

***mm Emission from Dust
in Galaxies***

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Why is Dust Important?

- ◆ Thermal emission may extend into mm region, if grains are cool enough, **BUT:**
- ◆ Draine & Lazarian have shown that grains may produce emission due to:
 - **Electric Dipole** radiation from aspherical charged rotating grains **OR**
 - **Magnetic Dipole** radiation from rotating magnetically-active grains.



ISO Data on PNe:

An amazing variety of grain species have been detected:

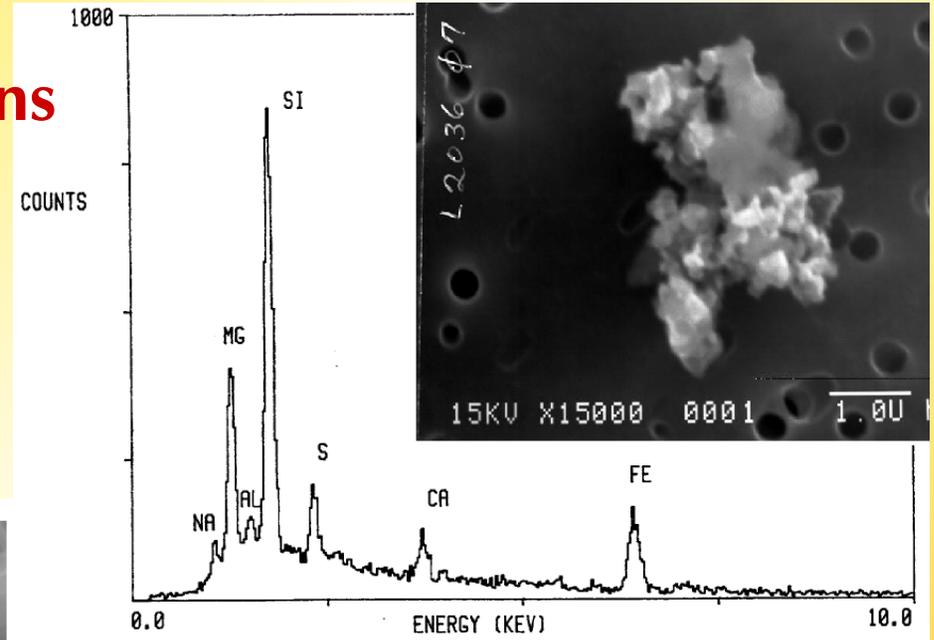
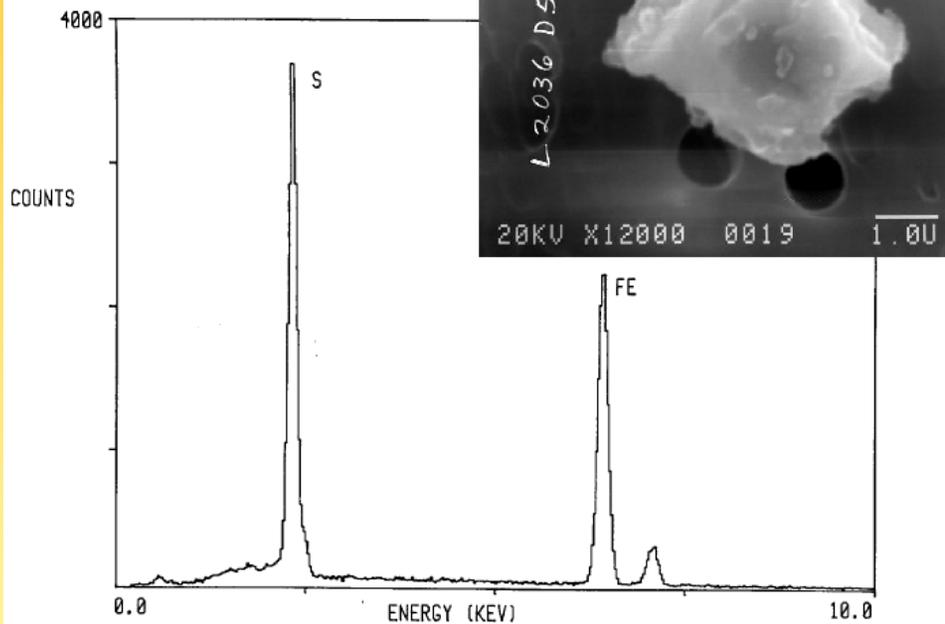
- ◆ **crystalline silicates** (enstatite MgSiO_3 , forsterite Mg_2SiO_4)
- ◆ **amorphous silicates**
(either fayalite Fe_2SiO_4 or amorphous olivine $(\text{Fe},\text{Mg})_2\text{SiO}_4$)
- ◆ **organic carbon grains**
 - aliphatic - aromatic - anthracite (*c.f.* 2200\AA feature)
 - surface hydrogenated nano-diamonds
- ◆ **water ice**
- ◆ **carbides** (SiC , MgC , TiC)
- ◆ **sulfides** (triolite FeS , MgS , SiS_2 ,)
- ◆ **carbonates** (!!) (CaCO_3 , $\text{CaMg}(\text{CO}_3)_2$)



