Improved Model of Spinning Dust Emission and Implications

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in collaboration with

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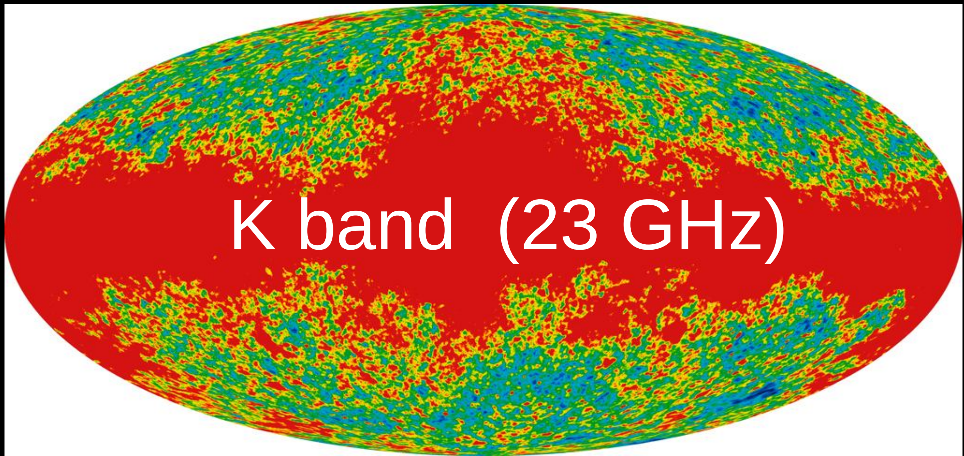
Outline

- Motivation
- Galactic Foregrounds to CMB and Anomalous Microwave Emission
- Draine & Lazarian Model (DL98, Alex’s talk)
- Improved Model of Spinning Dust
- Constraining Physical Parameters using WMAP data
- Summary and Future Works

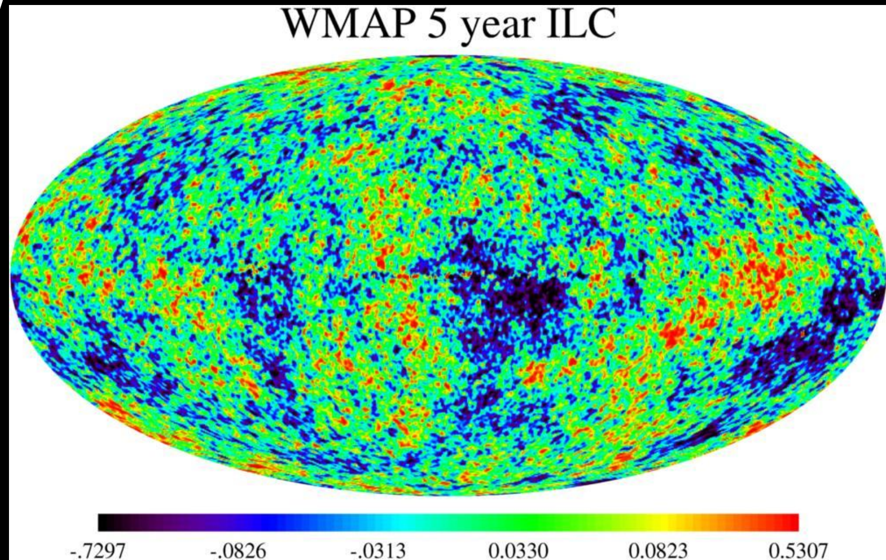
Motivation: Precision Cosmology



K band (23 GHz)

LAMBDA

cleaning



Understanding

Galactic Foregrounds

WMAP Cosmological Parameters Model: lcdm Data: wmap+sdss	
$10^2\Omega_b h^2$	$2.230^{+0.071}_{-0.070}$
$\Delta^2_{\mathcal{R}}(k = 0.002/\mathrm{Mpc})$	$(24.1 \pm 1.3) \times 10^{-10}$
h	0.710 ± 0.026
H_0	71.0 ± 2.6 km/s/Mpc
$n_s(0.002)$	$0.948^{+0.016}_{-0.015}$
$\Omega_b h^2$	$0.02230^{+0.00071}_{-0.00070}$
Ω_Λ	0.735 ± 0.030
Ω_m	0.265 ± 0.030
$\Omega_m h^2$	[illegible]

Spergel et al. 2003

Improved Model of Spinning Dust

Step 1: Improve grain rotational dynamics

-Grain precession, internal relaxation

(Hoang, Draine & Lazarian 2010, ApJ, 465, 1602)

Silsbee, Ali-Haimoud & Hirata 2011: Grain precession, no internal relaxation

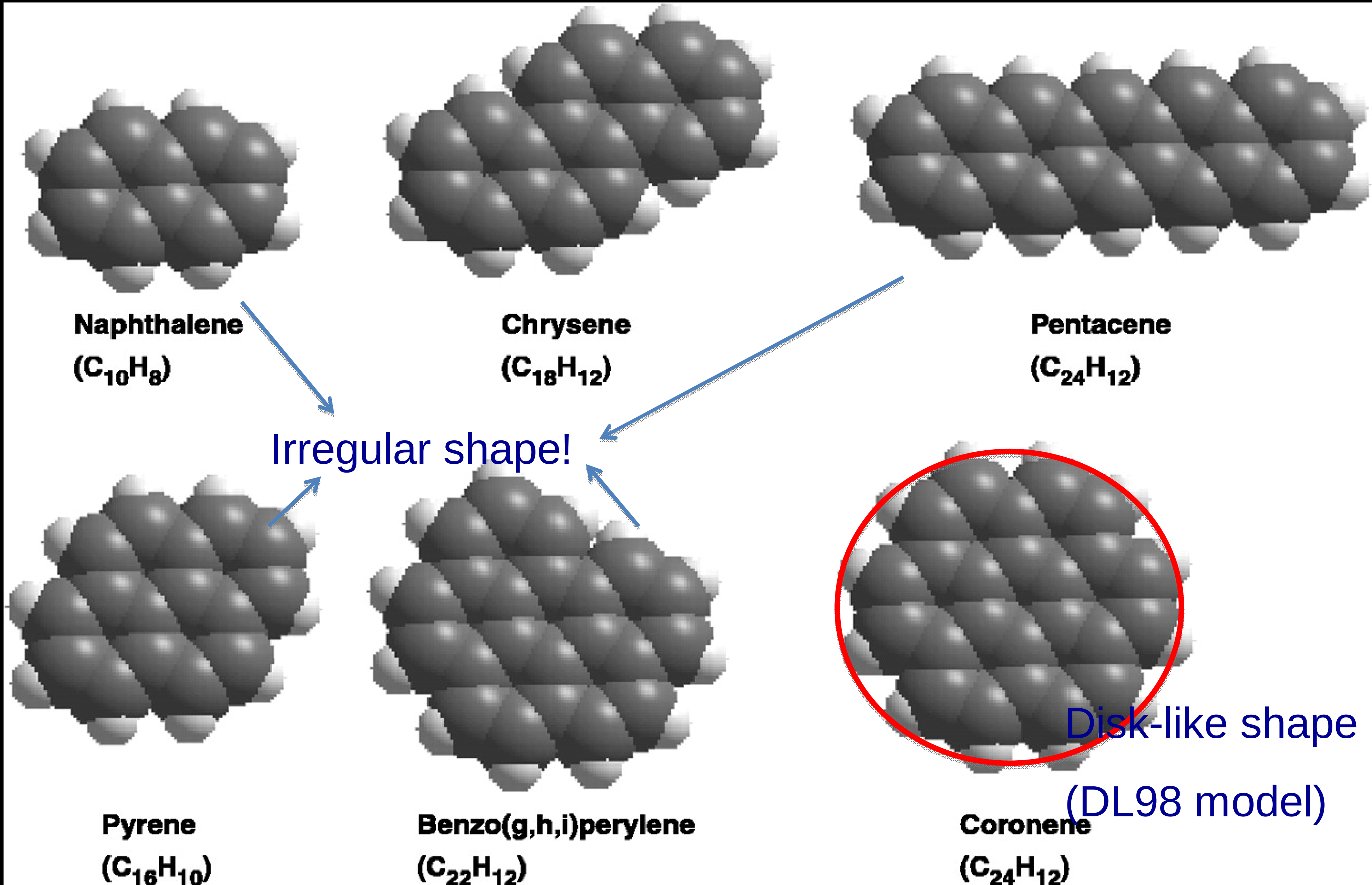
Step 2: Deal with realistic grain shape

- Triaxial ellipsoid (*irregular* shape)

