Magnetic Dipole Emission from Interstellar Grains

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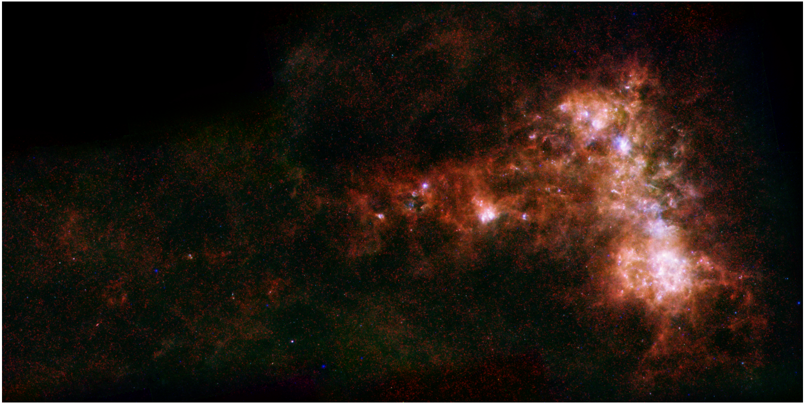
AME Workshop
July 2, 2012

Outline

- Draine, B. T. and Hensley, B. 2012a "Magnetic Nanoparticles in the Interstellar Medium: Emission Spectrum and Polarization", Submitted to ApJ, arXiv:1205.7021v2
- Draine, B. T. and Hensley, B. 2012b "The Submm and mm Excess of the SMC: Magnetic Dipole Emission from Magnetic Nanoparticles?" Submitted to ApJ, arXiv:1205.6810v1

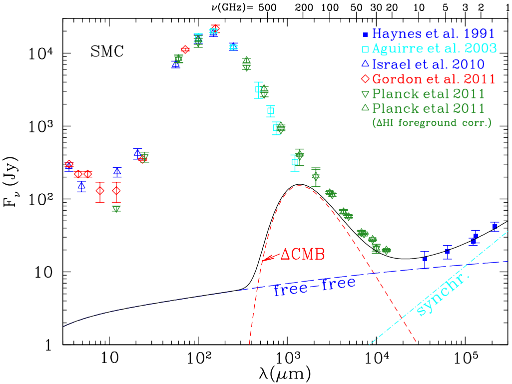
The SMC

- The SMC has been studied from the NIR to cm wavelengths, including recent mm and sub-mm measurements by Planck



