Opportunities for Dust Polarization Surveys

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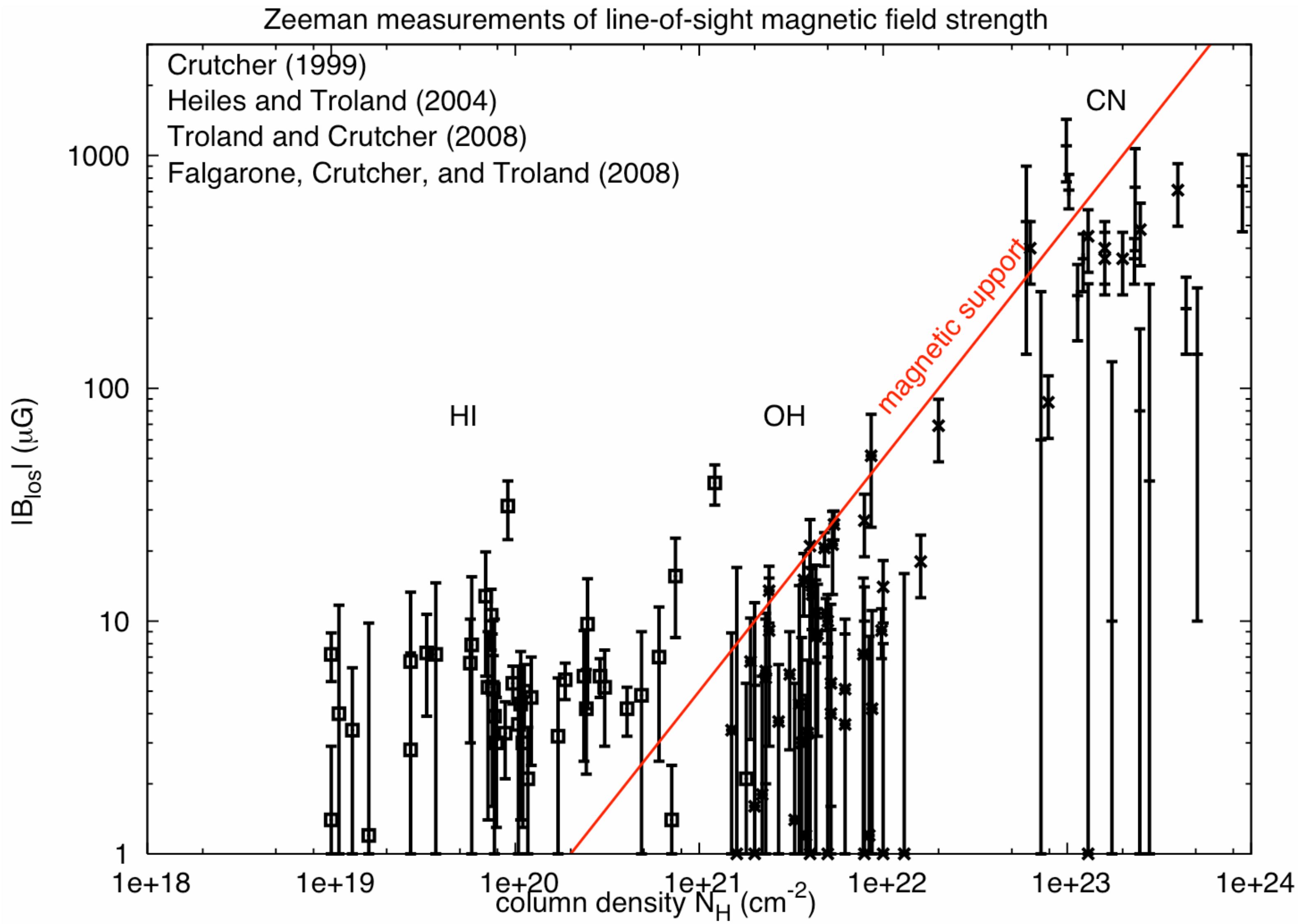
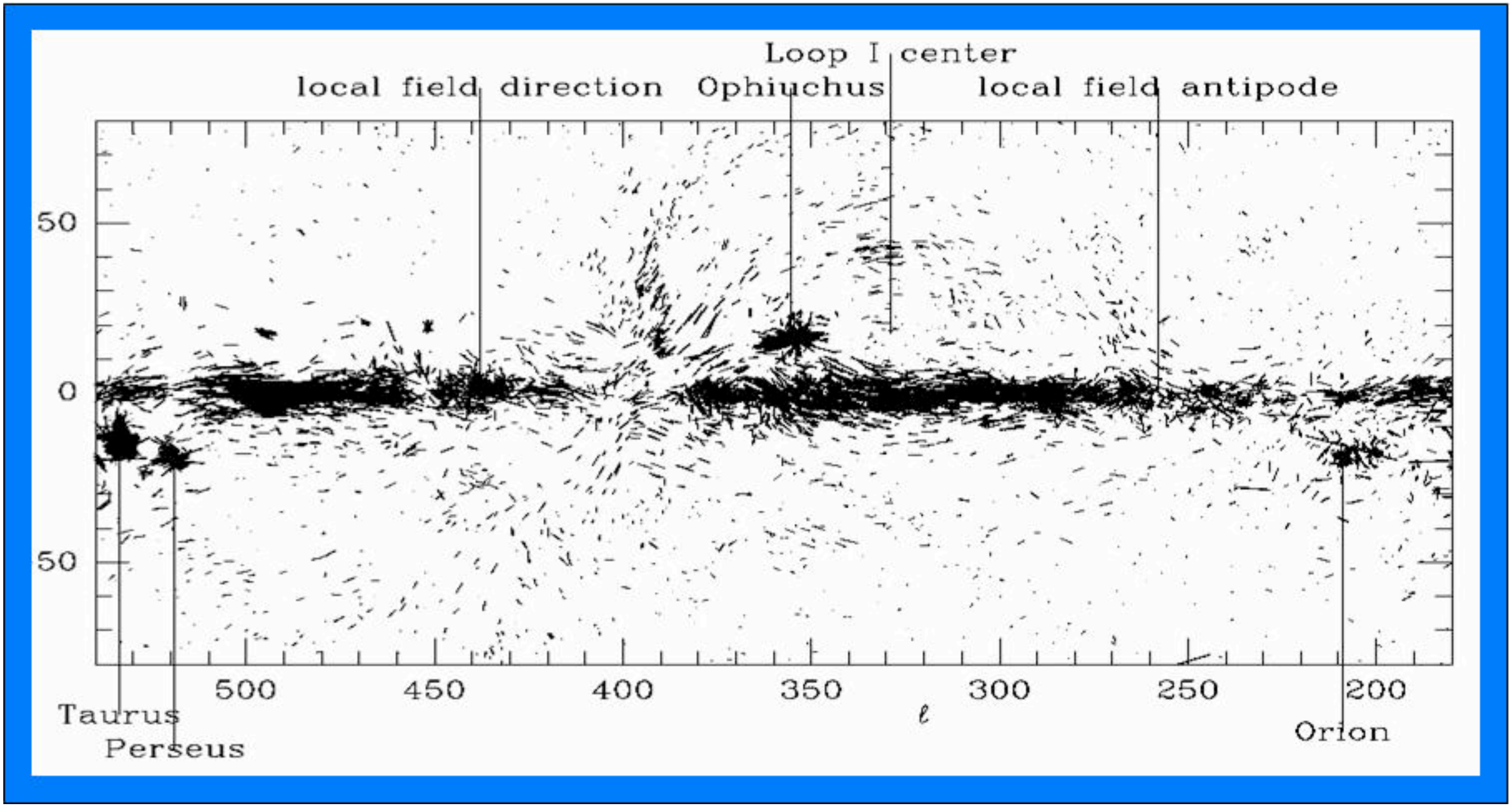
Outline

- magnetic fields in interstellar clouds
- observational and theoretical approaches
- dust composition, shape, and alignment
- sensitivity comparison
- survey approaches

