Towards a Unified Model of Polarized Emission and Extinction from Interstellar Dust

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The Inverse Problem

- Bohren and Huffman: Determining the composition of interstellar dust is like describing a dragon based on its tracks

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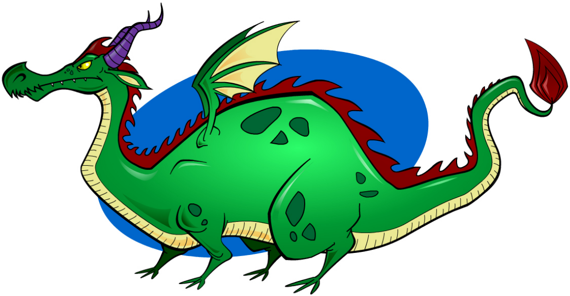
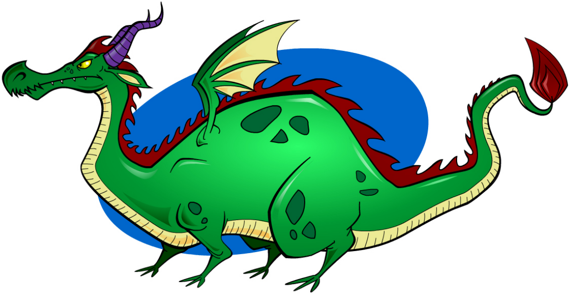


Laura32

The Payoff

- Dragons are interesting creatures in their own right...



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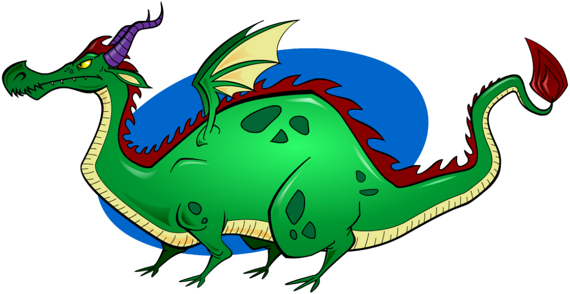
The Payoff

- Dragons are interesting creatures in their own right...
- ... but they also like to hide treasure

B-modes!

Dark Matter Annihilation!

High-z Galaxies!



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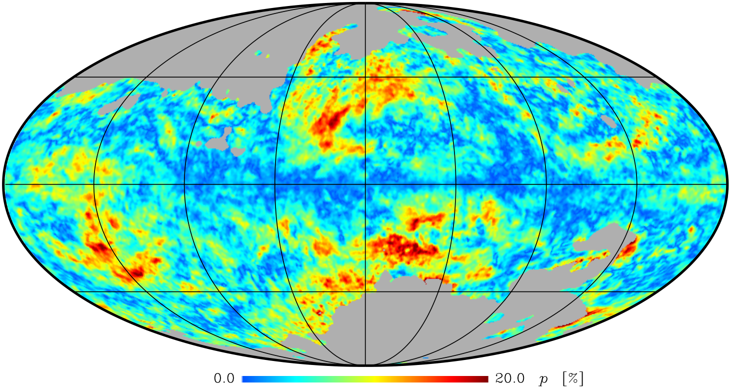
Dust Modeling in the *Planck* Era

- *Planck* polarization maps will be an unprecedented window into the polarization properties of grains



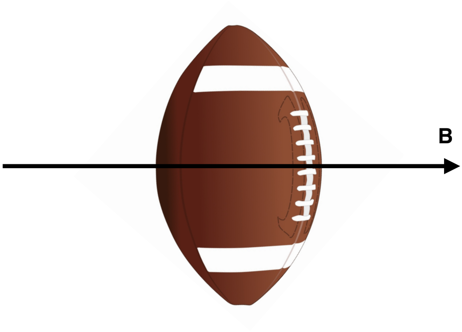
Planck 2014

Dust Modeling in the *Planck* Era

- Excellent synergy with (3D!) extinction maps, WISE maps, starlight polarization...
- Need a **model** to apply to the data