ESA/NASA/JPL-Caltech/STScI

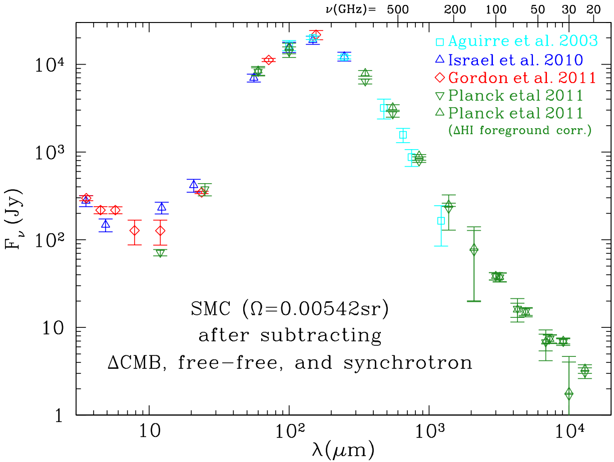
SMC SED



Draine and Hensley 2012b

- We decompose into emission from the CMB, free-free, and synchrotron

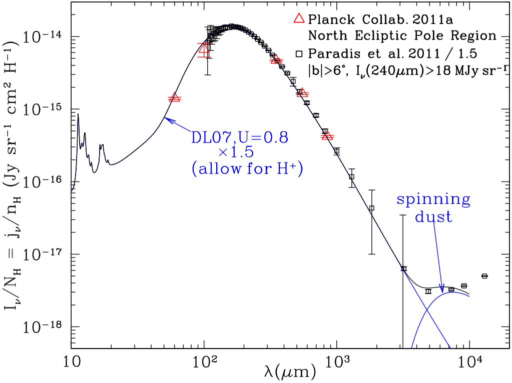
SMC SED



Draine and Hensley 2012b

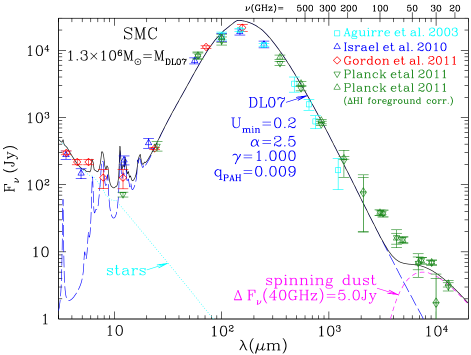
Fitting Dust Models

Milky Way in the sub-mm and mm



- Draine and Li 2007 model works well for our Galaxy at sub-mm and mm wavelengths

Fitting Dust Models



Draine and Hensley 2012b

- Best fit Draine and Li 2007 model with a spinning dust component
- Insufficient 60 - 300 GHz emission, violates abundance constraints

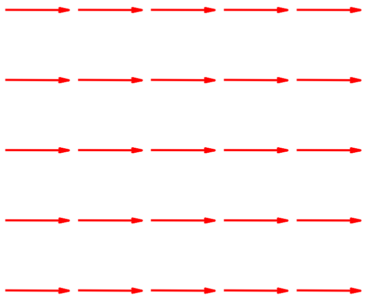
Fitting Dust Models

- Models that respect abundance constraints produce even poorer fits
- Likewise, Plank Collaboration 2011 was unable to fit the emission with cold dust or spinning dust alone

Magnetic Materials

- **Ferromagnetic** materials, such as metallic Fe, have all unpaired spins aligned along a preferred axis
- **Ferrimagnetic** materials, such as magnetite and maghemite, are made up of two spin lattices with opposing but unequal magnetic moments

Ferromagnetic spin lattice



Magnetic Materials

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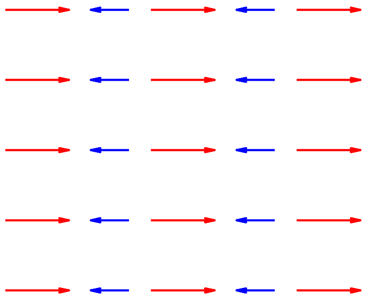
Ferrimagnetic spin lattice

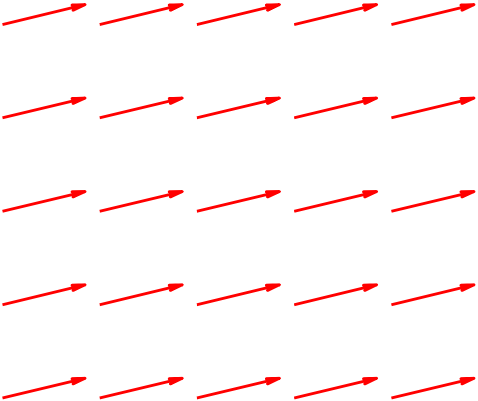


Magnetic Dipole Emission

- Preferred direction of magnetization implies a minimum energy state with all unpaired spins aligned along preferred direction
- Thermal excitations can move the spins away from this state
- Then magnetization vector precesses about the preferred direction and produces radiation

