Microwave Emission from Spinning Dust and its Polarization Spectrum

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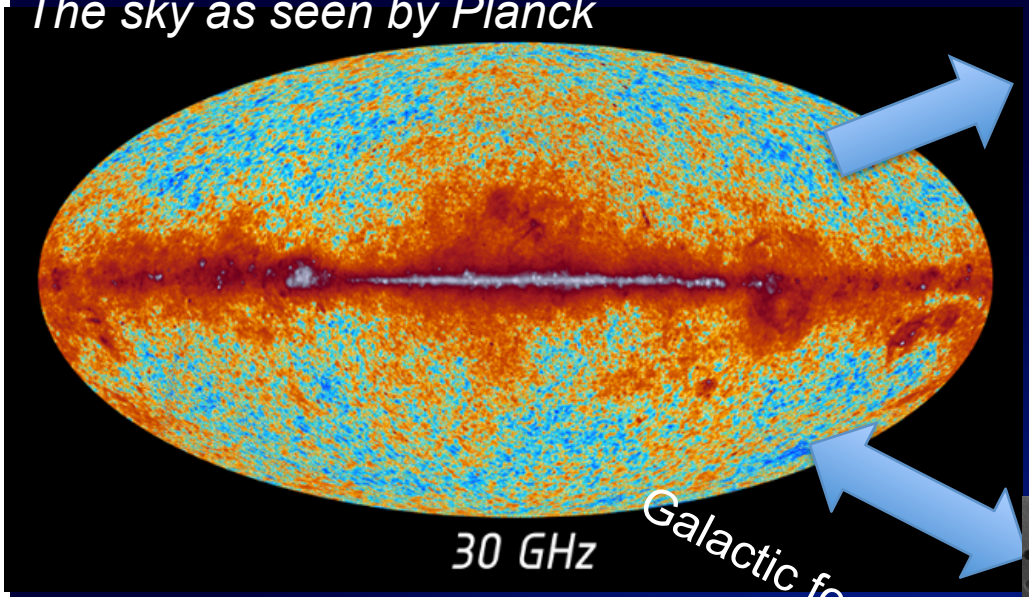
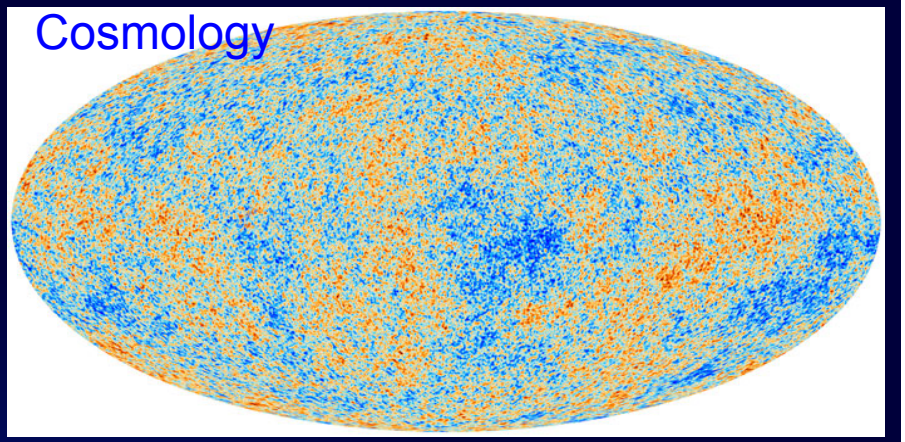
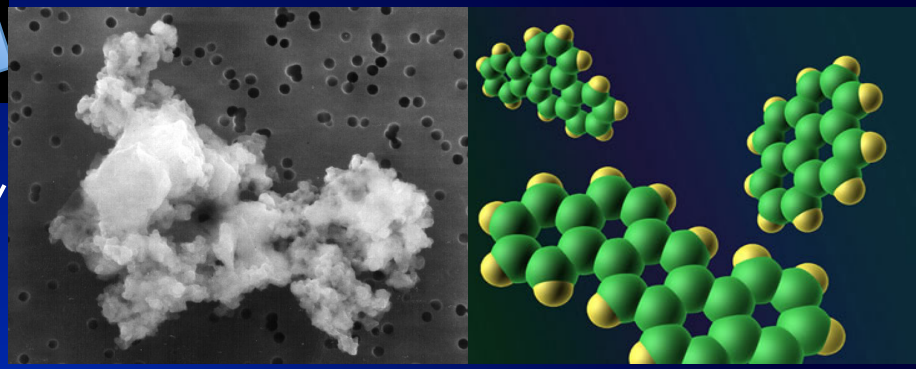
Stiftung/Foundation

Planck: Cosmology and Galactic Science

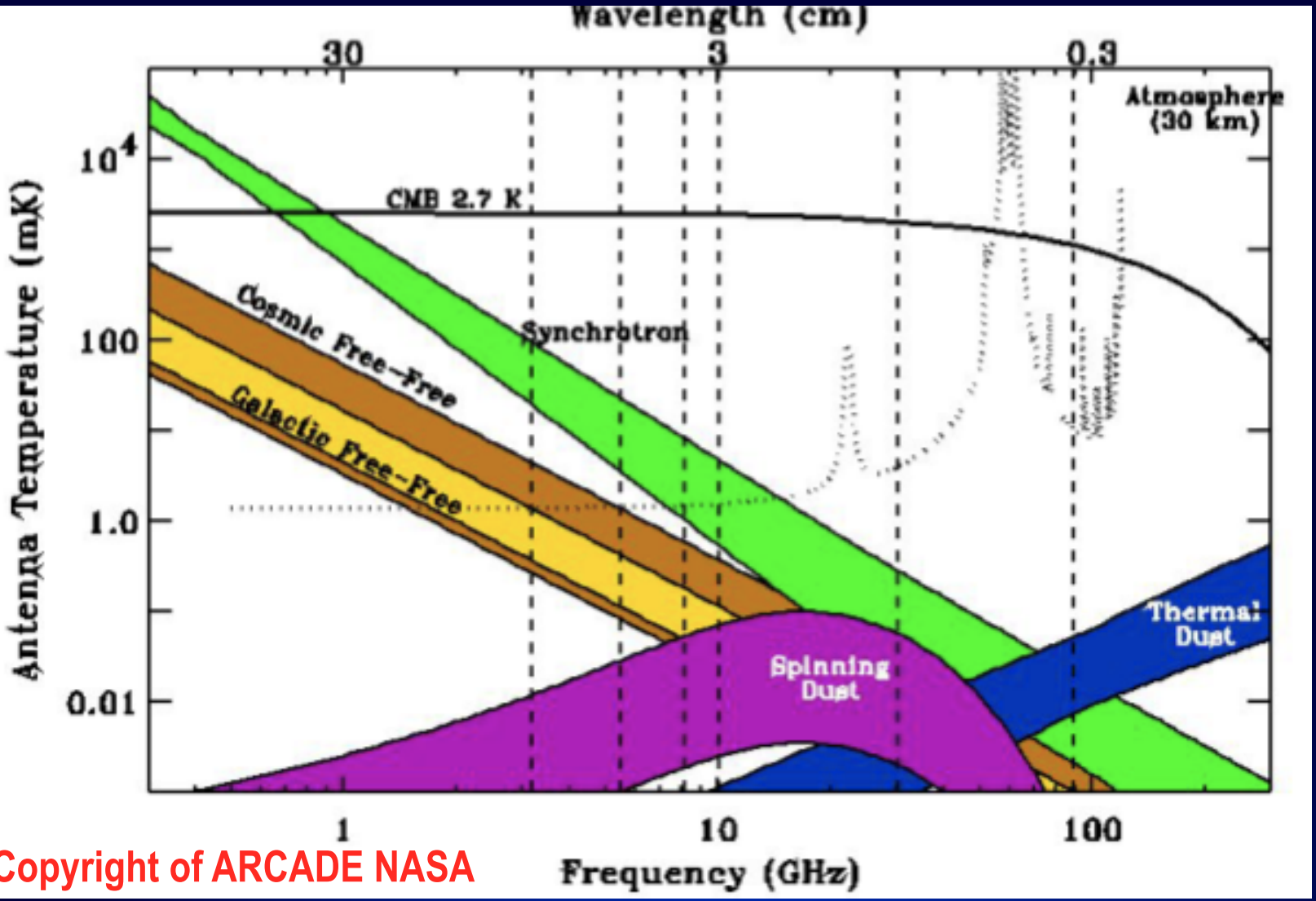




Galactic science

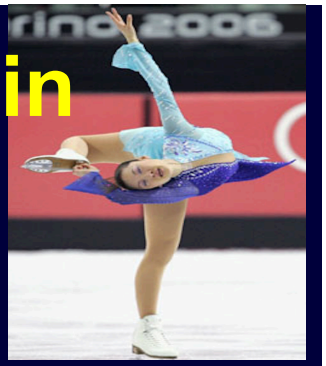


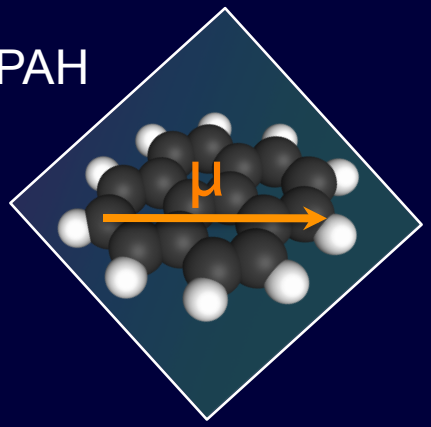
New Galactic Foreground Components



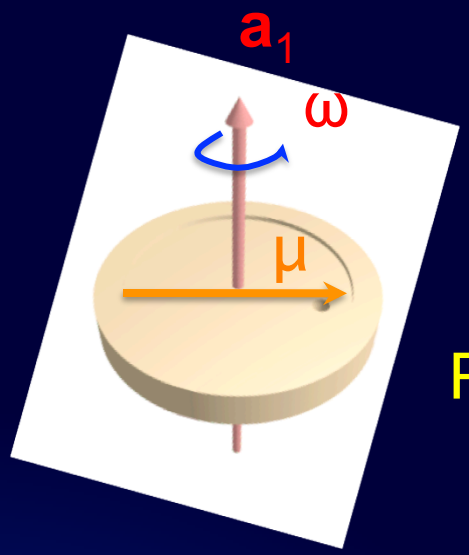
Discovery of anomalous microwave emission: Kogut et al. (1996), Leitch+1997

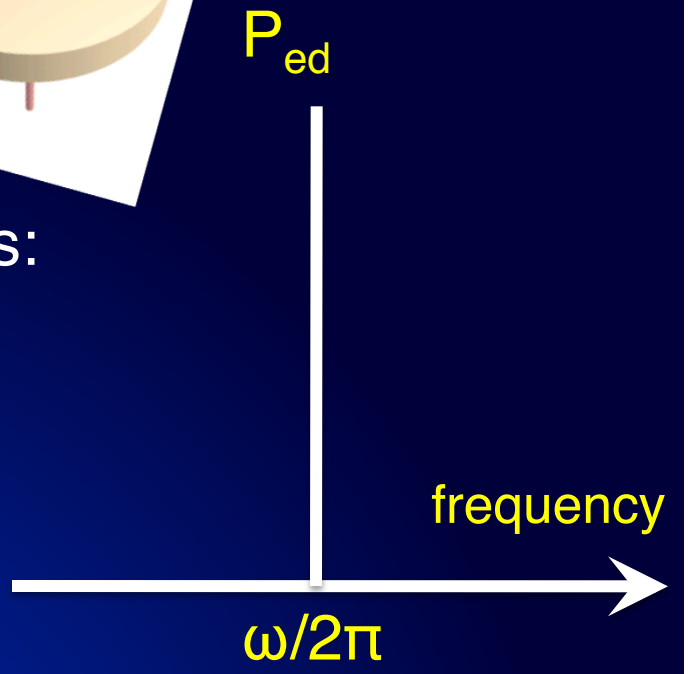
Draine & Lazarian Model: Spinning Grain





modeling





1. Spinning grain of moment μ, **ω** ll $\mathbf{a}_1$ emits:

- single frequency mode: $\nu = \frac{\omega}{2\pi}$
- emission power: $P_{\rm ed}(\omega) = \frac{2}{3}\frac{\mu^2\omega^4}{c^3}$

2. ω follows Maxwellian distribution: f_ω

Discovery of PAHs: Leger & Puget (1984)

Earlier works: Erickson 1957; Ferrara & Dettmar 1994

A lot of great work, galactic and extragalactic studies, many different objects support DL98 model.

Instruments used to study spinning dust: OVRO, COBE-DMR, Tenerife, Saskatoon, Green Bank,VCA, CBI WMAP etc.

