Magnetic Field Strengths and Grain Alignment Variations in the Local Bubble Wall

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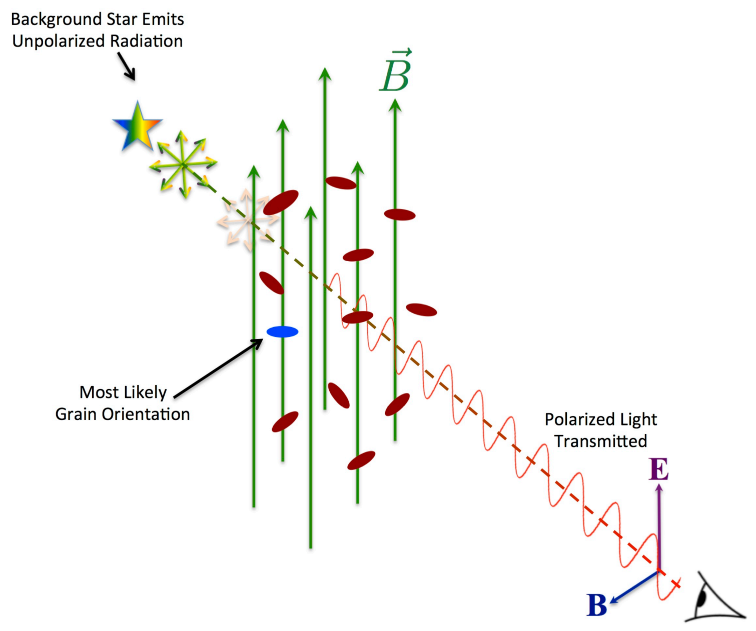
Outline of Talk

- Intro to polarization, grain alignment theory and the Local Bubble
- Archival data used for study and assumptions made
- Variations in the Local Bubble Wall
  - Geometric effects
  - Grain alignment
  - Magnetic field strength

ISM Polarization

- ISM polarization caused by asymmetric dust grains aligned with magnetic field
  - Unpolarized light is randomly orientated
  - Passing through magnetic field polarizes light (aligns in common direction)
- Allows us to:
  - Understand grain alignment
    - Understand dust characteristics and radiation field
  - Trace magnetic fields
  - Measure magnetic field strength (Chandrasekhar-Fermi Method)



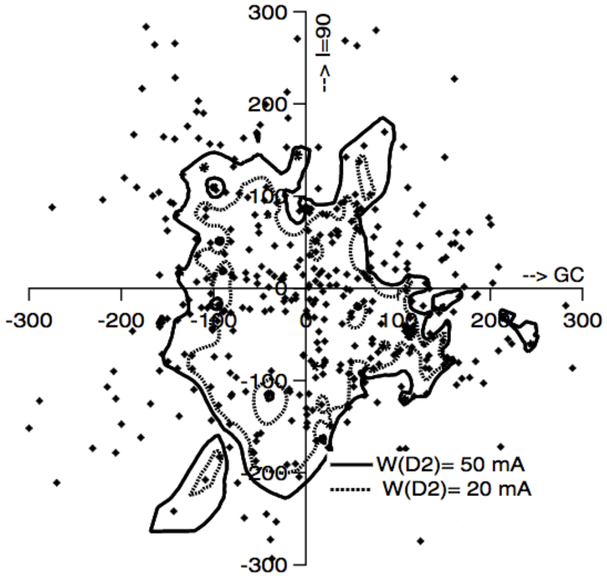
Source: Andersson, BG. "B-G Andersson – Astronomer." *BG Andersson Astronomer. N.p., n.d. Web.*

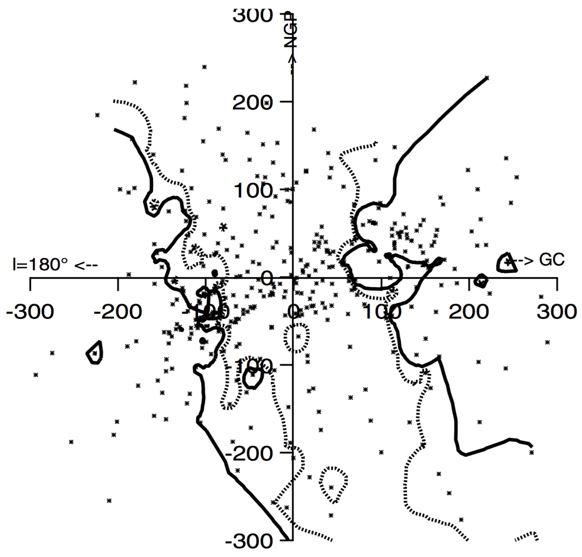
Grain Alignment Theory

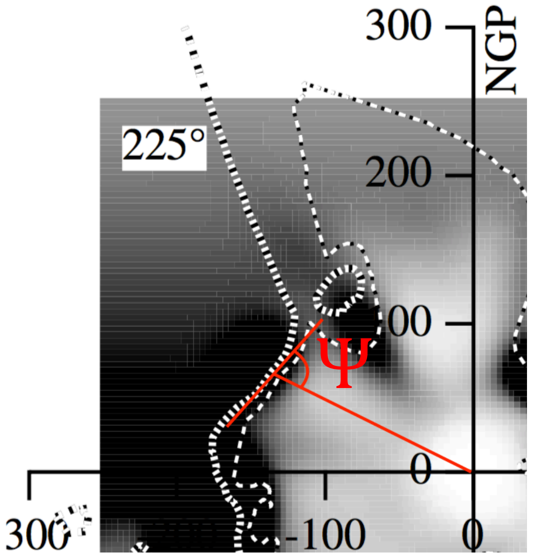
- Radiative Alignment Torque (RAT) theory
  - Grains “spun up” by torques imparted by a radiation field
  - Grain then precesses around magnetic field
  - Grain begins to “wobble” – torques turn spin axis to line up with magnetic field
- Other factors to consider
  - Size, shape and minerology
  - Density and turbulence (disalignment due to gas-grain collision)

