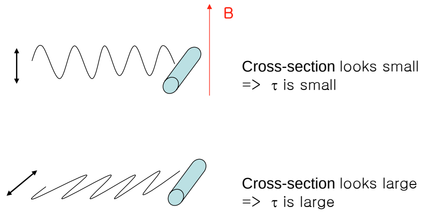
Grain alignment by radiation

Cho & Lazarian
2005, ApJ, 631,361

Fact 1. Grains are aligned

- 1st evidence: star light polarization
  Hall (1949,science, v109) & Hiltner (1949, science, v109)
- Degree of polarization: $P=(I_{max}-I_{min})/I_{avg}$
- Why is star light polarized?

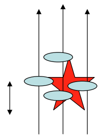


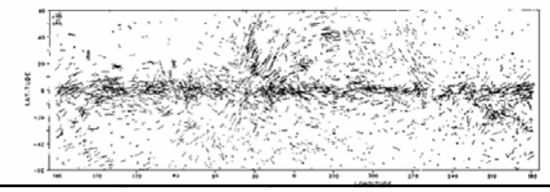
$\tau_{\|}<\tau_{\perp}$

Introduction: grains are aligned

- Star light polarization (optical)

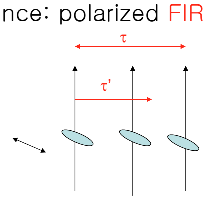
$$P_{abs}=\frac{e^{-\tau_{\|}}-e^{-\tau_{\perp}}}{e^{-\tau_{\|}}+e^{-\tau_{\perp}}}\approx-(\tau_{\|}-\tau_{\perp})/2$$





Introduction: grains are aligned

- 2nd evidence: polarized FIR emission



$$I_{\nu}(\tau_{\nu})=\int_0^{\tau_{\nu}} S_{\nu}(\tau'_{\nu})e^{-\tau'_{\nu}}\,d\tau'_{\nu} \propto 1-\exp(-\tau)$$

$$P_{em}=\frac{(1-e^{-\tau_{\|}})-(1-e^{-\tau_{\perp}})}{(1-e^{-\tau_{\|}})+(1-e^{-\tau_{\perp}})}\approx\frac{\tau_{\|}-\tau_{\perp}}{\tau_{\|}+\tau_{\perp}}$$

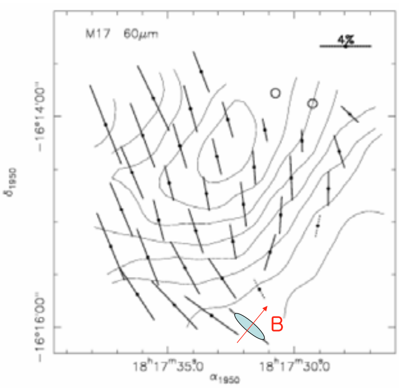
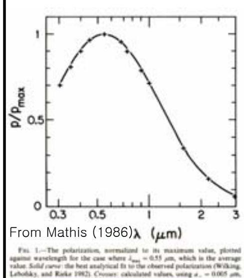
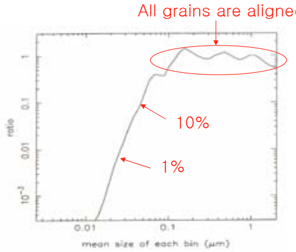


Fig. 37. 60 μm linear polarization toward M17. Flux contours are at 20%, 30%, ...,90% of the peak flux. From Dotson et al (2000).

Fact 2: only large grains are aligned



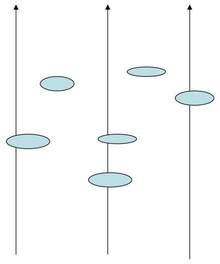
From Mathis (1986)



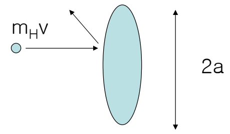
Serkowski's law implies
only large grains are aligned

Kim & Martin 1994

Question: why/how are they aligned?



Note that grains are rotating!