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).

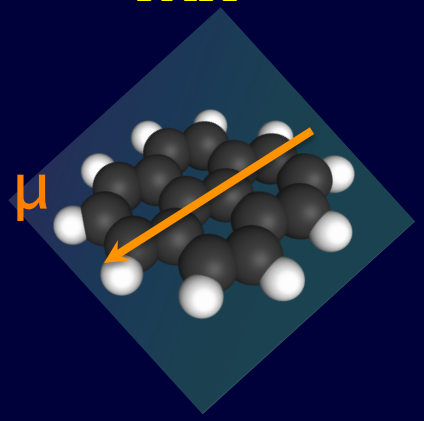
Discussed as means of study ISM and dust properties (Tibbs et al.)

New AME regions from Planck (Vidal's talk).

Precision CMB missions require precision spinning dust model.

Wobbling Grain

PAH

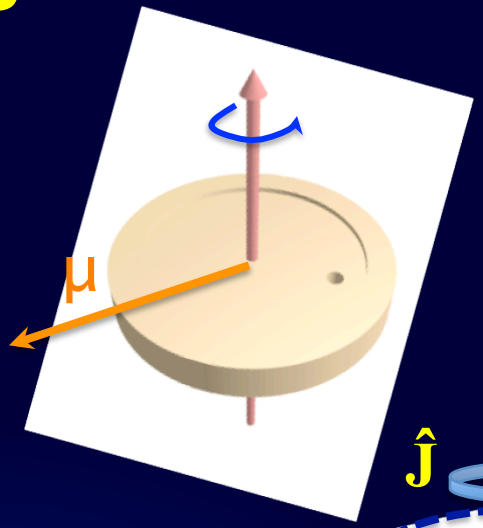


DL98 model

modeling

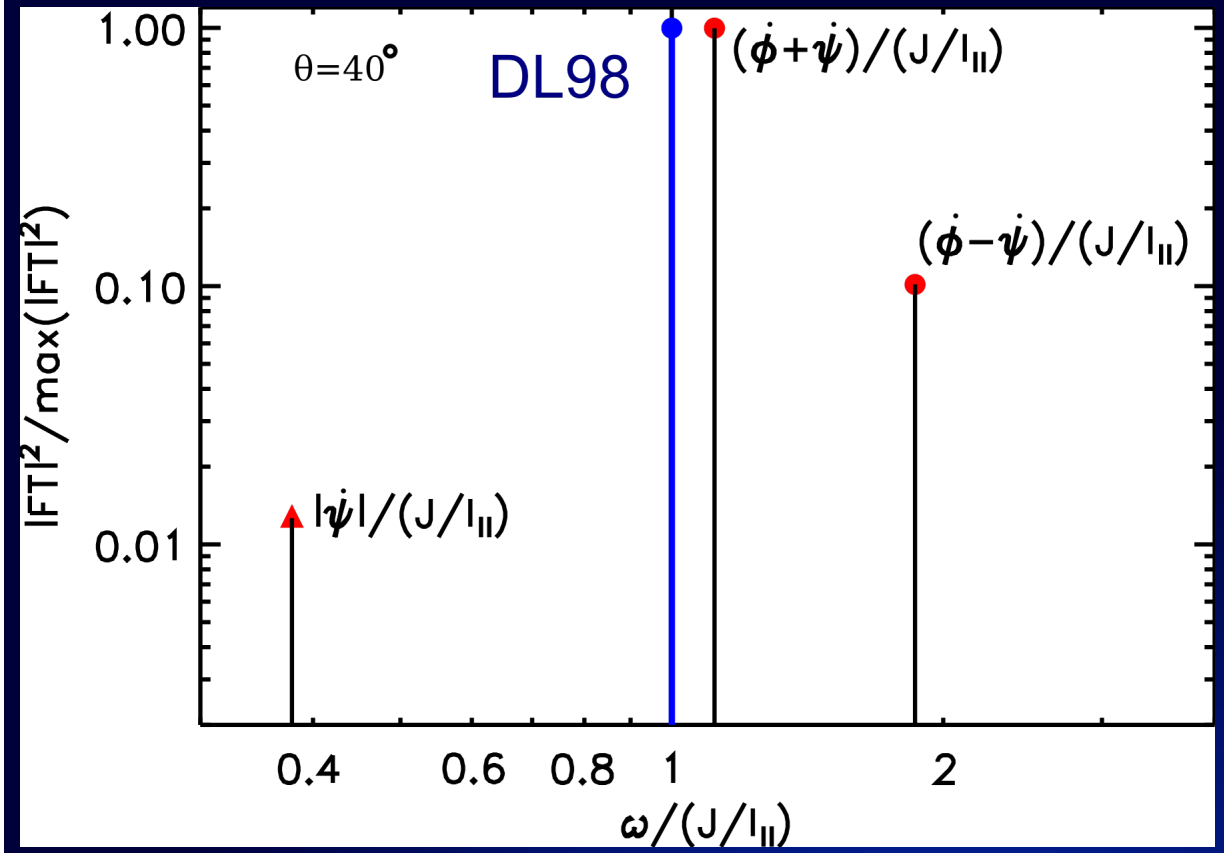
Hoang, Lazarian, & Draine 10

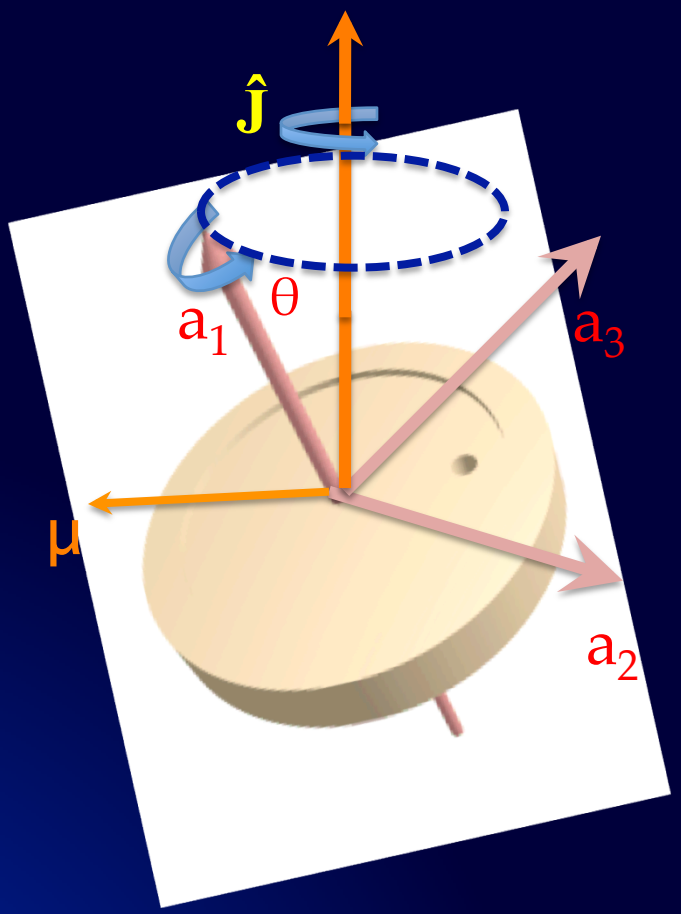
1D rotation



Thermal fluctuations within the grain results in the wobble of the grain.

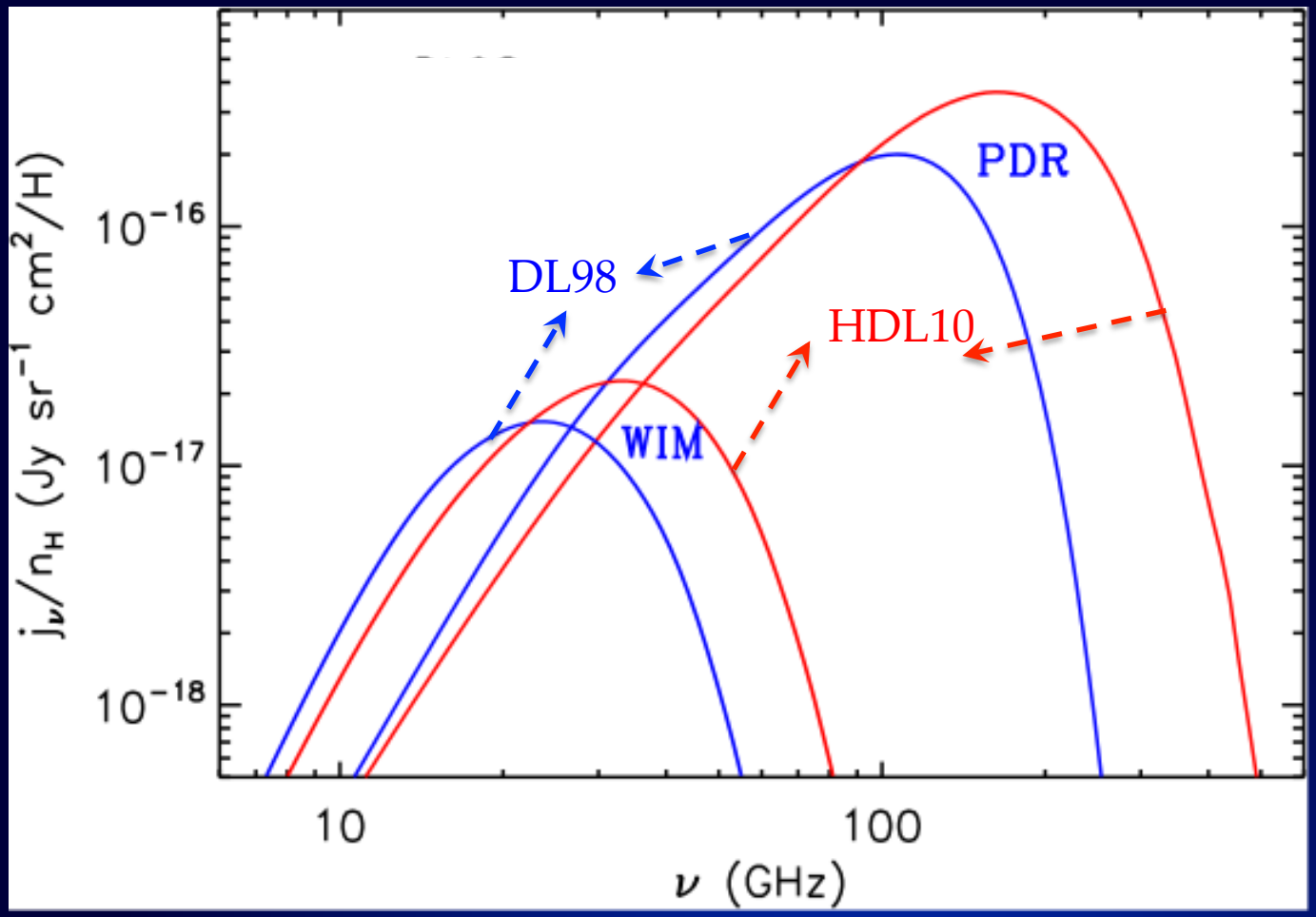
Precessing grain emits at 4 frequency modes.

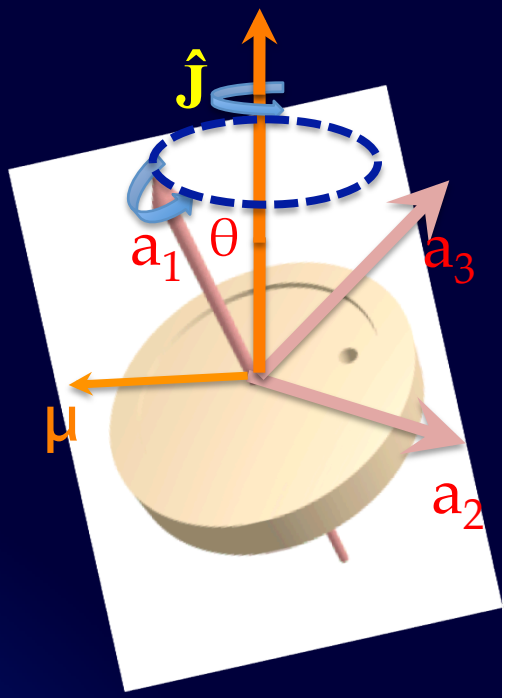




Hoang et al. 2011

Wobbling grains emit 2 times more energy than "spinning" grains.

