INTERSTELLAR MAGNETIC FIELDS AND POLARIMETRY OF DUST EMISSION

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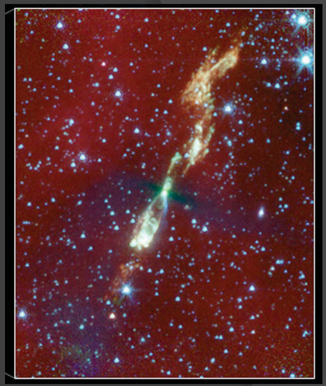
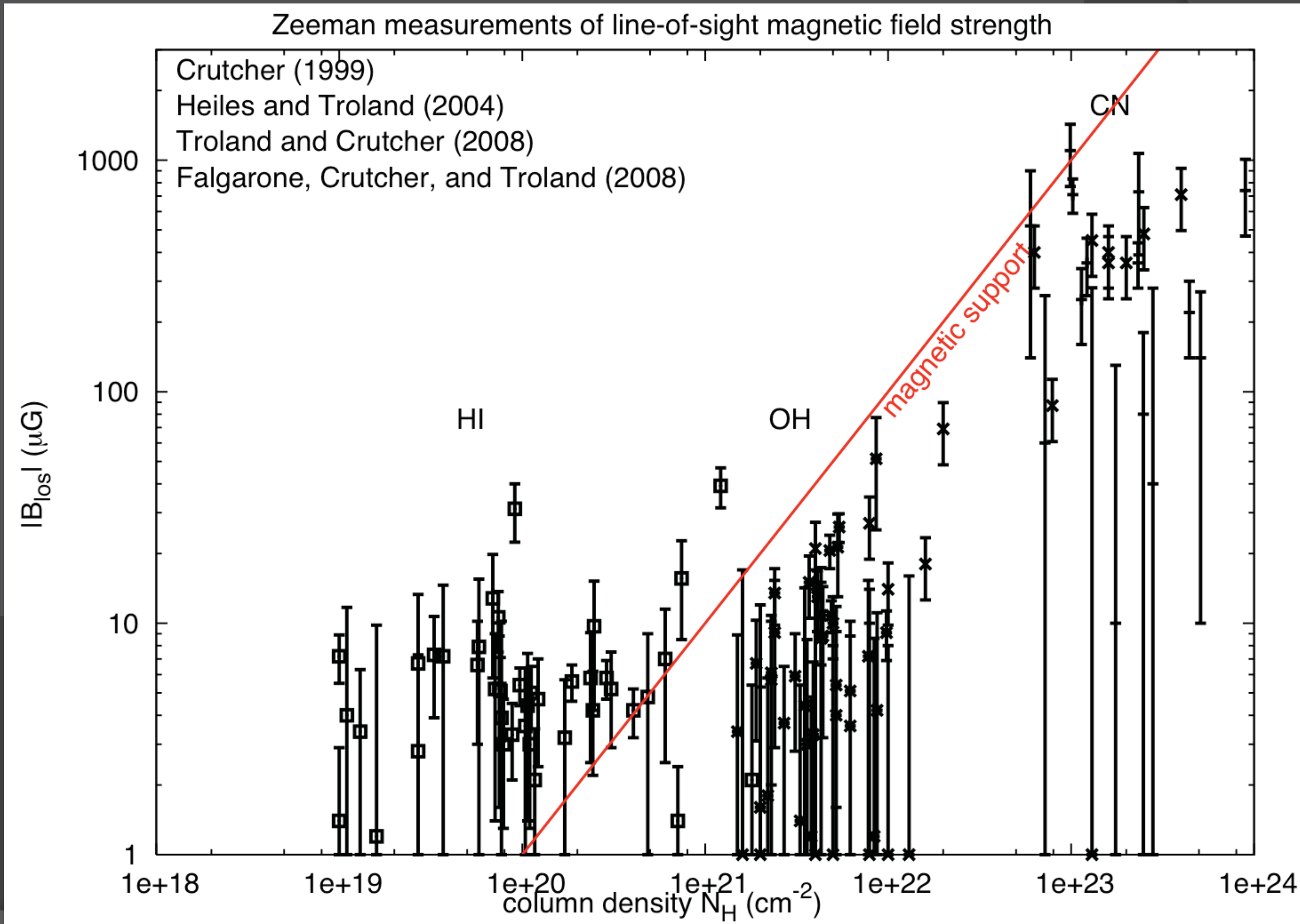
- Government sponsorship acknowledged.

Magnetic fields: an important ingredient in the stormy cosmos



- Magnetic fields:
  - are intimately involved with winds from AGN and stars
  - create at least some of the structures observed in the ISM
  - modulate the formation of clouds, cores, and stars within a turbulent medium
  - may be dynamically important in protostellar accretion disks
  - smooth weak shocks (C-shocks)

Magnetic Field Strengths in Interstellar Clouds



Observational Approaches to Studying Magnetic Fields

- Zeeman line splitting (e.g., Crutcher 1999)
- Faraday rotation (e.g., Han et al. 2006)
- synchrotron polarization (e.g., R. Beck)
- starlight polarization
- polarized dust emission (e.g, Hildebrand 1988)
- structure in gas velocity (e.g., Houde et al. 2000; Li & Houde 2008; Heyer et al. 2008)