NASA Samples of Cosmic Grains

(collected by Aerogel on U2 Aircraft)

Iron Sulfide



Amorphous Silicate



Thermal Emission

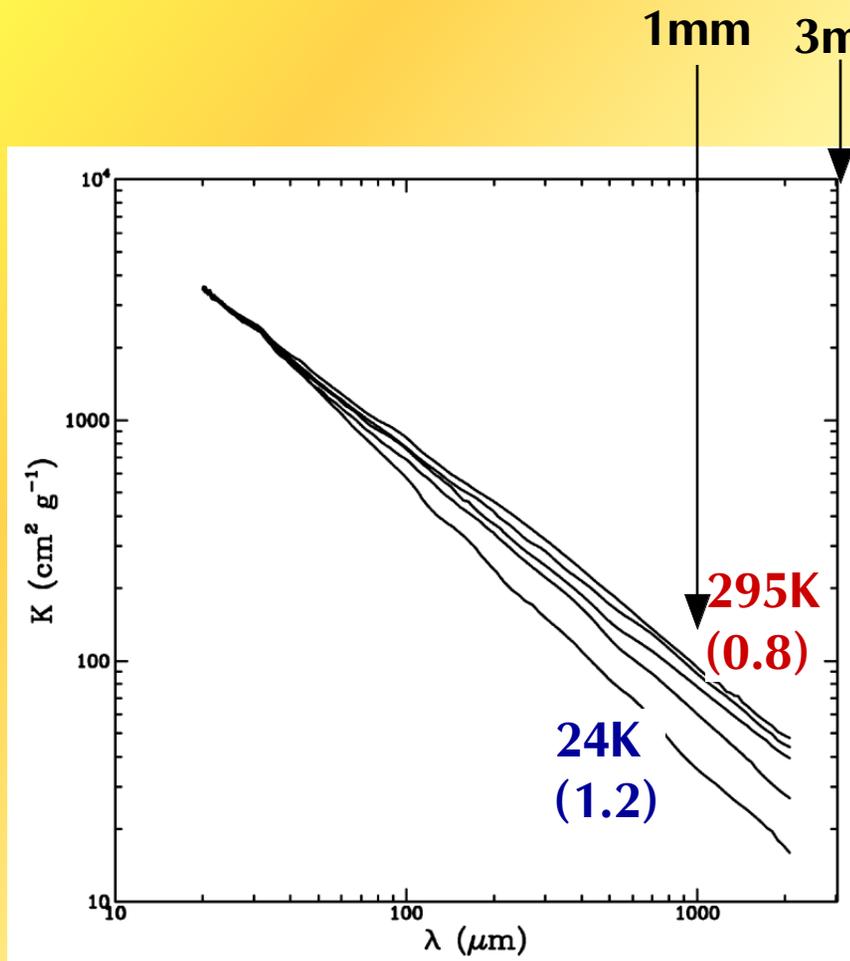
- ◆ Usually, the slope of the thermal component at low frequency (lattice vibration) is assumed to be:

$j_V = AV^{1.7}$ which is determined by the slope of the absorption coefficient, $\kappa = V^{0.7}$:

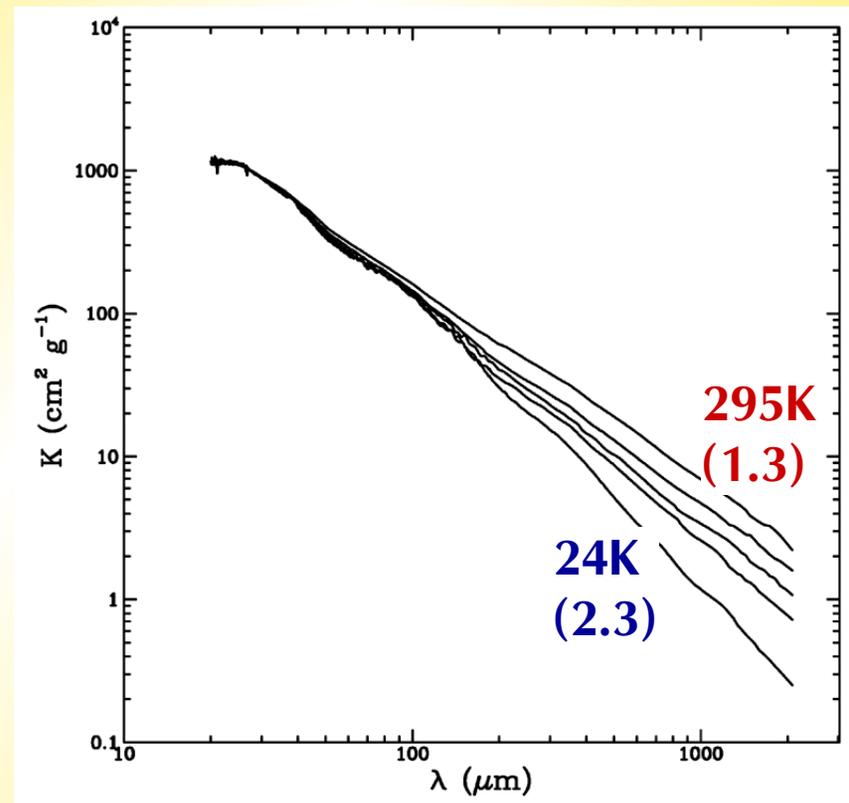
$$Q_{\text{em}}(a, \lambda) \sim \frac{16\pi a \kappa}{3\lambda}$$

- ◆ However, Menella et al. (1998) showed that κ is strongly dependent on grain temperature!