Magnetic Field Strengths in Interstellar Clouds

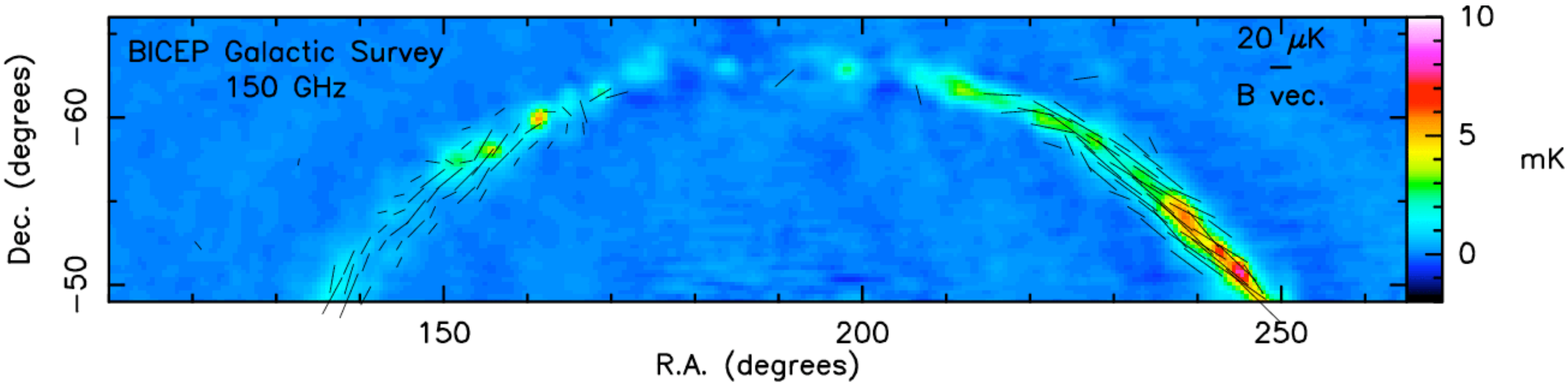


Galactic Field in $A_V \approx 1$ Medium



optical polarimetry

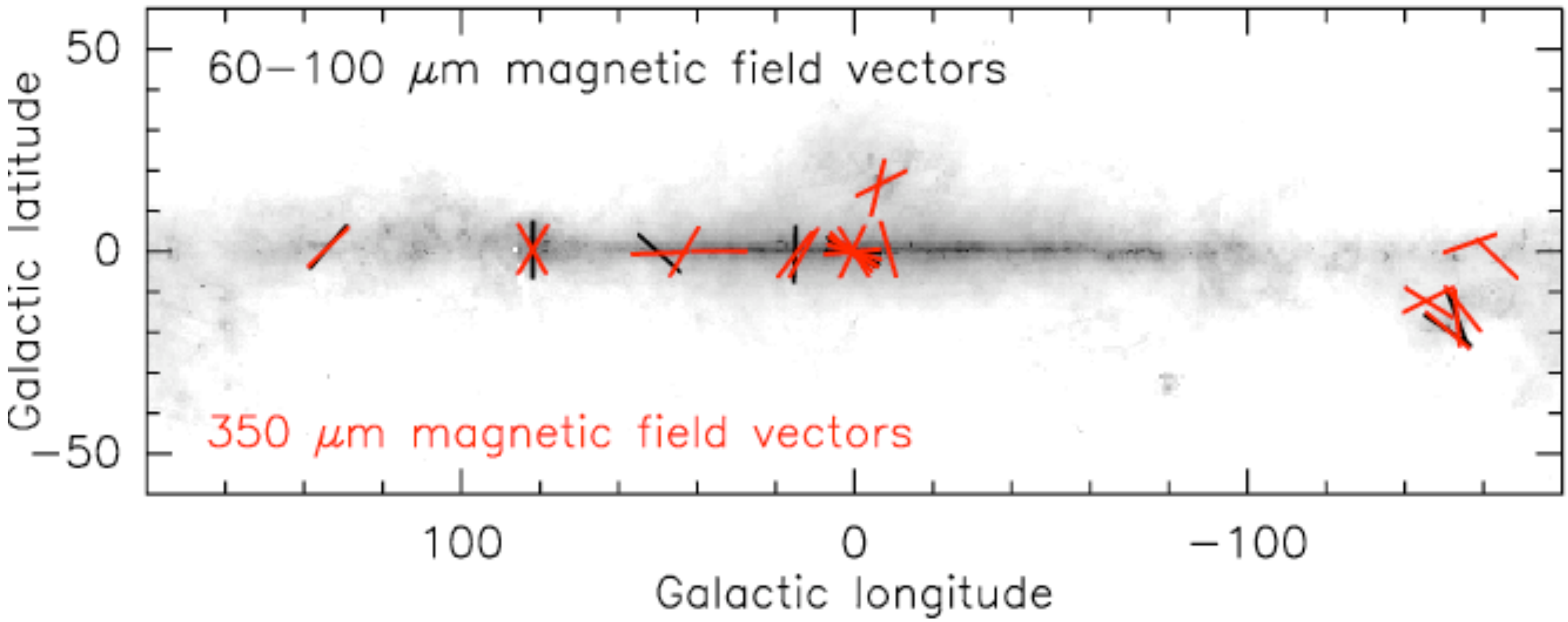
Galactic Field in $A_V \approx 10$ Medium



BICEP: southern sky at λ = 2 mm, 1º 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 **B** = (B_x, B_y, B_{los})
  - B_{los}: Zeeman, Faraday rotation
  - $\tan^{-1}(B_y/B_x)$: synchrotron, dust polarization

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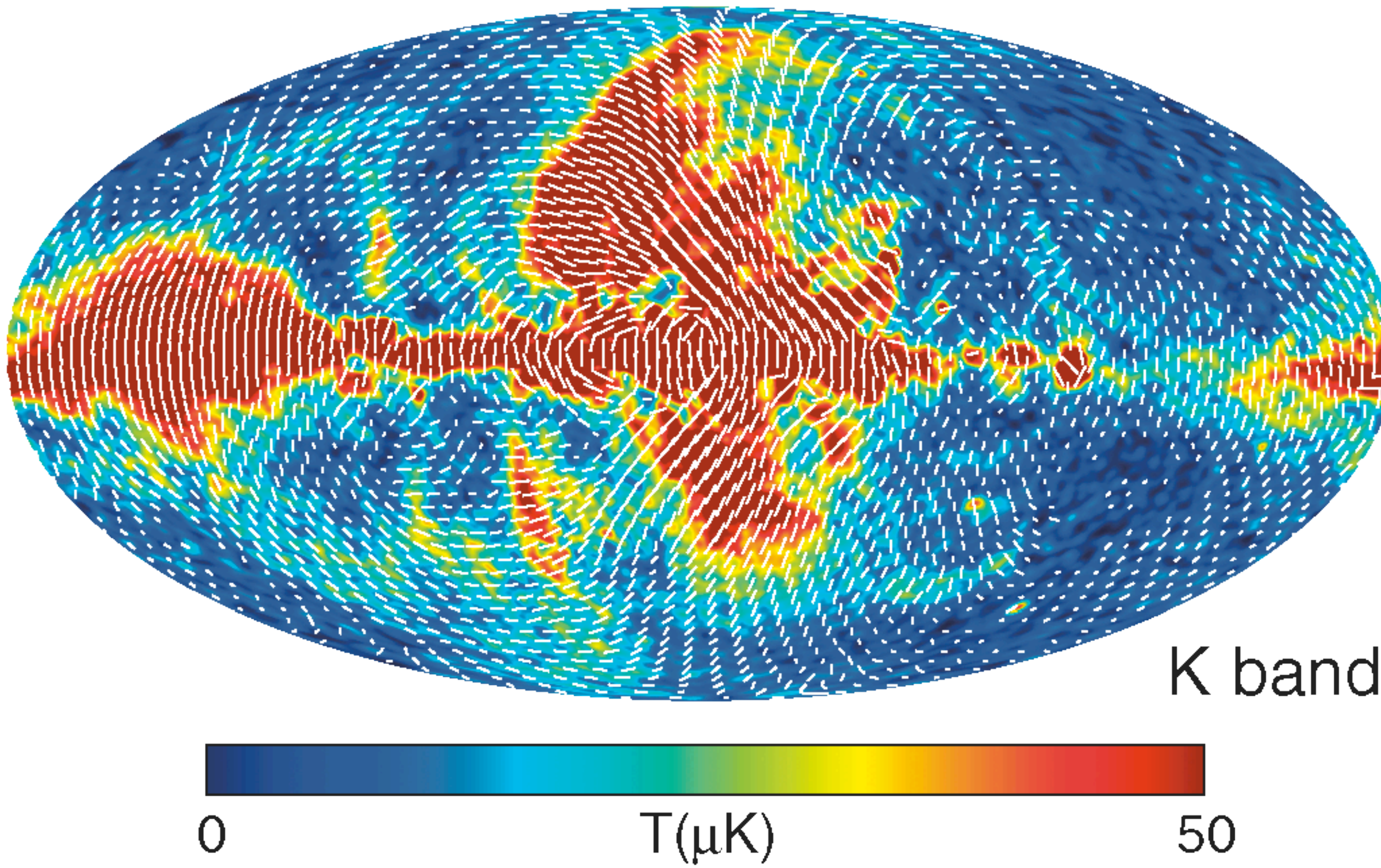
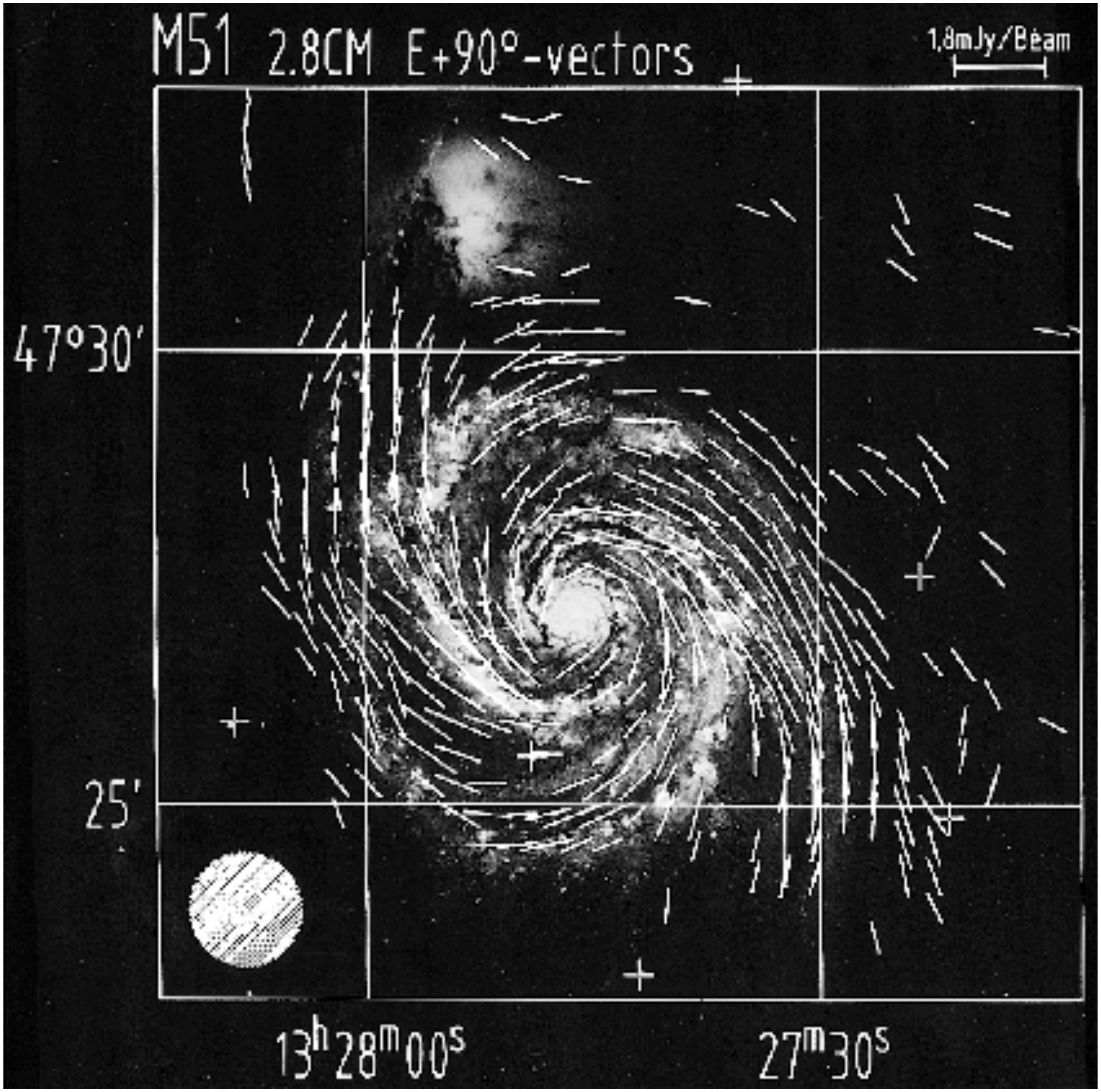
  - $\sqrt{(B_x^2+B_y^2)}$: dust polarization via Chandrasekhar-Fermi approach?