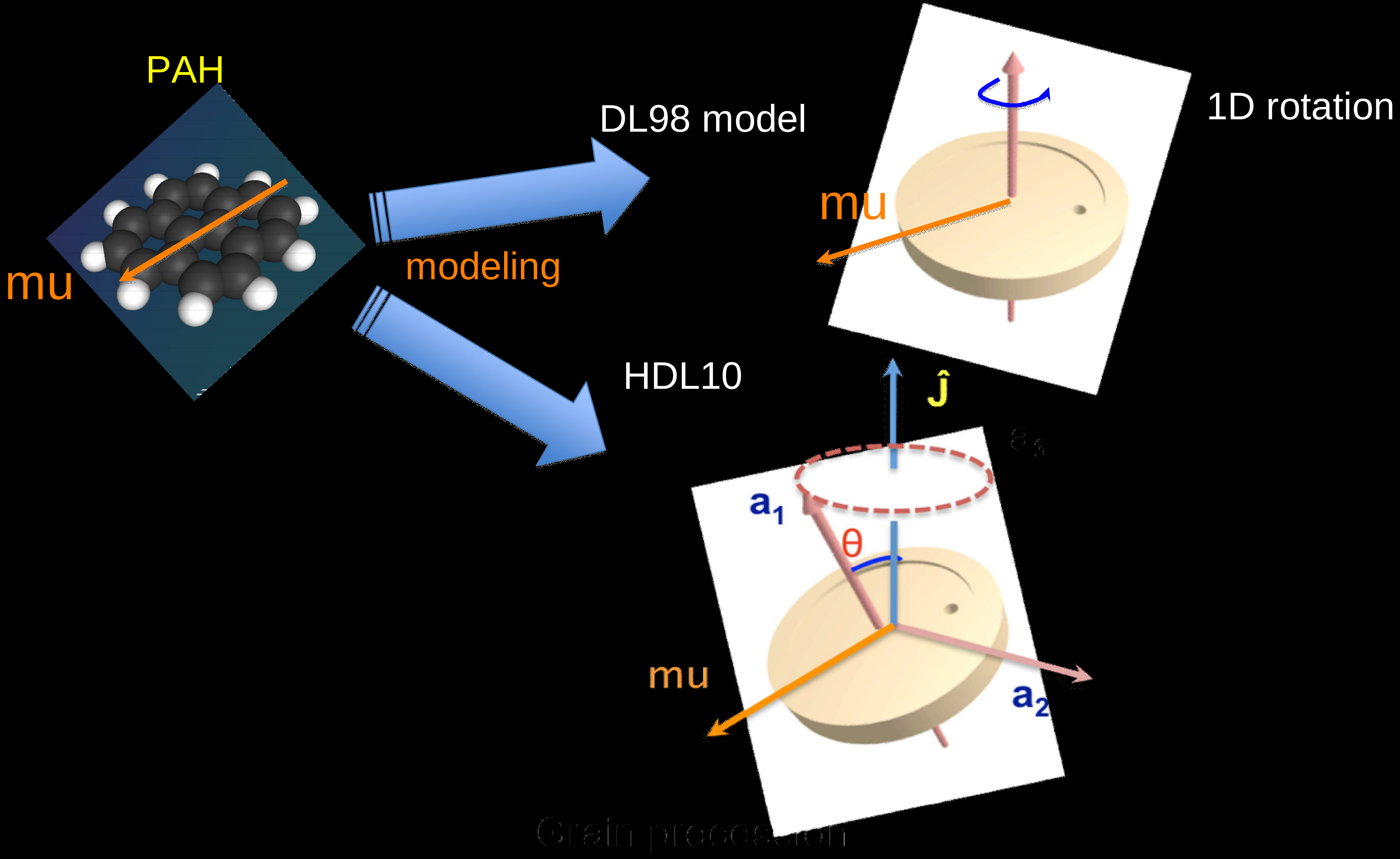
- Grain wobbling

(Hoang, Lazarian & Draine 2011, ApJ, 741, 87)

What are small dust grains? PAHs



Step 1: Grain Precession

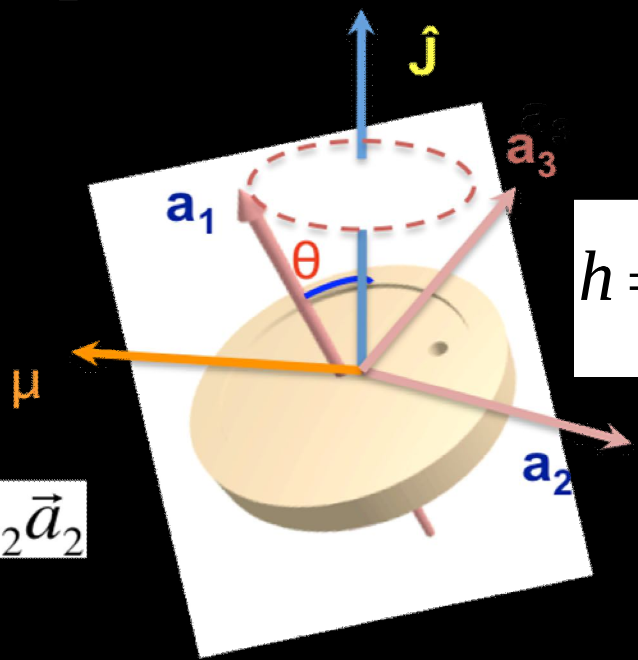


Spinning Dust: Power Spectrum

- Torque-free motion: Euler angles ϕ, ψ, θ

and rates: $$\dot{\theta} = 0, \dot{\psi} = \frac{J \cos\theta (1-h)}{I_1}, \dot{\phi} = \frac{J}{I_2}$$

