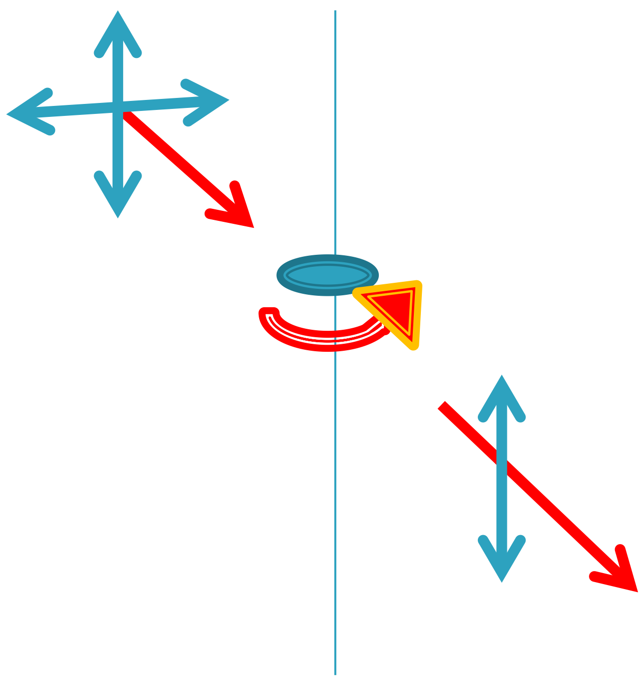
Linear Polarization in the Molecular Clouds

Polarization: measure B field perpendicular to line of sight, $B_\perp$

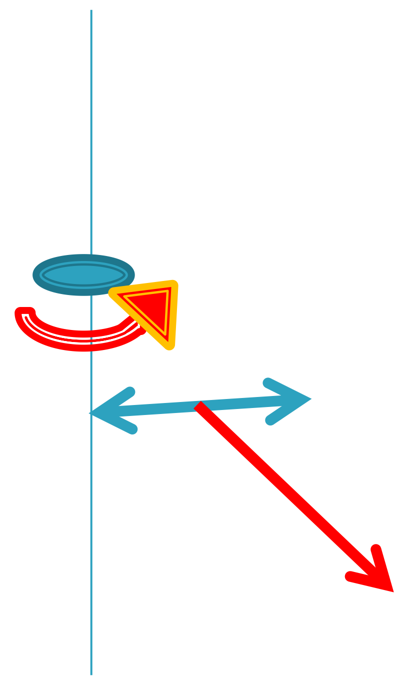
- Reason: grains are aligned by B
- Polarization from extinction of starlight passing through dust.
- Polarization from dust continuum emission.
- How to estimate the strength of B?

