Atacama Submillimeter Telescope

ISM Polarimetry

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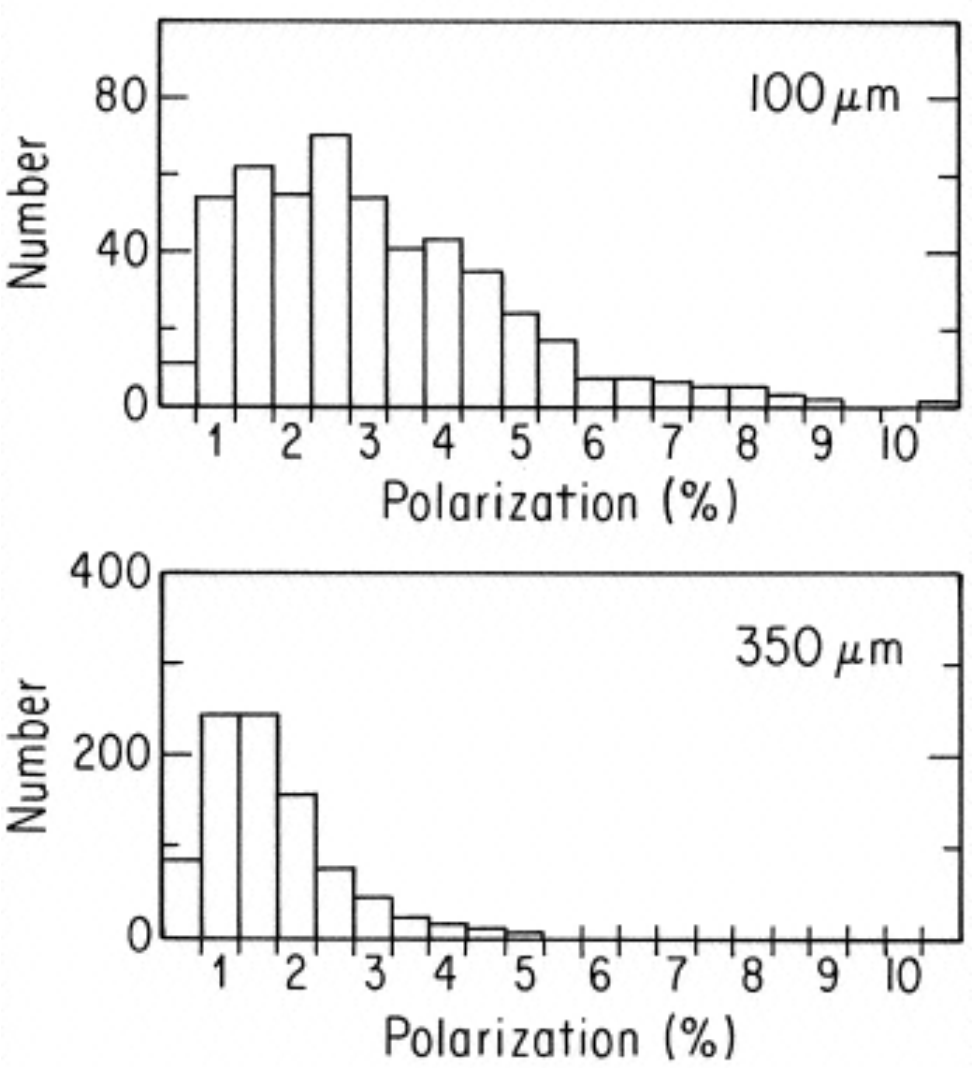
2003 October 11

Outline

- Sensitivity
- Extended Sources:
  - Magnetic fields confront other forces in the Galaxy.
  - Large-scale magnetic field order in dense ISM of other galaxies
  - Polarization spectrum
- Point Sources:
  - Sgr A*
  - T Tauri stars
  - Blazars: emergence of jets
  - High-z: Just because we can?
- Techniques
- Requirements of telescope

Typical ISM Polarization: 2%

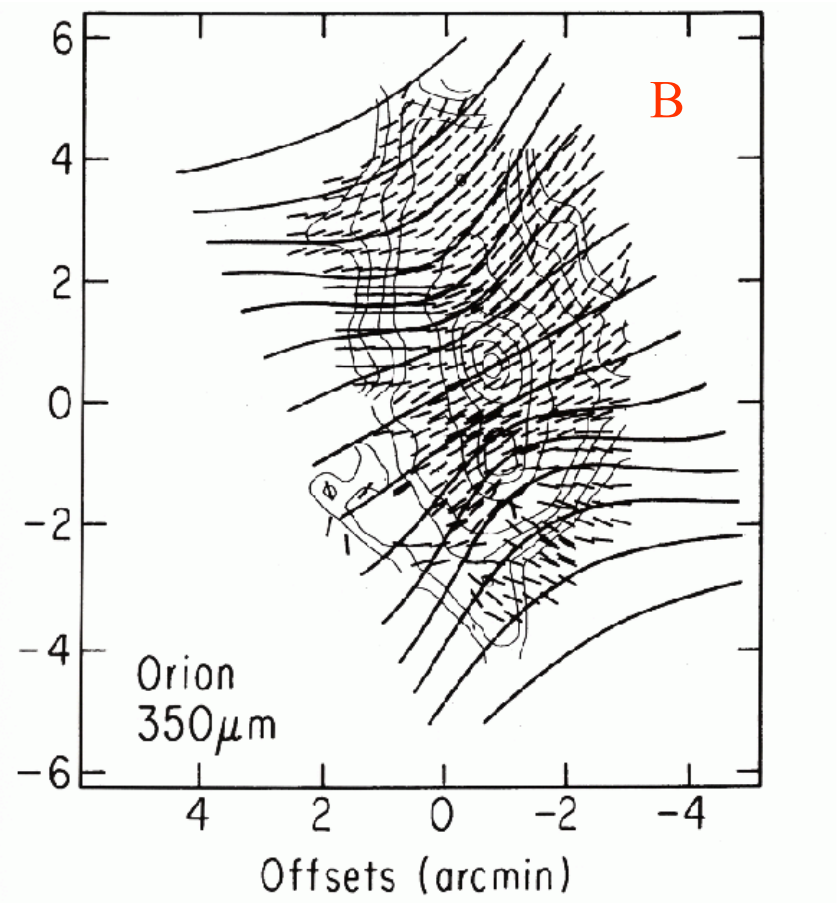


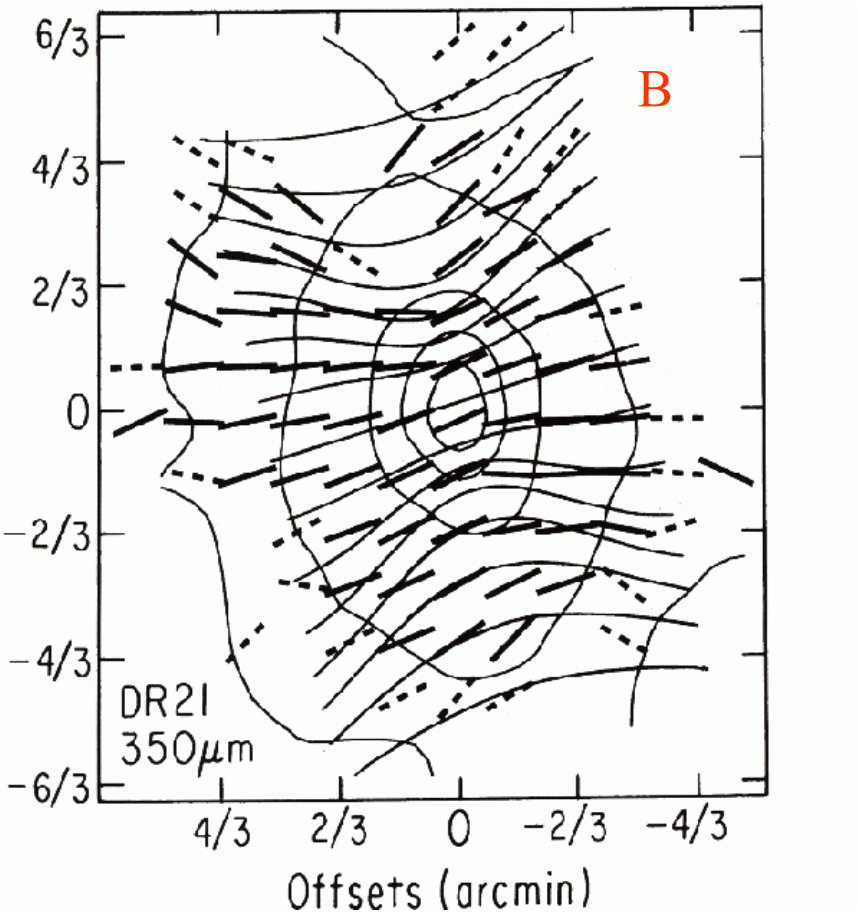
Hildebrand et al. (1999)

