Polarization of Starlight: Optical/Near IR Observations & the Connection to sub-mm Surveys

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Collaborators:

- **Polarimetry Group - IAG, U. São Paulo**

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- Jean-Philippe **Bernard** & CESR team
  Frederick Poidevin
    - ISM/PILOT, PLANCK

- Caroline **Bot**, U. Strasbourg
    - SMC

- Karen **&** Jon **Bjorkman**, U. Toledo
  John **Wisniewski**, U. Washington
    - Magellanic Cloud ISM, circumstellar disks

- Pris **Frisch**, U. Chicago
  B-G **Andersson**, SOFIA/USRA
  V. **Piirola**, U. Turku, Finland
    - Local ISM

Outline of the Talk

- **Basic Facts**
  - Starlight & Emission Polarization & the ISM
- **Solar Neighbourhood**
  - Local ISM vs. Heliosphere
- **Galactic ISM**
  - Southern IS Pol Survey at IAG-USP
  - Dark Clouds
  - Fields on small & large scales
  - High Galactic Latitudes
- **ISM in Nearby Galaxies**
  - SMC dust
  - SMC/LMC connection
- **ISM & Stars**
  - Relation between **Envelopes** & **Ambient Field**
- **SOUTH POL**
  - Survey of the Polarized Southern Sky
- **Conclusions**

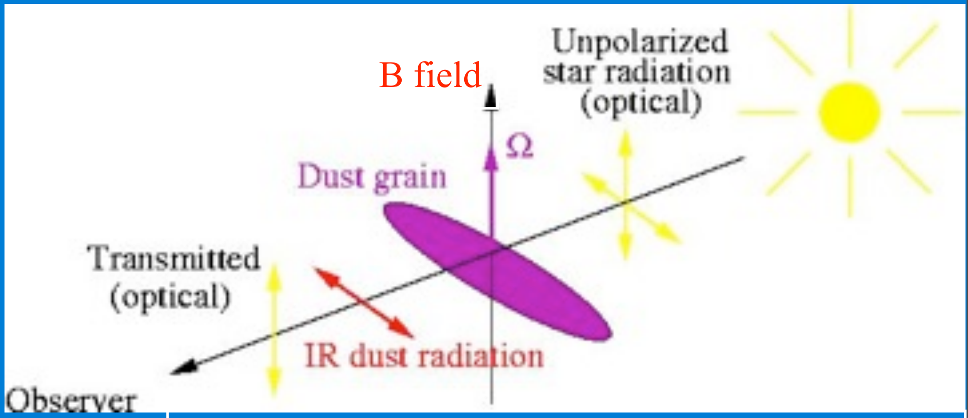
Sky in the sub-mm

- **Galactic Dust Emission**

Basic Facts

- **Polarization arises from**
  - **Dust grains**

    aligned by
  - ISM's **Magnetic Field, B**



adapted from Ponthieu, Lagache; www.planck.fr

- **Polarization provides info on**
  - **Dust properties**
    - size distribution, composition
  - $\mathbf{B_{sky}}$
    - B component projected on the sky

Basic Facts

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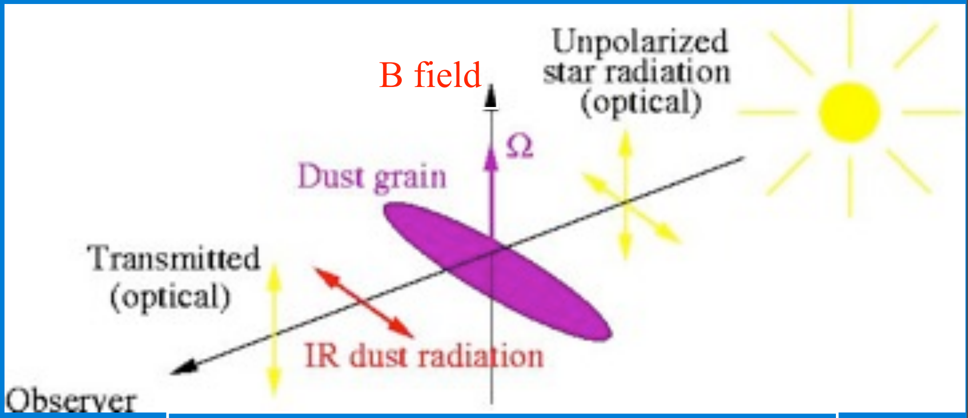

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- **Polarization provides info on**
  - **Dust properties**
    - size distribution, composition
  - **B_{sky}**
    - B component projected on the sky

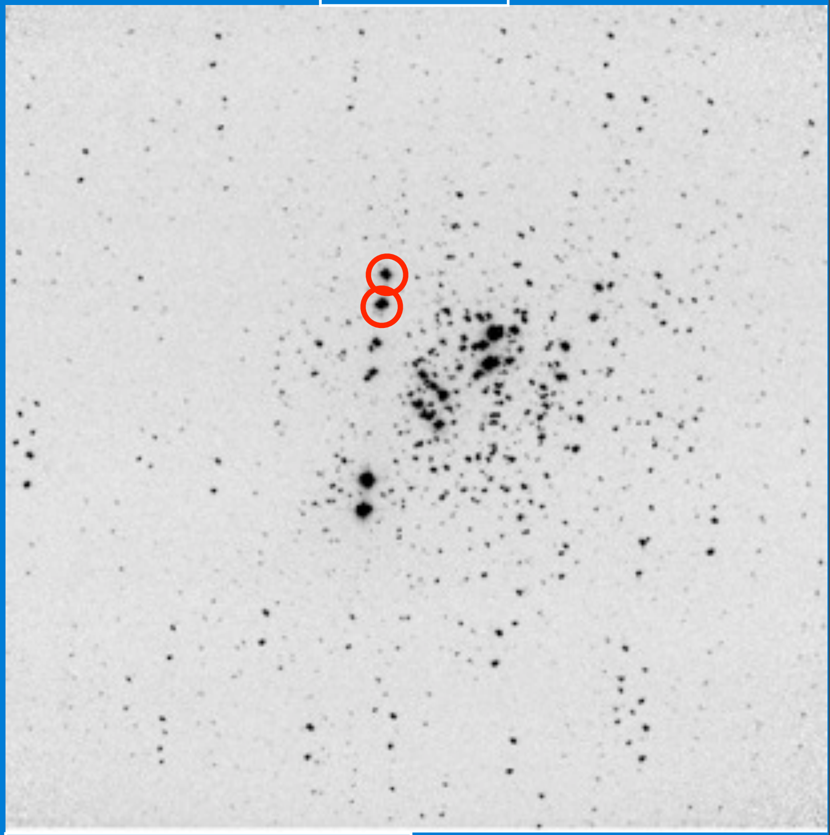
In the **Optical/NIR**: PA // B_{sky}

In the **Sub-mm**: PA $\perp$ B_{sky}

Basic Facts

- **Optical/NIR Technique**
  - IAGPOL polarimeter
    - Rotatable waveplate
      +
      calcite prism
      +
      detector (**CCD** or **NIR array**)

κ Crucis



Magalhães et al. 2005

Basic Facts

- **Optical/NIR Technique**
  - IAGPOL polarimeter
    - Rotatable waveplate
      +
      calcite prism
      +
      detector (**CCD** or **NIR array**)

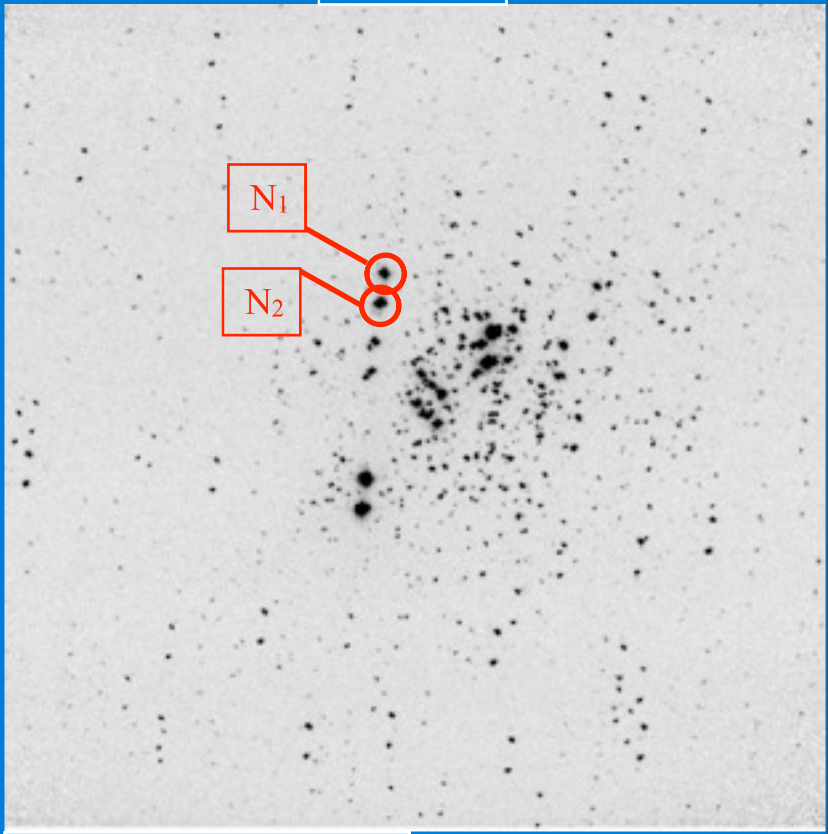
- **Counts @ waveplate angles ψ_i:**

$$z_i = \frac{N_1 - N_2}{N_1 + N_2}\Big|_i = Q \cdot \cos(4\psi_i) + U \cdot \sin(4\psi_i)$$

$$\Rightarrow \mathbf{Q} = z_1 - z_3 + z_5 - z_7$$

$$\mathbf{U} = z_2 - z_4 + z_6 - z_8$$

κ Crucis



Magalhães et al. 2005

Basic Facts

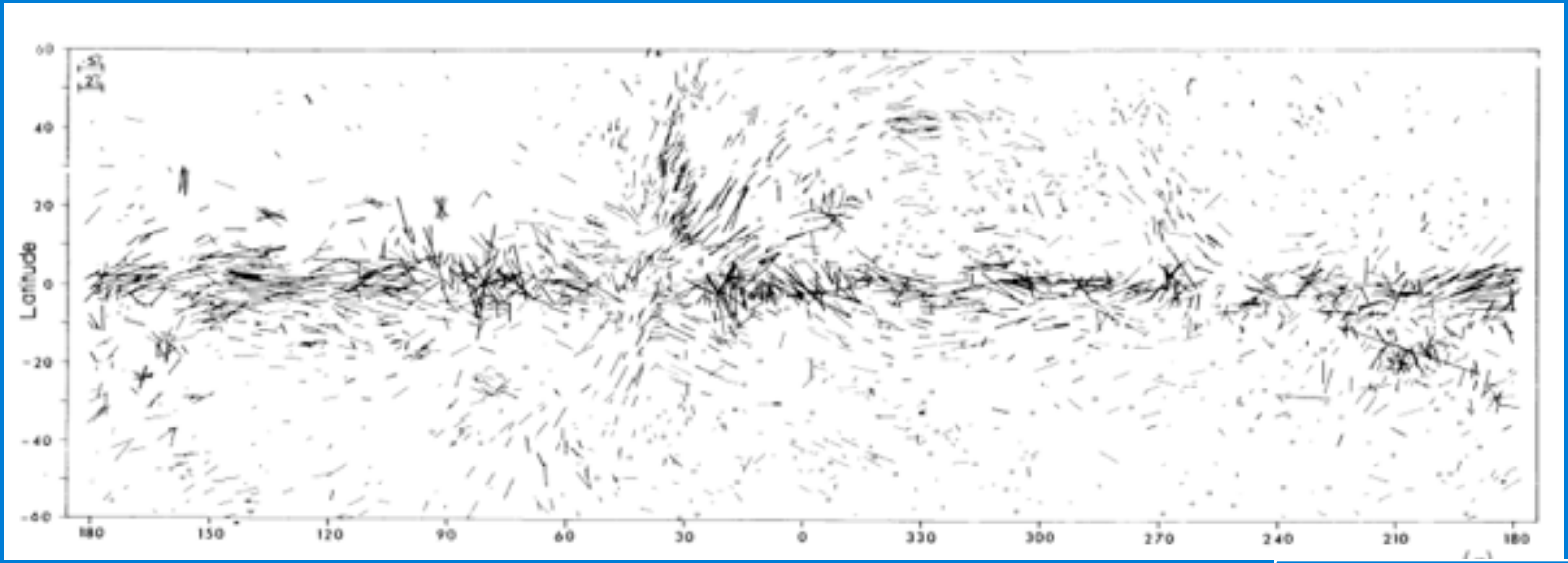
- **Observational uncertainties**
  - Hiltner 1951, ApJ 114, 241:
    - p.e. = 0.0022 mag ⇔ $\sigma = 0.15\%$ (!) (photoelectric)
  - Tinbergen 1982, A&A 105, 53:
    - $\sigma = .007\%$ (photoelectric, combining data)
  - Carciofi, Magalhães 2007, ApJ 671, L49:
    - $\sigma = 0.002\%$ (CCD imaging, single obs)

      ($\sigma_\theta = 28.6\ \sigma/P$ deg)

- **High accuracy now possible opens up interesting possibilities!**

Basic Facts

- **B-field of the Galaxy from stellar (optical) polarization**



Mathewson & Ford 1970

- Heiles (1996)
  - Center of curvature, R_{cc}, and direction of center, l_{cc}:
  - R_{cc} = (8.8 +- 1.8) kpc, l_{cc} = (-7.2^o +- 4.1^o)
- (northern) Galactic Plane IR Polarization Survey (GPIPS)
  - Clemens (2009)

Basic Facts

- **B-field info from stellar polarization**

– Statistical analysis (Fosalba et al. 2002)

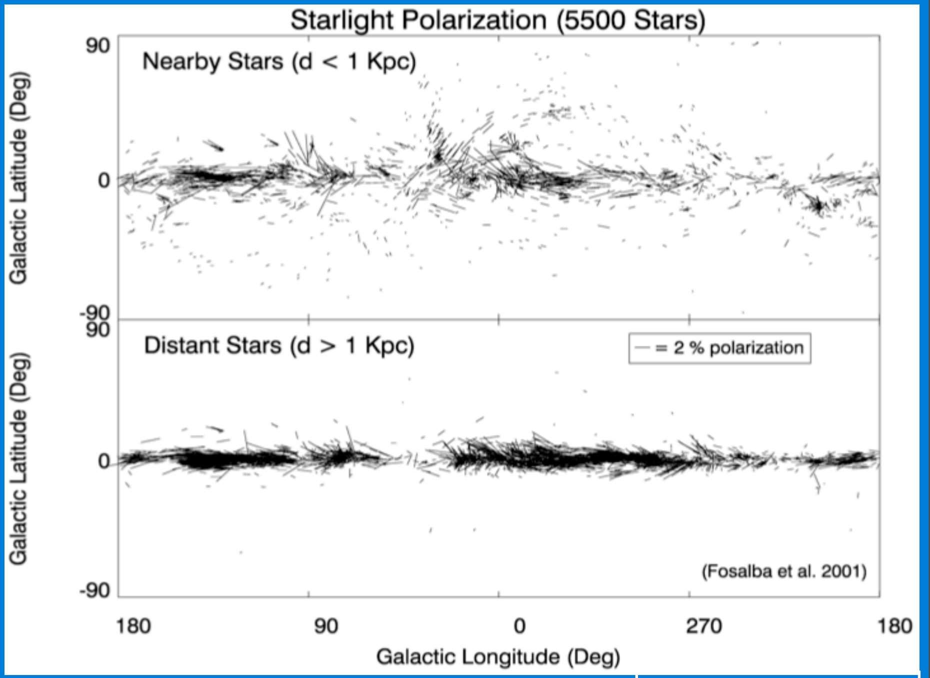
- $$\frac{P_{obs}}{P_{max}} = \frac{B_u^2}{B_u^2 + B_r^2} \cong 0.39 - 0.69$$

$$\Rightarrow \quad \frac{B_u}{B_r} \approx 0.80 - 1.27$$

u = **u**niform
r = **r**andom

– also: Heiles (1996)

- Angular spectrum: $\mathbf{P = C_{\mathit{l}} \propto \mathit{l}^{-1.5}}$
  – does reflect underlying polarized continuum
  CAVEAT EMPTOR: This is for **Galactic Plane**
  – important for modeling Galactic **polarized emission in sub-mm**
  Cho & Lazarian (2010)

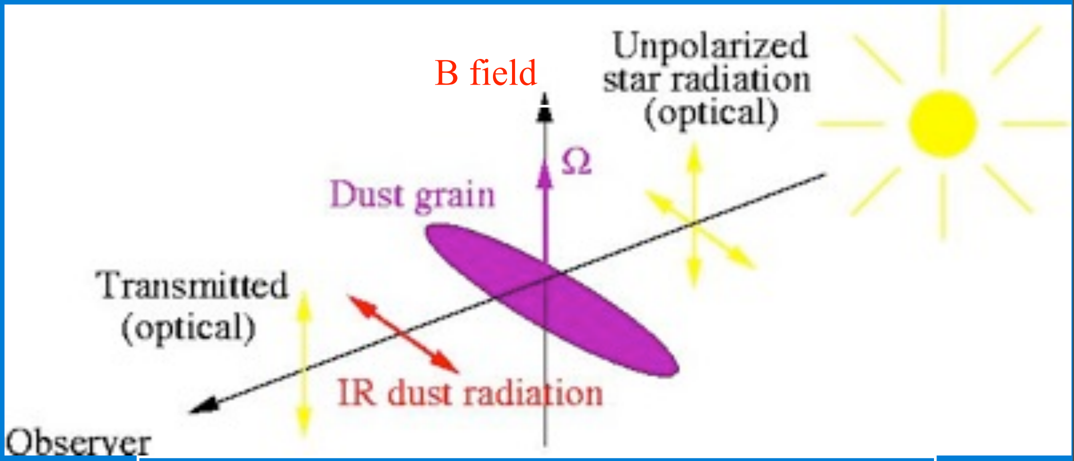


Fosalba et al. 02

Polarization by ISM Dust

- **Optical polarization**
  - works w/ low **A_V** (1 - 5 mag)
    - Ex., **outskirts** of dark clouds

- **Sub-mm polarization**
  - works w/ high **Av** (10 - 100)
    - Ex., **central regions** of dark clouds



adapted from Ponthieu, Lagache; www.planck.fr

Basic Facts

- **Some Surveys of the Milky Way in the sub-mm**
  - WMAP
    - 23, 33, 41, 61 & 94 GHz, $\theta > 0.2°$
  - BICEPS
    - Bierman et al. (2011)
    - 100 GHz (0.93°), 150 GHz (0.6°), 220 GHz (0.42°)
    - 3 seasons, 3 large areas of the Southern Sky
  - Planck
    - LFI: 30 - 70 GHz, 12' (70GHz)/ 33'(30GHz)
    - HFI: 100 - 860 GHz, 5' (850GHz)/ 9.2'(100GHz)
  - More to come: CMBPol (USA), COrE (ESA)

Basic Facts: B-field strength

Pereyra & Magalhaes 07

- Chandrasekhar & Fermi method
  - C & F (53)
- **Equipartition** between **kinetic** & perturbed **magnetic** energies

  +

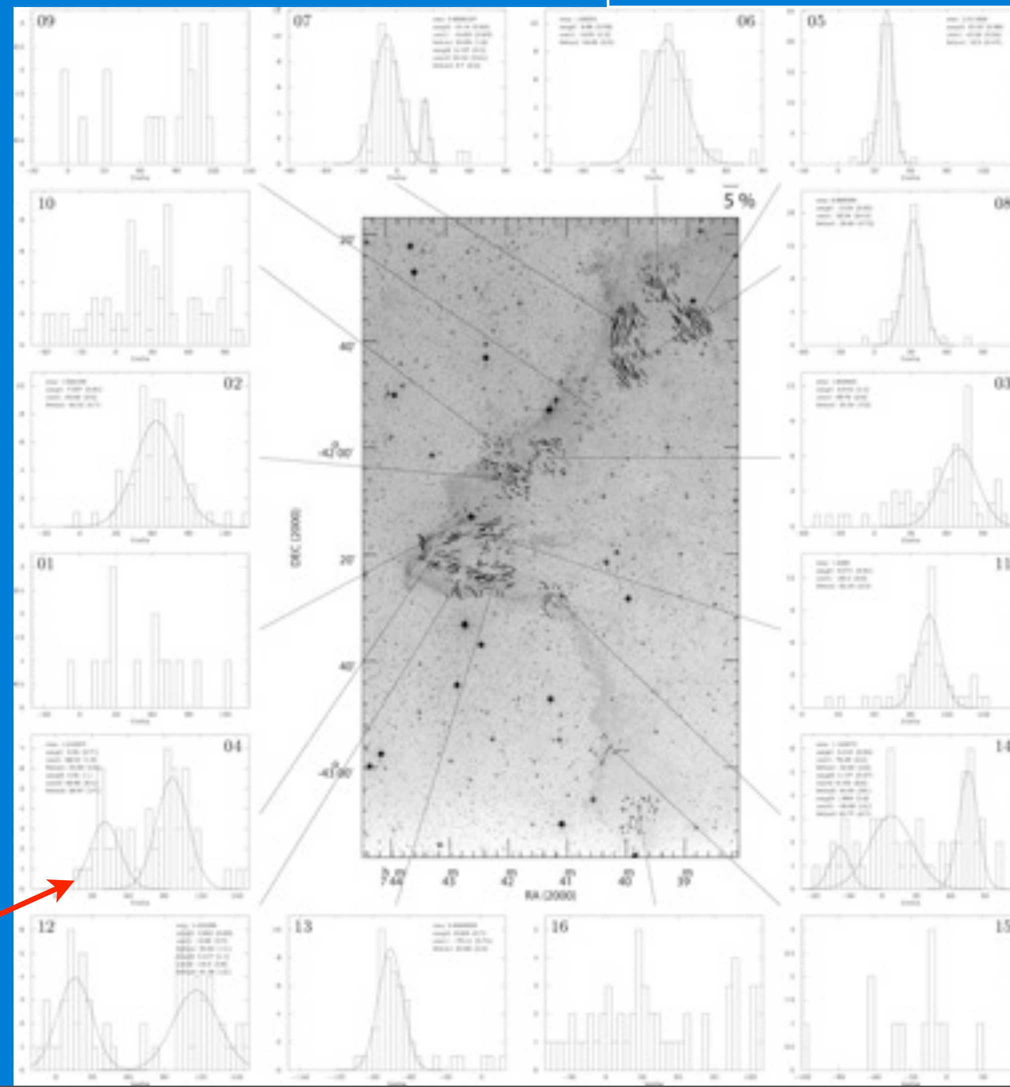
  isotropic rms velocity:

$$\frac{1}{2}\rho\delta V_{\rm LOS}^2 \sim \frac{1}{8\pi}\delta B^2$$

$$\Rightarrow \boxed{B_{sky} + \delta B \approx \sqrt{4\pi\rho}\,\frac{\delta V_{los}}{tan(\delta\phi)}}$$

Falceta-Gonçalves et al. (08)