Polarization

- Extinction

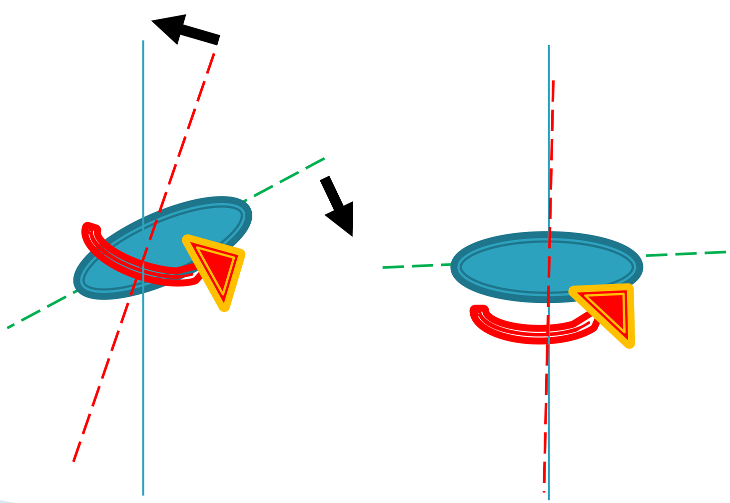


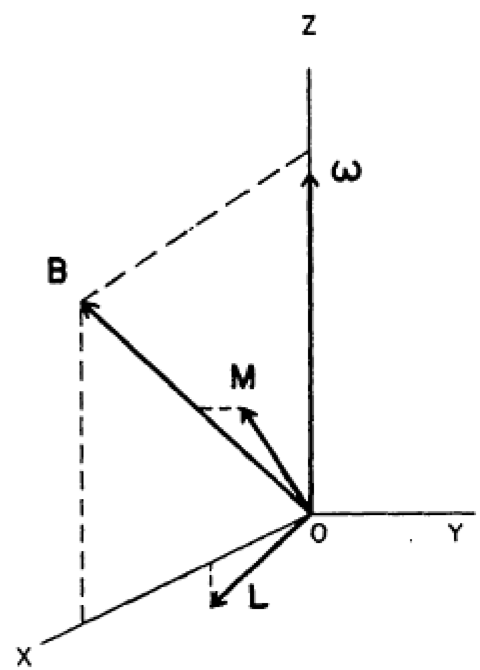
- Emission



Grain Alignment

- Davis-Greenstein Mechanism(1951)
  - paramagnetic material
    ->"paramagnetic absorption"
  - Make the rotation energy as small as possible
    ->rotation along short axis





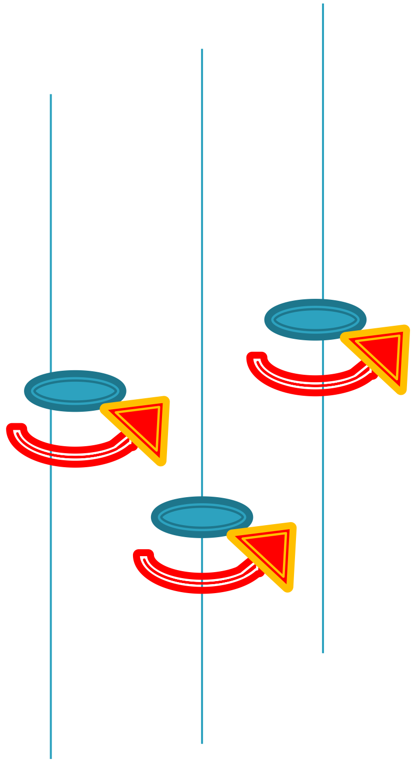
Grain Alignment

- Davis-Greenstein Mechanism(1951)
  - Timescale:

  ~10^7-10^12 years [long!]

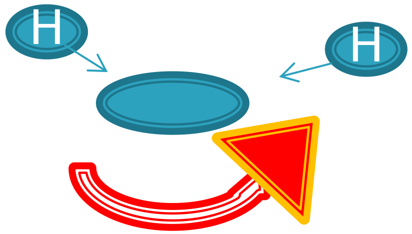
$$\tau_{DG} \approx 1.6 \times 10^{11} \frac{a_{eff}^2 \rho_{gr} T_{gr}}{B^2} \text{ seconds}$$

- In fact
  - Predict B~100 μG but typically ~1 μG
  - Predict small grains are greater aligned than big ones.
    But in fact it's opposite



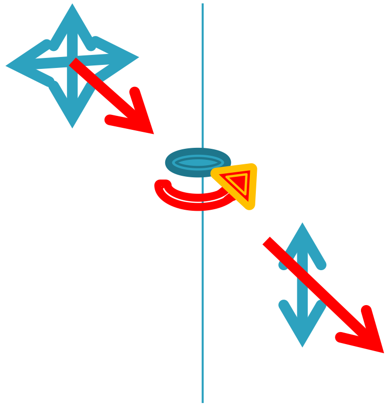
Grain Alignment

- Superparamagnetic grains
  (Purcell & Spitzer 1971)
  - bigger dust has more metallicity-> aligned faster
  - Correct the much more aligned big grains
- Superthermal spins
  Consider be embedded in a hot gas
  - H_2 formation on the grain surface gives a torque (Purcell 1979)
  - Radiation also gives a torque (Draine 1996)