Sensitivity Comparison with Existing Facilities

λ (μm)	Atacama vs. CSO	Atacama vs. JCMT	Flux/beam for $\sigma(P) = 0.1\%$ in 10^4 sec
350, pt. src.	70× better		200 mJy
350, ext. src.	10×		200 mJy
850, pt. src.		50×	30 mJy
850, ext. src.		20×	30 mJy

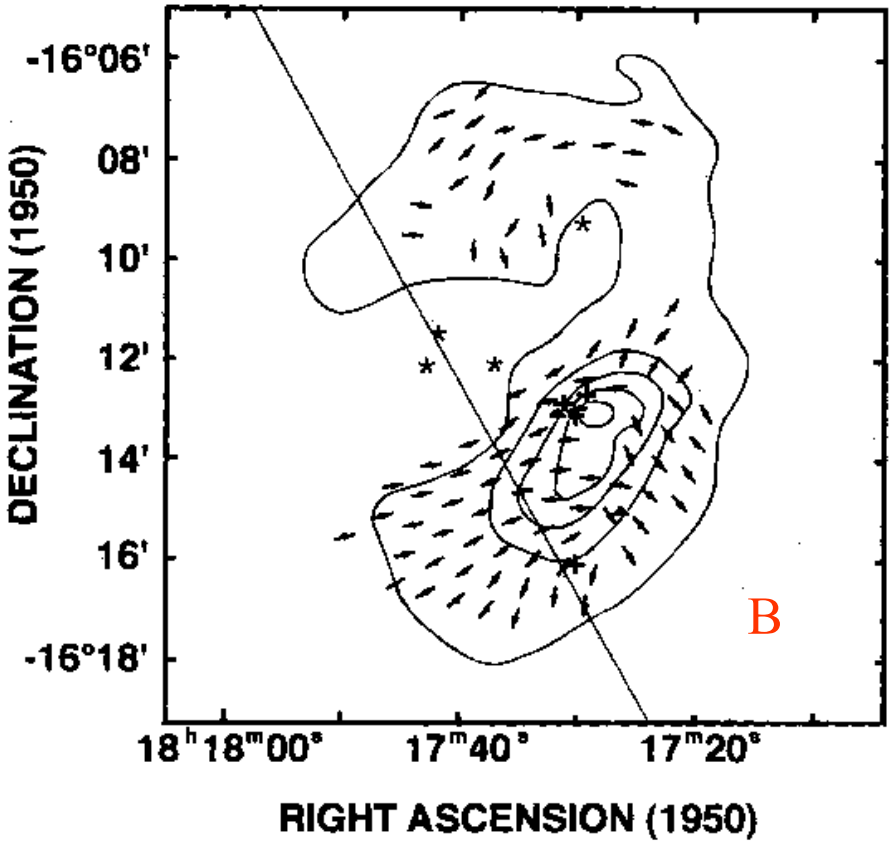
Orion and DR21: Magnetic Fields / Gravity

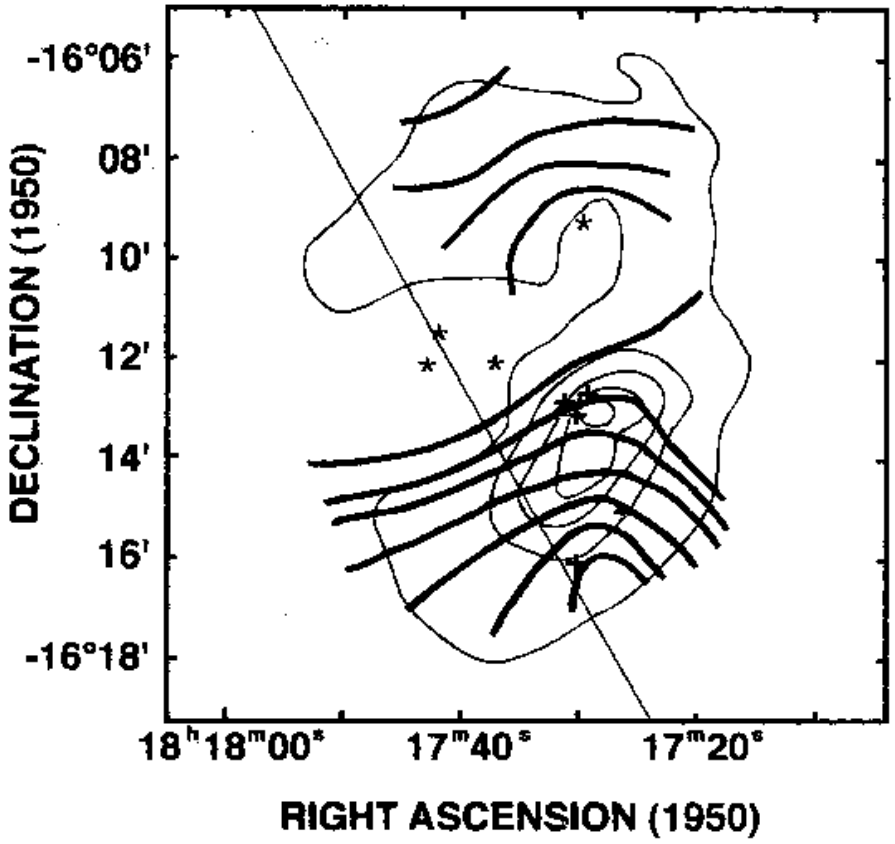




Dowell et al. (2002)