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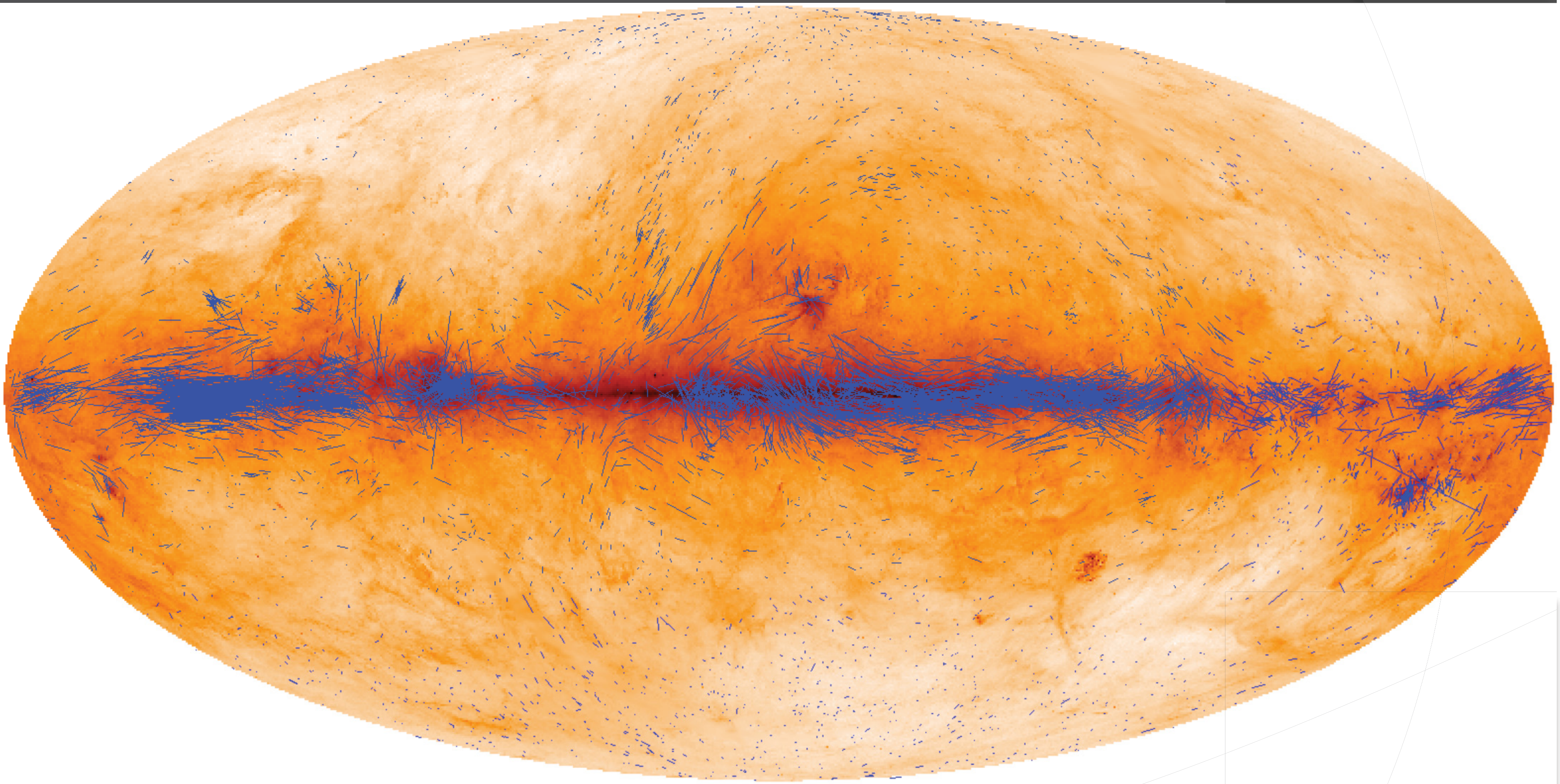
Galactic Field in $A_V \approx 1$ Medium



starlight polarimetry

(Heiles catalog)

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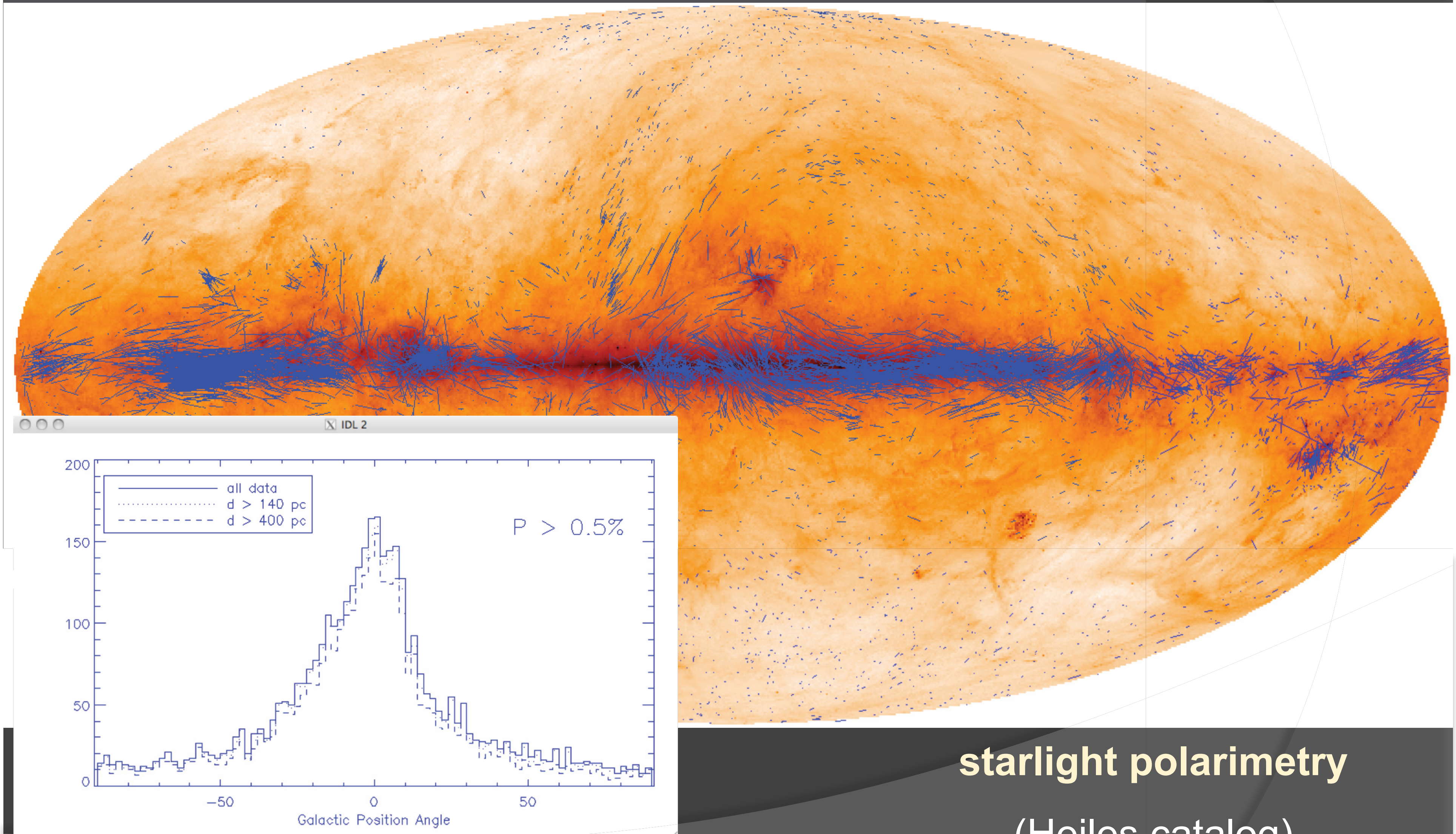
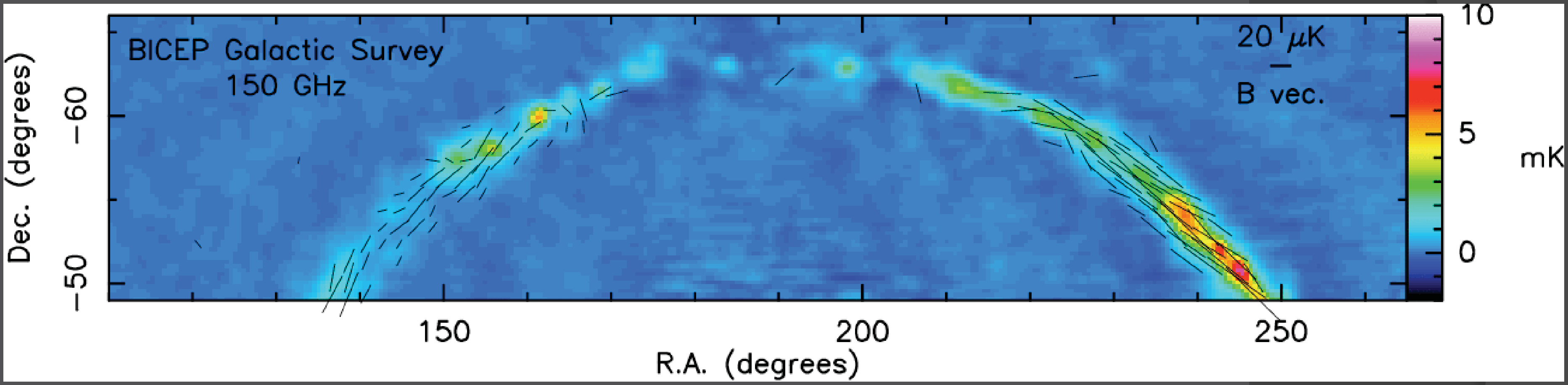