Polarization PA distributions
$\Rightarrow$ **B estimates**

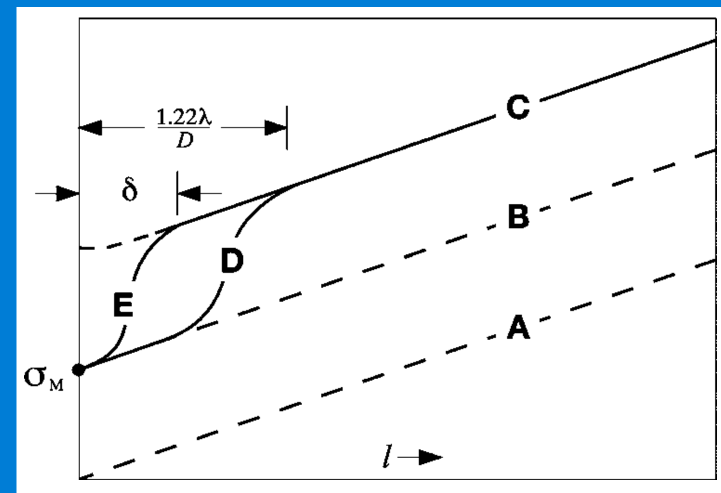


Basic Facts: B-field strength

- Another approach
  - Motivation: sub-mm
    - Falceta-Gonçalves et al. (2008)
    - Hildebrand et al. (2009)
- Construct **Dispersion Function**:

$$\langle \Delta\Phi^2(\ell)\rangle^{1/2} \equiv \left\{ \frac{1}{N(\ell)} \sum_{i=1}^{N(\ell)} [\Phi(\mathbf{x}) - \Phi(\mathbf{x}+\boldsymbol{\ell})]^2 \right\}^{1/2}$$

$\Rightarrow$



- One expects:

$$\langle \Delta\Phi^2(\ell)\rangle \simeq b^2 + m^2\ell^2, \tag{2}$$

or, realistically,

$$\langle \Delta\Phi^2(\ell)\rangle_{\rm tot} \simeq b^2 + m^2\ell^2 + \sigma_M^2(\ell), \tag{3}$$

δ = correl. length of $\mathbf{B}_{\rm turb}$

d = correl. length of $B_{\rm unif} = B_0$

l = angular separation between points

δ < l << d

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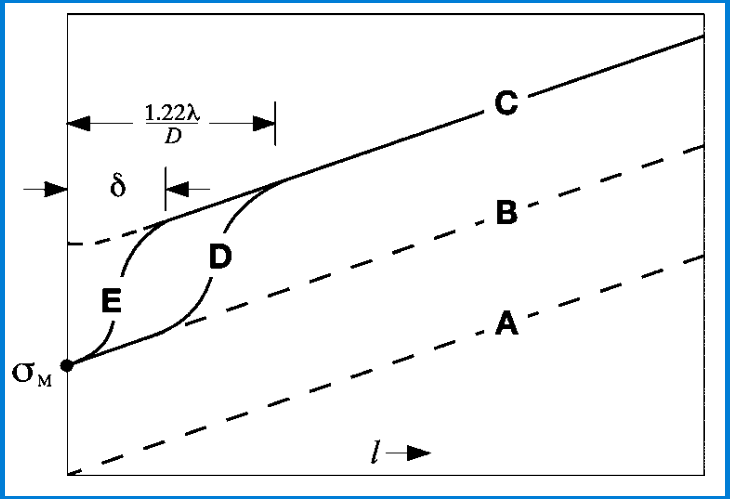

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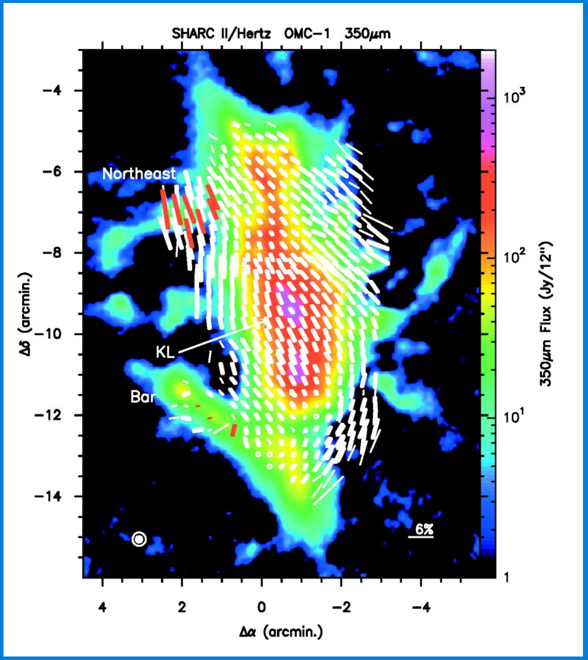
$\Downarrow$

$$\frac{\langle B_t^2\rangle^{1/2}}{B_0} = \frac{b}{\sqrt{2-b^2}}$$

$$B_0 \simeq \sqrt{(2-b^2)4\pi\rho}\,\frac{\sigma(v)}{b}$$

Basic Facts: B-field strength

Houde et al. 2004



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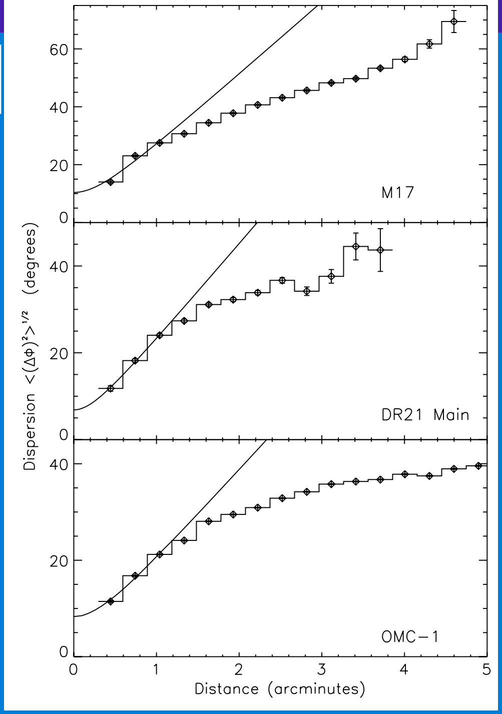

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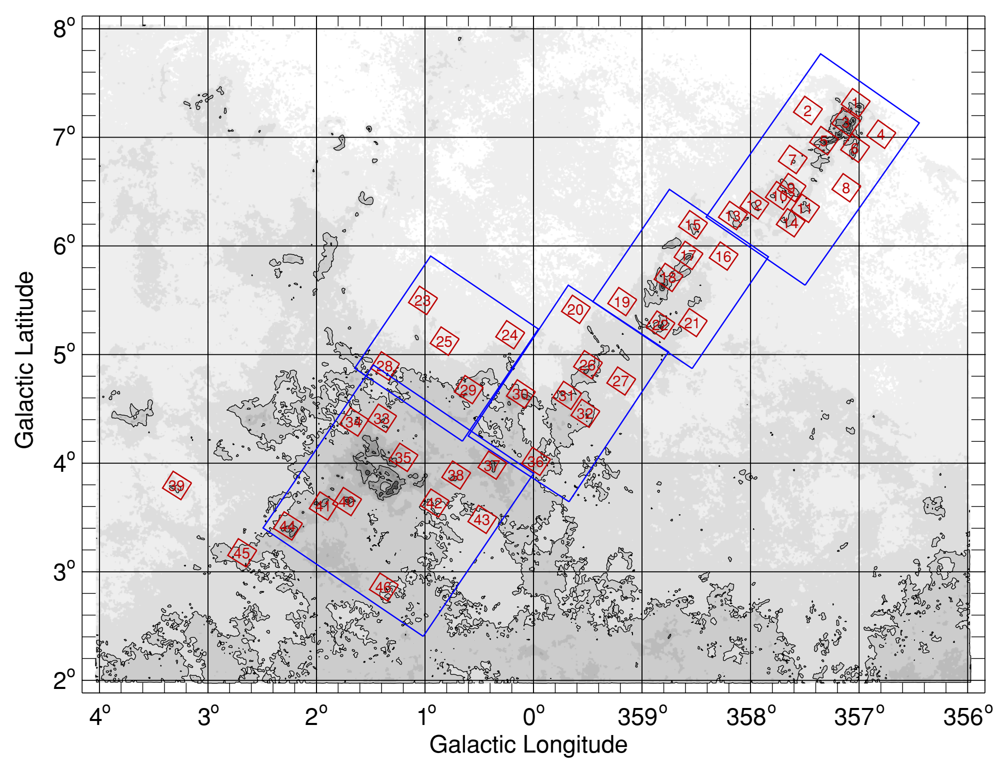
Table 1

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

Basic Facts: B-field strength

- Use of DF with **optical** data
- Ex. Pipe Nebula
  - Franco/**Alves**/Girart (2010)



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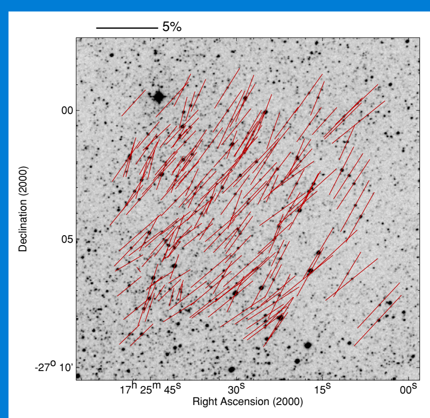

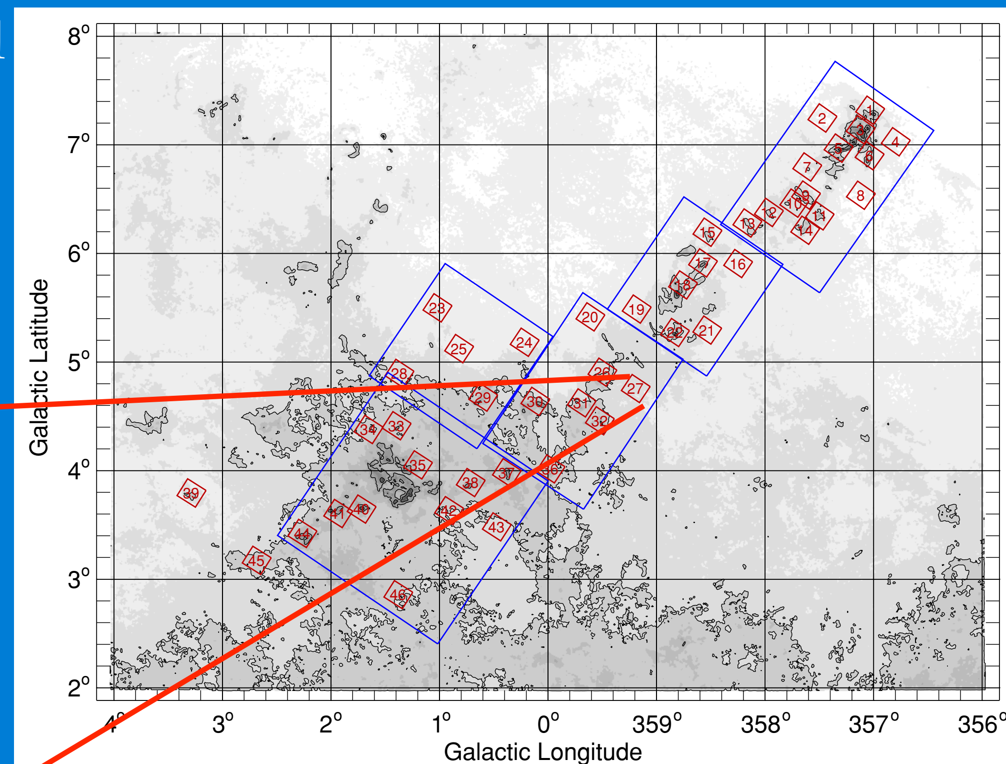

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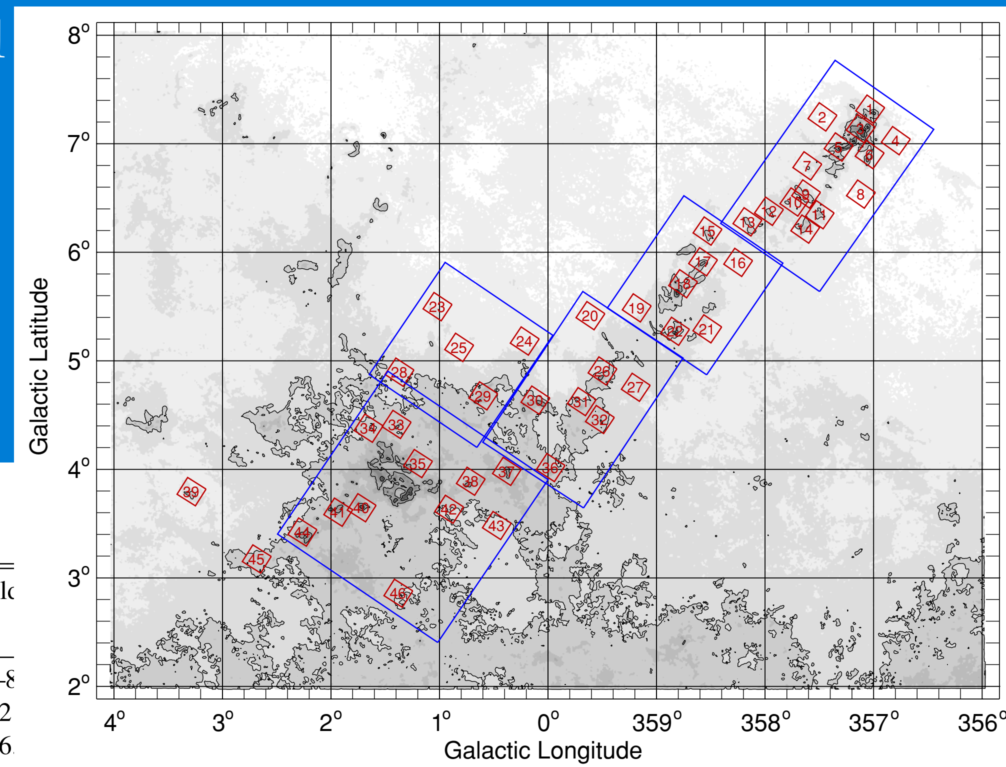


Table 4
Structure Function Parameters for the Pipe Nebula

Region	a_0 $\left(\frac{\text{radian}^2}{\text{pc}}\right)$	a_1 (radian^2)	δ_t (mpc)	$(\delta B_t^2/B_0^2)^{a}$	Fielc
B 59	0.44	0.025	2.1	0.4	1–8
Stem	0.08	0.021	4.8	0.2	9–19, 2
Stem–Bowl	0.38	0.054	$\leqslant$2.1	0.8	20, 26.
Bowl	0.01	0.008	4.4	0.1	28–46

Note. [a] Estimated for $N = 30$ (see the text).

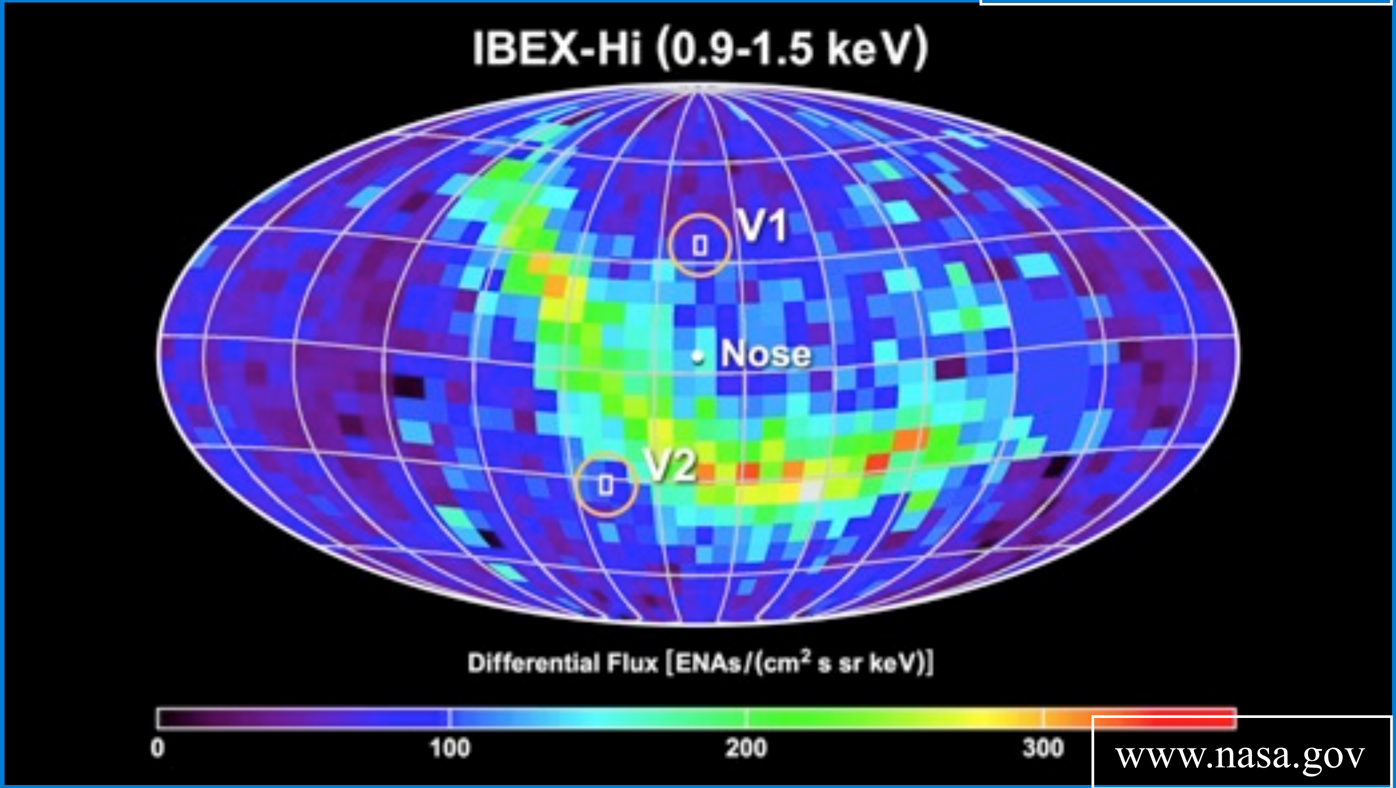
Solar Neighbourhood

- **Solar System and the Local ISM**

Solar Neighbourhood

- **IBEX probe:**
  Detection of the SS interaction with the Local ISM
  - ring of energetic particles

McComas et al. 2009



www.nasa.gov

Solar Neighbourhood

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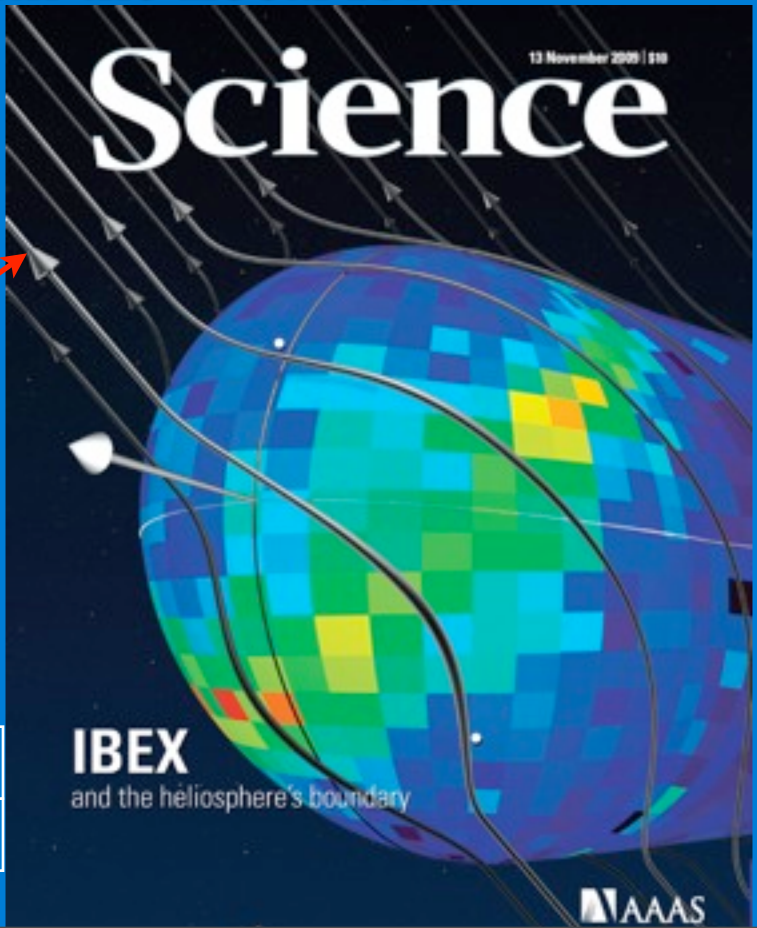
Galactic Local Magnetic Field



McComas et al. 2009

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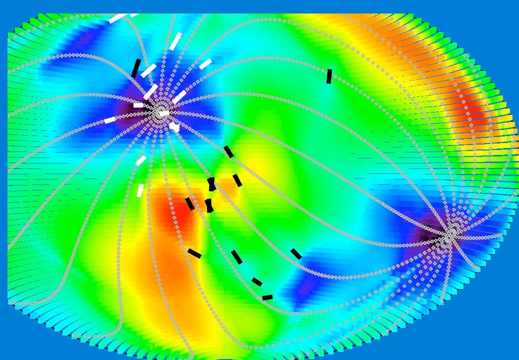
Solar Neighbourhood

- **Comparison with the Local ISM Magnetic Field**
  - Starlight polarization within 40pc
    - **Polarization** pole: (l , b) = (38°, 25°) (±33°)
      IBEX pole: = (33°, 55°)

Frisch et al 2010



ıme as Figure 3, except quantities are plotted in galactic coordinates ı on the galactic center. The best fit to the ISMF in the galactic ystem, $B_{\rm i=best}$, is directed toward $\ell, b = 38°, 23°$.

  - New polarization data are being gathered
    - in both Hemispheres

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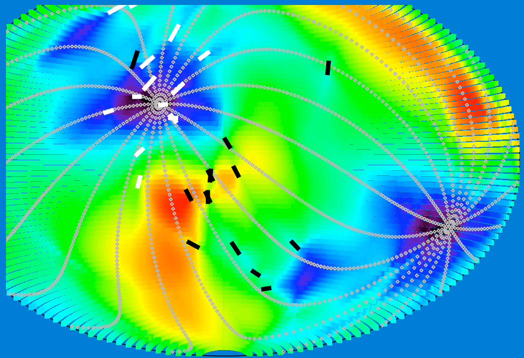
      IBEX pole: = (33°, 55°)
      same pole within errors!

