Comprehensive Model of Spinning Dust Emission and Polarization

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Special thanks to

Alex Lazarian

Bruce Draine

Peter Martin

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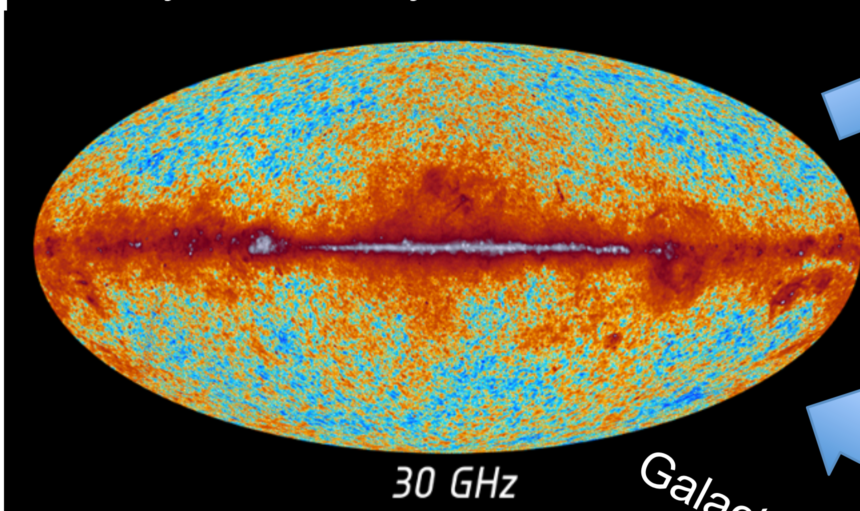
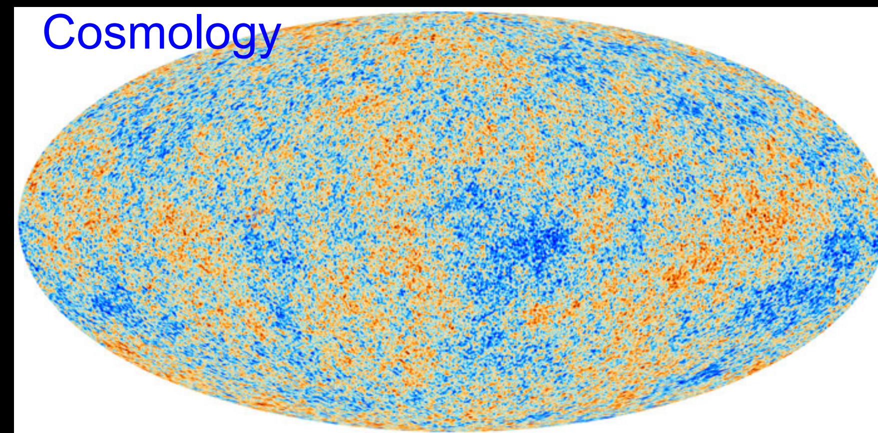
Outline

- Draine & Lazarian Model of Spinning Dust Emission
- Comprehensive Model of Spinning Dust Emission
- Constraining PAH properties using observation data
- Polarization of Spinning Dust Emission
- Summary

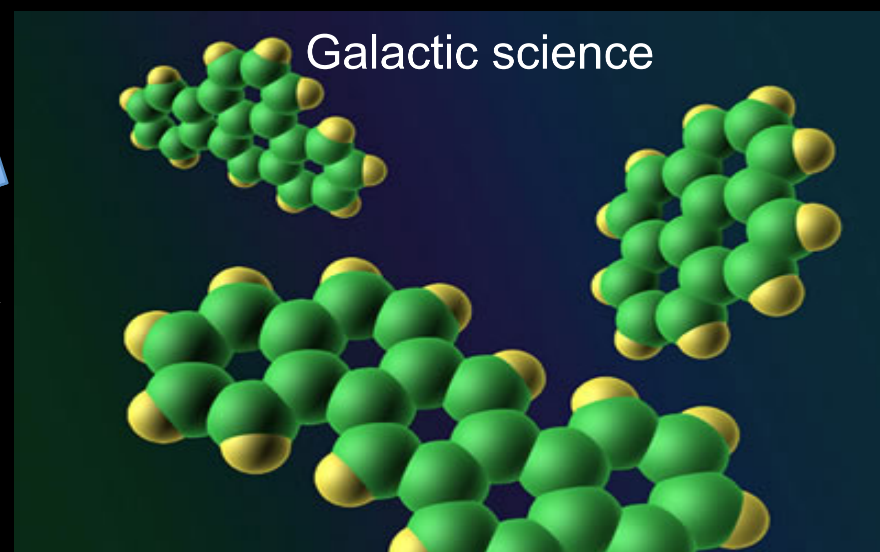
Planck: Cosmology and Galactic Science

The sky as seen by Planck

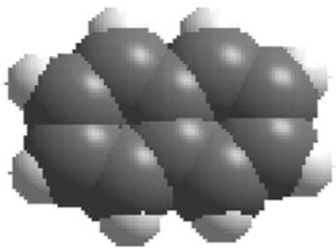




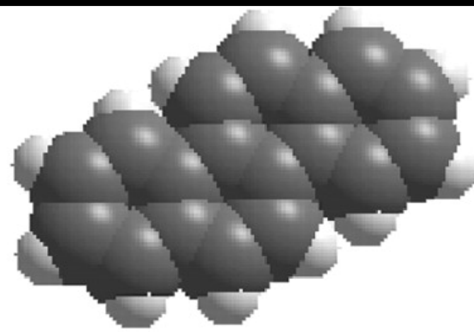
Galactic foreground



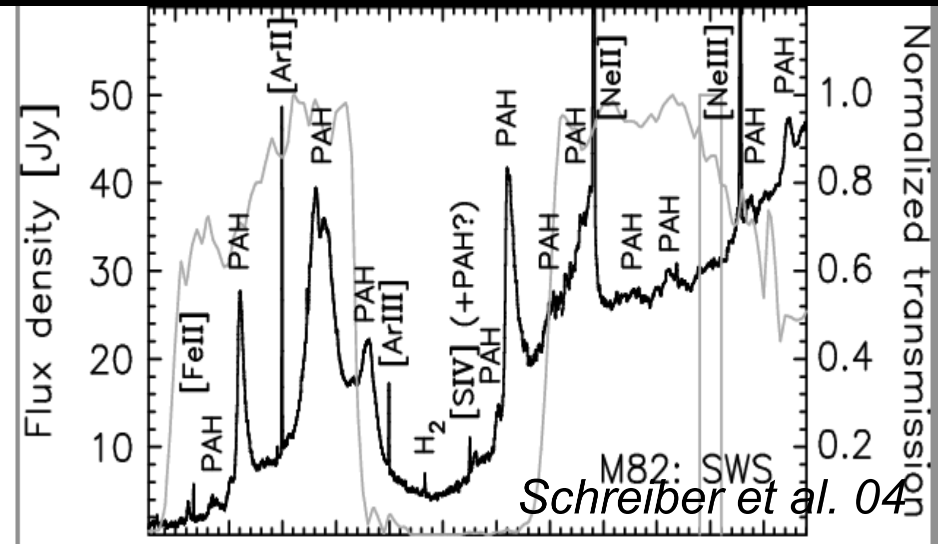
PAHs and Unidentified Infrared Emission (UIE) features



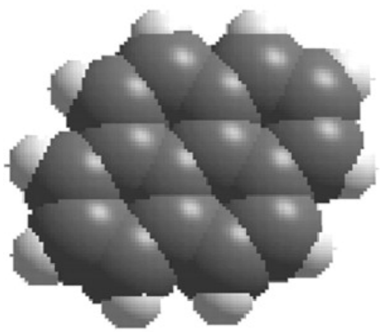
Naphthalene
($C_{10}H_8$)



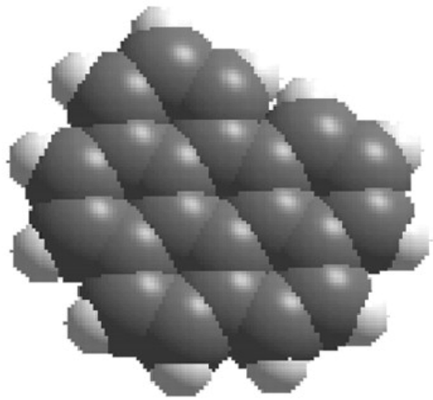
Chrysene
($C_{18}H_{12}$)



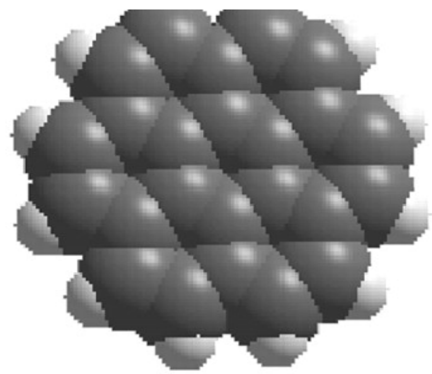
Schreiber et al. 04



Pyrene
($C_{16}H_{10}$)