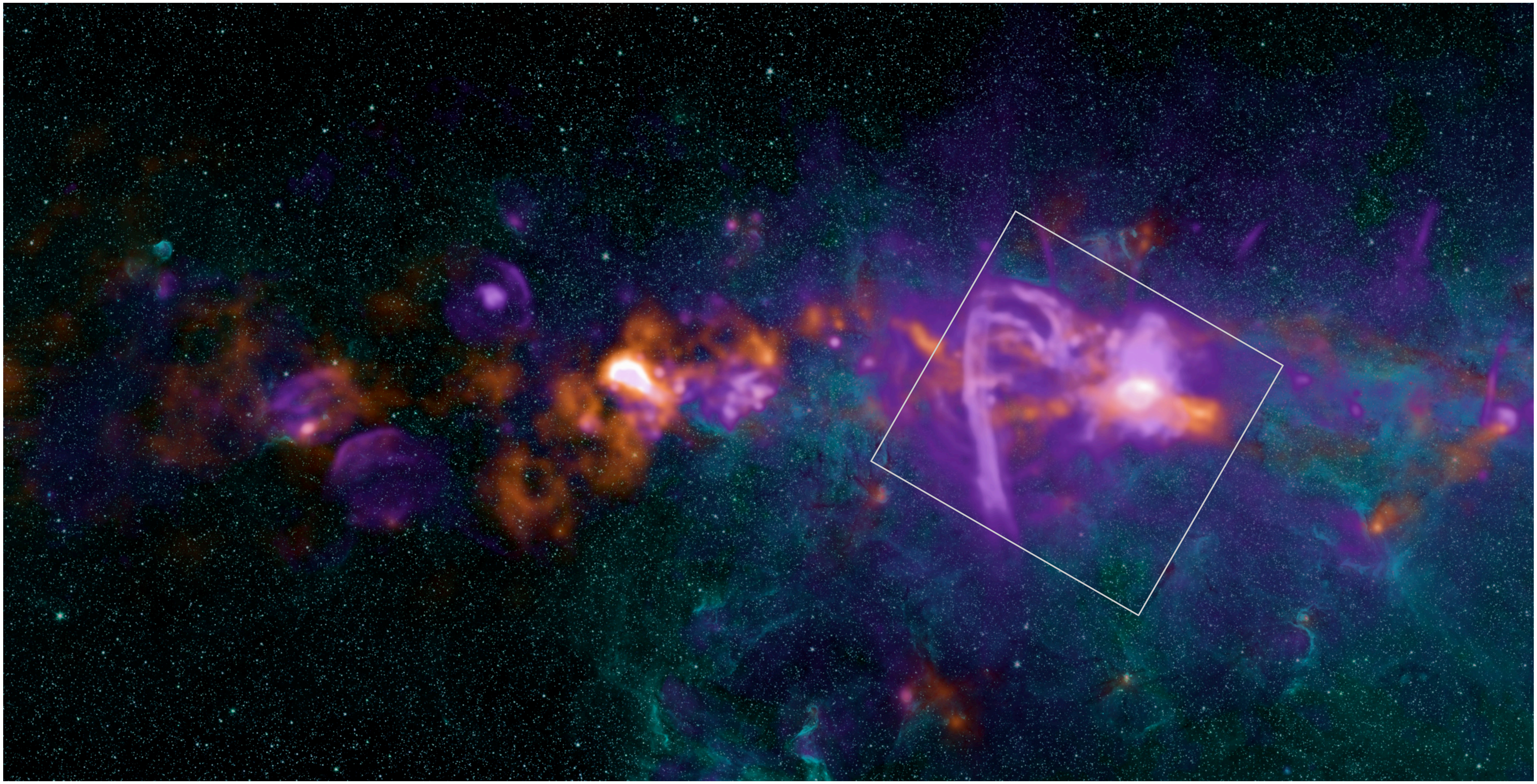
WMAP all-sky synchrotron map





Berkhuijsen (1997)

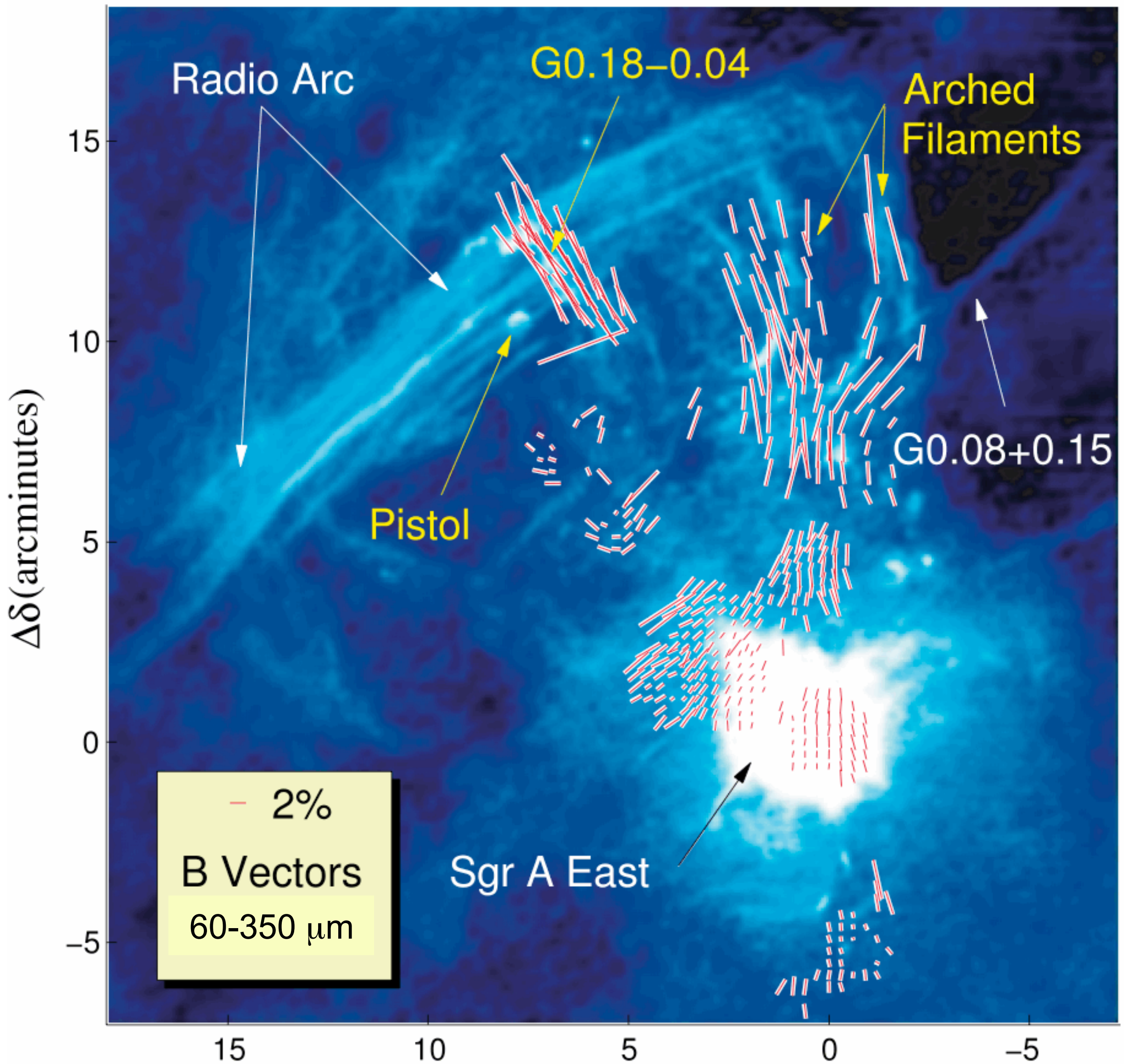
complementarity of synchrotron and dust mapping



