Starlight Polarization

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Collaborators:

- **Polarimetry Group at IAG-USP**:

  Antonio **Pereyra** (postdoc, now at Nat'l Obs.-Rio)
  Alex **Carciofi** (postdoc)
  Frédérick **Poidevin** (postdoc)

  Livia **Ferreira** (grad student)

  Cláudia **Rodrigues** (now at INPE)

  Undergrads: Aiara Gomes & Marcelo Rubinho
  (plus several former undergrads)

- FAPESP - São Paulo State Funding Agency

  CNPq, CAPES - federal agencies

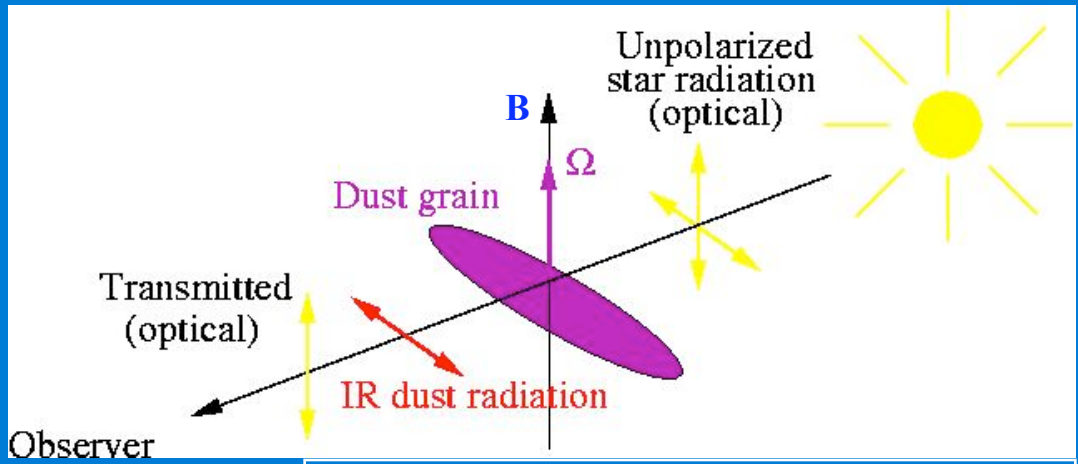
Other collaborators:

- **P. Frisch**, U. Chicago, **B-G Andersson**, SOFIA/USRA & **V. Piirola**, Turku
  - Solar System+ISM
- **Hugo Schwarz**, CTIO & **David Spergel, Aurelien Fraisse** (Princeton), **Steven Majewski, Ricky Patterson** (U. Virginia)
  - ISM/WMAP
- Jean-Philippe **Bernard**, Isabelle **Ristorcelli**, Martin **Giard** (CESR), Ludovic **Montier**, Nicolas **Ponthieu** (IAS), France
  - ISM/PILOT, PLANCK

Summary

- **Basic Facts**
- **Feedback to/from CMB Studies**
  - On-going projects
- **(Not so distant) Future projects**
  - towards 'all-sky' data
- **Conclusions**

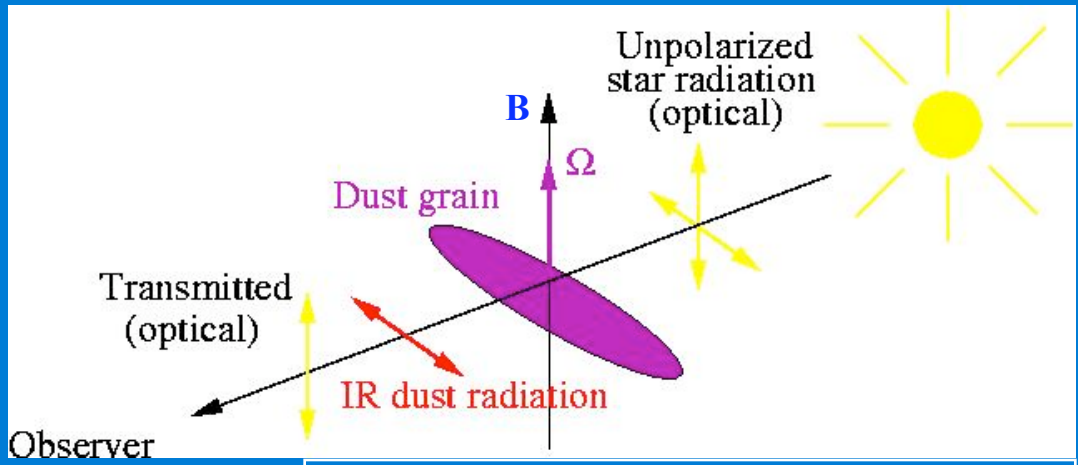
Basic Facts



adapted from Ponthieu, Lagache; www.planck.fr

Basic Facts

- **Starlight Polarization comes from**
  - **dust grains** aligned by
  - **interstellar magnetic field (B)**
- **It provides info on:**
  - **dust** properties
    - size, chemical composition
  - **B structure**
    - component projected on the sky
  - In general, Polarimetry provides info on **asymmetries**



adapted from Ponthieu, Lagache; www.planck.fr

Basic Facts

In the General ISM, Starlight Polarimetry

- **May be used for**
  - **Mapping B** on a Galactic scale
  - Determining the scale length of **B**
  - Ratio of-to-uniform $\mathbf{B}_{random}/B_{uniform}$
    - Heiles 1966
    - Crutcher et al. 2001

Basic Facts

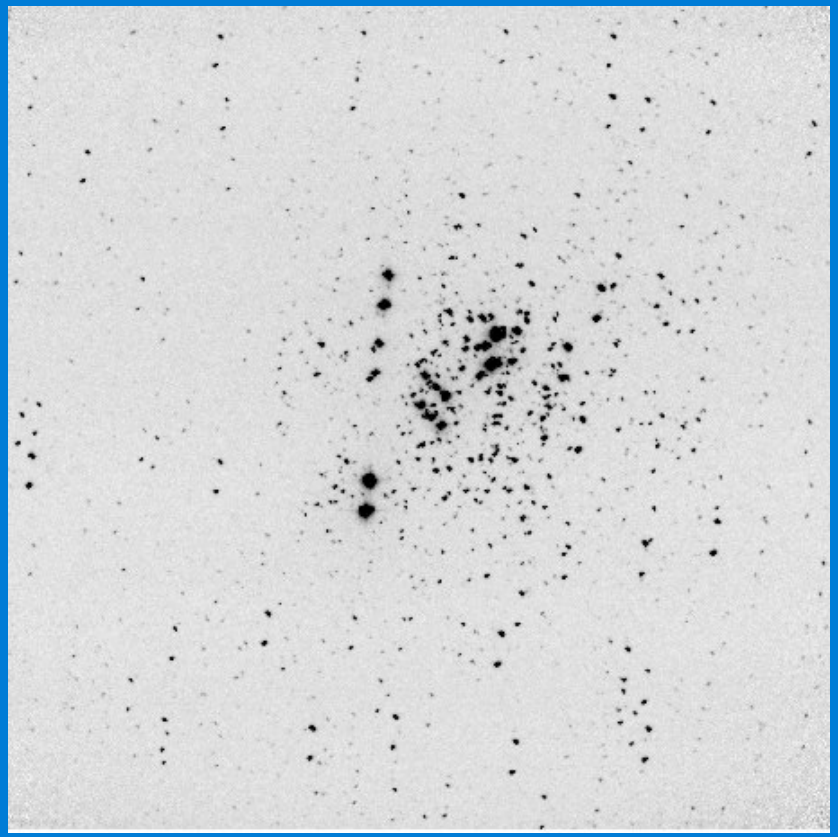
Basic Facts

Open Clusters

κ Crucis (a.k.a. Jewel Box)

CCD **Image with**

λ/2-plate + calcite prism



Magalhães et al. 05

Basic Facts

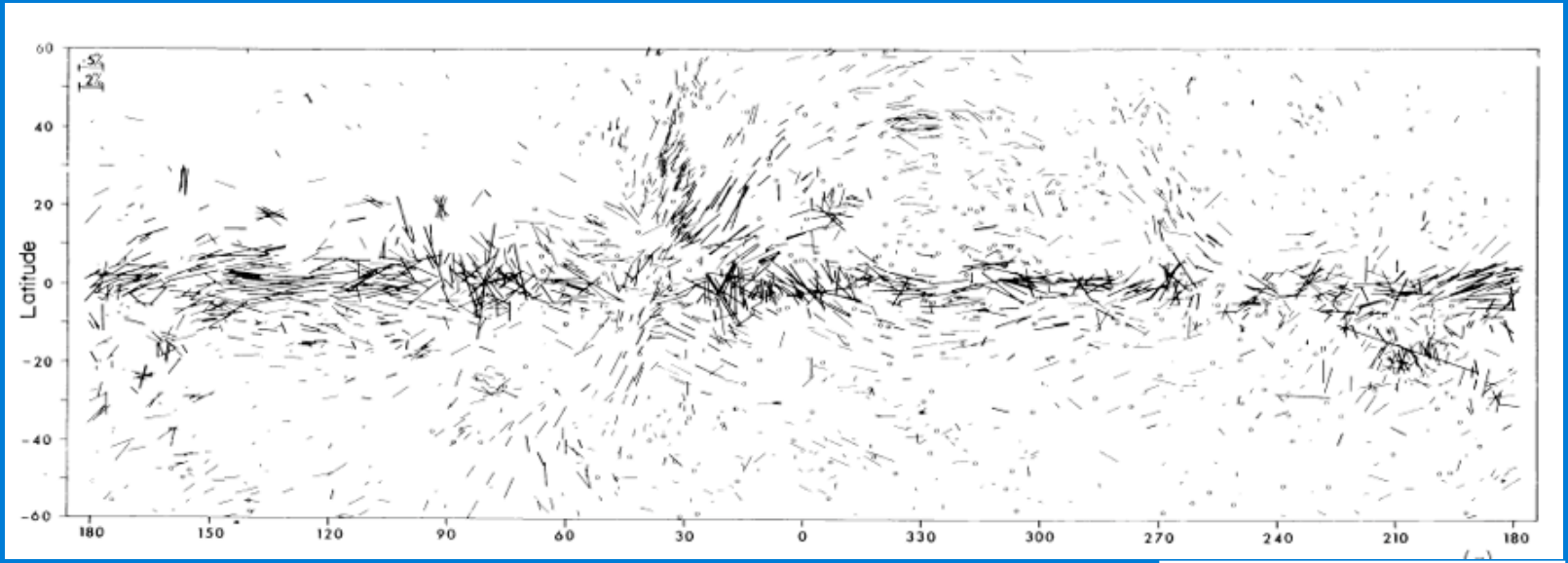
- **Observational uncertainties**
  - Hiltner 1951, ApJ 114, 241:
    - p.e. = 0.0022 mag ∪ σ = 0.15% (!) (photoelectric)
  - Tinbergen 1982, A&A 105, 53:
    - σ = .007% (photoelectric, combining data)
  - Carciofi, Magalhães 2007, ApJ 671, L49:
    - σ = 0.002% (CCD imaging, single obs)