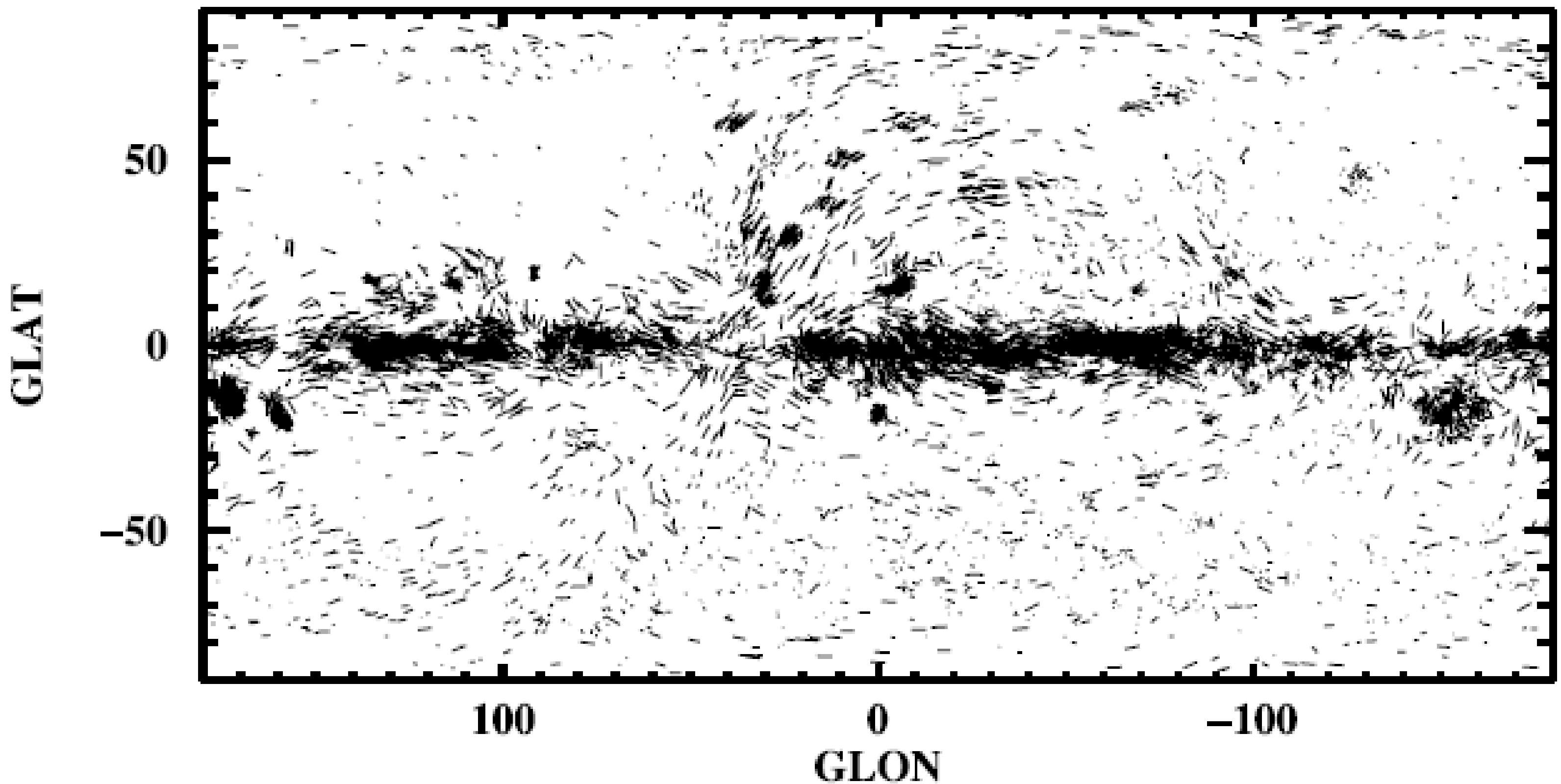


- ………..there are still many questions

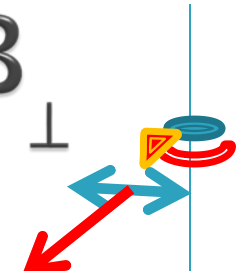
Extinction: parallel to $B_\perp$



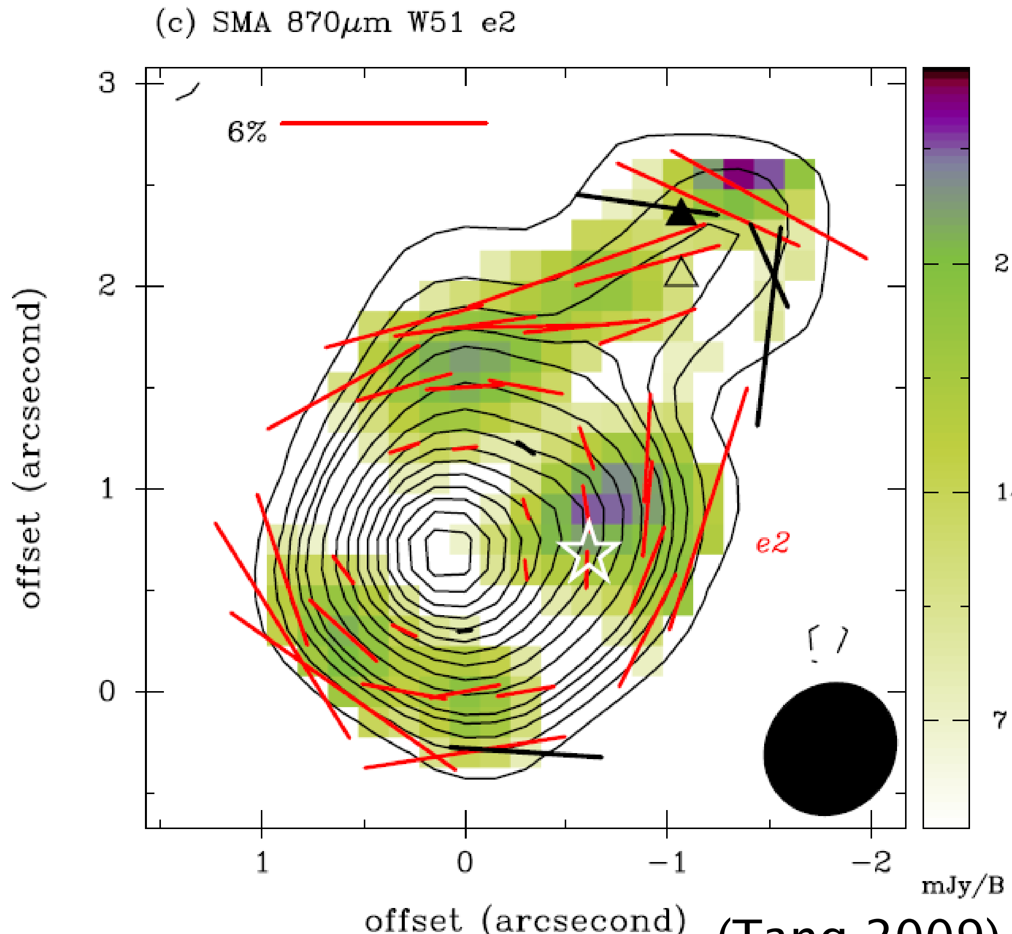
- Only could use to map the region where there are stars behind
- Map of our Milky Way (Heiles, 2000a)



Emission: perpendicular to B

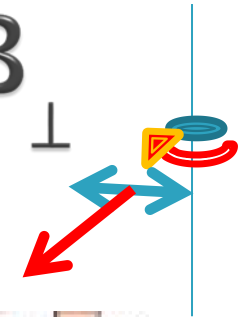


- Emit in infrared, submillimeter
- Radio: different! The direction can be either perpendicular or parallel (Heiles 2005)



(Tang 2009)