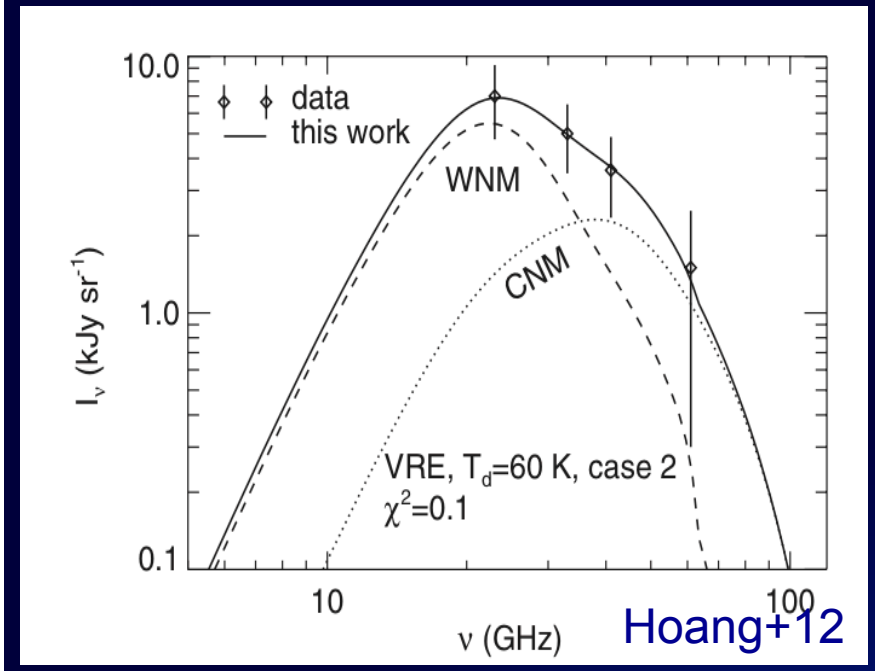


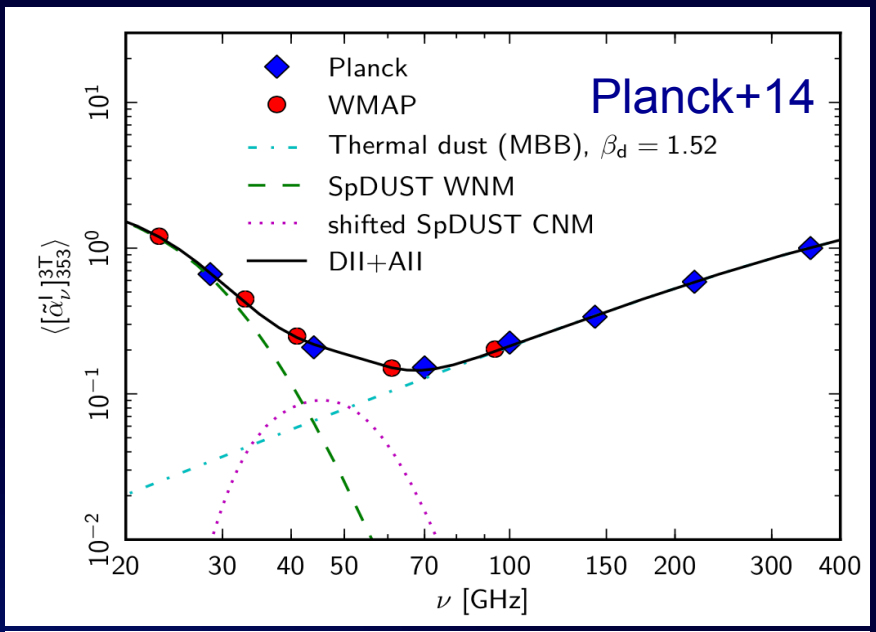


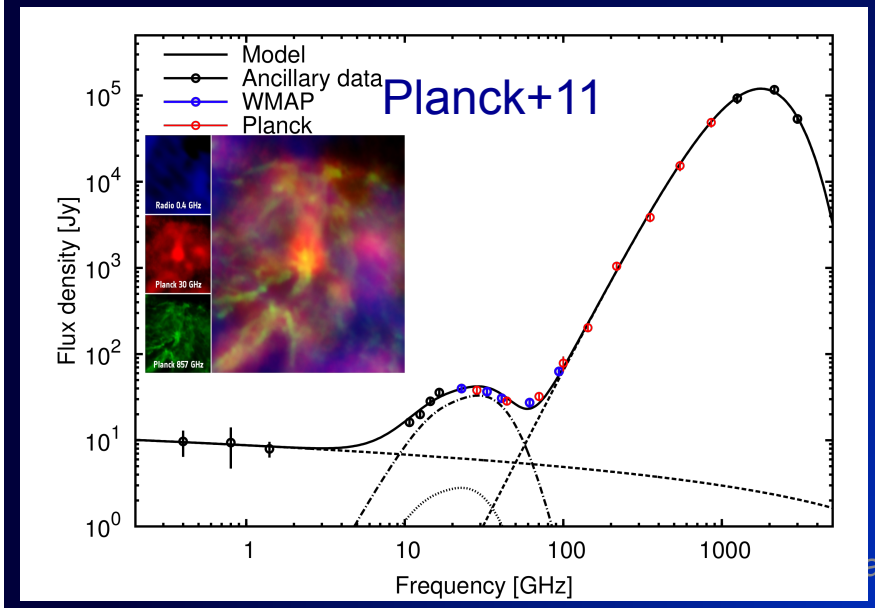
- Peak emissivity increases by a factor ~2 .
- Peak frequency increases by factors ~1.4 to 1.8.

