Interstellar magnetic fields

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LOFAR CAPABILITIES IN THAT FIELD:

Measurements of polarized synchrotron emission of the ISM (including depolarization) at high angular resolution and high sensitivity

OUTLINE:

- Recent advances on large scale **B** morphology in the ISM:
  - polarization measurements (visible, submm)
  - Faraday rotation and dispersion measure
  - polarization of synchrotron emission
- Questions LOFAR could address.

LOFAR workshop, Meudon, 28-29 March 2006

Why B with LOFAR? Why diffuse medium? Why small scale?

• Polarization observations at high latitude:
minimize the depth of gas sampled and depolarization effects, takes advantage of LOFAR sensitivity and high angular resolution (nearby material) (1” at 100 pc = 100AU)

• Little is known on **B** at small scale in the diffuse medium:
On average in the diffuse ISM, observed equipartition:
$P_{CR} = P_{turb} = P_B > P_{therm}$
Turbulence viscous dissipation length in the cold diffuse medium $\sim$ 10AU
Density structure observed in the diffuse ISM at similar scales
Structure in **B** expected down to similar scales

• Why is **B** small scale structure important?
- effect of small scale (turbulent) field on the evolution of the large scale (mean) field e.g. loss of small scale magnetic helicity in dynamo
- mechanisms driving turbulence dissipation

Measurements of B direction

$B_\perp$ = **B** component in the plane of the sky

$B_\parallel$ = **B** component along the line of sight

Polarisation due to dust

Thermal dust emission $\perp B_\perp$,

Dust absorption $\parallel B_\perp$

Faraday rotation

$RM \propto \lambda^2 \int B_\parallel n_e dl$

n_e estimated from DM = plasma dispersion measure

$DM \propto \int n_e dl$

from $\Delta t \propto (\nu_1^{-2} - \nu_2^{-2})\, DM$ (pulsars)