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

Bally et al. (2009)

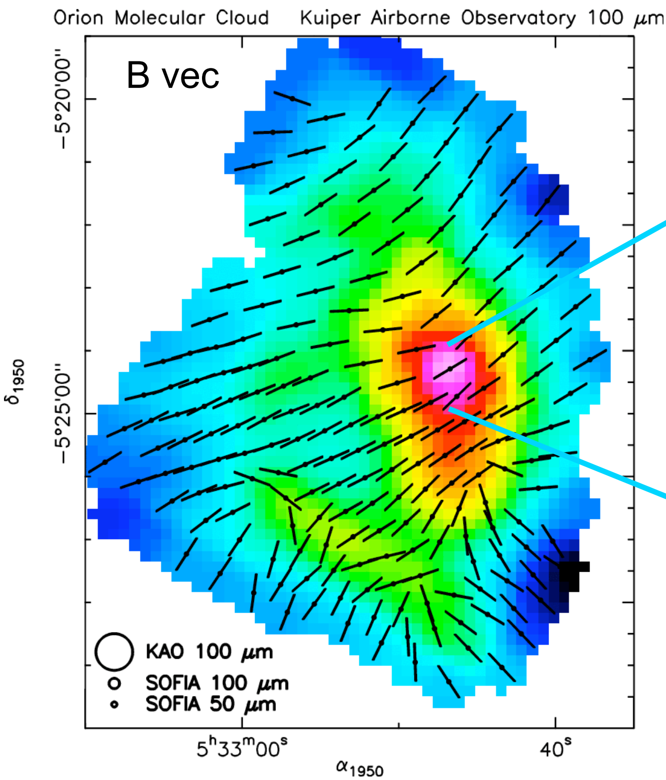
complementarity of synchrotron and dust polarization



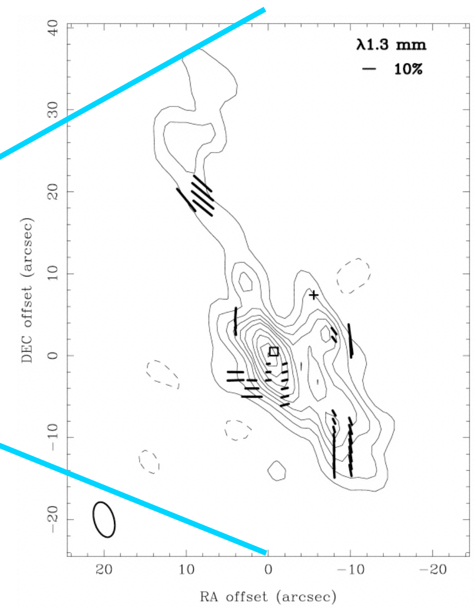
Chuss et al. (2003)

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

Orion Core

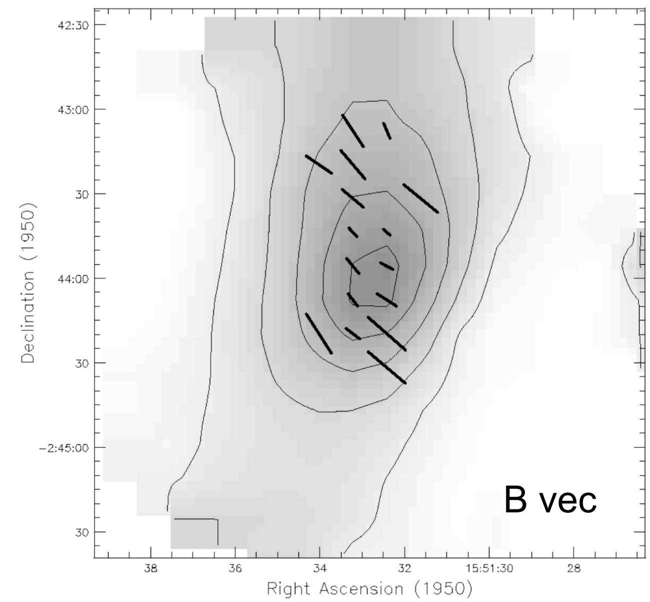


Schleuning (1998)



Rao et al. (1998)

L183 Dark Cloud



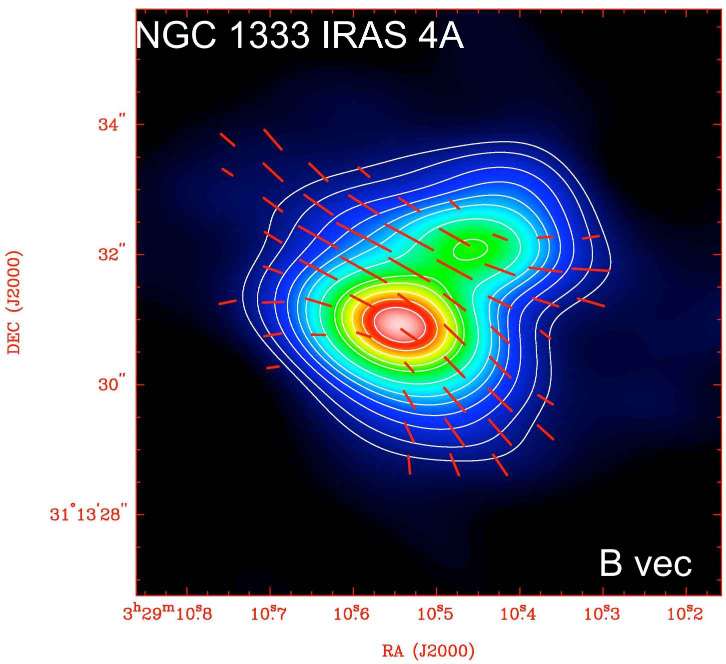
Ward-Thompson et al. (2000)

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

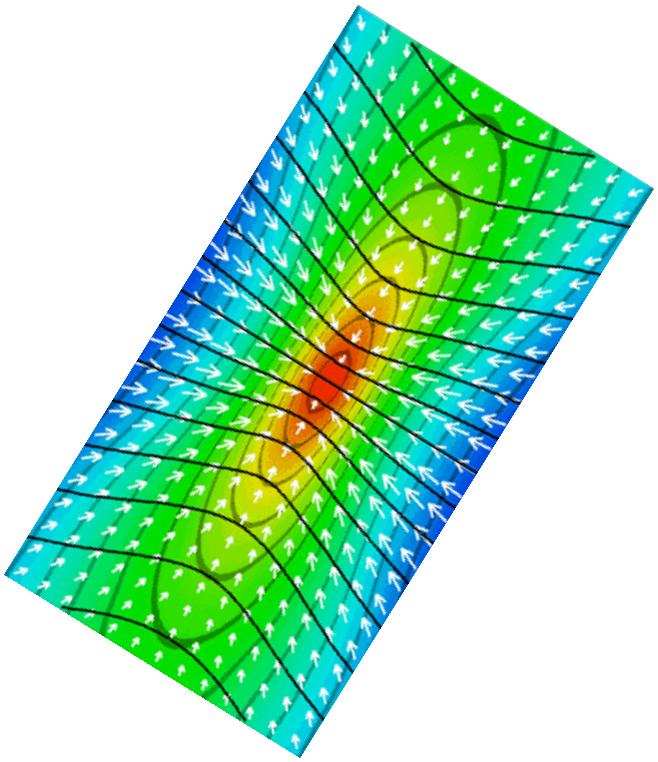
Far-IR polarimetry tests geometrical models of magnetic fields: protostars

“hourglass” field in protostellar envelope



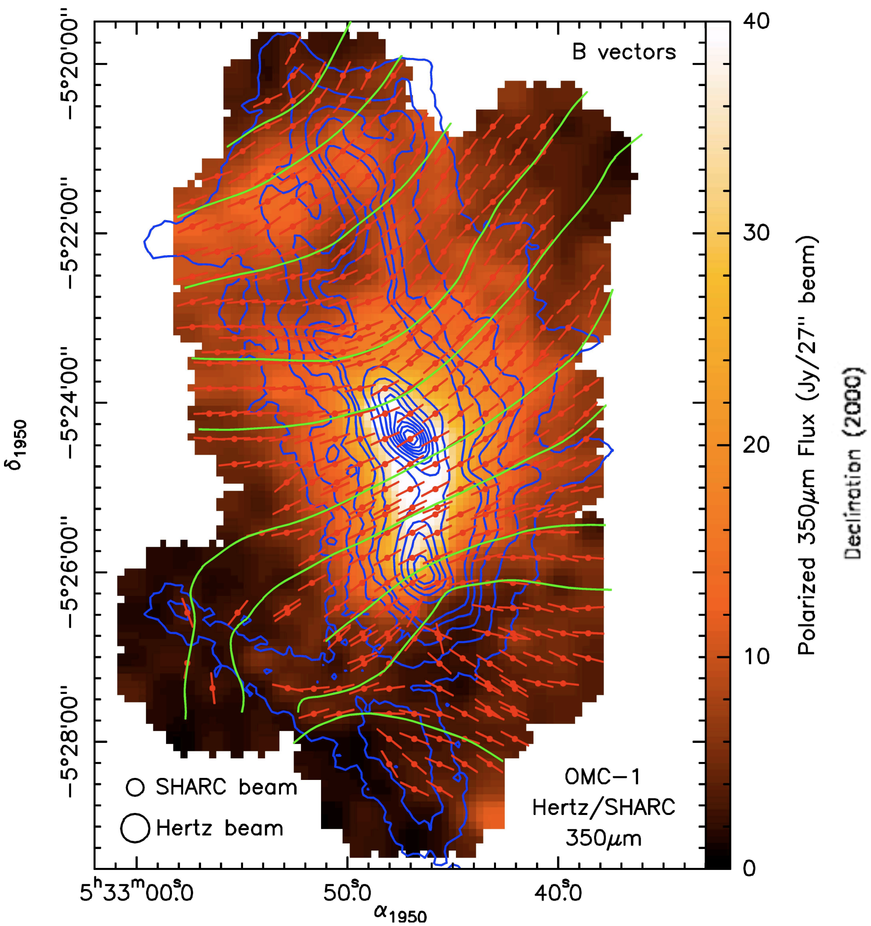
observation w/ interferometer:

Girart, Rao, & Marrone (2000)

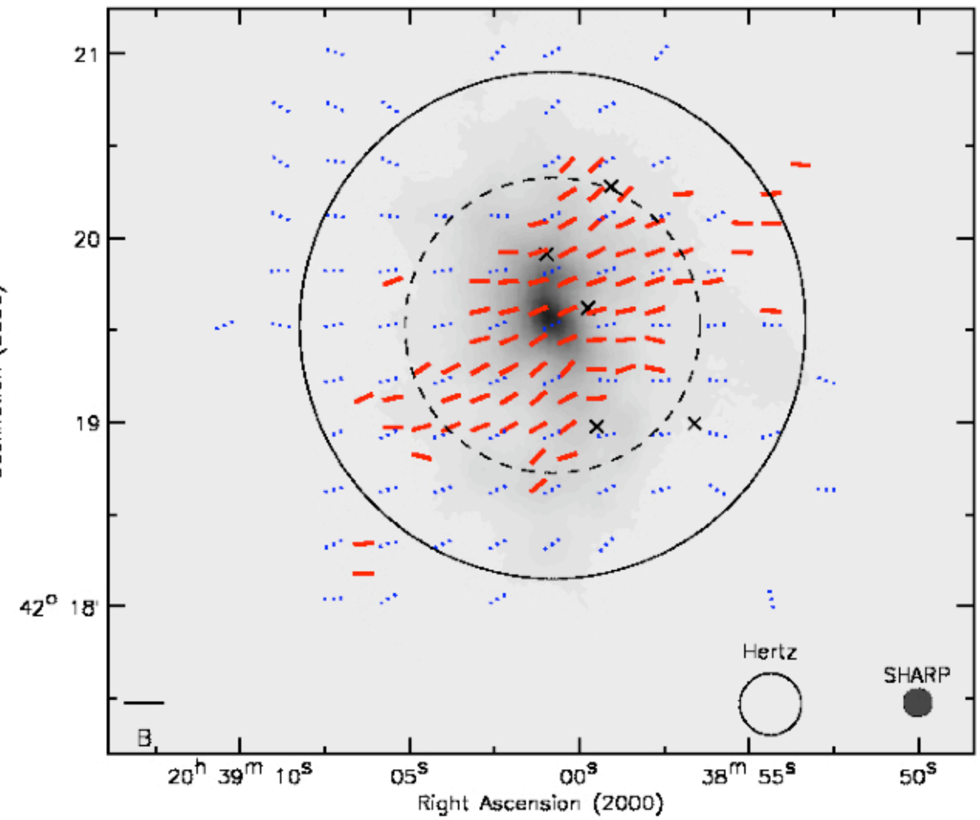


model:
Fiedler & Mouschovias 1993

Far-IR polarimetry tests geometrical models of magnetic fields: cloud cores



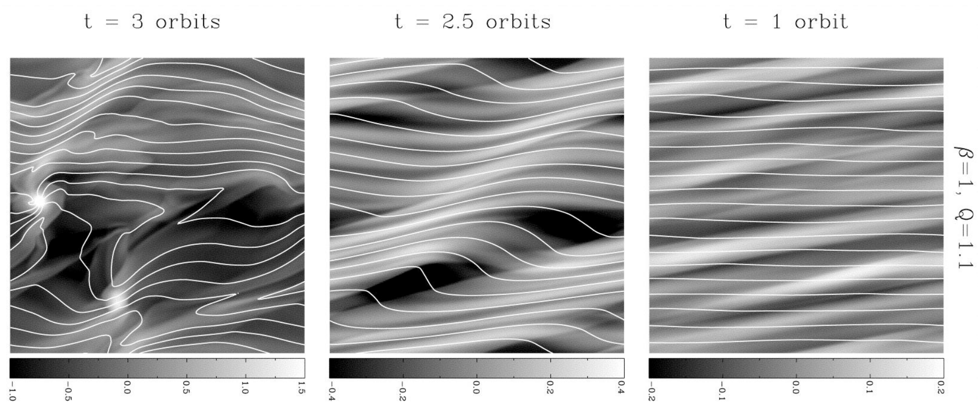
Schleuning (1998); Houde et al. (2004)



Kirby (2008)

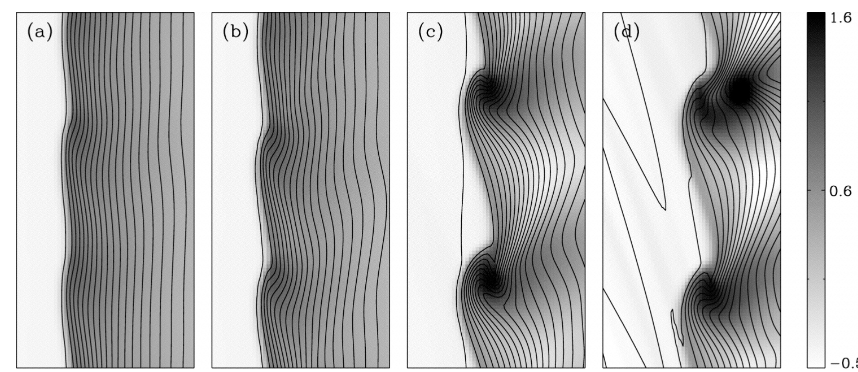
Far-IR polarimetry tests geometrical models of magnetic fields: cloud formation

swing amplifier effect



Kim & Ostriker (2001)

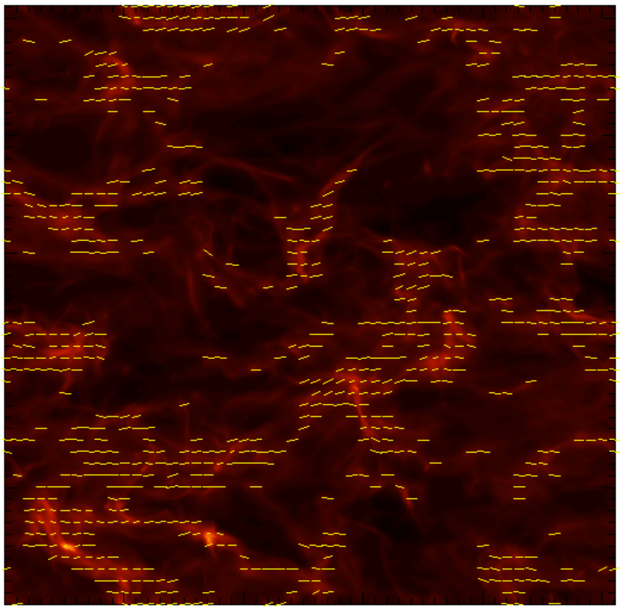
magneto-Jeans instability

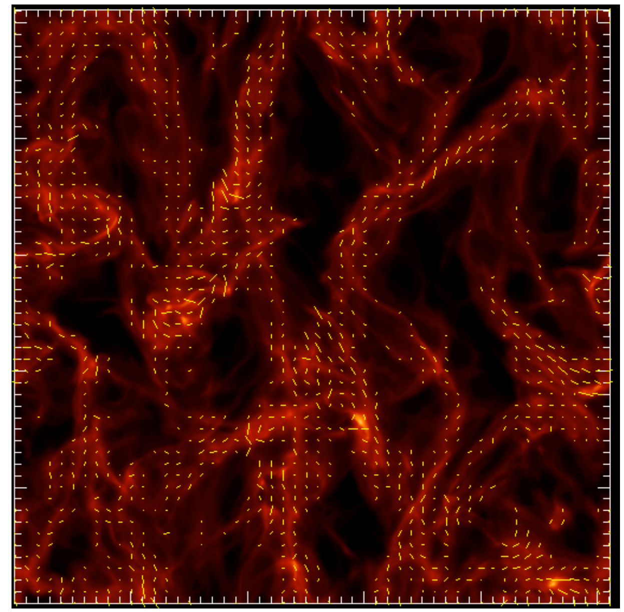


Kim & Ostriker (2006)