Magnetic Dipole Emission

Response to an excitation



Modeling the Emission

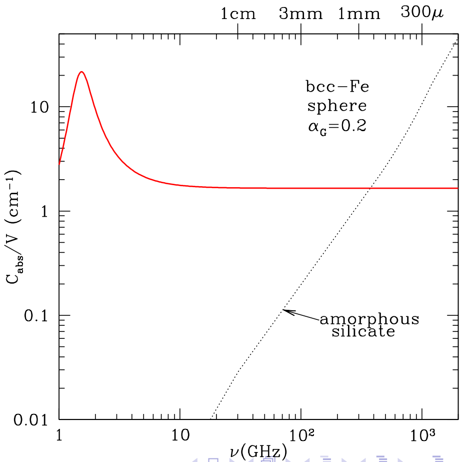
- Gilbert Equation

$$\frac{d\vec{\mathrm{M}}}{dt} = \gamma\vec{\mathrm{M}} \times \vec{\mathrm{H}}_T + \alpha_{\mathrm{G}}\frac{\vec{\mathrm{M}}}{|\vec{\mathrm{M}}|} \times \frac{d\vec{\mathrm{M}}}{dt}$$

- First term describes precession of the magnetization about the fictitious "effective field" $\vec{\mathrm{H}}_T$
- Second term describes the relaxation of the magnetization toward minimum energy solution (i.e. $\vec{\mathrm{M}}$ and $\vec{\mathrm{H}}_T$ parallel)

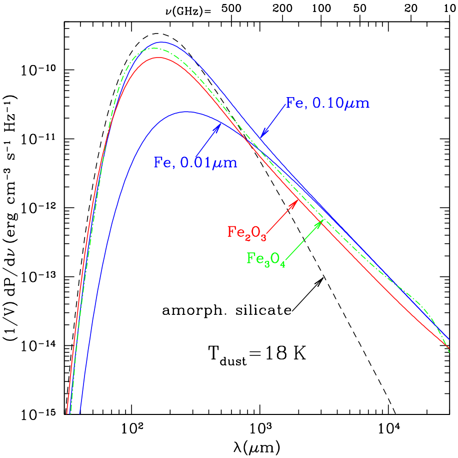
Absorption Cross-Sections

- Absorption cross-section per volume for metallic Fe spheres
- Sub-mm and mm absorption much stronger than amorphous silicate grains



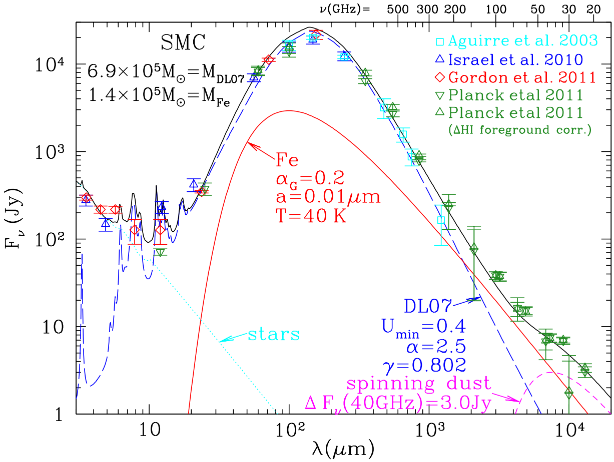
Emissivities

- 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 2012a

Fitting a Model with Magnetic Grains



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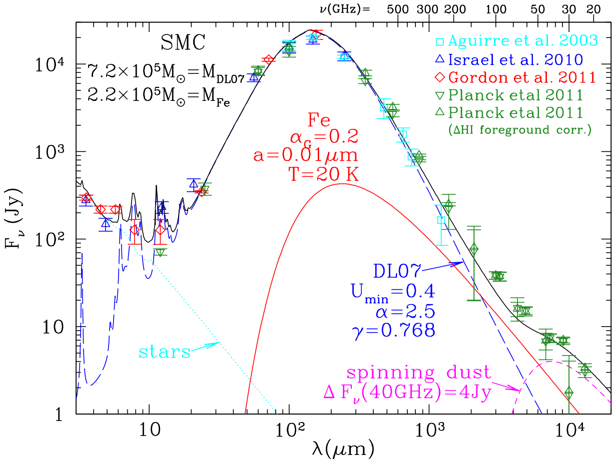
- Model with 40K Fe grains