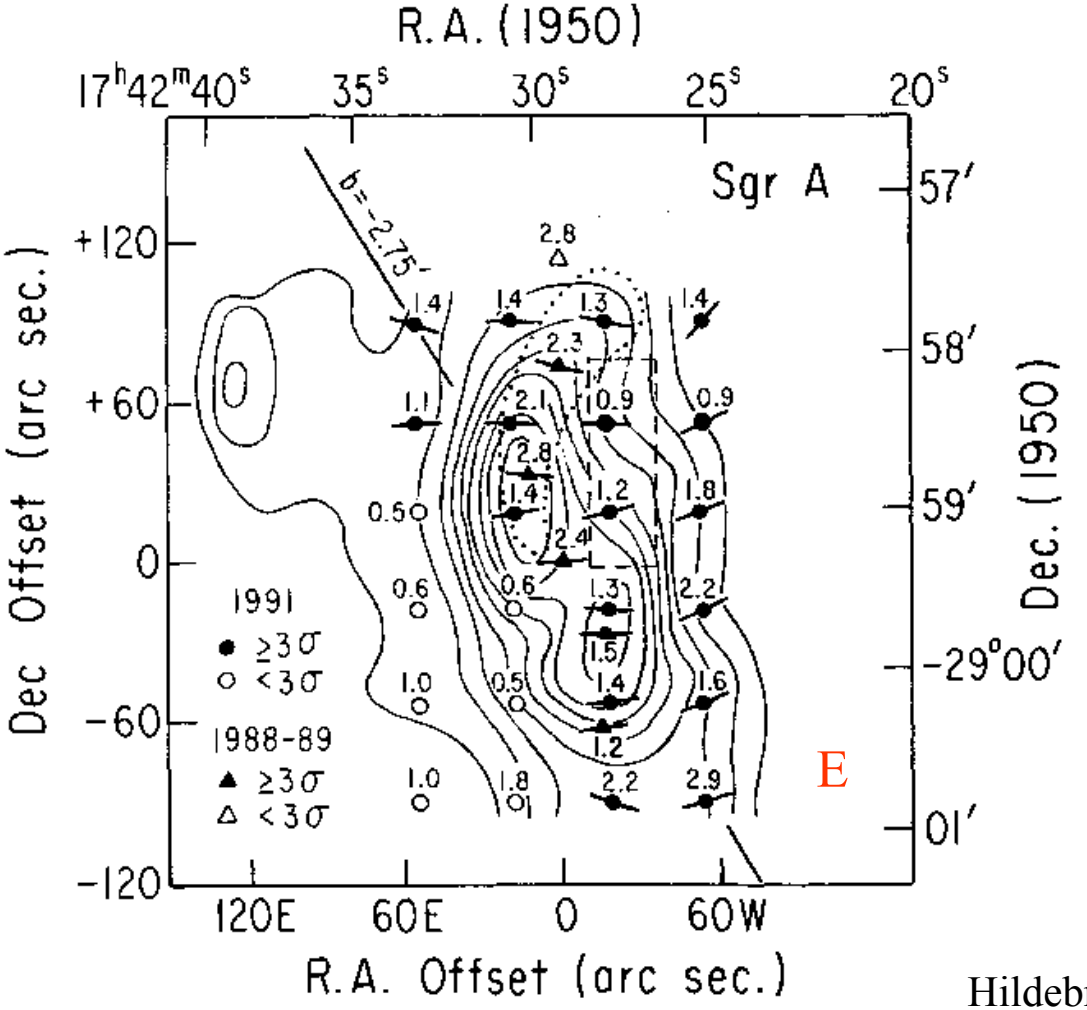
M17: Magnetic Fields / Stellar Winds

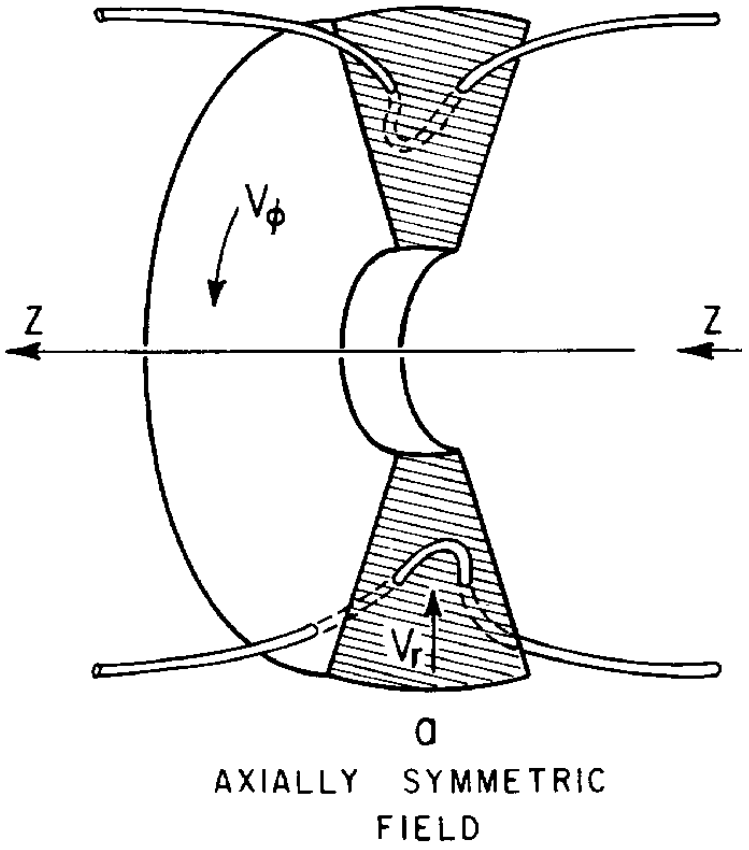




Dotson (1996)

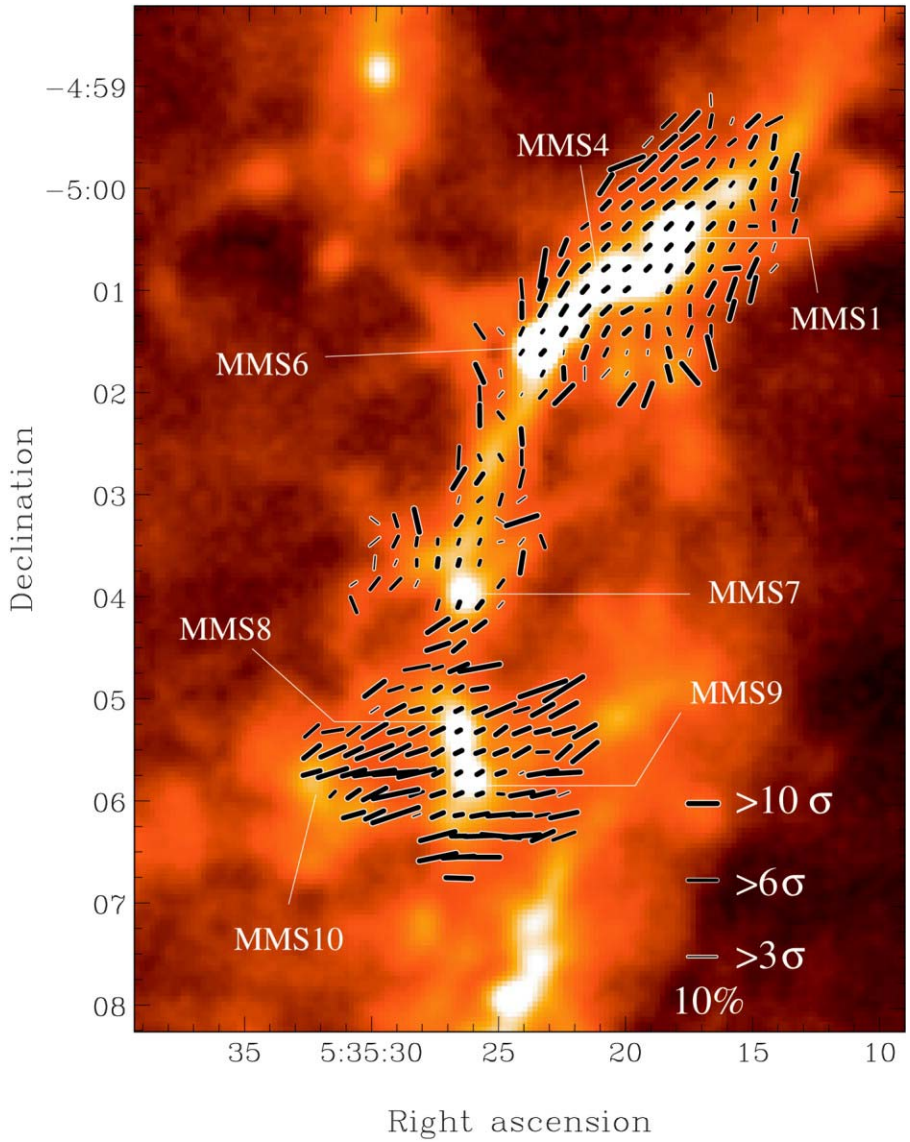
Galactic Center CND: Magnetic Fields / Rotation



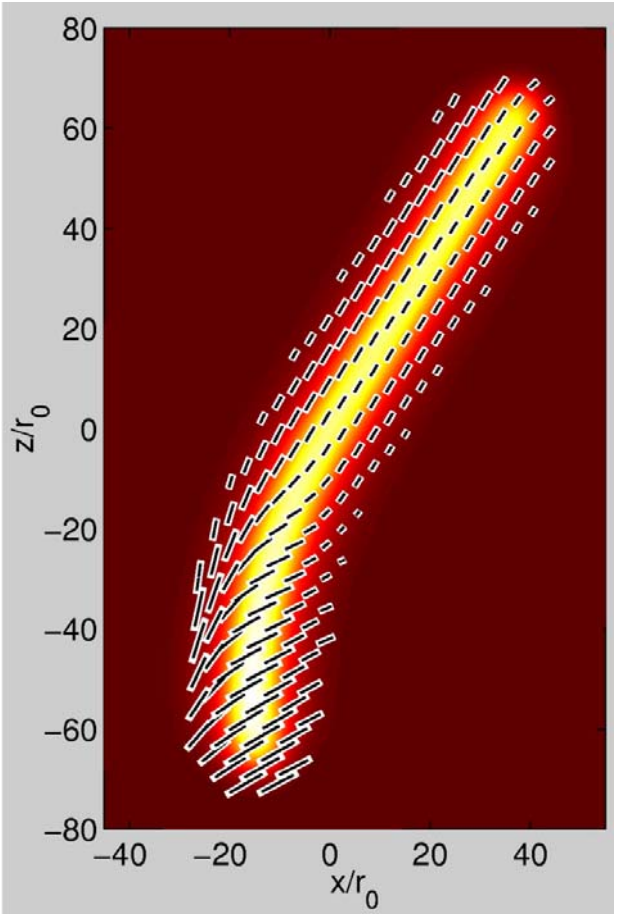


Hildebrand et al. (1993)