Local Bubble

- Low density, ionized cavity in ISM surrounded by higher density material
- Wall of bubble traced by Sodium Absorption line measurements
- Estimated angle of wall (Ψ) using these maps (Lallement et al. 2003)







Source: Lallement, R., Welsh, B. Y., Vergely, J. L., Crifo, F., & Sfeir, D. 2003, A&A, 411, 447

Archival Data Used

- 3D maps of Local Bubble (Lallement et al. 2003)
  - Used equivalent widths of the interstellar NaI D-line at 5890 A and NaI absorption measurments (Welsh et al. 1994, Sfeir et al. 1999) to create maps by mapping iso-equivalent width contours
- Polarization %, direction (Berdyugin et al. 2014)
  - Polarization maps of the regions around the north (*b*>30°) pole from data obtained with the DiPol polarimeter installed on 60 cm telescope and from past observations (Berdyugin & Teerikorpi 2002, Berdyugin et al. 2004) for a sample size of 2400 stars with distances of up to ~800 pc
- UBV photometry (Høg et al. 2000)
- JHK photometry (2MASS)
- Trigonometric parallax (Gaia DR2, DR1 & Hipparcos)
- Spectral Type (Wright et al. 2003)
- Combined, we have 1,066 stars with reliable Av

$$E_{B-V} = (B-V) - (B-V)_o$$

$$E_{V-K} = (V-K) - (V-K)_o$$

$$R_V = 1.1\frac{E_{V-K}}{E_{B-V}}$$

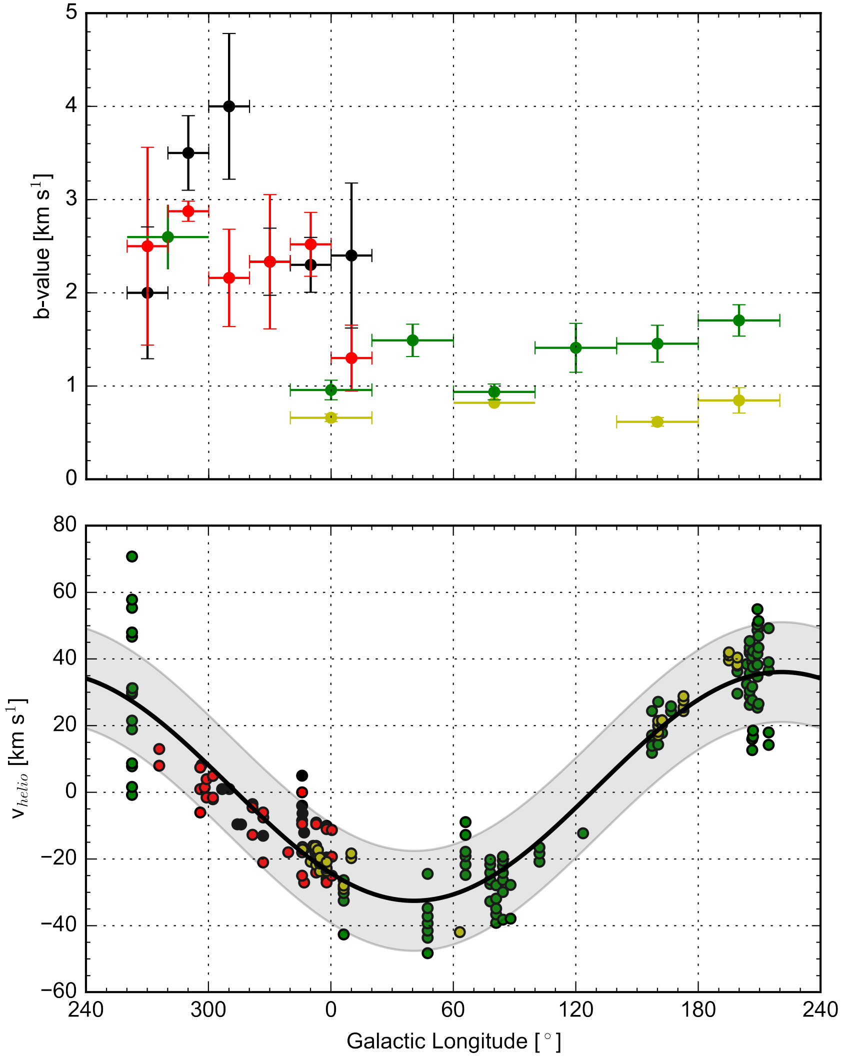
$$A_V = R_V E_{B-V}$$

Assumptions Made

- Assumed fixed parameters:
  - Size, shape and minerology of the grain distribution
  - Gas density (implications of variations discussed later)
- Magnetic field follows the Local Bubble wall
  - Can use wall angle to account for large-scale projection effects
- Disalignment constant (given fixed gas density)
- Can show that turbulence is (relatively) constant

Constant Turbulence

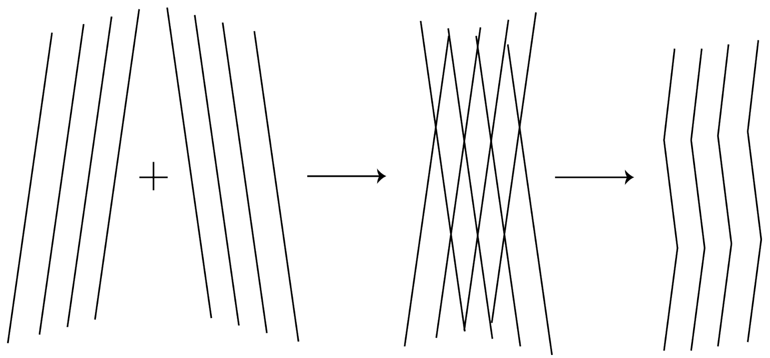
- Extracted line width b-values from multiple surveys to cover full sky
- Line width of gas if roughly constant
  - Exceptions in third quadrant
    - Larger variations in Crawford (1991) data, small compared to polarization data (discussed later)
    - Largest variation in Welty et al. (1996) data, most likely not tracing LBW gas kinematics though