starlight polarimetry

(Heiles catalog)

Galactic Field in $A_V \approx 10$ Medium



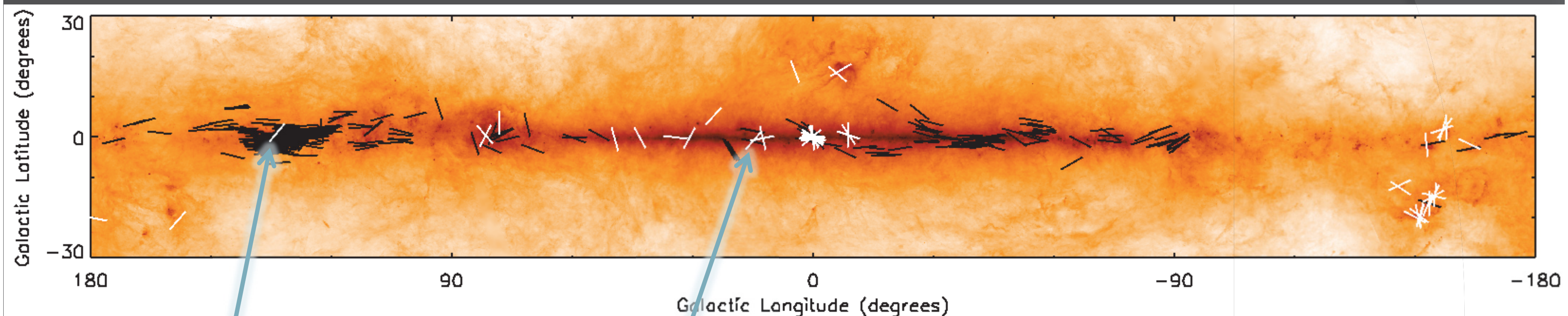
BICEP: southern sky at λ = 2 mm, 1º resolution

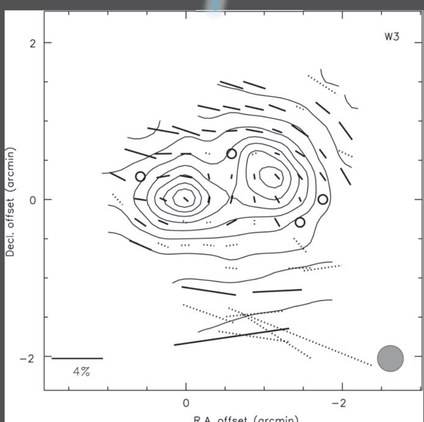
(Bierman et al., in prep., 2010)

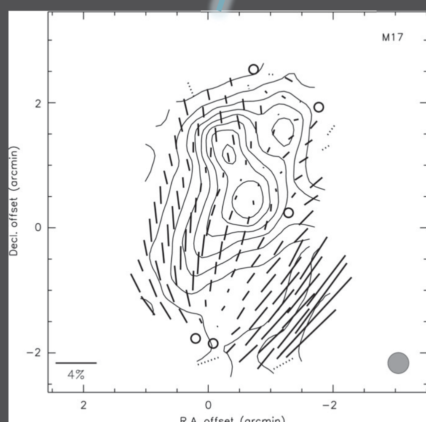
(See also: Benoit et al. 2004 – Archeops
WMAP dust component
Culverhouse et al. 2010 – QUaD)

Galactic Field in $A_V \approx 100$ Medium

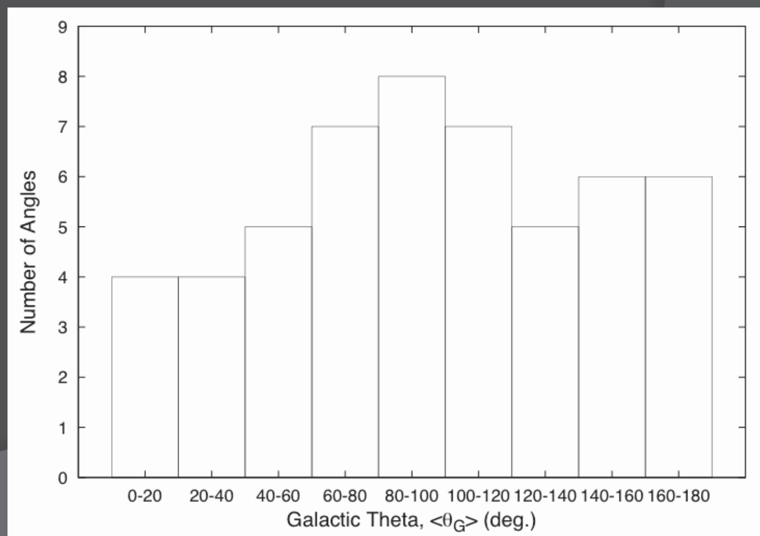
FIR-bright cloud cores (white vectors): no B angle correlation with Gal. plane