Test of Helical Field Model

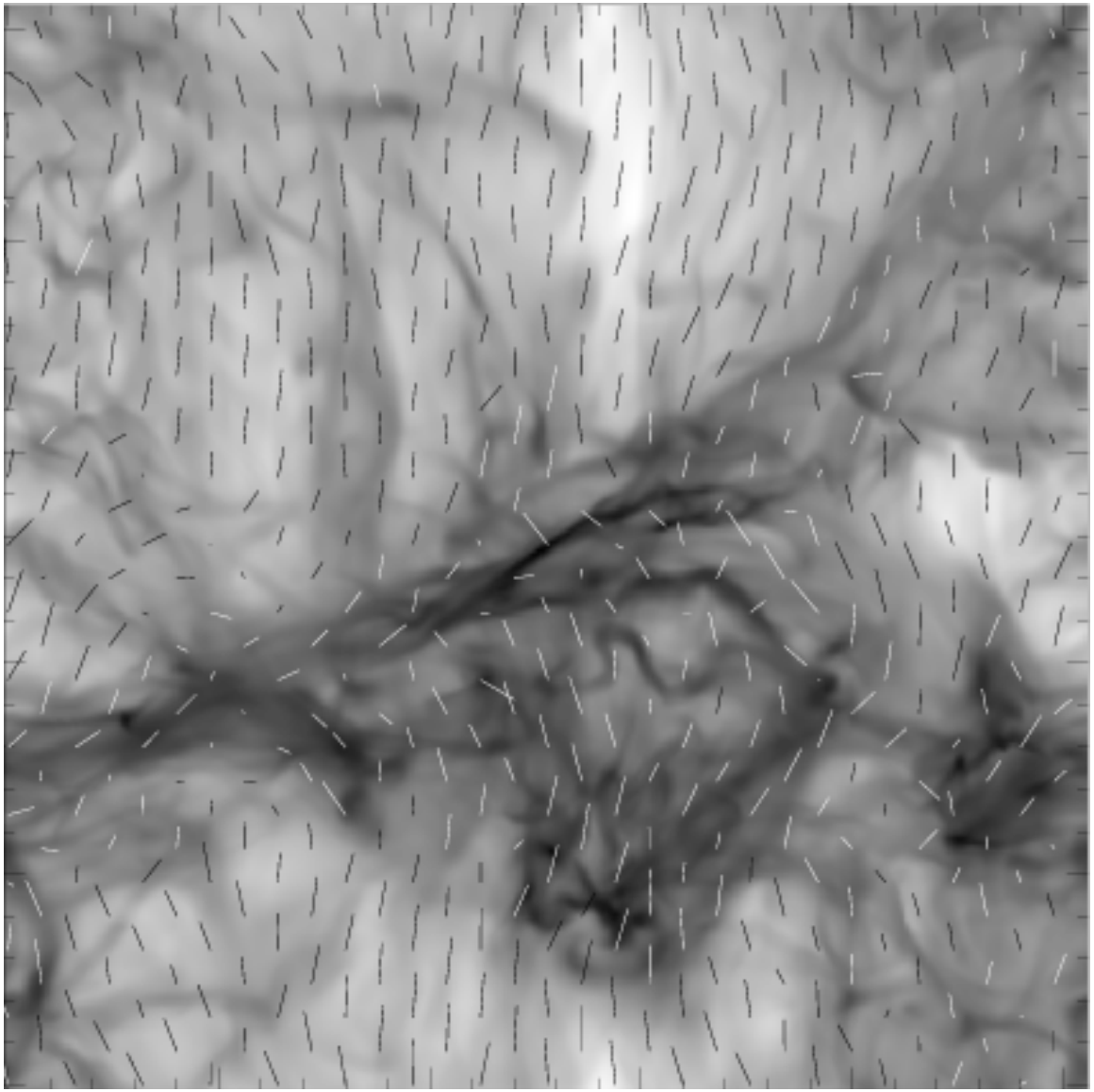


E



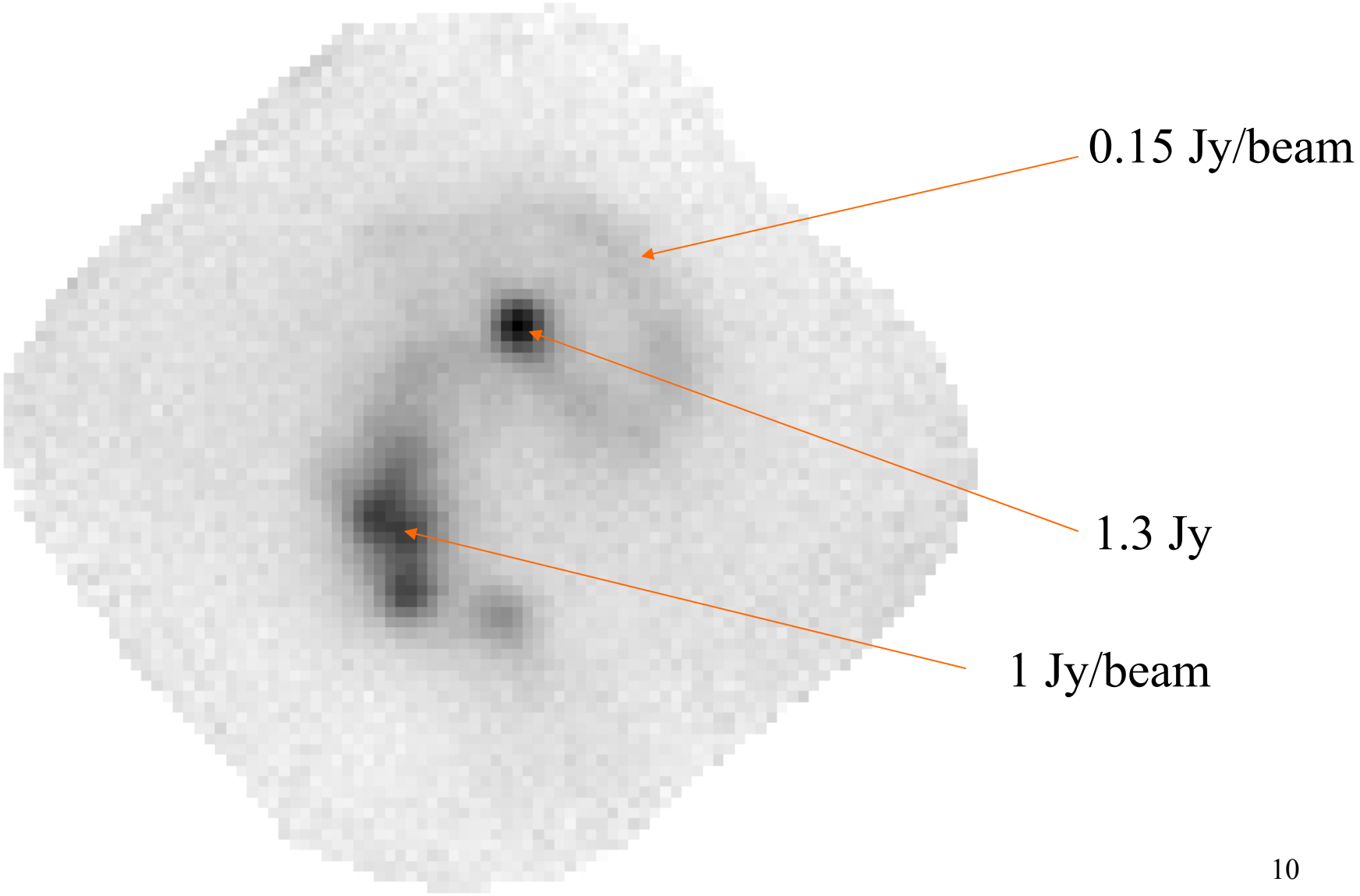
Matthews et al. (2001)