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

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

General ISM

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

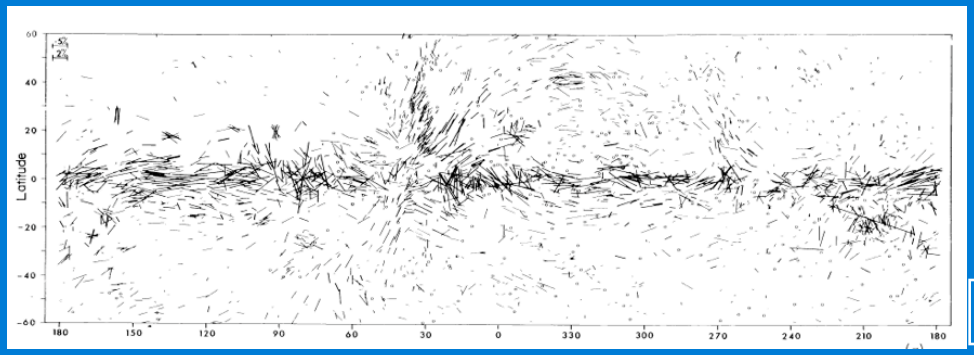


Mathewson & Ford 1970

  - Heiles (1996)
    - Center of curvature, R_{cc}, and direction of center, l_{cc}:
    - R_{cc} = (8.8 +- 1.8) kpc, l_{cc} = (-7.2° +- 4.1°)

General ISM

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



Mathewson & Ford 1970

– Statistical analysis of Fosalba, Lazarian et al. (2002)

$$\frac{P_{obs}}{P_{max}} = \frac{B_u^2}{B_u^2 + B_r^2} \cong 0.39 - 0.69 \quad \varnothing \quad \frac{B_u}{B_r} \approx 0.80 - 1.27$$

u = uniform
r = random

- Angular spectrum, $C_l \neq l^{-1.5}$, reflects underlying polarized continuum
  - important for modeling Galactic foreground

General ISM

- **Southern Optical/IR Survey of Interstellar Polarization**
  - IAG, Univ. Sao Paulo
  - on-going program
    - http://www.astro.iag.usp.br/~antonio/survey.

- **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

General ISM

- **Related, additional Goals**

  Study the Magnetic Field using polarization:

  - at **high Galactic latitudes**, through clouds and structures;
  - across **open clusters**, for mapping the field on small scales;
  - through **nearby dark clouds**;
  - through **Bok globules** (in the **IR**)
  - **near the Sun**, from the immediate neighborhood out to 300pc;

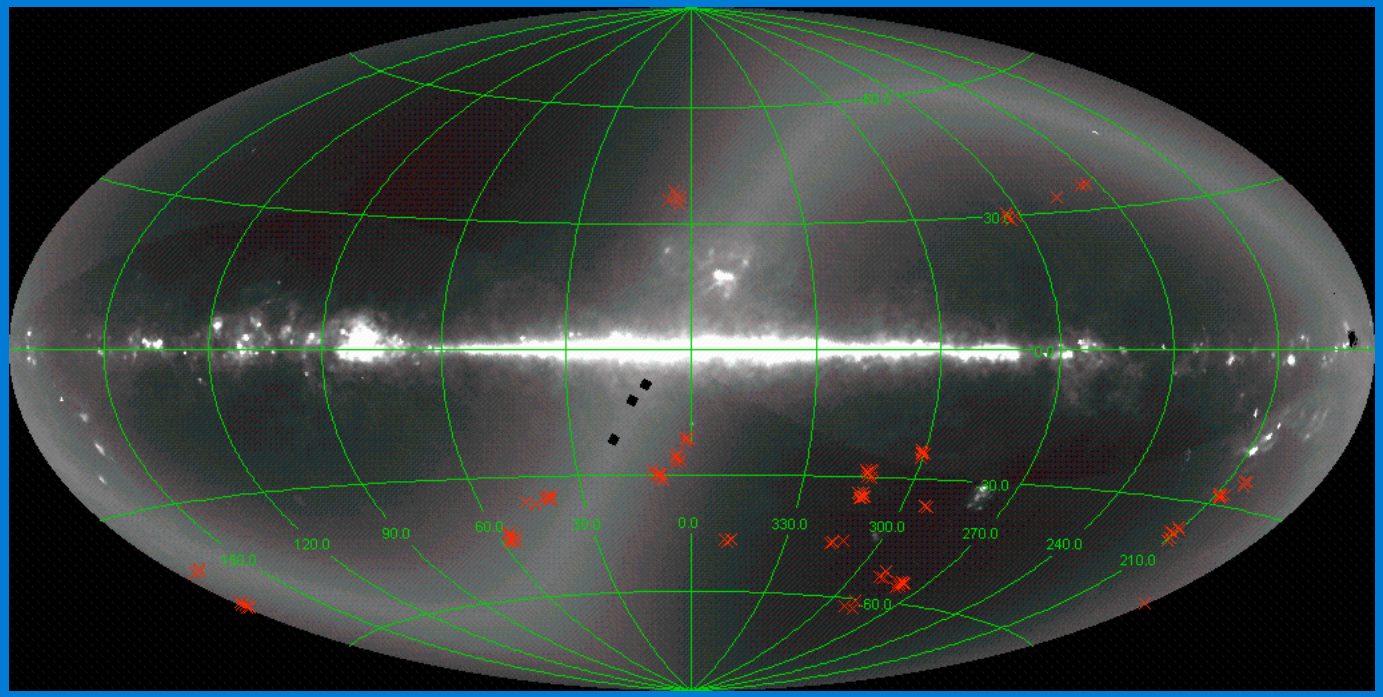
General ISM

High Latitude Clouds

- Regions from COBE/DIRBE (Reach et al. 98)
- Use of Hipparcos stars towards each cloud
  - short + long exposures
- For 10 HLCs:
  - High-resolution spectra for the HIP stars
    ➪ **distance estimates to these clouds**
- 24 HLCs observed thus far
  - **104 HIP stars**
- Data being presently reduced