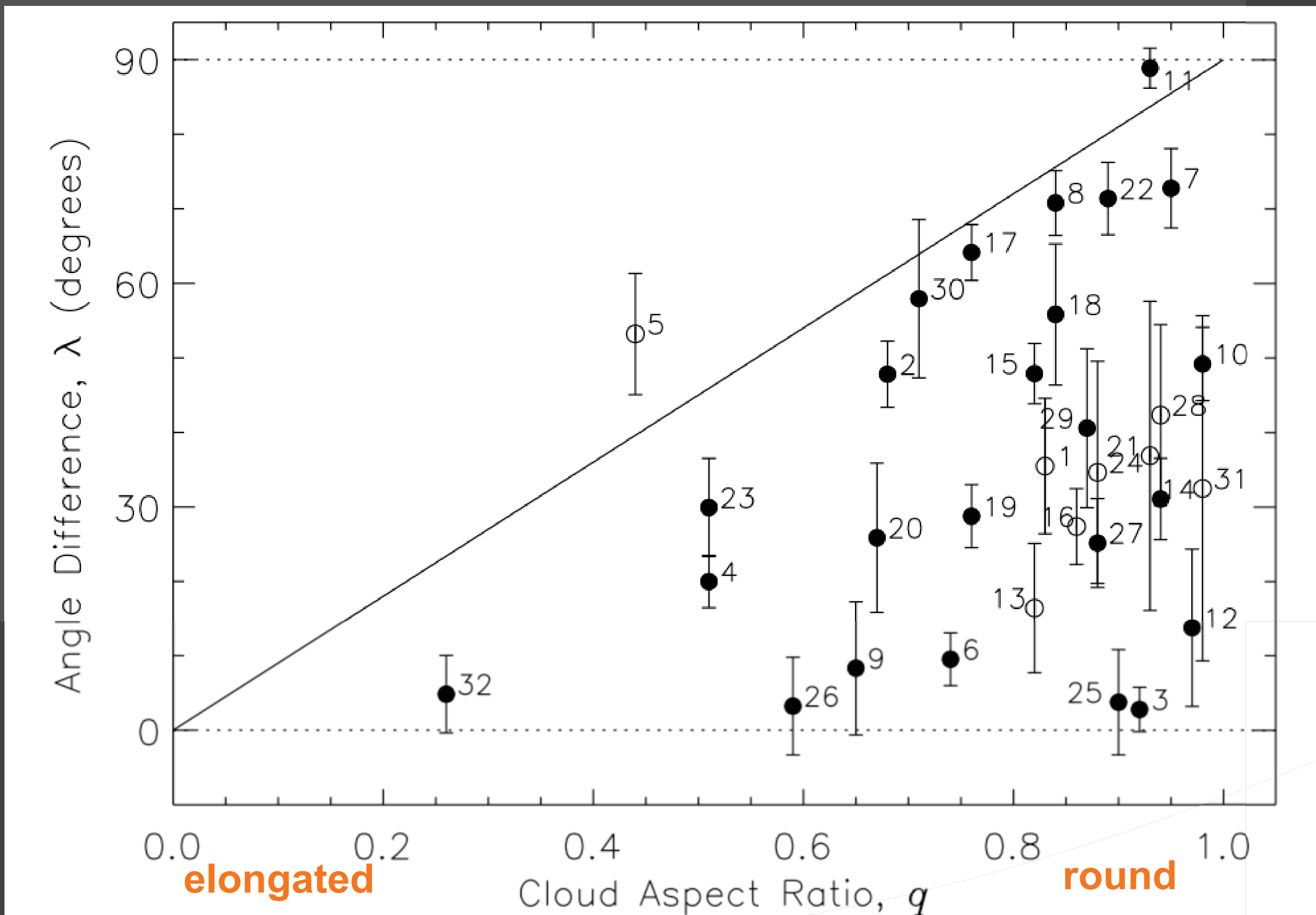


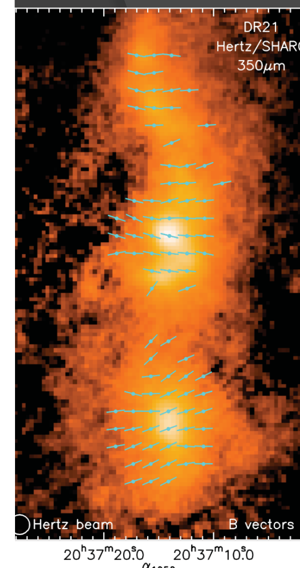


I. Stephens et al. (2010)

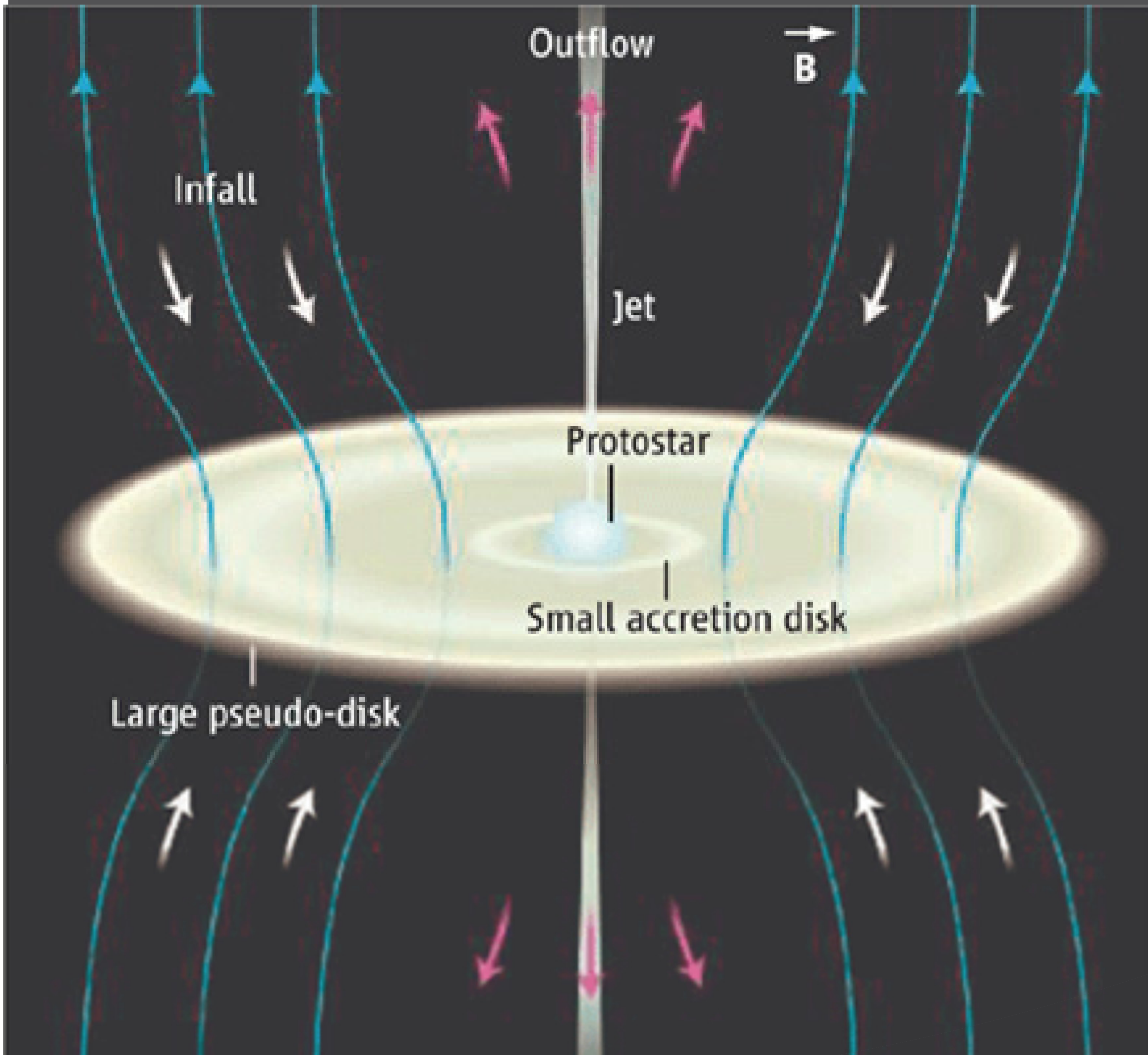


Magnetic field is preferentially along short axis of dense GMC cloud cores.





K. Tassis, et al. (2009)



cartoon from Crutcher ‘06

shows the idea behind “laminar” models of …

-Galli & Shu ’93

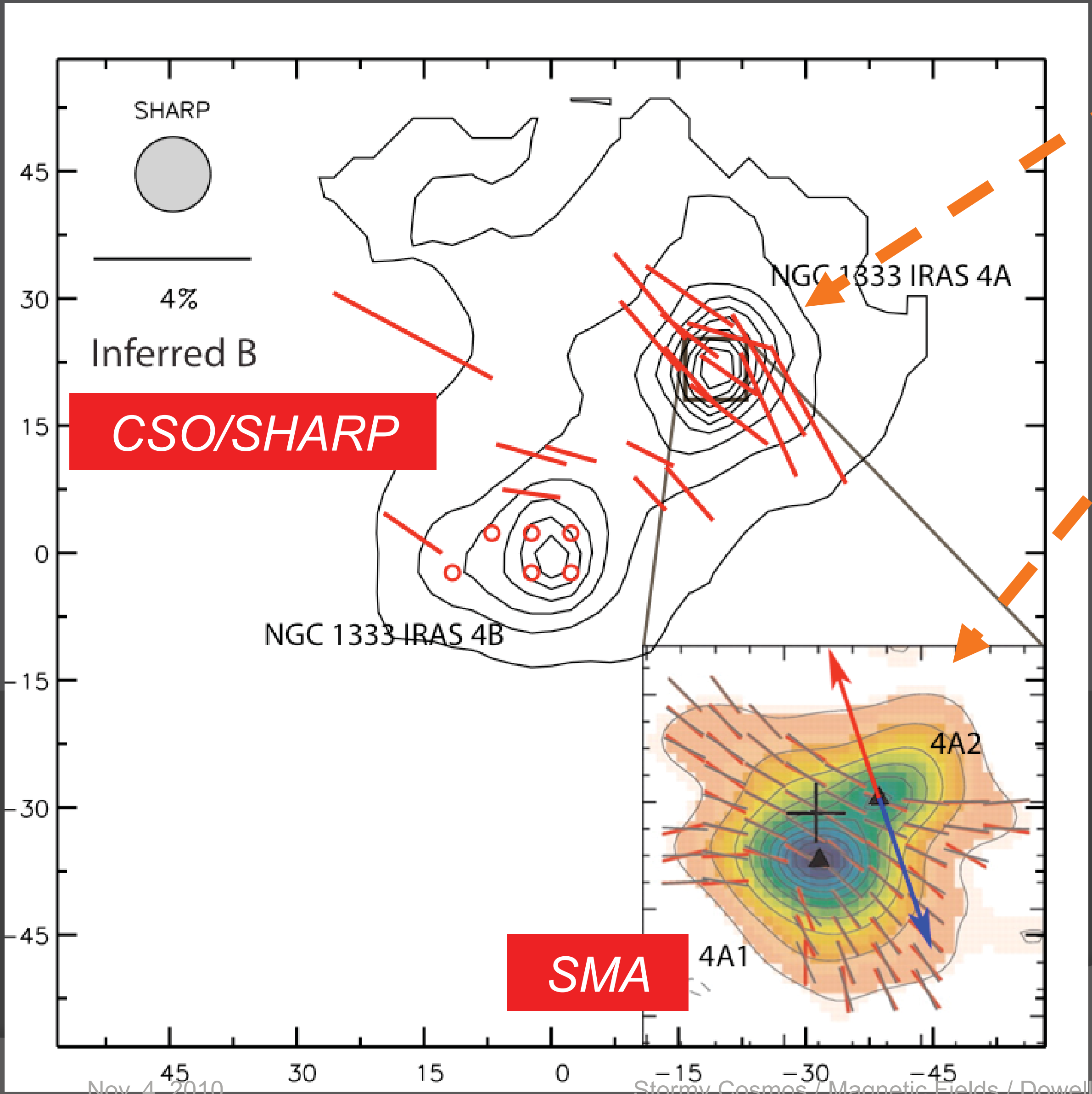
-Fiedler & Mouschovias ’93

-Allen et al ’03

-Shu et al ’04

… etc.

observation of a *complete magnetic hourglass* in a low-mass star forming region (NGC 1333 IRAS 4A)



outer, straighter part of the hourglass seen by CSO/SHARP *(Attard et al. '09)*

"waist" of the hourglass seen by SMA *(Girart et al. '06)*

"…at [the Class 0 phase] magnetic fields dominate over turbulence as the key parameter to control the star formation process."