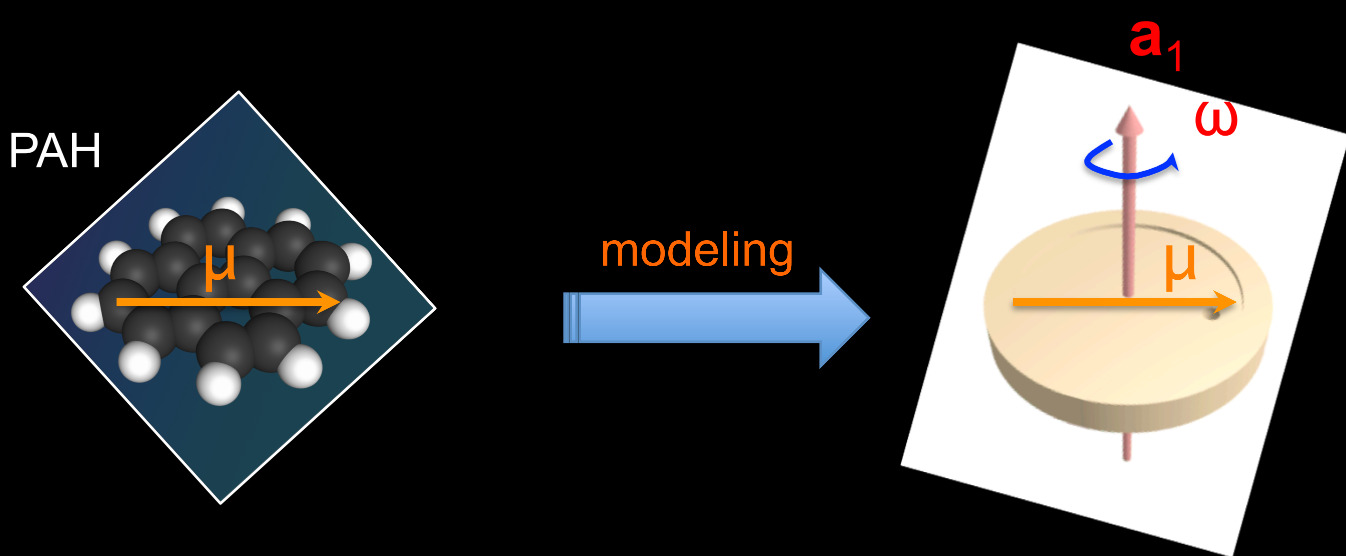
Benzo(g,h,i)perylene
($C_{22}H_{12}$)



Coronene
($C_{24}H_{12}$)

Credit: Internet

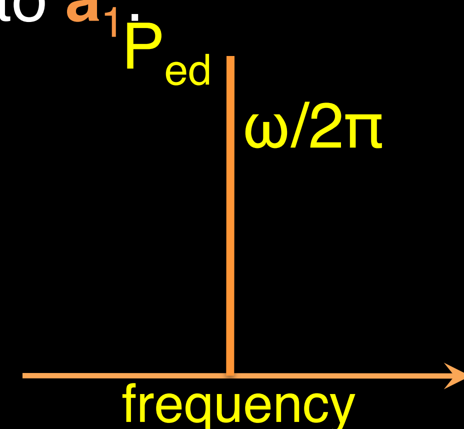
Draine & Lazarian 98 Model



Grain of dipole moment μ, rotating with $\boldsymbol{\omega}$ parallel to $\mathbf{a}_1$:

- radiates at frequency $$\nu = \frac{\omega}{2\pi}$$

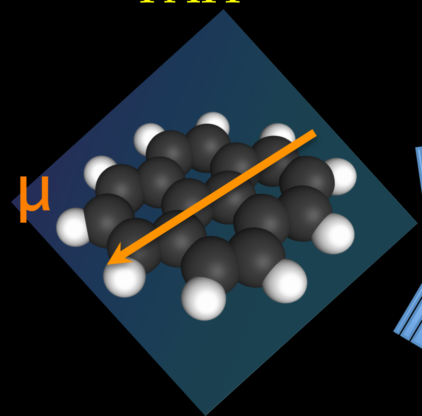
- Emission Power: $$P_{\rm ed}(\omega) = \frac{2}{3}\frac{\mu^2\omega^4}{c^3}$$



- Angular velocity distribution: $f_{\omega} \approx$ *Maxwellian*

Earlier works: Erickson 1957; Ferrara & Dettmar 1994

Grain Wobbling



DL98 model

modeling

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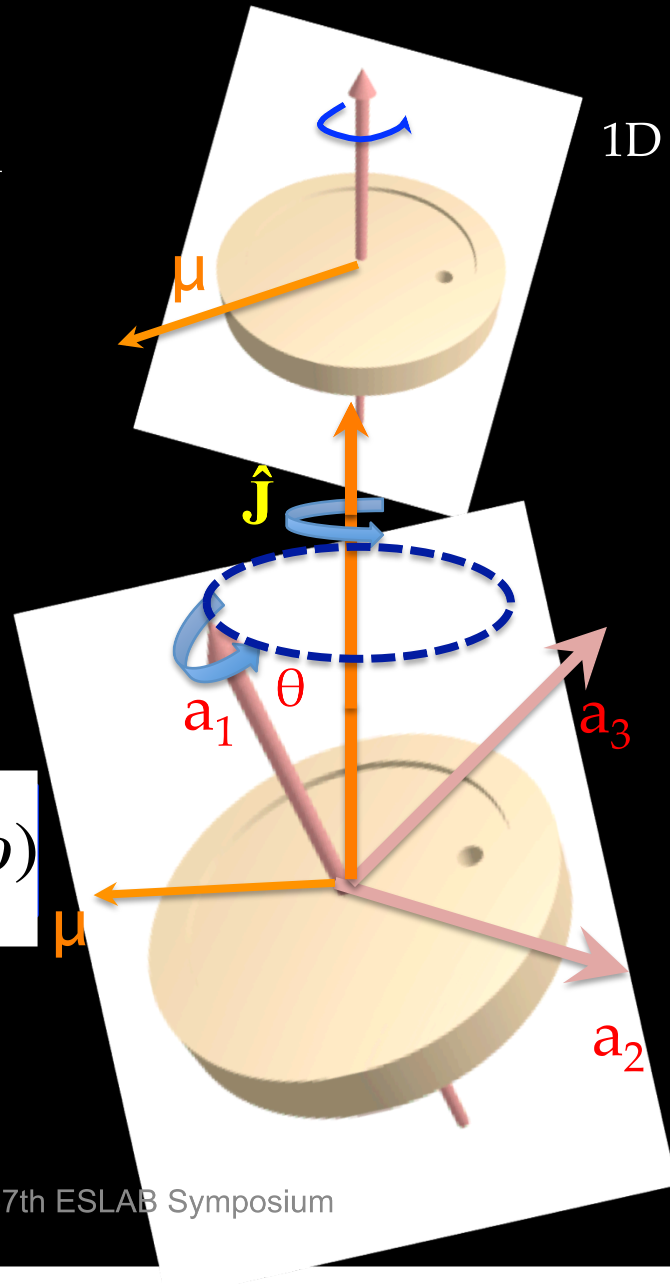
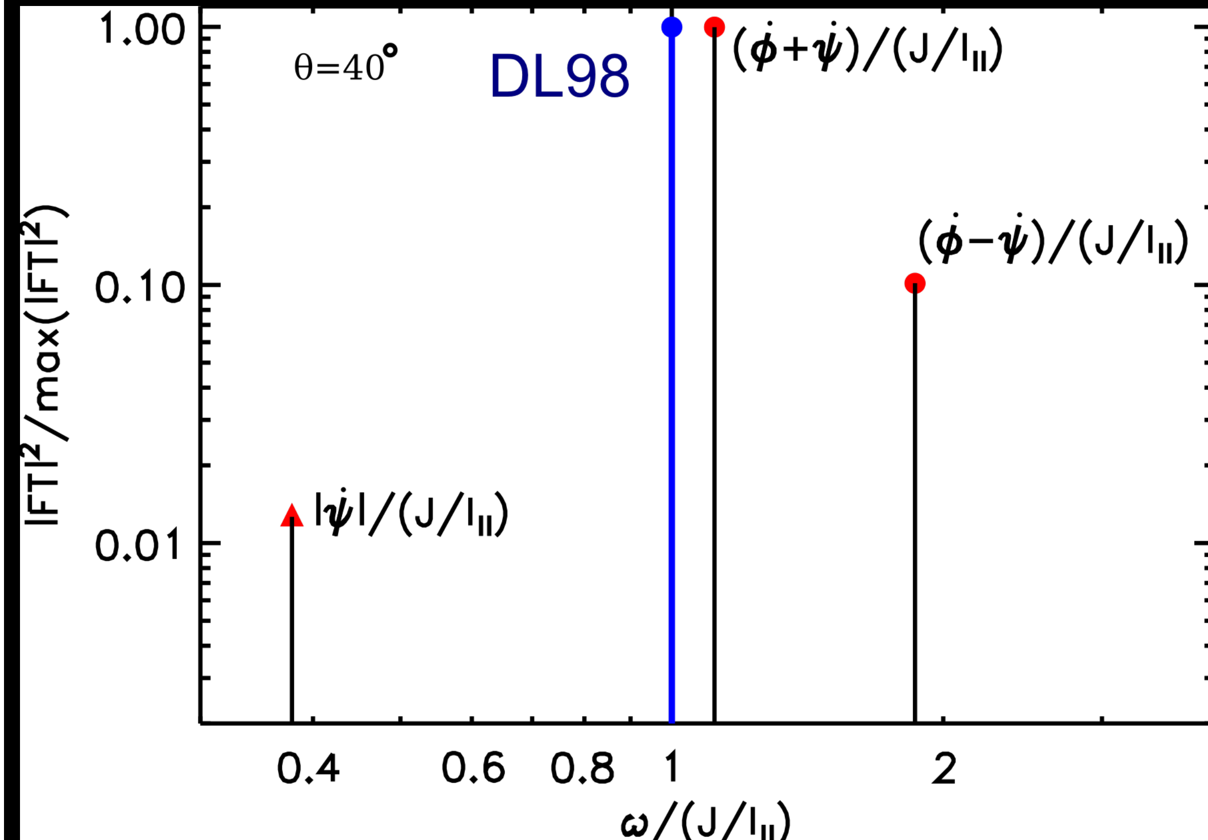
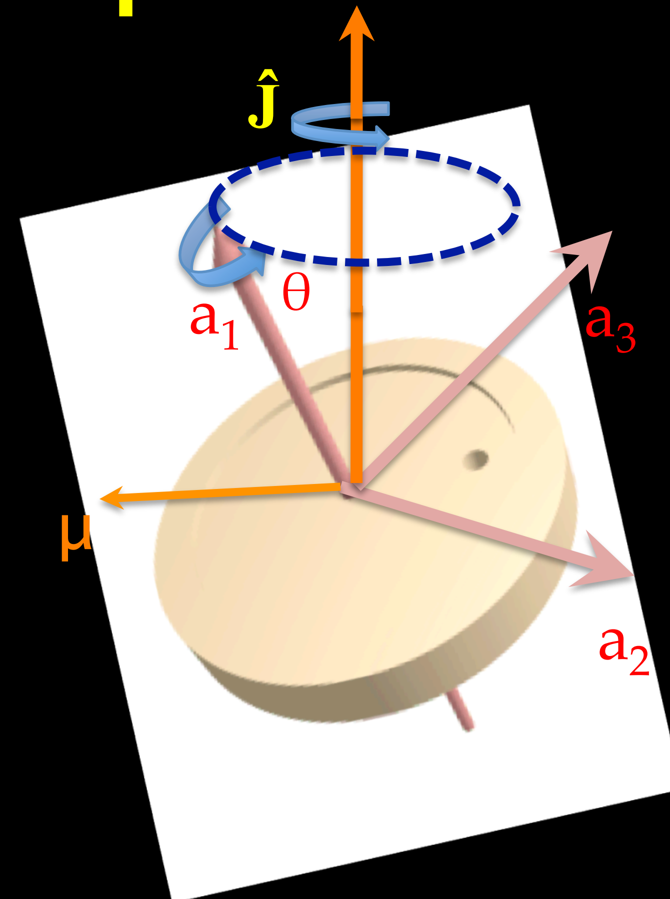