Frisch et al 2010



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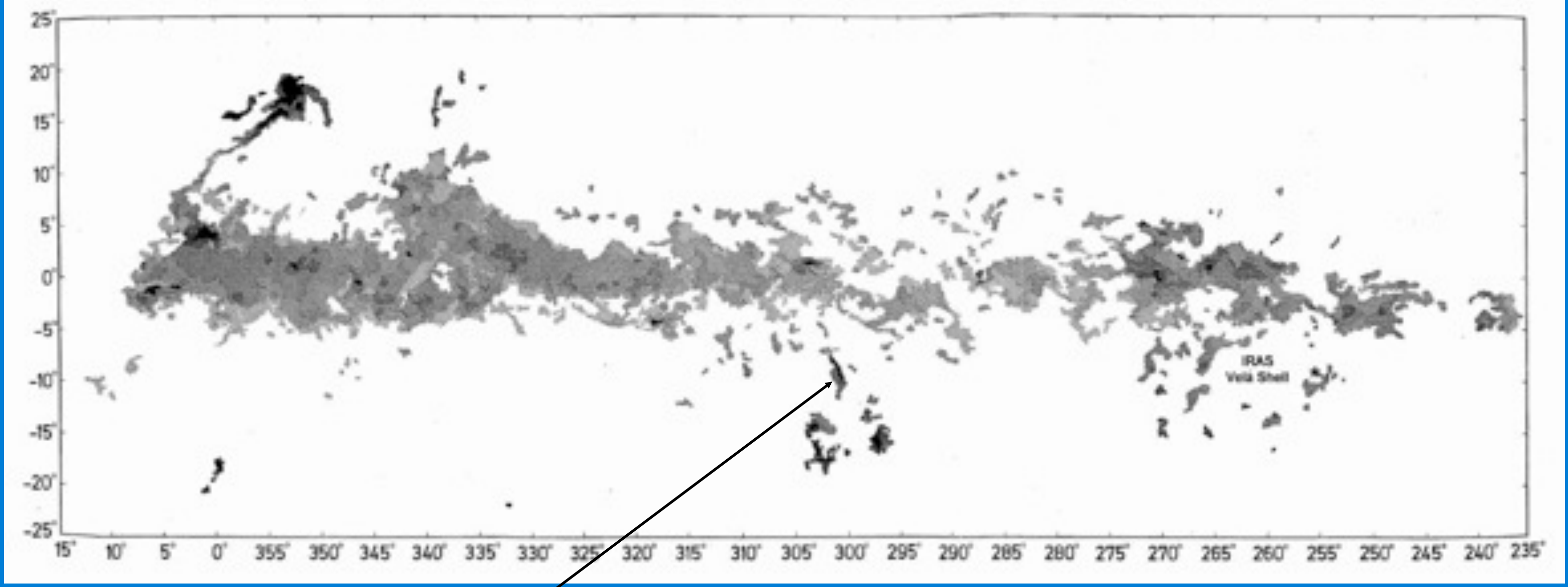
Optical/IR Survey of ISM Polarization

- **Conducted at IAG-USP**
  - LNA observatory (22 deg South)
  - initially in V
  - now at H (1.65μm) band
    - point sources & extended objects
    - http://www.astro.iag.usp.br/~polarimetria/survey
  - **Data being reduced & will become public**

- **Main Goal**
  - Improve our knowledge of:
    - Magnetic Field Structure of the Diffuse ISM
    - Ratio between random & uniform components of B
    - Scale Length, L, of the Magnetic Field

Collapsing Dark Clouds

- **Magnetic Field in Dark Clouds**
  - B and grain alignment in expanding shells and fronts?
  - Role of B in cloud collapse?



Musca Dark Cloud

Feitzinger & Stuve 84

Collapsing Dark Clouds

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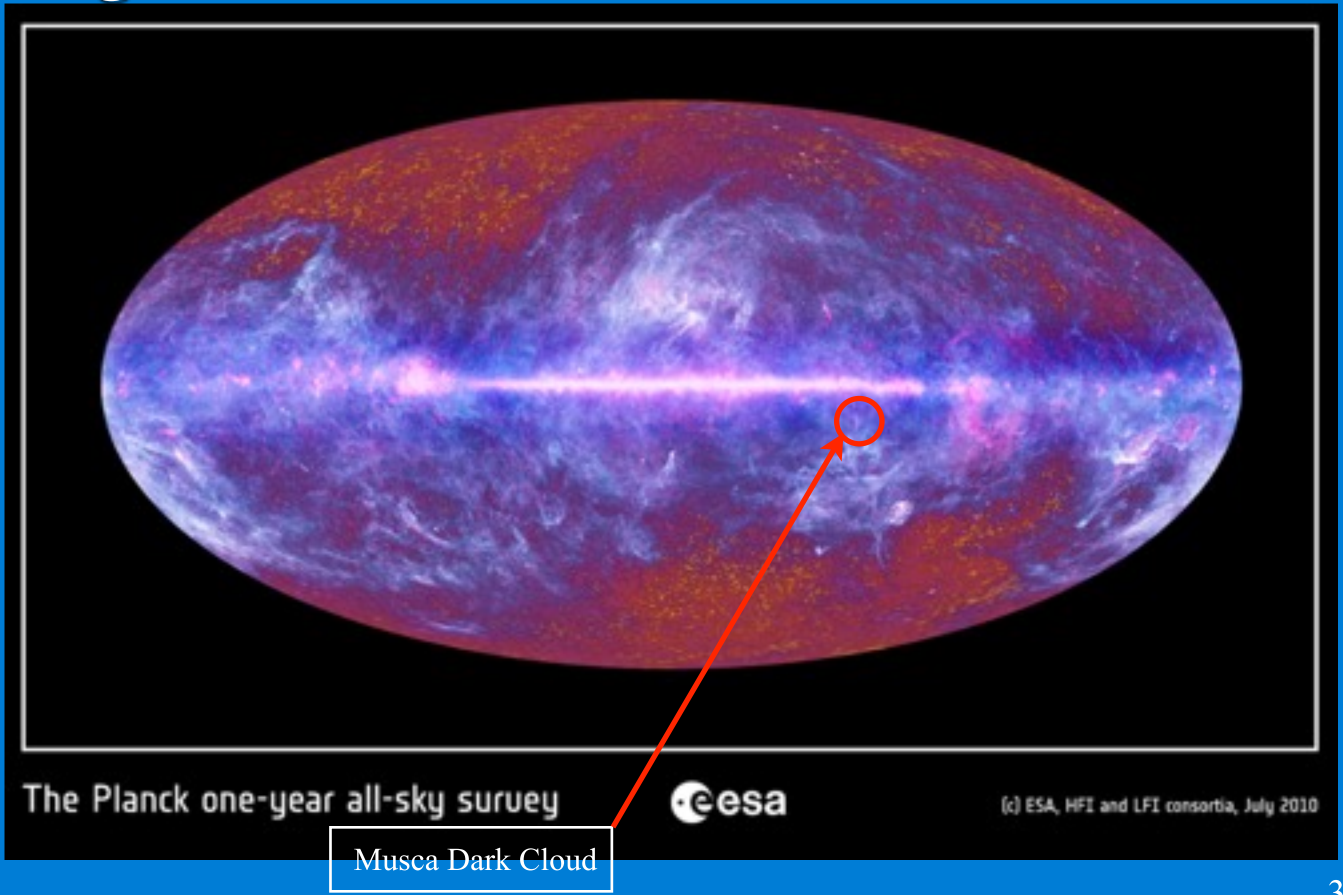
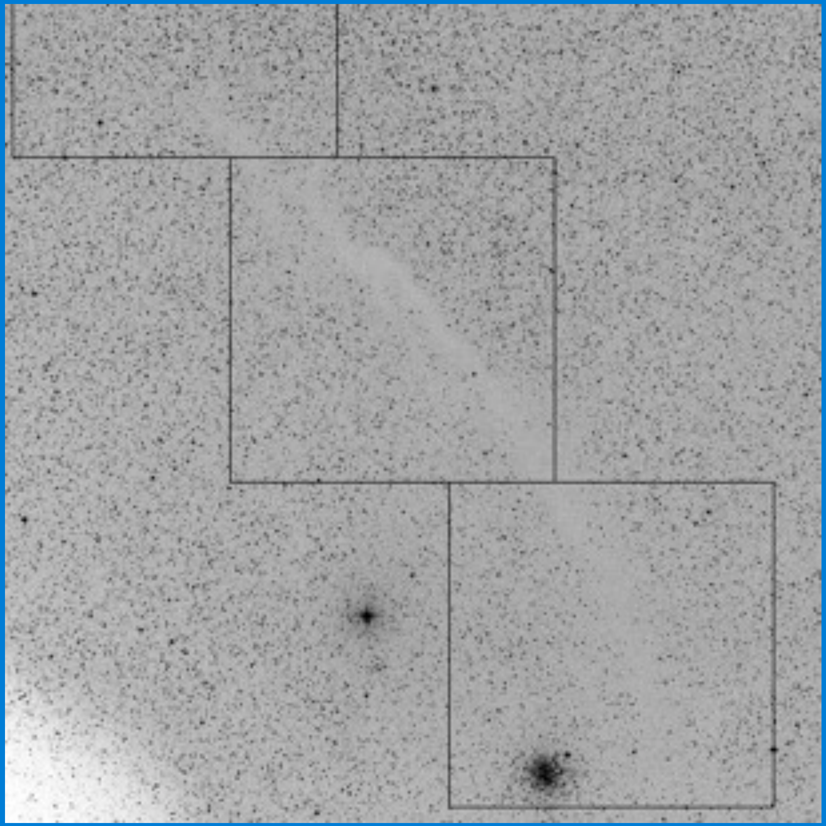


Collapsing Dark Clouds

Magnetic Field in Dark Clouds

- What is the role of **B** in cloud collapse?

- **Mapping the Musca Dark Cloud**



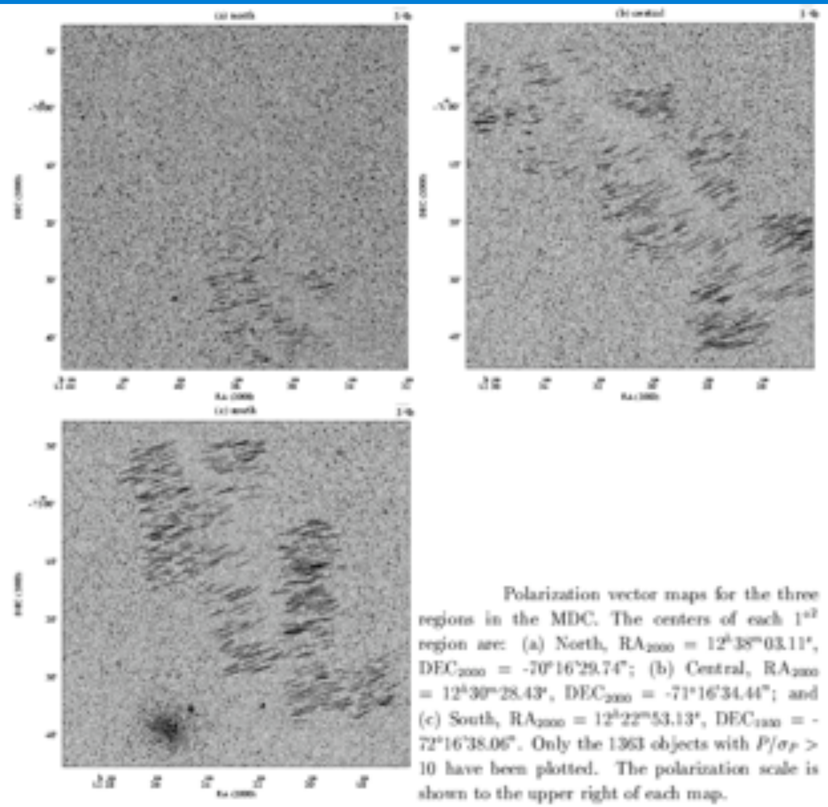
Collapsing Dark Clouds

Magnetic Field in Dark Clouds

- What is the role of **B** in cloud collapse?

- **Mapping the Musca Dark Cloud**
  - Pereyra & Magalhães 04

1,363 objects with P/σ ≥ 10



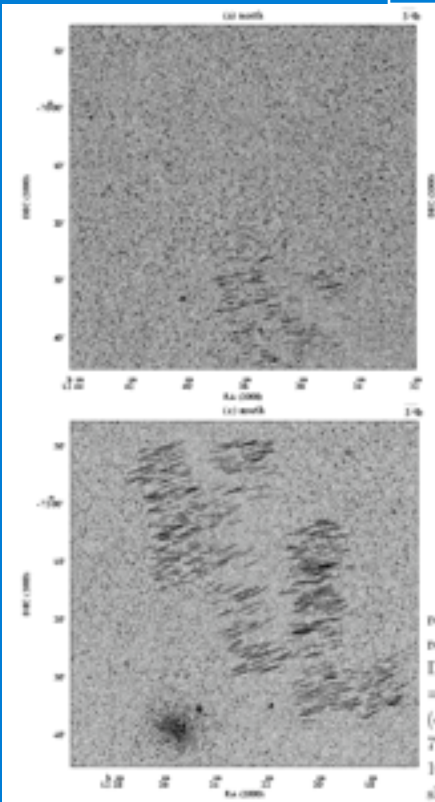
Polarization vector maps for the three regions in the MDC. The centers of each 1°² region are: (a) North, $RA_{2000} = 12^h38^m03.11^s$, $DEC_{2000} = -70°16'29.74''$; (b) Central, $RA_{2000} = 12^h30^m28.43^s$, $DEC_{2000} = -71°16'34.44''$; and (c) South, $RA_{2000} = 12^h22^m53.13^s$, $DEC_{1950} = -72°16'38.06''$. Only the 1363 objects with $P/\sigma_P >$ 10 have been plotted. The polarization scale is shown to the upper right of each map.

Collapsing Dark Clouds

- **Magnetic Field in Dark Clouds**
  - What is the role of B in cloud collapse?

- **Mapping the Musca Dark Cloud**
  - Collapse **along** B
    - $|B| \sim 0.03$ mG - 0.15 mG
    - $M_{cloud} \sim 140\ M_{\odot}$

Pereyra & Magalhaes 04



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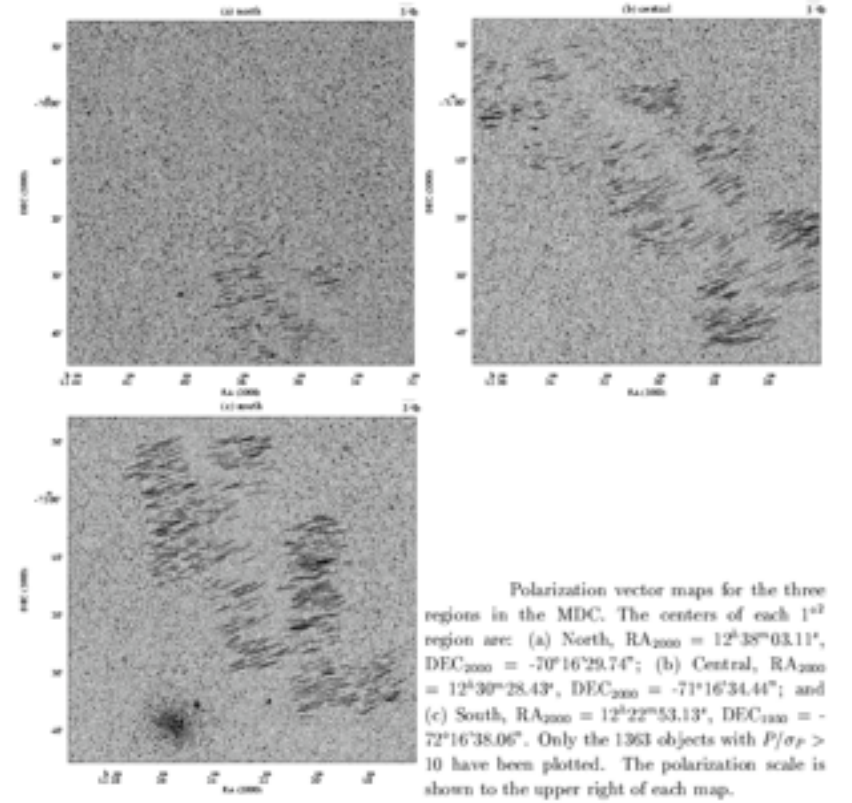
Collapsing Dark Clouds

- **Does Polarimetry Map the Field?**

Pereyra & Magalhaes 04



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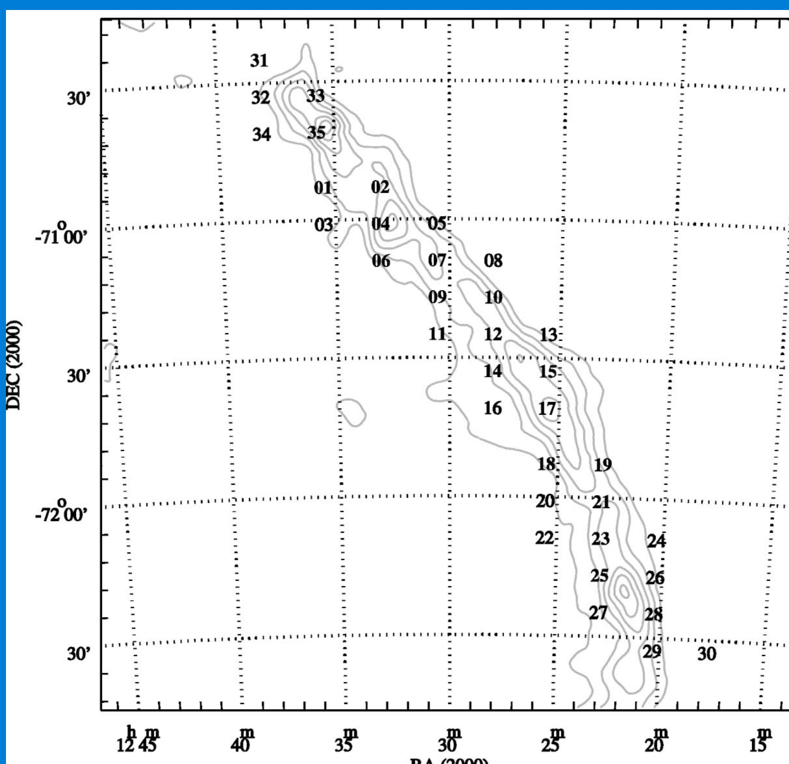
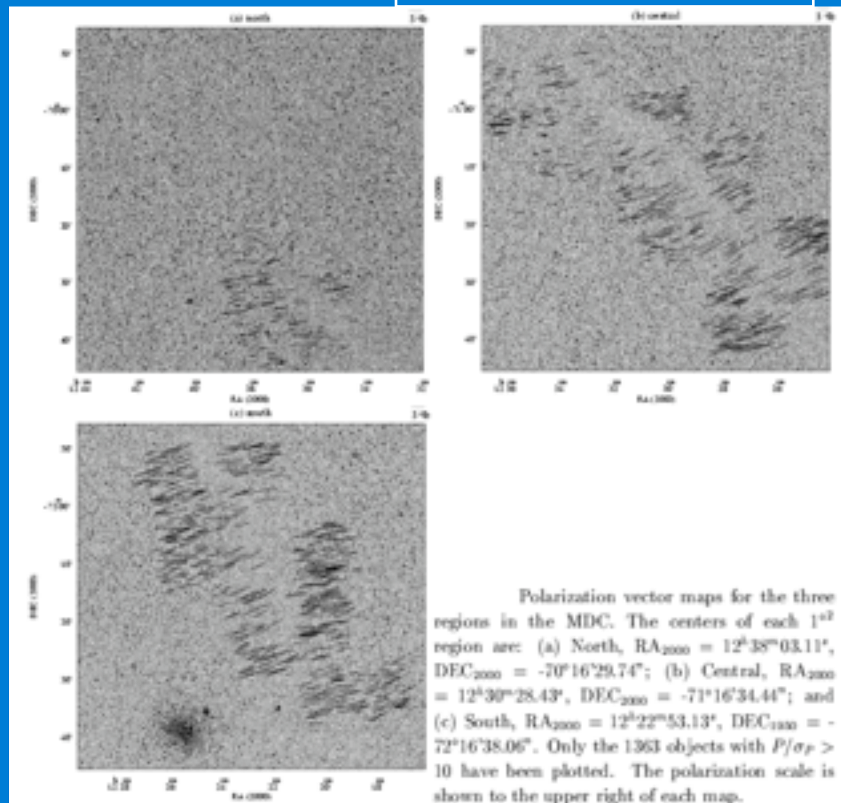
Pereyra & Magalhaes 04

Observed Fields in the Optical





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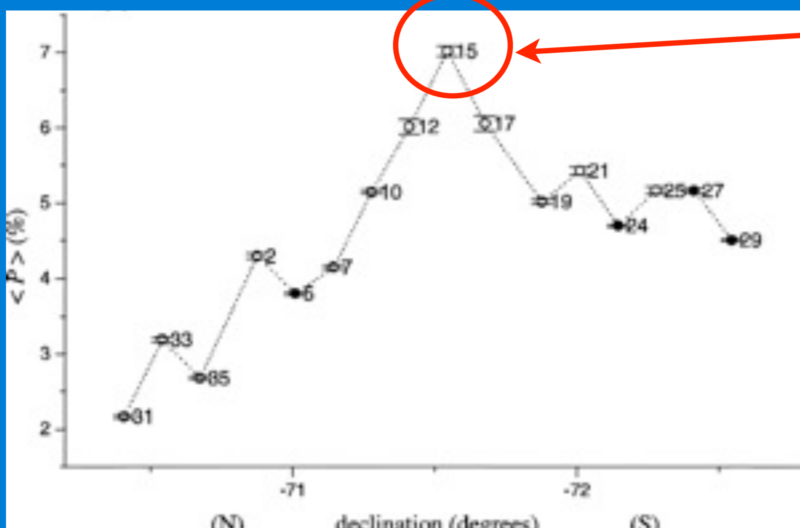
Collapsing Dark Clouds

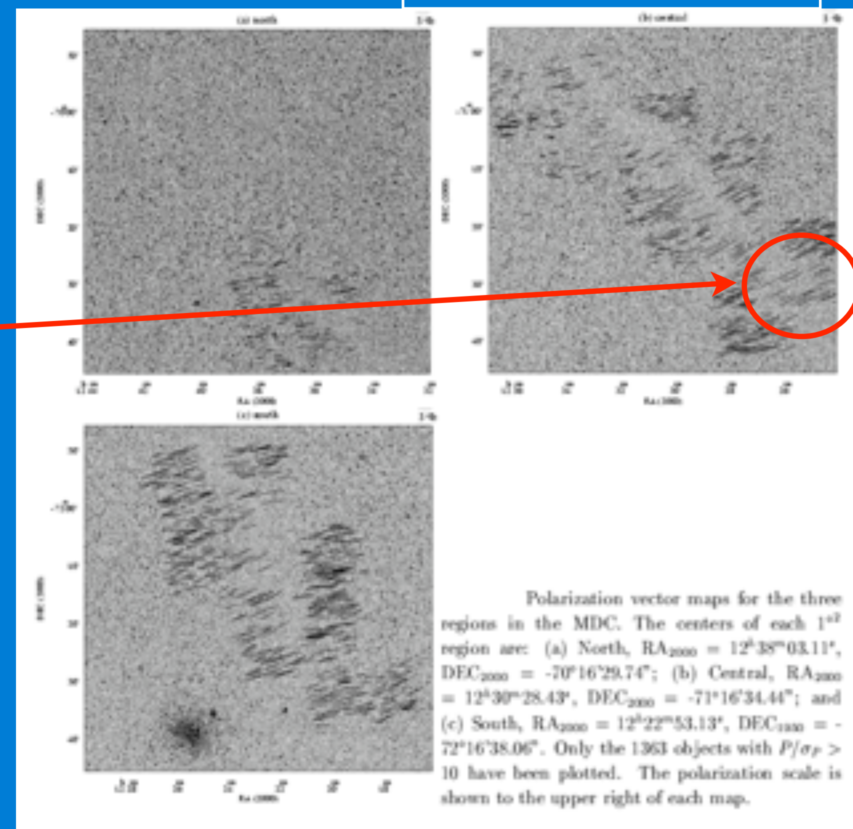
- **Does Polarimetry Map the Field?**

High Polarization associated w/ A_V~2-3mag



Polarization along the Cloud

Pereyra & Magalhaes 04

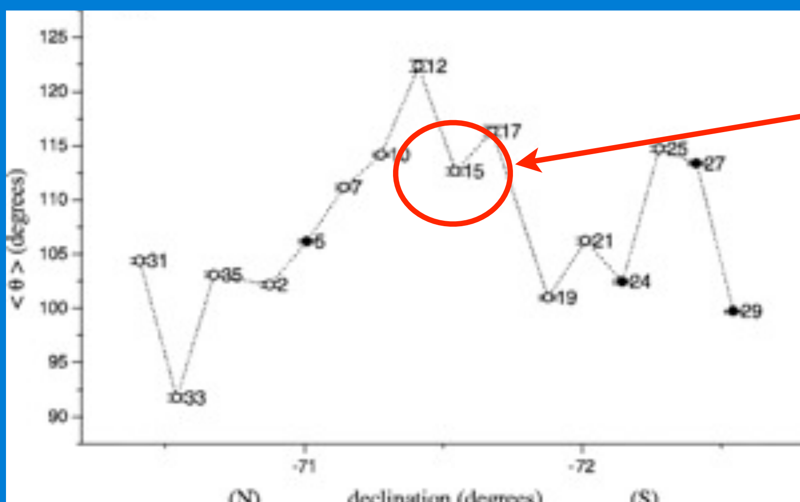


Polarization vector maps for the three regions in the MDC. The centers of each $1^{\circ 2}$ region are: (a) North, $RA_{2000} = 12^h38^m03.11^s$, $DEC_{2000} = -70°16'29.74''$; (b) Central, $RA_{2000} = 12^h30^m28.43^s$, $DEC_{2000} = -71°16'34.44''$; and (c) South, $RA_{2000} = 12^h22^m53.13^s$, $DEC_{2000} = -72°16'38.06''$. Only the 1363 objects with $P/\sigma_P >$ 10 have been plotted. The polarization scale is shown to the upper right of each map.