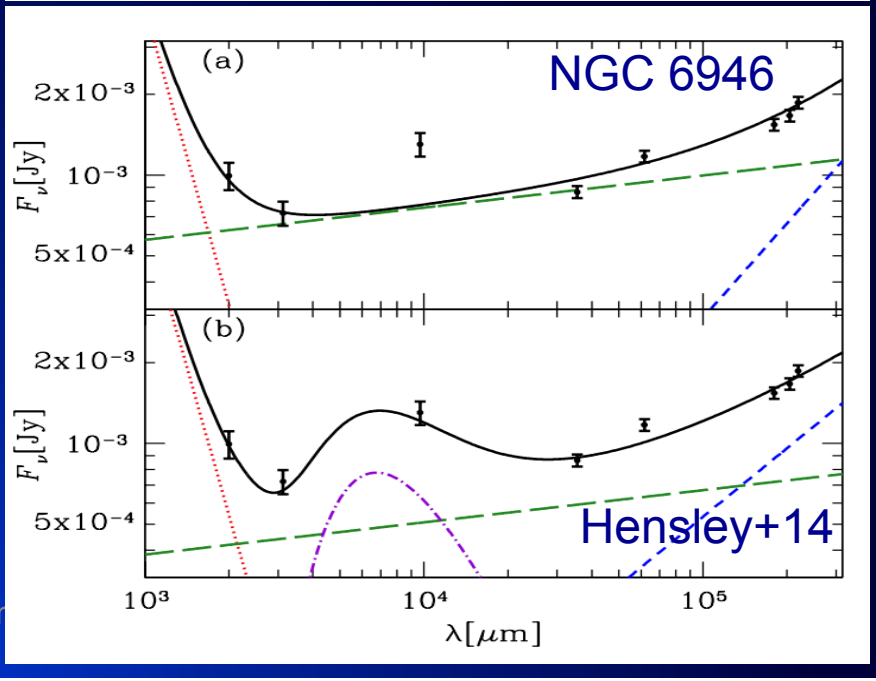
Hoang et al. 2011

Modern Observations of Spinning Dust

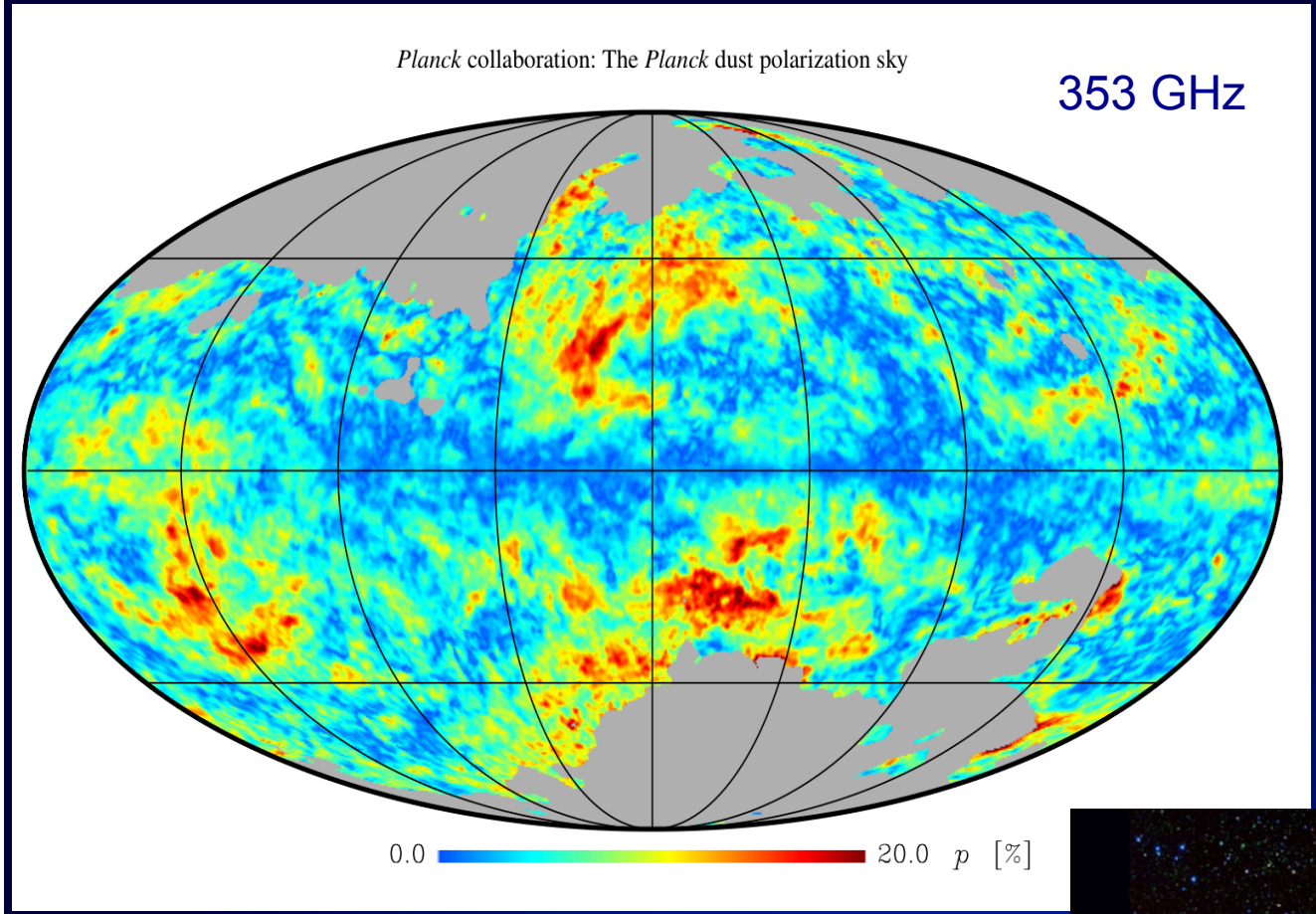


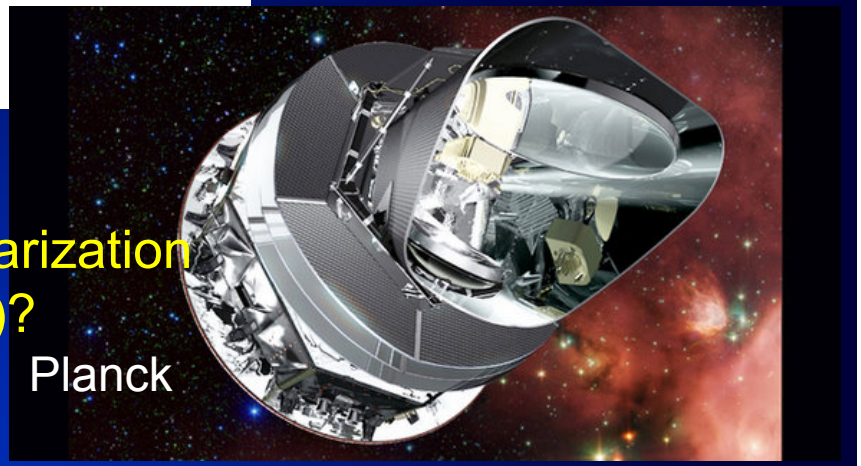






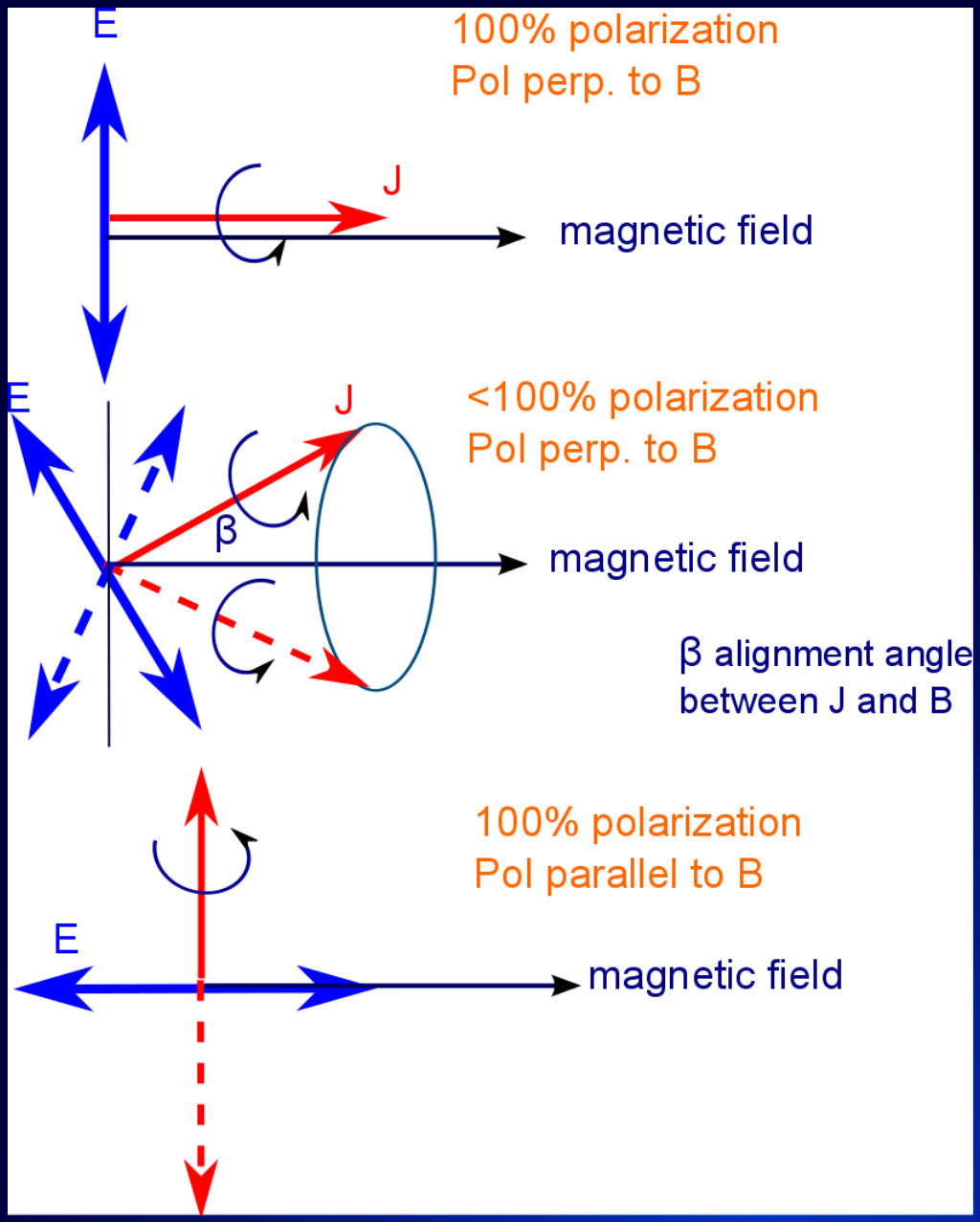
Is spinning dust emission polarized? Spectrum?





Are we confident to ignore spinning dust polarization in component separation (see Welhun's talk)?

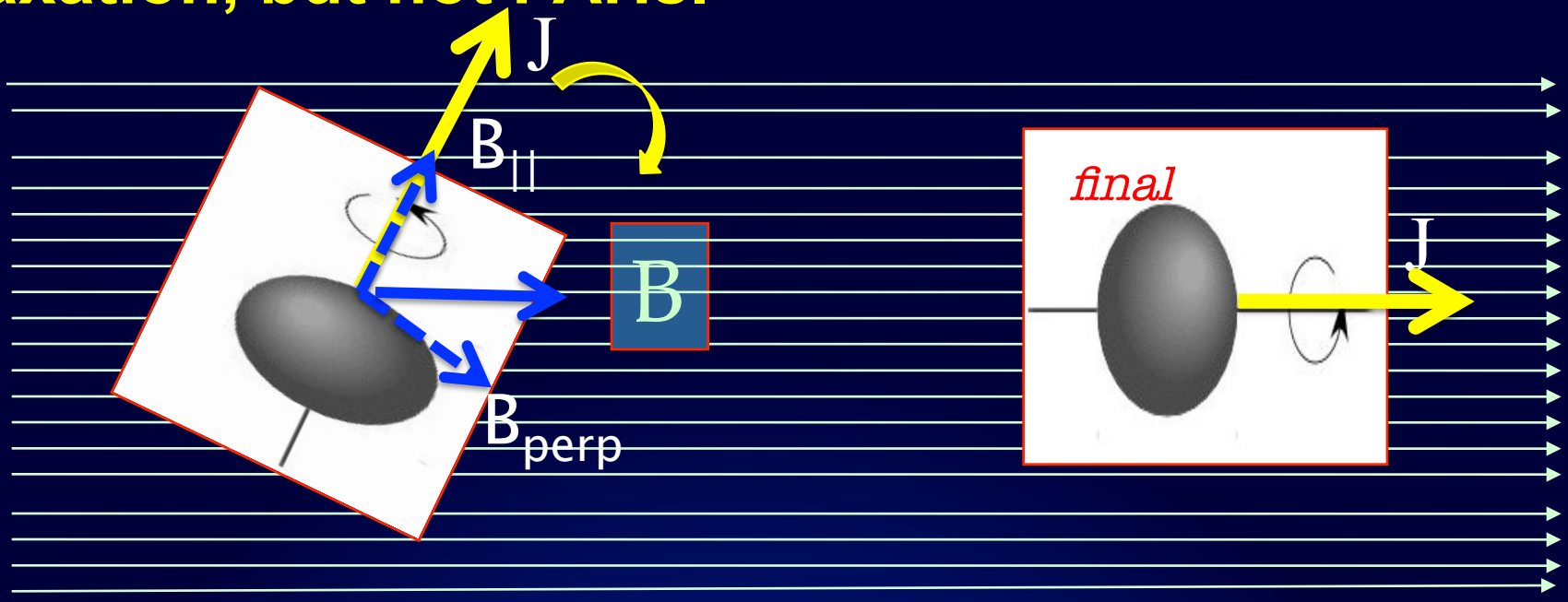
PAHs must be aligned to emit polarized radiation.



PAH's momentum changes randomly due to gas collisions and photon excitation

See Boulanger's talk for grains

Small grains weakly aligned by classical paramagnetic relaxation, but not PAHs.



magnetic susceptibility

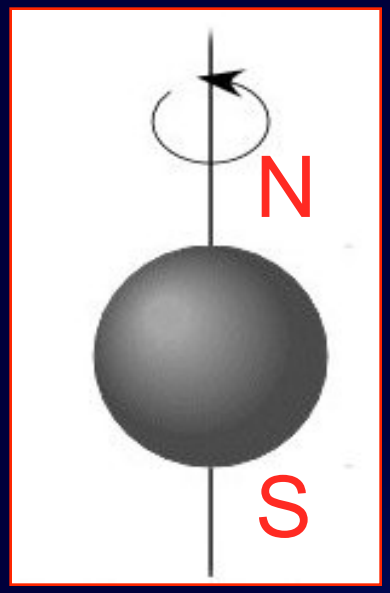
$$K_{\rm sil}(\omega) \approx 1.2 \times 10^{-13} \left(\frac{T_{\rm d}}{15\,{\rm K}}\right)^{-1} \frac{1}{[1+(\omega\tau_2/2)^2]^2}\ {\rm s}.$$

Magnetic susceptibility *K* goes to zero when $\omega >> 1/\tau_2$

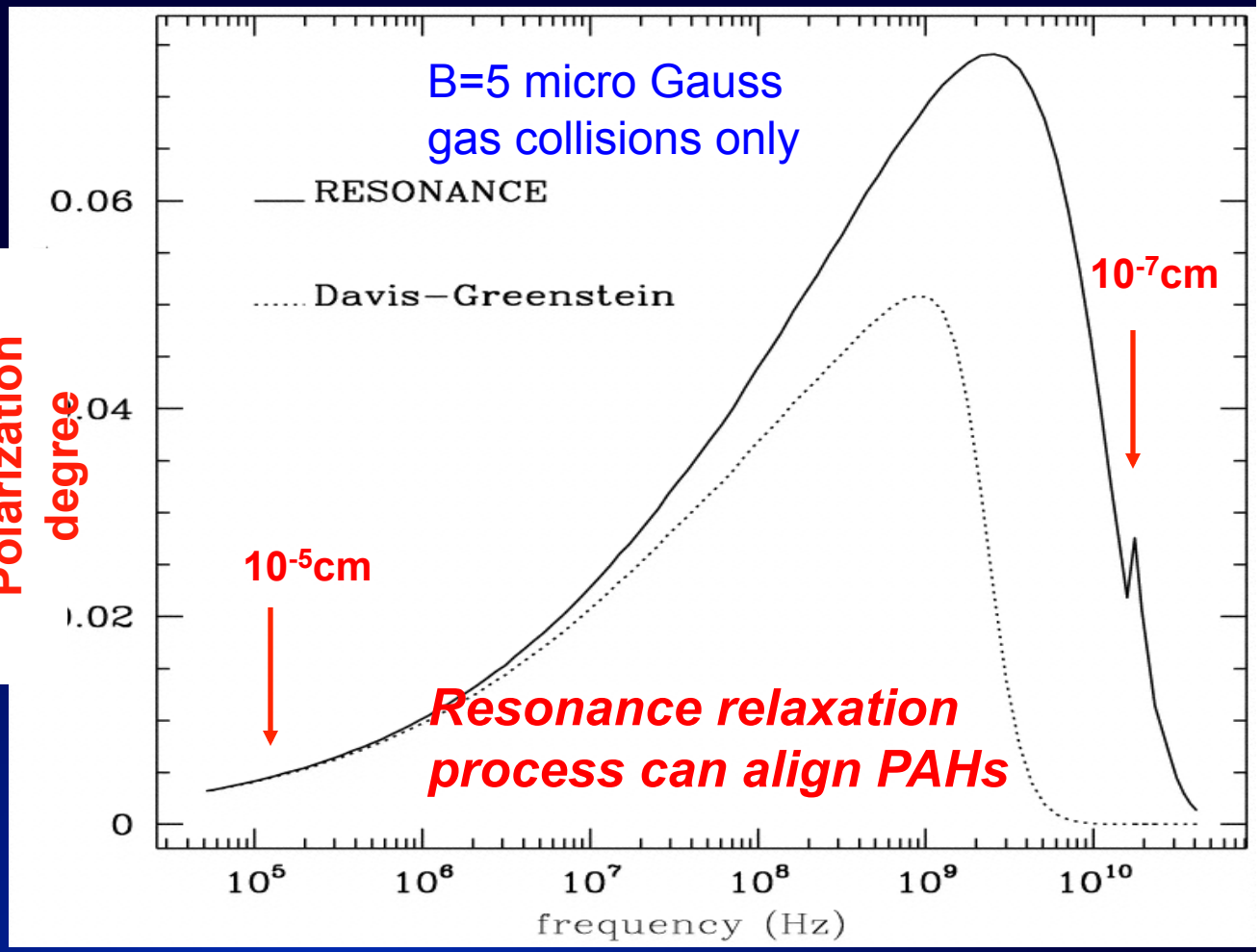
Davis & Greenstein (1951)

τ_2 spin-spin relaxation time

Grains get magnetized as they rotate and this results in resonance paramagnetic relaxation.