- K I: Welty & Hobbs (2001), spec. reso. ~0.4-1.8 km/s, yellow
- Ca II: Welty et al. (1996), spec. reso. ~0.3-1.2 km/s, green
- Na II & Ca II: Crawford (1991), spec. reso. ~3.6 km/s, black and red

Geometric Effects

- As mentioned, need to account for large-scale projection effects due to LBW angle with line of sight
- Allows us to separate (inherent) polarization efficiently and (observed) fractions polarization
- Not applicable to regions where mean direction in magnetic field is close to line of sight
- Preformed Student’s t-test
  - 93.9% likelihood we are able to distinguish between these two types of regions
  - $\bar{\beta} = 0.15 \pm 0.04$ for $\Psi < 13°$

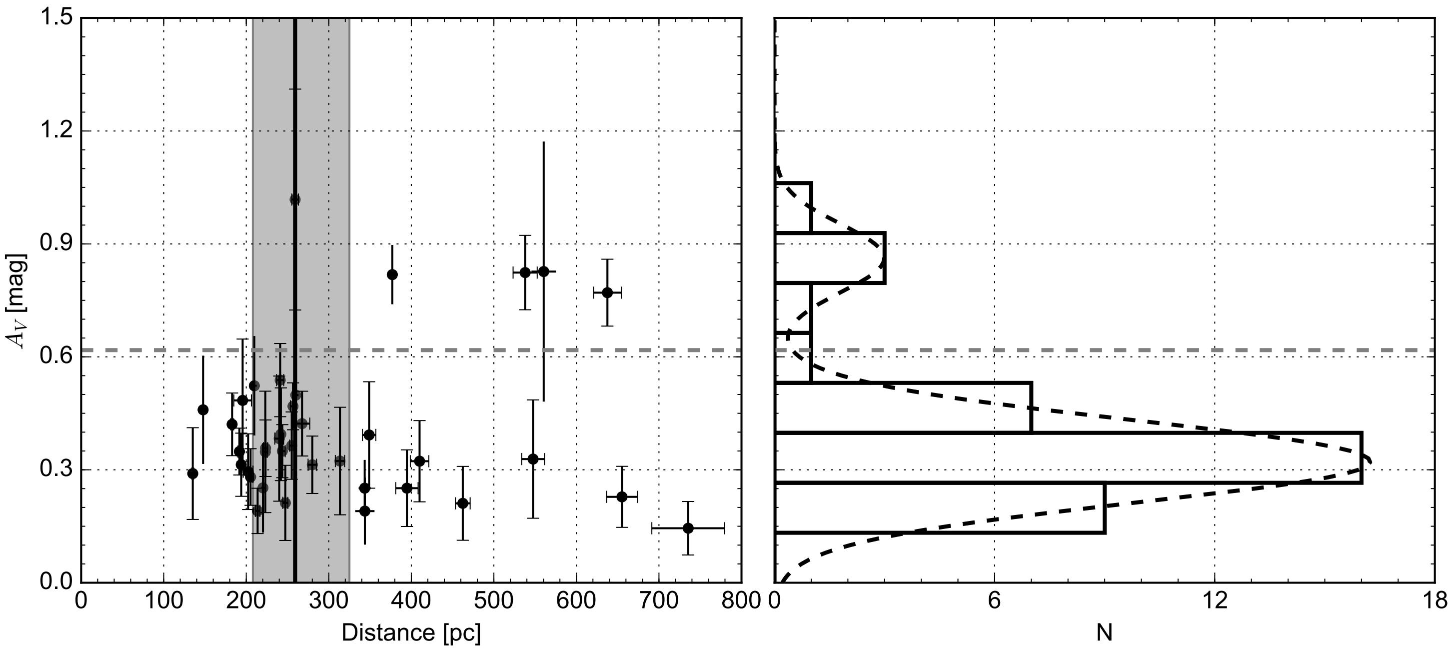


Grain Alignment Variations

- With characteristics of dust grains and gas assumed (or shown fixed), consider grain alignment variations
- Variations in distance
  - Could be due to additional “screens” besides LBW, would introduce errors in subsequent analysis
- Variations in longitude
  - With previous assumptions, this due to some primary aligning mechanism

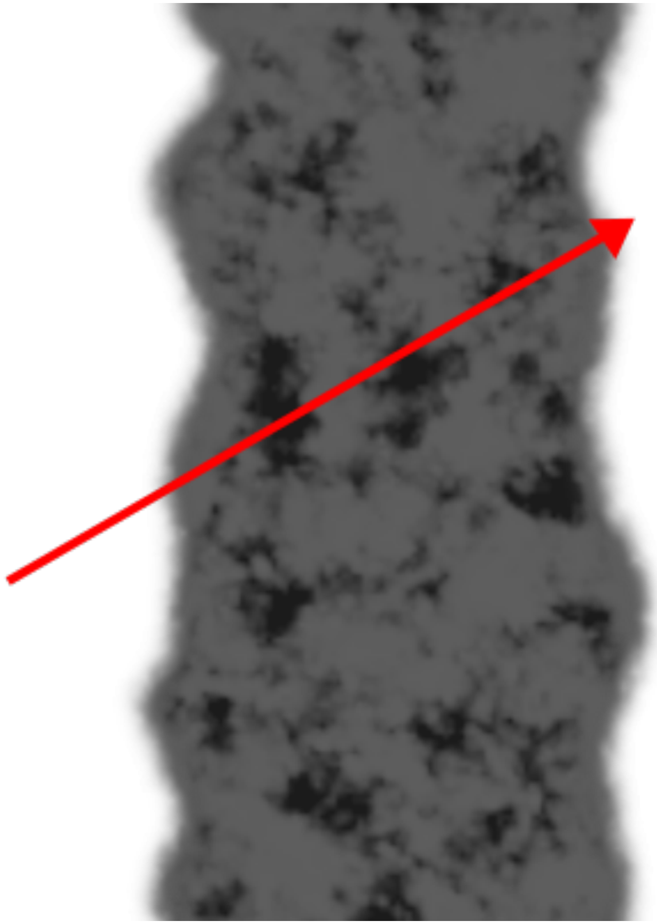
Grain Alignment Variations - Distance

- Fit A_V and p distributions with one and two component Gaussians
- Identify regions where two component Gaussian favored and means separated by $> 3\sigma$
- Distance to second screen is distance to nearest star