Collapsing Dark Clouds

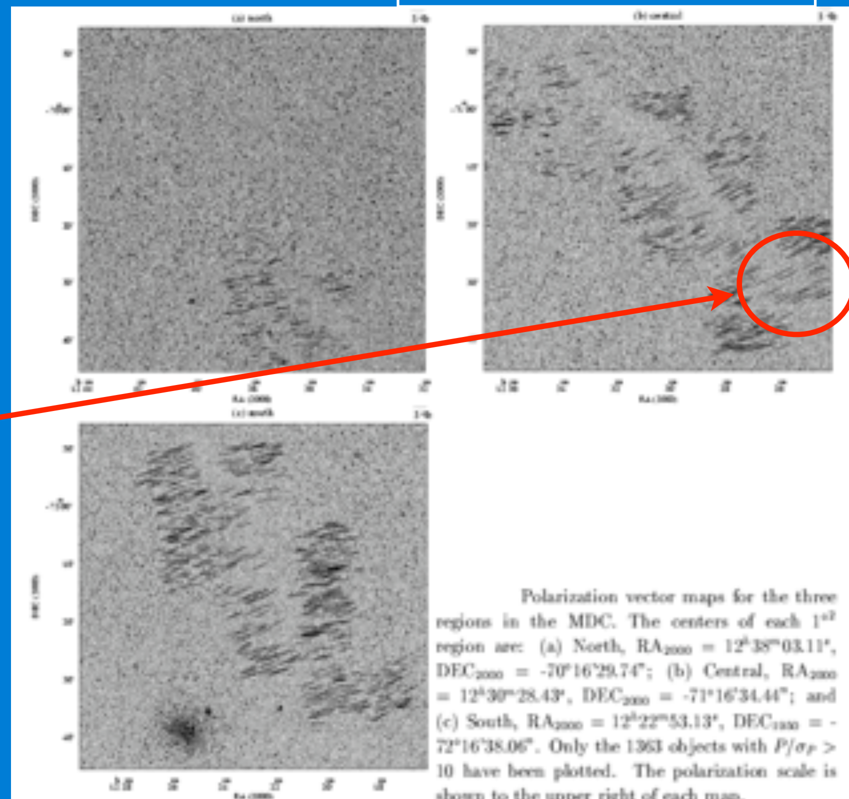
- **Does Polarimetry Map the Field?**

Change in PA associated w/ A_V~2-3mag



Position Angle along the Cloud

Pereyra & Magalhaes 04



Polarization vector maps for the three regions in the MDC. The centers of each 1°² region are: (a) North, RA_{2000} = 12ʰ38ᵐ03.11ˢ, DEC_{2000} = -70°16'29.74"; (b) Central, RA_{2000} = 12ʰ30ᵐ28.43ˢ, DEC_{2000} = -71°16'34.44"; and (c) South, RA_{2000} = 12ʰ22ᵐ53.13ˢ, DEC_{2000} = -72°16'38.06". Only the 1363 objects with $P/\sigma_P >$ 10 have been plotted. The polarization scale is shown to the upper right of each map.

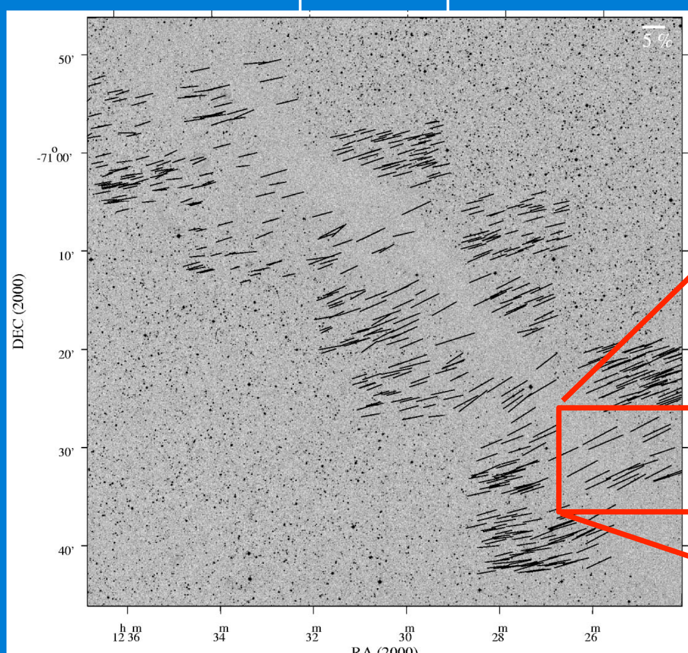
-
-
- *Optical/NIR Polarization of Starlight Polarization*

Collapsing Dark Clouds

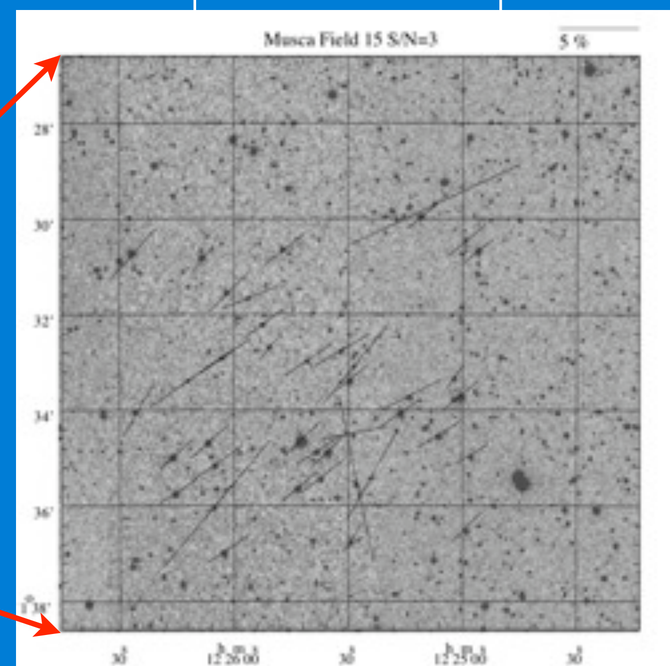
- **Does Polarimetry Map the Field?**

Near IR Polarimetry confirms optical PA

Optical



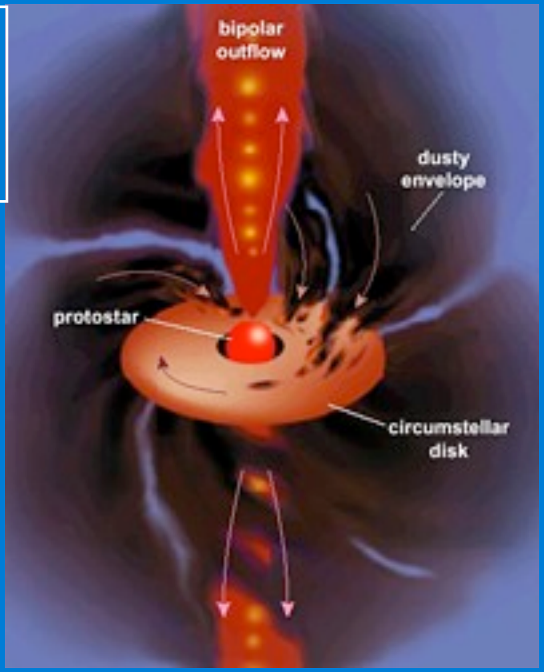
Near IR (1.65µm)



Sub-mm Polarization from Bok Globules

- **CB3**
  - Basic data
    - 6.7x5.6 arcmin
    - d ~ 2.5 kpc
    - 2 embedded YSOs
    - intermediate mass star formation site

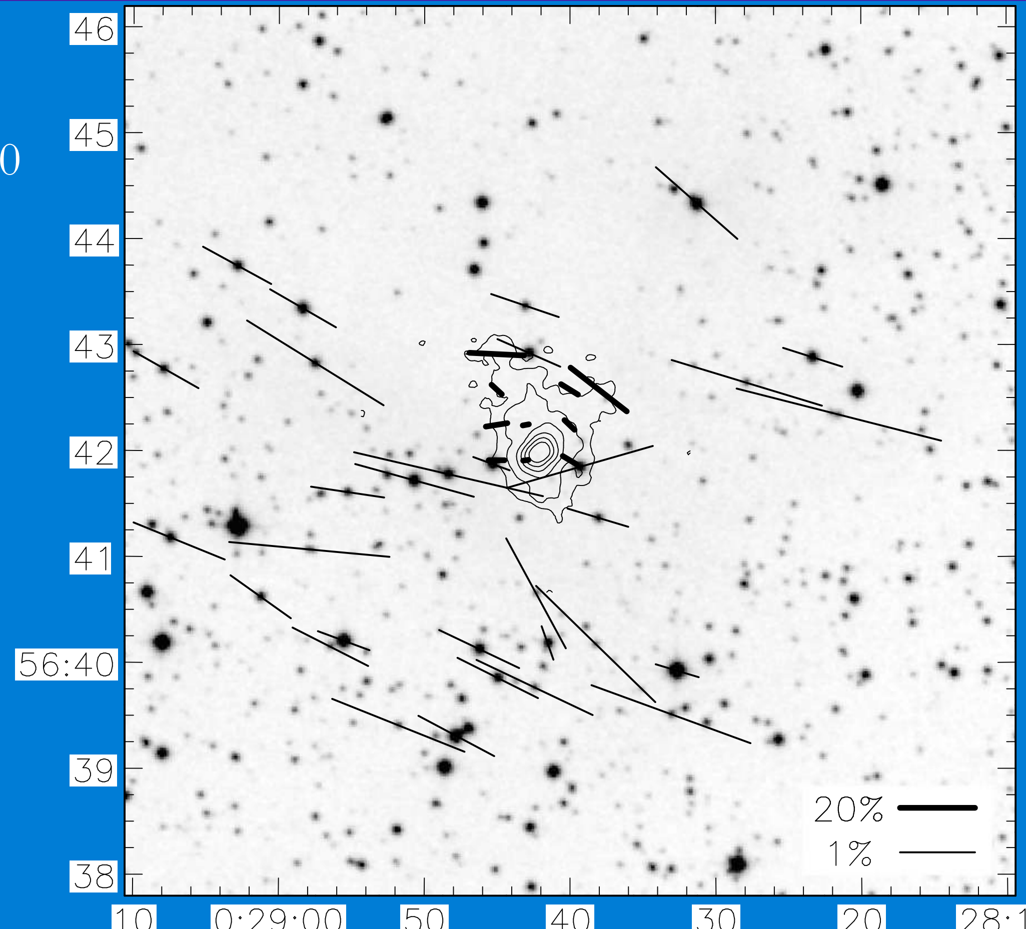
YSO = **Y**oung **S**tellar **O**bject



http://www.cfa.harvard.edu/rg/star_and_planet_formation/young_stellar_objects.html

Sub-mm Polarization from Bok Globules

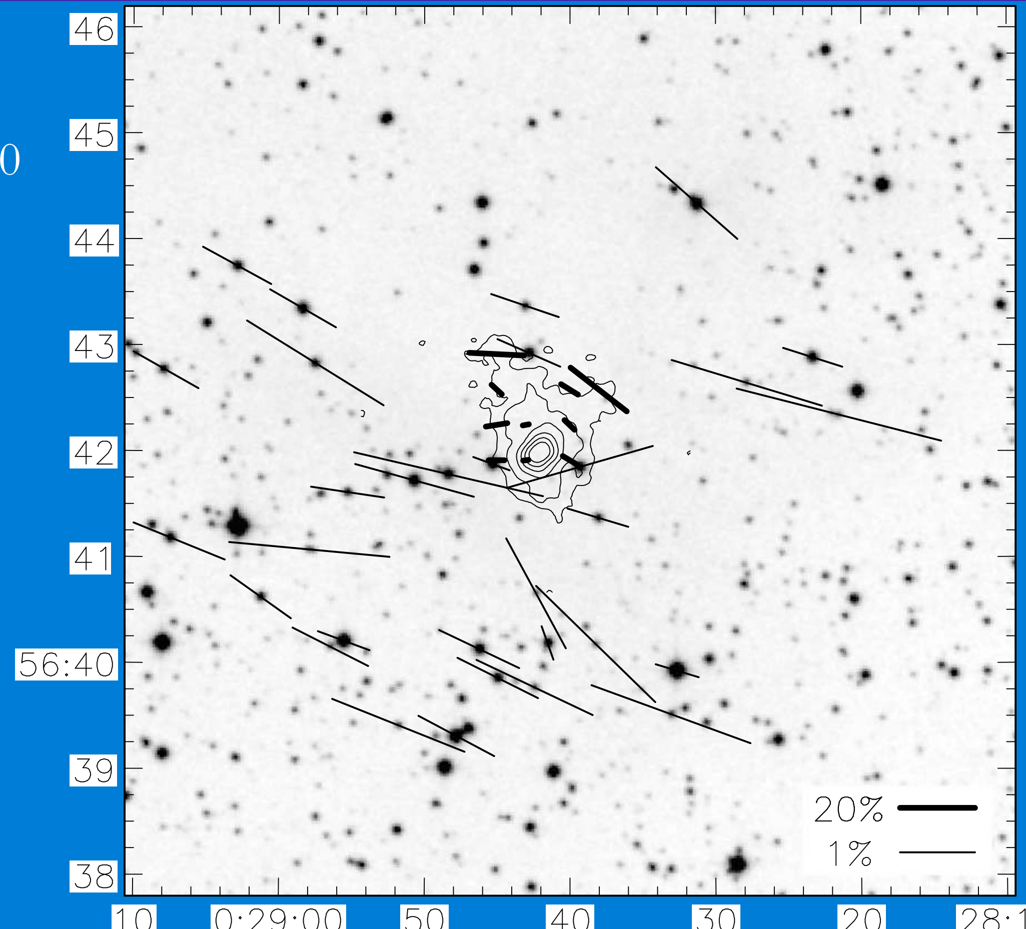
- **CB3**
  - Ward-Thomson et al. 2010
  - Polarization maps
    - optical
    - sub-mm
    - contours: 850µm (353 GHz)
  - Stars near the border
    - $PA_{opt} \approx PA_{sub\text{-}mm}$
  - Optical:
    - Av ~ 0.3 - 1.8
  - Sub-mm:
    - N~10[22] cm[-2] ⇒ Av ~ 10



Obs: $PA_{sub\text{-}mm}$ rotated by 90°

Sub-mm Polarization from Bok Globules

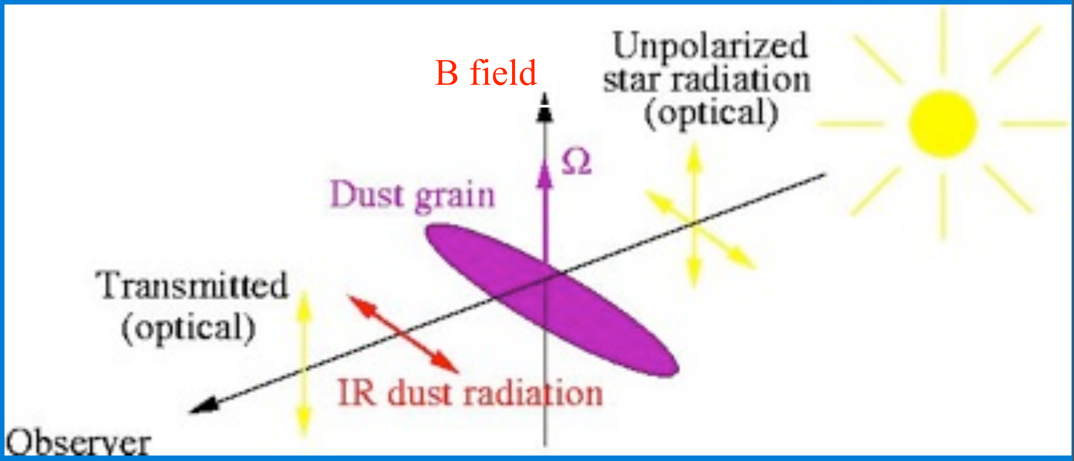
- **CB3**
  - Ward-Thomson et al. 2010
  - Polarization maps
    - optical
    - sub-mm
    - contours:
      850µm (353 GHz)
  - **Stars near the border**
    - **$PA_{opt} \approx PA_{sub\text{-}mm}$**
  - Optical:
    - Av ~ 0.3 - 1.8
  - Sub-mm:
    - $N \sim 10^{22}$ cm^{-2} $\Rightarrow$ Av ~ 10



Obs: $PA_{sub\text{-}mm}$ girado de 90deg

Polarization by ISM Dust

- **Optical polarization**
  - works w/ low **A_V** (1 - 5 mag)
    - Ex., **outskirts** of dark clouds
- **Sub-mm polarization**
  - works w/ high **Av** (10 - 100)
    - Ex., **central regions** of dark clouds



adapted from Ponthieu, Lagache; www.planck.fr

Important role of telescopes like:

JCMT, APEX

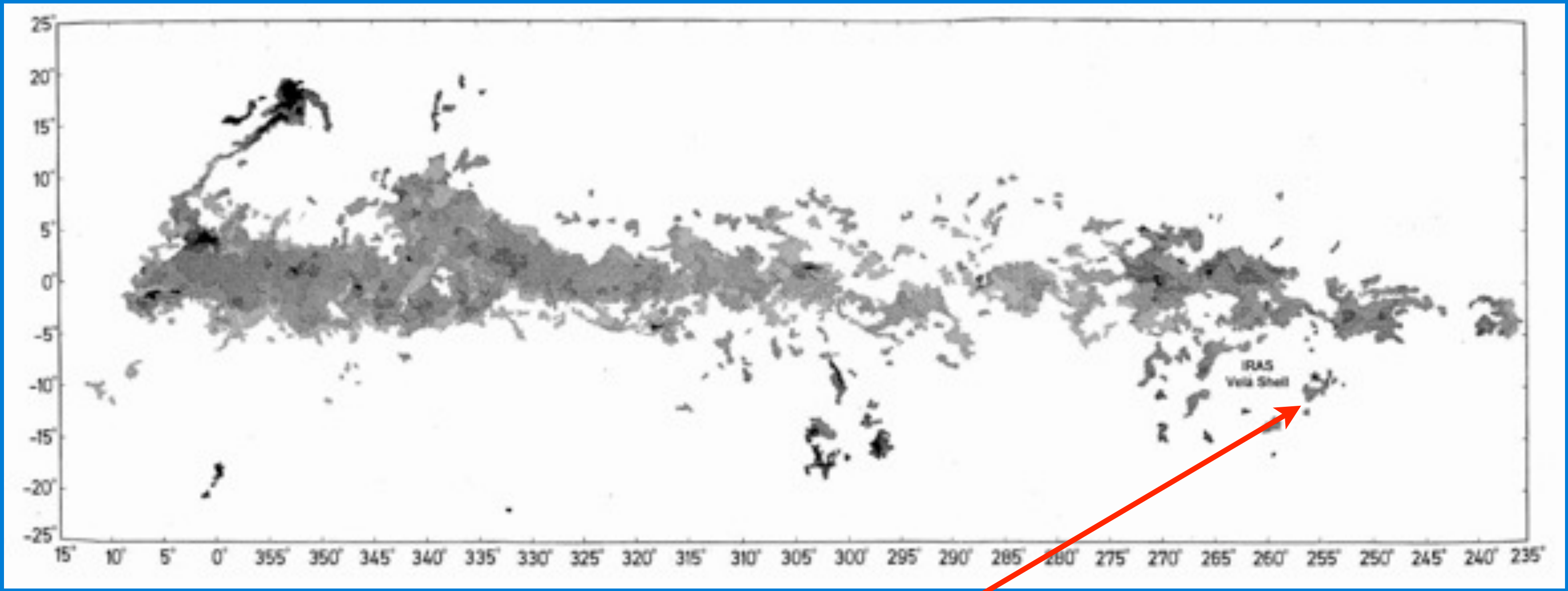
LLAMA (proposed)

Polarization by ISM Dust

- **In summary:**
  - From Optical/NIR
    - **B-field in the ISM & collapsing cloud periphery**
  - From JCMT, APEX, (LLAMA)…
    - **B-field in the denser parts of the dark cloud**
  - From ALMA, SMA…
    (+ ALMA/LLAMA)
    - **B-field in cloud cores**

Collapsing Dark Clouds

- **Magnetic Field in Dark Clouds**
  - B and grain alignment in expanding shells and fronts?
  - Role of B in cloud collapse?