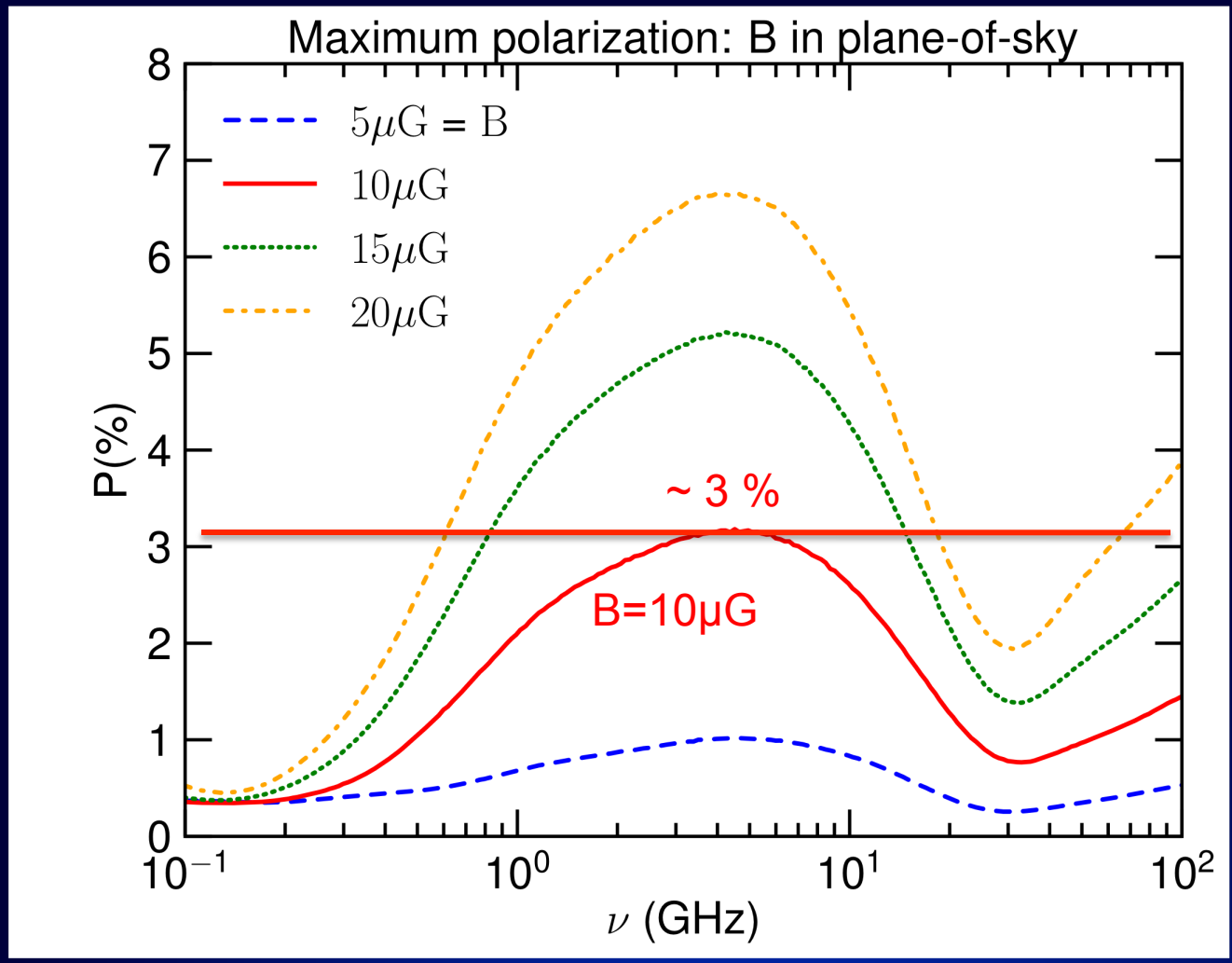


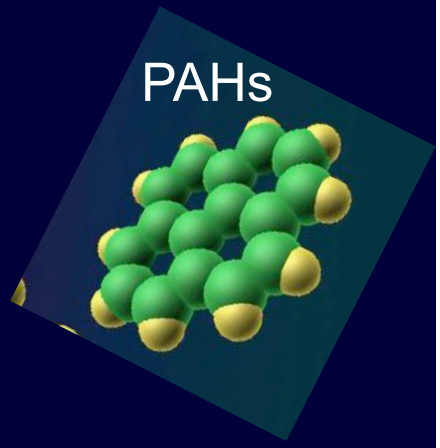
Magnetization by rotation (Barnett effect)



Lazarian & Draine 2000

Theory: maximum polarization ~ 3 % for typical ISM field.

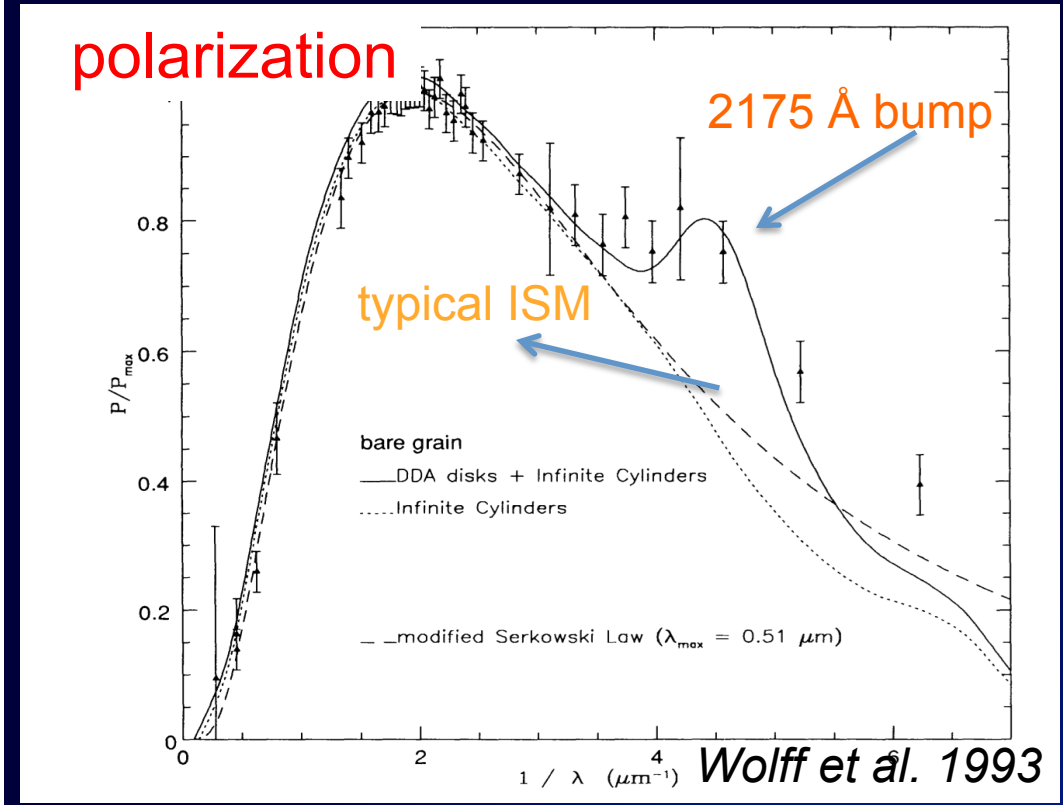


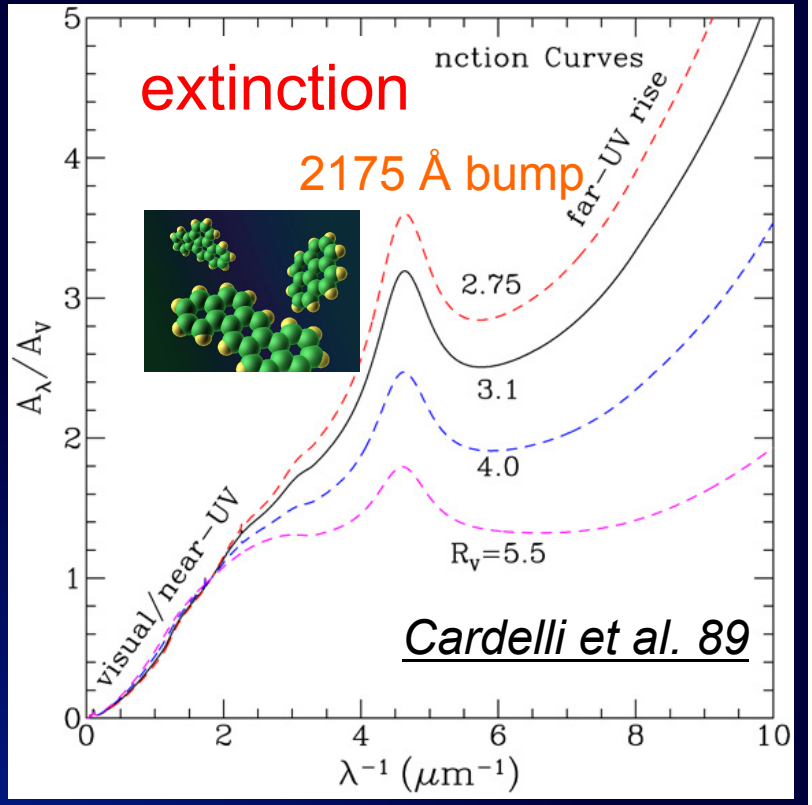


- Maximum polarization increases with increasing B strength.

Hoang et al. 2015

Observational Constraints: Inversion Problem

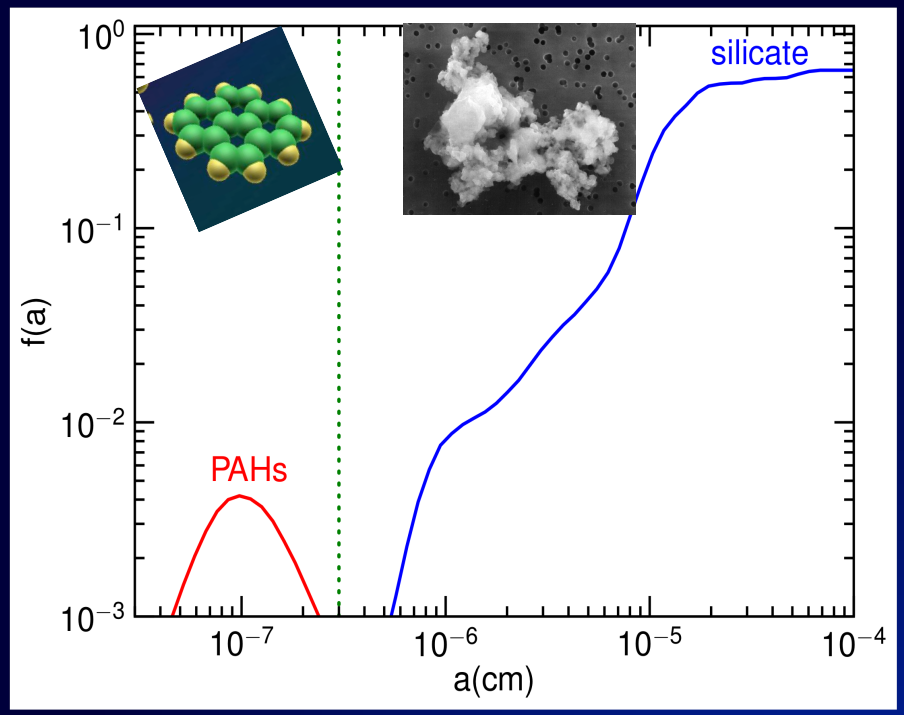


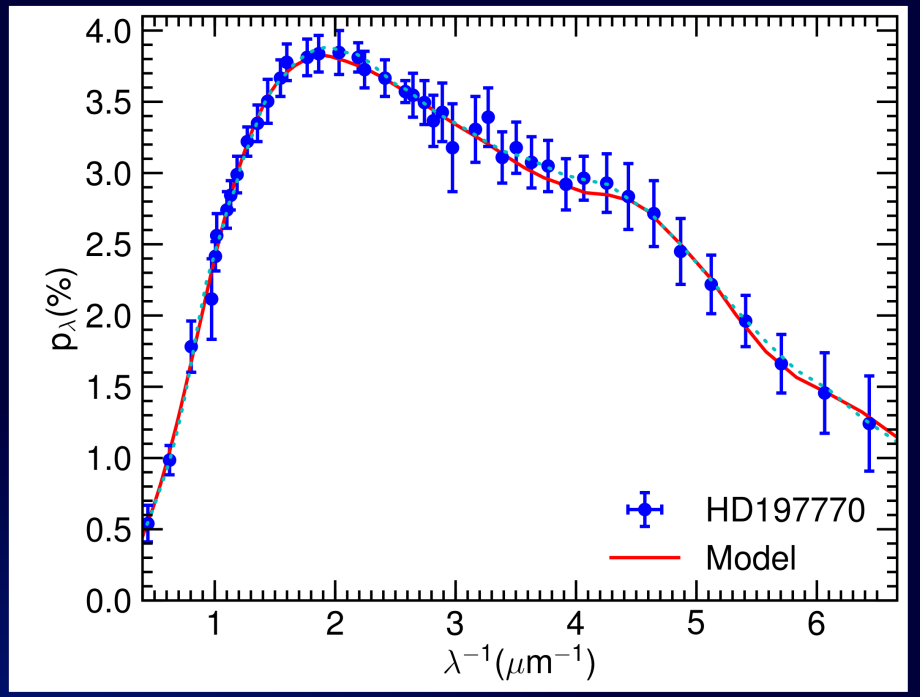


see Martin's talk

- Two stars exhibit 2175 Å polarization bump.
- PAHs produce 2175 Å bump and radiate microwave emission.
- How efficient are PAHs aligned?