Amorphous Carbon Grains



Fayalite

from Mennella et al. (1998) ApJ, 496, 1058



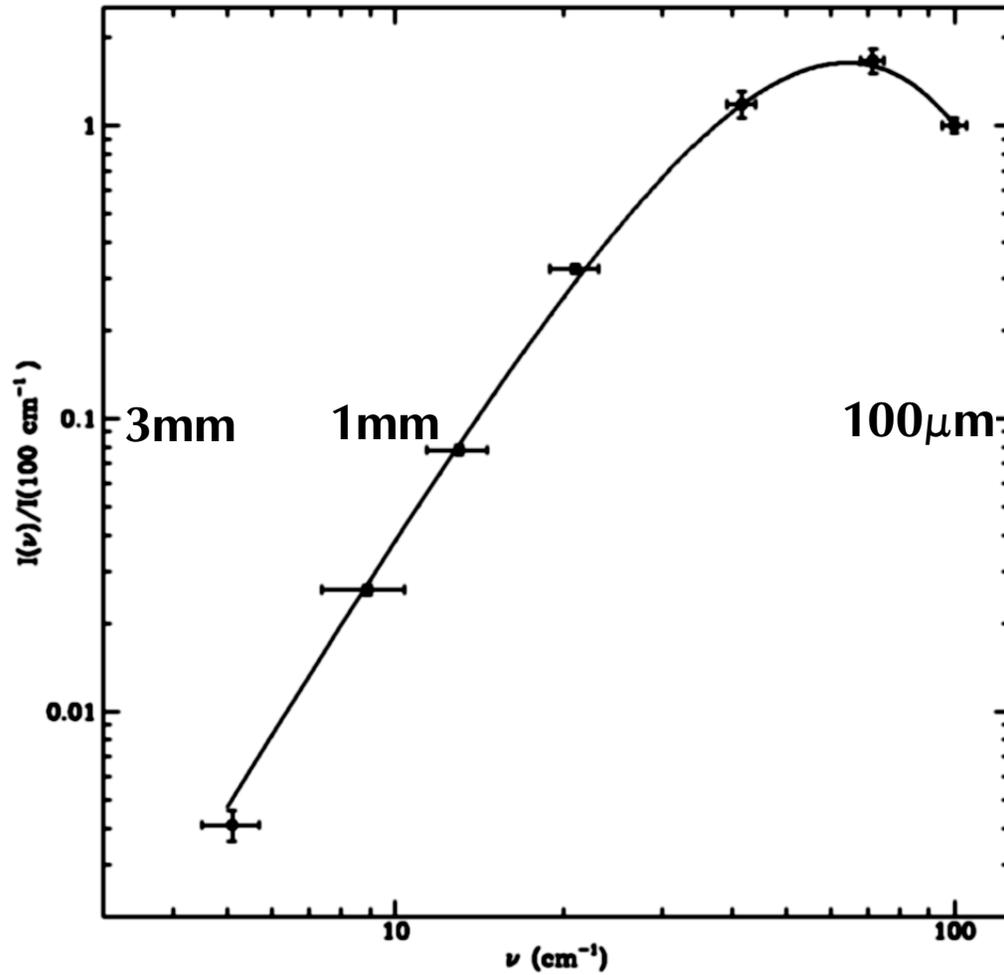


FIG. 10.—Fit of the interstellar dust emission in Aquila ($l = 35^\circ$). The data set, from Masi et al. (1995), consists of their ARGO balloon-borne measurements at 0.5, 0.8, 1.2, and 2 mm and of the 140 and 240 μm COBE DIRBE and IRAS 100 μm observations. All the data are normalized to the 100 μm brightness detected by IRAS. The line is the best fit obtained by using the laboratory emissivity for silicate and carbon grains at 20 K and $T_{\text{carb}} = T_{\text{sil}} = 20$ K. The best-fit silicate-to-carbon mass ratio is 4.47 ± 0.36 with $\chi^2/\text{dof} = 2.6$.



The Implications:

The lattice vibrational spectral slope in the mm region should be flatter where there is hot dust: i.e. in regions with AGN or in violent (warm) starbursts.



Dipole Emission from Grains

The grain has an intrinsic dipole moment

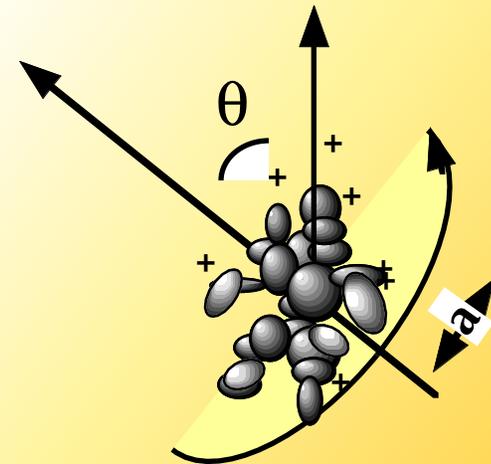
$$\mu = N^{1/2}\beta$$

and a dipole moment due to charge

$$\mu = Ze\Delta a$$

...so a rotating grain produces dipole emission with power:

$$P = (2/3c^2)\omega^4\mu^2\sin^2\theta$$

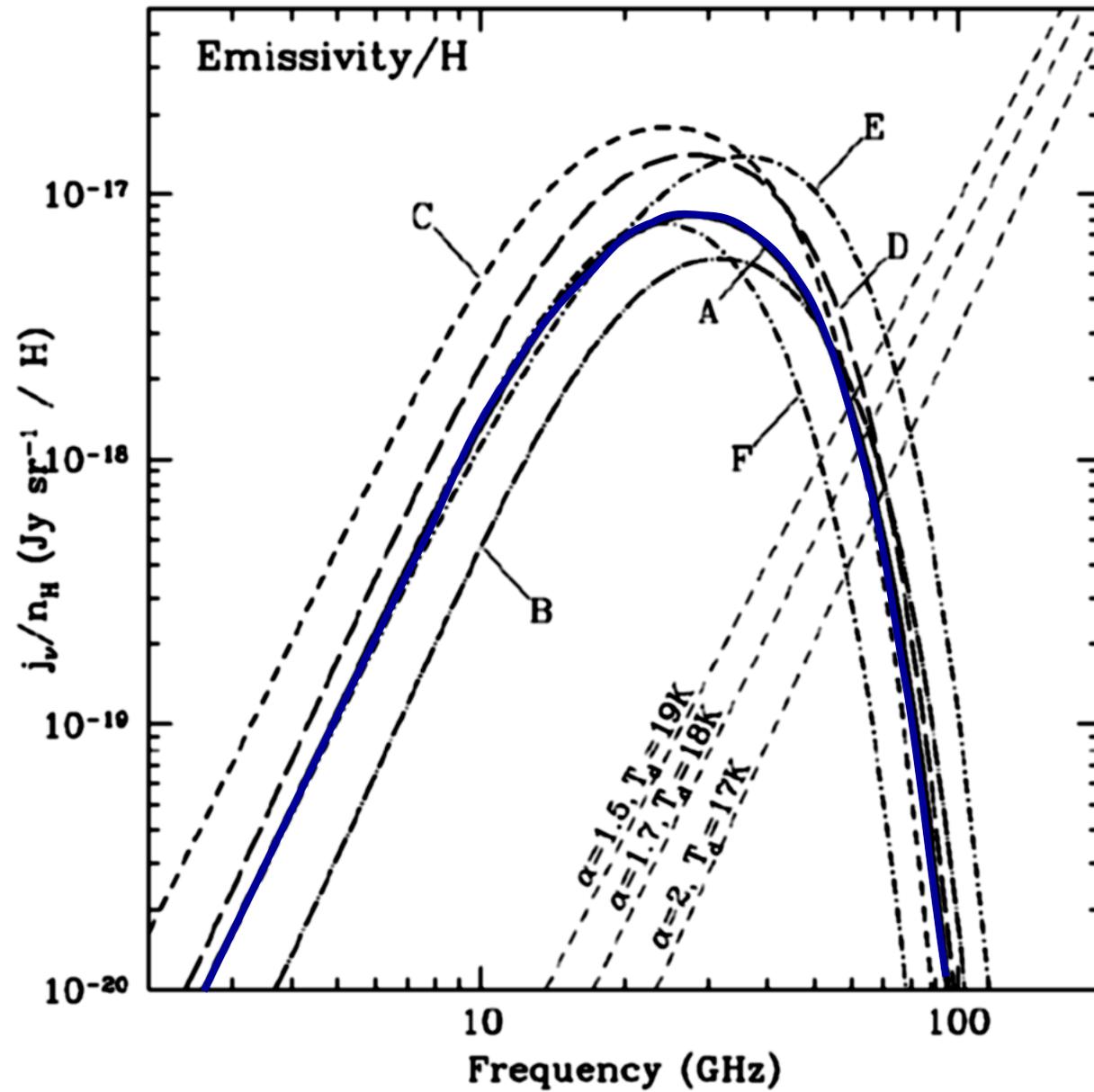


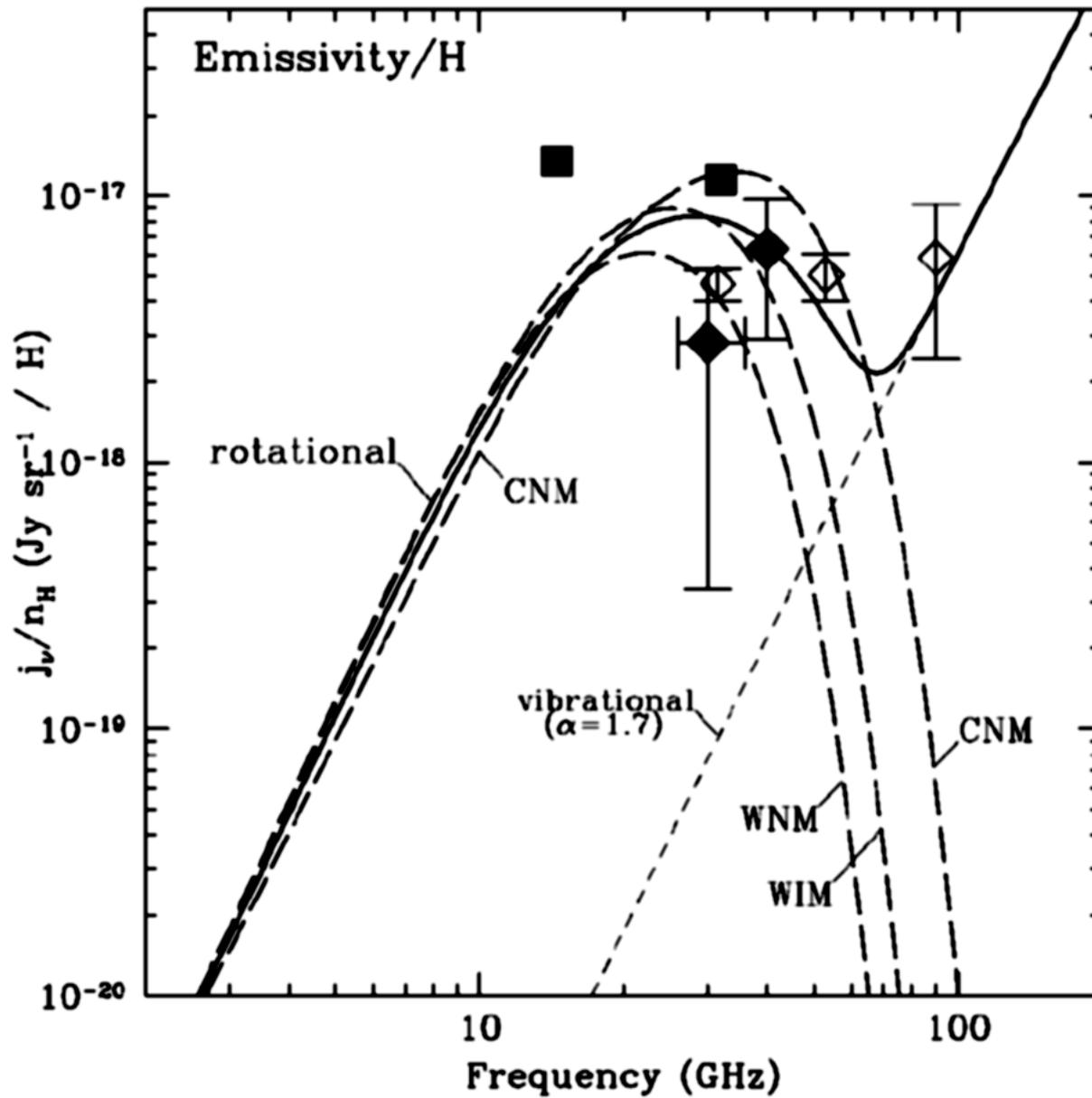
Rotational Rate of Grains:

- ◆ Determined by “plasma drag” & “electrostatic focussing”
- ◆ “Plasma drag” - is the interaction of the dipole moment with the electric field produced by passing ions.
- ◆ “Electrostatic Focussing” - or rather defocussing, deflects +vely charged ions with high angular momentum away, reducing rotational energy deposition.
- ◆ As a consequence, peak dipole emission is at ~ 30GHz.



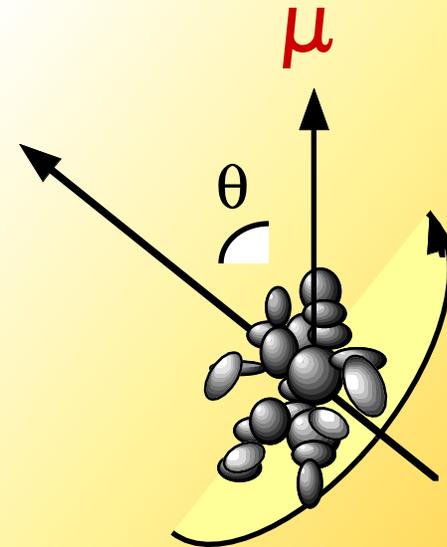
Draine &
Lazarian 1998
ApJ 494, L19





Magnetic Dipole Emission

- ◆ Magnetically active rotating grains produce electric dipole emission.
- ◆ Theory is rather more complex than for electric dipole emission (Draine & Lazarian, 1999 ApJ, 512, 740)



MAGNETIC COMPOUNDS CONTAINING Fe^a

Mineral Y	Form ^b	$4\pi M_s$ (G) ^c	ρ_Y (g cm ⁻³)	V_Y/V_0 ^d
Fe ₂ SiO ₄ (fayalite)	Antiferromagnetic ^e	0	4.39	0.51 f_Y
FeSiO ₃ (pyroxene)	Antiferromagnetic ^e	0
FeS (troilite)	Antiferromagnetic ^e	0	4.83	0.39 f_Y
FeCO ₃ (siderite)	Antiferromagnetic ^e	0	3.96	0.63 f_Y
FeMgSiO ₄ (olivine)	Antiferromagnetic ^e	0	4	0.92 f_Y
α Fe ₂ O ₃ (hematite)	Antiferromagnetic ^e	0	5.26	0.33 f_Y
FeO (wustite)	Antiferromagnetic ^e	0	5.75	0.27 f_Y
Fe _{1-x} S (pyrrhotite)	Ferrimagnetic	1130 ^f	4.6	0.41 f_Y
MgFe ₂ O ₄ (magnesioferrite)	Ferrimagnetic	1760	4.18	0.51 f_Y
NiFe ₂ O ₄ (trevorite)	Ferrimagnetic	3770	5.35	0.47 f_Y ^g
γ Fe ₂ O ₃ (maghemite)	Ferrimagnetic	4780 ^h	4.88	0.36 f_Y
Fe ₃ O ₄ (magnetite)	Ferrimagnetic	6400	5.2	0.32 f_Y
Fe (iron)	Ferromagnetic	22000	7.86	0.15 f_Y