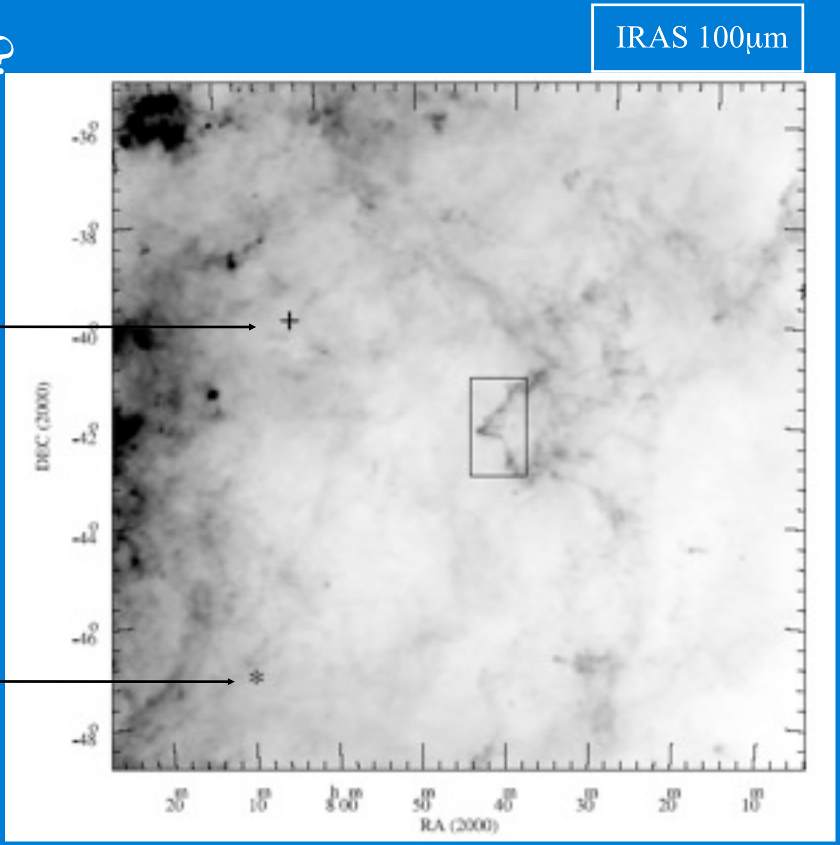


IRAS Vela Shell

Feitzinger & Stuve 84

Collapsing Dark Clouds

- **Magnetic Field in Dark Clouds**
  - B in expanding shells and fronts?
- **Mapping the IRAS Vela Shell**
  - Churchwell et al. 96 (in CS)



Collapsing Dark Clouds

Magnetic Field in Dark Clouds

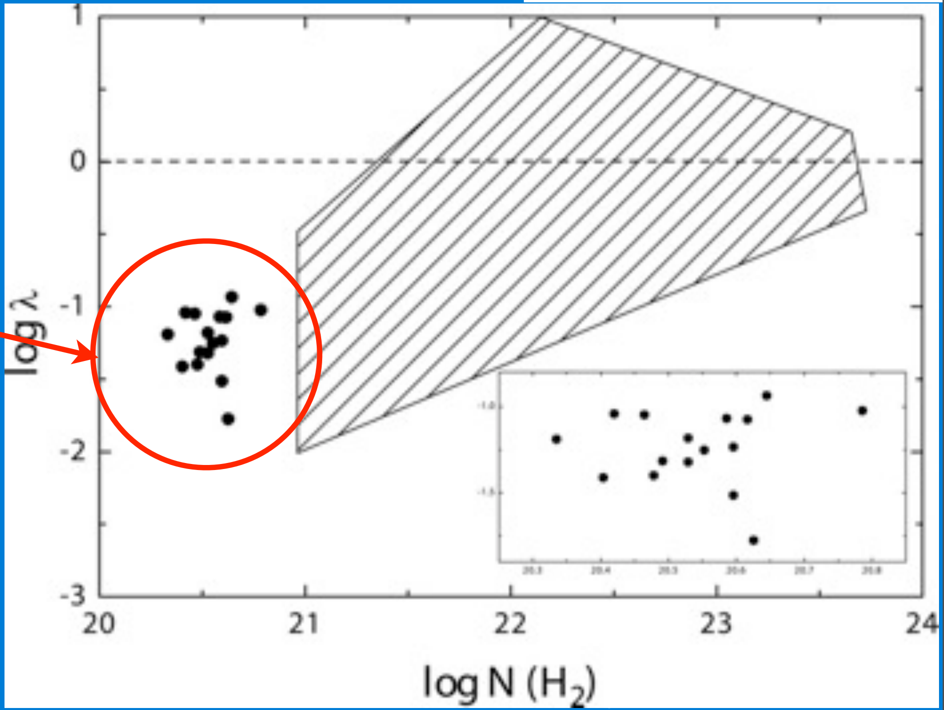
– **B** in expanding shells and fronts?

- **Mapping the IRAS Vela Shell**
  - Mass-to-Flux Ratio, λ

$$\lambda \equiv \frac{(M/\Phi)_{actual}}{(M/\Phi)_{crit}} = 7.6 \times 10^{-21} \frac{N(H_2)}{B}$$

  - All regions **sub-critical**
  - They join smoothly w/ **molecular cloud** data of Crutcher 04

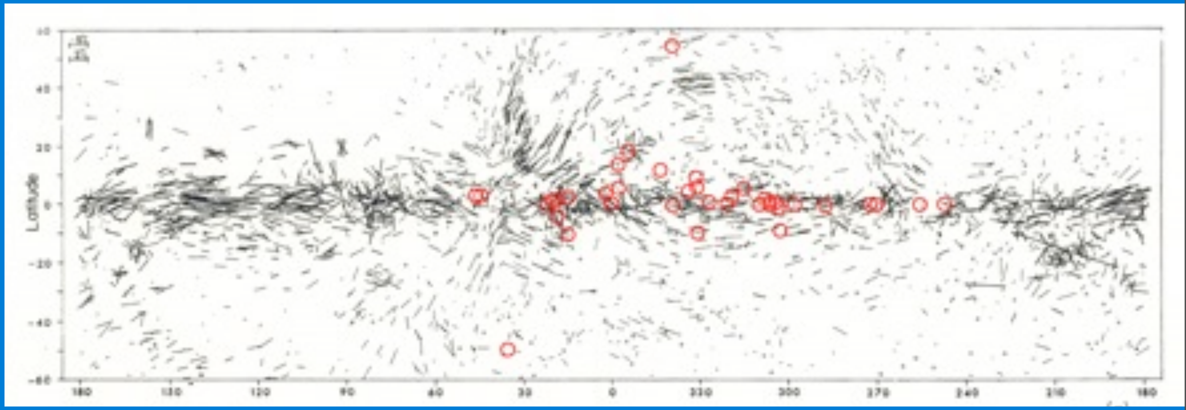
Pereyra & Magalhaes 07



Large Scale Magnetic Field

- **42 General ISM fields observed**
  - 2-3 integrations/field
  - $\sim 10^2$ objects/field with $\sigma_P/P \geq 10$

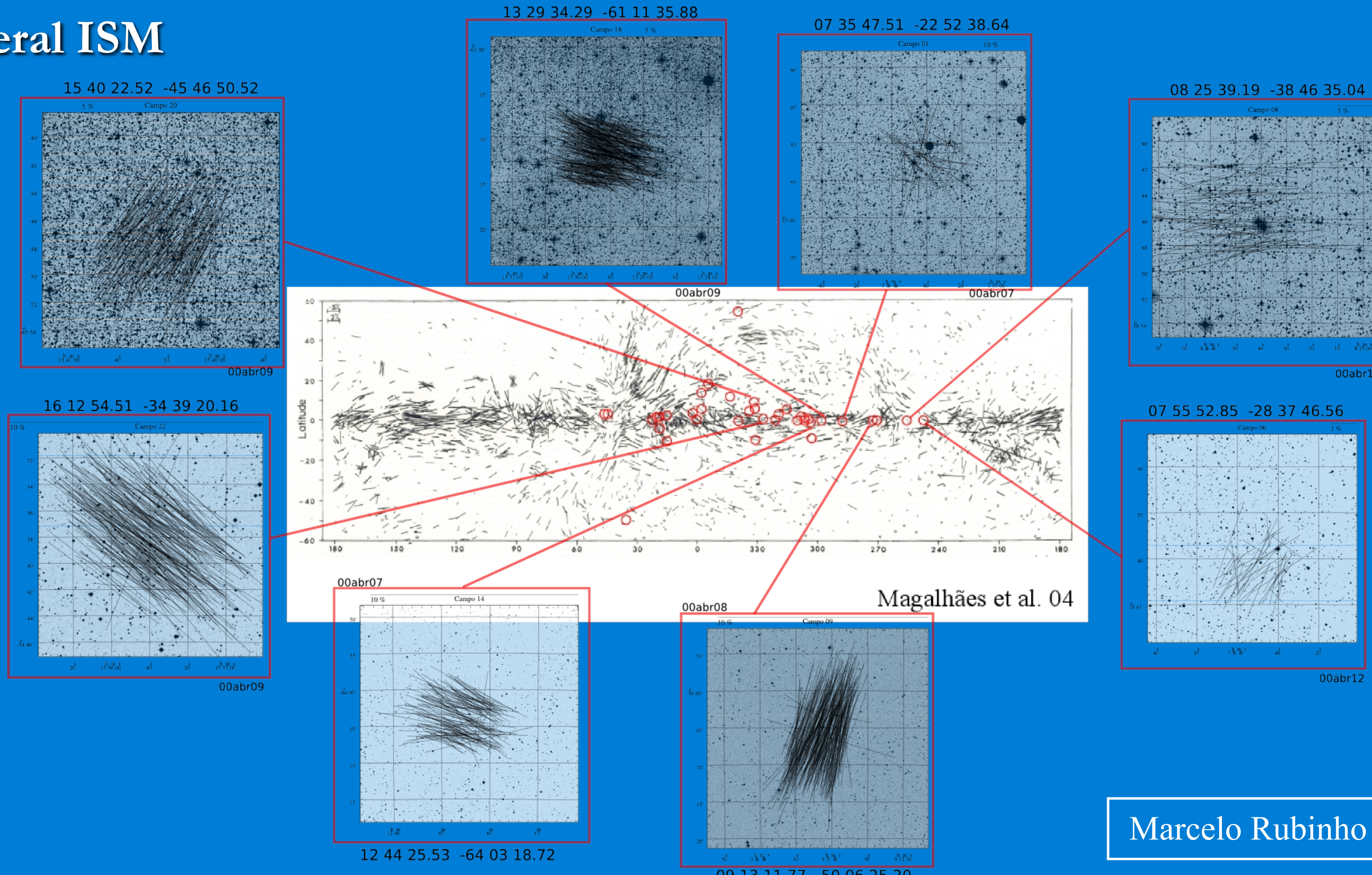
- **Observed pointings**



-
-
- *Optical/NIR Polarization of Starlight Polarization*

Large Scale Magnetic Field

General ISM

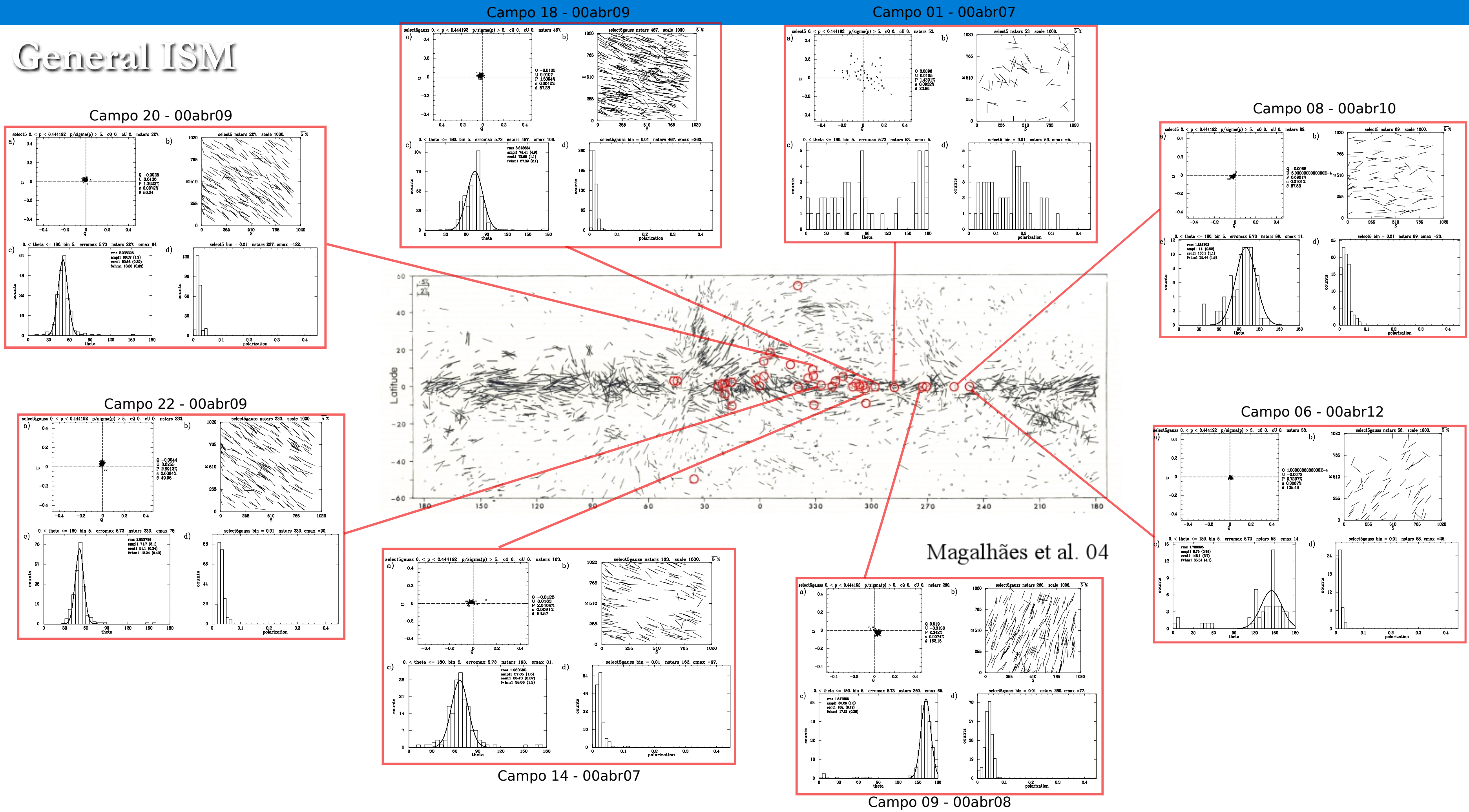


Marcelo Rubinho

•
•
• *Optical/NIR Polarization of Starlight Polarization*

Large Scale Magnetic Field

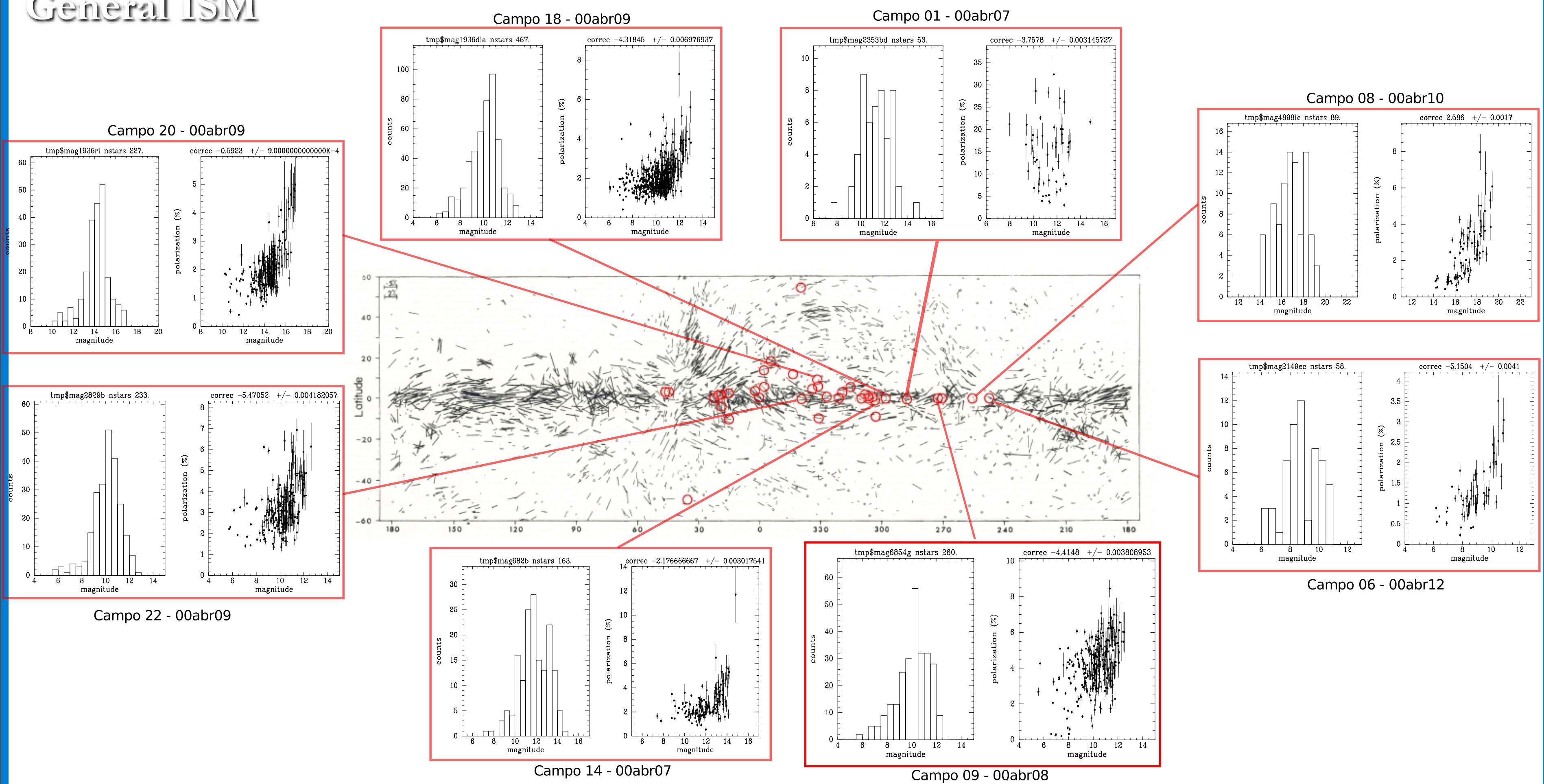
General ISM



- *Optical/NIR Polarization of Starlight Polarization*

Large Scale Magnetic Field

General ISM



Large Scale Magnetic Field

General ISM

Estimates of B-strength (preliminary)

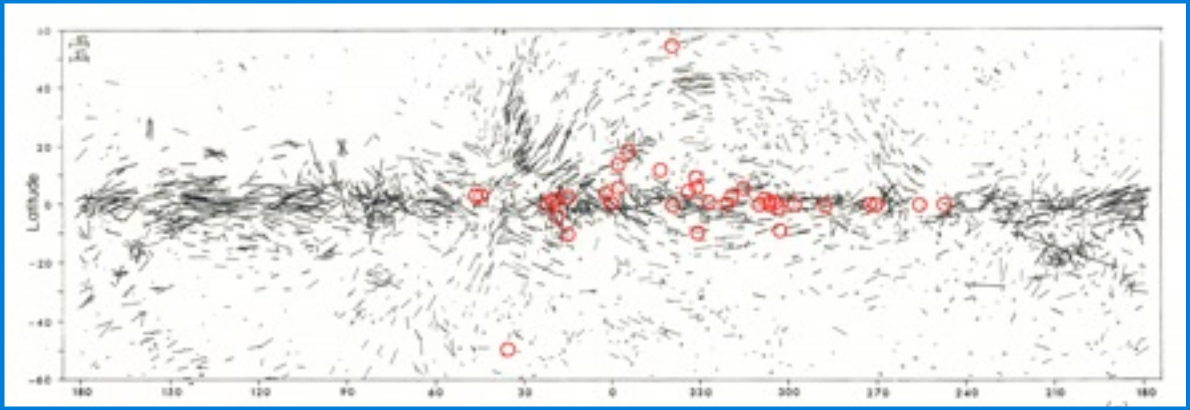
Campo	AR2000 (h m s)	DEC2000 (o ' ")	P (%)	V (mag)	δB (μG)	B_{sky} cold/warm(μG)
06	7 55 52.85	-28 37 46.56	1.37	10	2.5	6.8(9)/6.8(9)
08	08 25 39.19	-38 46 35.04	1.96	10	2.5	6.8(5)/6.8(5)
09	09 13 11.77	-50 06 25.20	5.48	10.9	2.5	17.0(3)/17.1(3)
14	12 44 25.53	-64 03 18.72	2.9	10	2.5	10.8(9)/10.8(9)
18	13 29 34.29	-61 11 35.88	1.42	10	2.5	9.7(9)/9.7(9)
20	15 40 22.52	-45 46 50.52	2.04	10.7	2.5	18.0(5)/18.1(5)
22	15 55 39.60	-54 38 36.60	2.5	10.4	2.5	22(1)/22(1)

Marcelo Rubinho

Large Scale Magnetic Field

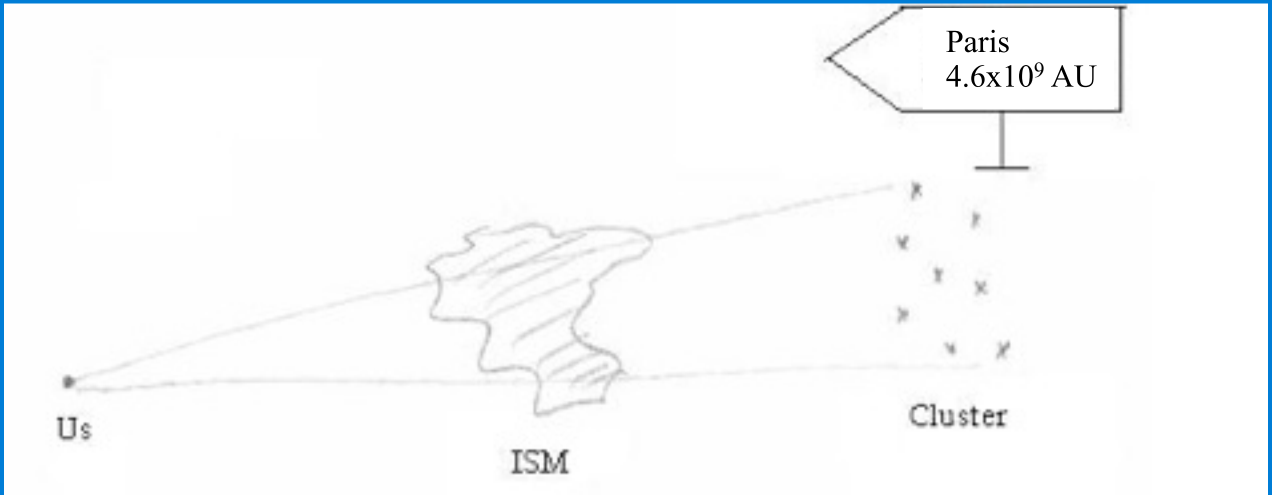
- **Future:**
  - Use of data w/ Parallax missions
    - Gaia:

⇒ 3D-Map of Galactic Magnetic Field



Small Scale Magnetic Field

- **Open Clusters**



  - allow study of the **field structure on smaller scales**

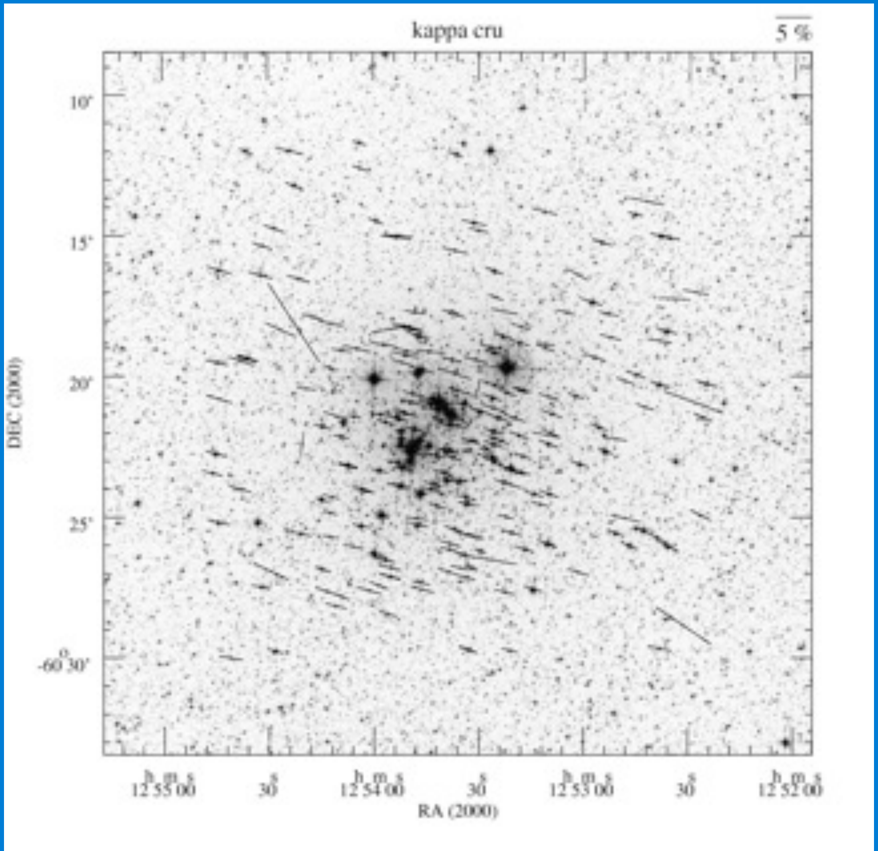
Small Scale Magnetic Field

Open Clusters

κ Crucis

CCD **Image with**

λ/2-plate + calcite prism



Magalhães et al. 05

Small Scale Magnetic Field

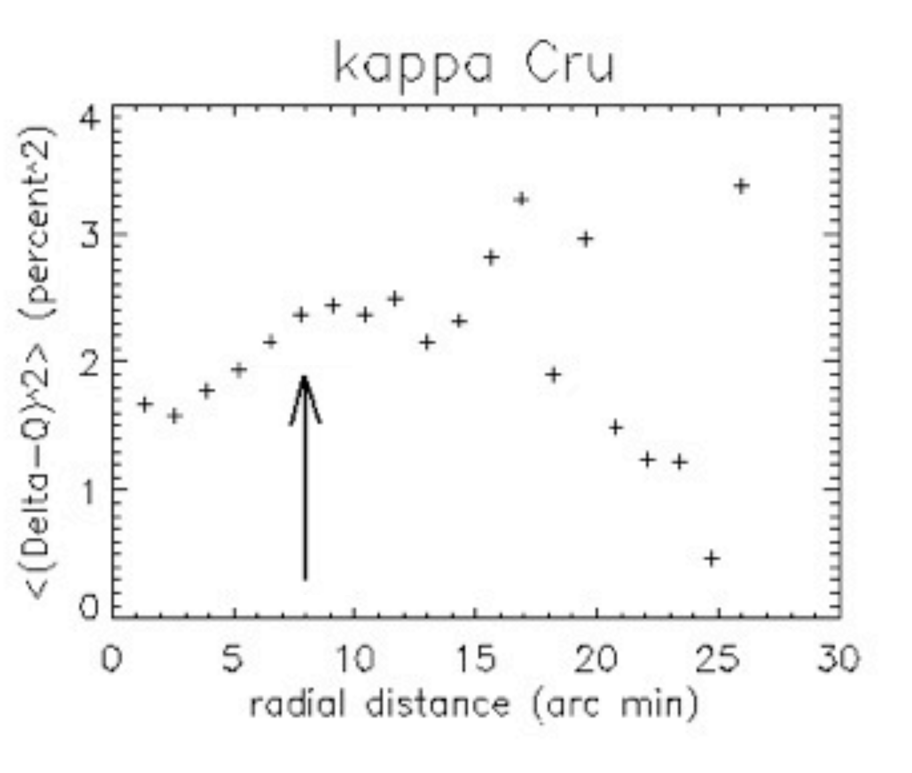
Open Clusters

k Crucis

- distance = 1900 pc
- angular decorrelation size for B_{unif}:

$\alpha_0 \sim 8'$

⇒ L ≤ 4.6 pc



Magalhaes et al 2005

Small Scale Magnetic Field

- **Open Clusters**

Decorrelation length

Cluster	l (o)	b (o)	Distance (pc)	L (‘) <	L (pc) <
C1115-624	292	-2	1240	5.5	2
C1250-600	303	3	1980	8	4.6
C1714-429	345	-3	1000	6.8	2
C1828-192	14	-4	620	21	3.8
C1836+054	36	5	480	33	4.6

Ferreira & Magalhães 2009

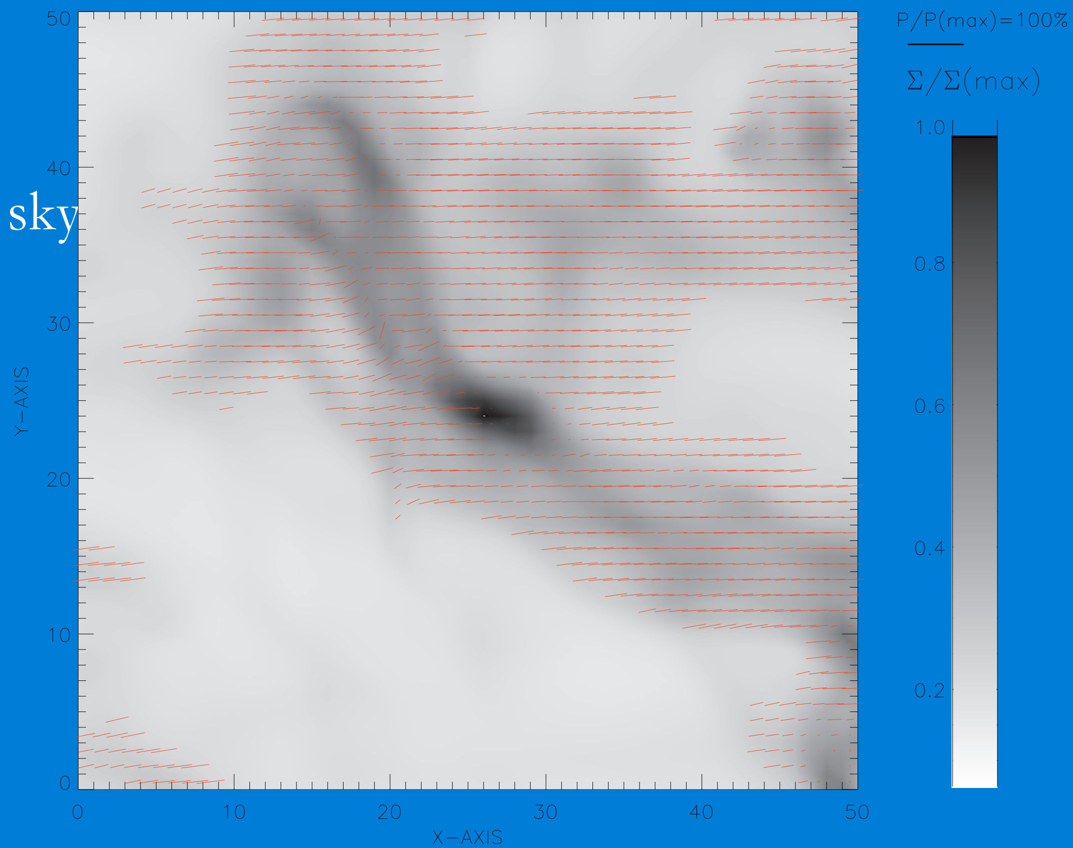
- **L ≲ few pc**
- L ≪ values from the General ISM data
  - 1 kpc (Jones et al. 92; Heiles 96)
  - not unexpectedly though...
- L ≈ values from Faraday rotation
  - from Extragalactic sources (Minter & Spangler 1996; Haverkorn 08)
- **L: Input to CMB Foreground Polarization**
  - **L away from the Plane has to be determined**

MHD Turbulence Simulations

- Supersonic, sub-alfvenic

– B **on the plane** of the sky

– Pol. vectors show the effects of B_{sky}



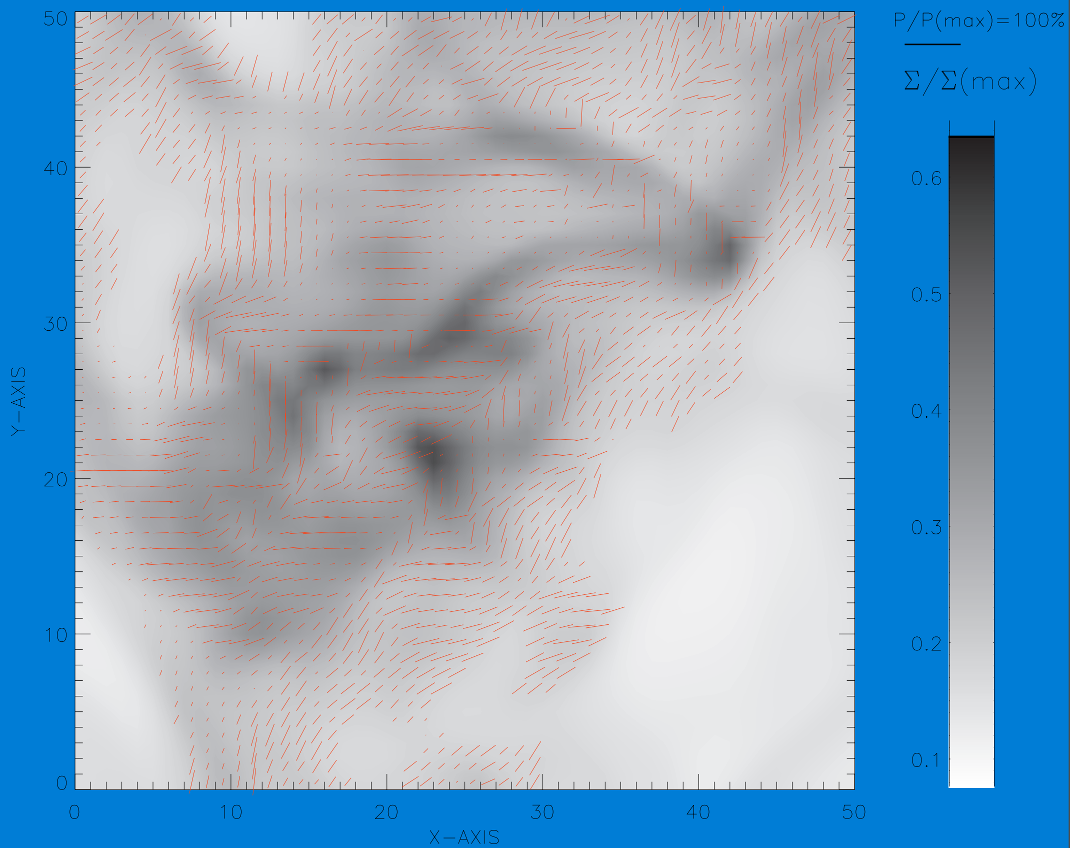
Falceta-Gonçalves, Gouveia Dal Pino

MHD Turbulence Simulations

- Supersonic, sub-alfvenic

– B **along** l.o.s

– Polarization vectors show effects of B_{rand}

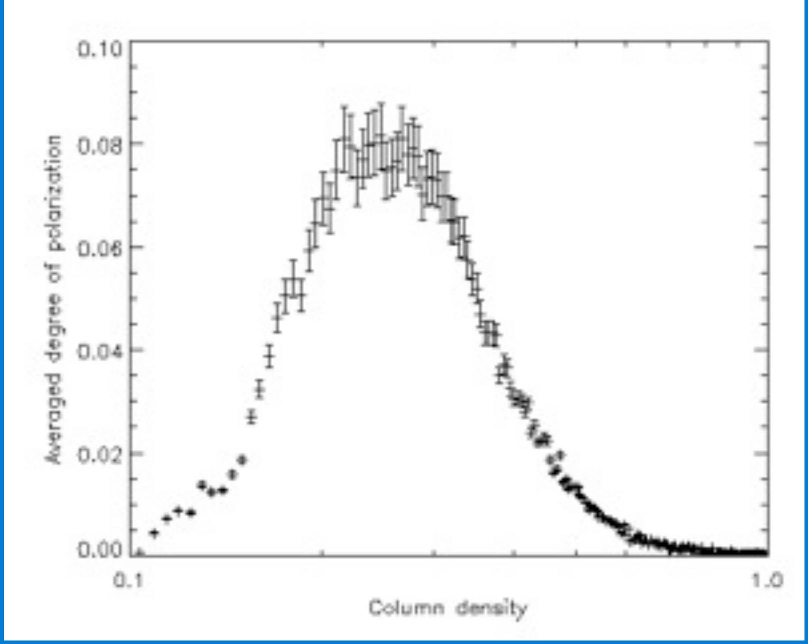


Falceta-Gonçalves, Gouveia Dal Pino

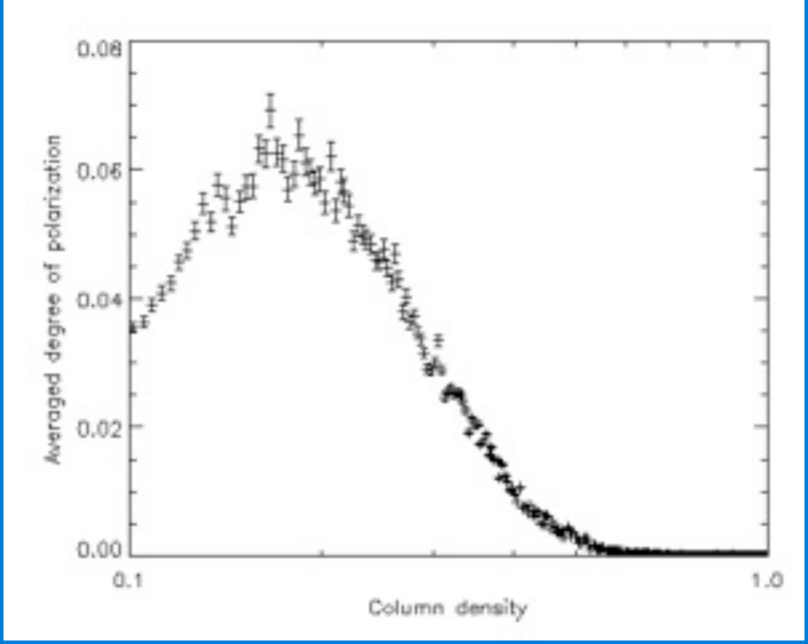
MHD Turbulence Simulations

- **Polarization vs. Density**

B_{sky}



B_{rand}

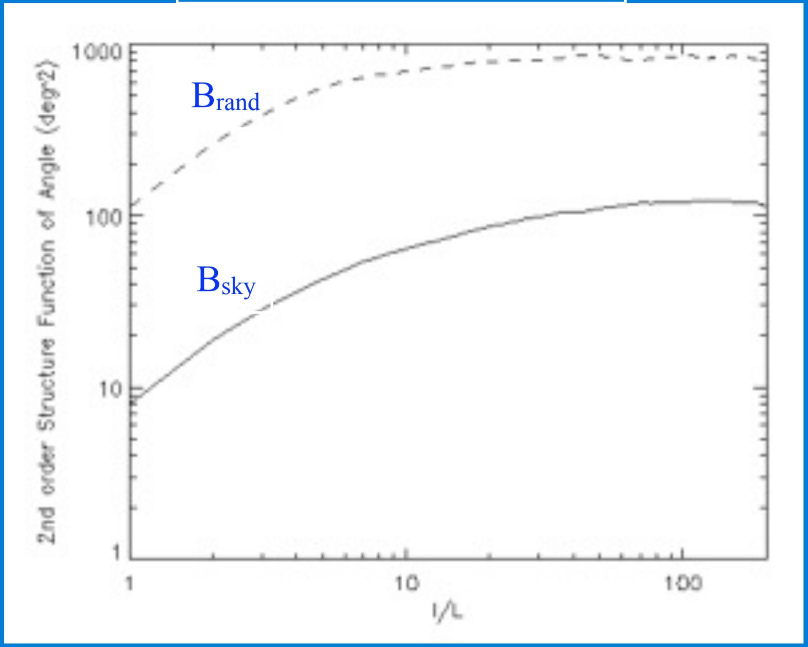


Falceta-Gonçalves, Gouveia Dal Pino

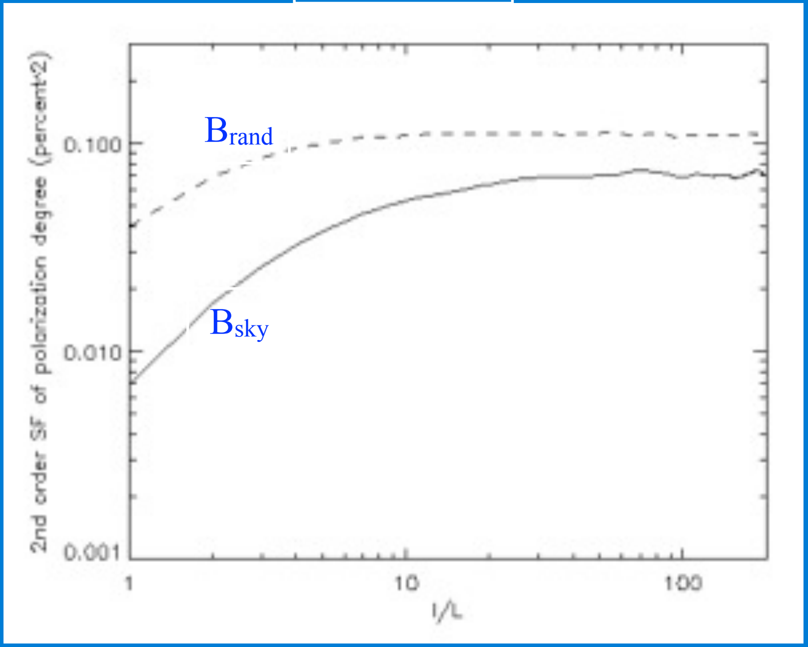
MHD Turbulence Simulations

- **Structure functions**

Polarization Position Angle



Polarization

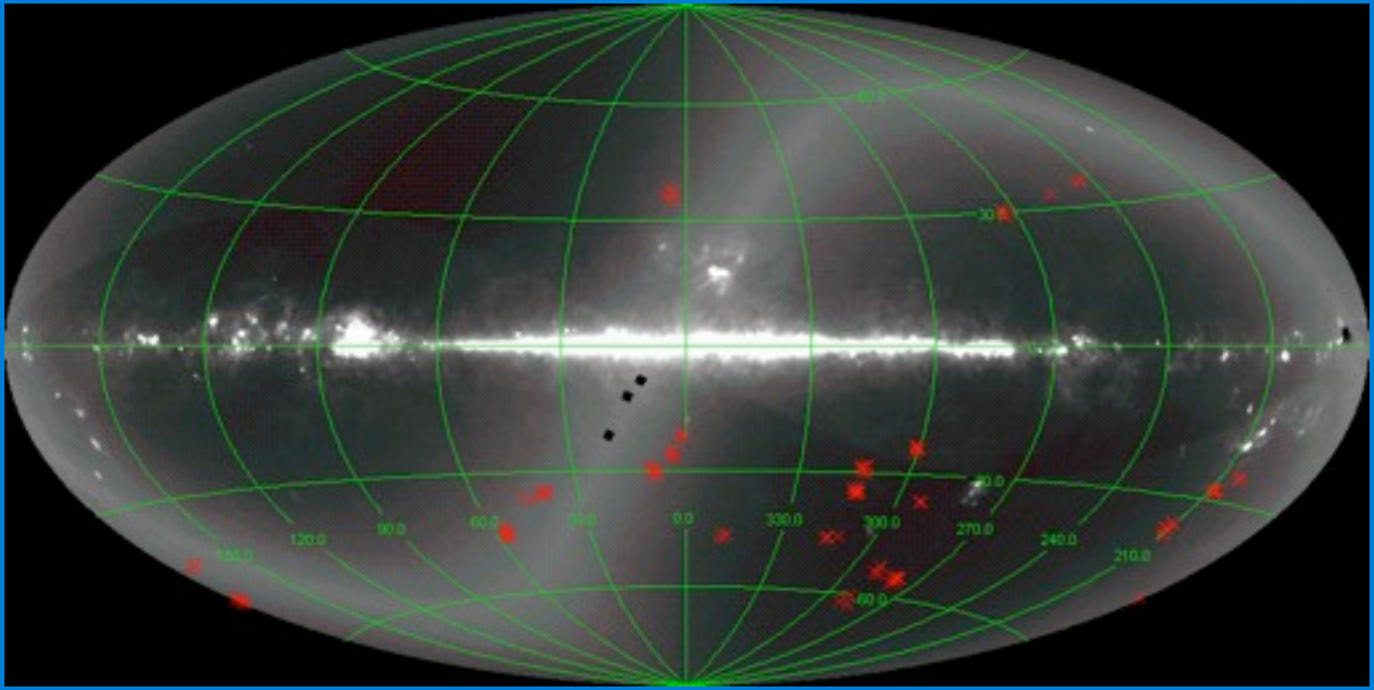


Falceta-Gonçalves, Gouveia Dal Pino

Optical/IR Survey of ISM Polarization

High Latitude Clouds

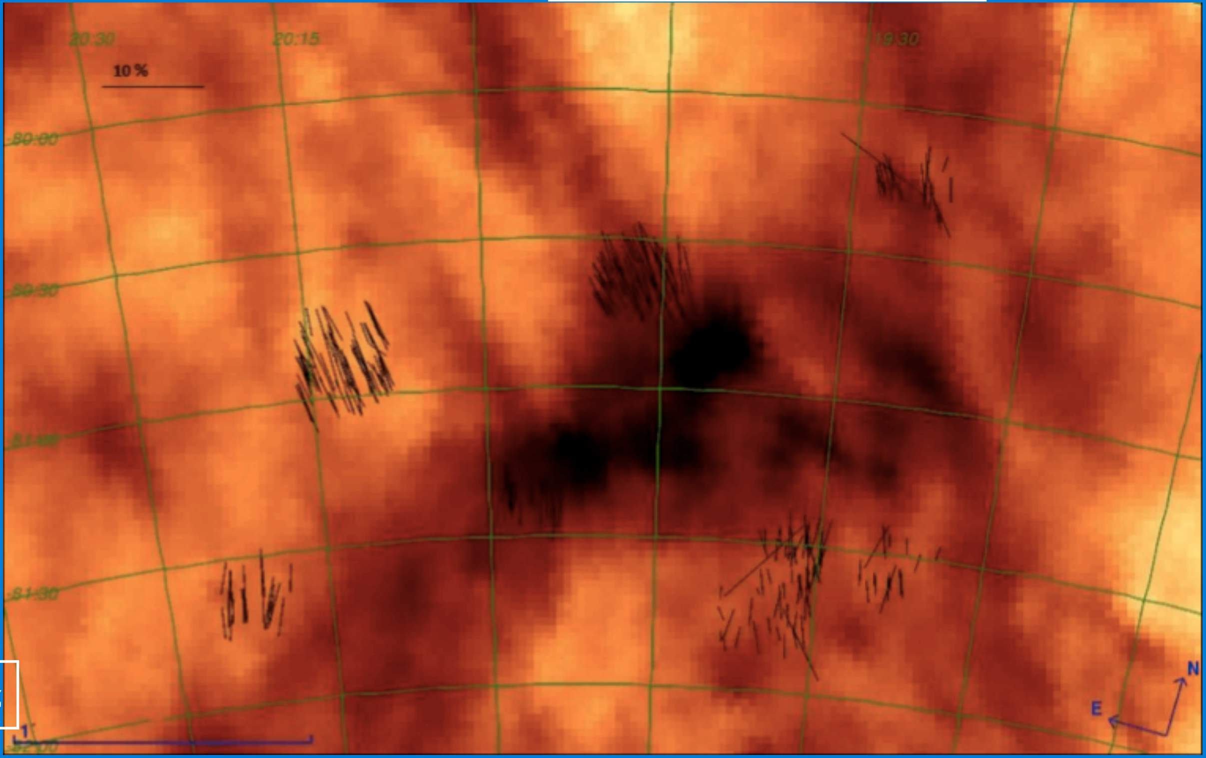
– Regions from COBE/DIRBE (Reach et al. 98)



High Latitude Clouds

Fields towards DIR313-29

Magnetic field along ISM filaments ⇒



Cassia Fernandez

General ISM - The IAG Survey

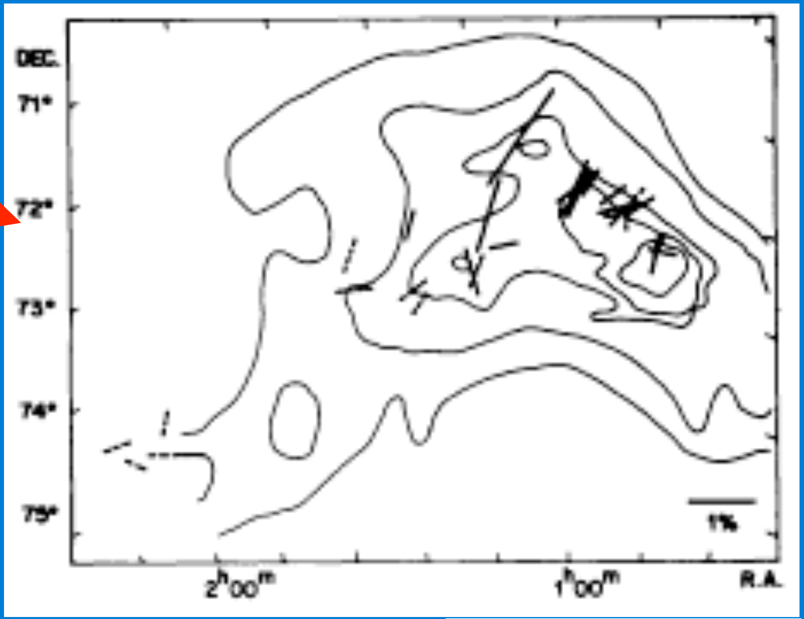
High Latitude Clouds

- By-products:
  - Zero-point of **P vs. column density**
  - **Position angles away from the Plane**
- Important for CMB!