Best-fit Model Parameters

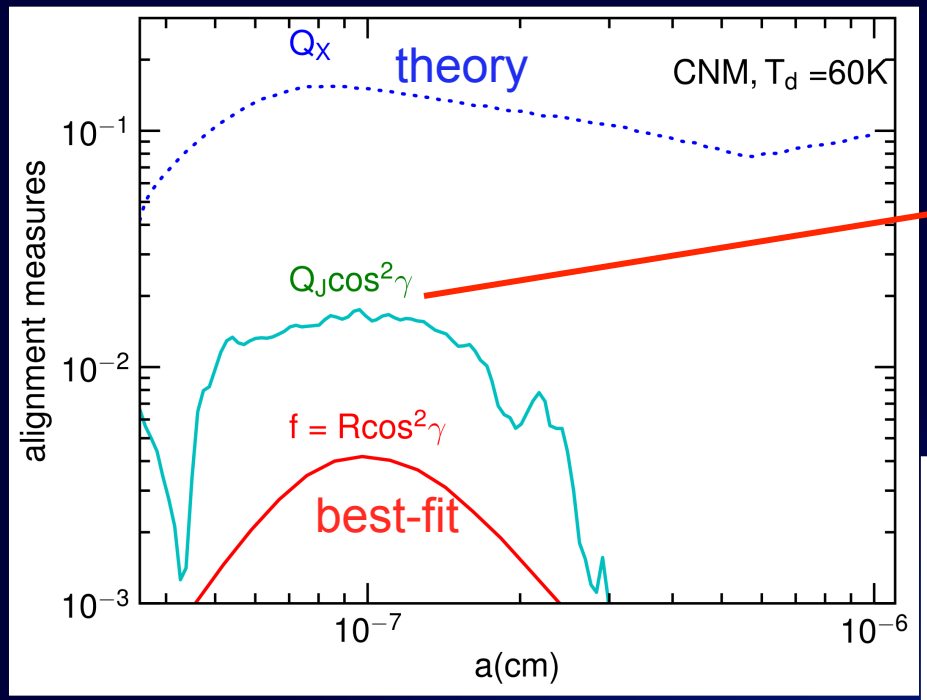




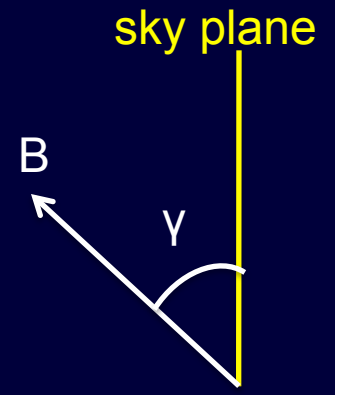
- PAHs are very weakly aligned
- Big silicates are efficiently aligned.

Hoang et al. 2013

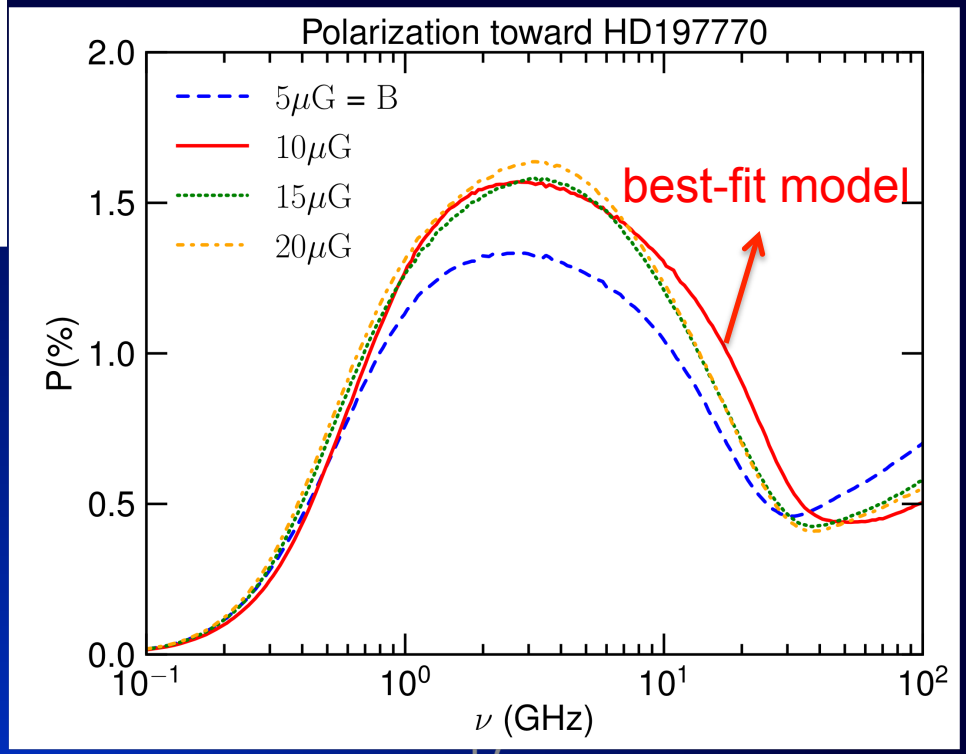
HD 197770: Peak polarization of spinning dust ~ 1.6 percent.



$$P \propto Q_J \cos^2 \gamma$$

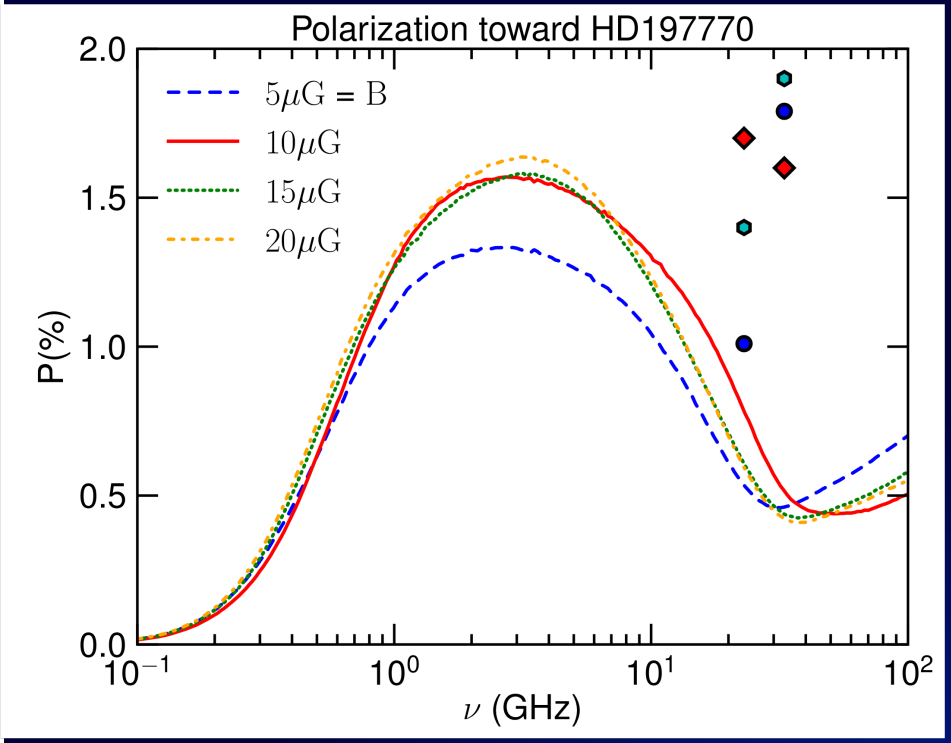


Polarization



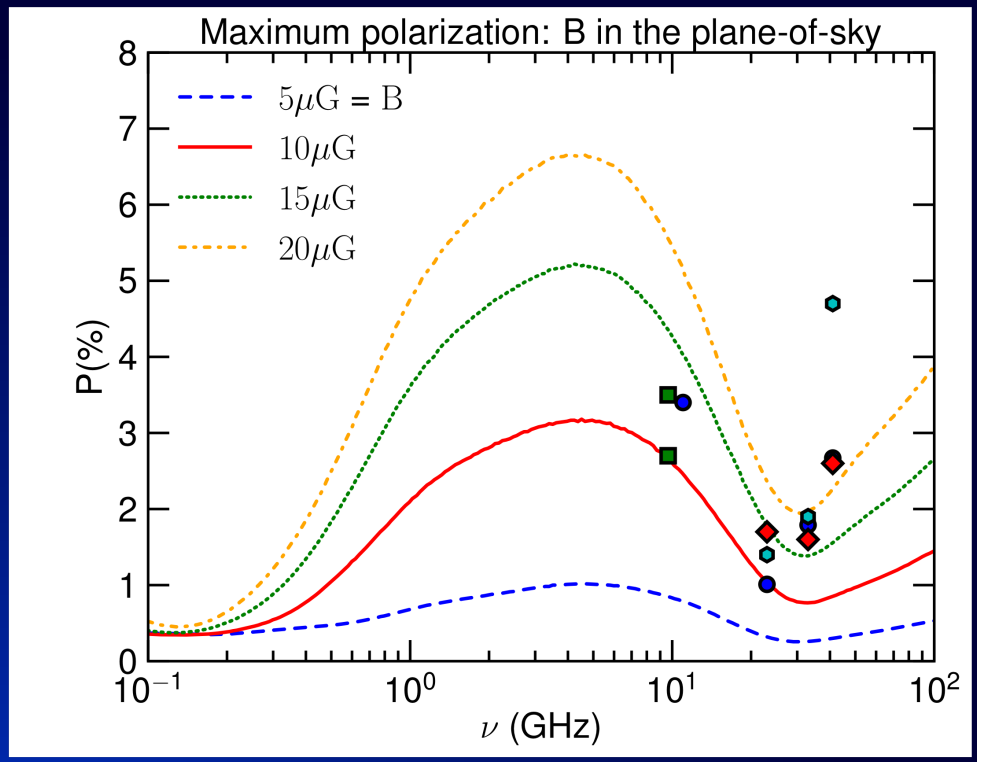
Hoang et al. 2013

Theory vs. Observations



Hoang et al. 2013

Upper limits from observations:
Battisteli + 2006 (•), Mason + 2009 (■)
Dickinson + 2011(◆), Lopez-Caraballo +2011(•)



Magnetic field along the line of sight to HD197770 may not be perpendicular to the sky, reducing achievable polarization.

Upper limits observed are consistent with maximum polarization predicted by theory.

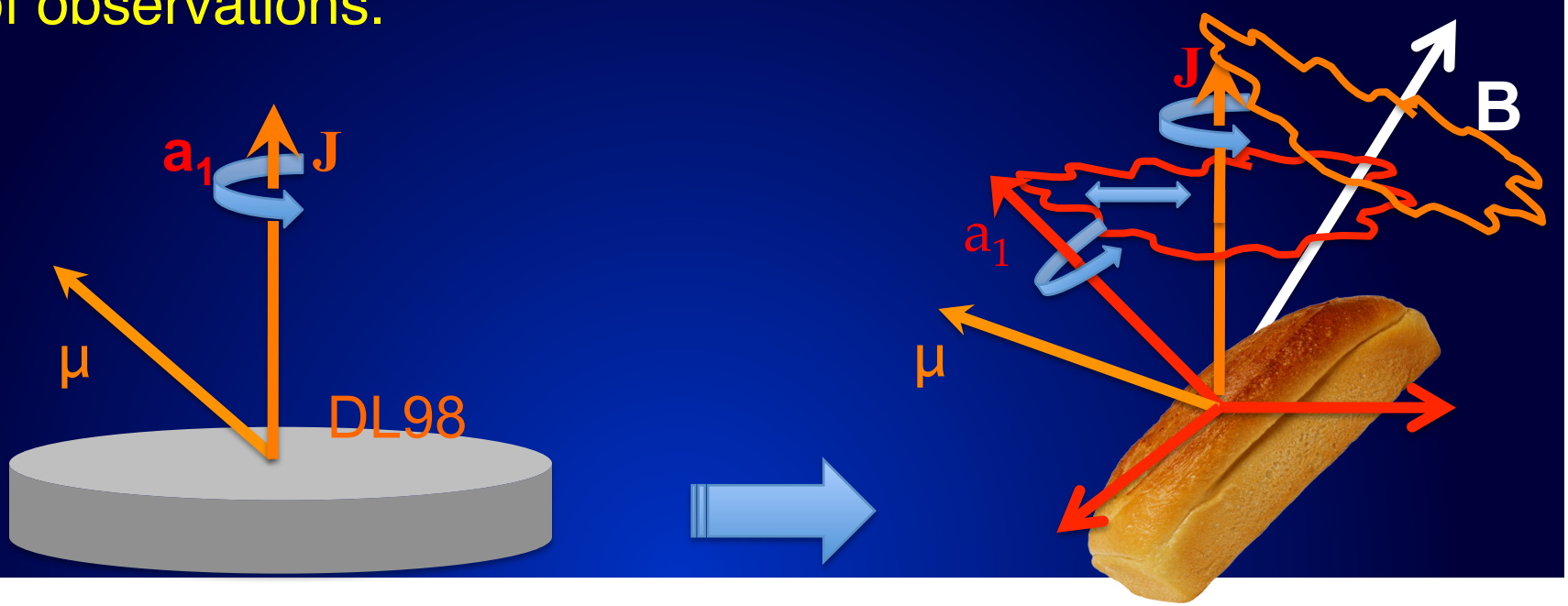
 Hoang et al. 2015

Summary

1. Comprehensive model of spinning dust accounts for internal relaxation, grain wobbling, irregular shape, transient events, and turbulence.