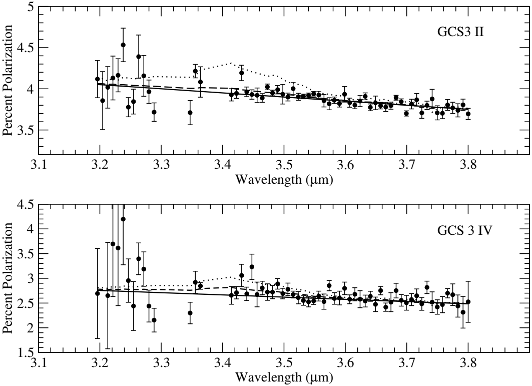
Polarization Primer

- 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

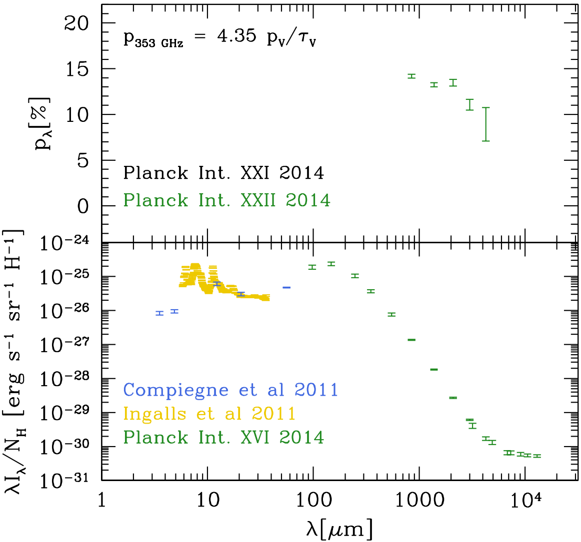


Chiar et al 2006

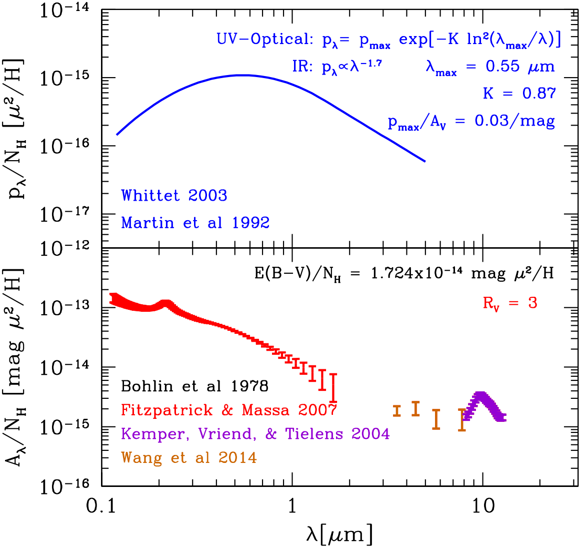
Modeling Dust Materials

- Determine optical properties of grain materials
- Calculate cross-sections and temperatures for **aspherical** particles in standard radiation field
- Determine size distribution and alignment efficiency capable of reproducing observed dust properties

Emission Constraints

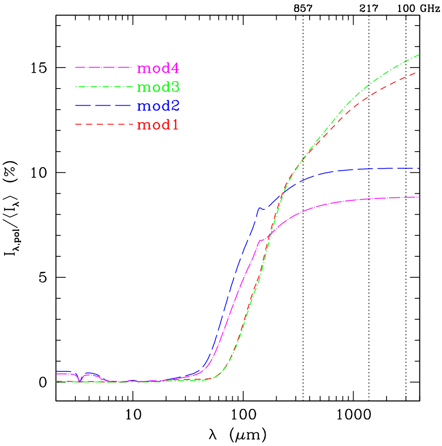


Extinction Constraints



Draine and Fraisse 2009

- Used Draine and Li dust materials to make predictions for polarized emission in the *Planck* bands
- Model predicts too much extinction per unit emission (Planck Int XXIX 2014)



Draine and Fraisse 2009

A New Model

- Fit to extinction (total and polarized), emission (total and polarized), and abundance constraints
- Match observed relation between emission and extinction

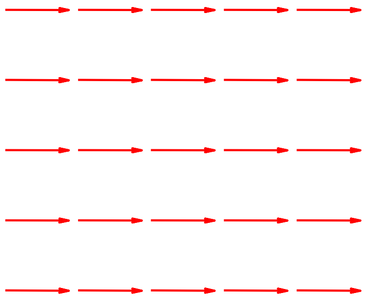
Polarized Dust Emission

- Models with silicate and carbonaceous grains alone have difficulty reproducing the observed decline in the polarization fraction with increasing wavelength
- A new ingredient– magnetic nanoparticles

Magnetic Materials

- **Ferromagnetic** materials, such as metallic Fe, have all unpaired spins aligned along a preferred axis
- Preferred direction of magnetization implies a minimum energy state with all unpaired spins aligned along preferred direction
- **Ferrimagnetic** grains such as Fe_3O_4 and γ-Fe_2O_3 are also viable