$$\frac{j_{\nu}}{n_H} \propto \int_{a_{\rm min}}^{a_{\rm max}} da \frac{dn}{da} 4\pi\omega^2 f_{\omega} 2\pi P_{\rm ed}(\omega)$$

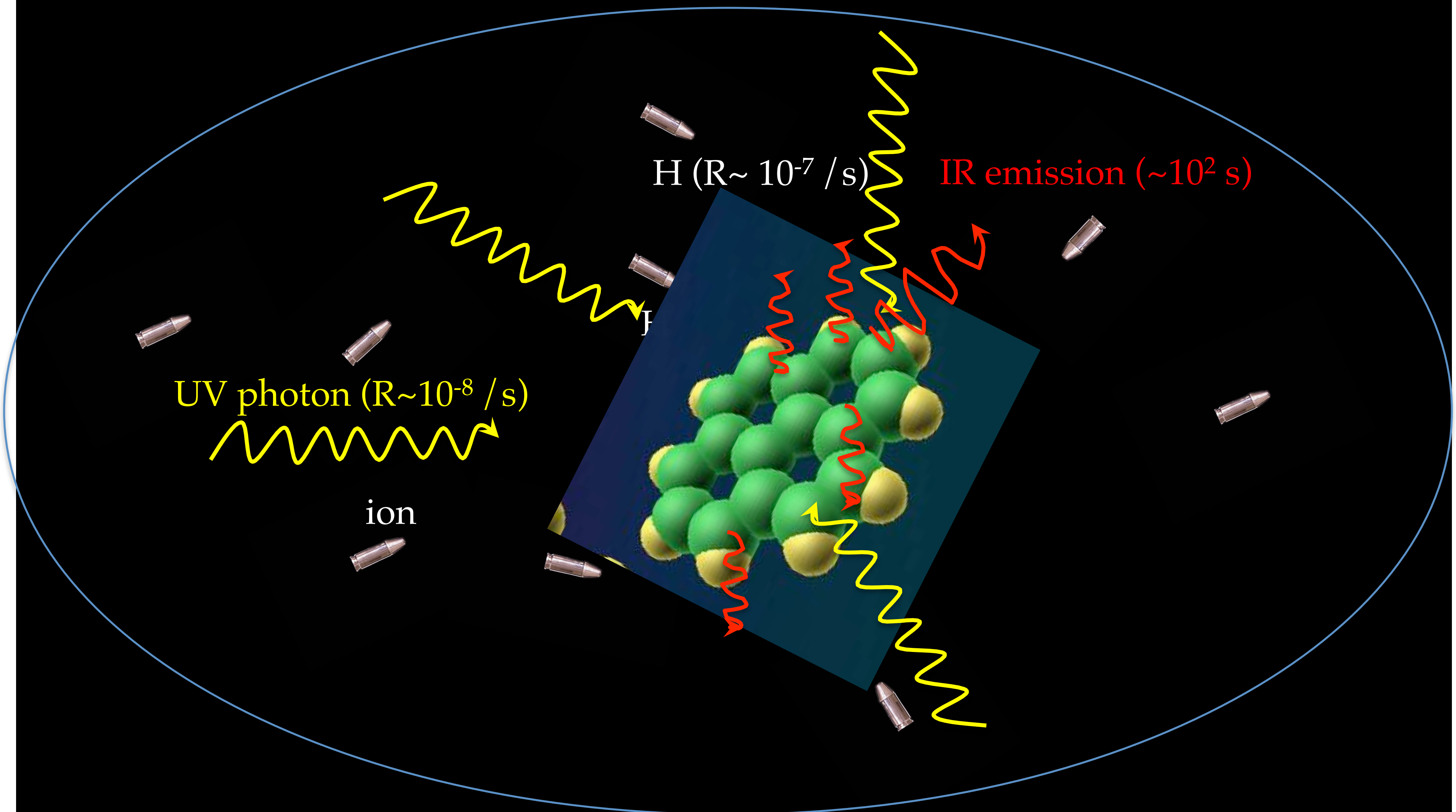
Power Spectrum: Four Freq. Modes





- Precessing grain radiates at 4 frequency modes:
- What induces grain rotation?