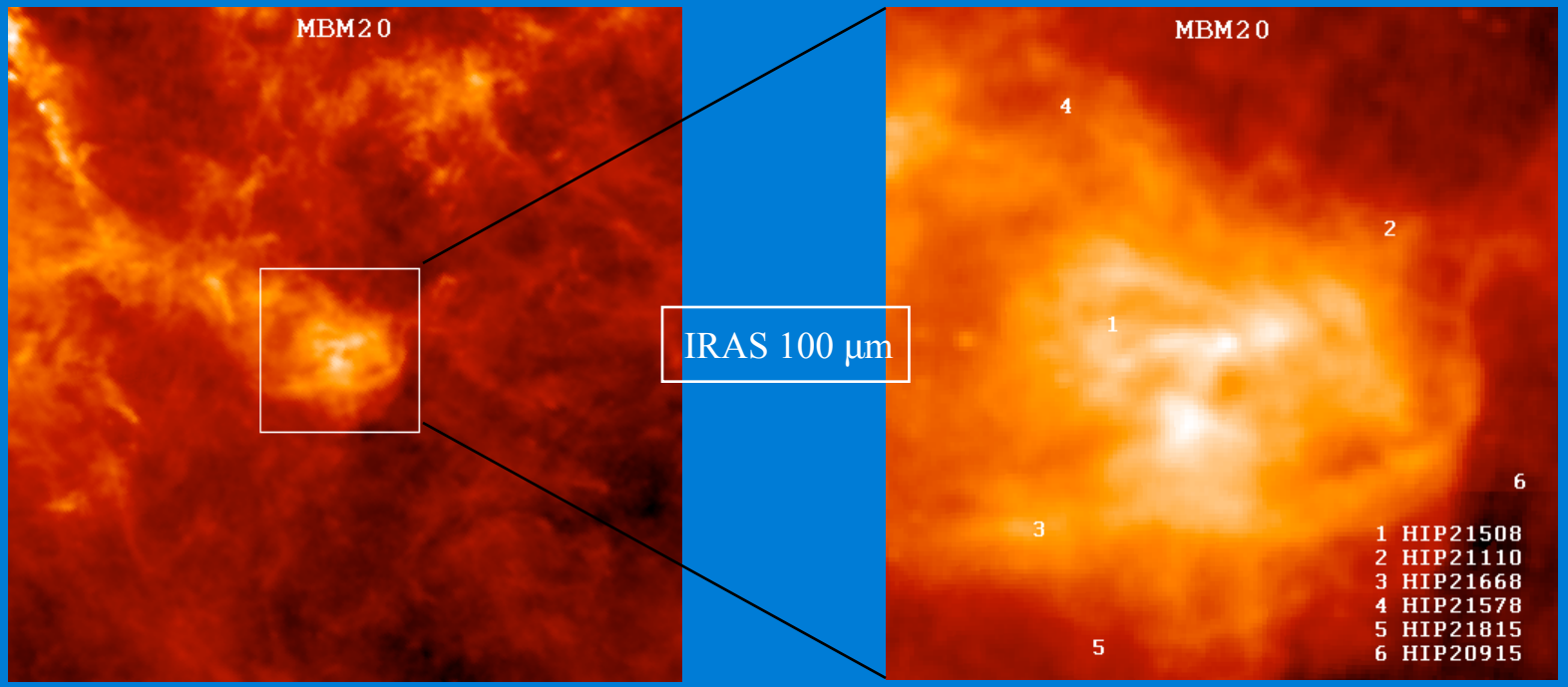
General ISM

– HLC's observed in by the IAG Survey thus far



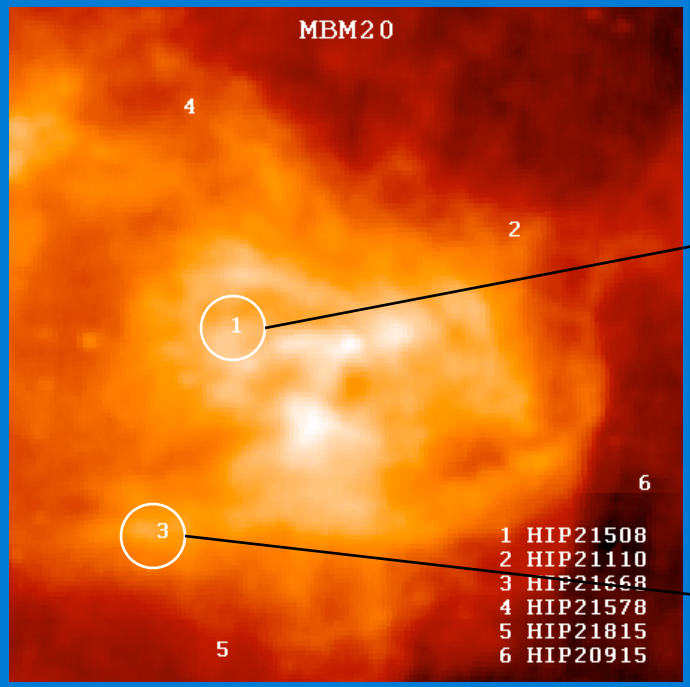
Results

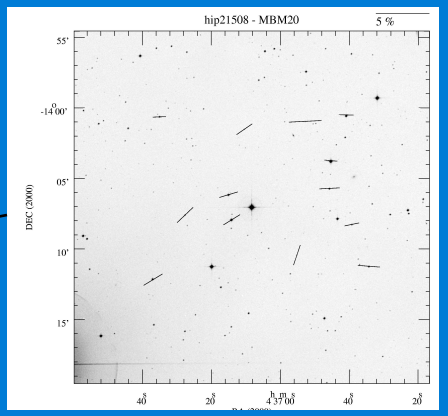
High Latitude Clouds: MBM 20

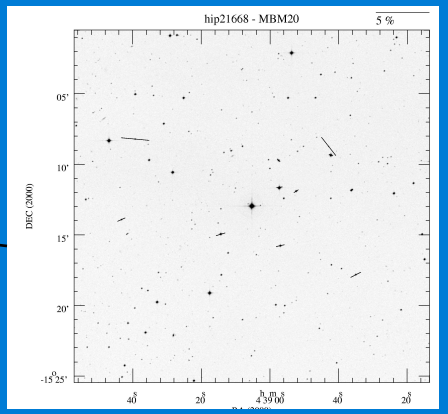


Results

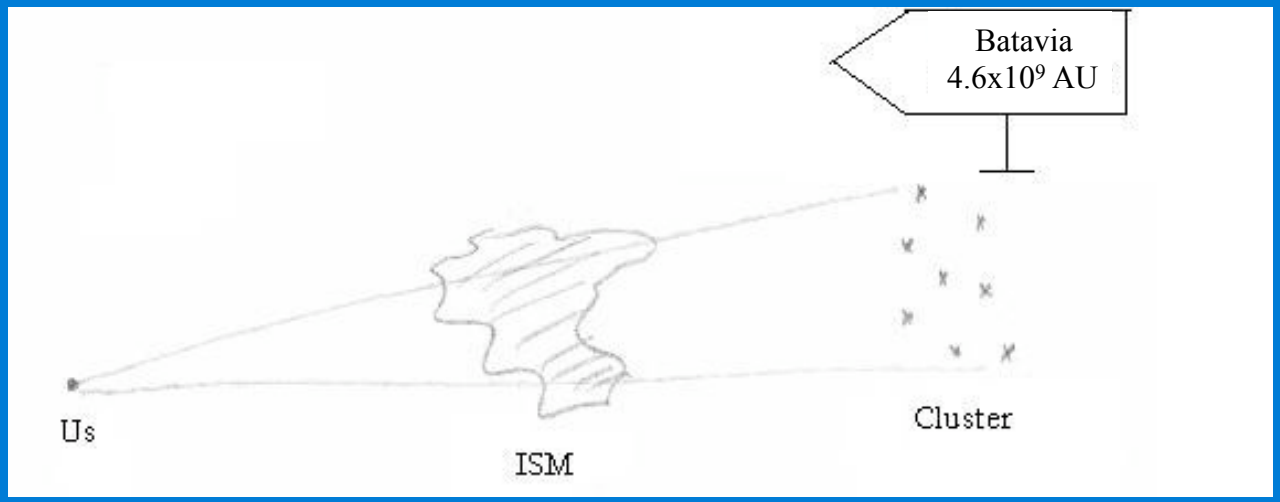
High Latitude Clouds: MBM 20





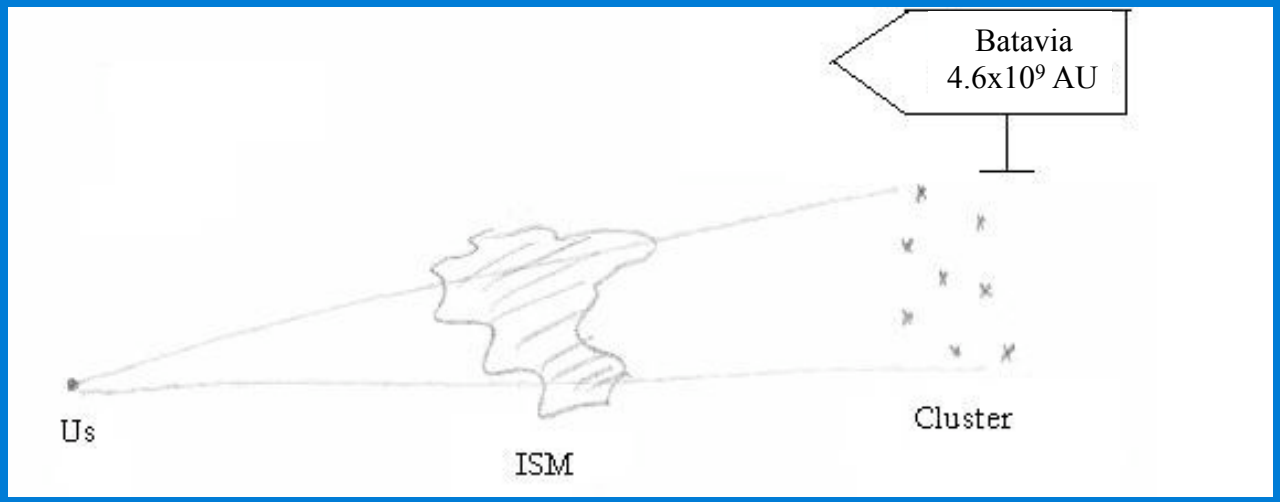


General ISM



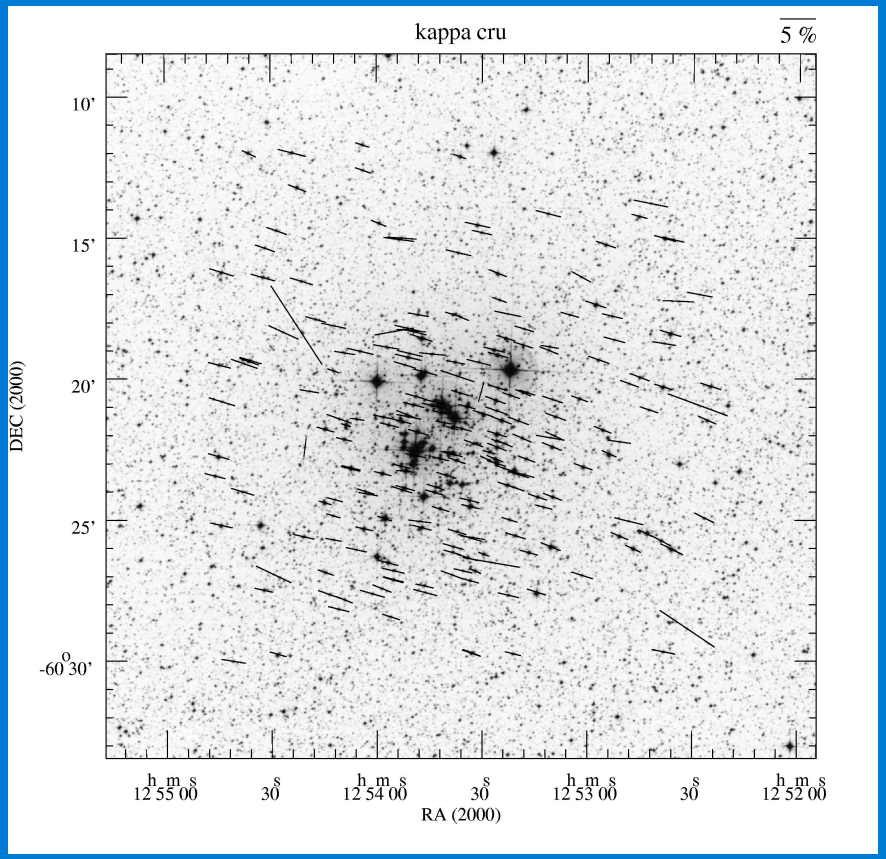
General ISM

- **Open Clusters**



  - allow study of the **field structure on smaller scales**
    - Serkowski 1966, Kobulnicky et al. 94