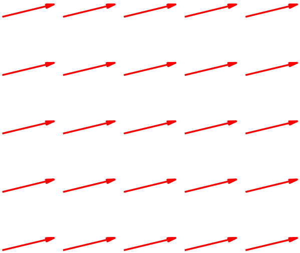
Ferromagnetic spin lattice



Magnetic Dipole Emission

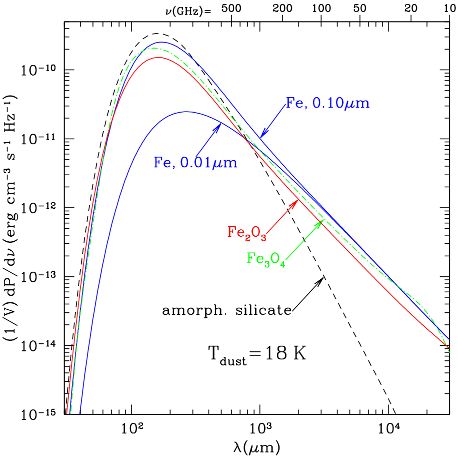
- Thermal fluctuations can move the spins away from this state
- Then magnetization vector precesses about the preferred direction and produces radiation

Response to a fluctuation



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 2013

Polarization

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

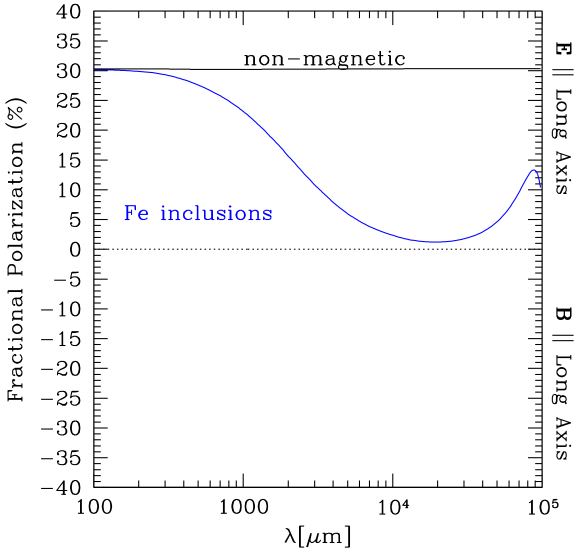
Free-Fliers

Inclusions

Inclusions

Of course, interstellar grains are nonspherical...

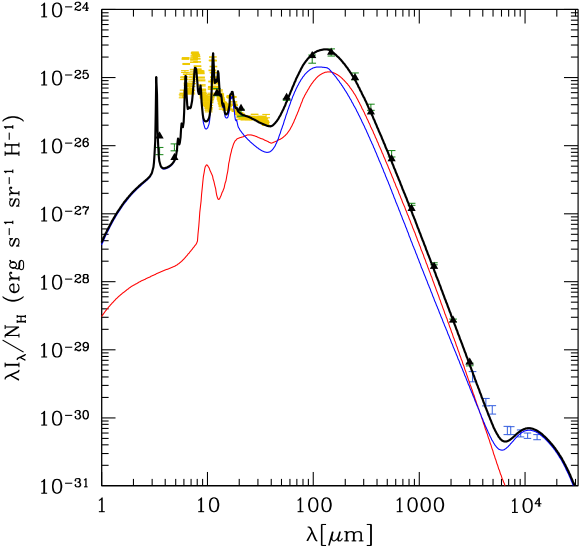
Polarization



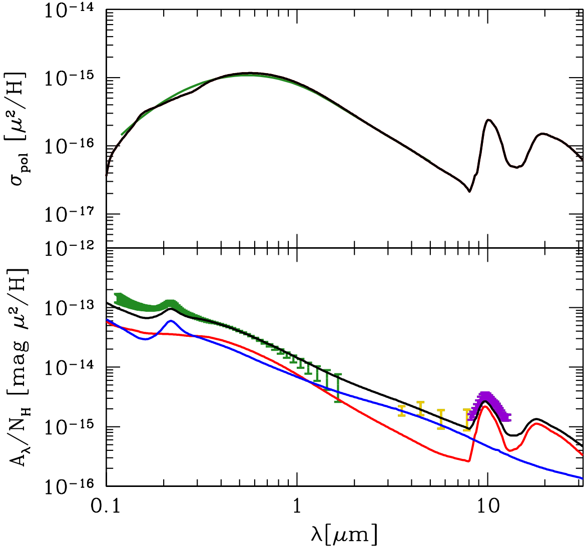
Example

- 1.6:1 spheroidal silicate grains with 5% iron nanoparticles by volume as inclusions
- Spherical carbonaceous grains
- PAHs