Emission: perpendicular to $B_\perp$



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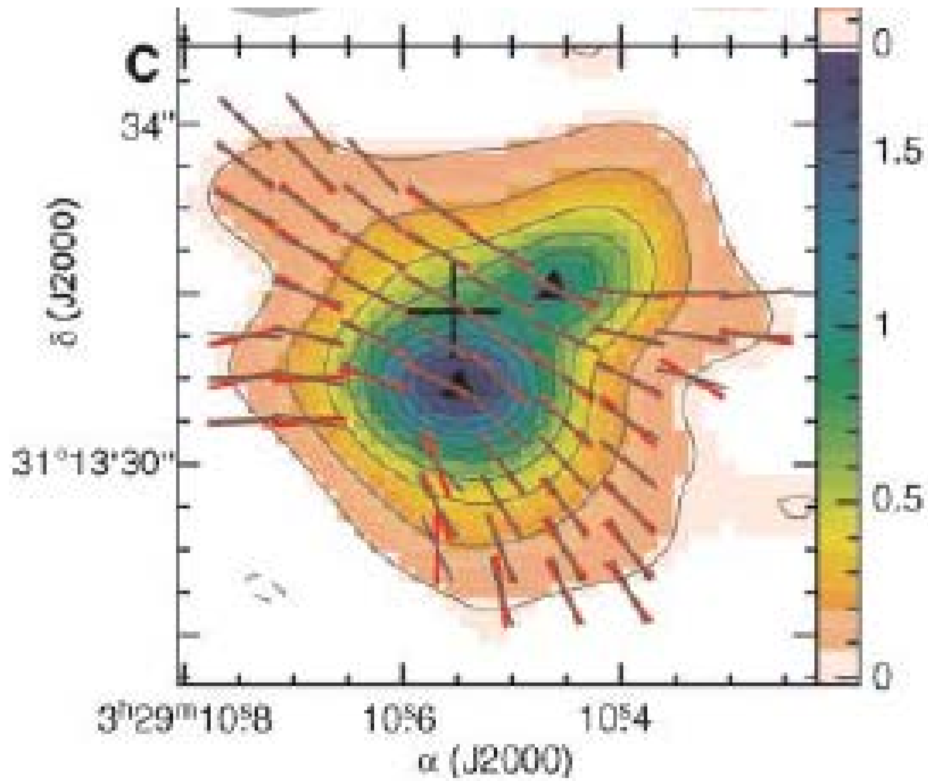


IRAS 4A: hour glass shape
(Girart 2006)

So far, we just know the direction. How about the field strength?

- Chandrasekhar–Fermi relation (1953) $$\frac{\delta B}{B_0} \simeq \frac{\sigma(v)}{V_A},$$
  - The fact: B is frozen into the matter in matter
  - Thus, dispersion of the direction of the polarization decreases as the field strengths.
- But the source causes dispersion is different:
  - In the galactic arms: MHD waves ->perpendicular to the direction of propagation
  - In molecular clouds: Turbulence ->random

Dispersion of magnetic field in molecular clouds

- Roger H. Hildbrand 2009
- Diffuse ISM -> molecular clouds
  - Need to concern gravitation, rotation…
- Assumption: $B(x)=B_0(x)+B_t(x)$,
  $\Phi(x)$=angle between B, B_0
  x is a point on sky-plane
- $\Delta\Phi(l)= \Phi(x)- \Phi(x+l)$, $l<<d$ (local measure)
  $<\Delta\Phi^2(l)> \sim b^2+m^2l^2$
- Thus we can estimate
  $B_0 \sim \mathrm{sqrt}(8\pi\rho)\,\frac{\sigma(v)}{b}$