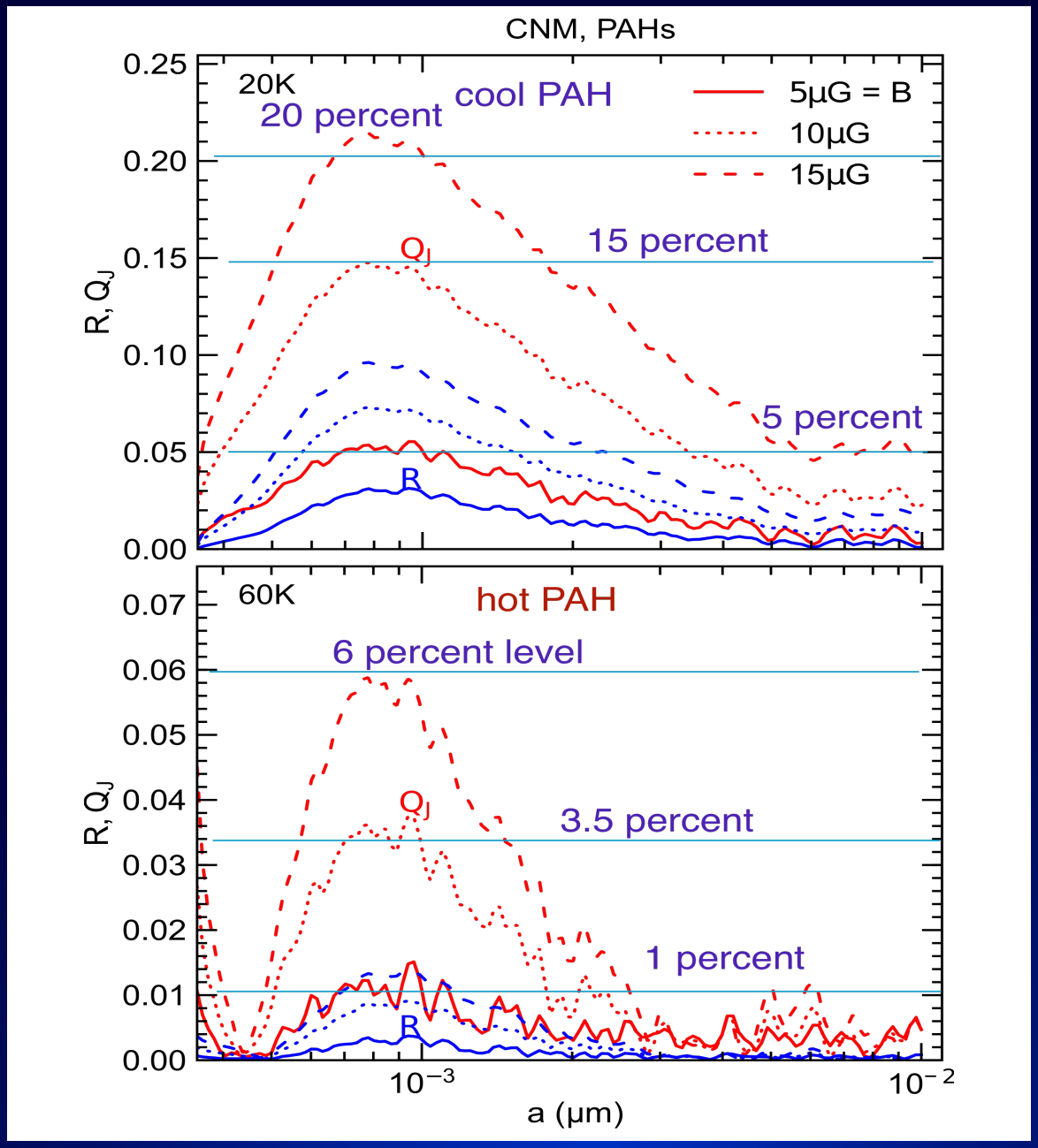
2. Alignment of PAH by resonance relaxation induces polarization of spinning dust emission. Peak frequency < 10 GHz.

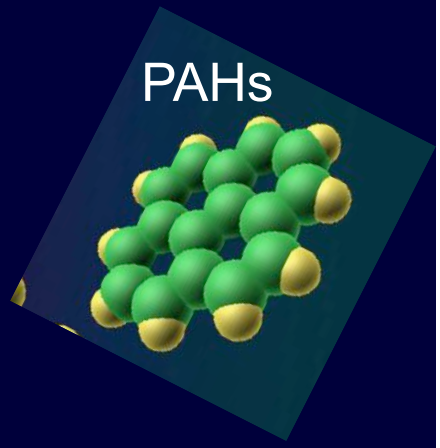
3. Polarization of spinning dust is low and consistent with upper limits of observations.



Papers	Internal Alignment	Grain Shape	Treatment	Single ion collisions	Transient heating	Turbulence
DL98 model	Perfect J // a	oblate	Classical	Identified, not quantified		
Ali-Haimoud et al. 09	Perfect	oblate	classical			
Ysard & Verstraete 10	Perfect	oblate	quantum			
Hoang et al. 10	not perfect: Precessing +wobble	oblate	classical	quantified		
Silsbee et al. 11	Not perfect, precessing +nutating	oblate	classical			
Hoang et al. 11	Not perfect Precessing +wobble	triaxial	classical	quantified	quantified	quantified

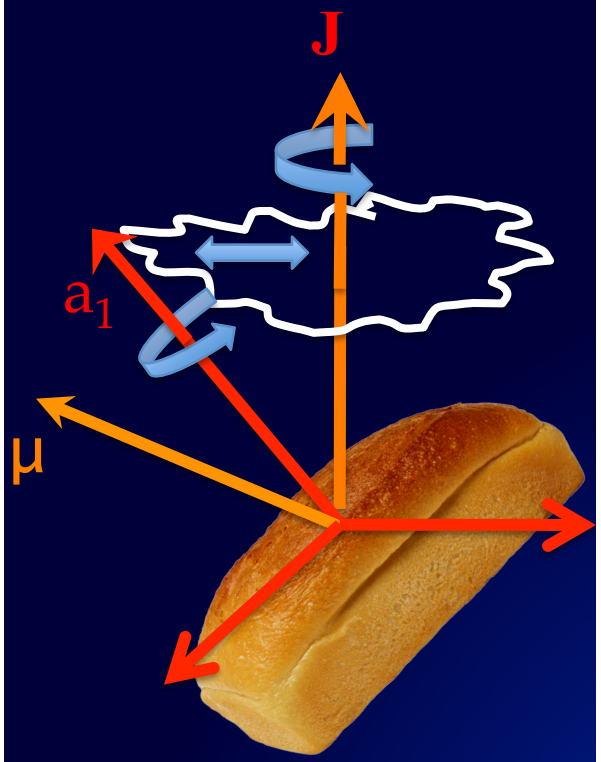
Theory: alignment degree increases with B strength