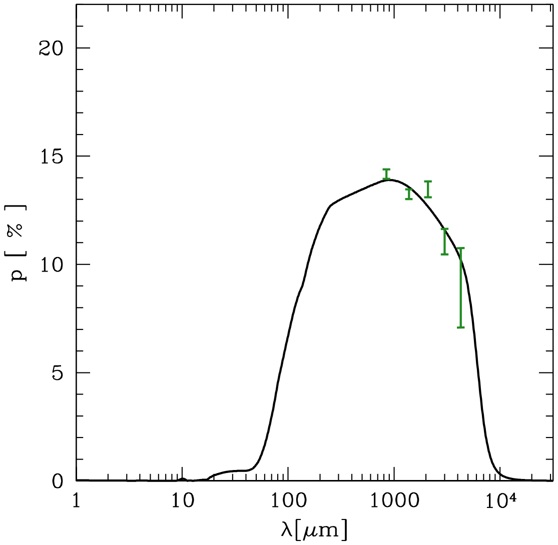
Emission


10^{-24}
10^{-25}
10^{-26}
10^{-27}
10^{-28}
10^{-29}
10^{-30}
10^{-31}
$\lambda I_\lambda / N_H$ (erg s^{-1} sr^{-1} H^{-1})
1
10
100
1000
10^4
$\lambda[\mu m]$

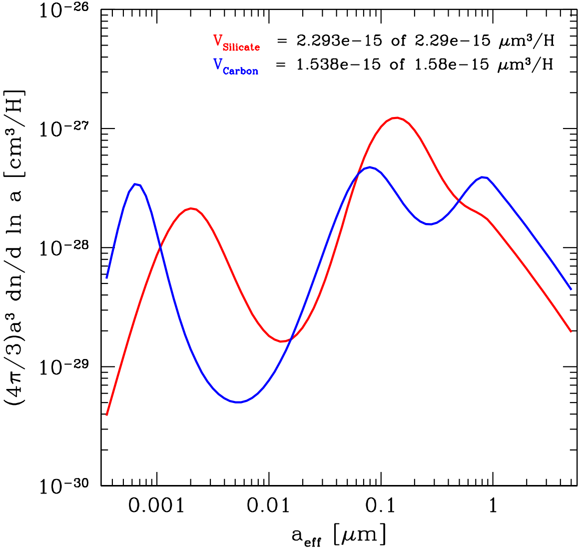
Extinction


10^{-14}
10^{-15}
10^{-16}
10^{-17}
σ_{pol} [μ^2/H]
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{-16}
A_λ/N_H [mag μ^2/H]
0.1
1
10
$\lambda[\mu m]$

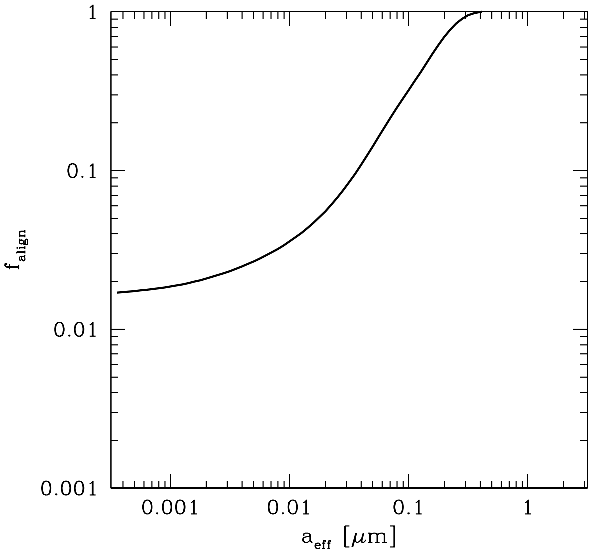
Polarized Emission



Size Distribution



Alignment



Summary

- Inclusion of iron grains allows us to match the frequency-dependence of the polarized emission
- We alleviate the tension between emission and extinction in the Draine and Li 2007 model by making silicates more emissive at long wavelengths
- Library of optical properties and fitting tools allow us to fit the dust properties of any region with these new models

Next Steps

- Apply models to specific regions
- Relate spatial variations in extinction, polarization, etc. to changes in dust properties
- Physically-motivated foreground modeling!