Observational prospects

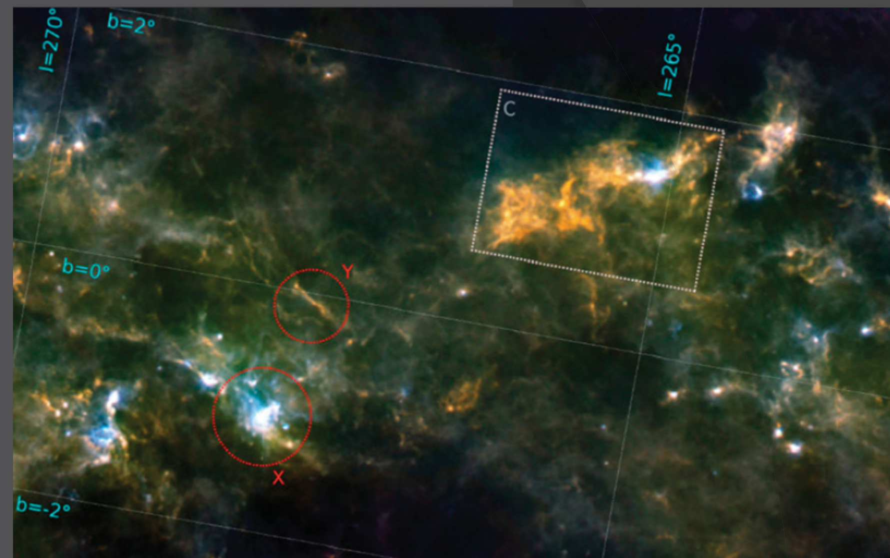
- Current measurements are starved for sensitivity and/or resolution. But better measurements are on the way soon:

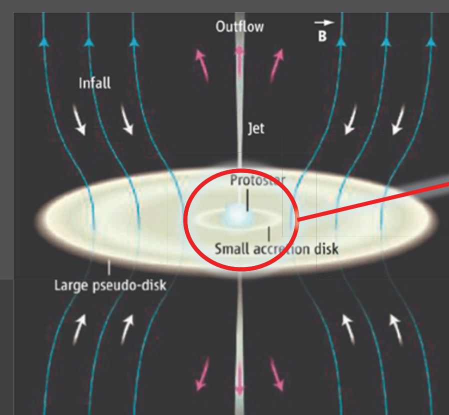
- Sensitive to polarization from columns of $A_V \approx 1$:
  - **Planck** (launched 2009): full sky, 300” resolution
  - **BLAST-Pol** (first flight end of 2010): 30’ fields, 30” resolution
  - **SOFIA**, e.g., HAWC polarimeter (2013): 10’ fields, 5-10” resolution

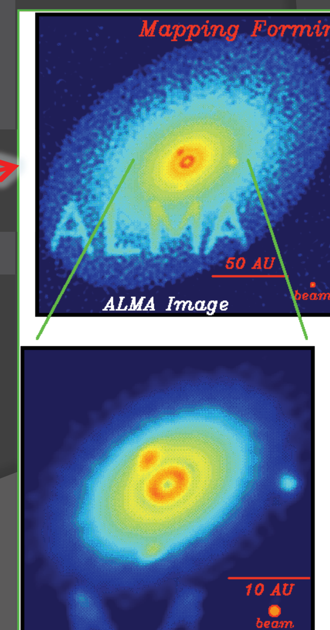
- Sub-arcsecond resolution
  - **SMA** (2004 to date): 1’ fields, 1” resolution
  - **ALMA** (2012): 30” fields, 0.02” resolution

- Large spatial dynamic range:
  - **CCAT** (2017): ~1° fields, 3.5” resolution

- BLAST-Pol (U. Penn./Northwestern U./U. Toronto/Cardiff U./U.B.C./+)
  - Balloon-borne far-IR telescope reconfigured for polarimetry
  - Field of view and resolution well matched to GMC's
- ALMA will map density, velocity, and magnetic fields in accretion disks.