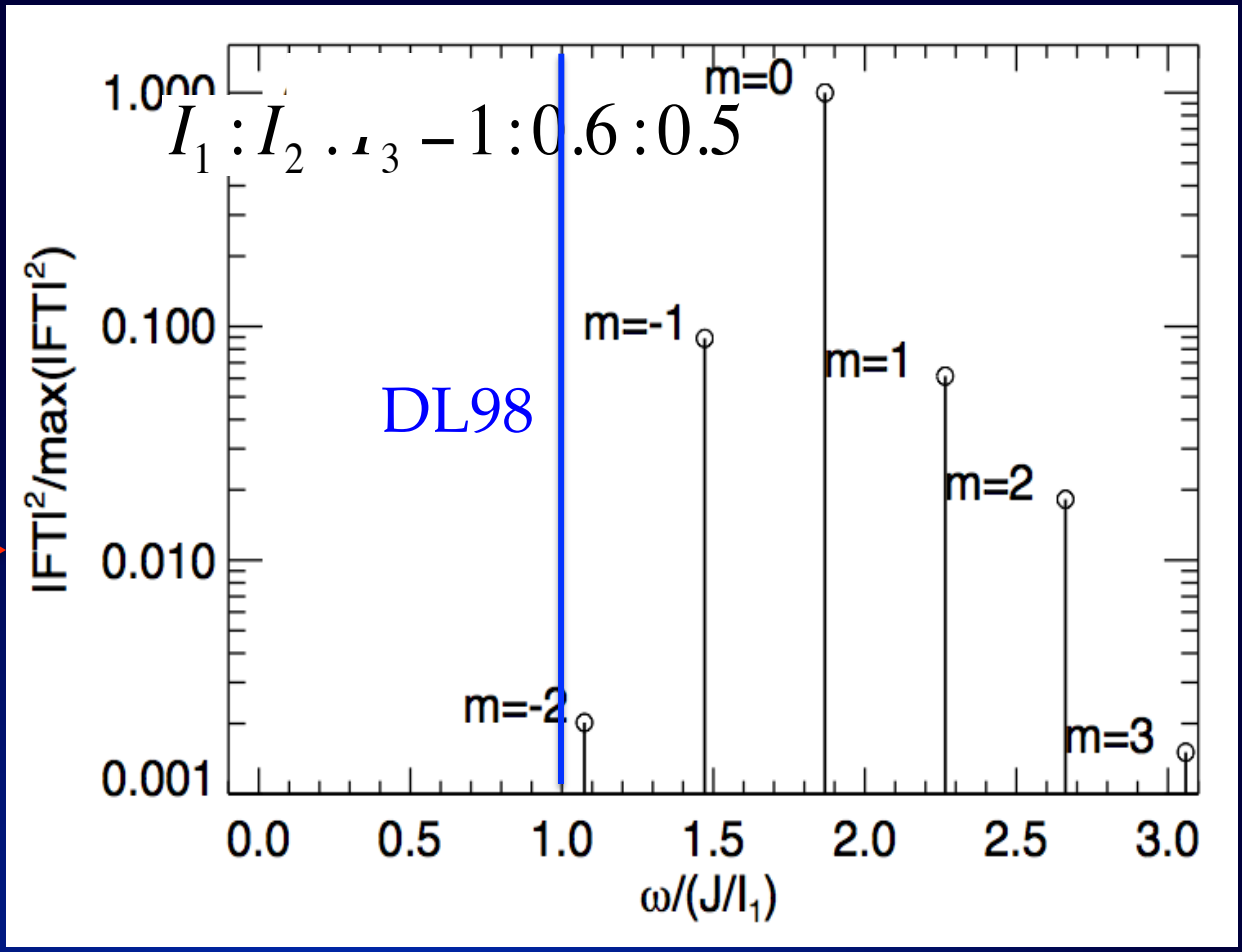




Hoang et al. 2014

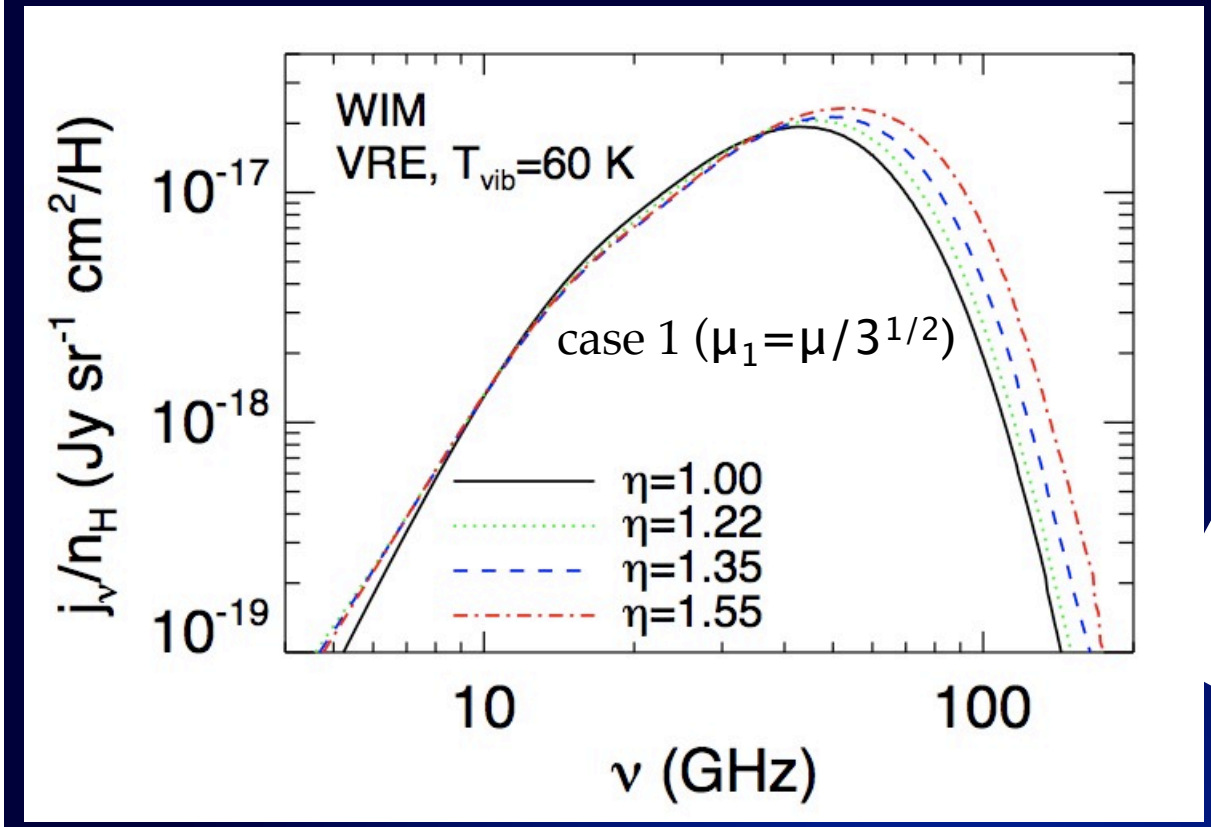
Wobbling irregular grain emits at multiple modes

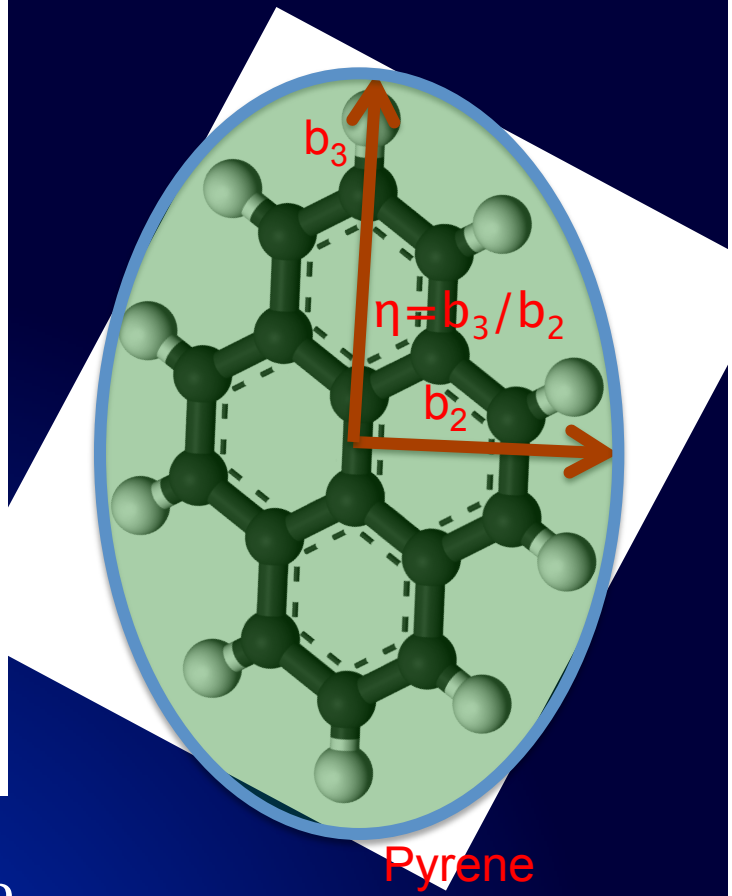




Hoang et al. 2012

Emissivity increases with grain irregularity





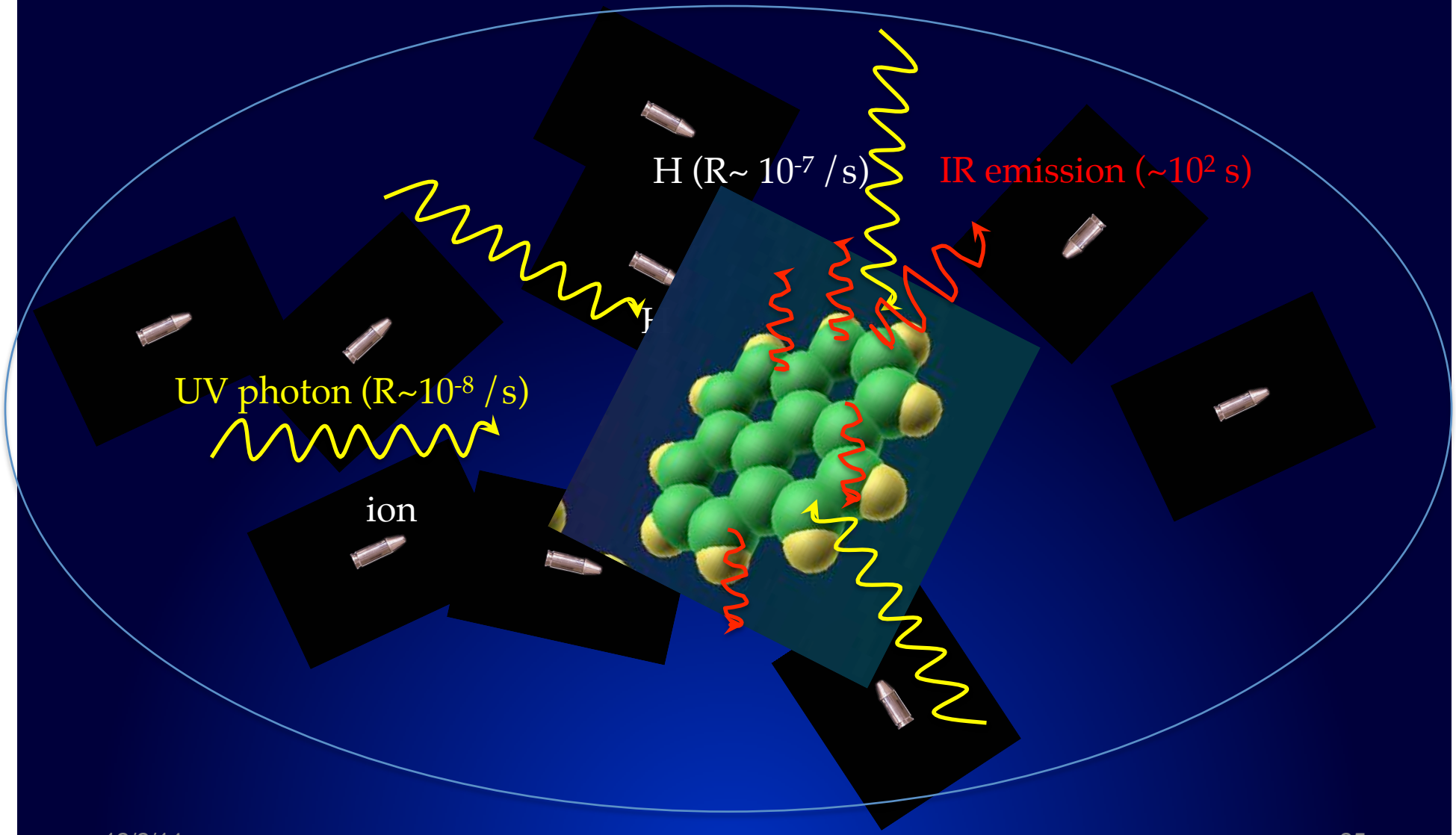
- Working model: simple irregular shape
- Irregularity: $\eta=b_3/b_2$

Future is so exciting because we do not know it!

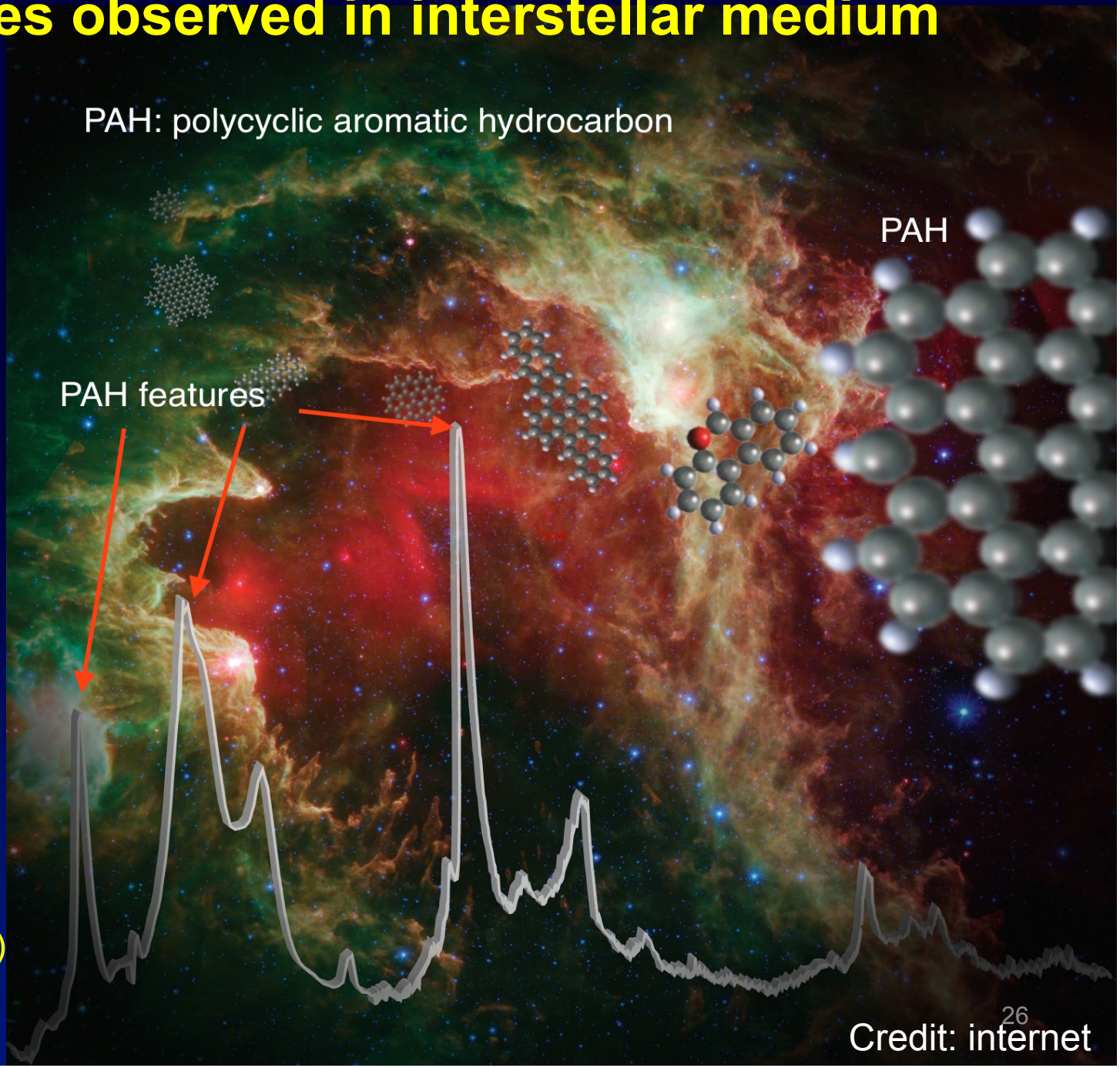
Winnie the Pooh found the search for the Eastern Pole so appealing because no one knew where it is!

Borrow from Alex's slide

Rotational Damping and Excitation



PAH molecules observed in interstellar medium



Discovery of PAHs:
Leger & Puget (1984)