General ISM


kappa cru
5 %
10'
15'
20'
25'
-60° 30'
DEC (2000)
h m s
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30
12 54 00
30
12 53 00
30
12 52 00
RA (2000)

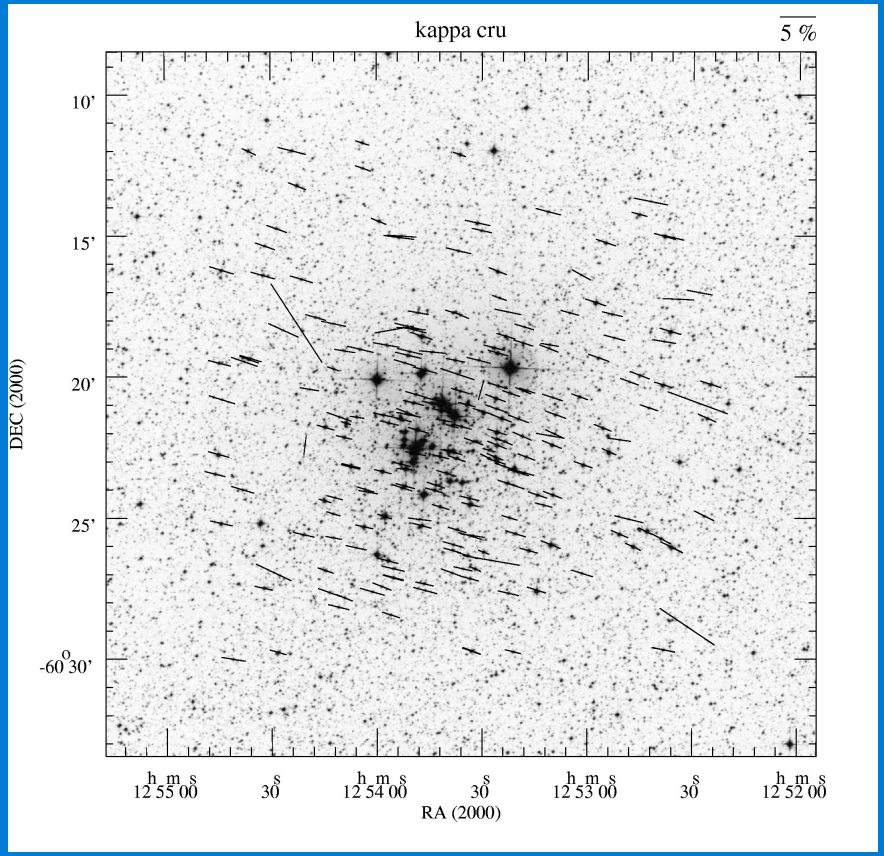
General ISM

Open Clusters

κ Crucis

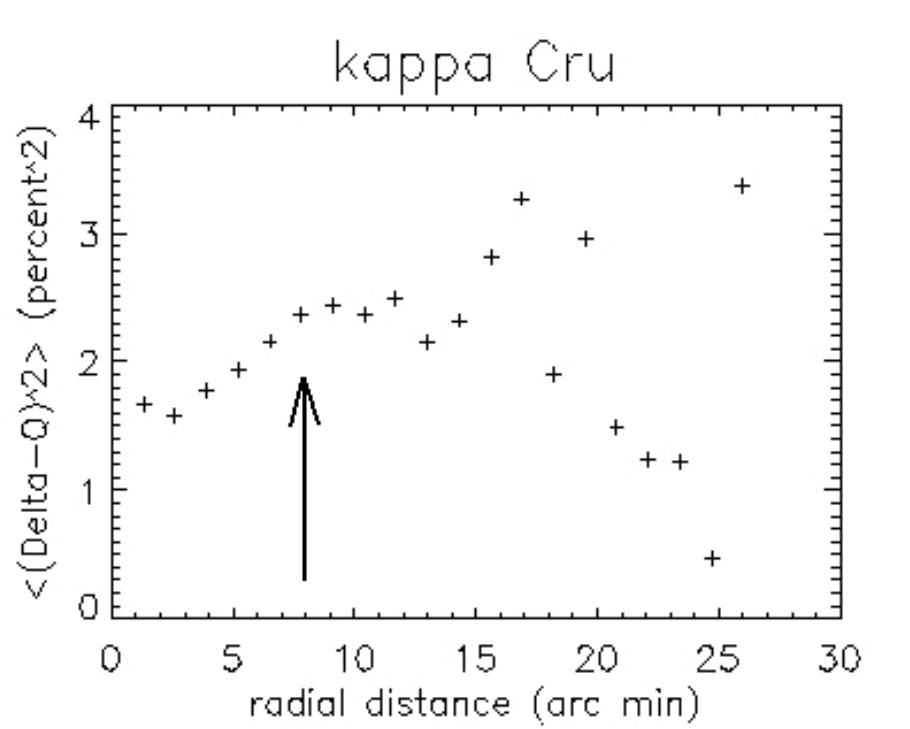
CCD **Image with**

λ/2-plate + calcite prism



Magalhães et al. 05

General ISM



Magalhaes et al 2005

General ISM

Open Clusters

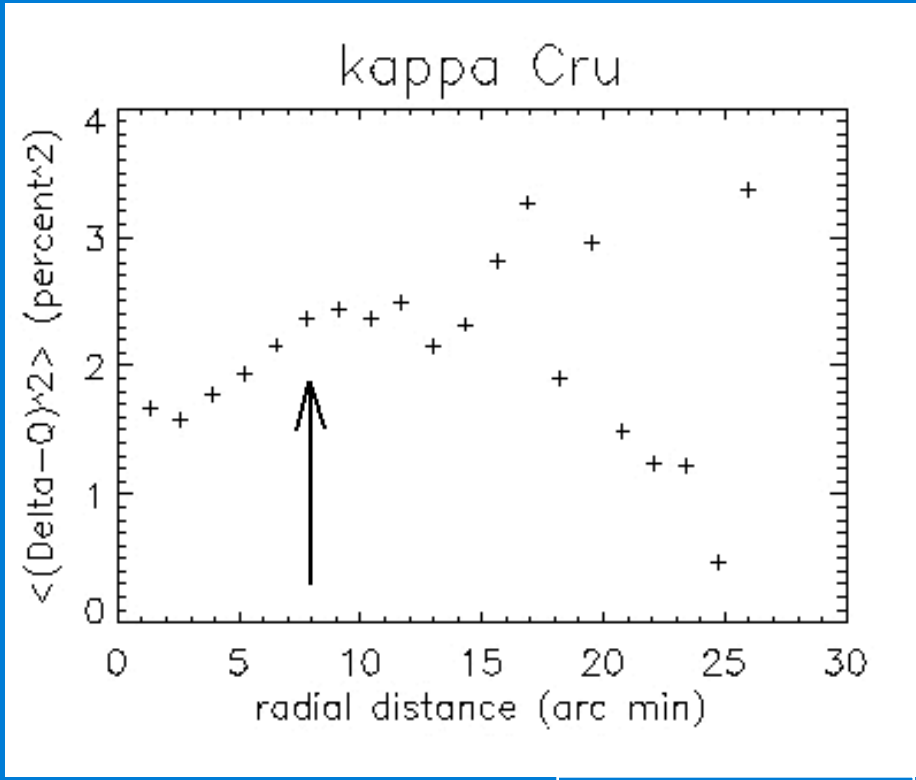
k Crucis

distance = 1900 pc

angular decorrelation size for B:

$\alpha_0 \sim 8'$

$\Rightarrow L \leq 4.6$ pc



Magalhaes et al 2005

General ISM

- **Open Clusters**

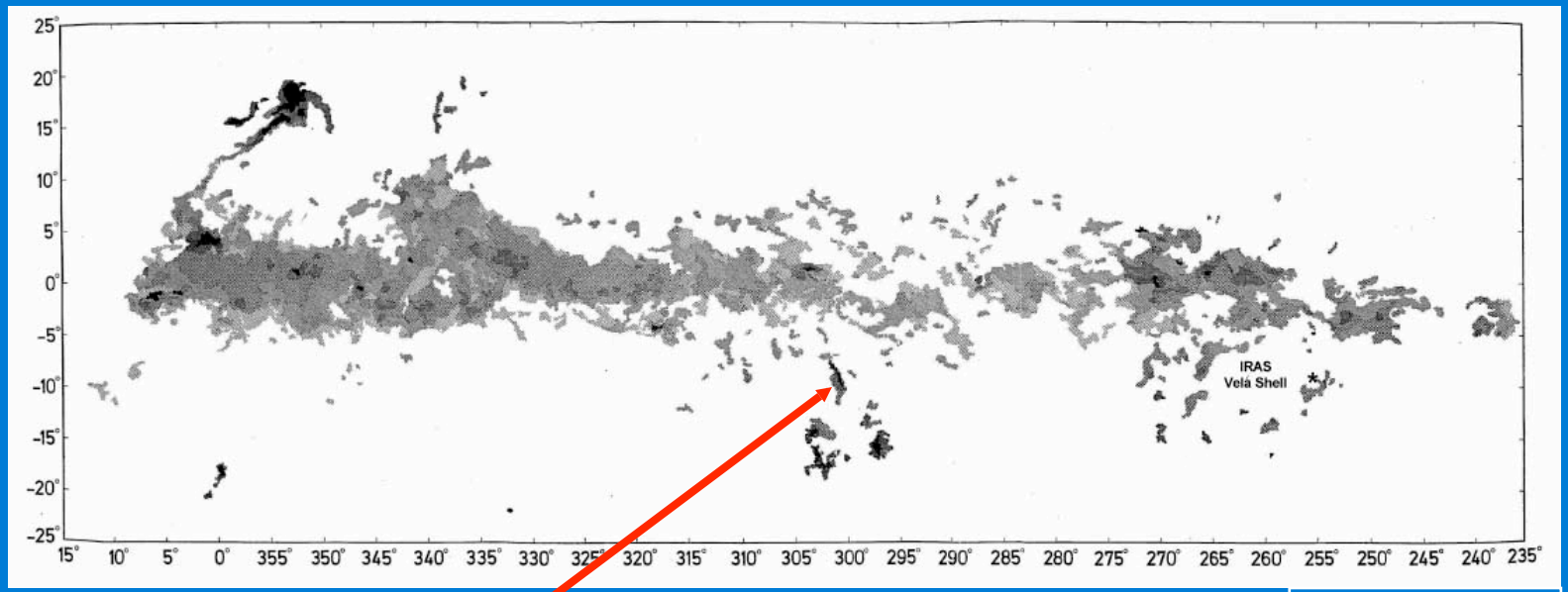
Ferreira & Magalhães 2008

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

  - **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)
  - **Input to CMB Foreground Polarization**
    - **L away from the Plane has to be determined**

ISM Regions of Interest

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

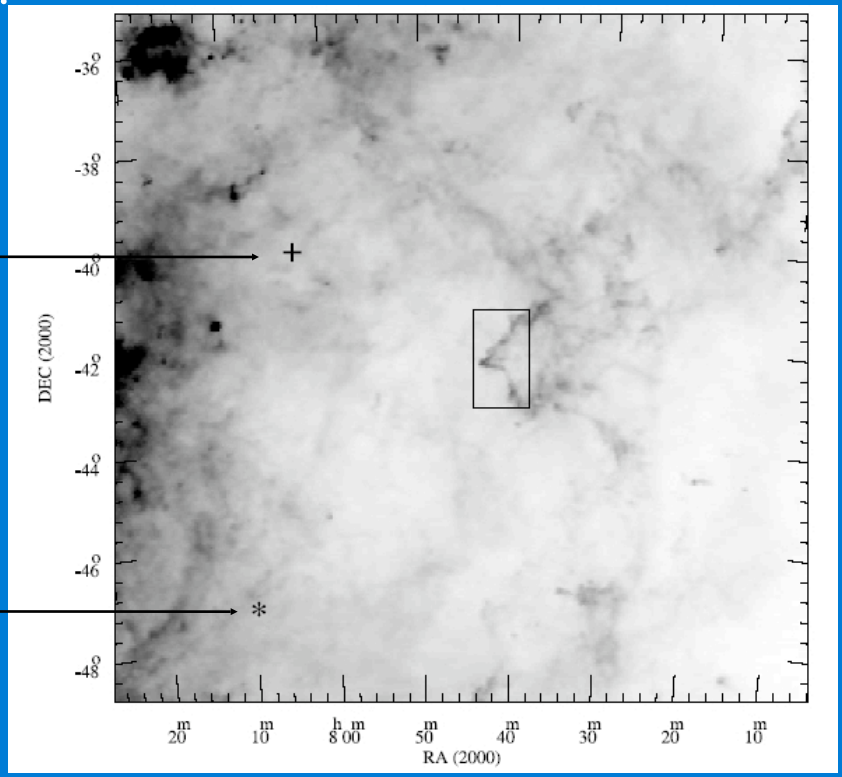


Feitzinger & Stuve 84

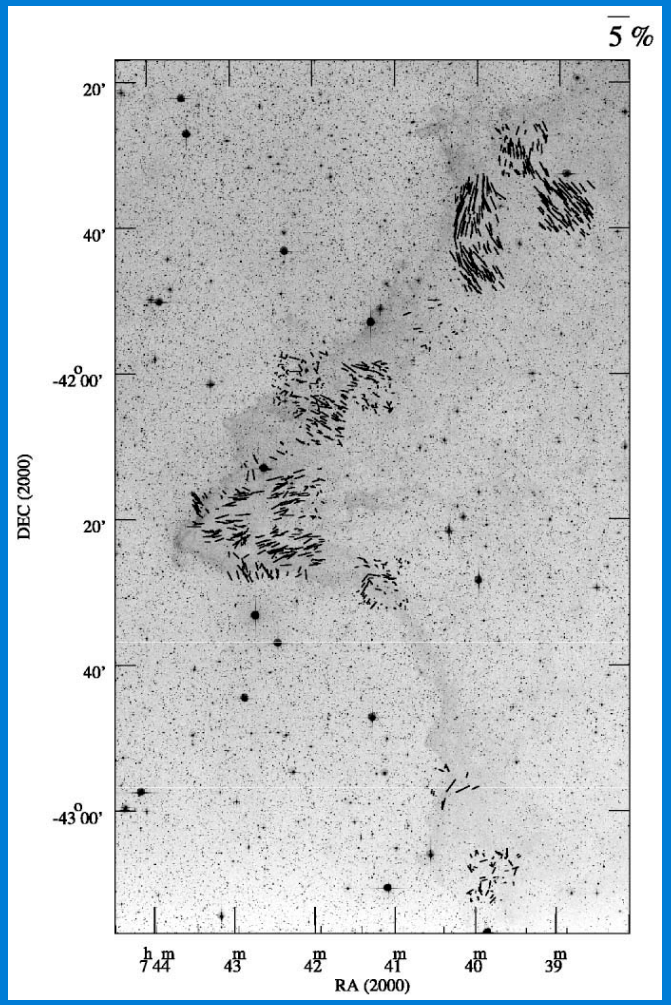
ISM Regions of Interest

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

IRAS 100μm



ISM Regions of Interest



ISM Regions of Interest

Magnetic Field in Dark Clouds

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

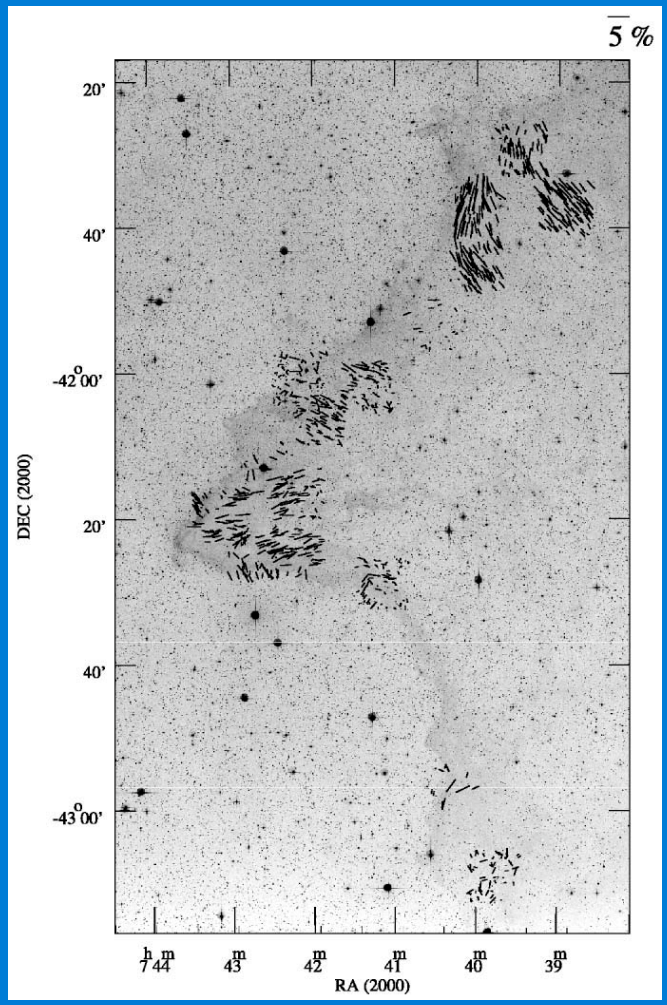
- **Mapping the IRAS Vela Shell**

  regions with vectors

  - parallel to I-front
  - ⊥ or w/rotation into I-front
  - affected by gas streaming