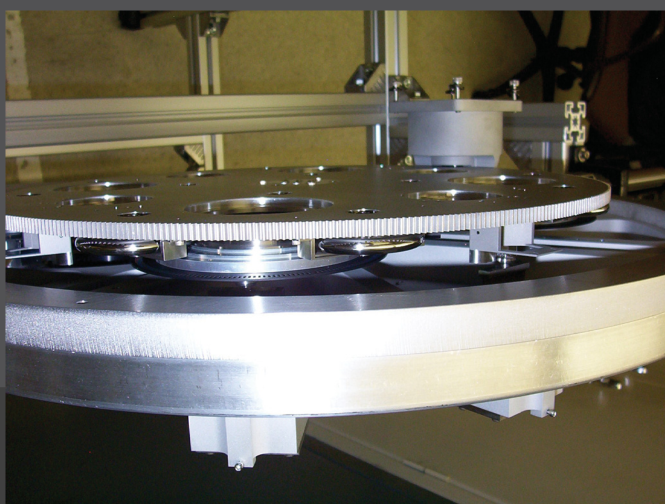


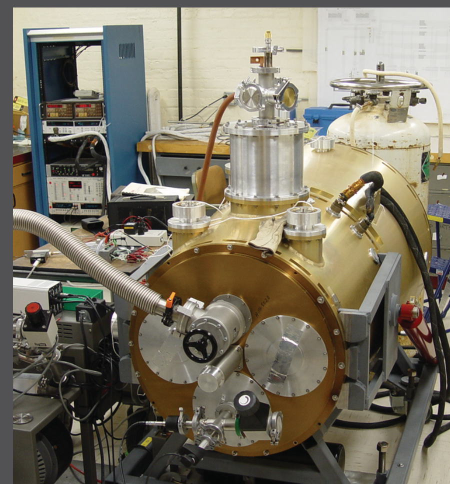




L. Mundy/A. Wootten

HAWCPol/SOFIA

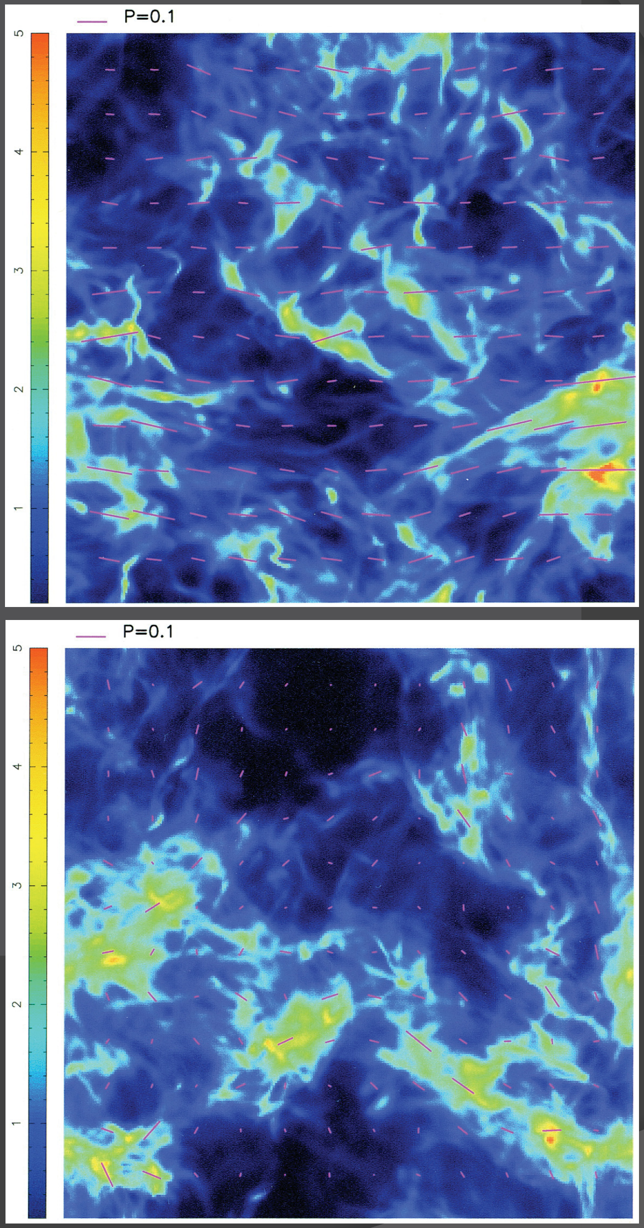




observation bands	53, 89, 155, 216 μm
angular resolution	5 – 22 arcsec
field of view	0.5×1.2 – 1.6×4.3 arcmin^2
polarization modulation technique	quartz half-wave plate, 15 rpm
minimum flux density to achieve σ(P) = 0.2% in 5 hour integration	9, 6, 6, 5 Jy
minimum column density to achieve σ(P) = 0.2% in 5 hour integration	A_V = 1, 2, 5, 4
systematic error goal	δP < 0.2%; δθ < 2°

- JPL polarimeter for Chicago camera
- should offer 100x improvement in mapping speed compared to KAO, with room for another factor of 10 growth in detector

Magnetic Field Energy Density via Chandrasekhar-Fermi Method



strong field:

small dispersion

weak field:

large dispersion

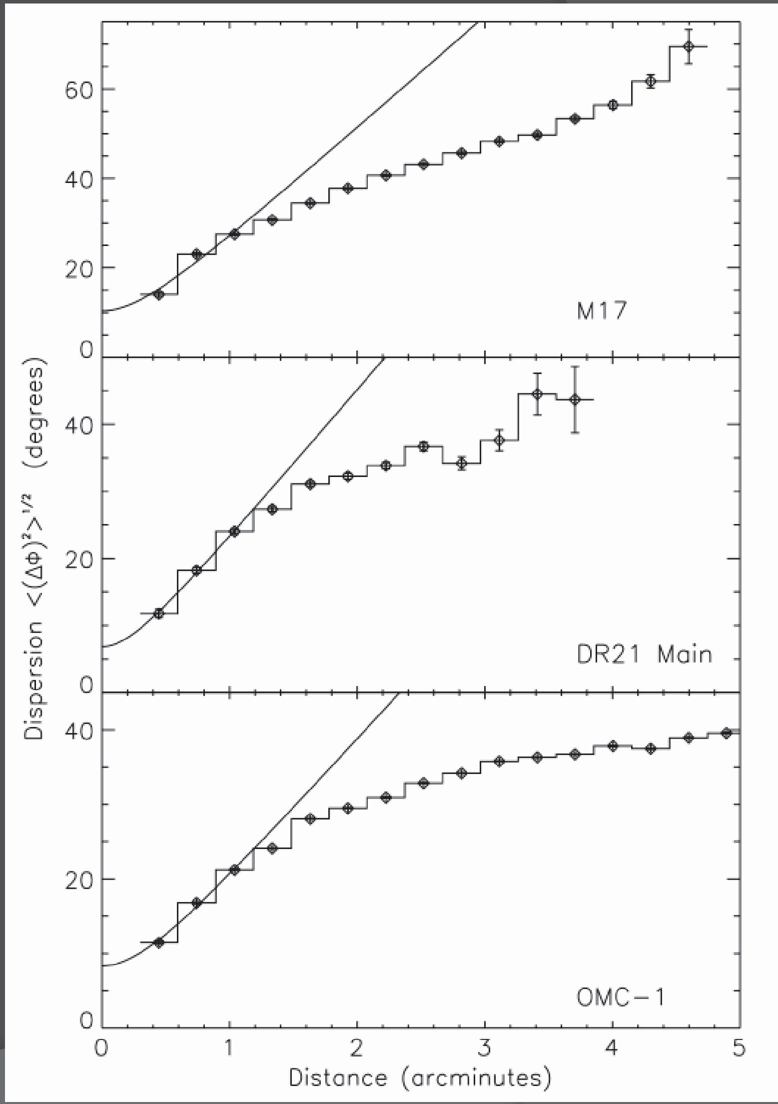
Ostriker, et al. (2001)

- $B = x\,\rho^{1/2}\,\Delta v / \Delta\theta$
- x: Ostriker et al.(2001); Padoan et al. (2001); Heitsch et al. (2001); Falceta-Gonçalves et al. (2008); Houde et al. (2009)

Polarization Structure Function

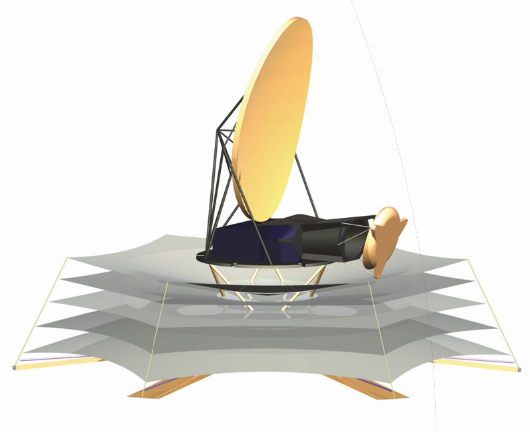
$$\langle \Delta\Phi^2(\ell) \rangle^{1/2} \equiv \left\{ \frac{1}{N(\ell)} \sum_{i=1}^{N(\ell)} \left[\Phi(\mathbf{x}) - \Phi(\mathbf{x}+\boldsymbol{\ell}) \right]^2 \right\}^{1/2}$$

- Method described by Hildebrand+ (2009), Houde+ (2009), Houde+ (2010)
- Given map of polarization angles with sufficient resolution and coverage, can get:
  - magnetic field strength, following Chadrasekhar & Fermi
  - correlation length of turbulence
  - spectral index of power spectrum of turbulence