Rotational Damping and Excitation



Numerical Method: Langevin Equation

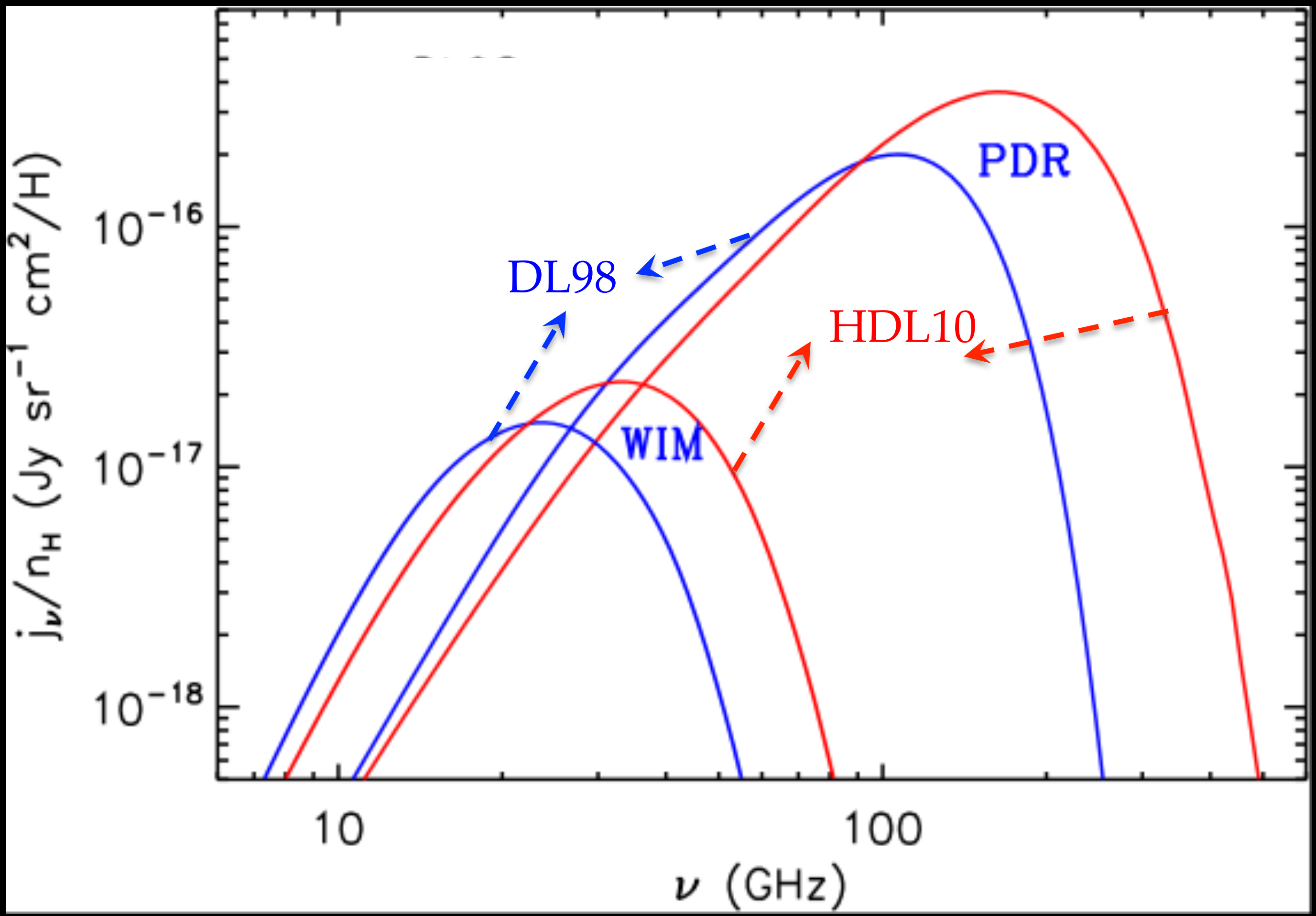
- Angular momentum **J** in the lab system is described by Langevin equations (LEs):

$$dJ_i = A_i dt + \sqrt{B_{ii}}\, dq_i\,,$$
$$A_i = \sum \left\langle \frac{\Delta J_i}{\Delta t} \right\rangle, B_{ii} = \sum \left\langle \frac{(\Delta J_i)^2}{\Delta t} \right\rangle, \langle dq^2 \rangle = dt$$

- Integrate LEs to get J(t) and find momentum distribution f_J
- Emissivity per H atom:

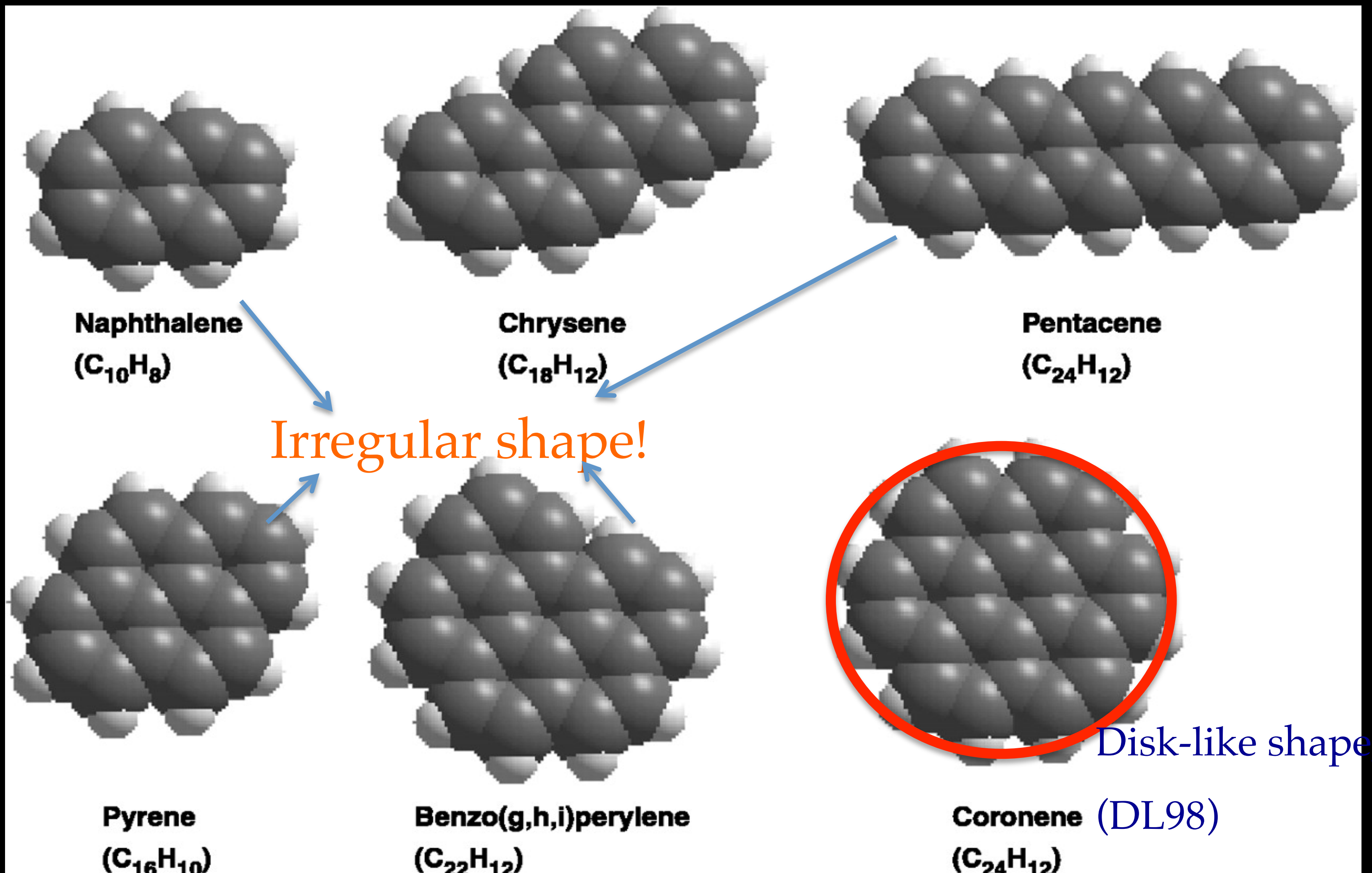
$$j_\nu^a = \int \sum_{\rm mod} prob(\omega \mid J) P_{\rm ed}(J) 2\pi f_J dJ \quad \Rightarrow \quad \frac{j_\nu}{n_{\rm H}} = \frac{1}{4\pi} \frac{1}{n_{\rm H}} \int da \frac{dn}{da} j_\nu^a$$

Wobbling Grain Increases Emissivity



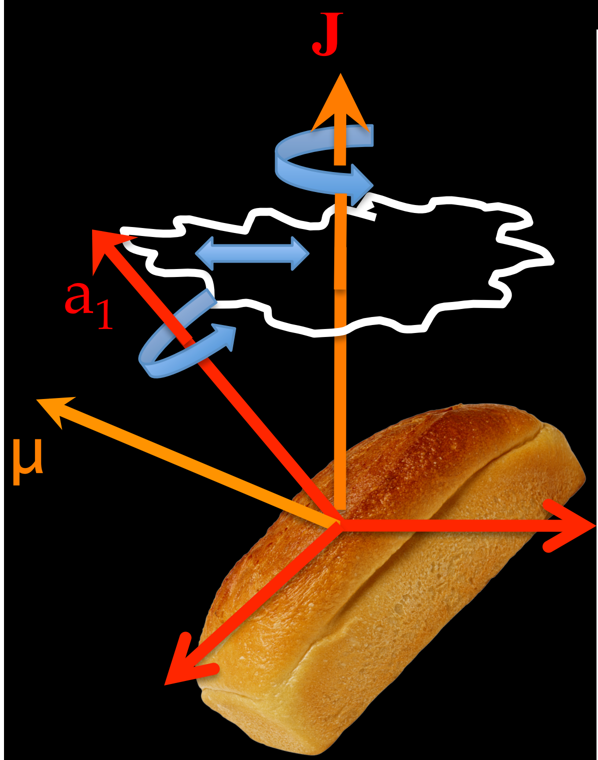
- Peak emissivity increases by a factor ~2 .
- Peak frequency increases by factors ~1.4 to 1.8.