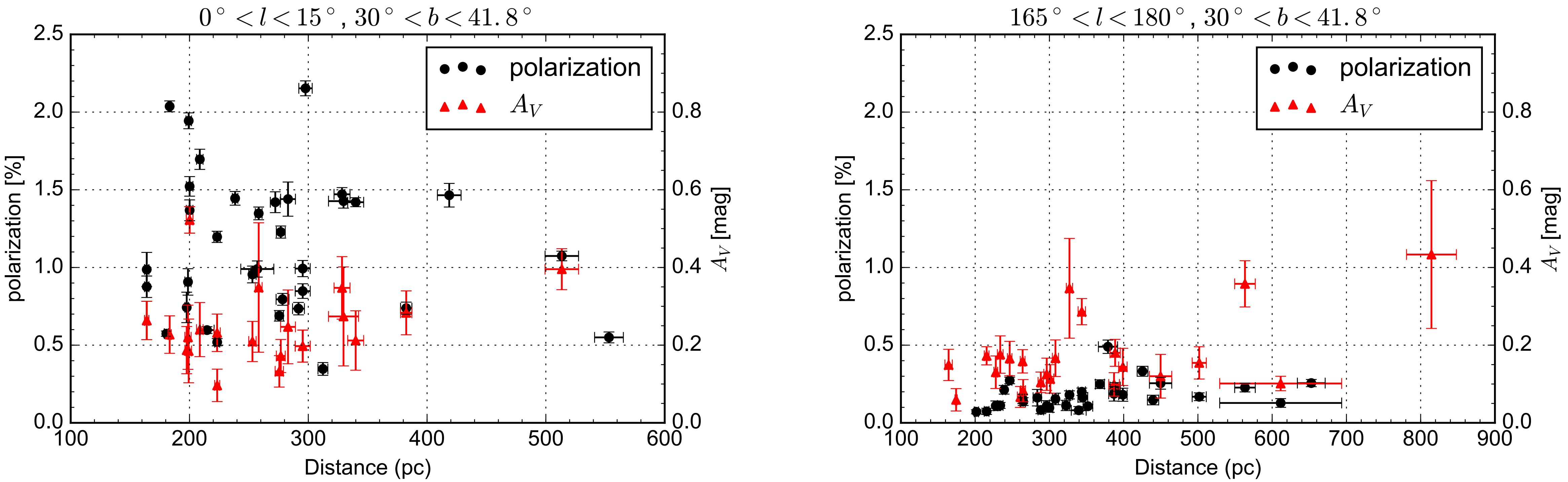
Grain Alignment Variations - Distance

- Identified six regions with some step increase
- All steps consistent with Local Bubble wall distance
- Observe these steps as an inhomogeneous screen can have properties similar to screen
- As seem to only observe effects of “clumpy medium”, will assume single extinction and polarization screen for all bins



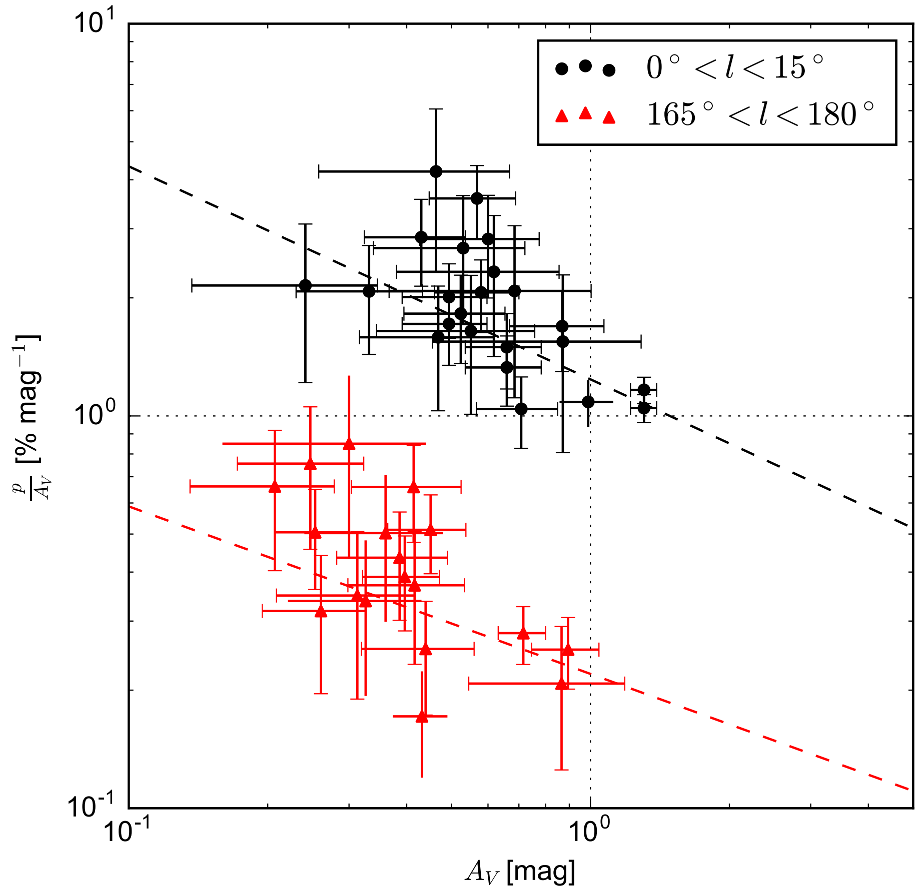
Grain Alignment Variations - Longitude

- Noticed large spike in polarization around galactic center
- Want to quantify level of alignment for all regions to trace variationa