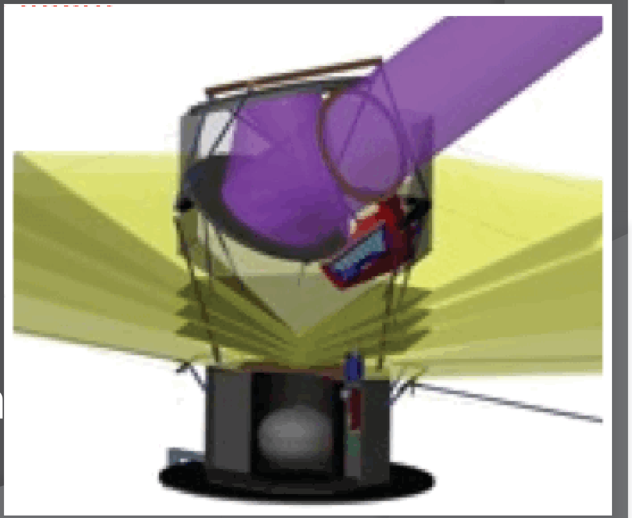


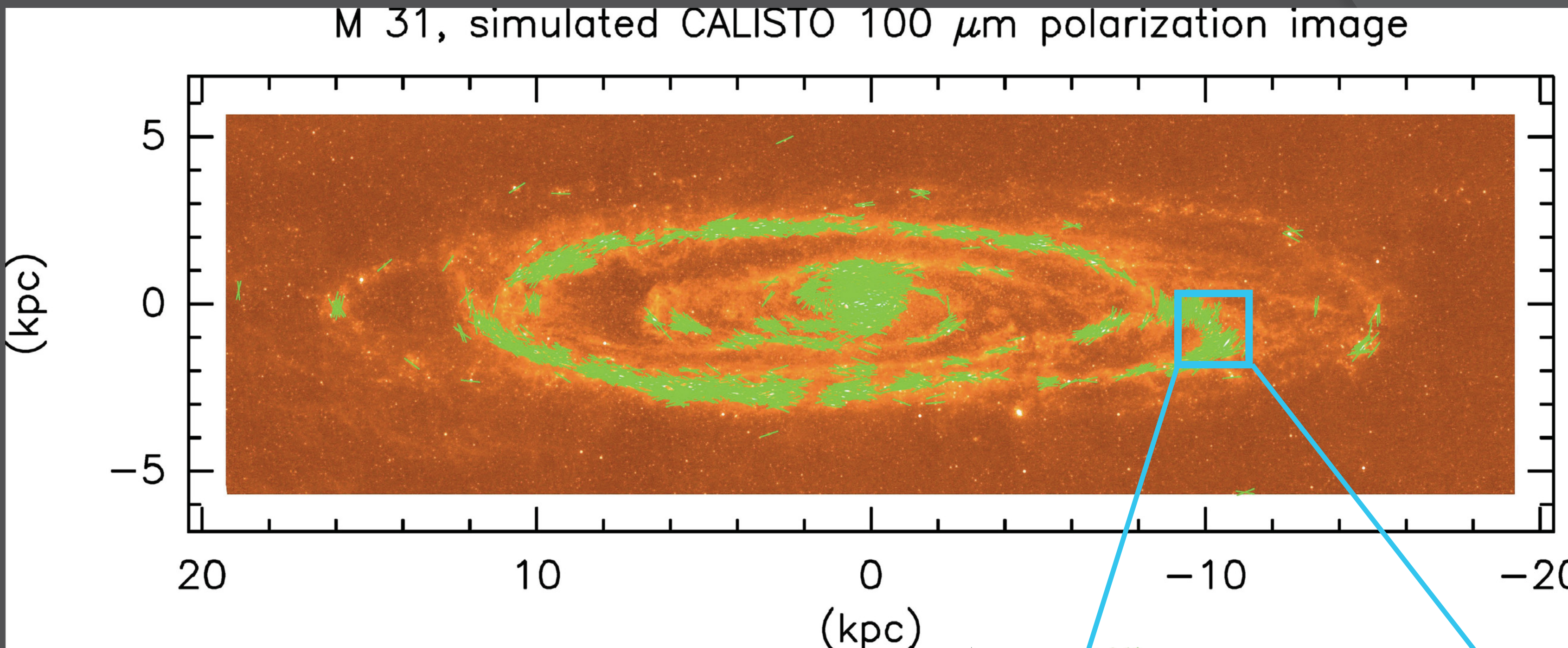
Far-IR Polarimetry from Space

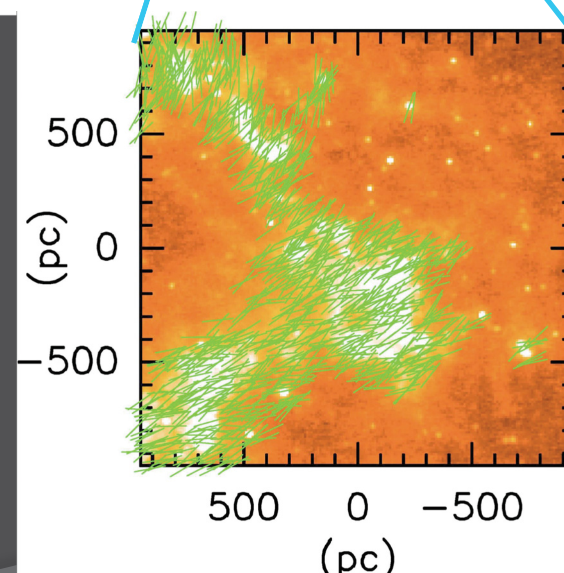
- SAFIR
  - far-IR observatory after Herschel and SPICA
  - **CALISTO**: JPL concept for SAFIR
    - 6 m × 4 m telescope
  - Instrument suite could include polarimetry.



- CMBPol
  - CMB mission after Planck; all-sky survey
  - **EPIC**: JPL concept for CMBPol
  - We studied the option of a high frequency polarization channel: λ = 350 μm, 1' resolution







with SAFIR/CALISTO:

5 hours integration time (10^4 detectors)

5” = 20 pc resolution at λ = 100 μm

likely detection of polarization wherever $A_V > 0.3$

Conclusion

- In this decade, far-IR/mm polarimetry will push from measuring $A_V > 10$ to $A_V \approx 1$.
- As part of a balanced program in studying the cycling of gas in galaxies and stars, the NRC Galactic Neighborhood and Planetary Systems/Star Formation panels endorse:
  - continued efforts in starlight polarimetry
  - SOFIA polarimetry
  - polarimetry with ground-based submm telescopes including CCAT
  - deeper Zeeman measurements with, e.g., eVLA & ALMA
- Statistical analysis (Chandrasekhar-Fermi, structure functions) will have an increasing role as data depth, volume, and quality dramatically improve.