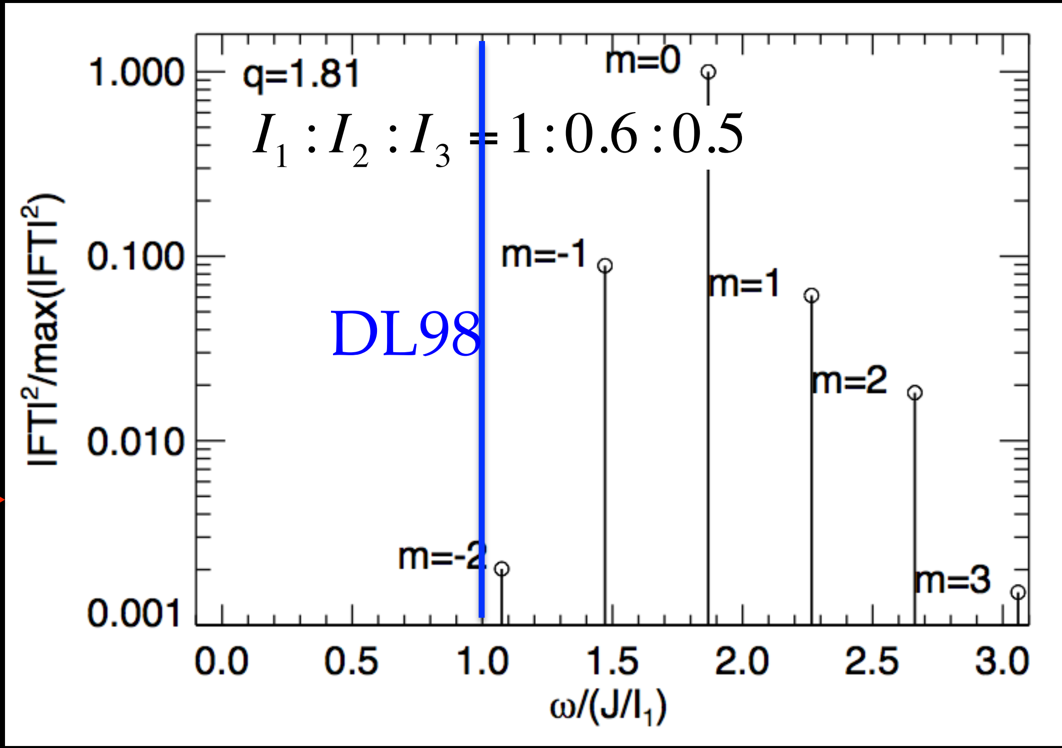
PAHs have Irregular Shapes



Credit: Internet

Power Spectrum: Multiple Freq. Modes





$$q = \frac{2I_1E_{\rm rot}}{J^2}$$

- Multiple frequency modes:

$$\omega_m = \langle\dot{\phi}\rangle + m\langle\dot{\psi}\rangle, m = 0, \pm1, \pm2...,$$
$$\omega_n = n\langle\dot{\psi}\rangle, n = 0,1,2$$

where <…> denotes time averaging.

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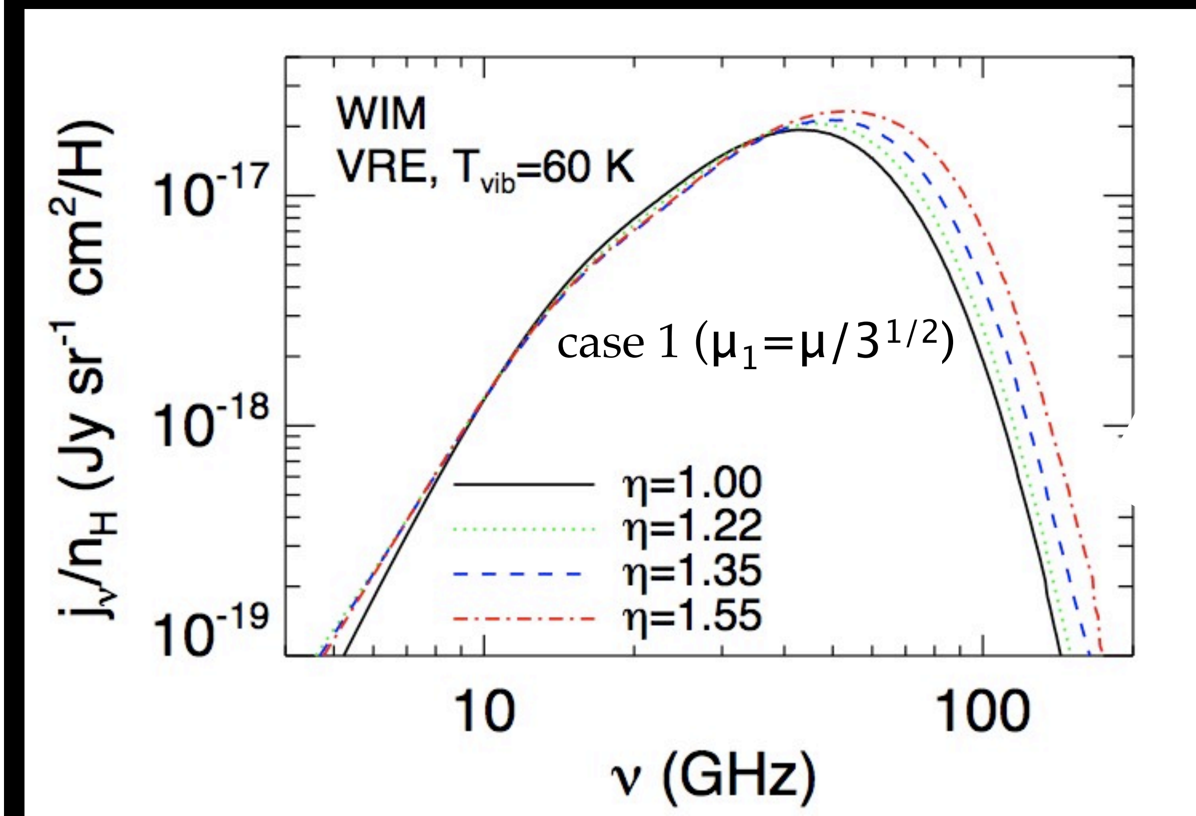
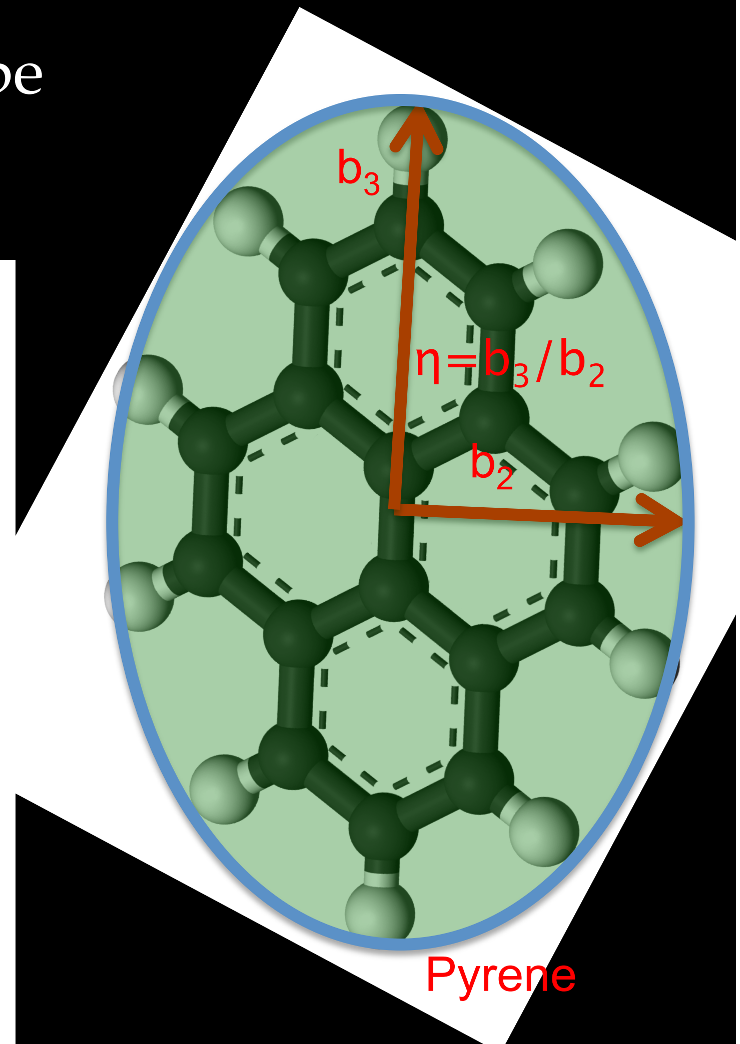
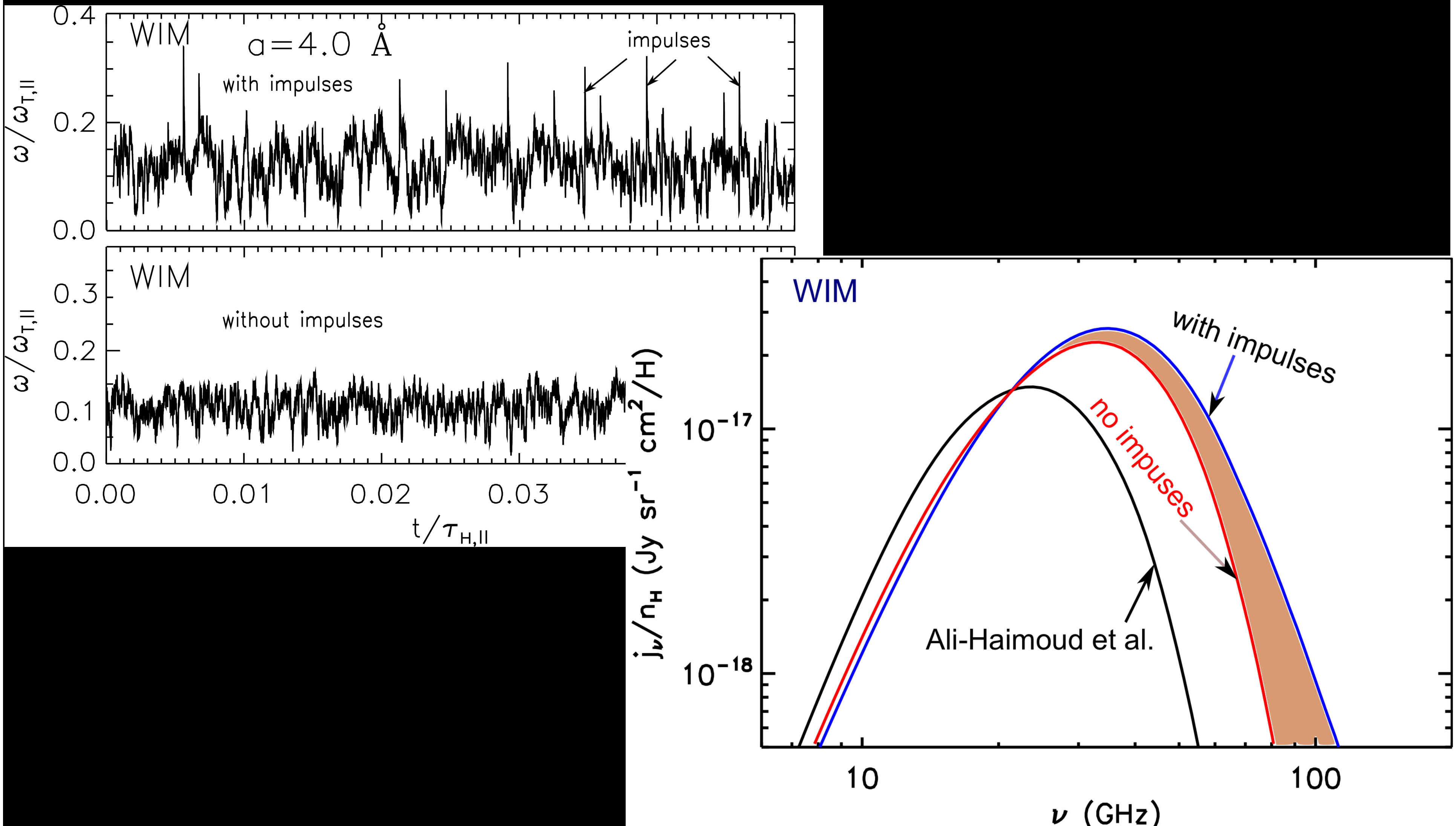
Emissivity Increases with Grain Irregularity