Grain Alignment Variations - Longitude

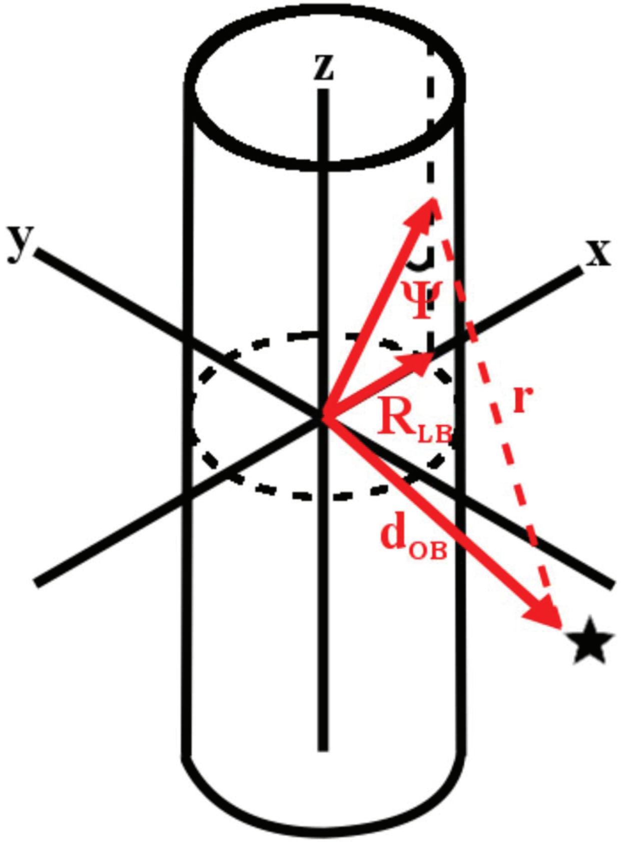
- Evaluate grain alignment efficiency with fractional polarization (p/Av)
  - Need to account for line of sight turbulence
- Jones et al. (1992) shows that in relationship:
  - α depends on turbulence of material
  - β is sensitive to number alignable grains (fixed), grain alignment efficiency (want to evaluate), and orientation of the field (can account for via LB geometry)
- $\beta(\sin\Psi)^{-1}$ probe for grain alignment efficiency



$$\log\left(\frac{p}{A_V}\right) = \alpha\log(A_V) + \beta$$

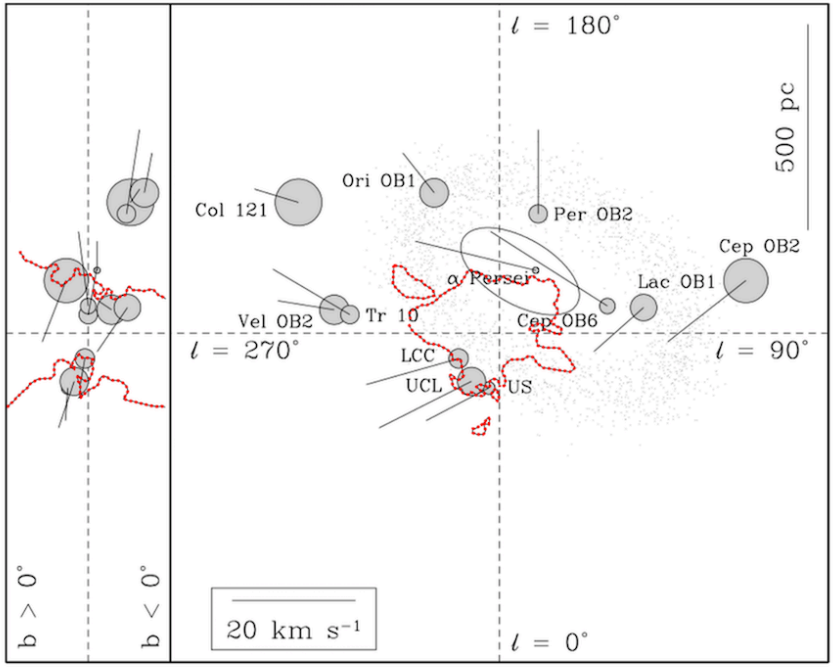
Alignment Driving Mechanisms

- Nearby radiation field (per RAT theory)
  - Simply scale modeled radiation field at the LB wall distance to compared to alignment efficiency: $\beta(\sin\Psi)^{-1}(l,b) = A + B\sum_{i=1}^{n}\frac{L_i}{r_i^2}$
- Variations could also be due to Galactic magnetic field
  - Modeled by: $\beta(\sin\Psi)^{-1}(l,b) = a + c\sin\left(l - 80^{\circ}\right)$ (Crutcher et al. 2003)