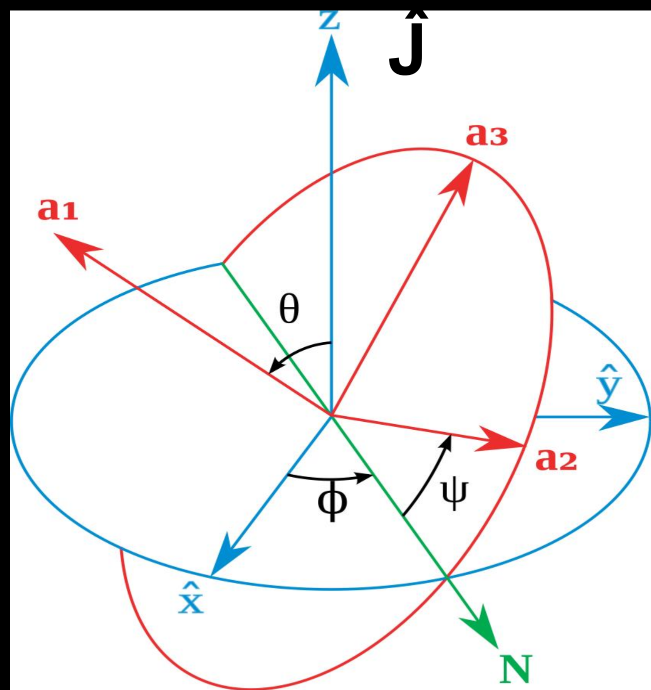
$$h = \frac{I_1}{I_2}$$



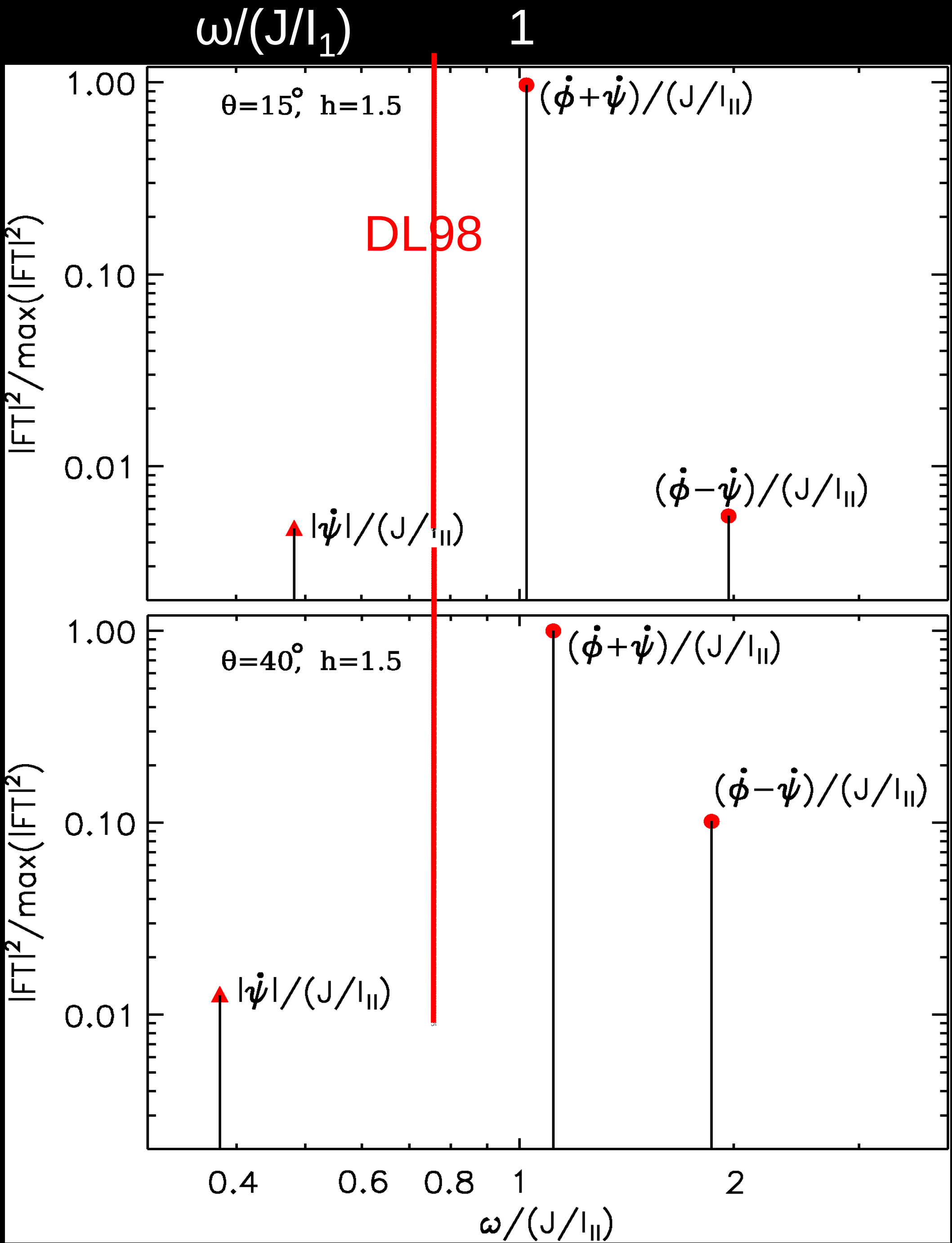
- Electric dipole moment: $\vec{\mu}(J,\theta,t) = \mu_1 \vec{a}_1 + \mu_2 \vec{a}_2$
- Fourier Transform:

$$\ddot{\mu}_{i,k} = \int_0^{\infty} \ddot{\mu}_i(t) \exp(-i 2\pi \nu_k t) dt, i = x, y, z$$

- Power Spectrum: $$P_{\mathrm{ed},k}(J,\theta) = \frac{2}{3c^3} \sum_i (\ddot{\mu}_{i,k})^2$$



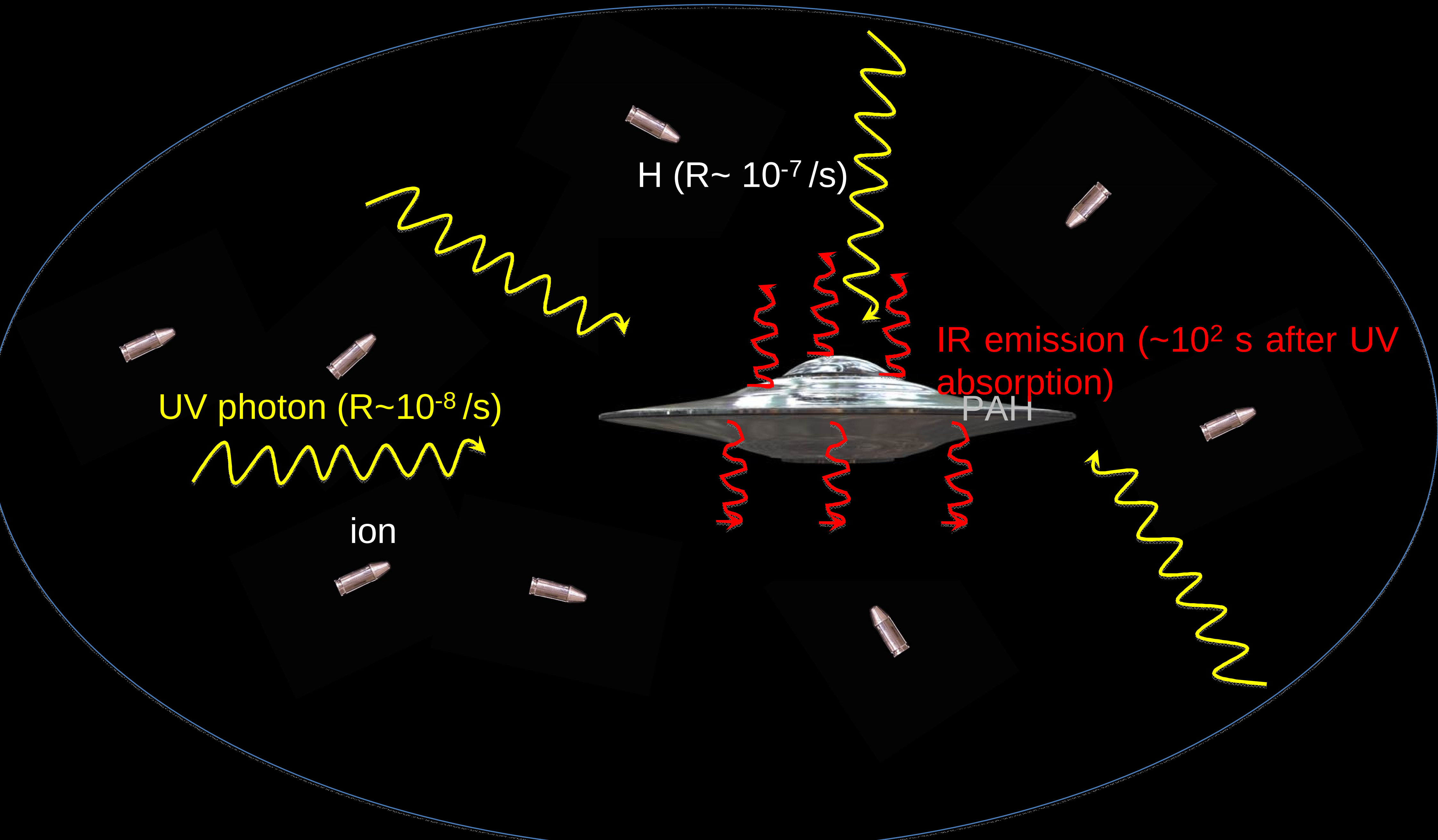
Power Spectrum



- Precessing grain radiates at frequency modes: $\omega_k = \dot{\phi}, \dot{\phi} \pm \dot{\psi}, \dot{\psi}$
- Dominant modes: $\omega_k = \dot{\phi} \pm \dot{\psi}$

What makes dust grain rotating?

