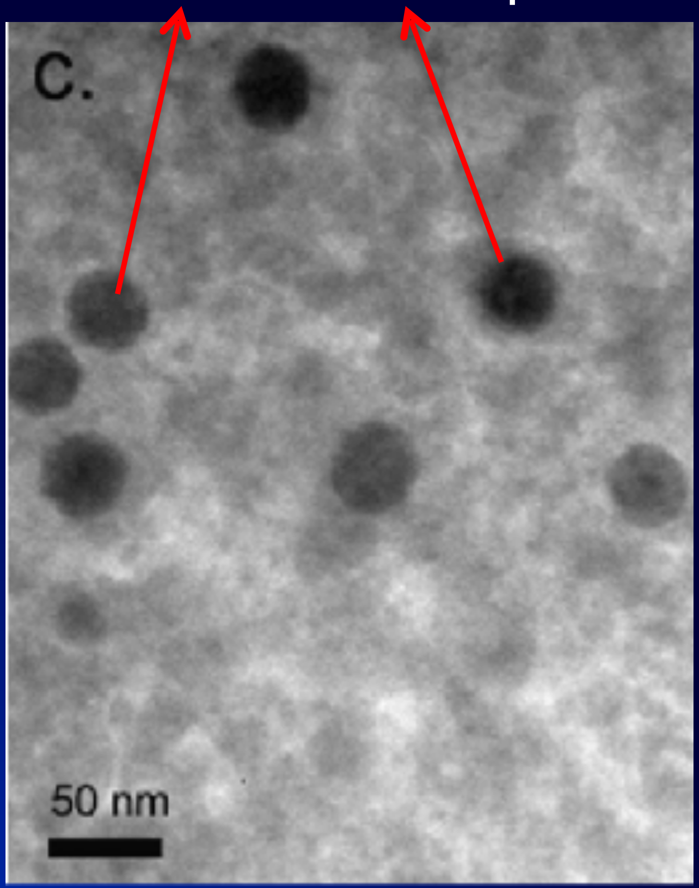
Polycyclic Aromatic Hydrocarbon



Microwave Emission from Magnetic Nanoparticles

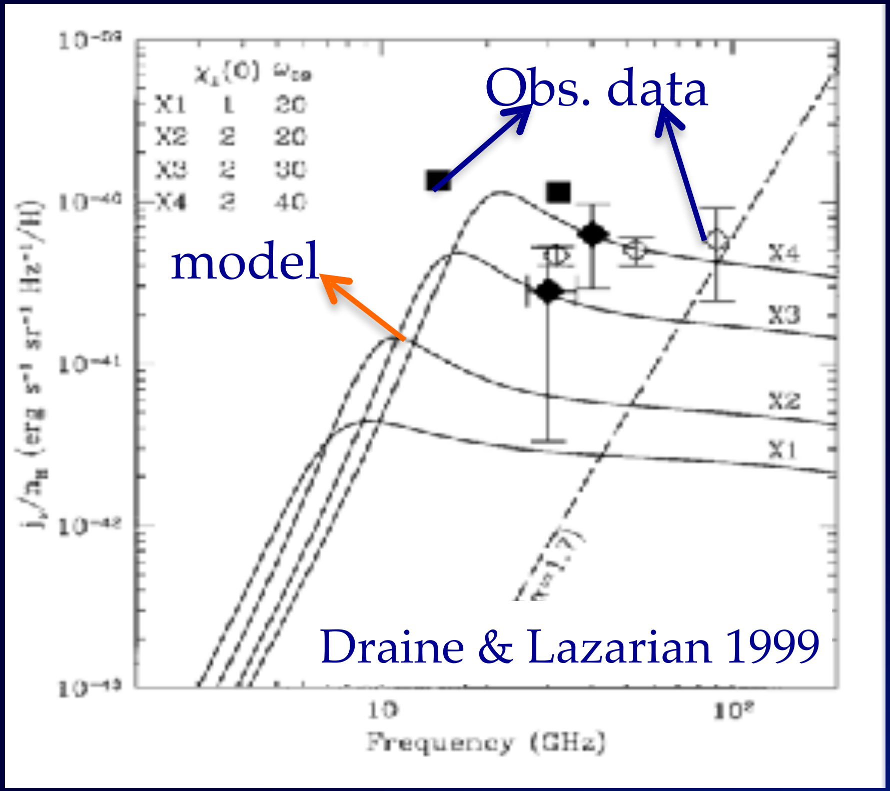
free-flying iron nanoparticles

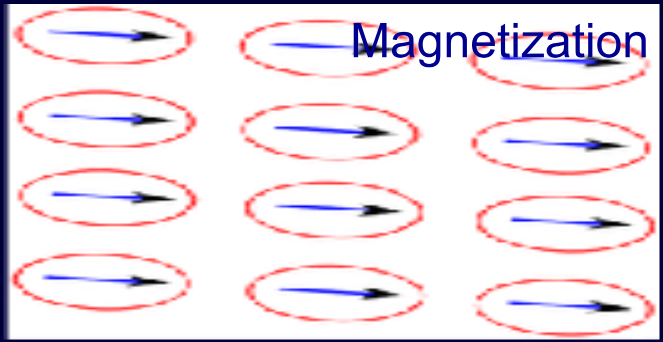
embedded iron nanoparticle



Iron in interplanetary dust (Noble + 2007)

Magnetic dipole emission from iron nanoparticle





Draine & Hensley 2013 revisited the model