$\rightarrow \langle B_\parallel \rangle = RM/DM$

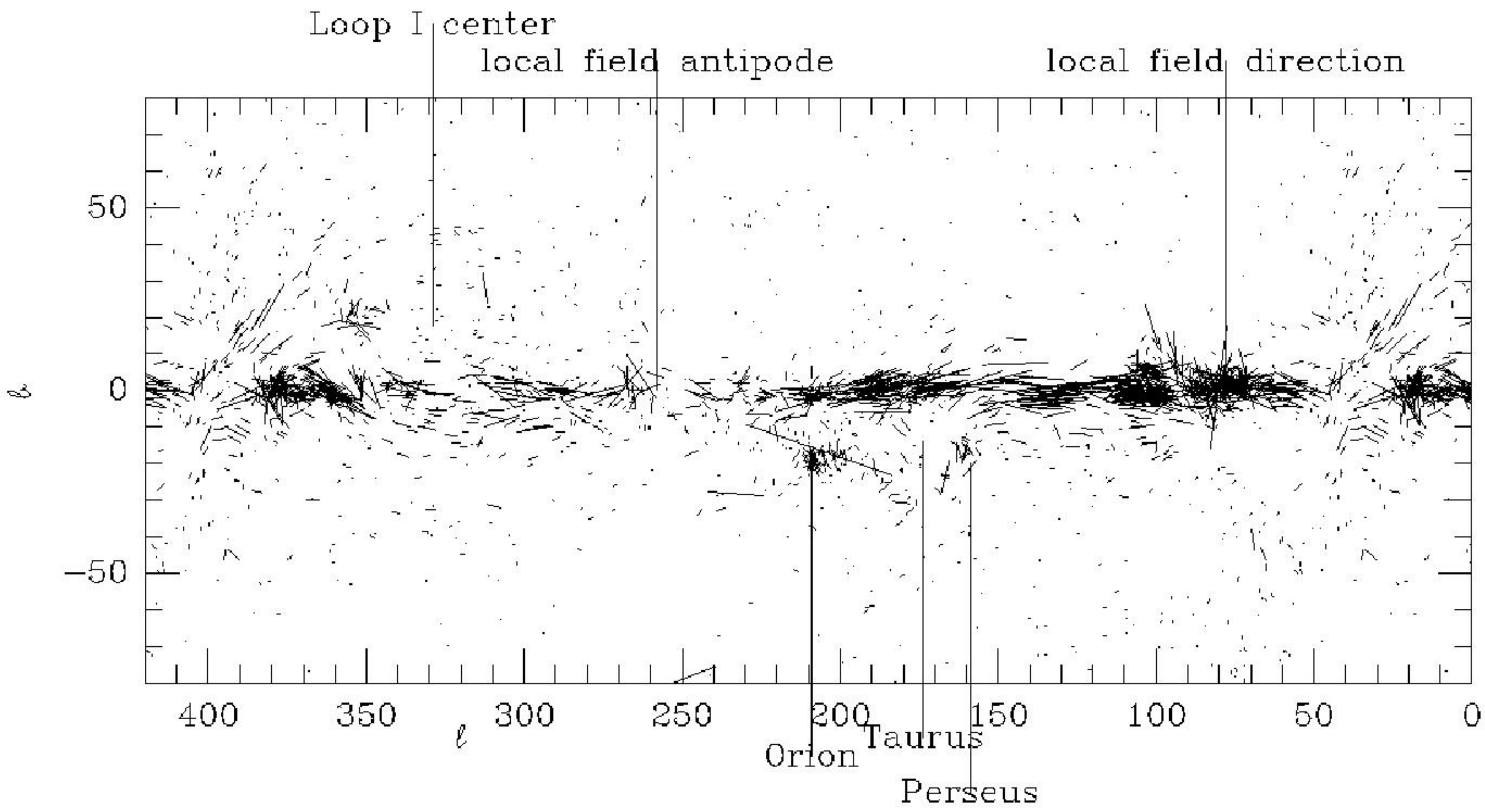
Polarisation of synchrotron emission

$I(\nu) \propto L B_\perp^{n+1} \nu^{-n}$

Energy spectrum of relativistic electrons $N(E)dE \propto E^{-p}dE$ and $n = (p-1)/2$