Rotational Damping and Excitation



Numerical Method: Langevin Equations

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

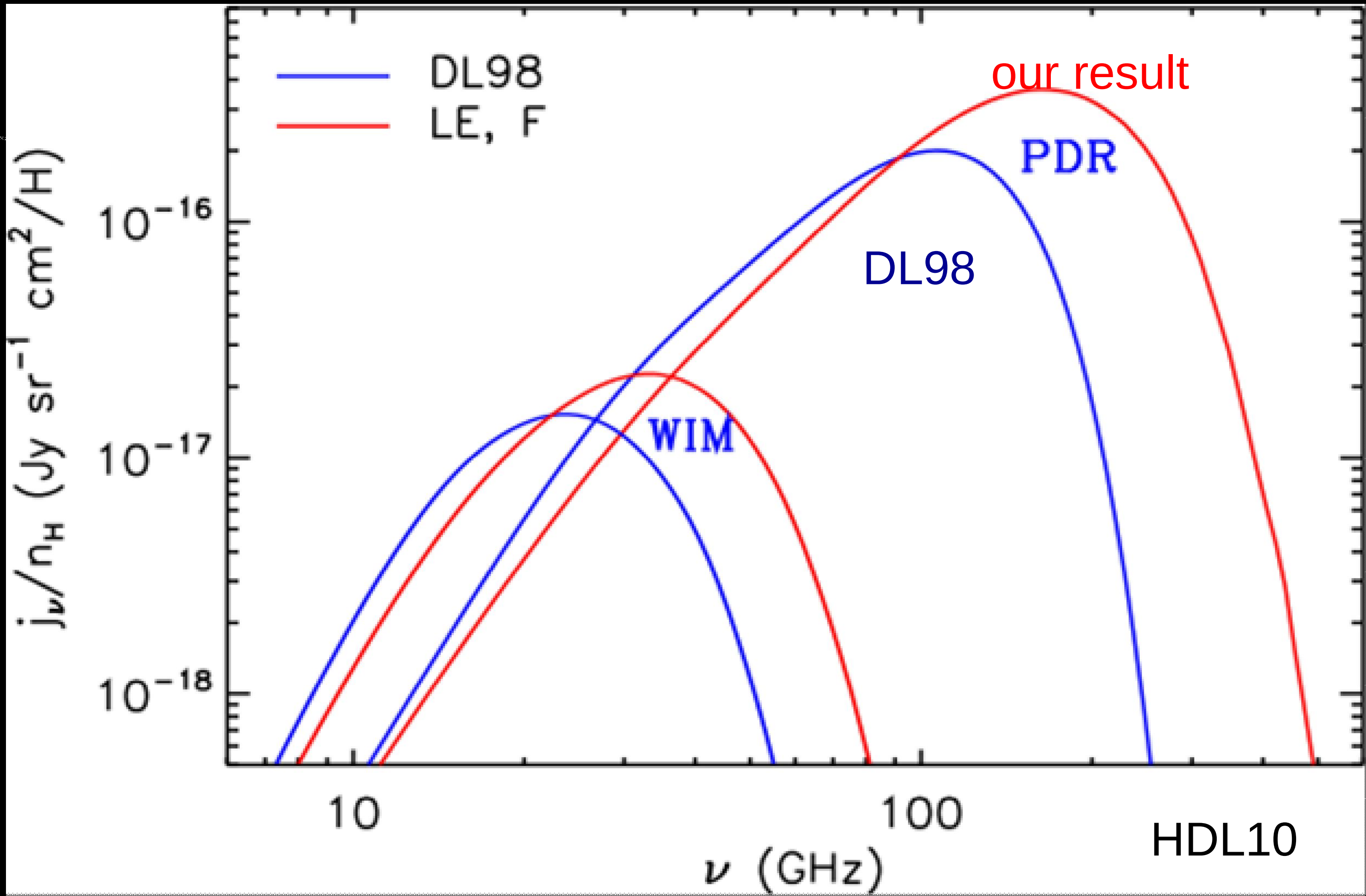
$$dJ_i = A_i dt + \sqrt{B_{ii}} dq_i ,$$

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

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

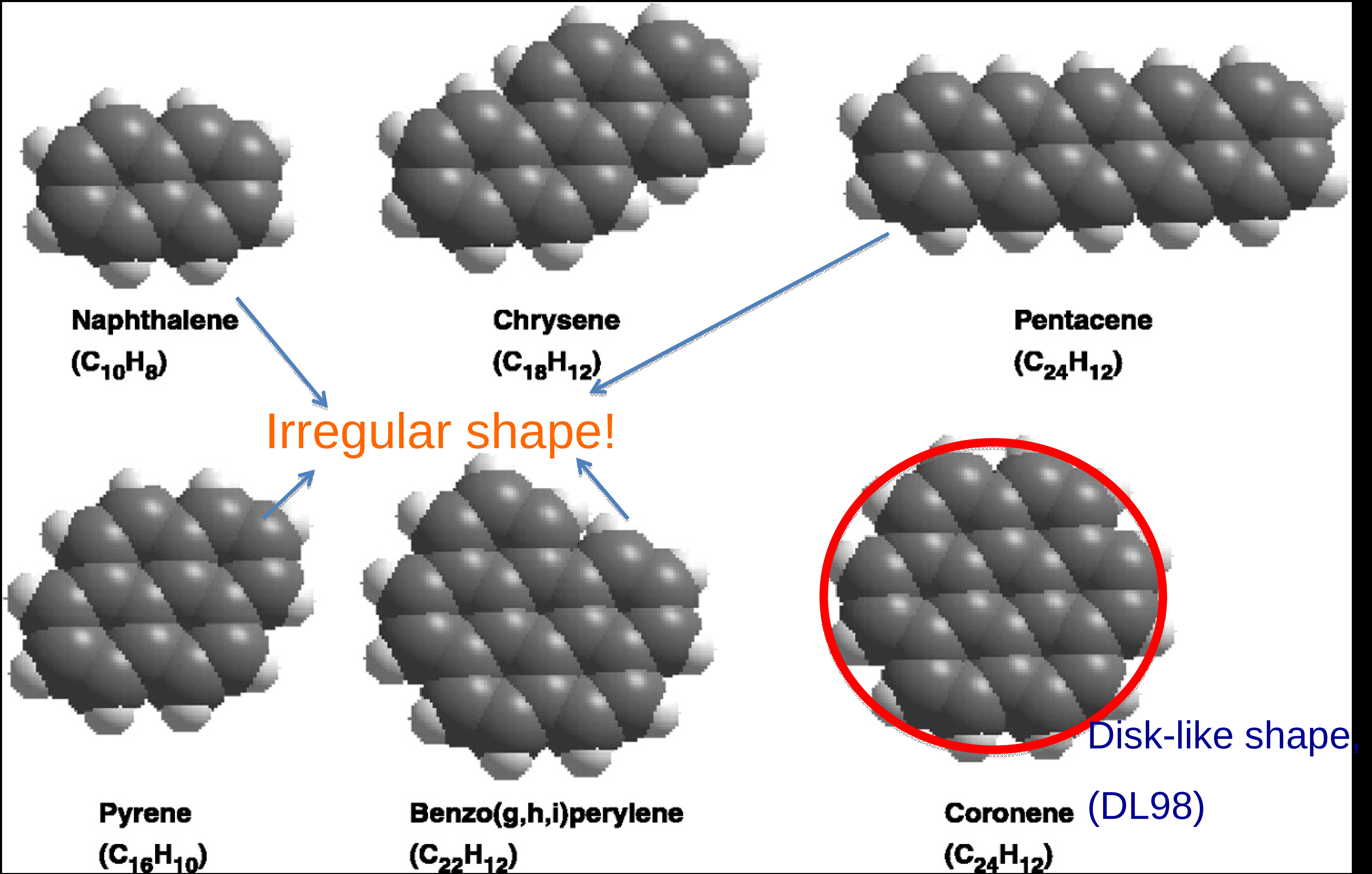
$$j_\nu^a = \int \sum_{\text{mod}} prob_{\text{mod}}(\omega \,|\, J) P_{\text{ed}}(J) 2\pi f_J dJ \quad \rightarrow \quad \frac{j_\nu}{n_{\text{H}}} = \frac{1}{4\pi} \frac{1}{n_{\text{H}}} \int da \frac{dn}{da} j_\nu^a$$

Emission Spectrum

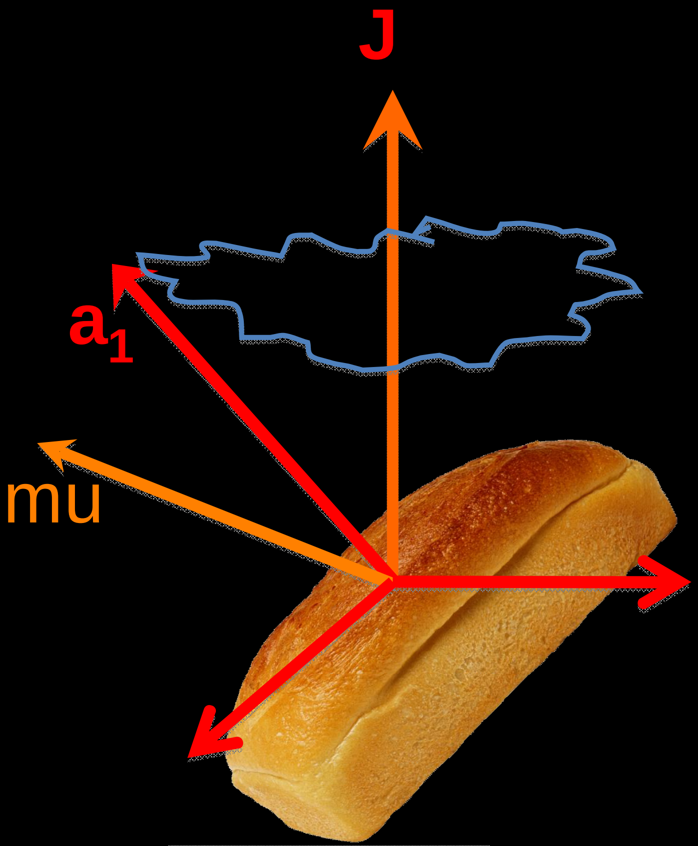


- Peak emissivity increases by a factor ~2 .
- Peak frequency increases by factors ~1.4 to 1.8.