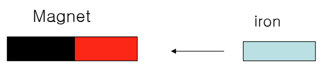


Angular momentum transfer per collision ~ $m_H va/3$

➔ After many collisions, rotational energy ~ (3/2) kT

$$\omega_T^2 = \frac{15kT}{8\pi\alpha_1\rho a_{eff}^5}$$ ← $I\omega^2$ ~ kT

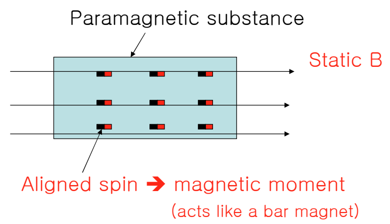
-Davis & Greenstein (1951): paramagnetic dissipation

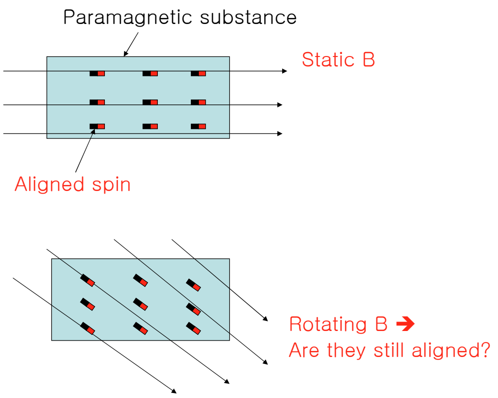


Strong attraction: ferromagnetic substance

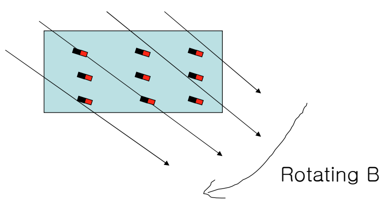
weak attraction: paramagnetic substance

PARAMAGNETS – Materials in which there are uncompensated spins (i.e. there is not a spin −1/2 for every spin +1/2).



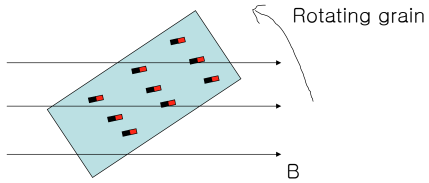


Answer: NO!



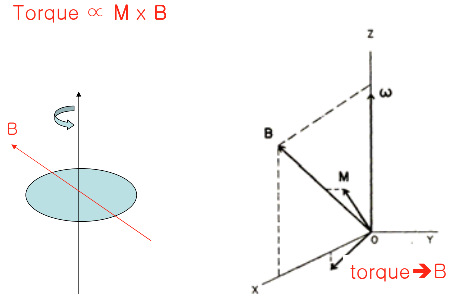
There is a phase lag!

In fact, grains are rotating



M is dragged along with the material and is not parallel to B.

Torque ∝ M x B



Davis-Greenstein (1951)

However, D-G mechanism is a slow process.
→Randomization through chaotic gaseous bombardments may be quicker.

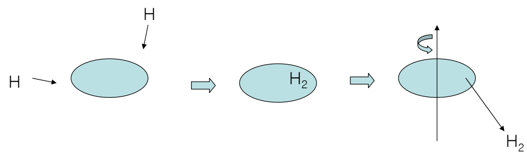
$t_{D-G} = 7\times10^{13} a^2_{(-5)} B^{-2}_{(5)} \mathrm{s}$

$t_{gas} = 3\times10^{12} n_{(20)} T^{-1/2}_{(2)} a_{(-5)}\ \mathrm{s}$

→Two new ideas (1970s):

Purcell's rocket vs. radiative torque

Purcell (1975,1979)'s rocket

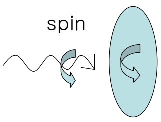


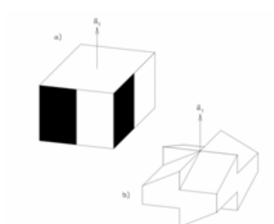
If H2 formation takes place on particular sites, these sites act as miniature rocket engines spinning up the grain.

→Supra-thermal rotation is possible
(When grains rotate supra-thermally, gaseous bombardments are NOT important)

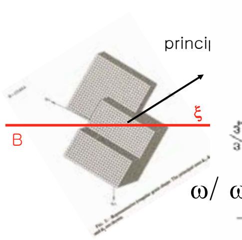
→DG mechanism can align grains

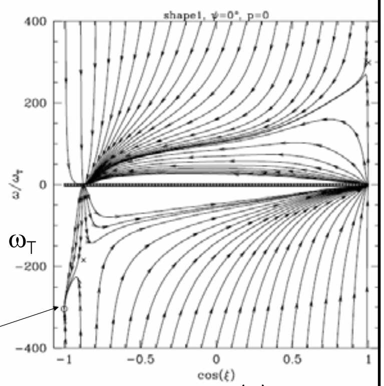
Radiative torque (Dolginov 1972)
→ It can better explain why only large grains are aligned
(← OK. This is an observational fact)
→ Now, quantitative calculations are possible





Draine & Weingartner (1996)

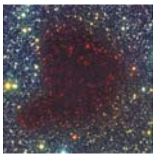


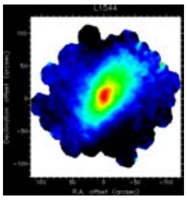


Draine & Weingartner 1997

When ω> ωT , alignment is possibl

Goals:
1. What is radiative torque in prestellar cores or M.C.?
2. Are all grains aligned?