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

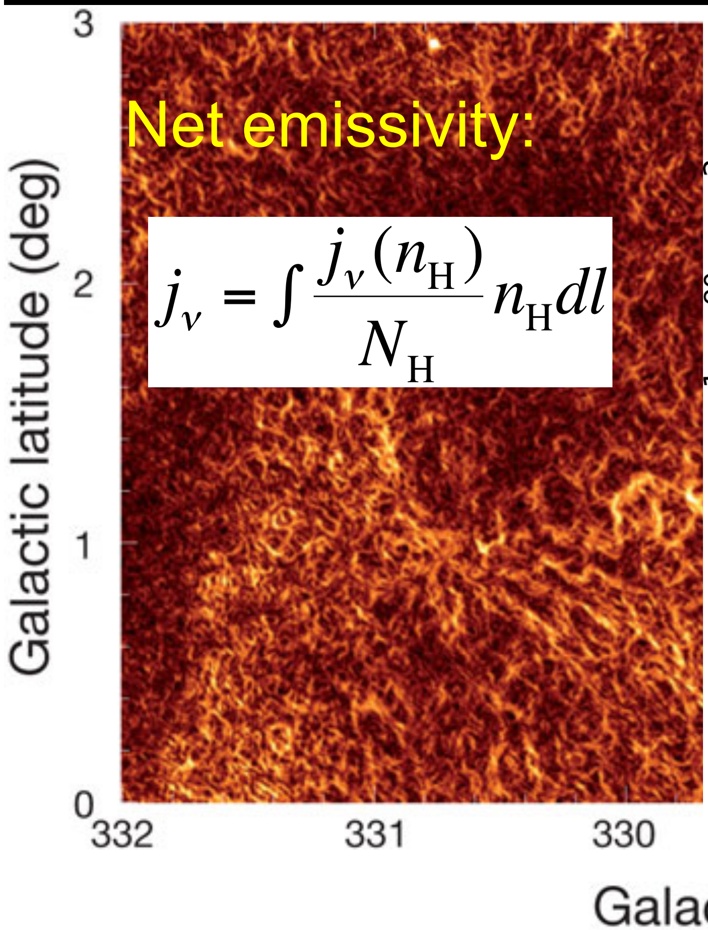


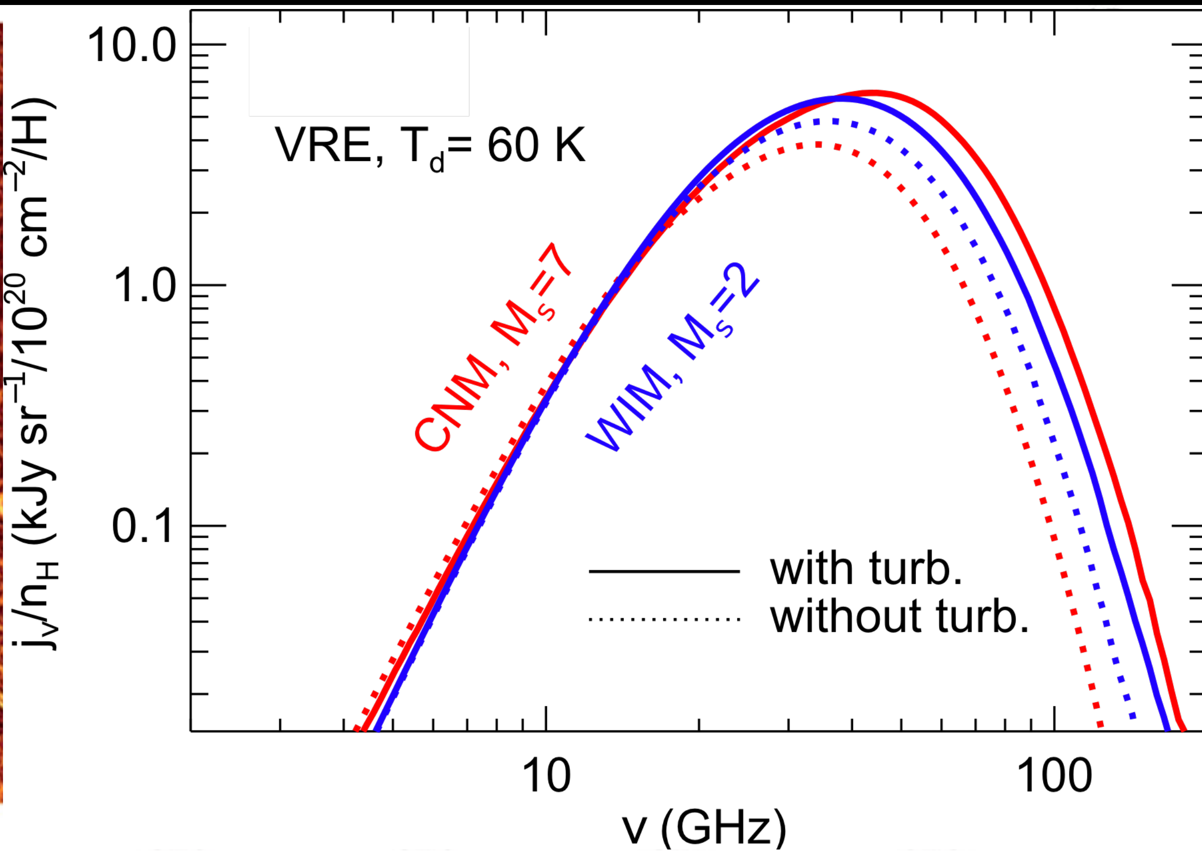


Impulsive excitation by single-ion collisions makes spectrum at ν > 30 GHz shallower