Magnetic Field Strength from Chandrasekhar-Fermi Method

strong field: small dispersion / **weak field: large dispersion**



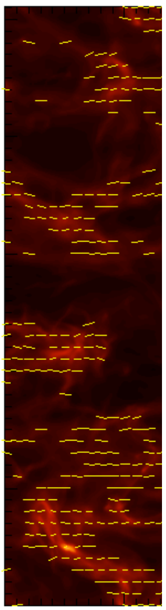


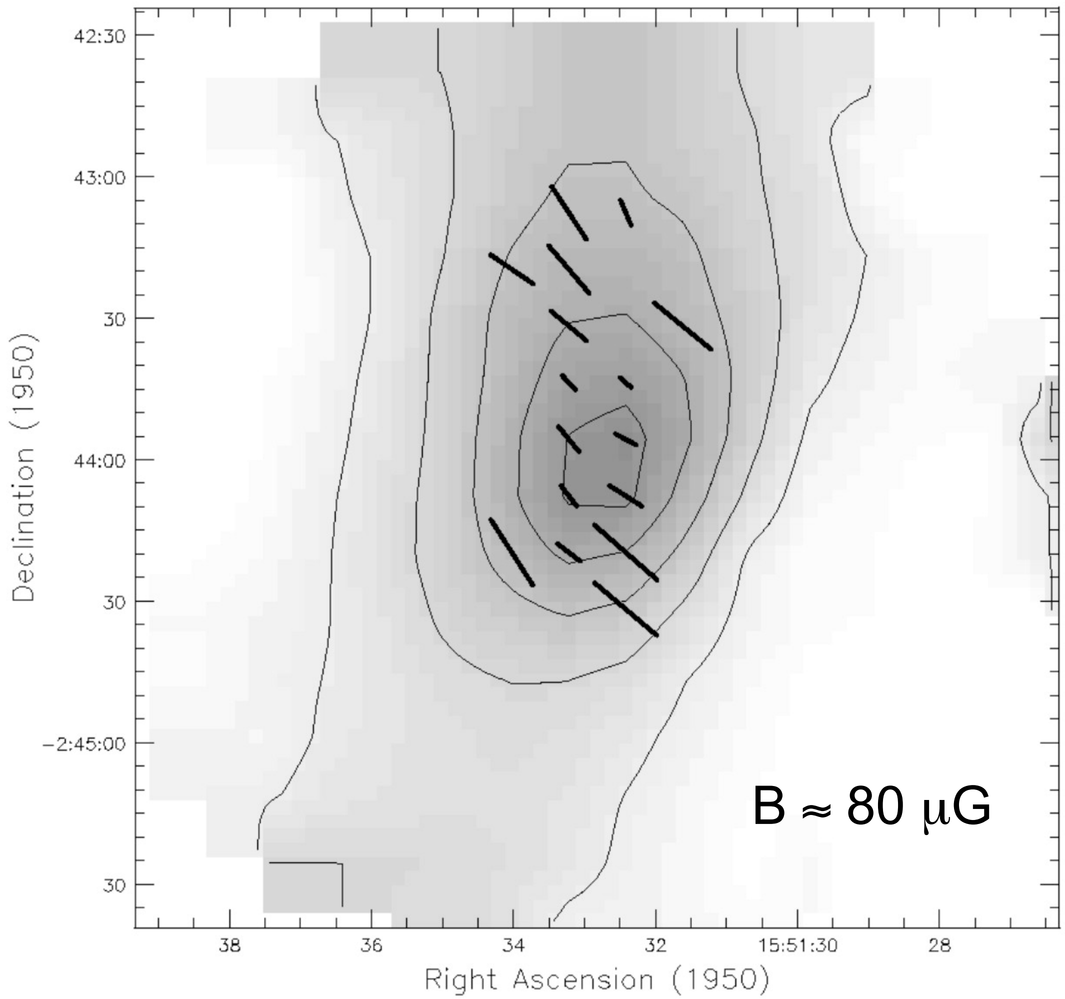
Falceta-Gonçalves, et al. (2008)

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

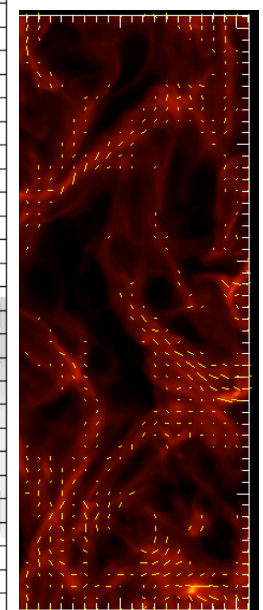
Magnetic Field Strength from Chandrasekhar-Fermi Method

strong fie





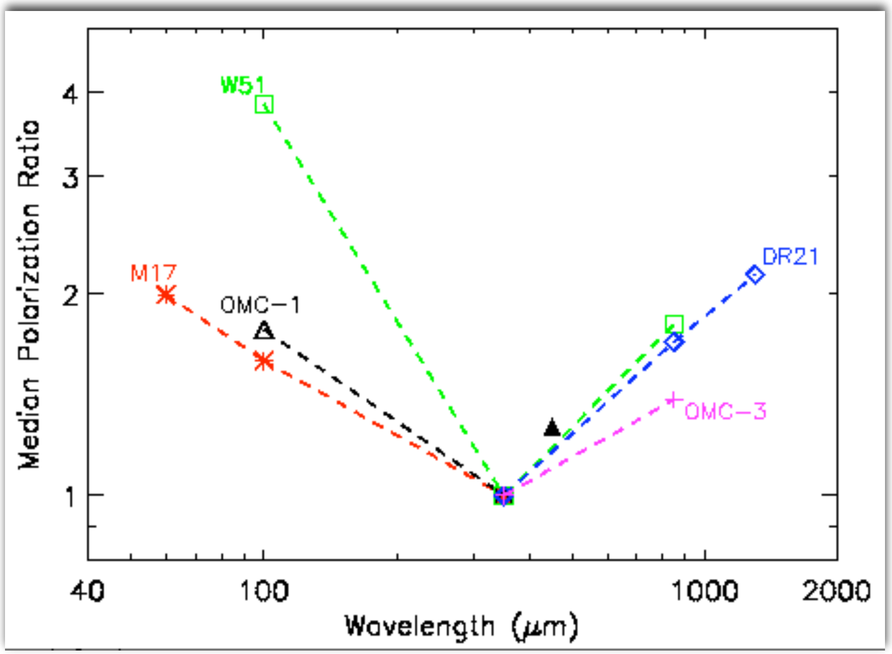
dispersion



- B = x
- x: Os 1); Heitsch et al. 8)

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.

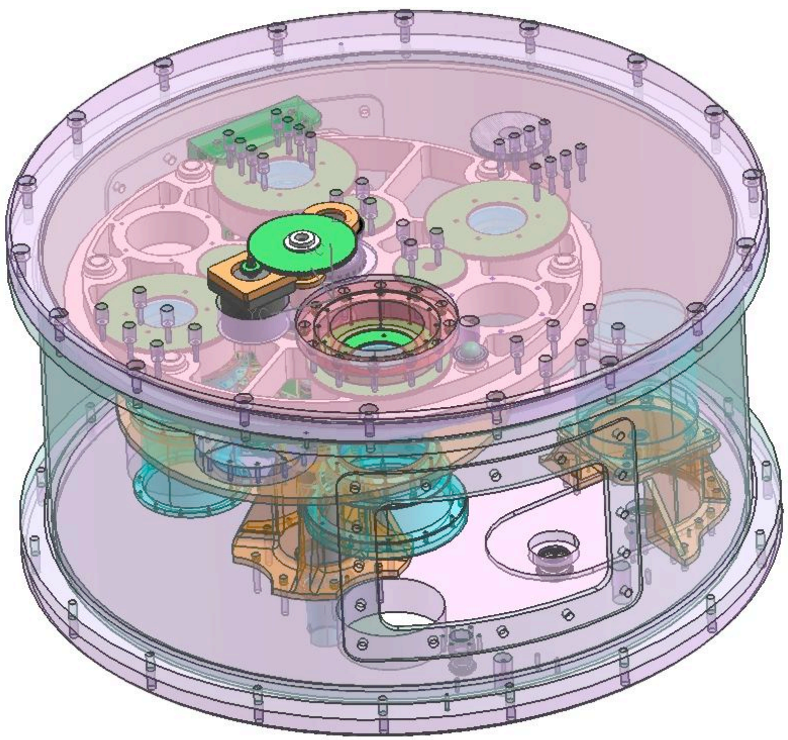


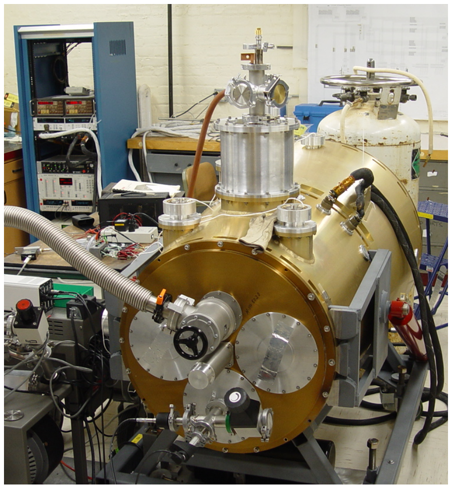
Vaillancourt et al. (2008)

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



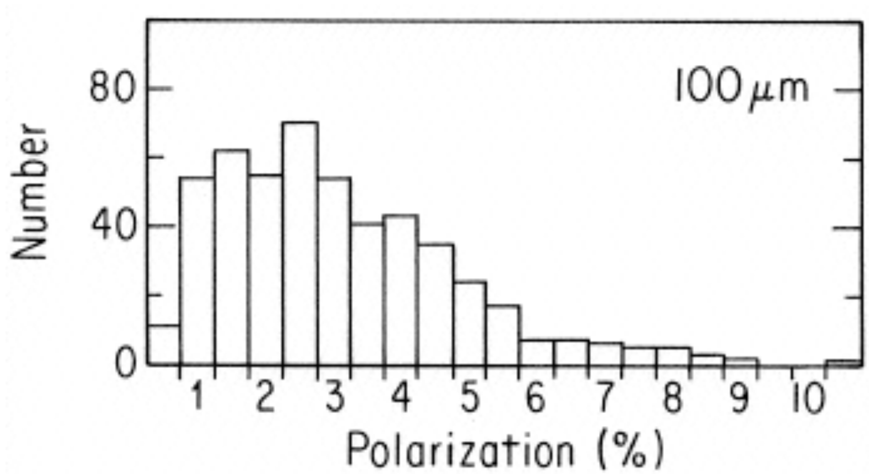


- started Oct. 2008 on JPL internal funds
- permanent upgrade to HAWC
- good for sources up to ~8’

