INTERSTELLAR MAGNETIC FIELDS AND POLARIMETRY OF DUST EMISSION
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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

Zeeman measurements of line-of-sight magnetic field strength

Crutcher (1999)
Heiles and Troland (2004)
Troland and Crutcher (2008)
Falgarone, Crutcher, and Troland (2008)
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)
Galactic Field in $A_V \approx 1$ Medium

starlight polarimetry
(Heiles catalog)
Galactic Field in $A_V \approx 10$ Medium

BICEP: southern sky at $\lambda = 2$ mm, $1^\circ$ resolution

(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.
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
  - 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.
HAWCPOI/SOFIA

- 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

<table>
<thead>
<tr>
<th>Observation bands</th>
<th>53, 89, 155, 216 μm</th>
</tr>
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<tbody>
<tr>
<td>Angular resolution</td>
<td>5 – 22 arcsec</td>
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<tr>
<td>Field of view</td>
<td>(0.5 \times 1.2 – 1.6 \times 4.3) arcmin^2</td>
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<tr>
<td>Polarization modulation technique</td>
<td>quartz half-wave plate, 15 rpm</td>
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<tr>
<td>Minimum flux density to achieve (\sigma(P) = 0.2%) in 5 hour integration</td>
<td>9, 6, 6, 5 Jy</td>
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<tr>
<td>Minimum column density to achieve (\sigma(P) = 0.2%) in 5 hour integration</td>
<td>(A_V = 1, 2, 5, 4)</td>
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<tr>
<td>Systematic error goal</td>
<td>(\delta P &lt; 0.2%; \delta \theta &lt; 2^\circ)</td>
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Magnetic Field Energy Density via Chandrasekhar-Fermi Method

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

Ostriker, et al. (2001)
Polarization Structure Function

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

- 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 Chandrasekhar & 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: $\lambda = 350 \, \mu m$, 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.