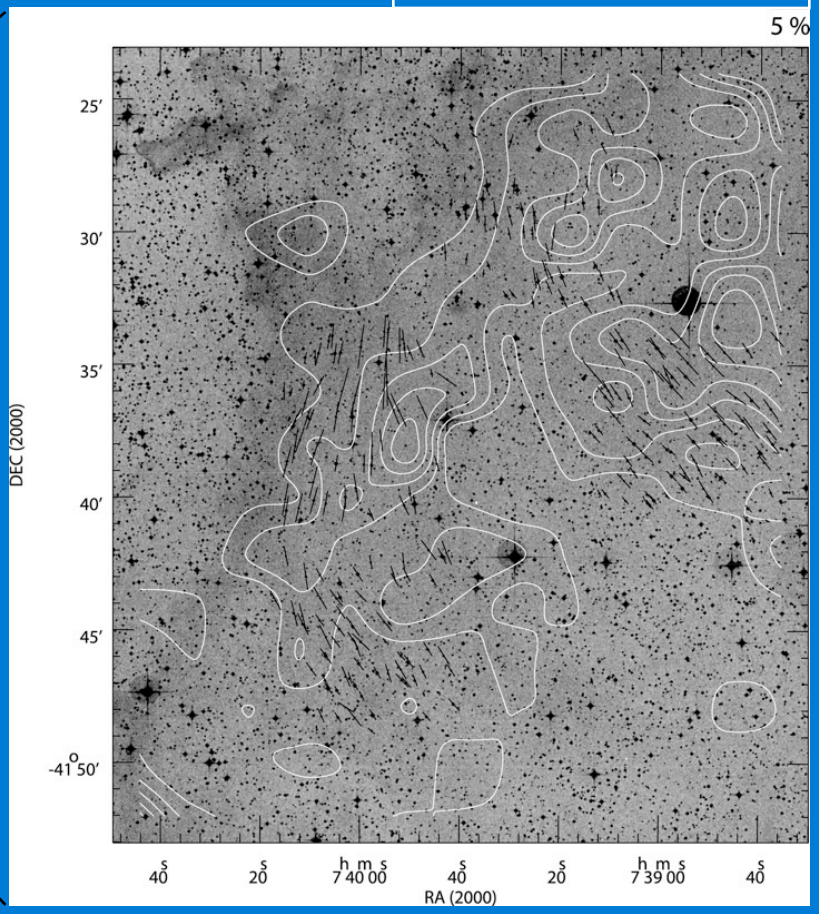
    Pereyra & Magalhães 02, 07

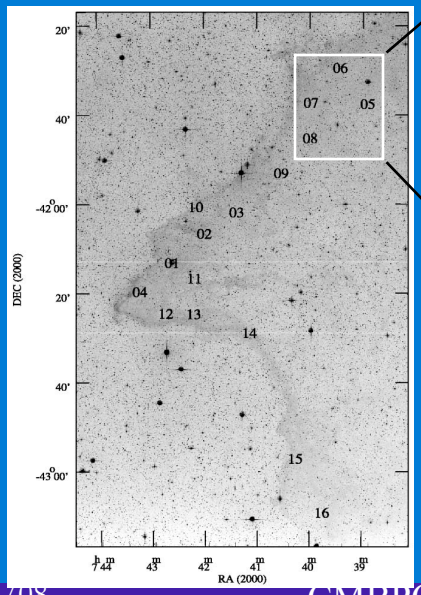
  - Simulations of Heitsch (08) agree well w/ data