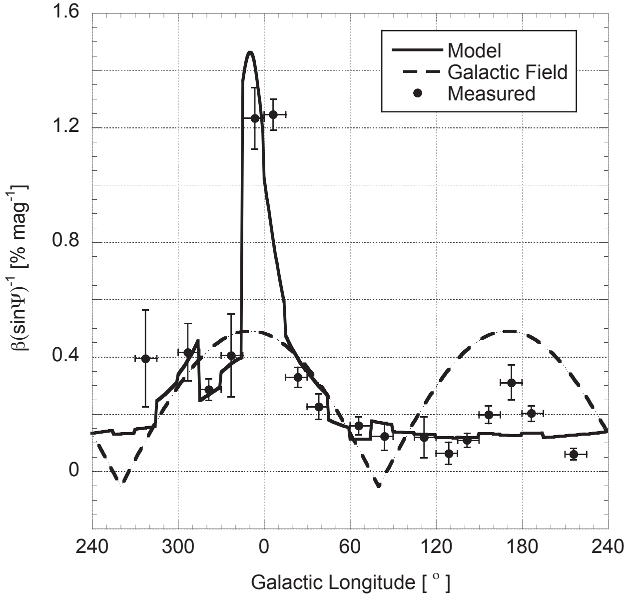
Nearby Sources of Radiation

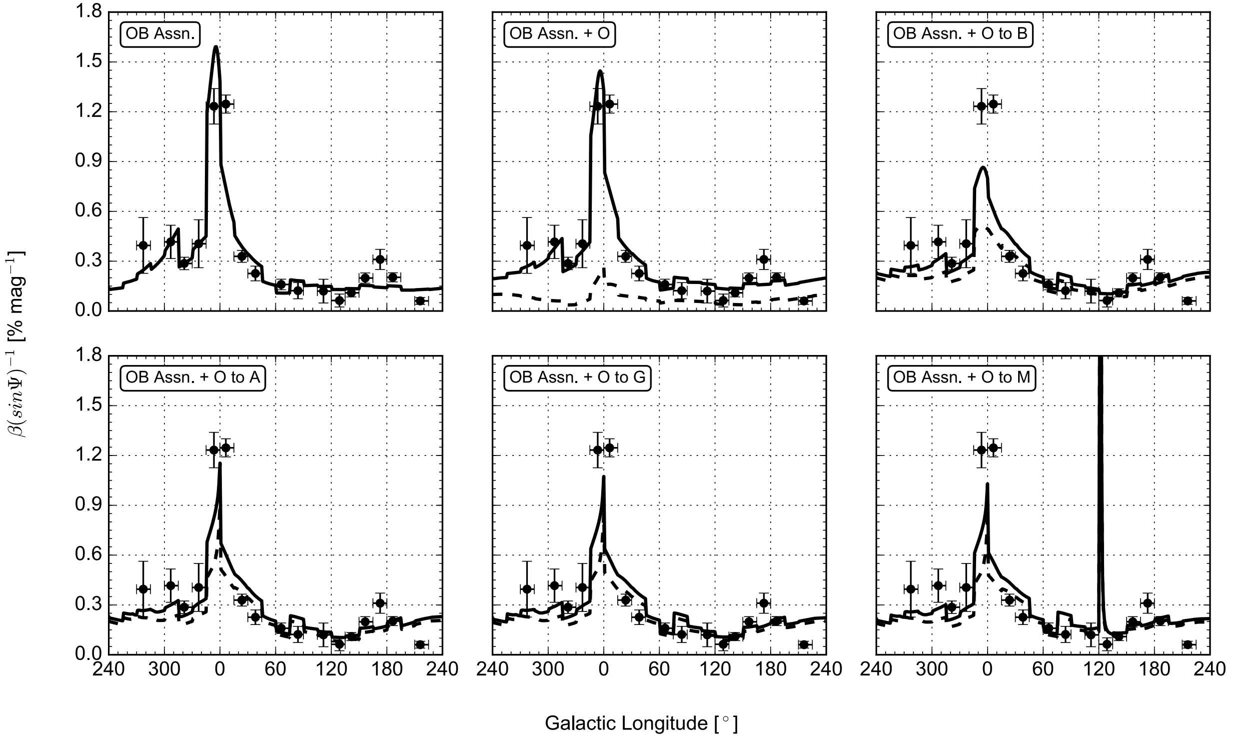
- Most likely to be nearby OB associations
  - de Zeeuw et al. (1999) conducted comprehensive census of OB associations within 1 kpc
  - Treat each OB association as point source with luminosity equal to sum of association candidates
- Also consider all spectrally classified nearby field stars
  - Michigan and Wright catalogs

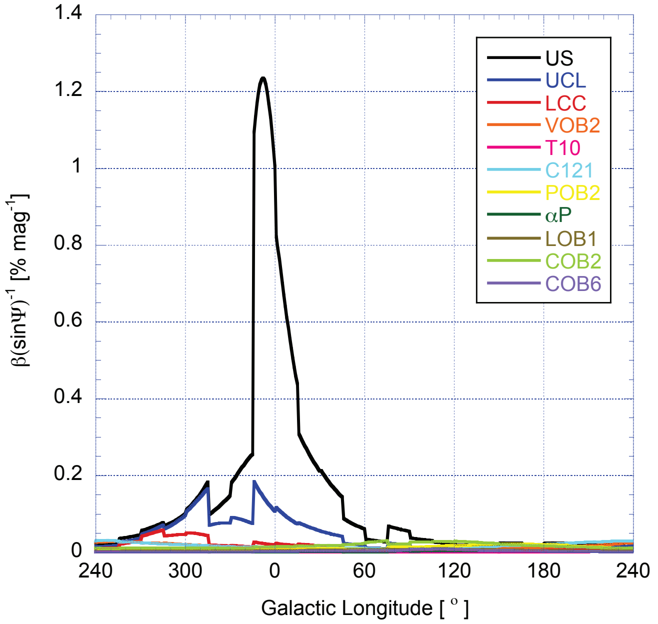


Grain Alignment Variations - Longitude

- Radiation field at LBW distance highly correlated with observations
- Field due to blue sources best aligns with observations (expected in RAT theory)