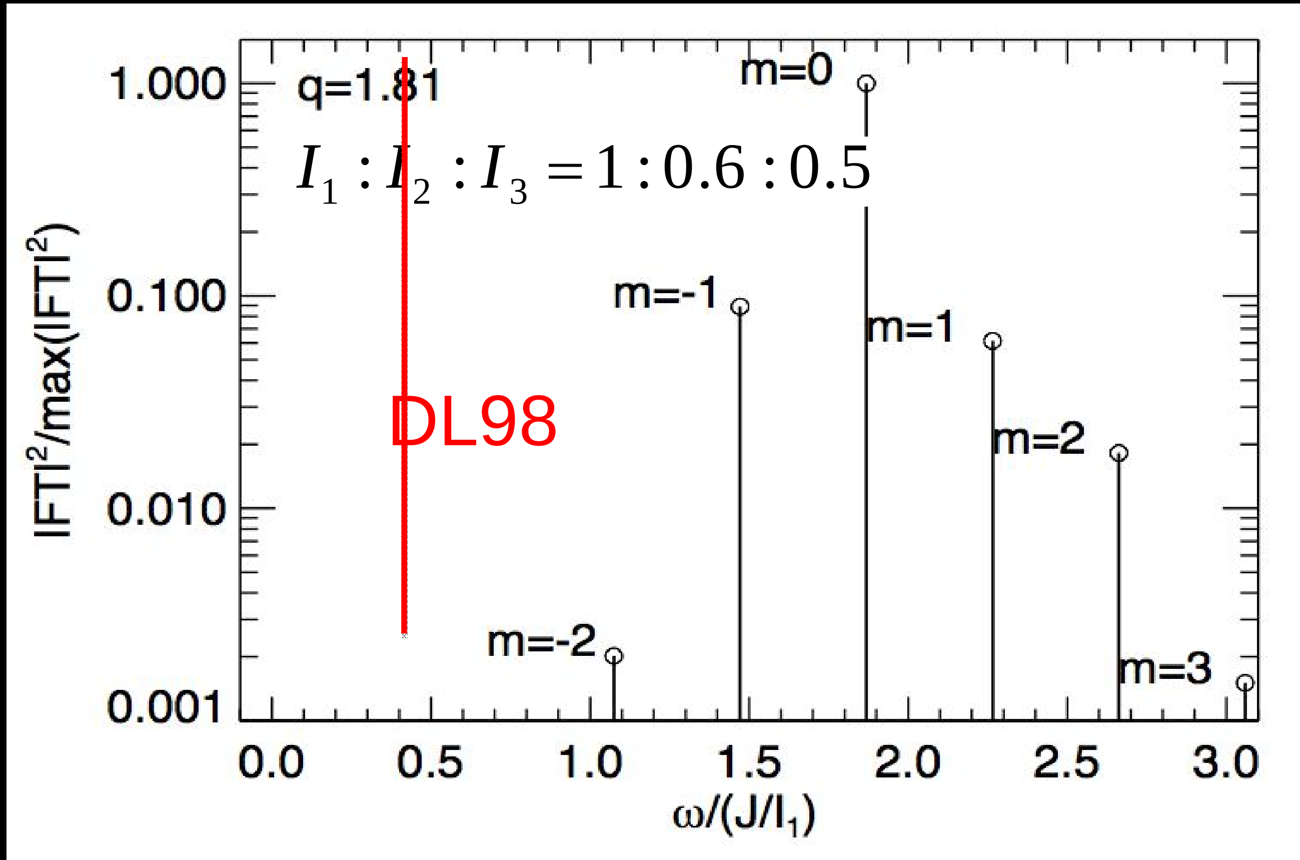
Step 2: Irregular Shape



Power Spectrum



$$q = \frac{2 I_1 E_{rot}}{J^2}$$



HLD11

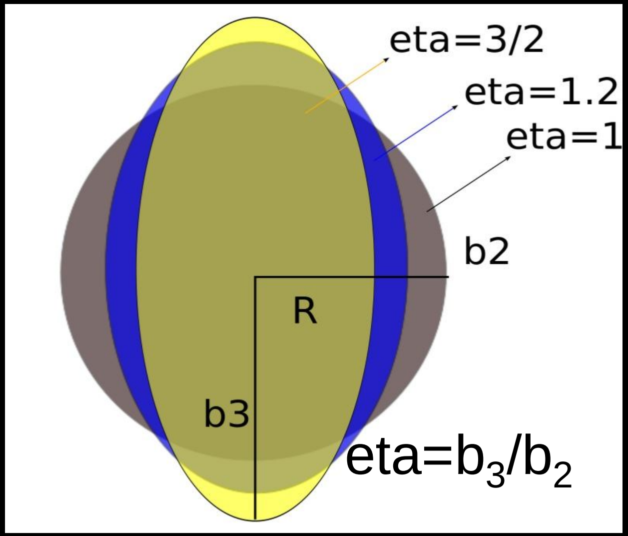
- Multiple frequency modes:

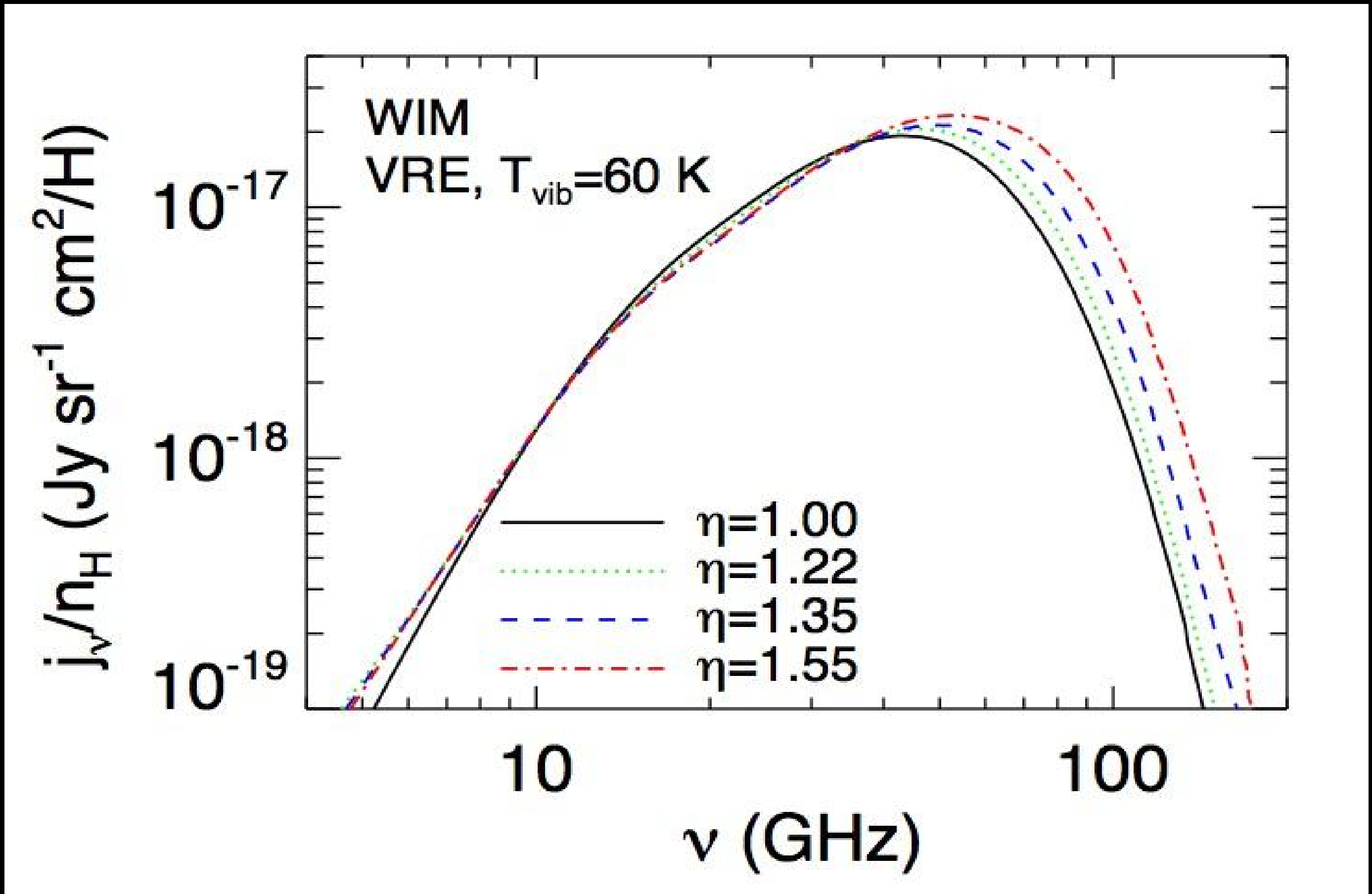
$$\omega_m = \langle \dot{\phi} \rangle + m \langle \dot{\psi} \rangle, m = 0, \pm 1, \pm 2 \ldots,$$
$$\omega_n = n \langle \dot{\psi} \rangle, n = 0, 1, 2$$

