Opportunities for Dust Polarization Surveys

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This work was performed at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration (NASA).
Outline

• magnetic fields in interstellar clouds
• observational and theoretical approaches
• dust composition, shape, and alignment
• sensitivity comparison
• survey approaches
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)
Galactic Field in $A_V \approx 1$ Medium

optical polarimetry
Galactic Field in $A_V \approx 10$ Medium

BICEP: southern sky at $\lambda = 2$ mm, $1^\circ$ resolution
Galactic Field in $A_V \approx 100$ Medium

FIR-bright cloud cores: no B angle correlation with Gal. plane

data from Dotson et al. (2000, 2008)
Measuring Magnetic Fields

• In addition to the usual problems with line-of-sight averaging and unresolved structure:

• vector $\mathbf{B} = (B_x, B_y, B_{\text{los}})$
  – $B_{\text{los}}$: Zeeman, Faraday rotation
  – $\tan^{-1}(B_y/B_x)$: synchrotron, dust polarization
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  – $\sqrt{(B_x^2+B_y^2)}$: dust polarization via Chandrasekhar-Fermi approach?
WMAP all-sky synchrotron map
complementarity of synchrotron and dust mapping

Blue: Spitzer 8 μm  red: Bolocam/CSO 1.1 mm  purple: VLA 20 cm

Bally et al. (2009)

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complementarity of synchrotron and dust polarization

Chuss et al. (2003)

60-350 µm
Far-IR polarimetry is an excellent tracer of magnetic fields at densities up to $10^6$ cm$^{-3}$.

Schleuning (1998)

Rao et al. (1998)

Ward-Thompson et al. (2000)
Tests of Cloud and Core Formation Theory with FIR Polarimetry

- Ordered structures
  - flow along field lines
  - tidal shear
  - swept-up shells
  - accretion disks

- Large features resulting from instabilities

- Dispersion in field
  - Chandrasekhar-Fermi approach
Far-IR polarimetry tests geometrical models of magnetic fields: protostars

“hourglass” field in protostellar envelope

observation w/ interferometer:

model:
Fiedler & Mouschovias 1993
Far-IR polarimetry tests geometrical models of magnetic fields: cloud cores

Schleuning (1998); Houde et al. (2004)

Kirby (2008)
Far-IR polarimetry tests geometrical models of magnetic fields: cloud formation

**swing amplifier effect**

Kim & Ostriker (2001)

**magneto-Jeans instability**

Kim & Ostriker (2006)
Magnetic Field Strength from 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)

Strong field: small dispersion
Weak field: large dispersion

Falceta-Gonçalves, et al. (2008)
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$B \approx 80 \mu G$

Falceta-Goncalves et al. (2008)
Grain Alignment & Composition

- current theory of grain alignment (Lazarian et al.):
  - Paramagnetic relaxation no longer needed.
  - Instead, radiative torques on asymmetric grains will do.
  - Alignment with polarization perpendicular to field still applies.
- Observational tests possible.

Vallancourt et al. (2008)
Into the Next Decade

- optical/near-IR: big surveys of starlight polarization
- FIR:
  - BLASTpol: mapping full molecular clouds
  - SOFIA: precision application of Chandrasekhar-Fermi
- submm:
  - Planck: all-sky polarization survey
  - ALMA: great for circumstellar dust?
- radio: EVLA, GBT
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 arcmin²
- 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°

- started Oct. 2008 on JPL internal funds
- permanent upgrade to HAWC
- good for sources up to ~8’
Required Polarization Sensitivity

- typical degree polarization = 3%
- typical intrinsic dispersion = 10° – 30°
  - $\sigma(\theta) = 3^\circ$, $\sigma(P) = 0.3\%$
  - photometric signal-to-noise of 500

Hildebrand et al. (1999)
Far-IR polarimetry is $10^6 \times$ faster from space.
Giant Steps

- MIDEX-class FIR polarization survey
- SAFIR polarimeter
- SPIRIT polarimeter
- EPIC (CMBPol) with extended high-frequency coverage
- SKA
Dedicated Polarization Survey

- **PIREX/M4 (Clemens, P.I.; Goodman; Jones)**
  - possible reasons for non-selection:
    - Polarimetry not a scientific priority for NASA.
    - Difficult for a cryogenic mission to compete on the NASA SMEX playing field.

- **Unsuccessful Origins Probe proposal to study FIR polarimeter and C\(^+\) heterodyne spectrometer on 0.5 – 1 m telescope (Dowell, Langer et al.)**

M4: 0.2 m cold telescope
with SAFIR/CALISTO:

5 hours integration time (10^4 detectors)

5'' = 20 pc resolution at \( \lambda = 100 \) \( \mu \text{m} \)

likely detection of polarization wherever \( A_V > 0.3 \)
EPIC Polarization Mapping

coverage map, $\sigma(P) \leq 0.3\%$

- EPIC/850 GHz can make accurate polarization maps with $10^8$ resolution elements.

- Planck/350GHz 5'
- EPIC/850GHz 4K, 1'
- EPIC/850GHz 40K, 5'

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Enabling Technologies for Space Far-IR Polarimetry

• polarization-sensitive detectors
• polarization modulation
  – low-power cryogenic rotating quartz half-wave plate
  – scan modulation only (Boomerang ⇒ Planck)
• Good polarimeters usually make good cameras.
  – NEP = 10^{-18} \text{ W Hz}^{-1/2} is adequate for detectors.
Antenna-Coupled 200 μm TES Detector

work by Peter Day et al.
(JPL/Caltech)

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“If nuclear and gravitational forces were the only forces at work in the universe, the broad pattern of cosmic evolution would be one of gradual thermal degradation punctuated by occasional explosive events. The cosmos would resemble the serene and monotonous heavens of classical conception. *There is, however, a cosmic agitator: the magnetic field.* Although only a small part of the available energy in the universe is invested in magnetic fields, they are responsible for most of the continual violent activity of the cosmos, from auroral displays in the earth’s atmosphere to stellar flares and X-ray emission, and the massing of clouds of interstellar gas in galaxies.”

E. Parker, Scientific American (1983)