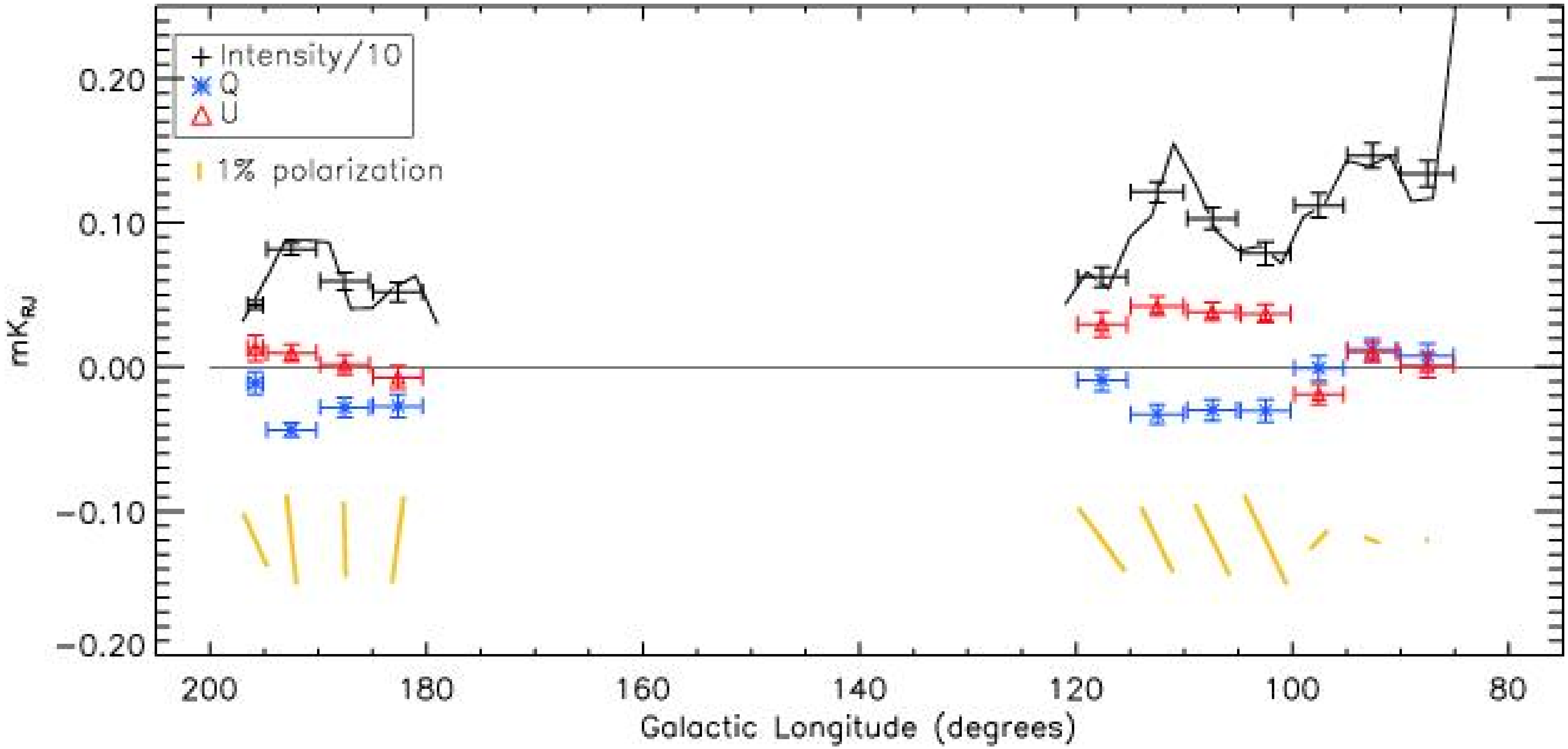
Emission linearly polarized $\perp B_t$

Optical starlight polarization due to dust absorption



10^4 stars, polarization $\parallel B_\perp$, max 3%, $B_u/B_r \sim 0.8$
(Crutcher, Heiles, Troland 2001)