Strategy: we put a grain in the cloud and calculate radiative torque using B. Draine's DDSCATT package.
➔ We need to know the radiation field

Numerical methods

-code: DDSCATT by Bruce Draine
-Grain shape:
-Radiation field (Mathis et al. 1983)

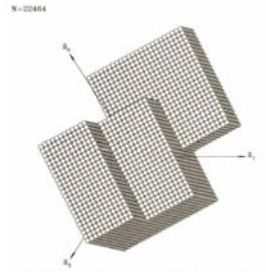


FIG. 3.—Representative irregular grain shape. The principal axes $\hat{a}_1$, $\hat{a}_2$, and $\hat{a}_3$ are shown.

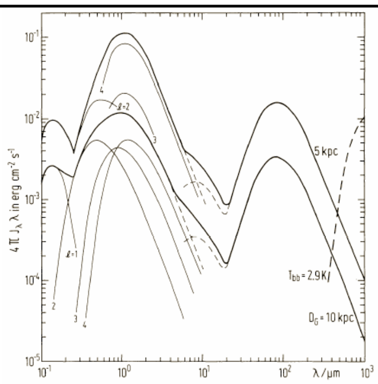


Fig. 1. The interstellar radiation field (ISRF) at galactocentric distances $D_G = 5$ and 10 kpc, respectively. Curves labelled $\ell = 1, 2, 3, 4$ relate to the contributions of the four stellar components to the ISRF. For wavelengths $\gtrsim 8\,\mu$m the ISRF is dominated by reemission from dust grains

Radiaion Field

ISRF

Mathis et al 1983

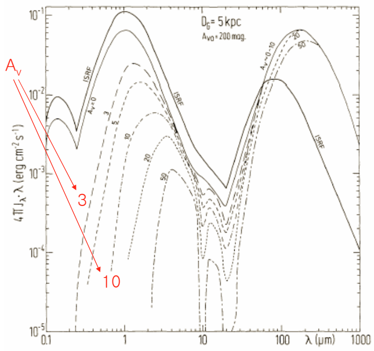


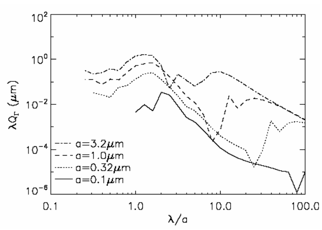
Fig. 4. The radiation field inside a giant molecular cloud, located at $D_G = 5$ kpc and with a visual extinction to its center of $A_{V_0} = 200$ mag. ISRF refers to the radiation field at far distances from the cloud, $A_V = 0$ is the radiation field at the surface of the cloud, $A_V = 3$, 5, 10 etc. is the radiation field inside the cloud at distances $A_V = 3$, 5, 10 etc. mag from the surface of the cloud

Radiaion Field

Molecular cloud

Results

Radiative torque



When $\lambda \sim a$, torque = maximum !

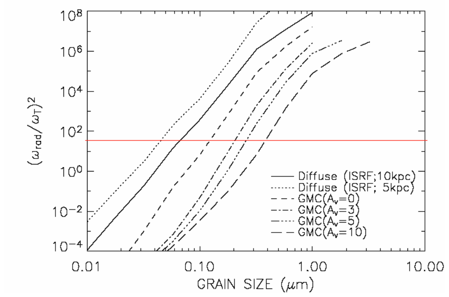
Note : $\lambda \sim 1\mu$m in the interstellar space

Results

Radiative torque ➔ rotation speed

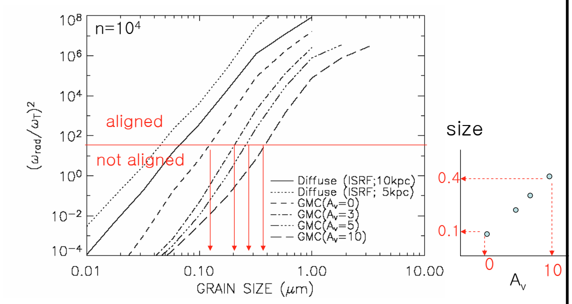
Results

Radiative torque ➔ rotation speed



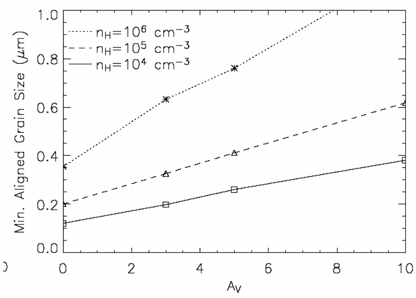
Results

Radiative torque ➔ rotation speed



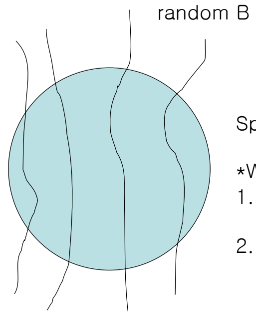
Large grains are aligned!