SMC Magnetic Field

- **Early optical polarization observations**
  - Mathewson & Ford (70)
  - Schmidt (76)
  - Magalhaes et al. (90)

⇒ Suggestion of a **Pan-Magellanic field**



Magalhaes et al. (90)

SMC Magnetic Field

- **Magnetic Field intensity**
  - From dispersion of position angles:

$$B_{sky} + \delta B \approx 5.2 \times 10^{-6}\ G$$

    - $n \sim 10^{-1}$ cm^{-3} , $\delta V_{los} \sim 22$ km s^{-1}
  - Estimating

$$\delta B \approx 3.5 \times 10^{-6}\ G$$

Mao et al. (08, synchrotron): 3.2×10^{-6} G

$$\Longrightarrow B_{sky} \approx 1.7 \times 10^{-6}\ G$$

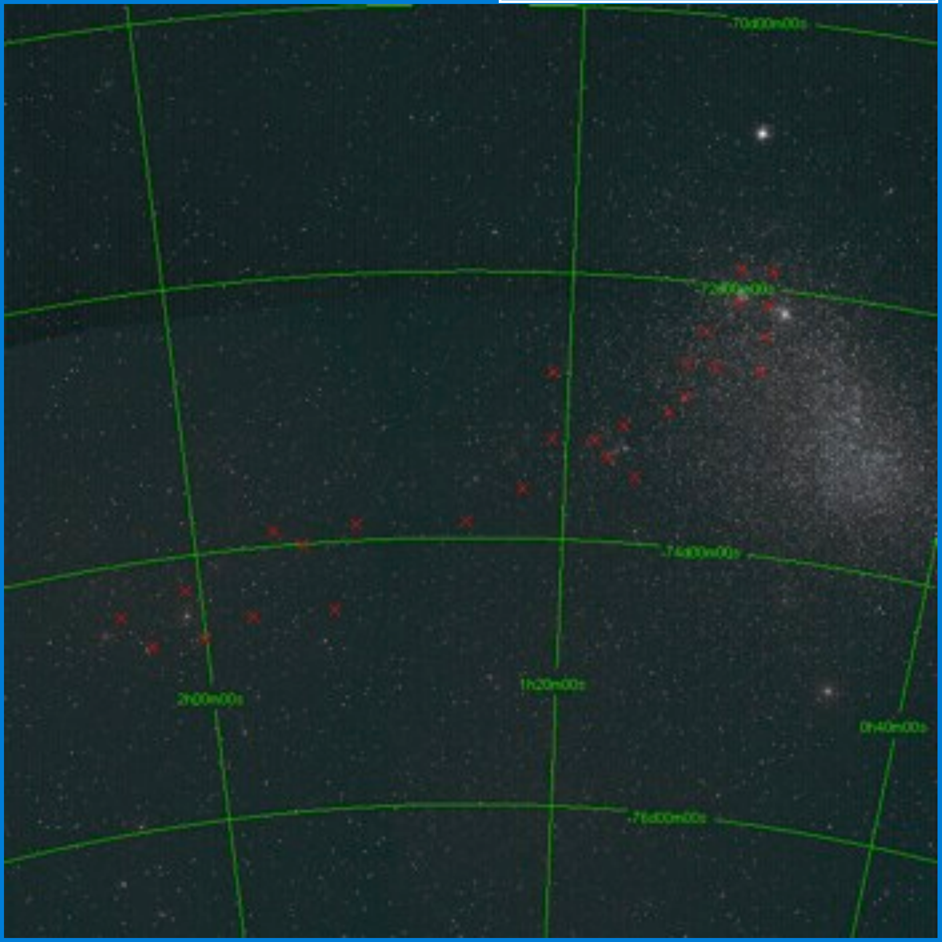
Mao et al. (08, synchrotron): $(1.6 \pm 0.4)\times 10^{-6}$ G

  - Formal uncertainty not too bad (~20%)
    - but answer probably within a factor of a few...

SMC Magnetic Field

- **On-going program**
  - Imaging polarimetry
  - 8'x8' CCD fields

Gomes & Magalhães 2009

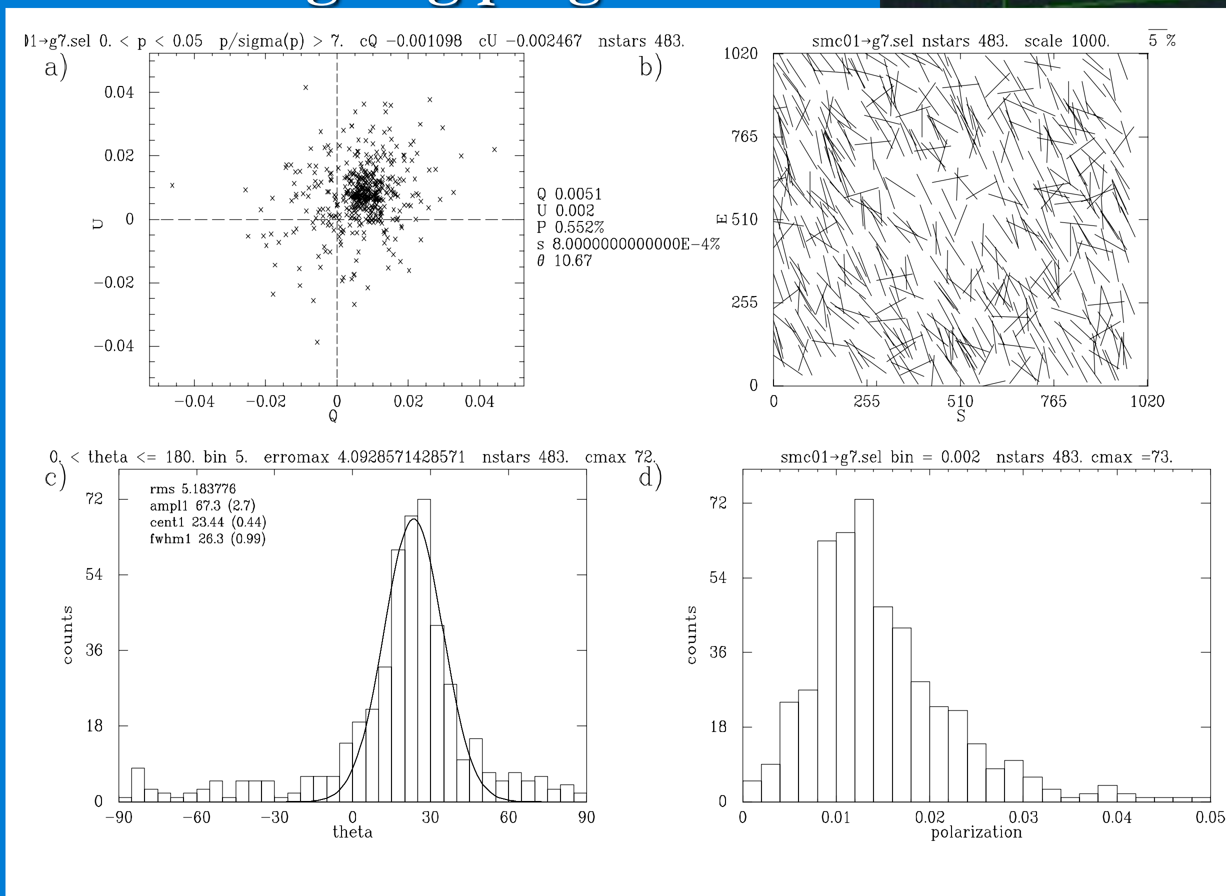


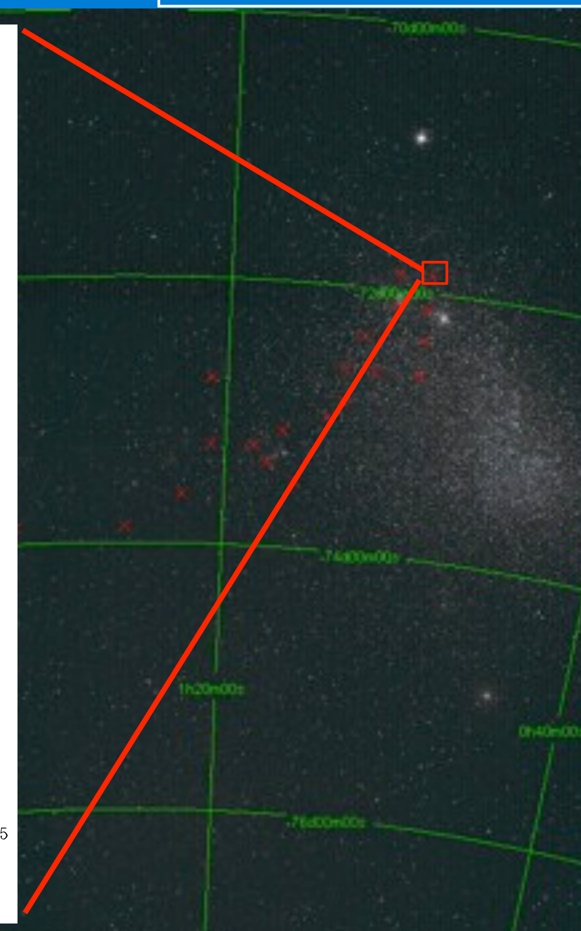
• Optical/NIR Polarization of Starlight Polarization

SMC Magnetic Field

• On-going program

Gomes & Magalhães 2009

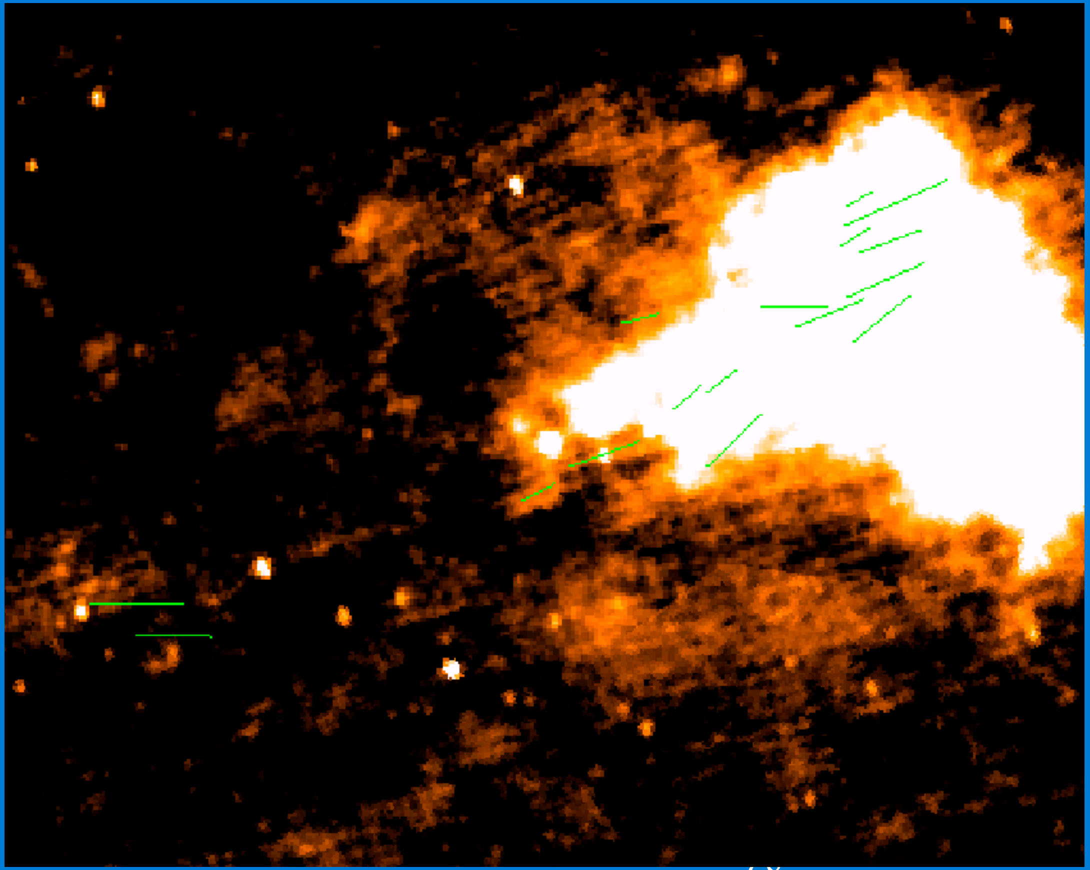




SMC Magnetic Field

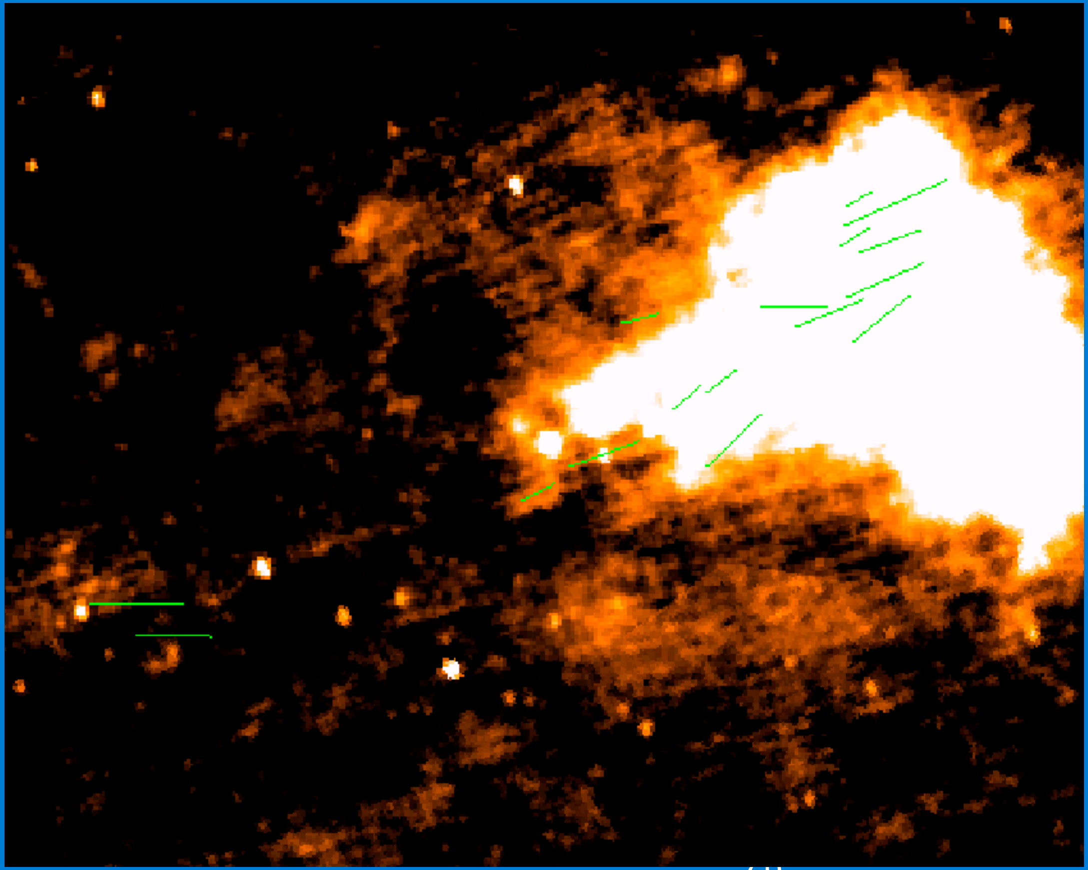
- **On-going program**
  - Imaging polarimetry
  - Preliminary results

SMC Magnetic field along SMC-LMC direction ⇒



SMC Magnetic Field

- **On-going program**
  - Imaging polarimetry
  - Preliminary results



SMC Magnetic field along SMC-LMC direction ⇒

Poster by Aiara Gomes

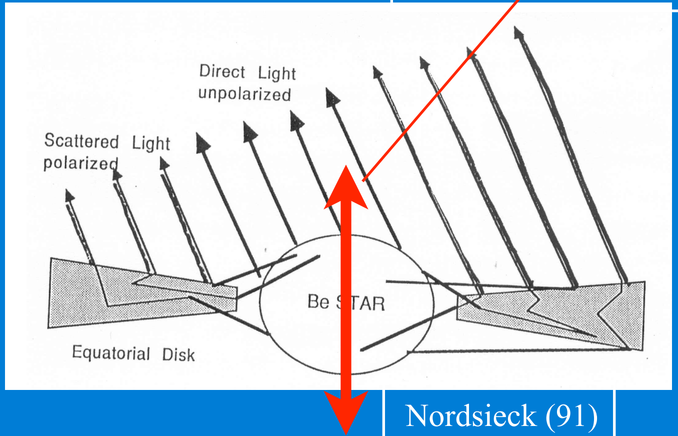
Orientation of Stellar Envelopes

- **Polarimetry of Herbig Ae/Be objects**
  - Pre-MS, intermediate mass stars
  - Comparison of
    Polar. Position Angle with ISM Magnetic Field direction
  - i.e.,
    Envelope Orientation vs. **ISM B-field**
  - **Statistics of**
    $\Delta\theta$ = Intrinsic PA - ISM Pol PA
    can be done.

Net **Polarization**

⊥ to

disk orientation



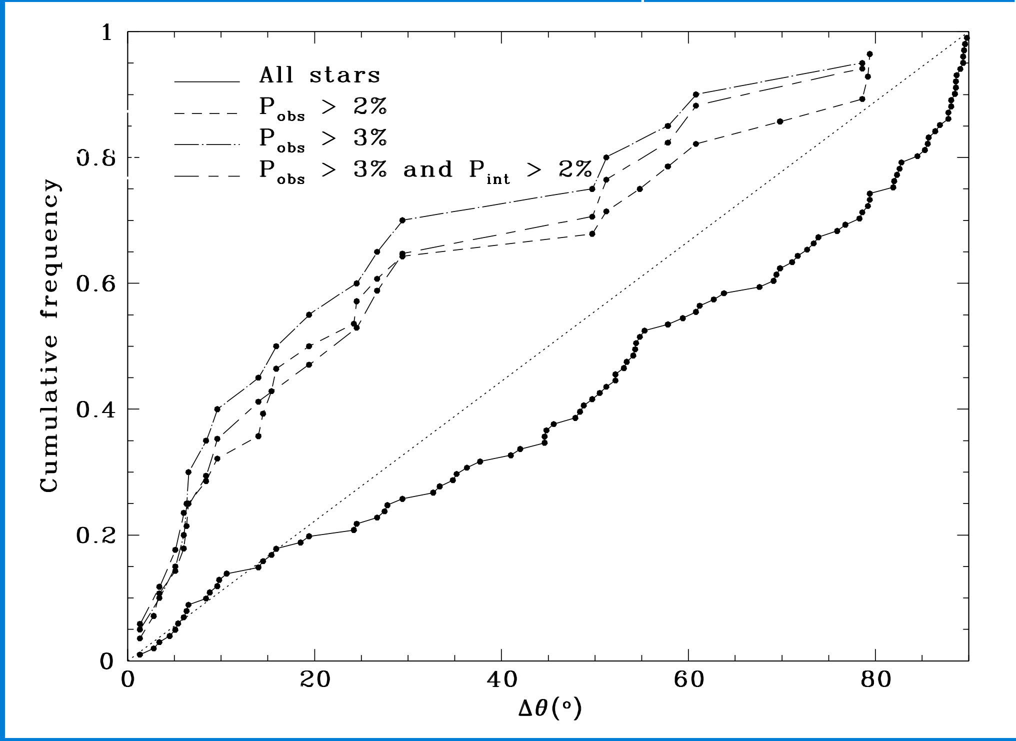
Nordsieck (91)