ISM Regions of Interest

Pereyra & Magalhaes 07





ISM Regions of Interest

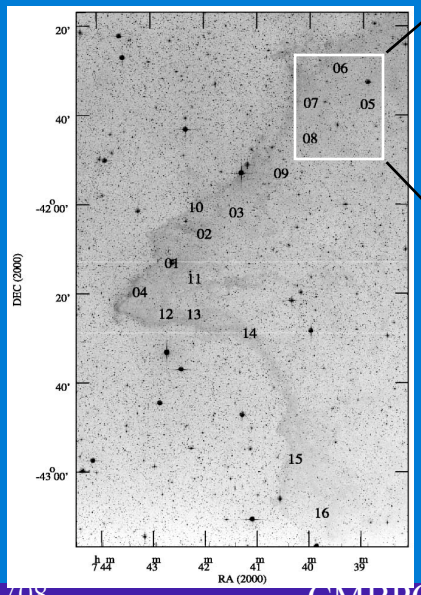
Magnetic Field in Dark Clouds

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

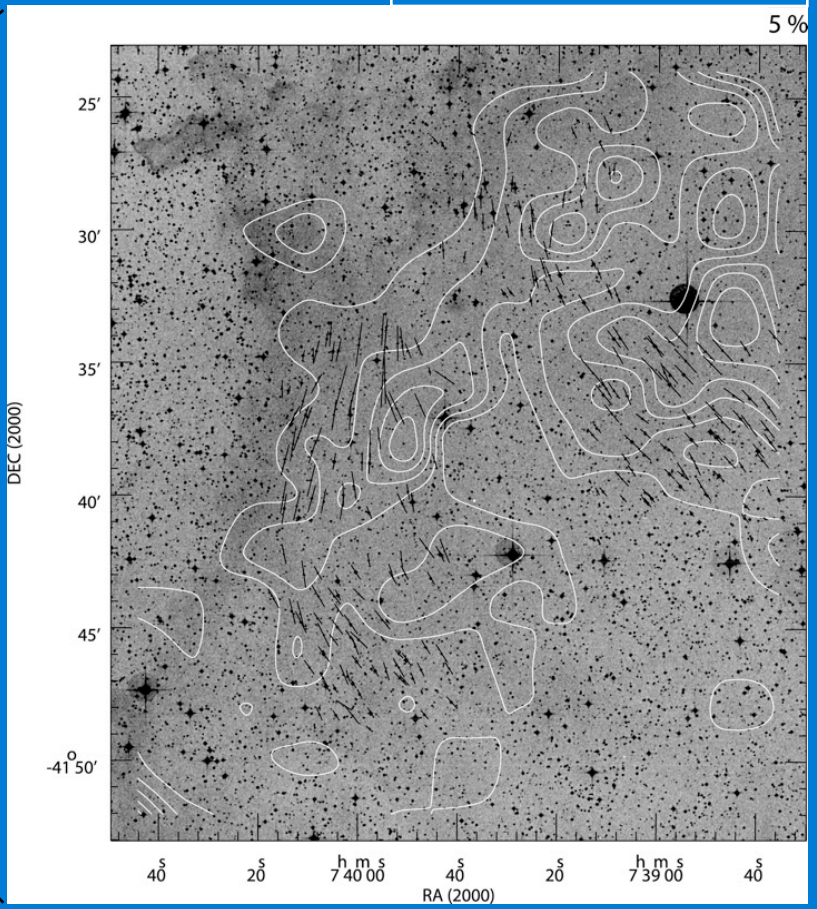
- **Mapping the IRAS Vela Shell**

  regions with vectors

  – parallel to I-front



Pereyra & Magalhaes 07

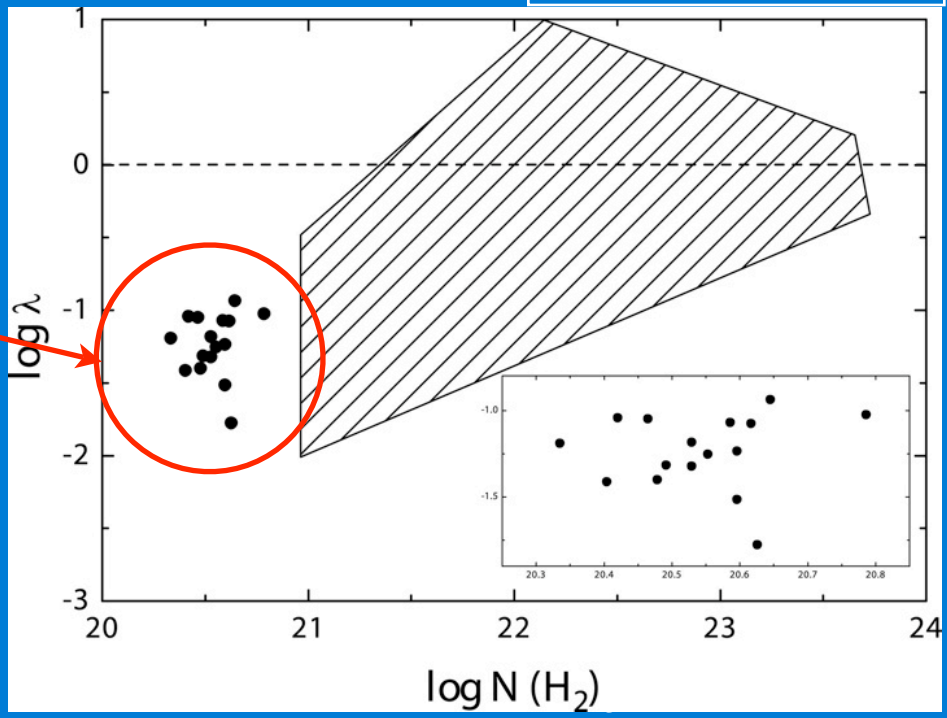


back

ISM Regions of Interest

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

Pereyra & Magalhaes 07



ISM Regions of Interest

Magnetic Field in Dark Clouds

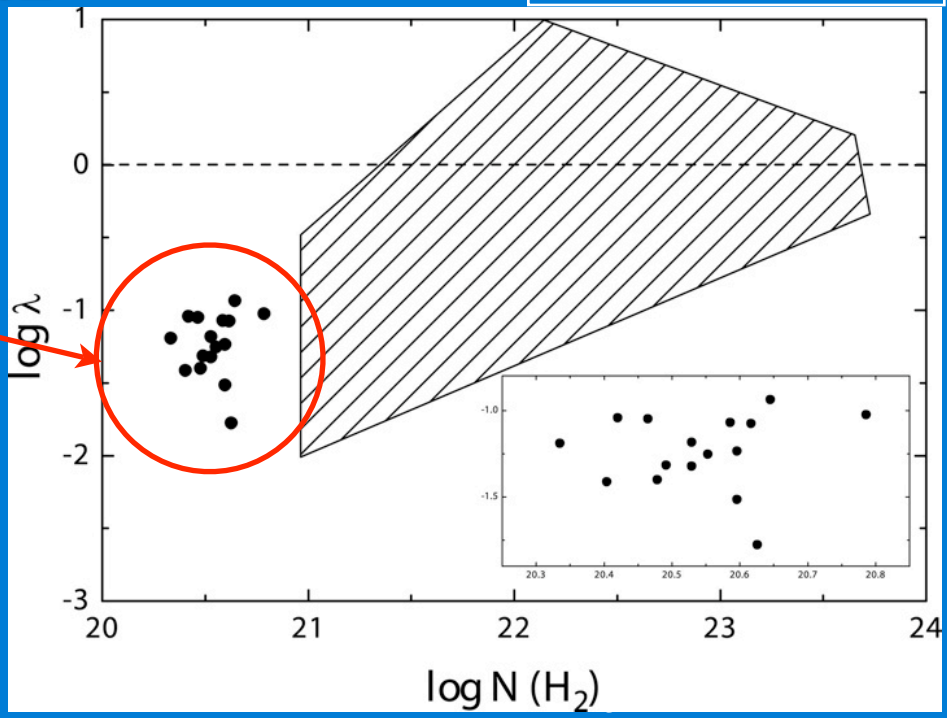
- **B** in expanding shells and fronts?

- **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



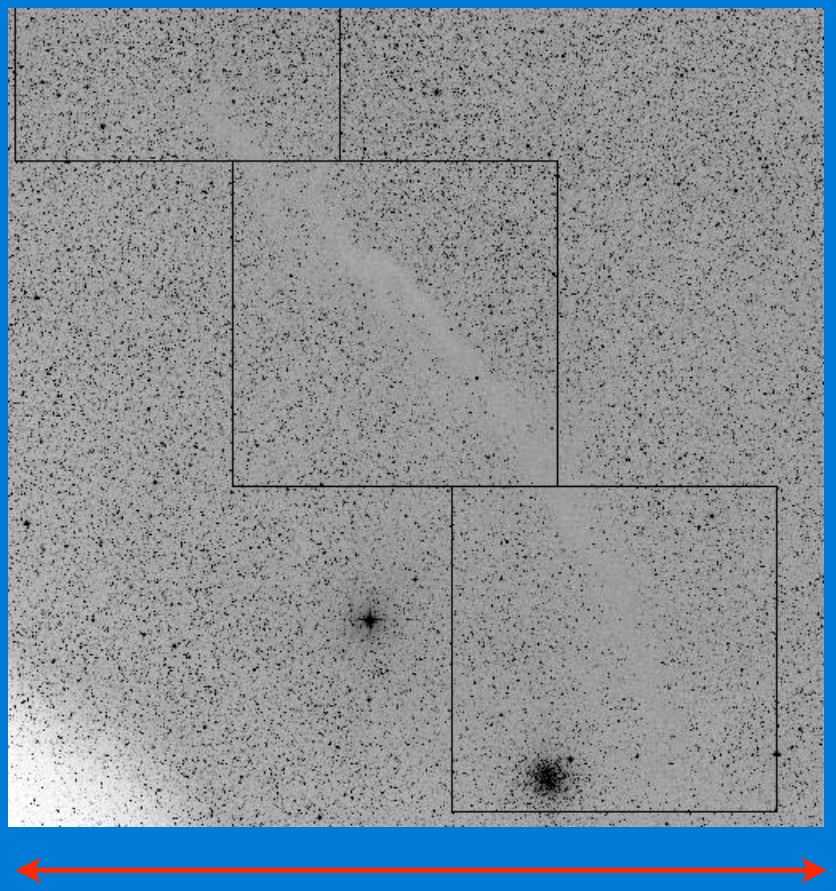
ISM Regions of Interest

ISM Regions of Interest

Magnetic Field in Dark Clouds

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

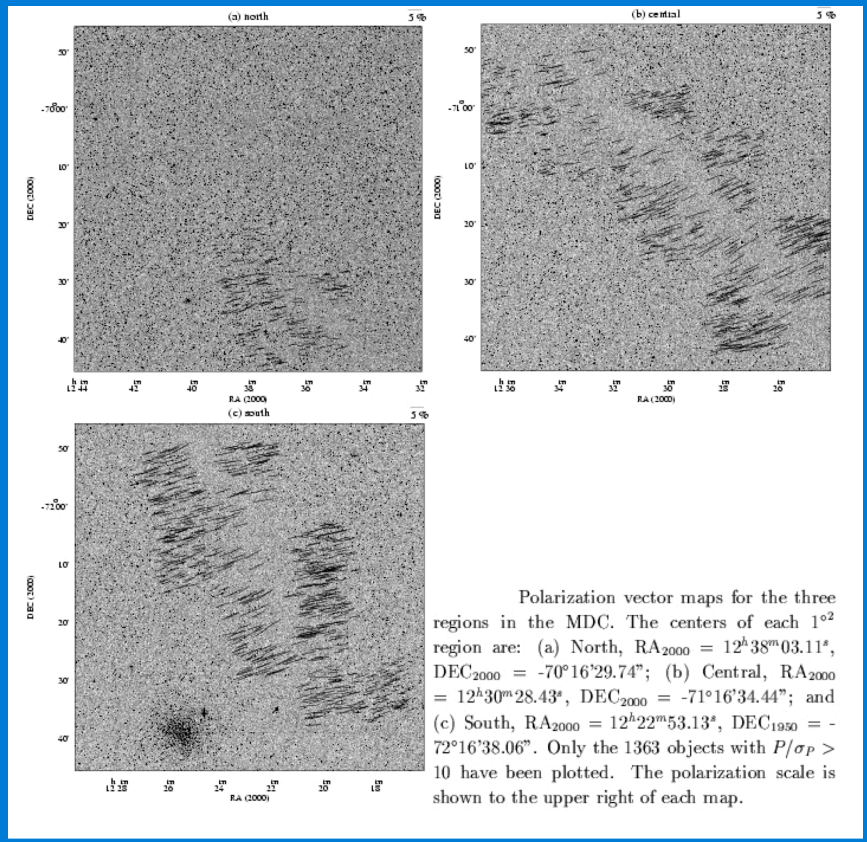
- **Mapping the Musca Dark Cloud**
  - earlier: Arnal et al. (93)
    - stellar polarimetry (~10 objects)



ISM Regions of Interest

- **Magnetic Field in Dark Clouds**
  - What is the role of B in cloud collapse?
- **Mapping the Musca Dark Cloud**
  - Collapse **along** B
    - |B| ~ 0.03 mG - 0.15 mG
    - M_{cloud} ~ 140 $M_\odot$

      Pereyra & Magalhães 04
  - Statistical study needed
    - (Heiles & Crutcher 2005)



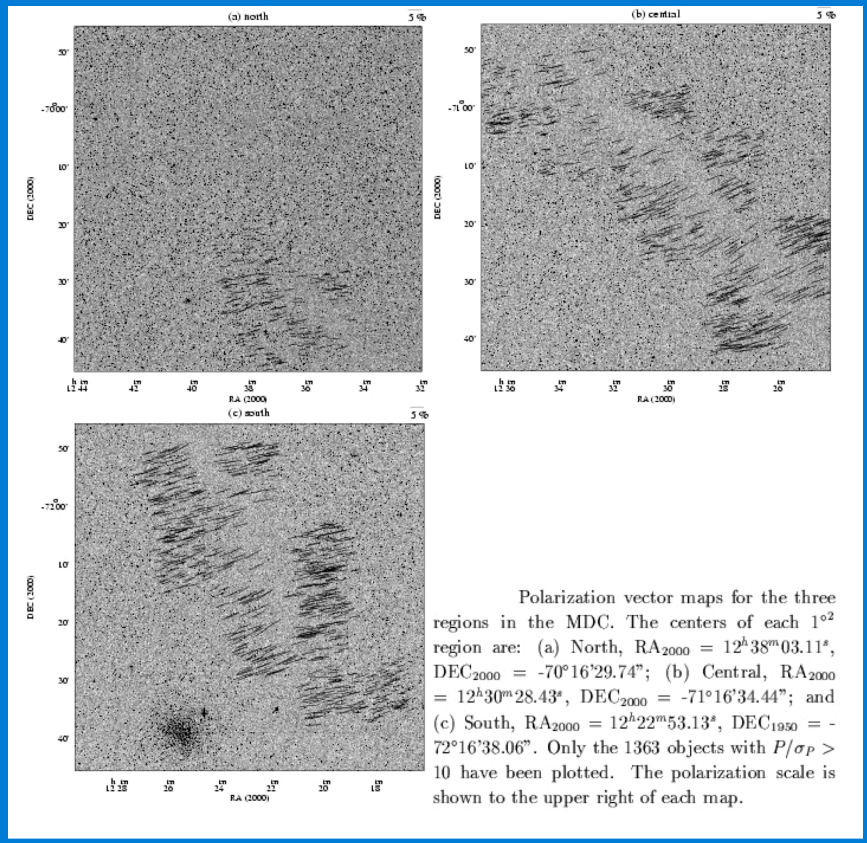
Polarization vector maps for the three regions in the MDC. The centers of each 1^{o2} region are: (a) North, $RA_{2000} = 12^h38^m03.11^s$, $DEC_{2000} = -70°16'29.74"$; (b) Central, $RA_{2000} = 12^h30^m28.43^s$, $DEC_{2000} = -71°16'34.44"$; and (c) South, $RA_{2000} = 12^h22^m53.13^s$, $DEC_{1950} = -72°16'38.06"$. Only the 1363 objects with $P/\sigma_P > 10$ have been plotted. The polarization scale is shown to the upper right of each map.