Simulations Out Pace the Observations

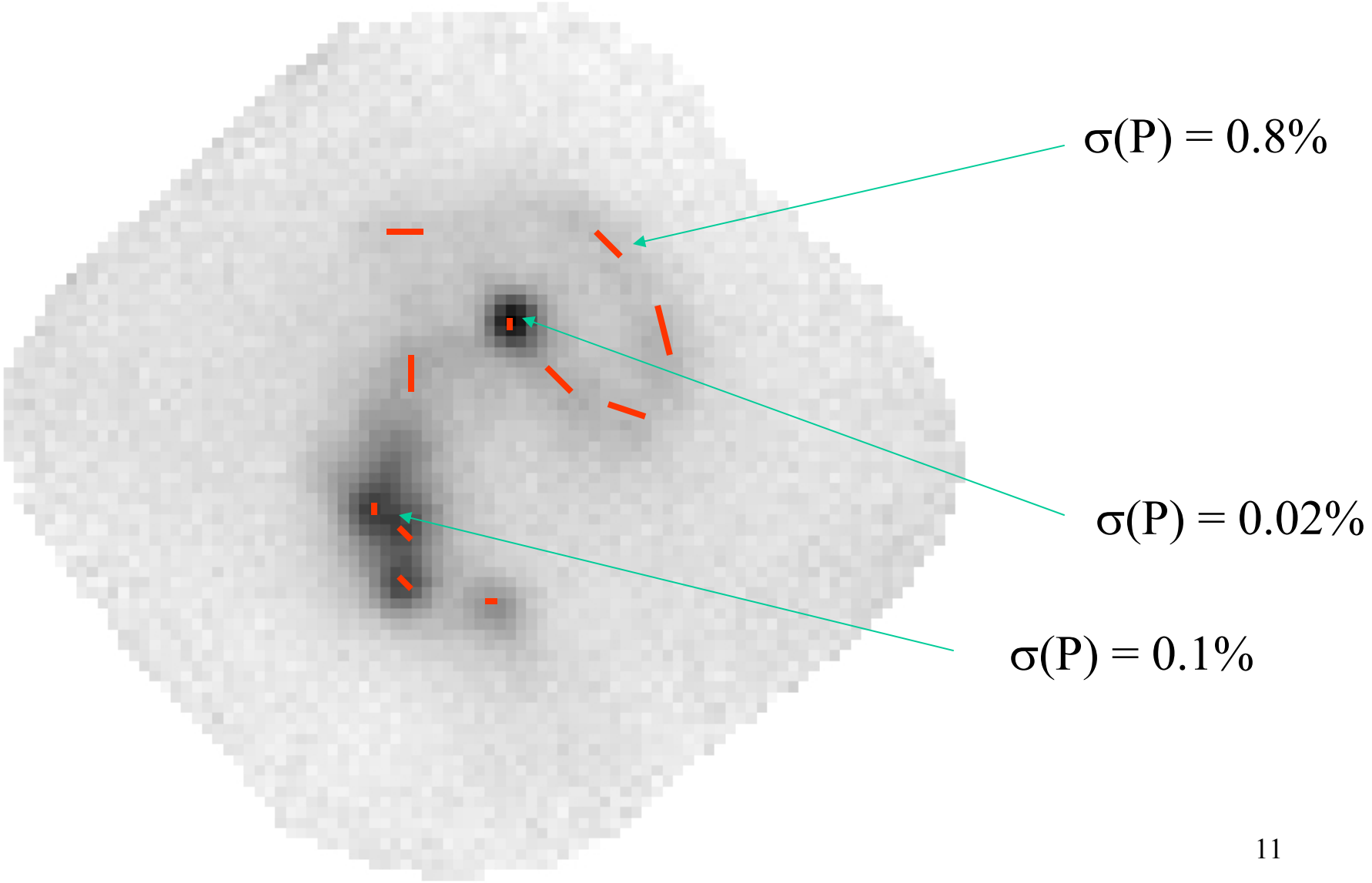


Heitsch, Zweibel, & MacLow

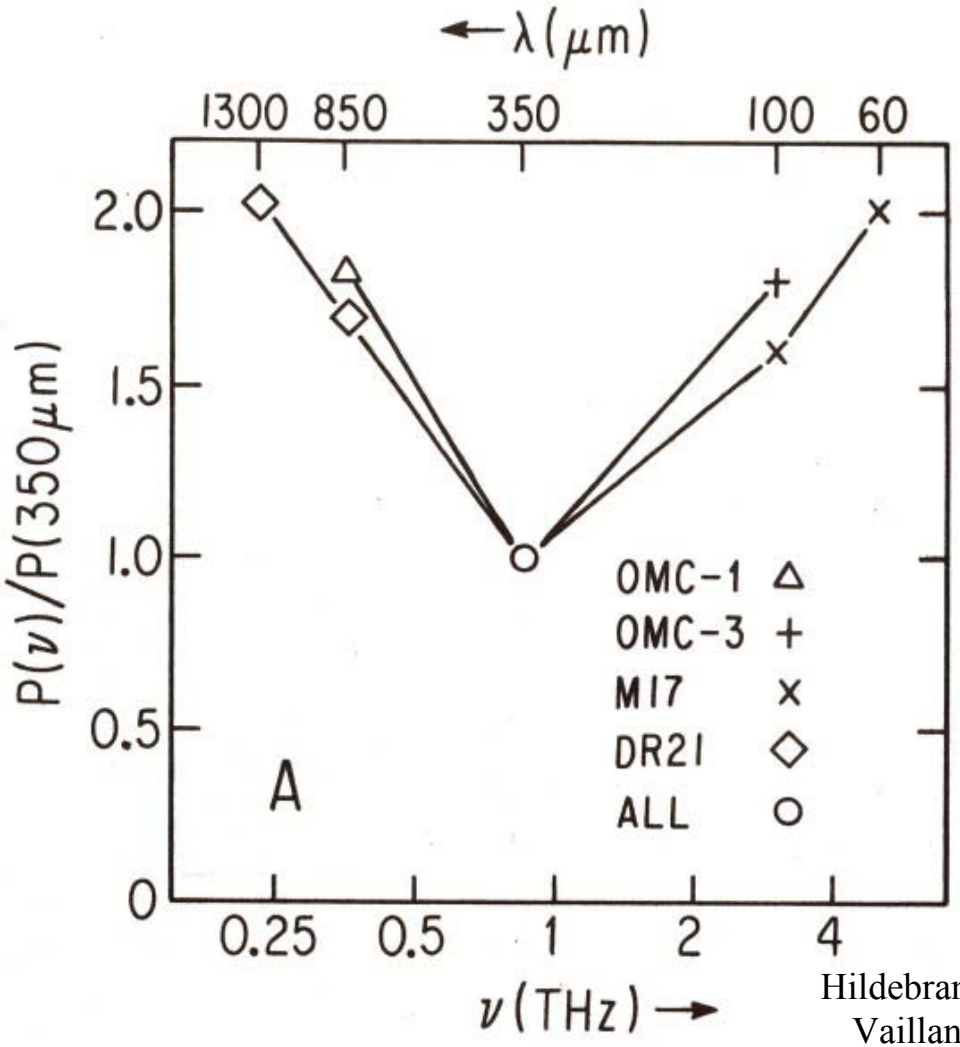
SHARC II 350 μm map of the Antennae



Atacama polarization map after 10^4 sec?