Fitting a Model with Magnetic Grains



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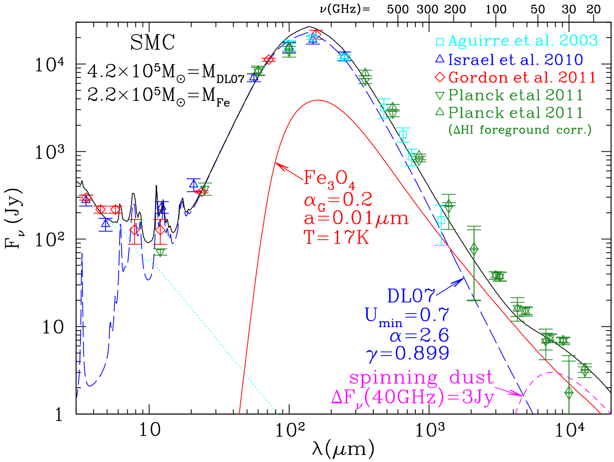
- Model with 20K Fe grains

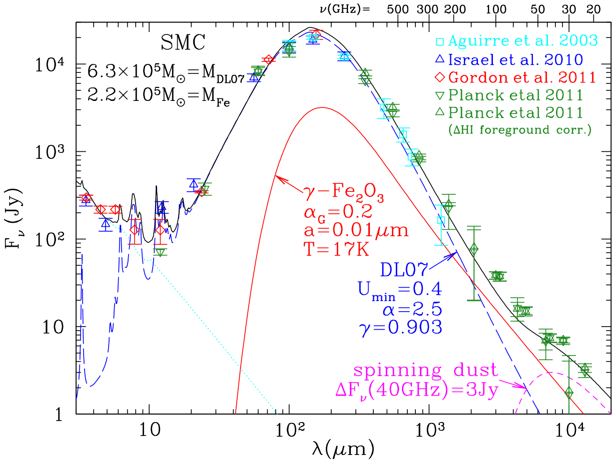
Fitting a Model with Magnetic Grains



Draine and Hensley 2012b

- Model with 17K magnetite grains

Fitting a Model with Magnetic Grains



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- Model with 17K maghemite grains

Fitting a Model with Magnetic Grains

- Models of the SMC emission can be constructed from any or all of these three materials assuming reasonable adundances

	Total Dust ($10^5 M_\odot$)	Magnetic Fe ($10^5 M_\odot$)	comment
Abundance limit	$\leq$**10.7**	$\leq$**2.3**	
Model 1: DL07 dust, $U_{\rm min} \geq 0.2$	13.	–	violates limit
Model 2: DL07 dust, $U_{\rm min} \geq 0.5$	9.7	–	very poor fit
Model 3: DL07 dust + 40 K Fe	8.3	1.4	OK
Model 4: DL07 dust + 20 K Fe	10.2	2.2	OK
Model 5: DL07 dust + 17 K γ-Fe_2O_3	9.4	2.2	OK
Model 6: DL07 dust + 17 K Fe_3O_4	7.2	2.2	OK

[a] Fe mass in magnetic material

[b] for $M_{\rm H} = 4.7 \times 10^8 M_\odot$ and $Z = 0.25 Z_\odot$

Polarization

- Polarization depends on whether grains are **free-fliers** or **inclusions** in larger grains

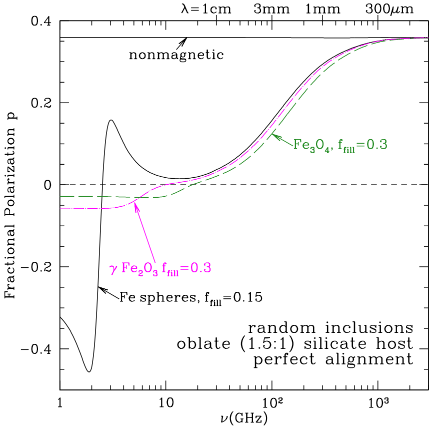
Free-Fliers

Inclusions

Polarization

- Predicted decrease in polarization from 500 to 50 GHz
- Possibly observable effect, but many contributing sources complicate interpretation