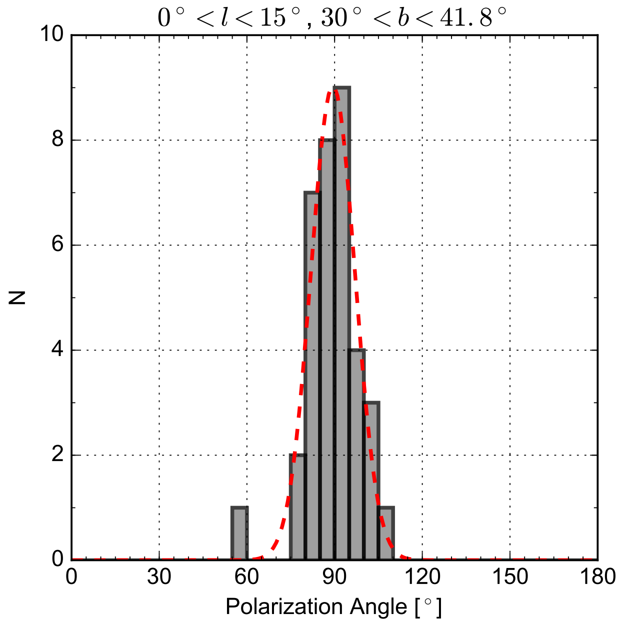


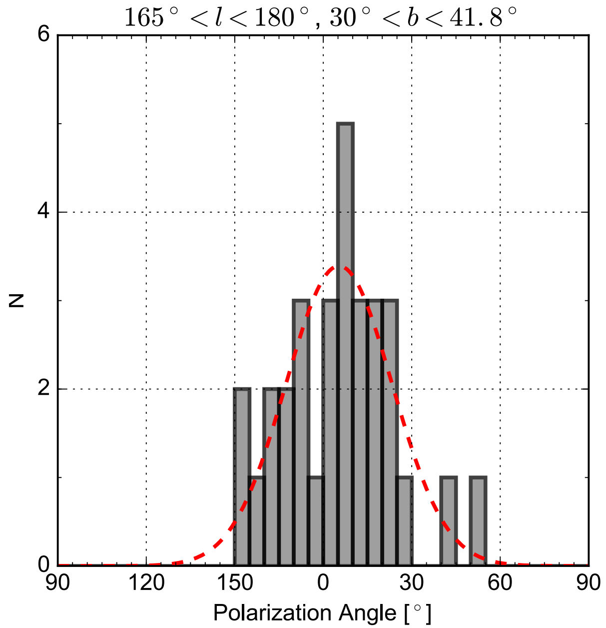
Chandrasekhar-Fermi Method

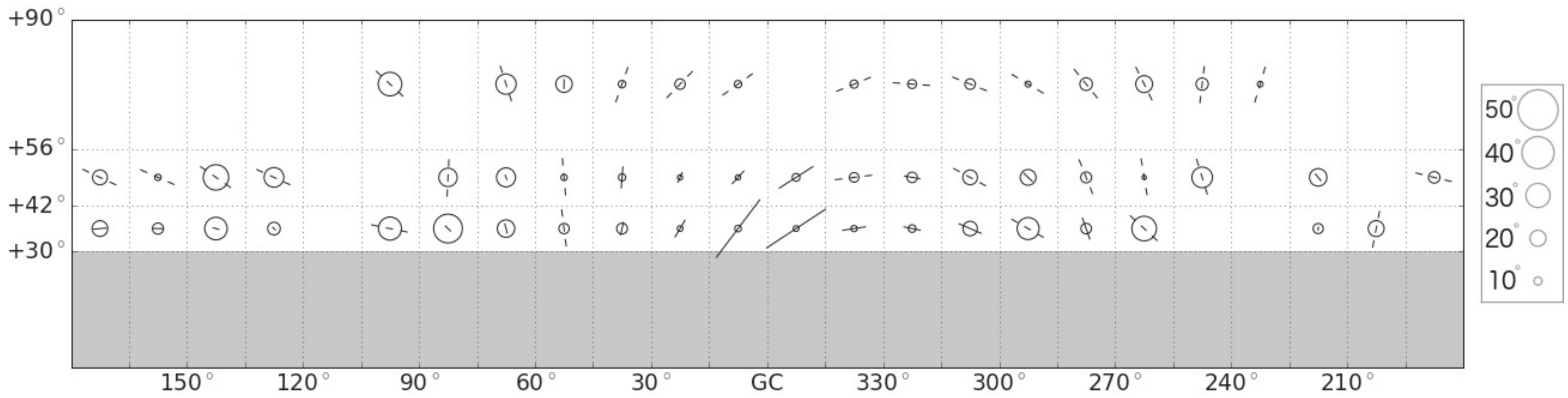
- With polarization angle data, we are able to estimate the magnetic field strength in LBW
- Chandrasekhar-Fermi Method: $\langle B_{\perp} \rangle^2 = \frac{4\pi\rho\Delta v_{los}^2}{\Delta\theta^2}$
  - We have assumed the gas density to be constant
  - Shown turbulence to be constant for all lines of sight
  - Variations in magnetic field strength then inversely proportional to position angle dispersions

Chandrasekhar-Fermi Method

- Fit Gaussian to distribution of polarization angles for each region to find dispersion
- Similar to grain alignment, observe variation in polarization angle dispersions
  - Low dispersion in similar regions as larger grain alignment efficiency