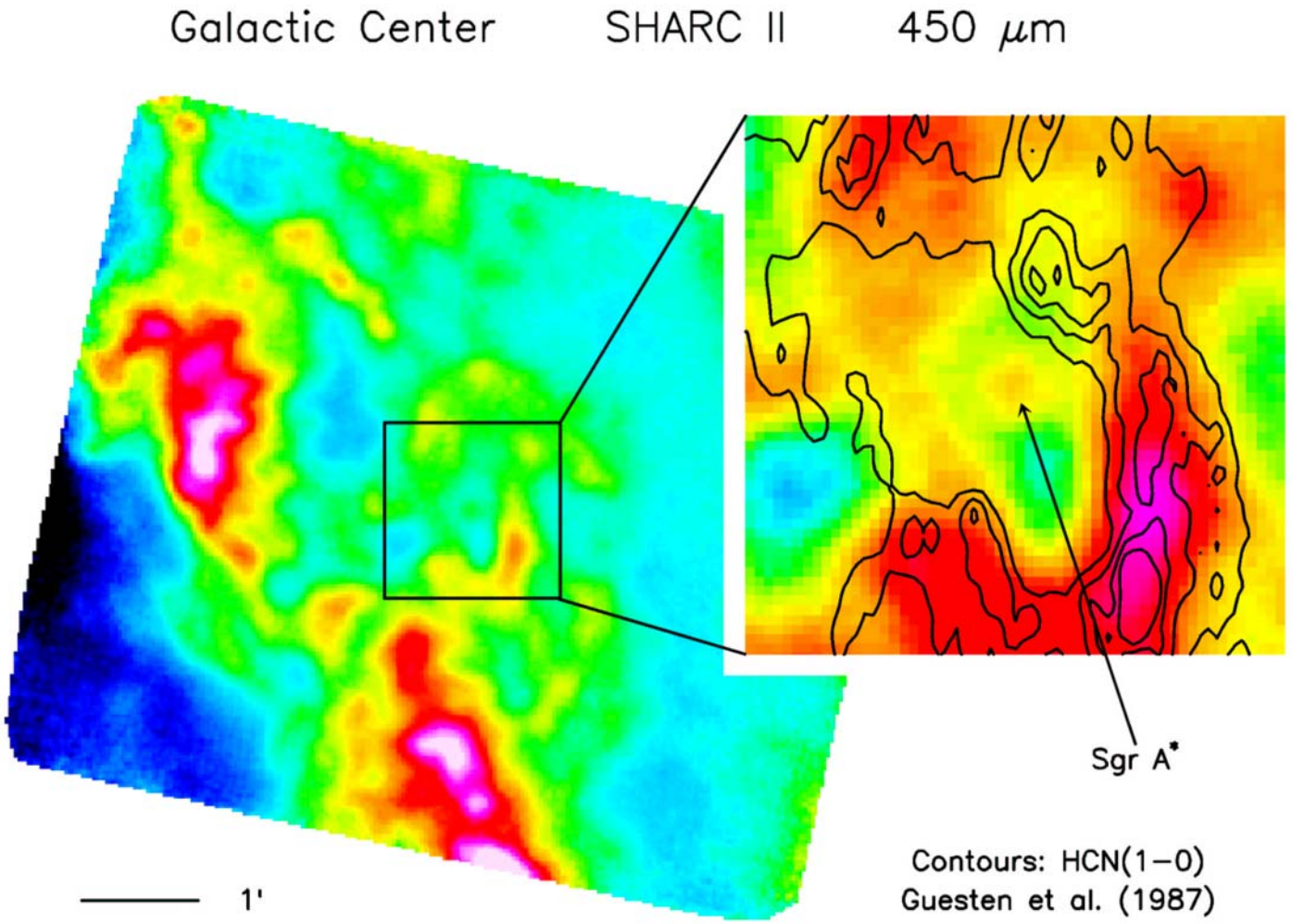
Polarization Spectrum: More Constraints on the Mix of Dust

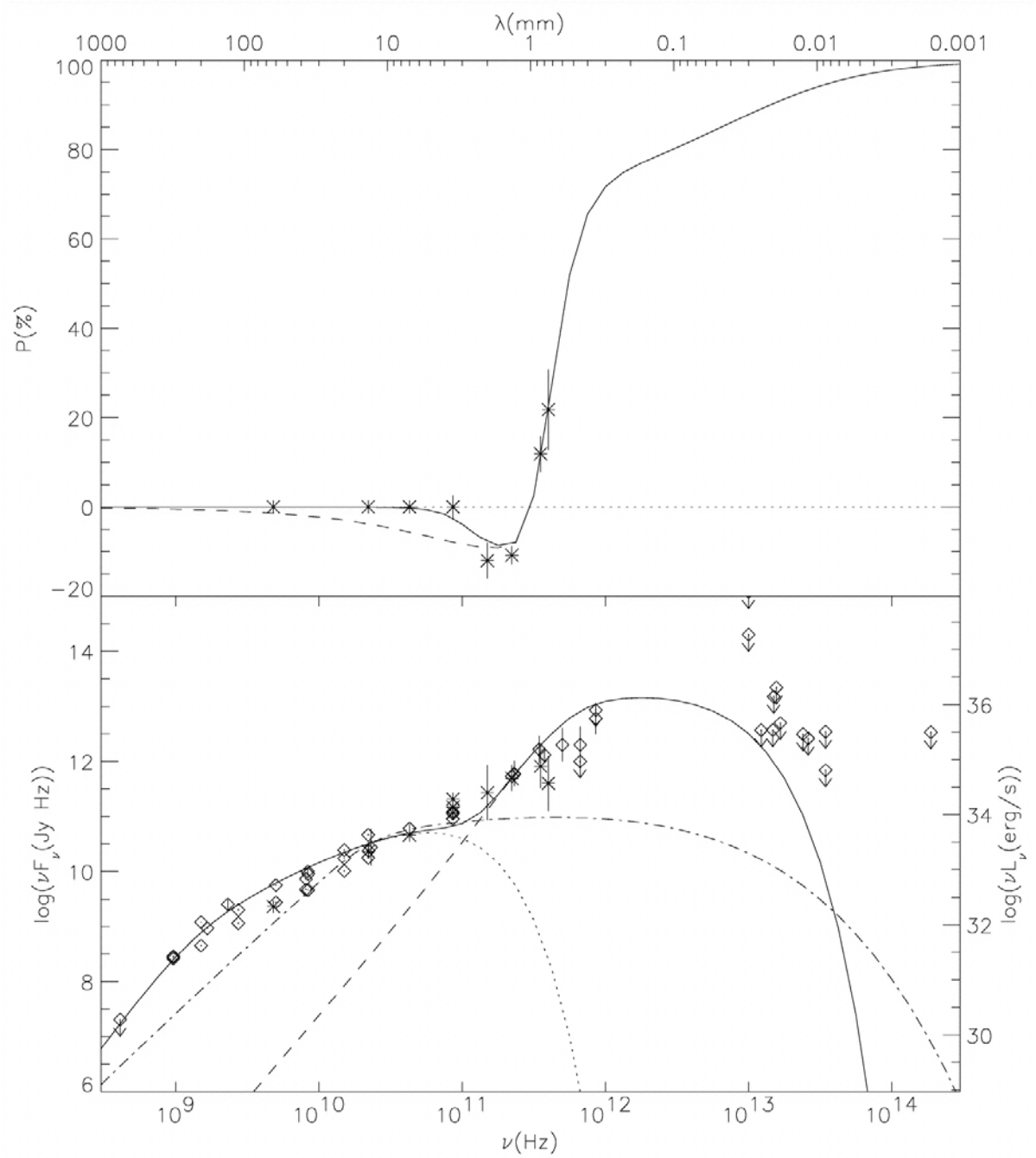


- No known single grain species will do this.
- Multiple dust components with different polarization efficiencies are required.

Hildebrand et al. (1999)
Vaillancourt (2002)

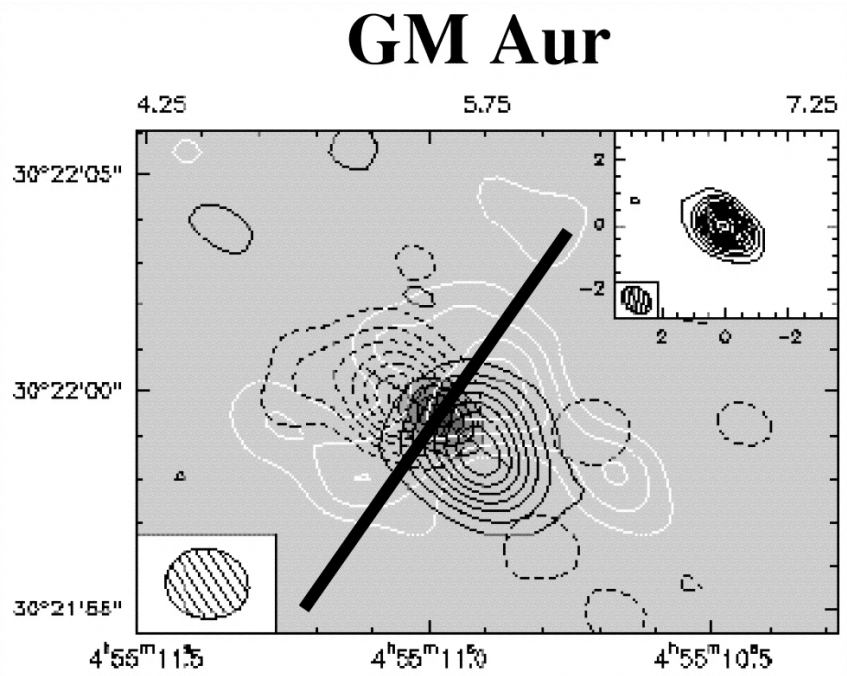
Sgr A*: Constraints on Accretion at a Few Schwarschild Radii