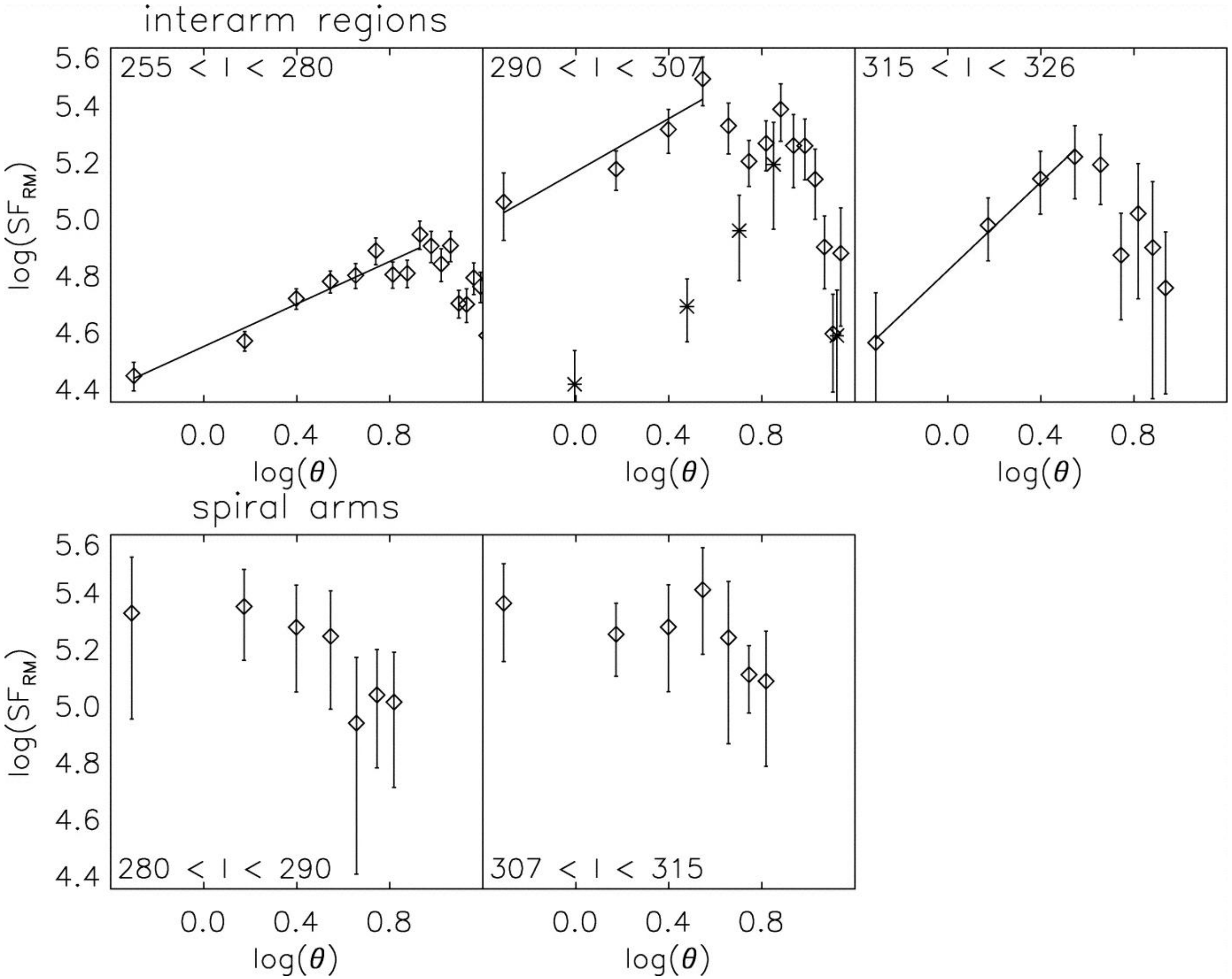
Polarization of diffuse dust emission: Archeops balloon 850 μm