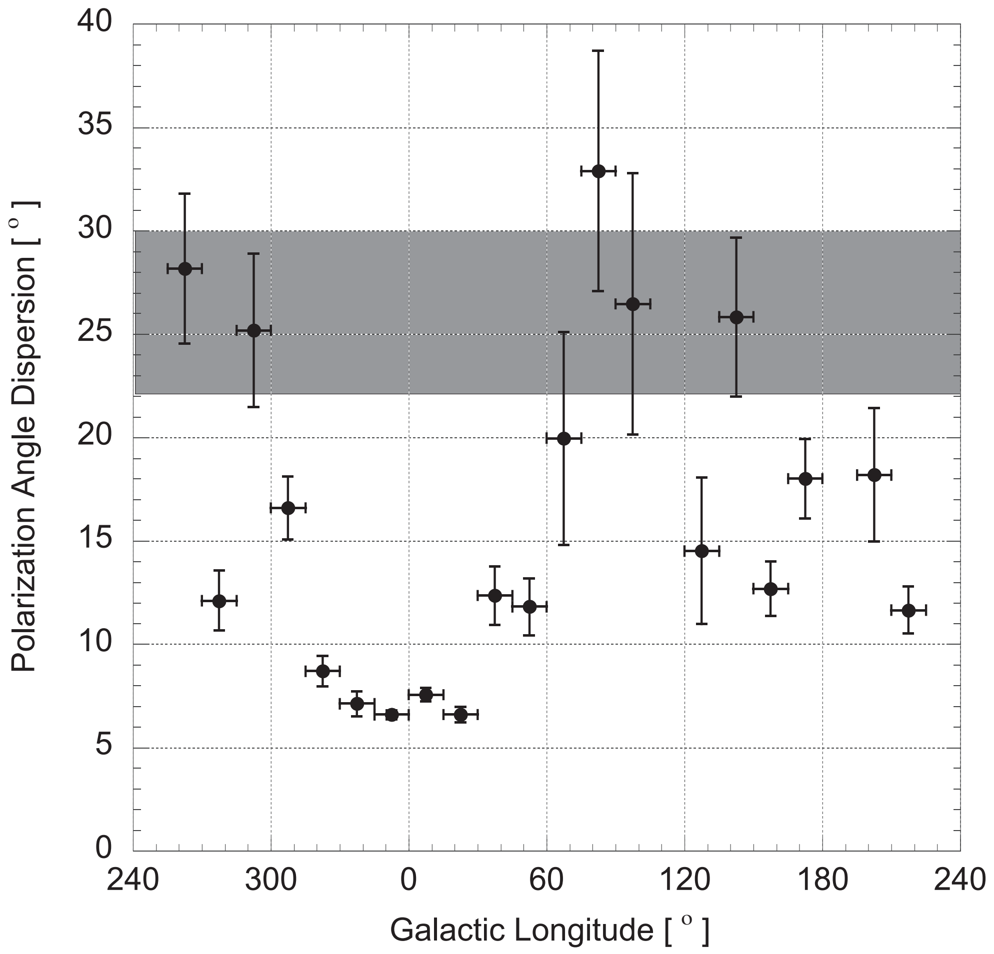






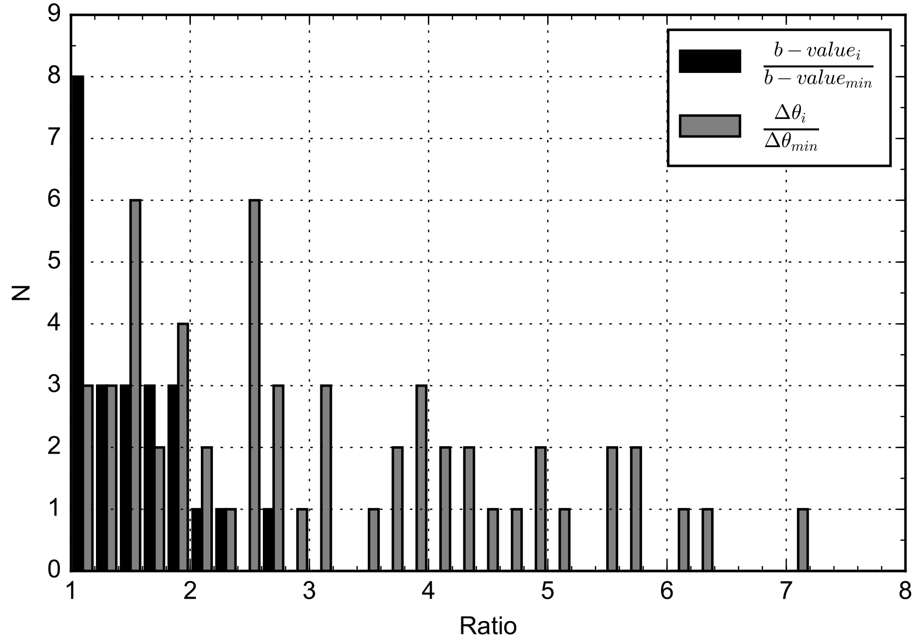
Polarization Angle Dispersion Variations

- Andersson & Potter (2006) found that $\Delta\theta = 26 \pm 4°$ towards the Southern Coalsack ($l, b = 300°$)
  - Our observations consistent with this in regions of lower grain alignment efficiency
- Spearman's Rank Order Correlation test: 0.03% probability dispersion random with respect to β



Polarization Angle Dispersion Variations

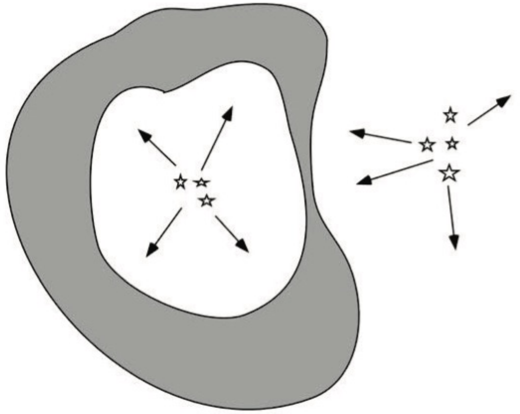
- As mentioned, turbulence roughly constant, but still small variations
  - Not comparable to dispersion though
- Assumed density to be constant
  - For magnetic field strength to be constant in LBW, there would have to be a large (~factor of 25) decrease in density towards Galactic center
- Alternative is correlation between low PA dispersion and grain alignment efficiency, feel this is probably the case

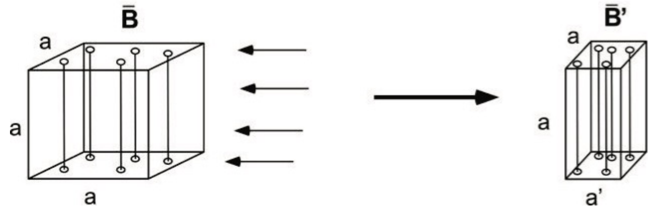


$$\langle B_\perp \rangle_i^2 = \langle B_\perp \rangle_o^2 \frac{\rho_i \Delta v_{los,i}^2 \Delta\theta_o^2}{\rho_o \Delta v_{los,o}^2 \Delta\theta_i^2}$$

Polarization Angle Dispersion Variations

- With this correlation, this would indicate OB associations are drivers of bifurcation in some way
- As stated, LB shaped internally by supernovae and stellar winds
  - OB associations could provide similar flows compressing wall in these regions
- With magnetic field parallel to wall and frozen in plasma, compression would cause increased strength
  - Density in regions would also stay same, or increase, not decrease





Results Summary

- Modeling the grain alignment as due to a dominant alignment mechanism accurately reproduces the data
  - This supports radiatively driven grain alignment
  - Demonstrates that polarimetry could potentially be used to probe radiation fields
- Correlation in grain alignment efficiency and relatively higher magnetic field strength suggests compression of LBW
- Addition of multi-band polarimetry and accurate space density measurements would allow further tests of the theory