Orientation of Stellar Envelopes

- **Polarimetry of Herbig Ae/Be objects**
  - **Statistics of**

    $\Delta\theta$ = Intrinsic PA - ISM Pol PA

Rodrigues et al. 2009

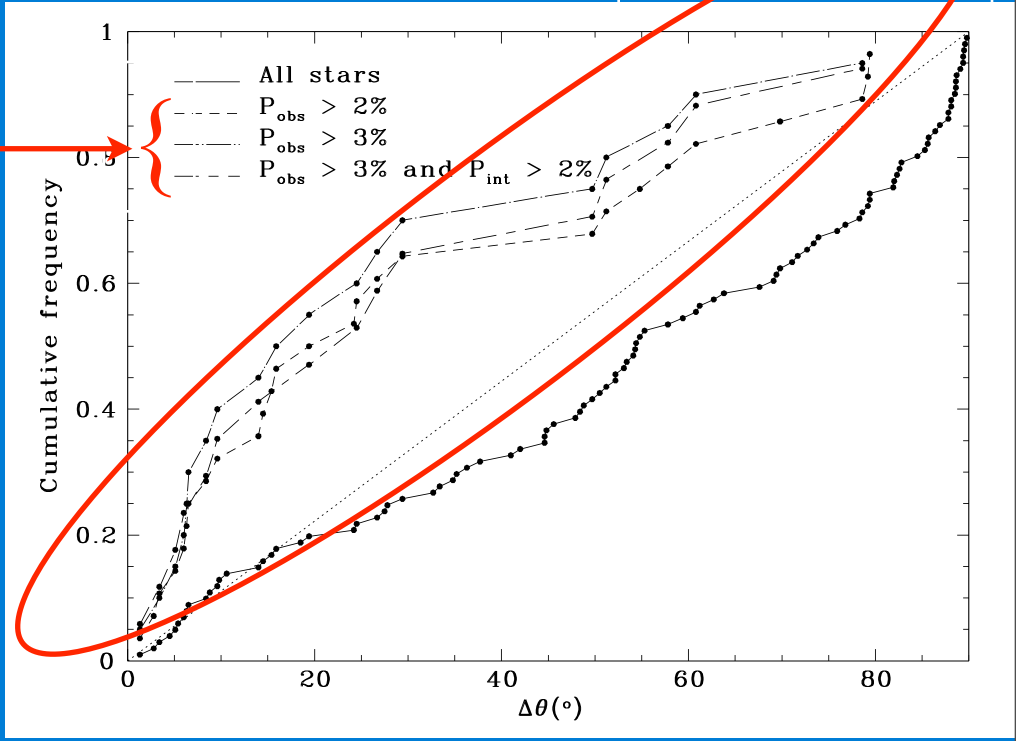


Orientation of Stellar Envelopes

- **Polarimetry of Herbig Ae/Be objects**
  - Statistics of

    $\Delta\theta$ = Intrinsic PA - ISM Pol PA

Rodrigues et al. 2009



– For the more highly polarized stars:

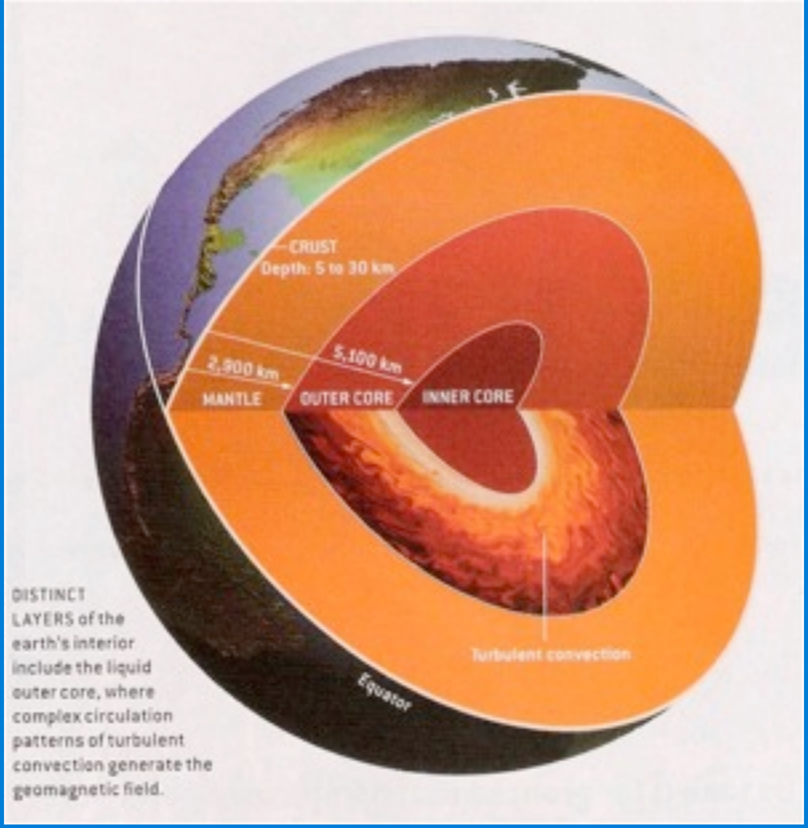
$\Delta\theta \rightarrow$ **parallel**

to ambient B-Field

Envelopes have memory of ISM B-field !

Orientation of Stellar Envelopes

- **Origin of Earth's Magnetic Field?**
  - Dynamo from Earth's rotation
  - Earth's rotation derived from Protosolar Nebula
  - Nebula probably had memory of ISM B field

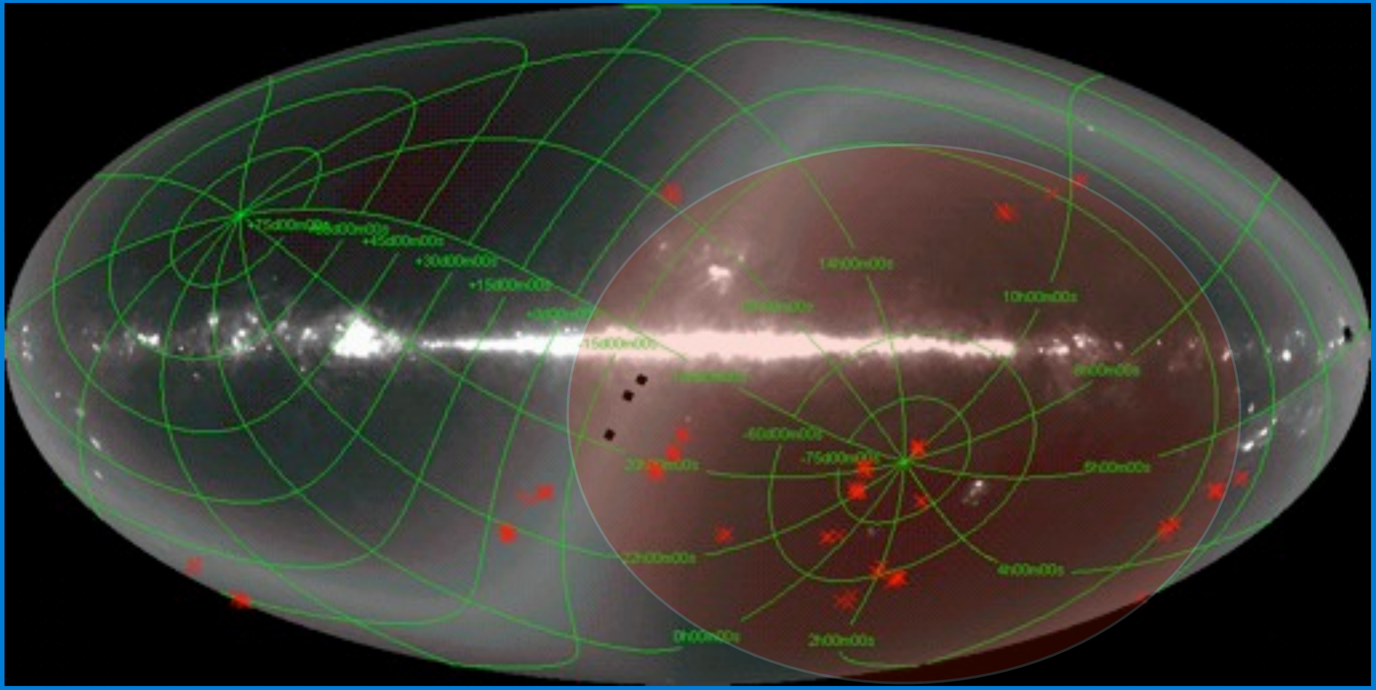


SOUTH POL

- **SOUTH POL:**
  - Survey of the Polarized Southern Sky in the Optical
- **Goal:**
  - Polarimetric accuracy of 0.1% at V=15-16
- **First epoch:**
  - Sky South of Dec -15°
  - Completed in ~ 2 years
- **It will steadly progress Northwards**

Optical Polarization by Dust

- **SOUTH POL:**
  - Survey of the Polarized Southern Sky
    - Support: FAPESP



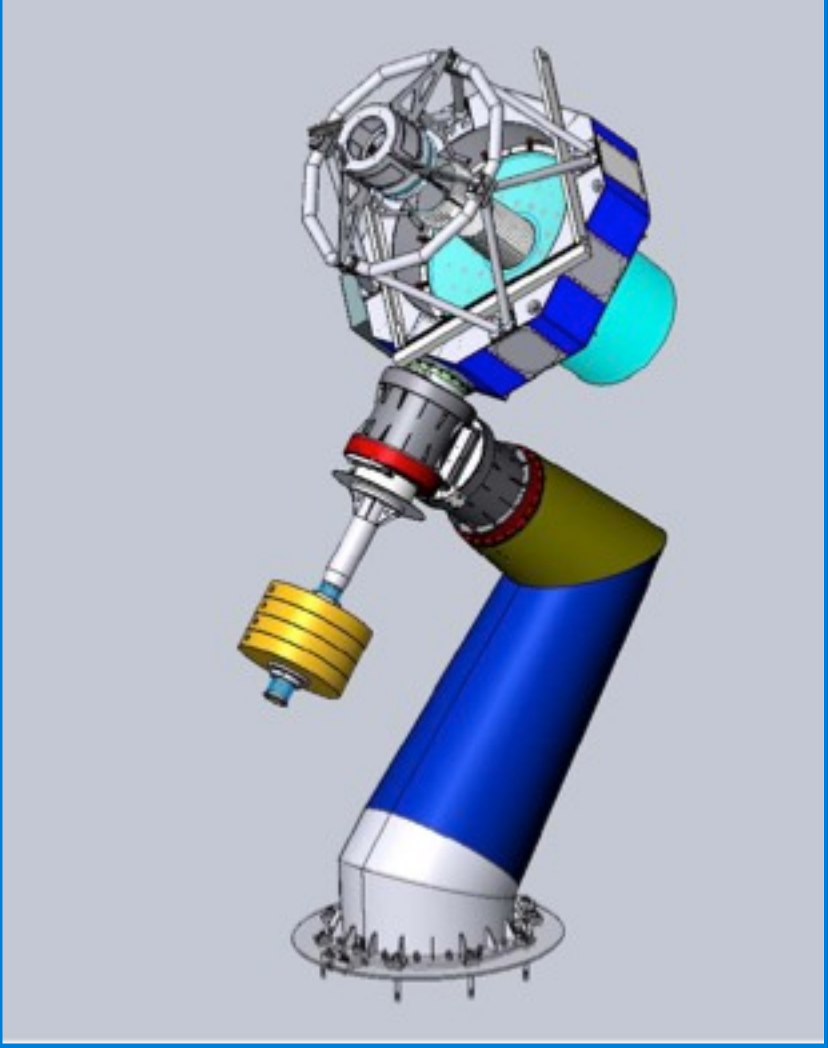
SOUTH POL

- **80cm Robotic Telescope**
  - TR-80S PI: C. M. de Oliveira
  - Instalation: 2012
    - CTIO, Chile

Table 1: Summary of the performance of the T80 design

	Performances of design
Aperture	0.840 m diameter
Plate scale	55.56 arcsec/mm
Focal length	3712 mm
Field of view	110 mm (1.7°) with optimized image quality
	155 nm (2.4°) with limited performances
Image Quality	50% EE = 5 μm / 0.28 arcsec (diameter)
	80% EE = 13 μm / 0.72 arcsec (diameter)
Distortion	0.6%

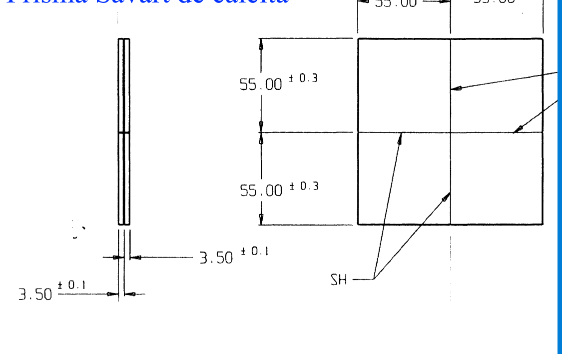
- CCD:
  - EEV, 9k x 9k, 92mm
  - 2.0 deg^2 (!)



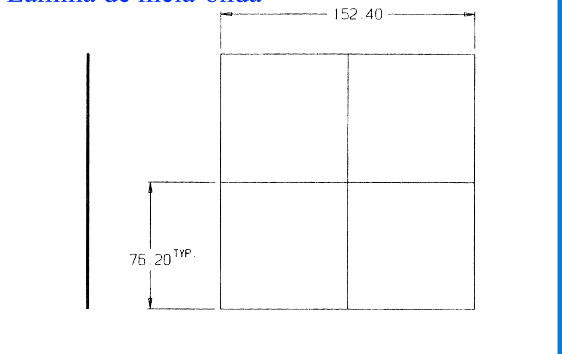
SOUTH POL

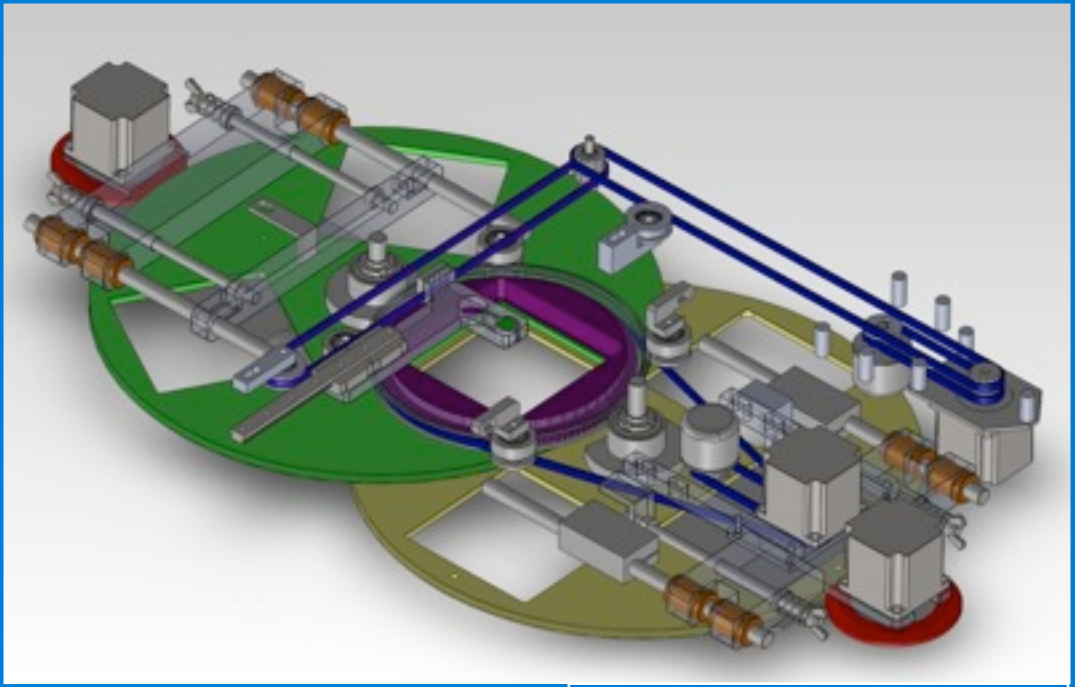
- **Polarimeter**

Prisma Savart de calcita



Lâmina de meia-onda

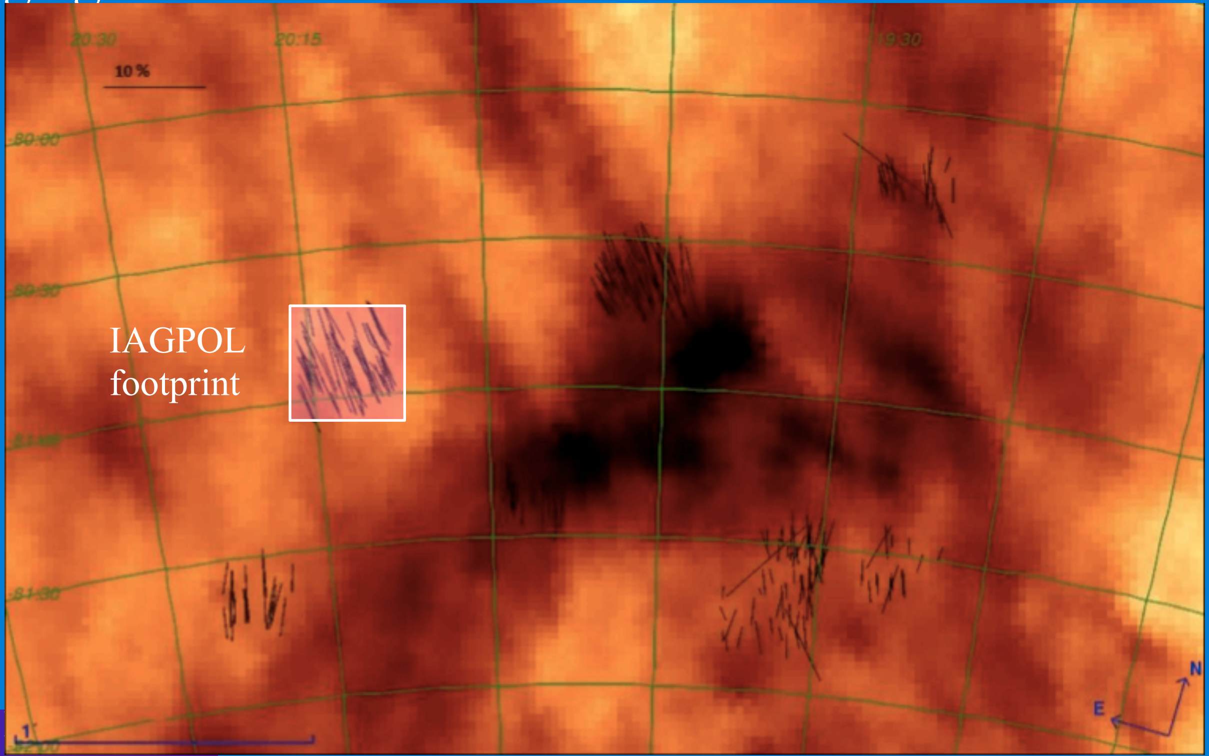




L. Marrara, preliminary design

SOUTH POL - How?...

- **Combination of**
  - Southern 80cm Robotic Telescope in Chile
    - just funded by FAPESP
  - Large field Imaging Polarimeter
    - 2.0 sq.deg.



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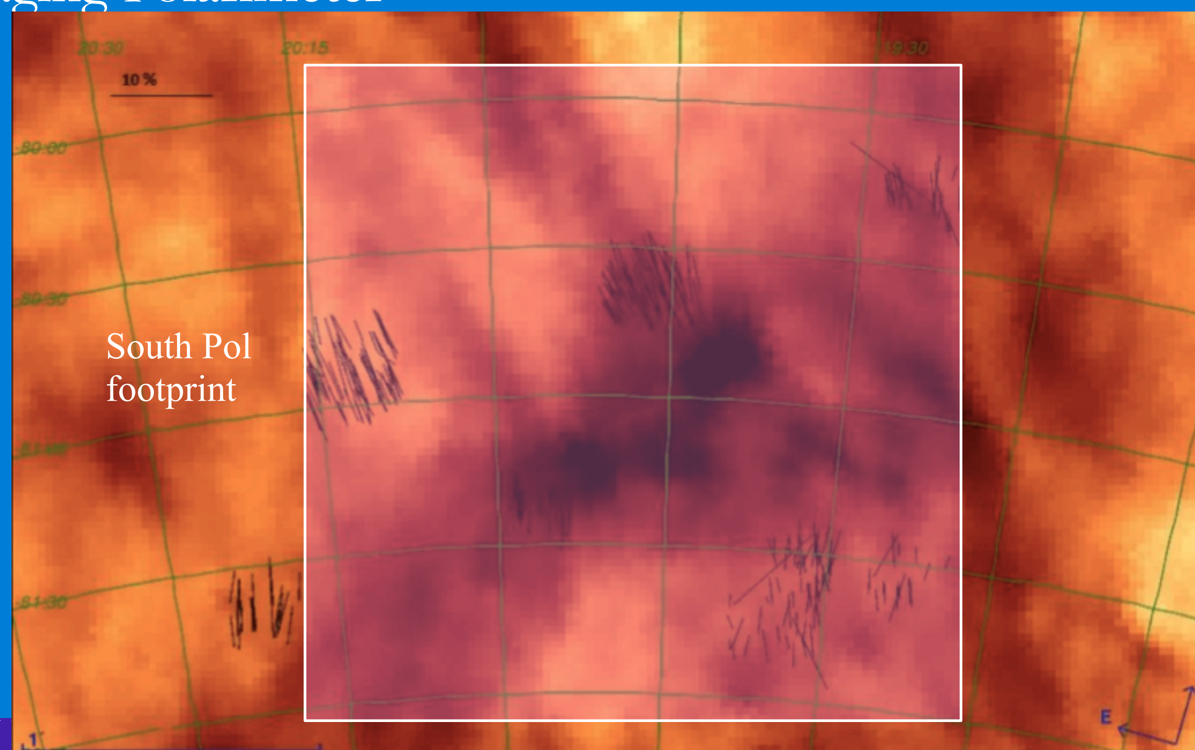

Como?...

- **High Galactic Latitude Clouds**
  - Need V~15-16 in order to map B
  - Av~0.3 typically

    $\Rightarrow P_V \lesssim 3.A_V \sim 0.1\text{-}1.0\%$
  - For $P/\sigma_P = 5$,

    if P~0.5%

    $\Rightarrow \boldsymbol{\sigma_P = 0.1\%}$

Table 1. Polarimetric accuracy, in %, with the 80cm Telescope(*).

V (mag)	8×60 sec	8×300 sec
10	0.022	0.010
11	0.035	0.016
12	0.055	0.025
13	0.088	0.039
14	0.140	0.062
15	0.223	0.100
16	0.361	0.160
17	0.600	0.263
18	1.051	0.449
19	2.011	0.830

(*) For a 22mag/arcsec^2, air mass=1, readout noise=5e$^-$.

SOUTH POL - Overall impact

- **Extragalactic Astronomy**
  - Many blazars will probably be discovered
  - EGRET & FERMI sources down to V~19
    - will be identified
  - Magnetic Field structure of interacting systems
    - eg., Magellanic Clouds

SOUTH POL - Overall impact

- **Galaxy, Interstellar Medium & Star Formation**
  - Magnetic Field structure of the Galaxy
    - **with paralaxes from GAIA**
    - Large (~kpc) & small ($\lesssim$ pc) scales
  - Grain alignment theory
  - Magnetic Field topology across Molecular Clouds
    - From less dense regions (optical, SOUTH POL) to denser regions (sub-mm, Planck)

SOUTH POL - Overall impact

- **Stellar Astrophysics**
  - Statistics & Time evolution of explosive phenomena
    - GRBs
    - SNe
  - Circumstellar environments
    - YSOs
    - Evolved objects
      - Galaxy & Magellanic Clouds
  - Census of magnetic White Dwarfs

SOUTH POL - Overall impact

- **Solar System**
  - Asteroids
    - Determinação de albedos, hence **sizes**
    - Inventory & size distribution
    - Curves of **Polarization vs. phase**:
      clarify population divisions among Main Belt, NEOs, etc.

SOUTH POL

- **SOUTH POL**
  - unprecedented undertaking in the optical
  - will impact several areas
    - from Cosmology to Solar System studies
  - accuracy of 0.1% down to V=15-16
  - will cover **-15° < dec < 90°** in first 2 yrs

Conclusions

- **Stellar polarimetry provides information on**
  - The general Galactic B field
    - at large scales (≳ 100 pc)
    - at small scales (≲ 1 pc)
  - B field structure in collapsing clouds of the ISM
  - Relation of circumstellar disks & Ambient ISM field
  - B field structure of Interacting galaxies (Magellanic Clouds)
  - The Polarized Foreground for CMBR studies.