Polarisation $\perp B_{\perp}$

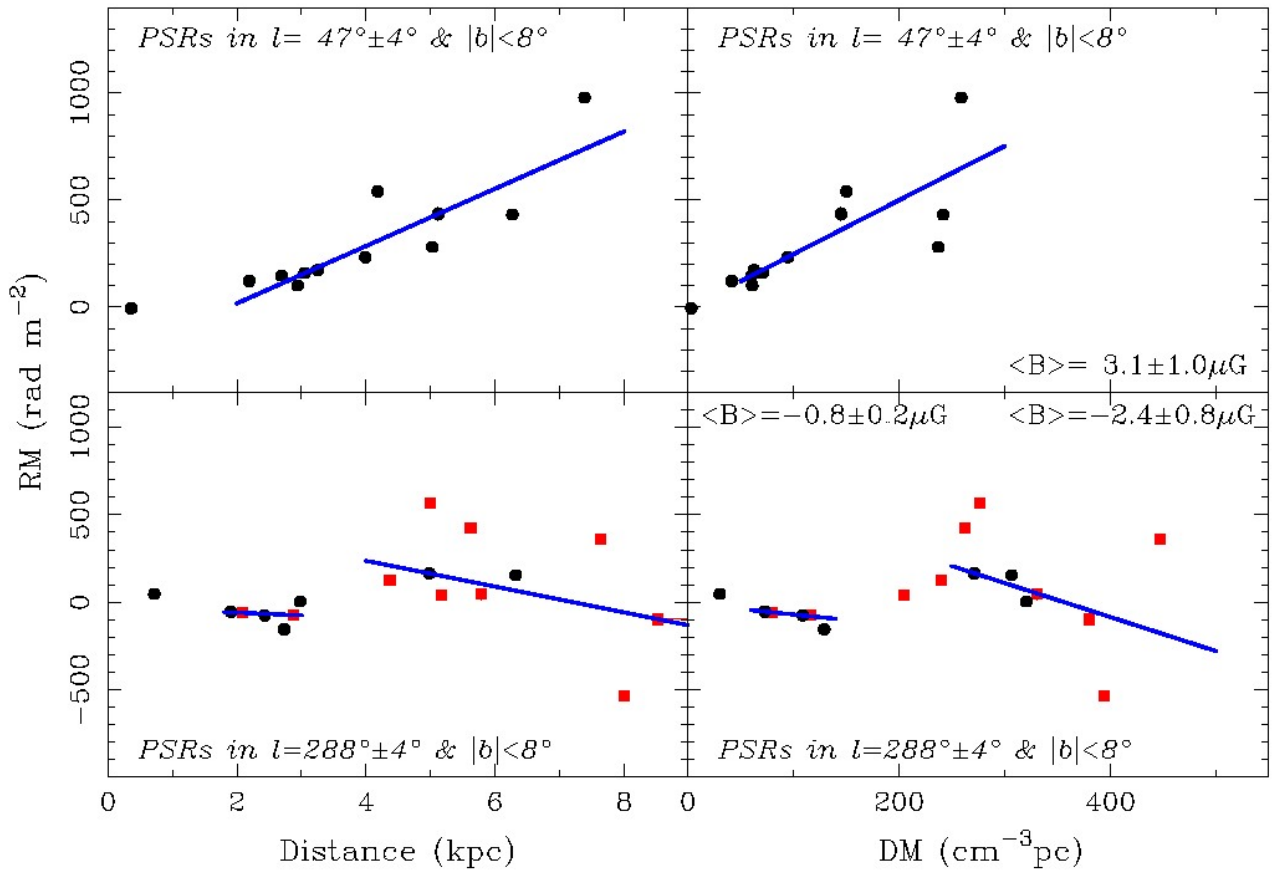
Average $|b| < 2°$ (Benoît et al. 2004)

Enhanced small scale Faraday rotation in spiral arms



RM structure functions: more field coherence between arms (Haverkorn M. et al. 2006)