ISM Regions of Interest

- **Magnetic Field in Dark Clouds**
  - What is the role of B in cloud collapse?
- **Needed work**
  - Study of selected regions in **Vis/NIR**
    - absorption polarization

    +

    sub-mm
    - emission polarization
  - **CMBPol** would be important



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Solar System-ISM interaction

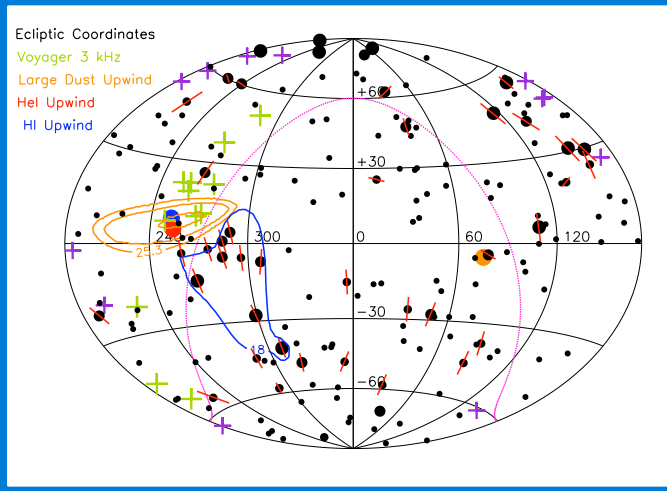
- **ISM B Field at the Sun**
  - Frisch (08)

  – Patch of polarizing dust
    - Tinbergen (82)

  is concentrated towards the heliosphere nose
    - ISM dust interacting with the outer heliosphere
    - Frisch (05, 07)

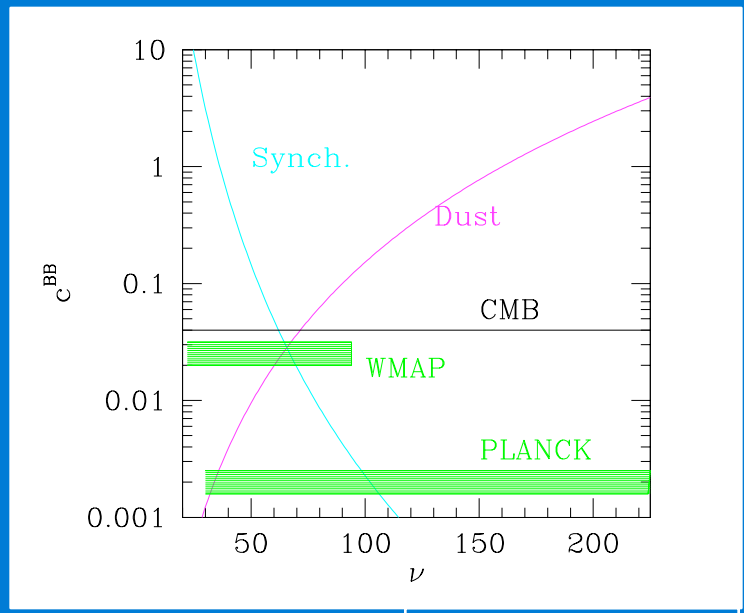
  – Further studies require $\sigma_P \approx 0.01\% - 0.003\%$
    - data to be gathered in 2008-2009

  – **Could be a contaminant to CMB Foreground**



On-going Projects

- **CMB Foreground**
  - **For WMAP & Planck data**
    - on-going program
      - Spergel et al.
    - data on ~2,000 Red Giants in the Halo
    - NOT (Northern) & CTIO (Southern Sky)
  - Goal: Initial Results in 2008/2nd Sem
  - By-product: zero-point of P vs. dust column density

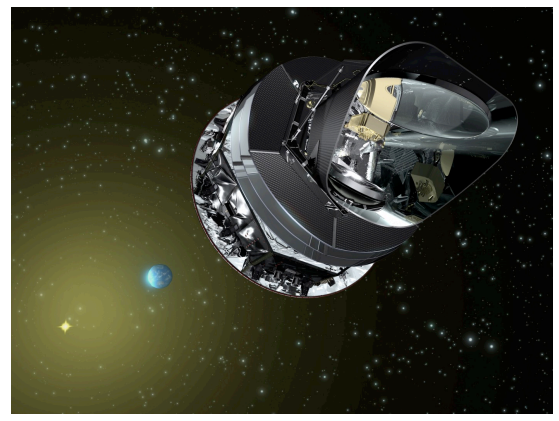


Spergel et al. 2005

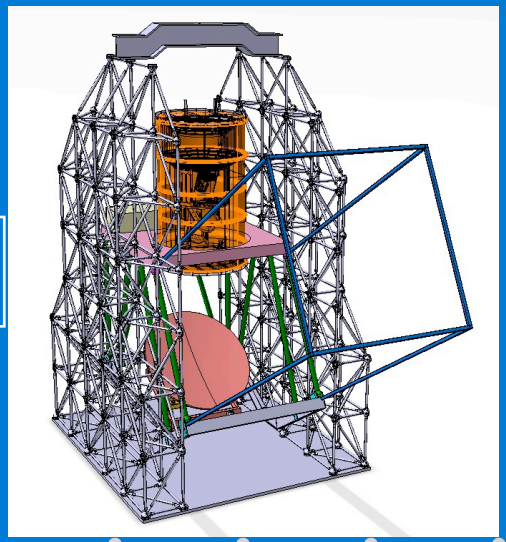
On-going Projects

- **CMBR Foreground**
  - USP/CESR collaboration

  – **For Planck data**
    - IAG **Survey** (optical) + **Toulouse's Pilot** (sub-mm) baloon data (2010)
    - Combination of optical/NIR + sub-mm
      Ø composition & size spectrum of dust



Planck/ESA



Pilot/CESR,
PI: J-P. Bernard

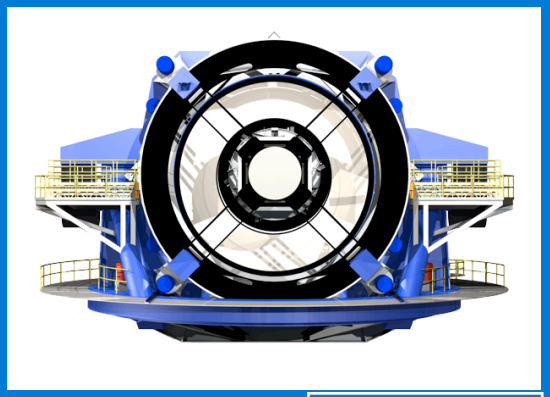
Future

Robotic Telescope

- feasibility study at IAG-USP
  - 2-3 m aperture
  - sited in the **Chilean Andes**
  - intended instrumentation
    - **polarimetric capability**
    - **CCD camera** (& low resolution spectrograph)
    - bench optical **IFU spectrograph**
    - **IR Camera**
    - **tip/tilt** (for ~ diffraction limited imaging @ near IR)
  - to be funded by São Paulo State agency **FAPESP**
  - **interested parties:**
    - Contact:: mario@astro.iag.usp.br

Future

- **LSST - Tool for Foreground Polarization**
  - **Large Synoptic Survey Telescope**, 8.4m, 10 deg^2 field
  - Instrument will provide **all available sky monitoring**
    - every few (~3) days
    - At each pointing
      - 2 × 10 sec integrations
  - Why not imaging through Polarizers?
    - Technology is there for big optical components
    - 3 exposures, through polarizer positions 60 deg apart
      ∅ $\sigma_P \approx 1\%$ for V=19-20 mag w/ 3x15 sec images
  - Complete survey of the sky in weeks (!)
    - polarimeter wouldn't have to be on all the time



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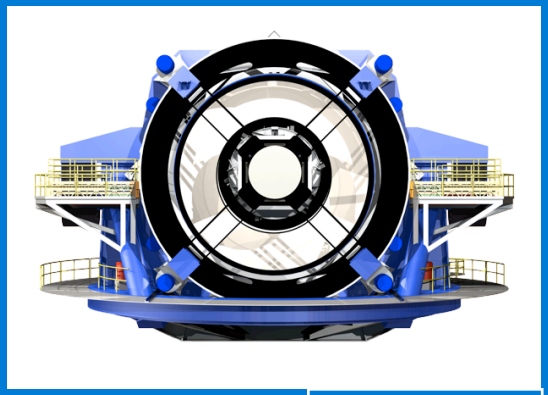
Future

- **LSST Polarimeter - a Tool for**
  - WMAP/Planck/CMBPol
    - Starlight much better sampled on the sky
  - Extragalactic work
    - QSO's, Blazars; B in galaxies...
      - Input to CMB extragalactic foreground signal
  - Galactic/ISM community
    - Remember: there'll be SIM, Gaia:
      - 3D structure of B field
  - Stellar astrophysics
    - envelopes, evolution...



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Conclusions

- **Stellar polarimetry provides information on**
  - The general Galactic B field
    - at large scales (≳ 100 pc)
    - at small scales (≲ pc)
    - accurate B position angle

    ∅ CMB Foreground modeling

  - **With** Planck/CMBPol:

    ∅ B field structure in denser regions of the ISM
    - important for star formation & ISM dynamics