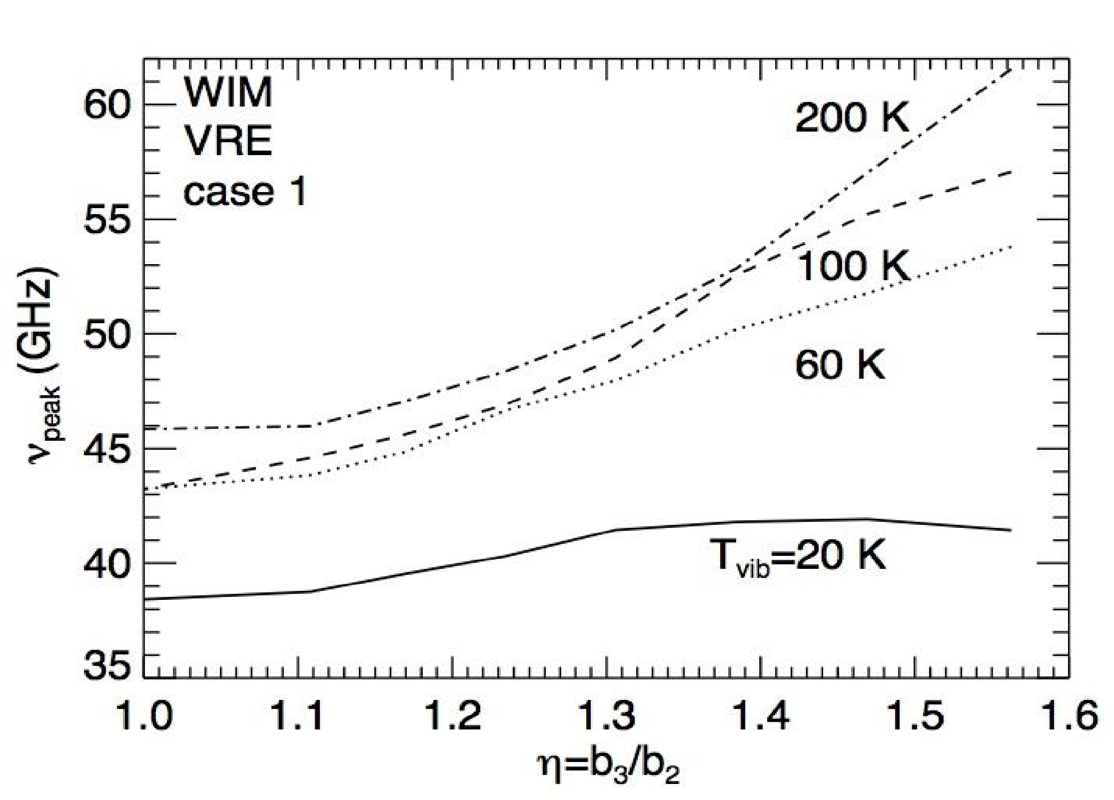
where <…> denotes time averaging.