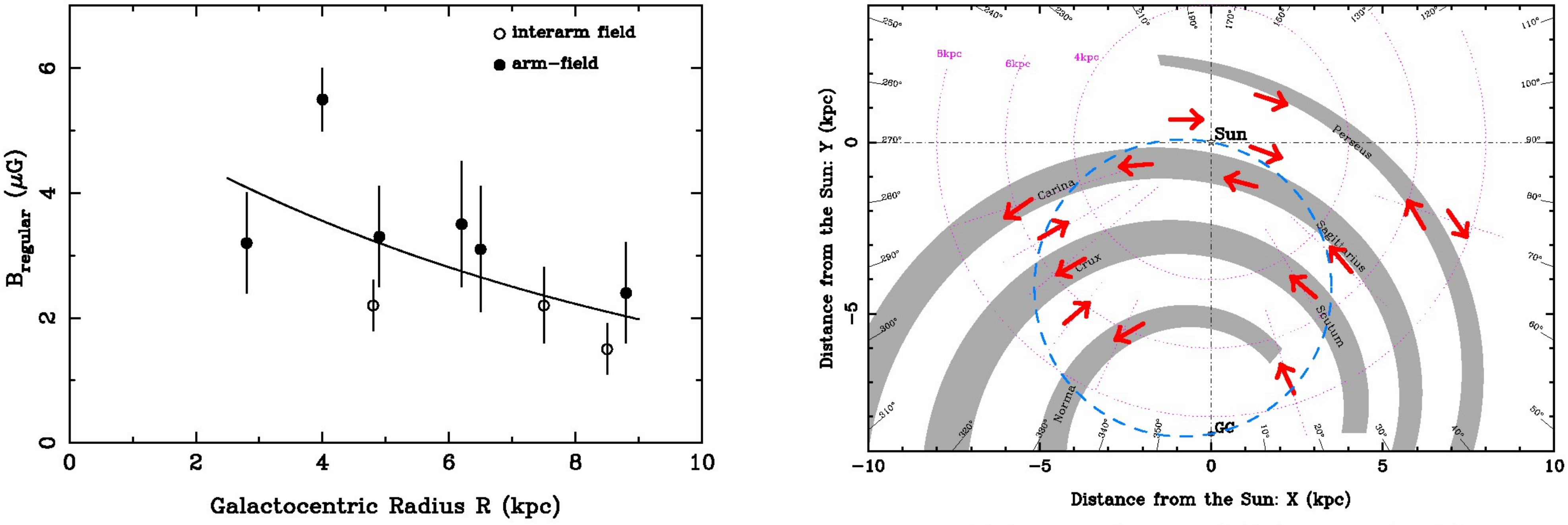
Examples of B determinations from RM/DM



223 RM measurements, (Han et al. 2006)

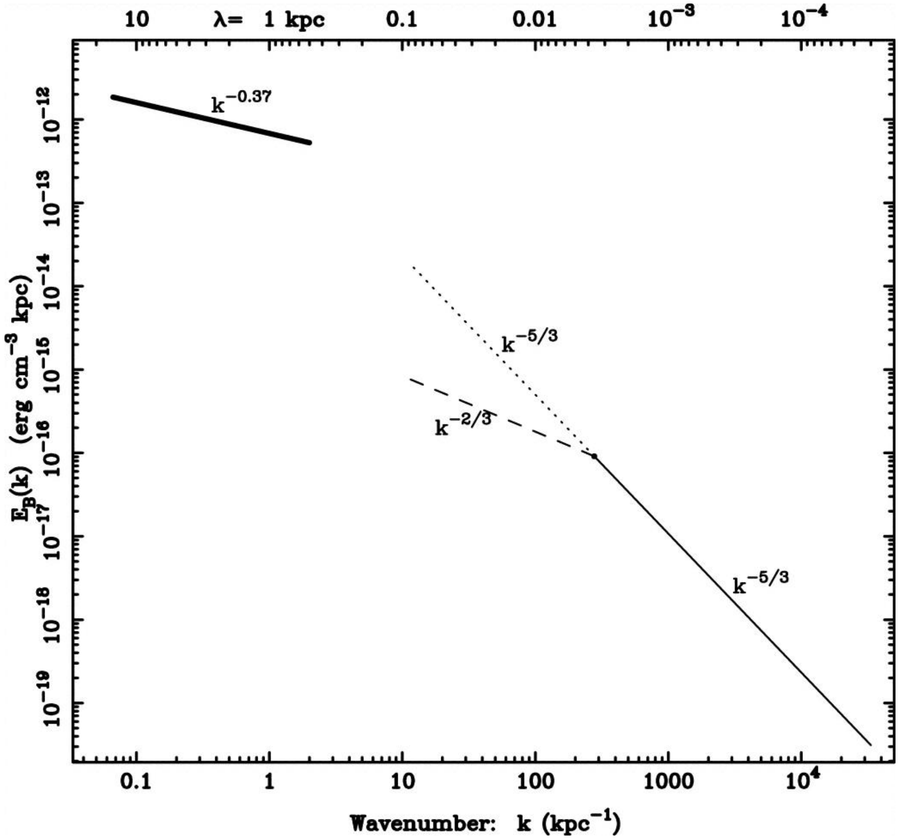
Arm/Interarm field: intensity and reversals