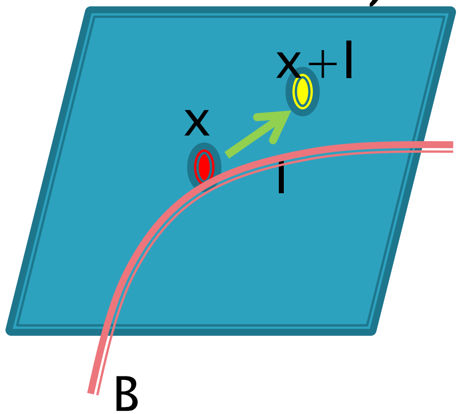
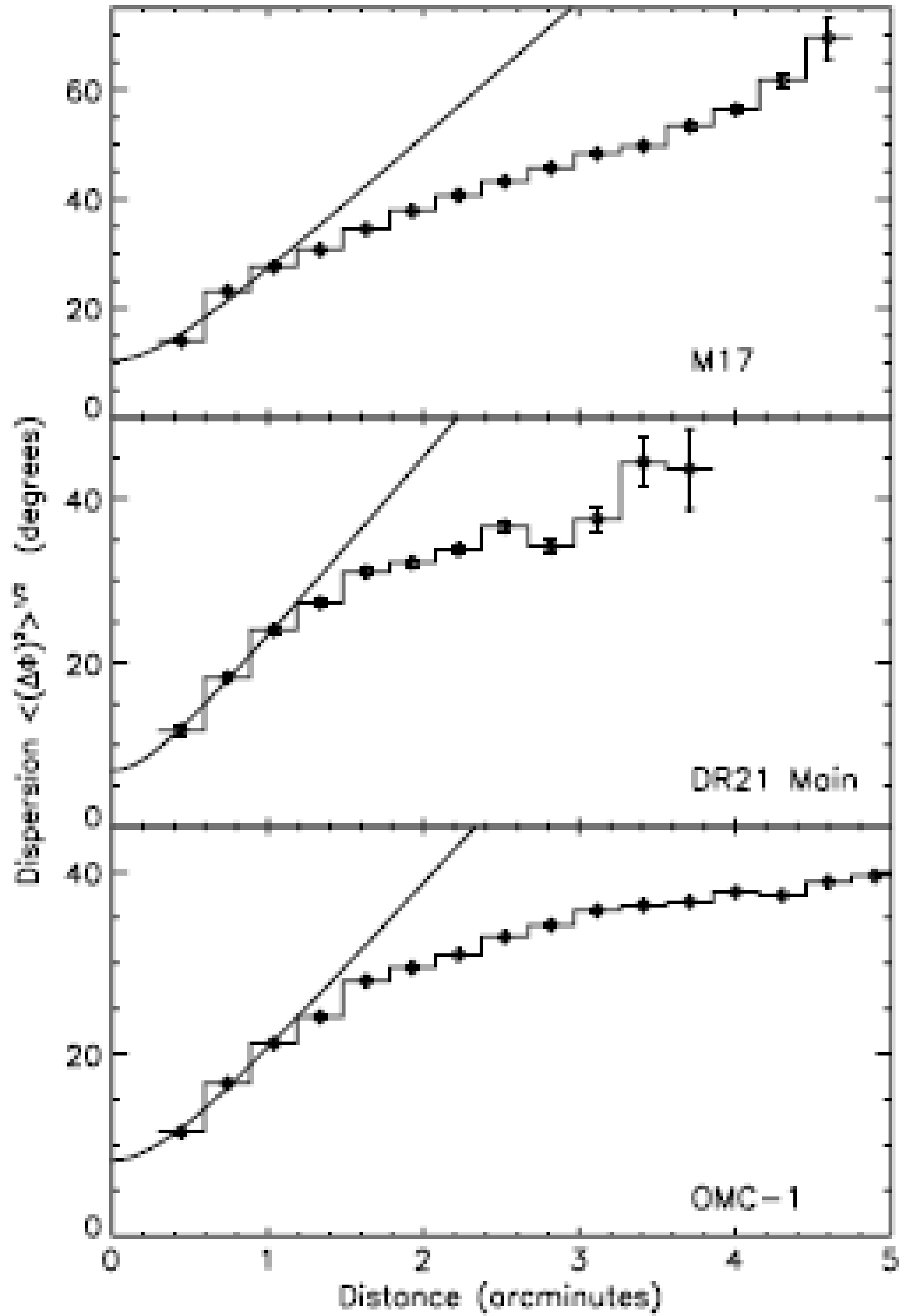


Table 1
Results for the Dispersion, the Turbulent-to-Mean Magnetic Field Strength Ratio, the Line Widths, and the Mean Field Strength