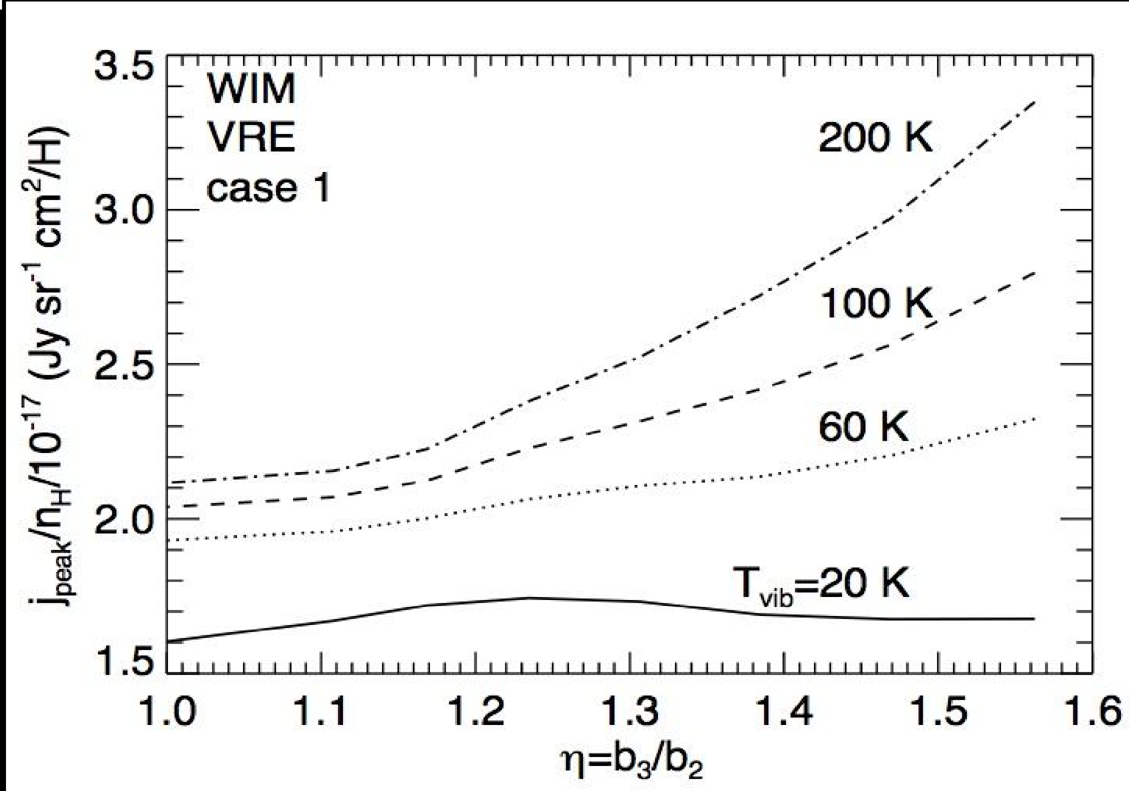
Emission Spectrum

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



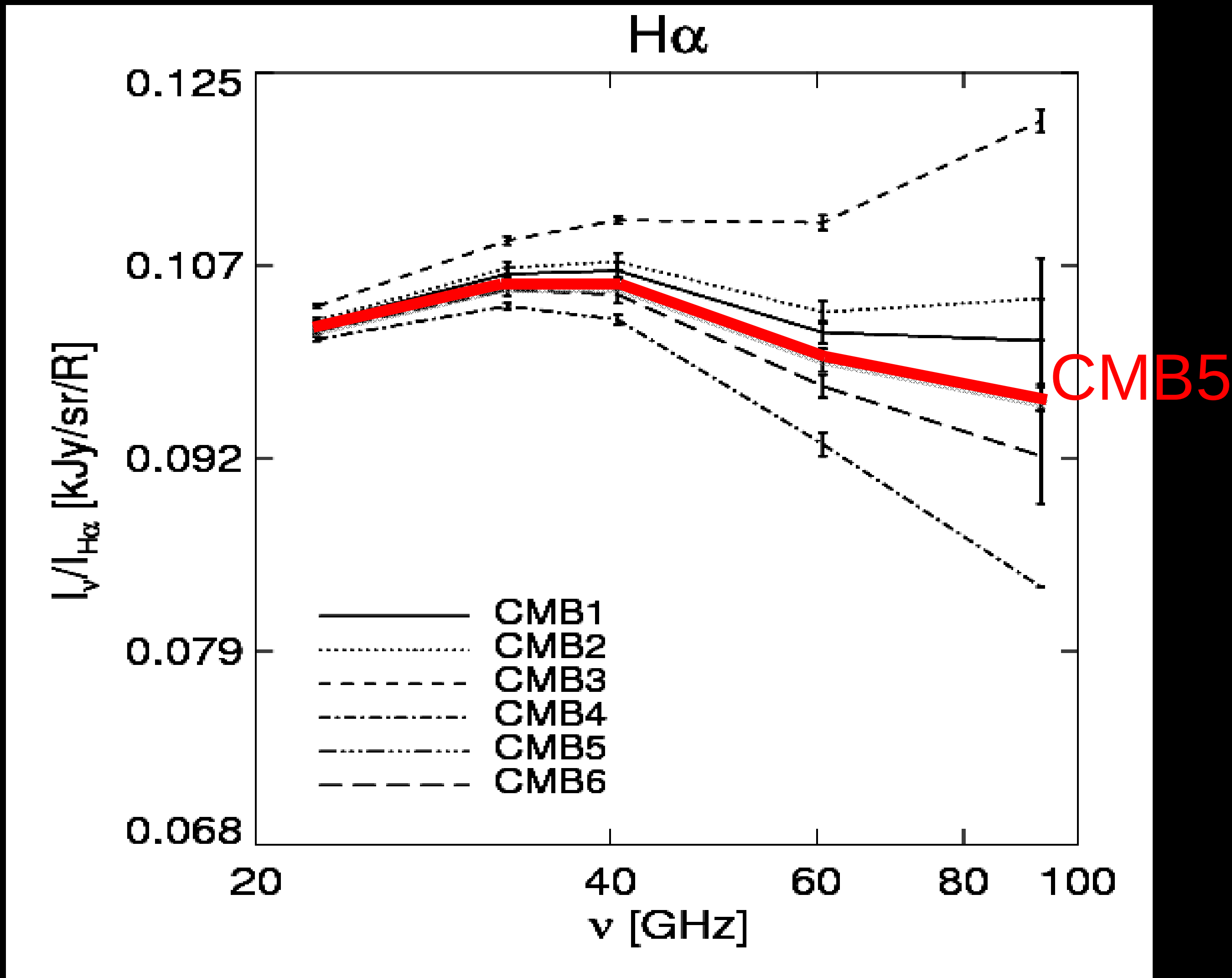






- Emissivity increases with η
- ★ Emissivity increases with T_{vib}

Constraining Physical Parameters: Fitting to WMAP data

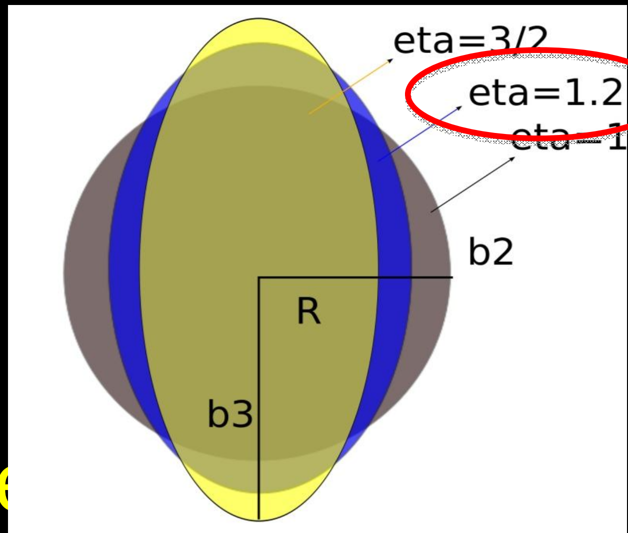


Dobler, Draine & Finkbeiner 2009

Fitting to H α -correlated spectrum

- Model: $$I_\nu^{\rm mod} = F_0\left(\frac{\nu}{23\rm GHz}\right)^{-0.12} + Sd_0\left[\frac{I_\nu^{\rm sd}}{I_{\rm H\alpha}}\right]_{\rm WIM} + C_0\left(\frac{\nu}{23\rm GHz}\right)^2$$

- Minimizing: $$\chi^2 = \sum_\nu \left(I_\nu^{\rm mod} - I_\nu^{\rm obs}\right)^2 / \sigma_\nu^2$$



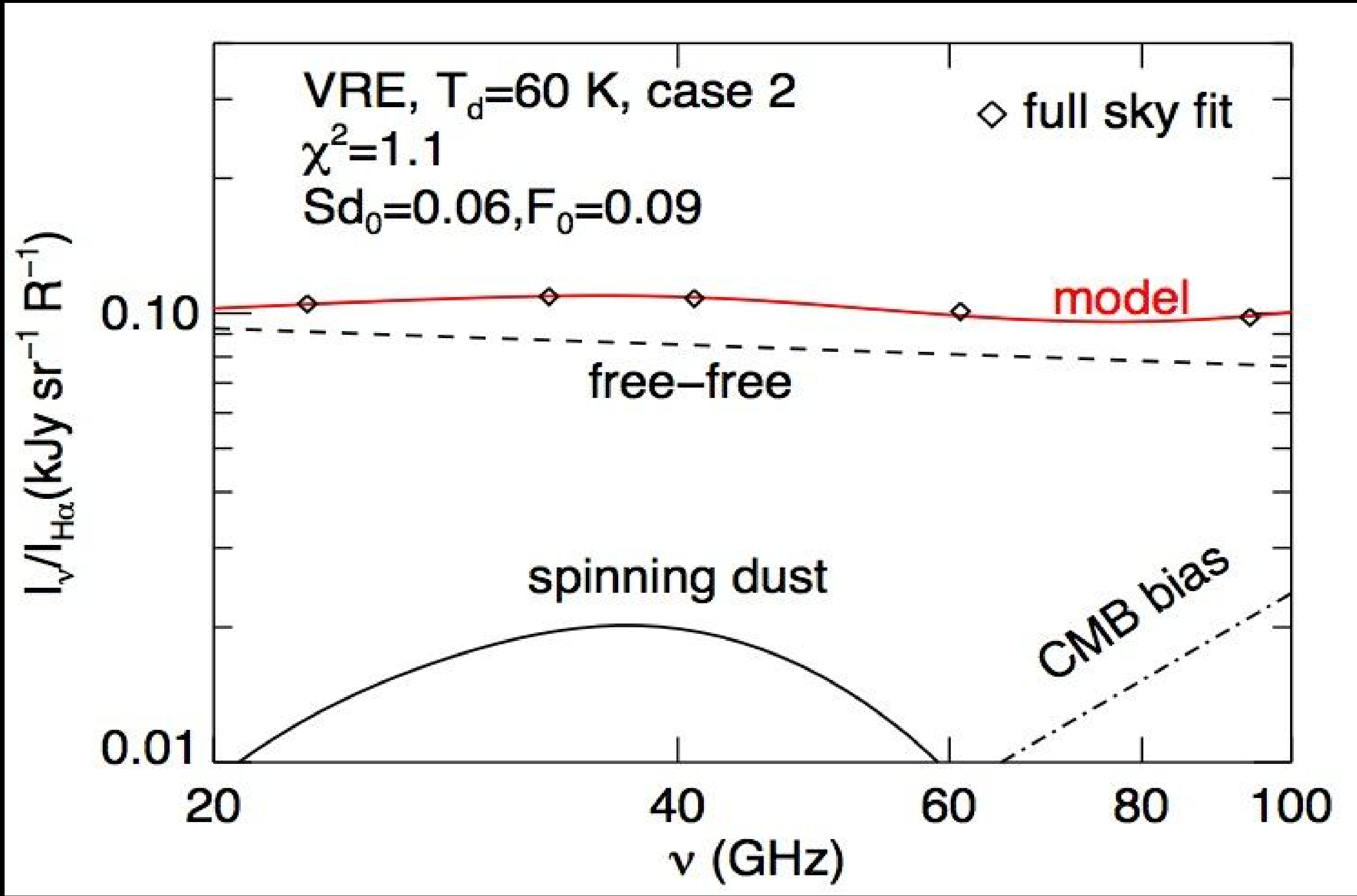
- Fitting parameters:

  F_0: e temperature

  Sd_0: variation of PAH abundance

  C_0: CMB bias

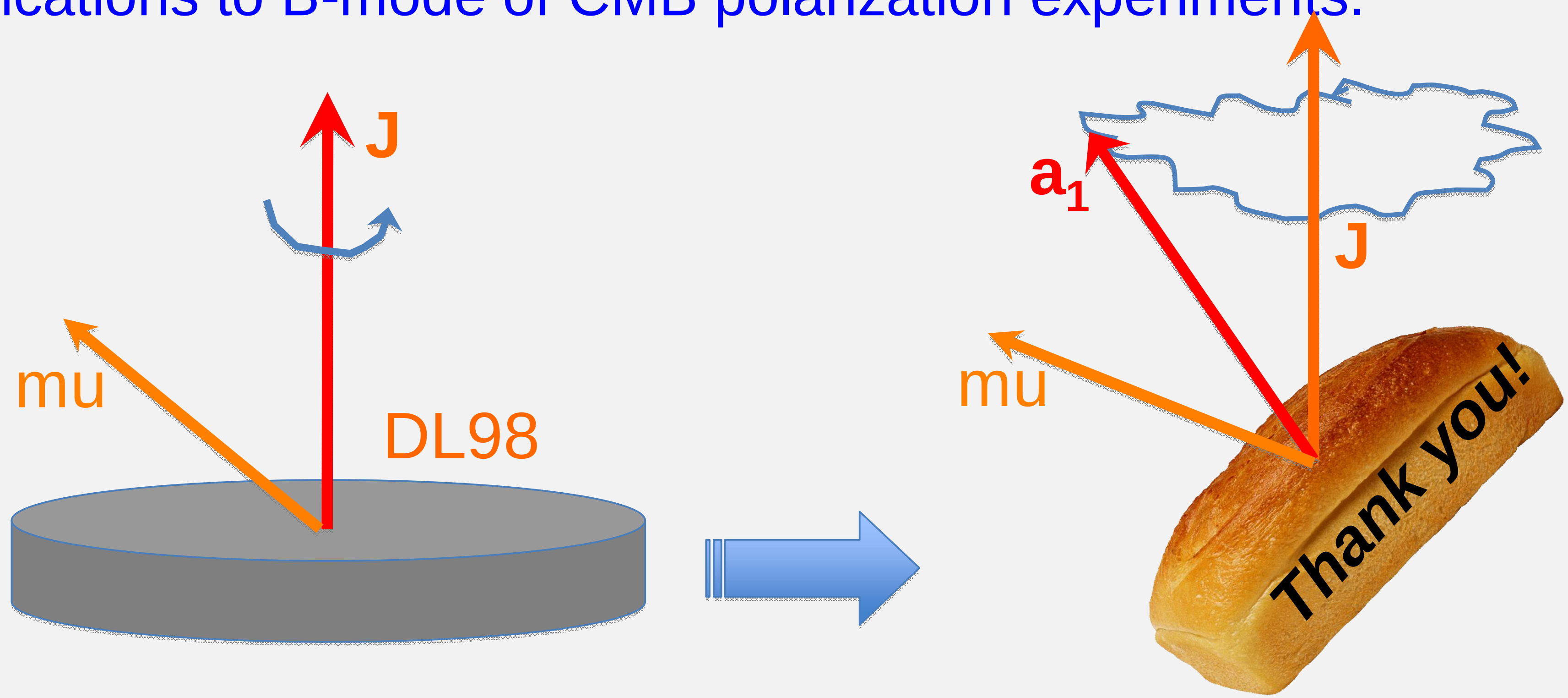
- Spinning dust parameters: n_H, dipole moment β_0



- ★ F_0=0.09 ➔T_e~ 2500 K (Dong & Draine 2011 explain low T_e)
- ★ Sd_0=0.06 ➔PAH depleted in WIM
- ★ Dipole β_0 ~ 0.65 D, n_H ~0.11 cm^{-3}

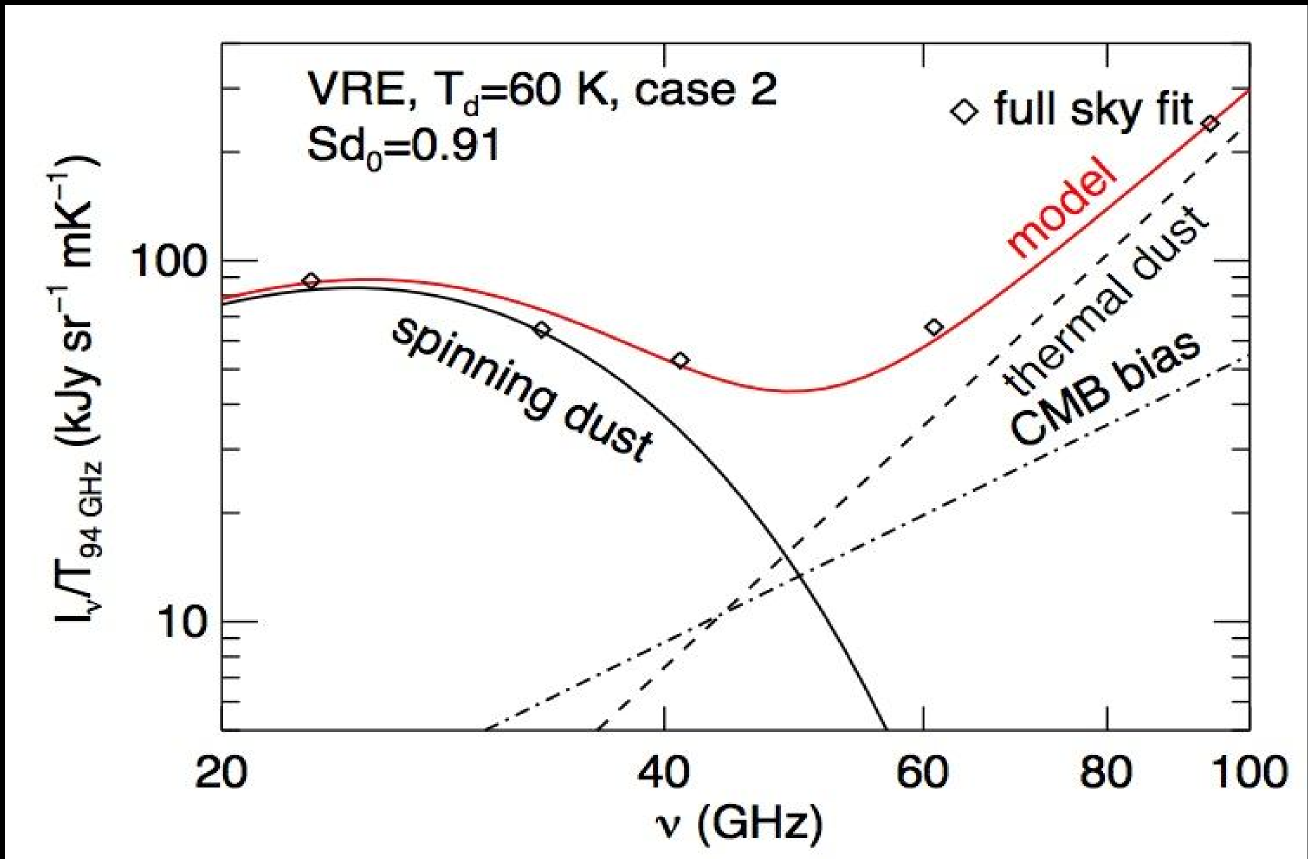
Summary and Future Works

1. Improved model accounts for wobbling grain, irregular shape internal relaxation, transient events.
2. Improved model can reproduce high peak frequency in Hα-correlated spectrum from WMAP data.
3. Improved model can be used to diagnose dust physical parameters.
4. Future works will address polarization from spinning dust and implications to B-mode of CMB polarization experiments.



Thermal Dust-Correlated Spectrum

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



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