Draine and Hensley 2012a



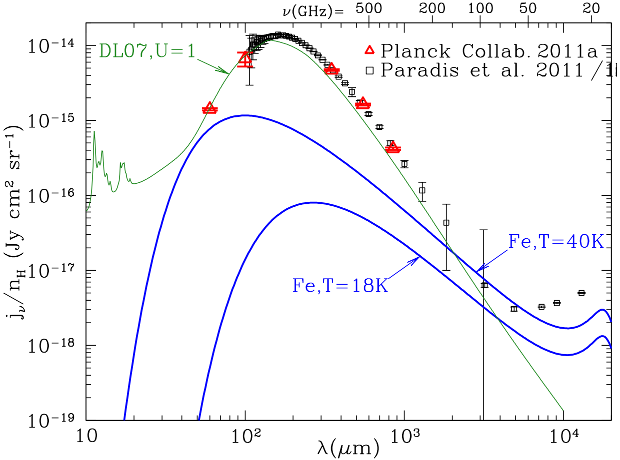
Possible Sources of Fe Grains

- Fe inclusions observed in lunar soil grains and interplanetary dust particles
- Low metallicity AGB stars with excess IR emission attributed to metallic Fe
- Grains in ISM result from balance between formation and destruction
- Sputtering leaves grain surfaces enriched in heavy elements, like Fe
- Fe-rich Supernova ejecta

Summary

- A new grain component is likely present in ISM
- Ferro/ferrimagnetic materials in the ISM will produce magnetic dipole radiation
- This emission can explain sub-mm excess in SMC

Magnetic Grains in the Milky Way



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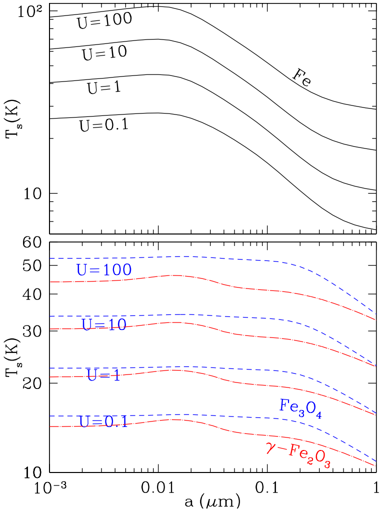
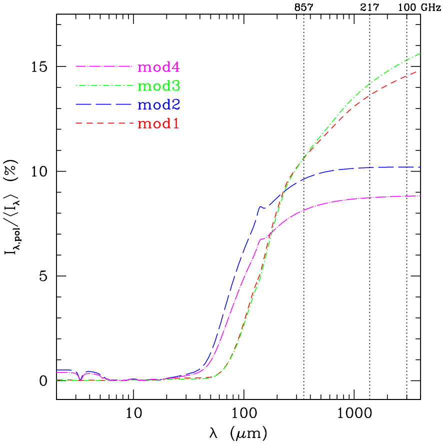
Magnetic Grain Temperatures



Draine and Hensley 2012a

Polarization of Dust Emission

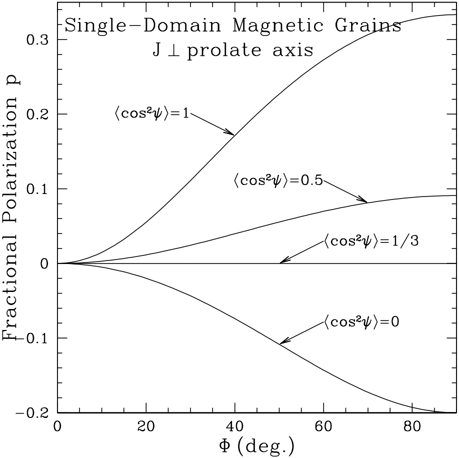
- If carbonaceous grains are relatively unpolarized, then the polarization fraction is expected to increase at longer wavelengths (Models 1 and 3)
- The presence of two grain populations would complicate the interpretation of polarization data at long wavelengths



Draine and Fraisse 2009

Polarization of Free-flying Grains

- The polarization fraction will depend upon the degree of alignment of the angular momentum vector with the magnetic field



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