Object	b[a] (deg)	$\langle B_t^2 \rangle^{1/2} / B_0$[b]	$\sigma(v)$ (km s^{-1})	B_0[c] (mG)
OMC-1	8.3 ± 0.3	0.10 ± 0.01	1.85	3.8
M17	10.4 ± 0.6	0.13 ± 0.01	1.66	2.9
DR21(Main)	6.8 ± 1.3	0.08 ± 0.02	4.09	10.6

Old method:
OMG-1, 26.8
M17, 27.2
DR21, 21

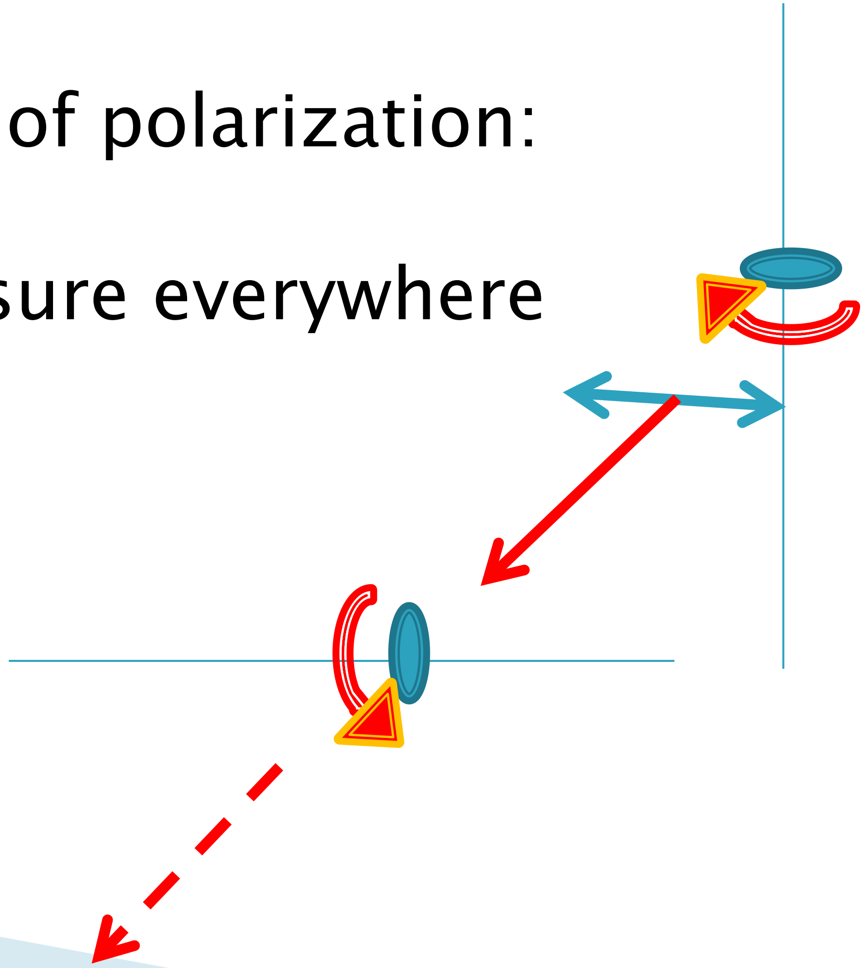
(Roger H. Hildbrand 2009)



Zeeman splitting v.s. Polarization

- Polarization is easier to measure than Zeeman splitting
- Disadvantage of polarization:

  We can't measure everywhere



Reference

- Heiles, Carl 2005
  Magnetic Fields in Diffuse HI and Molecular Clouds
- Davis & Greenstein 1951
  The Polarization of Starlight by Aligned Dust Grains
- Purcell 1971
  Orientation of rotating grains
- Purcell 1979
  Suprathermal rotation of interstellar grains
- Draine 1996
  Radiative Torques on Interstellar Grains
- Hildebrand 2009
  Dispersion of Magnetic Fields in Molecular Clouds. I
- Tang 2009
  Evolution of magnetic fields in high-mass star formation: linking field geometry and collapse for the W51 e2/e8 cores