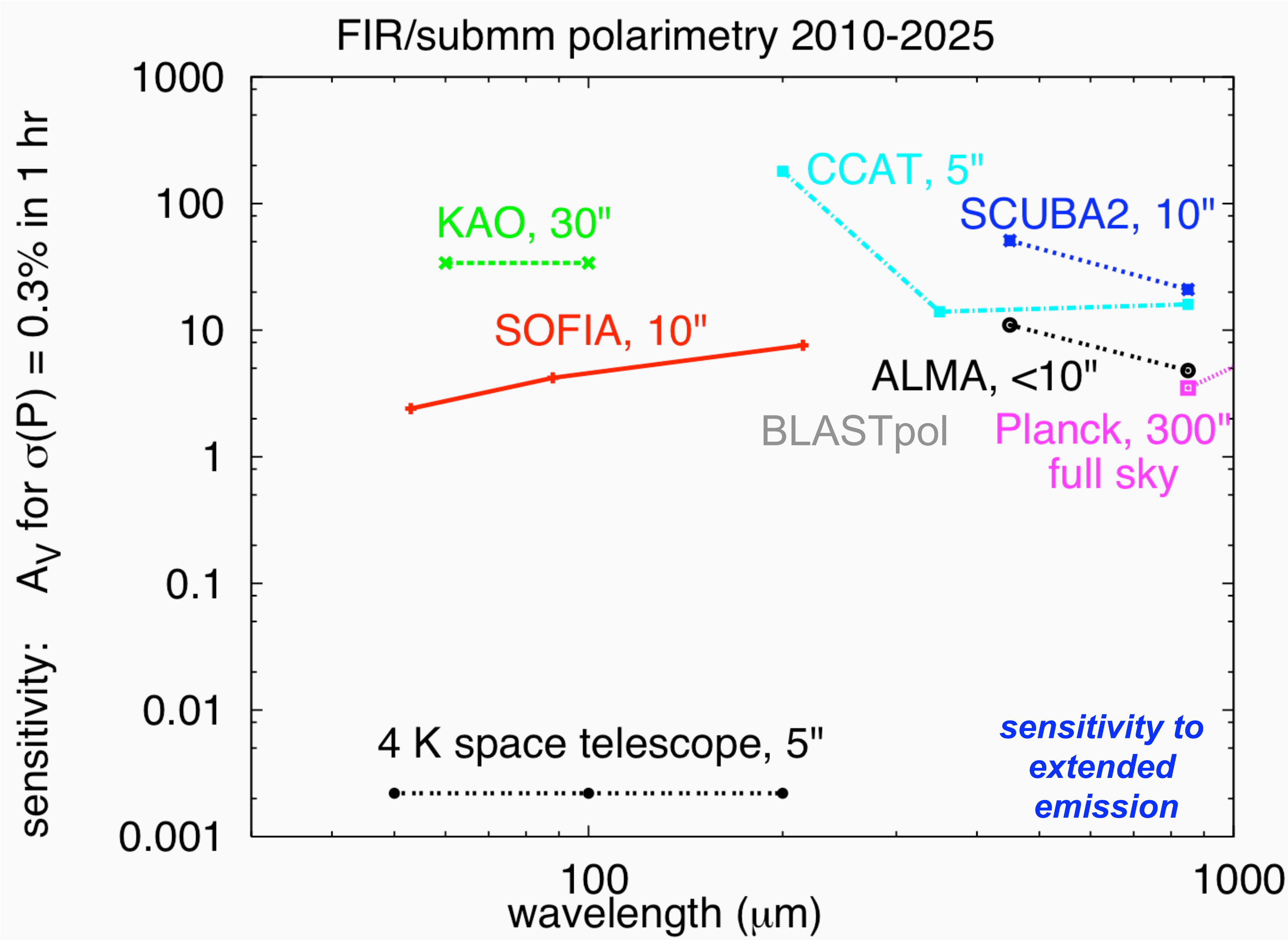
observation bands	**53, 89, 155, 216 μm**
angular resolution	**5 – 22 arcsec**
field of view	**0.5×1.2 – 1.6×4.3 arcmin^2**
polarization modulation technique	**quartz half-wave plate, 15 rpm**
minimum flux density to achieve $\sigma(P)$ = 0.2% in 5 hour integration	**9, 6, 6, 5 Jy**
minimum column density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

Required Polarization Sensitivity

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



Hildebrand et al. (1999)



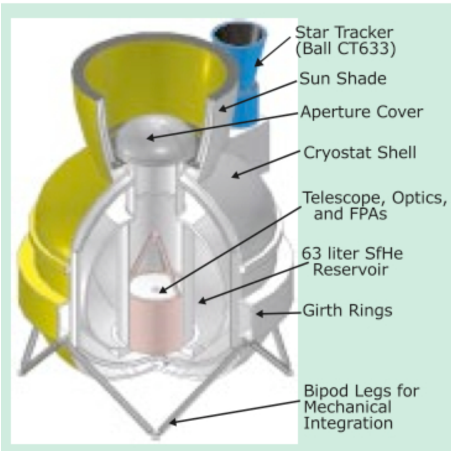
Far-IR polarimetry is 10^6 × faster from space.

Giant Steps

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

- SKA

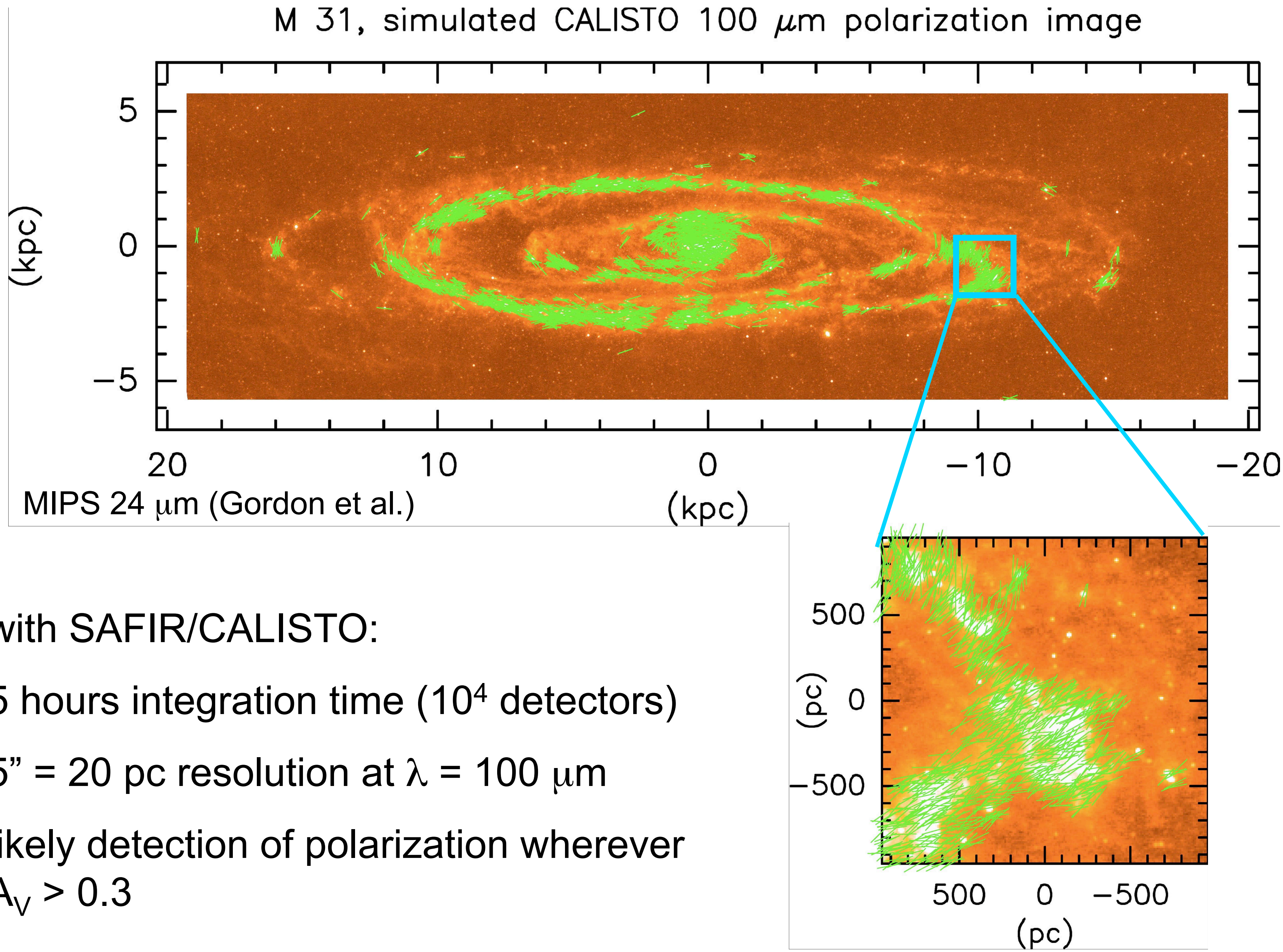
Dedicated Polarization Survey



M4:

0.2 m cold telescope

- PIREX/M4 (Clemens, P.I.; Goodman; Jones)
  - satellite proposed to NASA 1990, 1993, 1996
  - 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.)



with SAFIR/CALISTO:

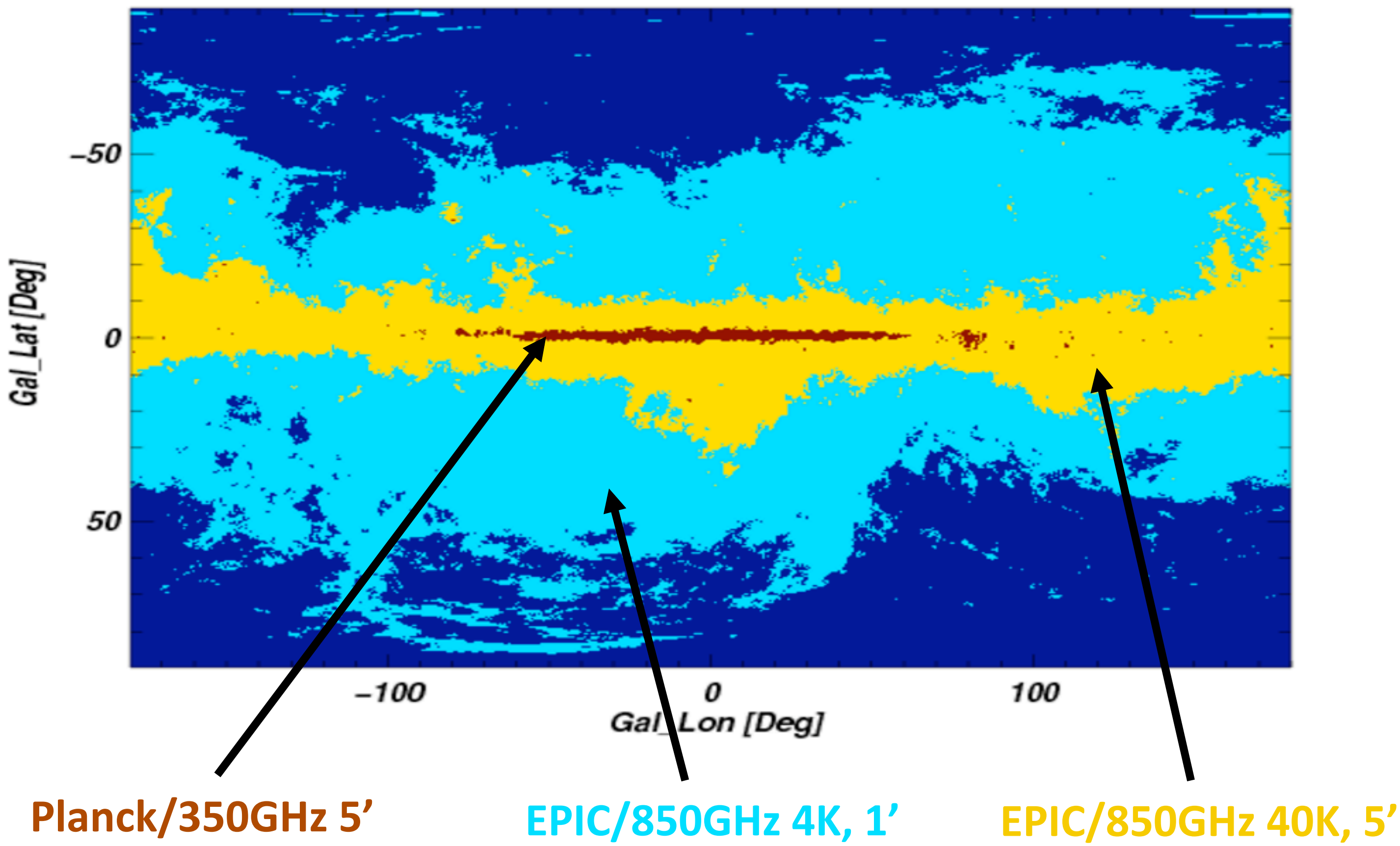
5 hours integration time (10^4 detectors)

5" = 20 pc resolution at λ = 100 μm

likely detection of polarization wherever $A_V > 0.3$

EPIC Polarization Mapping

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

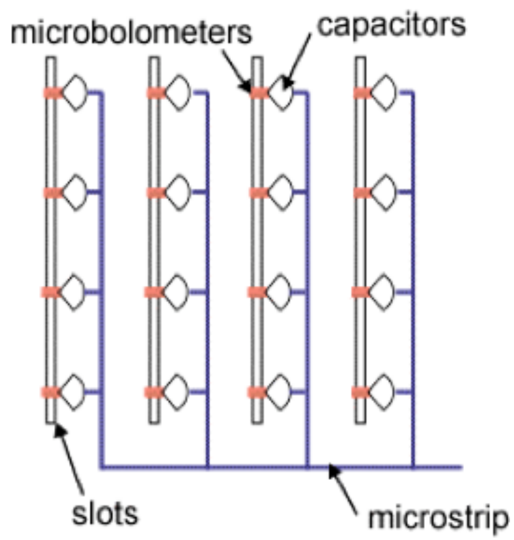


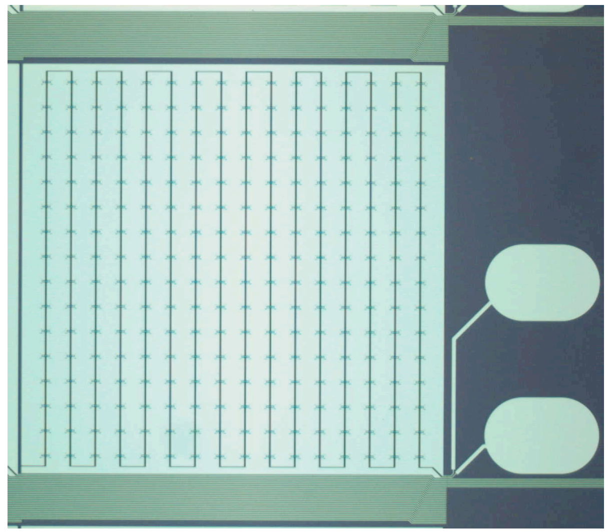
- EPIC/850 GHz can make accurate polarization maps with 10^8 resolution elements.

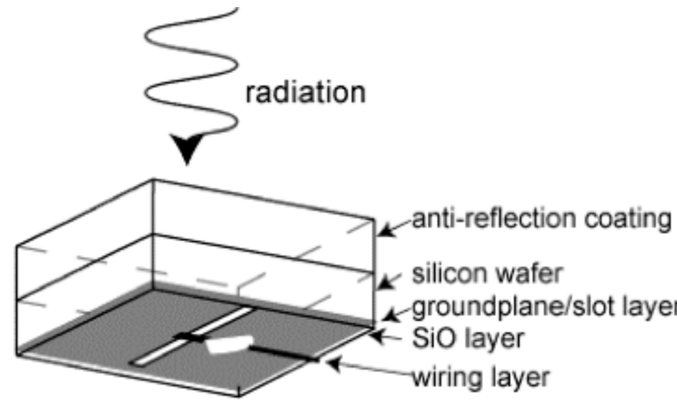
Enabling Technologies for Space Far-IR Polarimetry

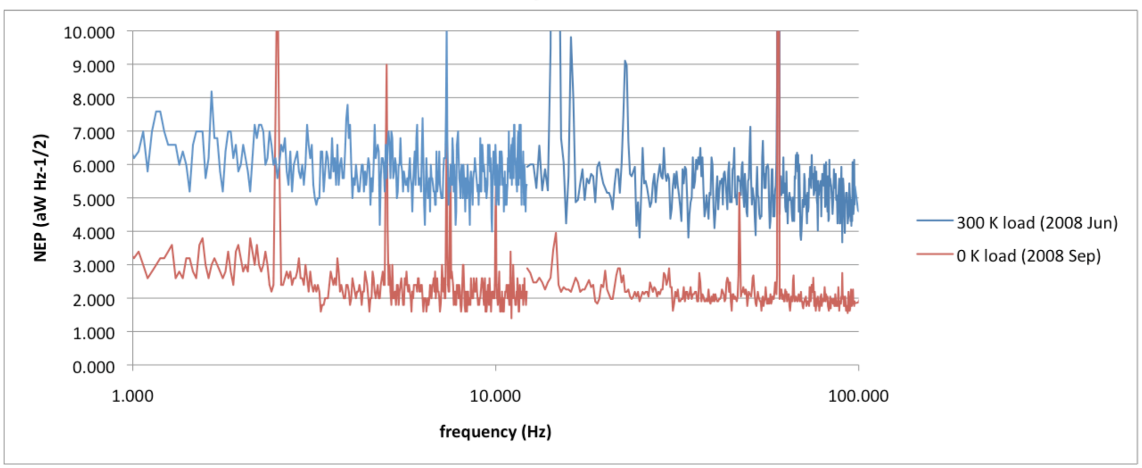
- polarization-sensitive detectors
- polarization modulation
  - low-power cryogenic rotating quartz half-wave plate
  - scan modulation only (Boomerang ⇒ Planck)
- Good polarimeters usually make good cameras.
  - NEP = 10^{-18} W $Hz^{-1/2}$ is adequate for detectors.

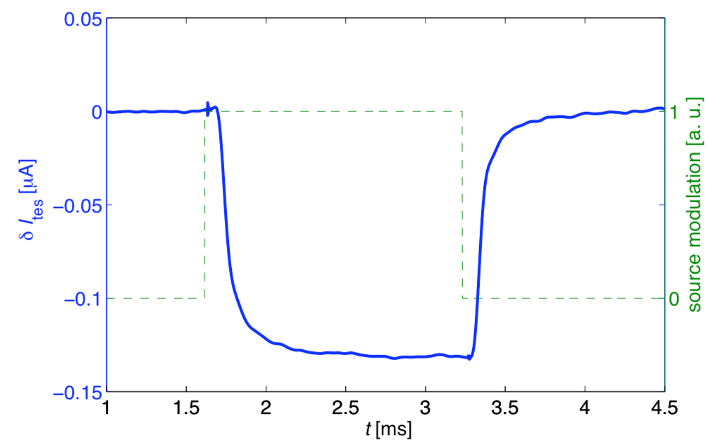
Antenna-Coupled 200 μm TES Detector











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

“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)