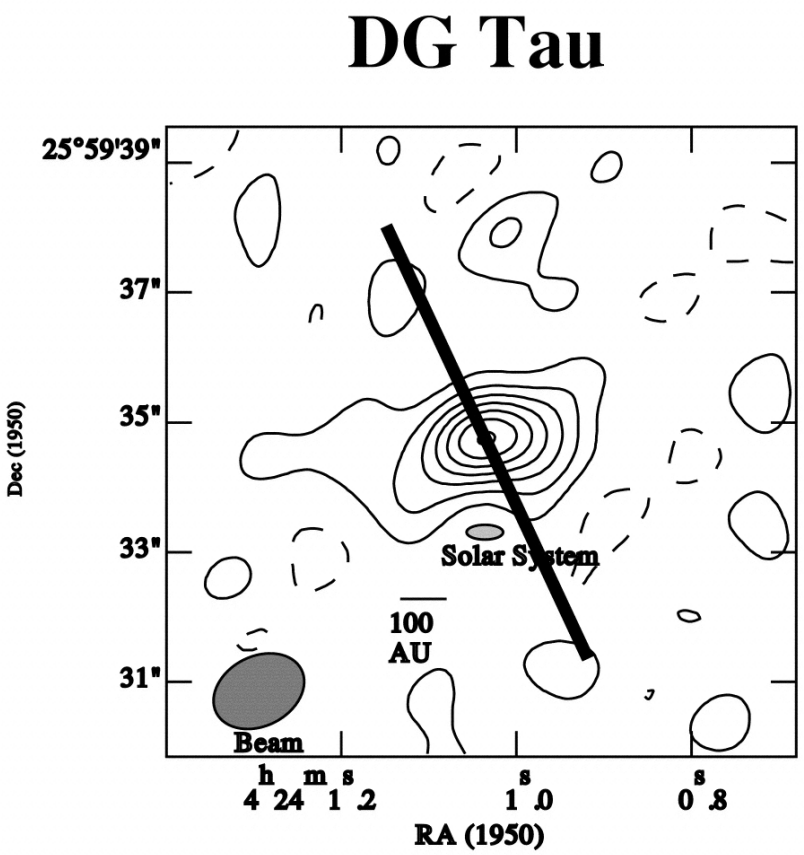



λ(mm)
1000
100
10
1
0.1
0.01
0.001
P(%)
100
80
60
40
20
0
−20
log(νF_ν(Jy Hz))
log(νL_ν(erg/s))
14
12
10
8
6
36
34
32
30
10^9
10^10
10^11
10^12
10^13
10^14
ν(Hz)

Agol (2000)

T Tauri Stars: Toroidal Fields In Accretion Disks





Tamura et al. (1999)

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Techniques

- Polarization modulation:
  - No strong incentive to improve upon the classic crystal quartz half-wave plate + wire-grid polarizer, except for large detector arrays at $\lambda > 1$ mm. Quartz is transparent enough to be used warm.
- Polarimeter design:
  - The right way: Two detector arrays observing the same field of view in orthogonal polarizations, preceded by half-wave plate
    - Maximum sensitivity, best rejection of atmospheric variations
    - At the cost of twice as many detectors per field of view.
  - Still worth doing: Polarization modulator in front of an array sensing a single polarization
    - Need edge of detector array "off source" to reject sky noise.
    - Use detector "total power" to track transmission variations.

Requirements on Telescope

- Would rather NOT have a radome:
  - JCMT, Goretex: 1%, 3% polarization at 850, 450 μm
- Oblique reflections and dichroics are to be avoided (prior to half-wave plate).
  - K-mirrors are undesirable field rotators since they polarize.
- Some polarimetrists would insist on a mechanical instrument rotator, but this is not essential.
- Avoid equatorial telescopes and the South Pole (no field rotation).
- Is a chopping secondary required for sufficient atmospheric rejection?

Polarization Uncertainty

$$\sigma(P) = \frac{2}{\sqrt{s}} \frac{\sigma(F)}{F}$$

$$\sigma(\theta) \approx \frac{90^\circ}{\pi} \frac{\sigma(P)}{P}$$

s = number of polarization states detected

Need photometric signal-to-noise of a few hundred to a thousand.

Extended Sources

$$S/N \propto \frac{\eta\sqrt{s}\left(1-\varepsilon_{atm}\right)\sqrt{\Delta\nu}}{\sqrt{\varepsilon_{atm}\left(1+n\right)}}$$

5× better than CSO at 350 μm?

$$n \propto \varepsilon_{atm}$$

η = Ruze factor

s = number of polarization states detected

ε_{atm} = atmospheric emissivity

Δν = bandwidth

Extended Sources

- For widely extended sources (nearby galaxies, dark clouds, IR cirrus), we don't necessarily need a big telescope
- Just a big field of view, high aperture efficiency, and a good site.

Point Sources

$$S/N \propto \frac{\eta A \sqrt{s}\left(1-\varepsilon_{atm}\right)\sqrt{\Delta\nu}}{\sqrt{\varepsilon_{atm}\left(1+n\right)}}$$

30× better than CSO at 350 μm?