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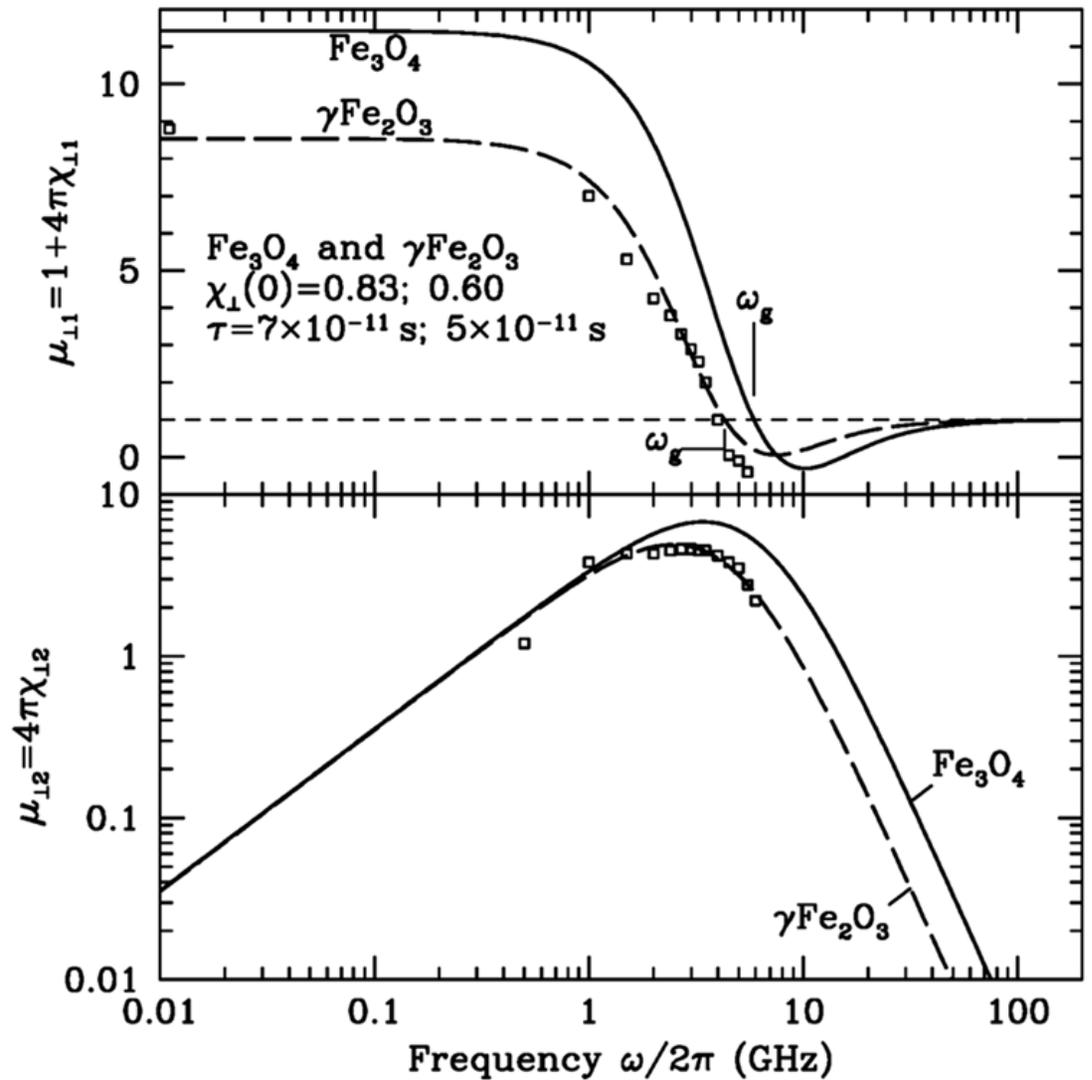
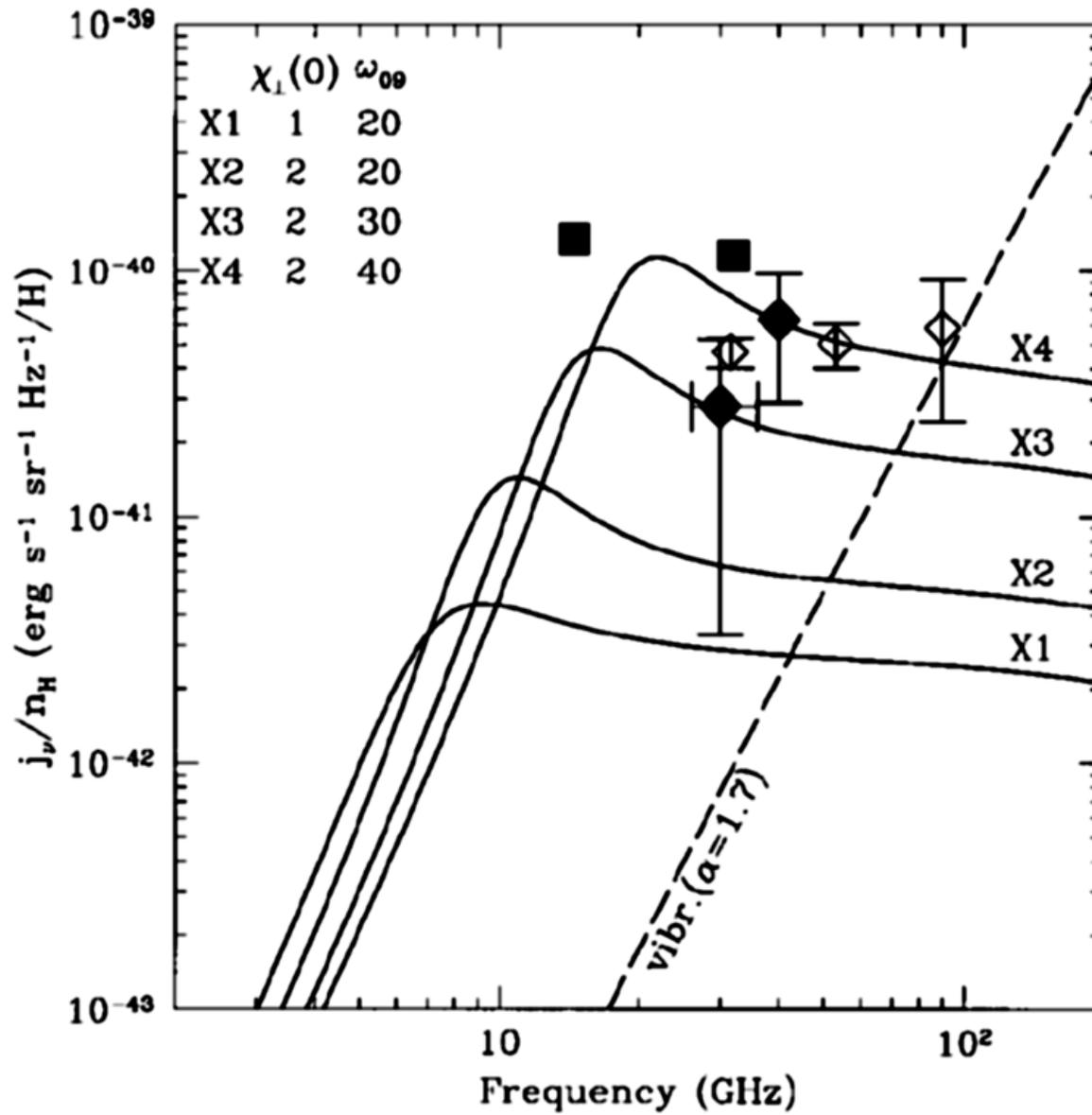


FIG. 6.—Same as Fig. 3 but for single-domain magnetite (Fe_3O_4) and maghemite ($\gamma\text{Fe}_2\text{O}_3$), examples of ferrimagnetic materials. Also shown (see text) are experimental results for $\gamma\text{Fe}_2\text{O}_3$ from Valstyn et al. (1962).







Research School of Astronomy & Astrophysics

mm Workshop 2001