Results: Aligned grain size



Polarization map

goal:



Spherical prestellar core

*We used 2 models for ρ

1. Bonner-Ebert shpere: r^{-2} envelope
2. Logatropic sphere: r^{-1} envelope

➔ Polarization map?

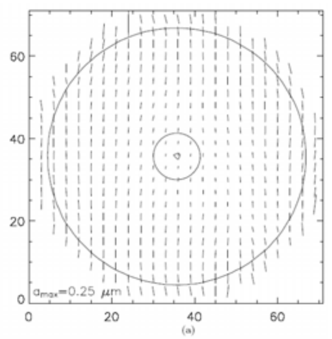


FIG. 5.— Polarization map and p-I scatter diagram for the origin

r^{-1} envelope;
MRN distribution

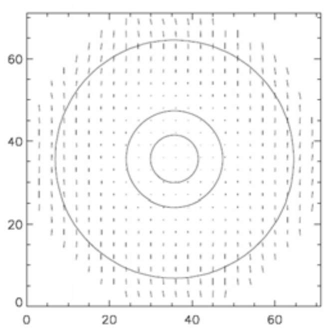
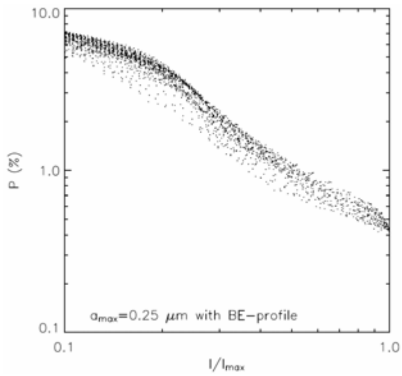
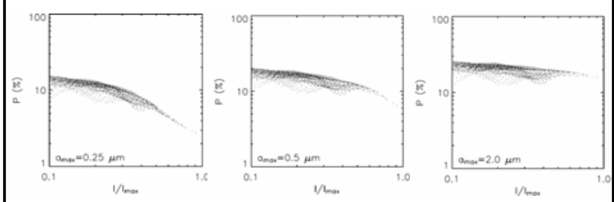


FIG. 7.— Polarization map and p-I scatter diagram for the or Bonner-Ebert sphere for density, which has a $\rho \propto r^{-2}$ envelop. (

r^{-2} envelope;
MRN distribution

P-I relation





Grain sizes are important

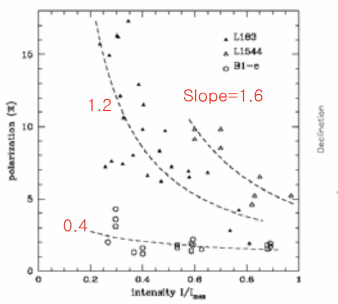
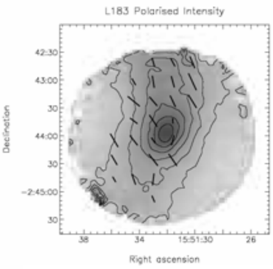


Fig. 1. Distribution of percentage of polarization p vs. intensity I normalized to its maximum value, for the starless cores L183 Crutcher et al. 2004), L1544 (empty triangles, from Ward-Thom the B1-c core (circles, from Matthews & Wilson 2002). The dash



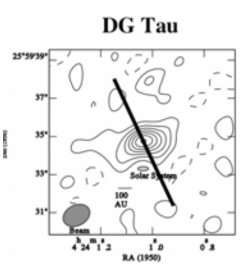
Crutcher et al 2004

Goncalves et al (2004)

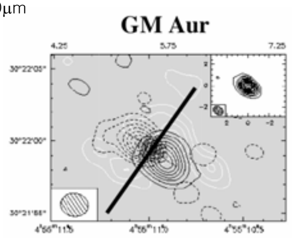
Conclusion

- Only large grains are aligned
- Large grains can be aligned even deep inside clouds/cores
- We produced p-I maps: grain size distributions are important

Current project:



850μm



Can we explain this?