$$n \propto \varepsilon_{atm}$$

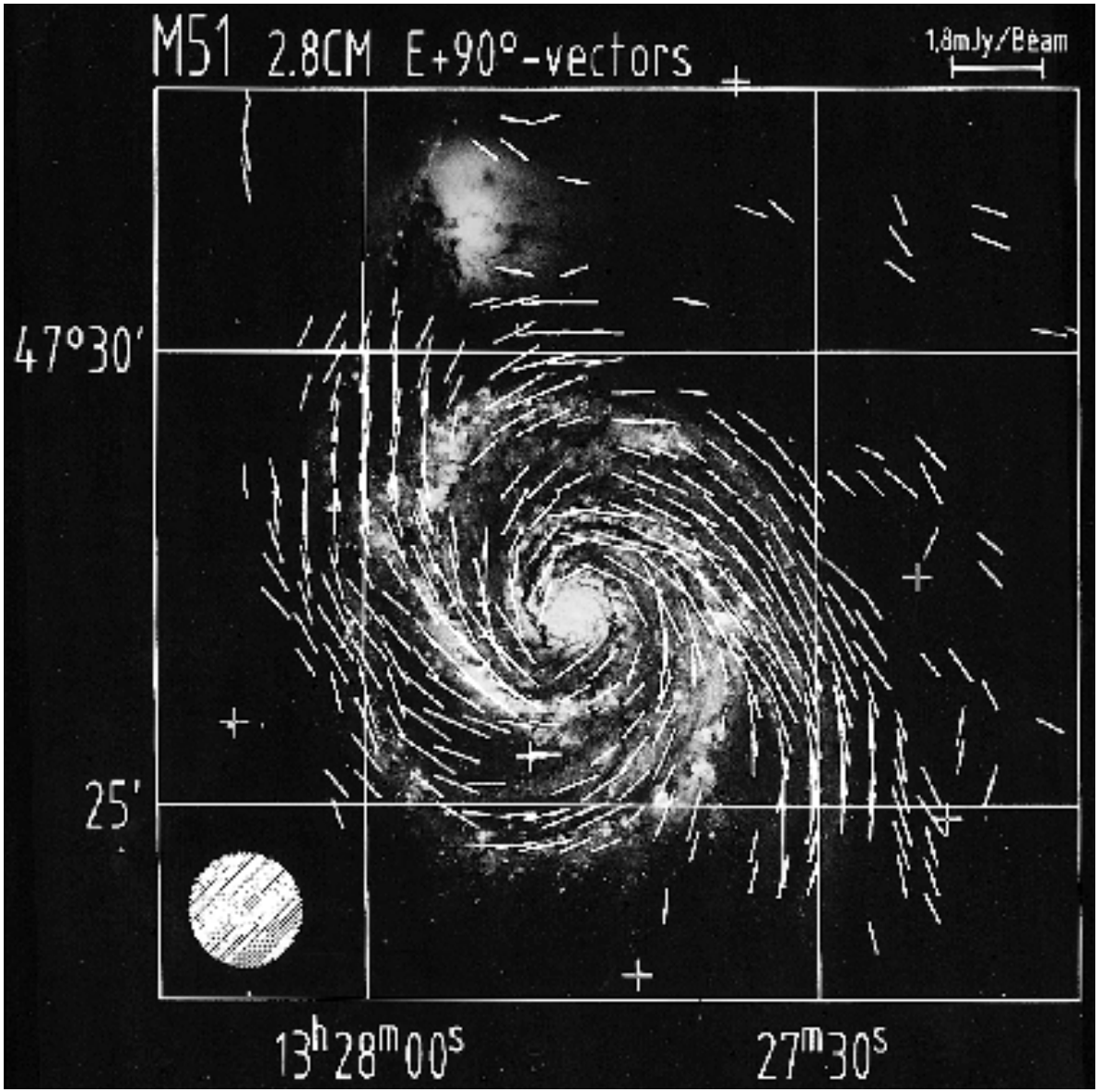
η = Ruze factor

s = number of polarization states detected

ε_{atm} = atmospheric emissivity

Δν = bandwidth

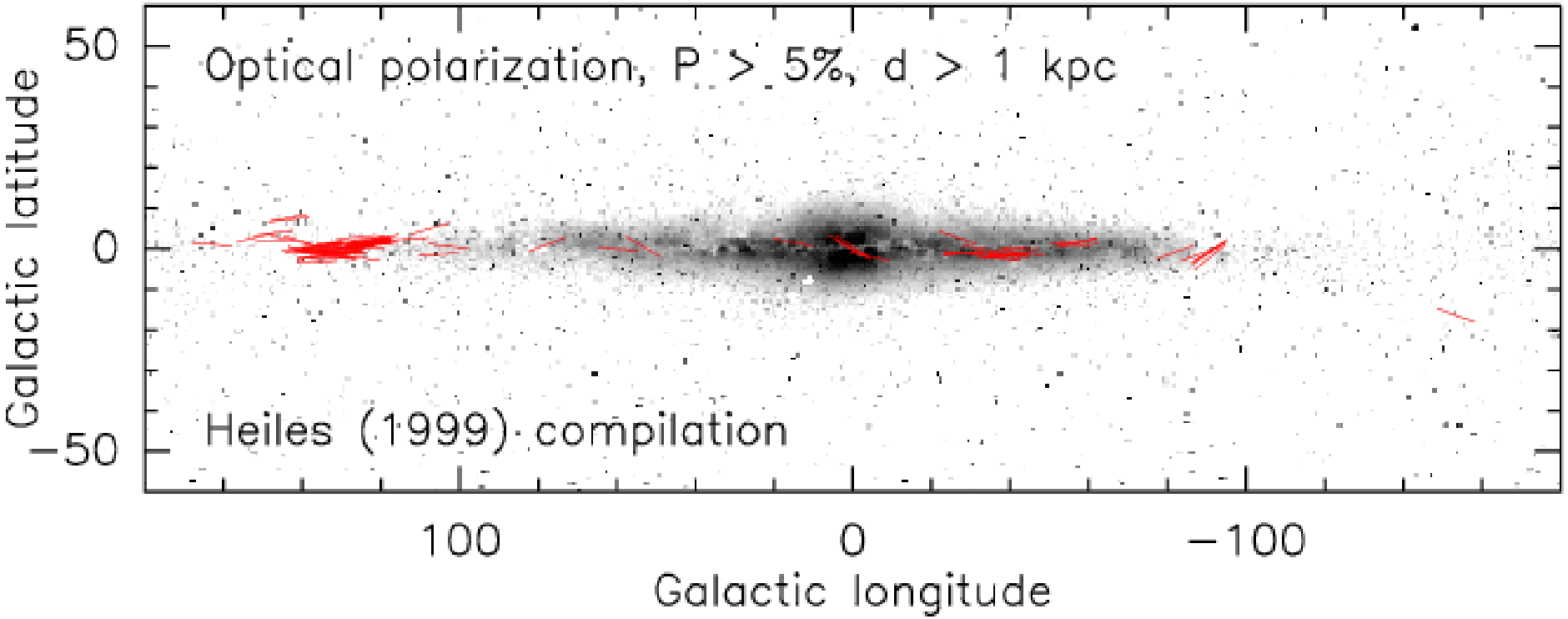
Evidence for ordered galactic magnetic fields



- Synchrotron emission from very diffuse ISM
- Magnetic fields along spiral arms

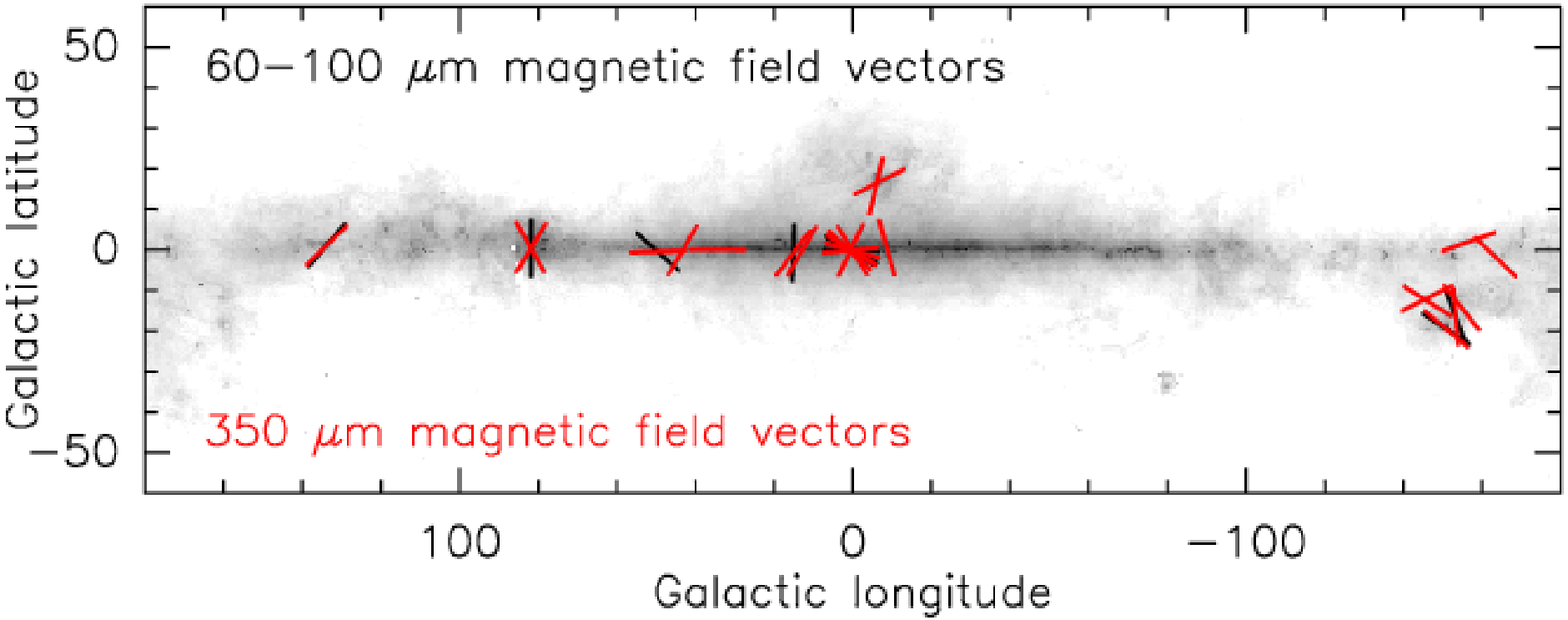
Berkhuijsen (1997)

Evidence for an ordered Galactic magnetic field



- Optical polarization samples diffuse ISM.
- Magnetic fields in the plane of the Galaxy.

Evidence for a disordered Galactic magnetic field



- For the dense ISM, the magnetic field component in the plane of the sky is nearly random with respect to the Galactic plane.

Barely-Resolved Sources

- Evolved stars – magnetic fields related to bipolar asymmetry?
  - Claimed detection of 850 μm polarization from CRL2688, but weak (0.3%); not aligned with axis (Greaves 2002)
- What about planetary nebulae?