Compressible turbulence enhances emissivity



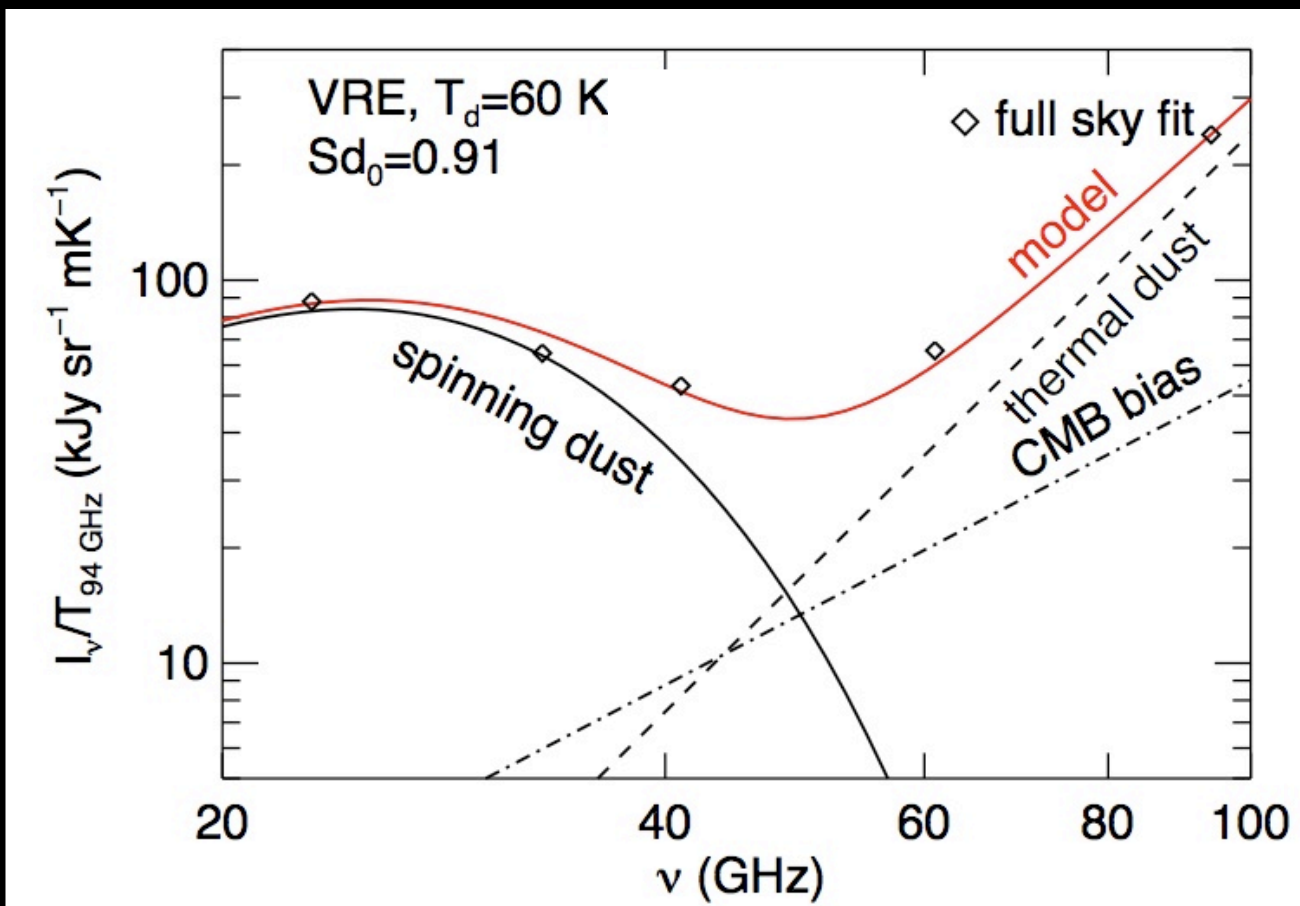


Gaensler et al. 2011, Nature

★ Emissivity increases with the amplitude of turbulence

Constraining PAH properties: Thermal Dust-Correlated Spectrum

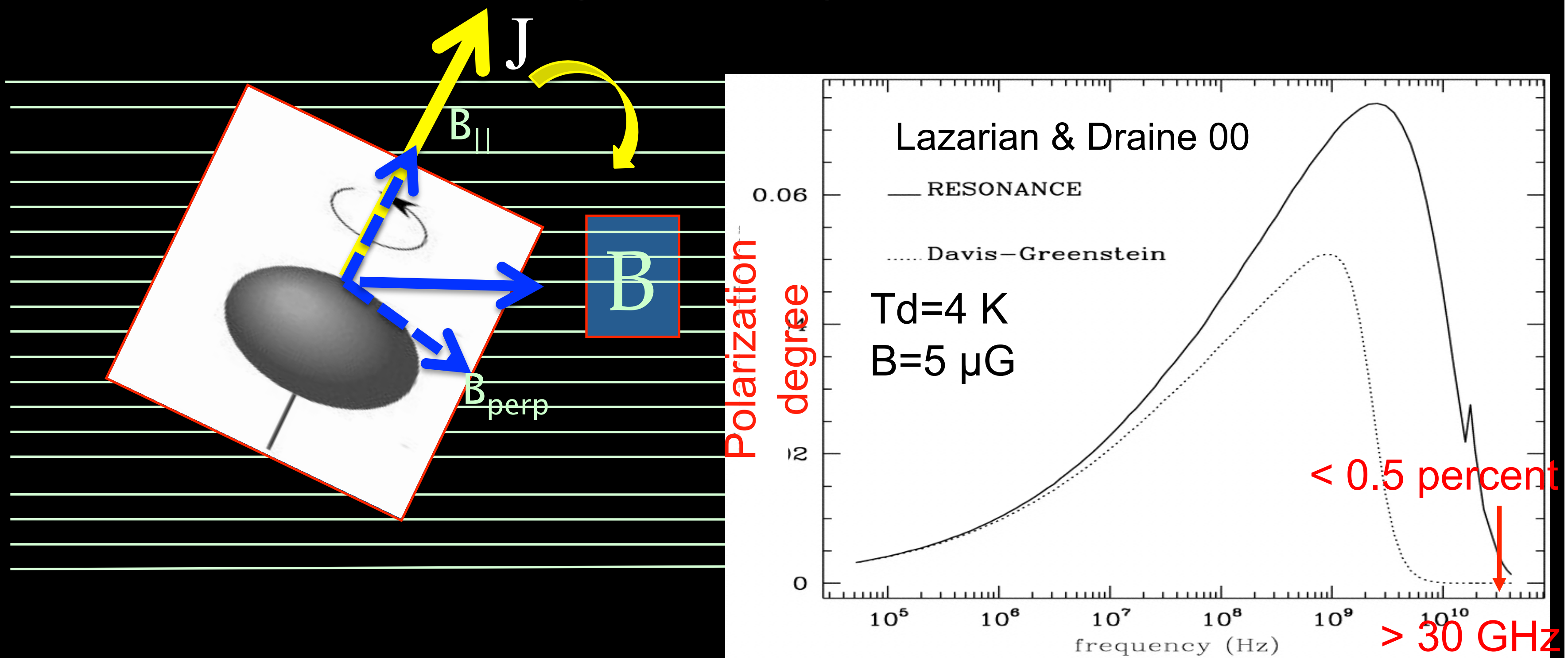
$$\frac{I_\nu^{\mathrm{mod}}}{T_{94\,\mathrm{GHz}}} = Sd_0 \frac{I_\nu^{\mathrm{sd}}(\mathrm{CNM})}{T_{94\,\mathrm{GHz}}} + C_0\left(\frac{\nu}{23\mathrm{GHz}}\right)^2 + T_0\left(\frac{\nu}{94\mathrm{GHz}}\right)^{3.8}$$



- ★ T_0=0.8
- ★ Sd_0 ~ 0.9
- ★ β_0=0.95 D,
- ★ n_H ~10 cm^{-3}

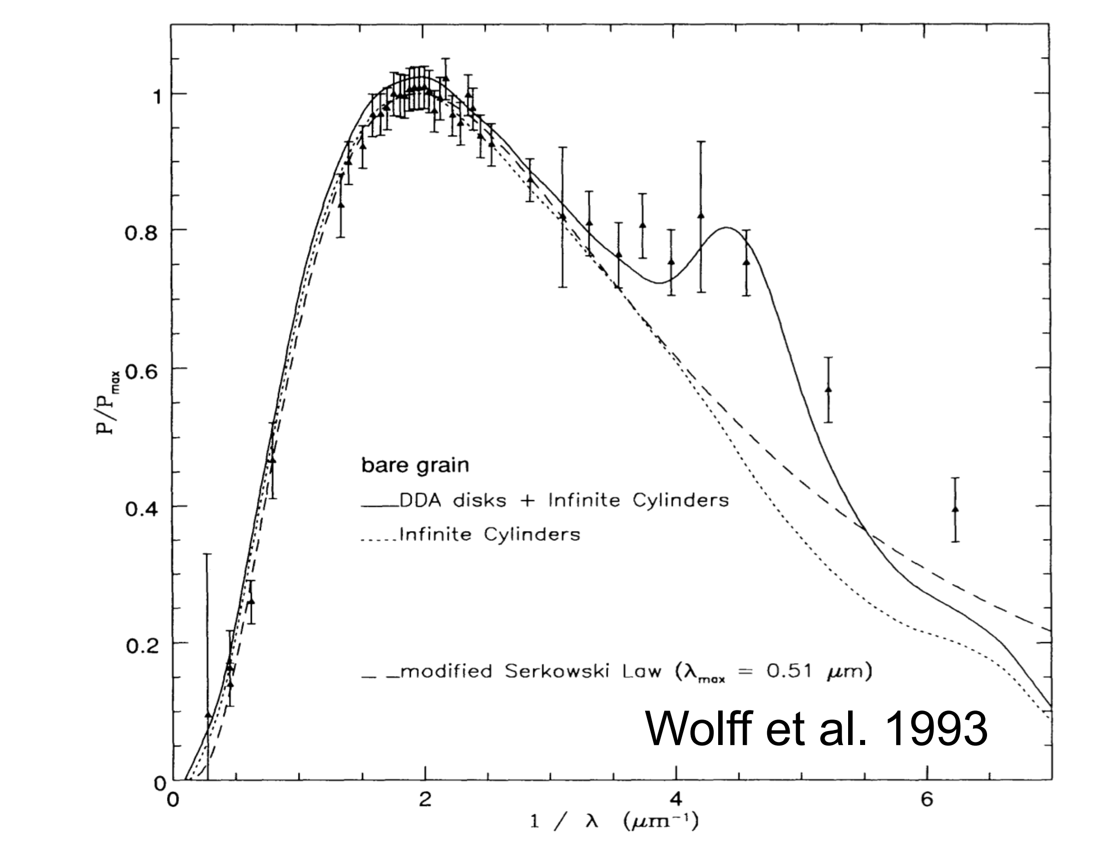
Polarization of Spinning Dust Emission

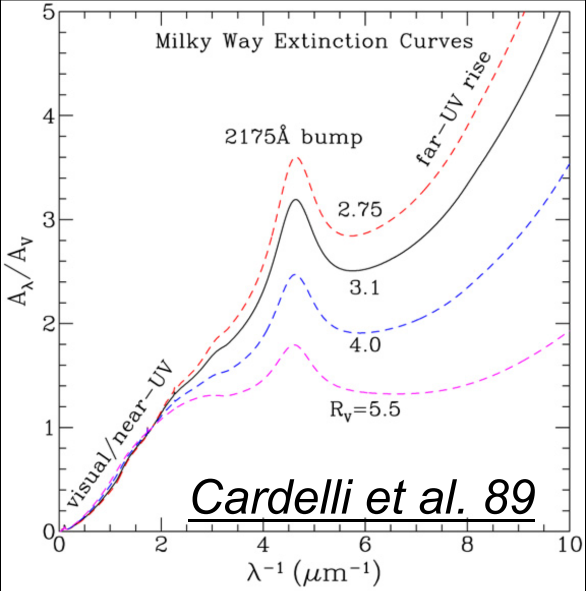
Davis-Greenstein paramagnetic alignment:

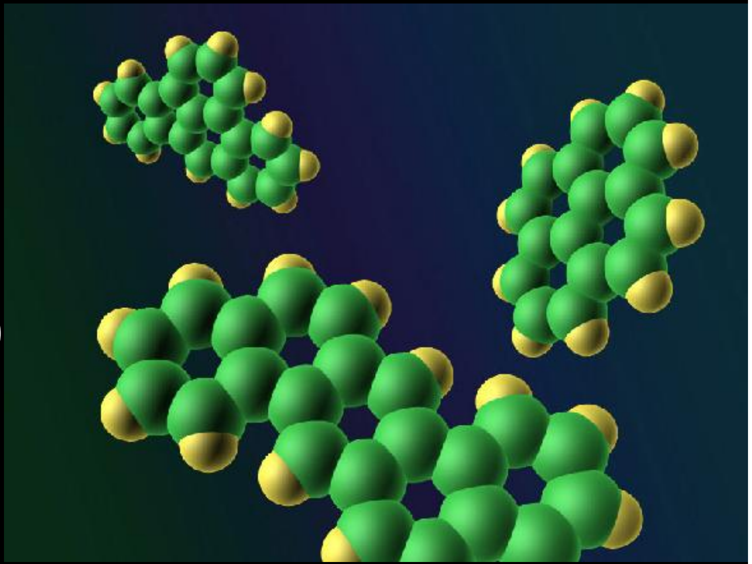


- Paramagnetic body gets magnetized parallel to external B
- Rotating magnetization by B_{perp} induces energy dissipation, decreasing angle between J and B.

Constraint by UV Polarization Bump

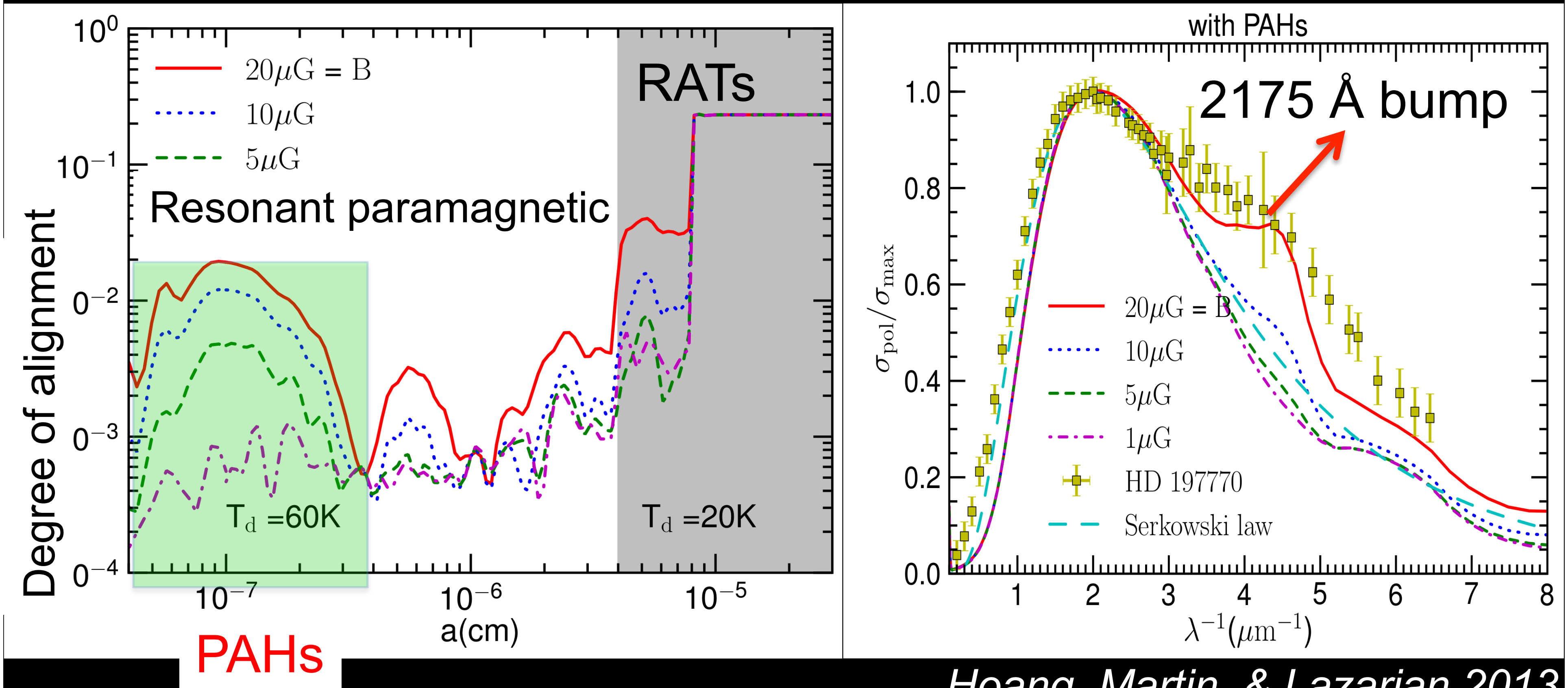






- PAHs produce 2175 Å (e.g., Draine 89)
- PAHs radiate spinnning dust emission
- How efficient are PAHs aligned?

Constraint by UV Polarization Bump



Hoang, Martin, & Lazarian 2013

- PAHs weakly aligned by resonant paramagnetic relaxation (LD00)
- UV polarization bump constrains magnetic field strength
- Polarization of spinning dust emission < 5%.

Summary

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

2. Comprehensive model can be used to probe PAH physical parameters using observational data (e.g., Planck data).

3. Spinning Dust Emission is very weakly polarized. Constraint of magnetic fields using spinning dust polarization.