8 Han et al.



Han et al. 2006

Composite magnetic energy spectrum



Han, Ferrière & Manchester 2004

Combined RM/DM of 490 pulsars known distances, up to 10 kpc

$E_B(k) = Ck^{-\alpha}$, $\alpha = -0.37 \pm 0.10$,

$B_{rms} \sim 6\mu$G

Small scale spectrum from high latitude field, Hα data

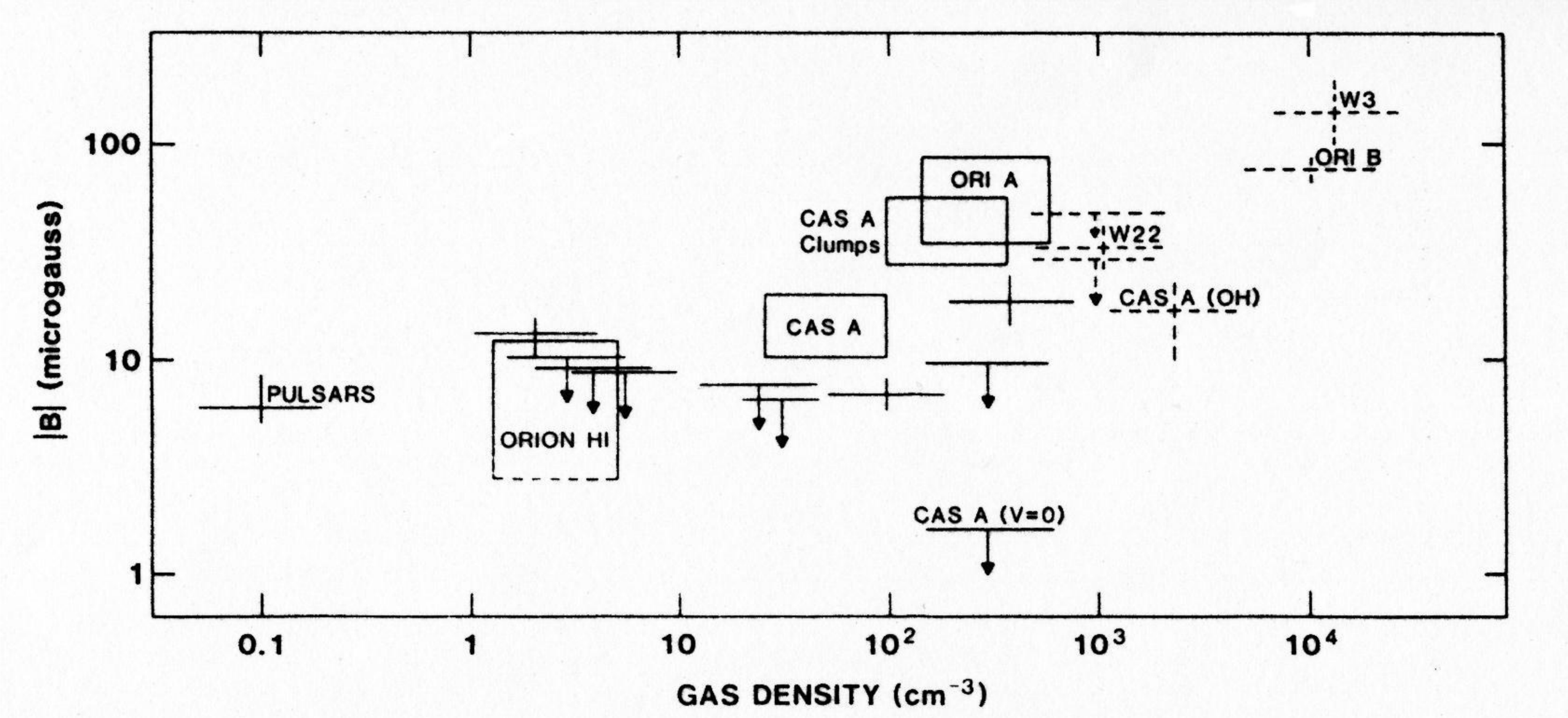
(Minter & Spangler 1996)

3 pc $< l <$100pc, uncertain 2-D turbulence

Possibly significant discontinuity at $\sim$ 80 pc:

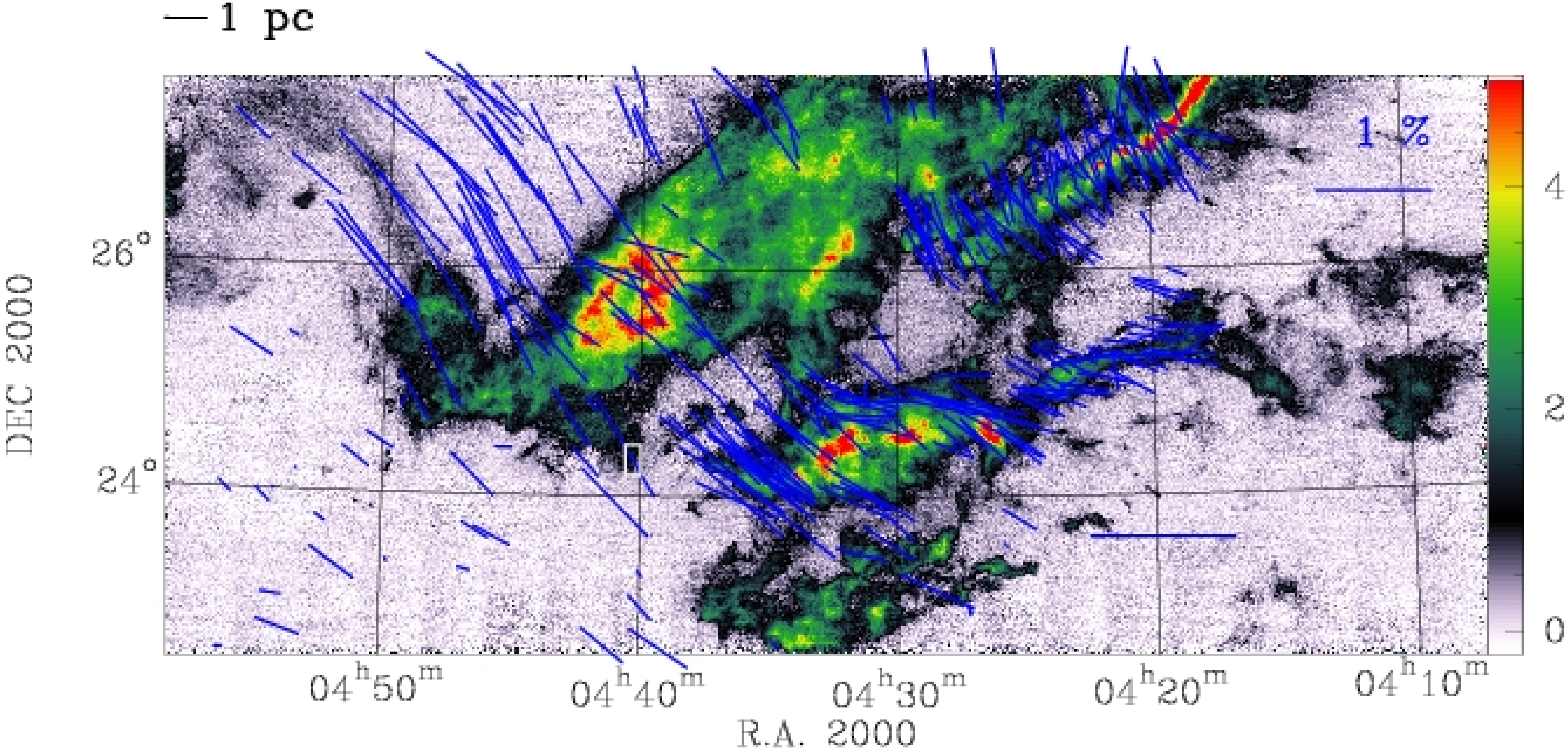
- energy injection scale: inverse cascade of magnetic helicity, direct cascade of magnetic energy
- spectra of different regions

B versus average gas density



HI, OH Zeeman splitting, synchrotron radiation
(Heiles & Troland)

Complexe du Taureau: ^{13}CO et champ magnétique

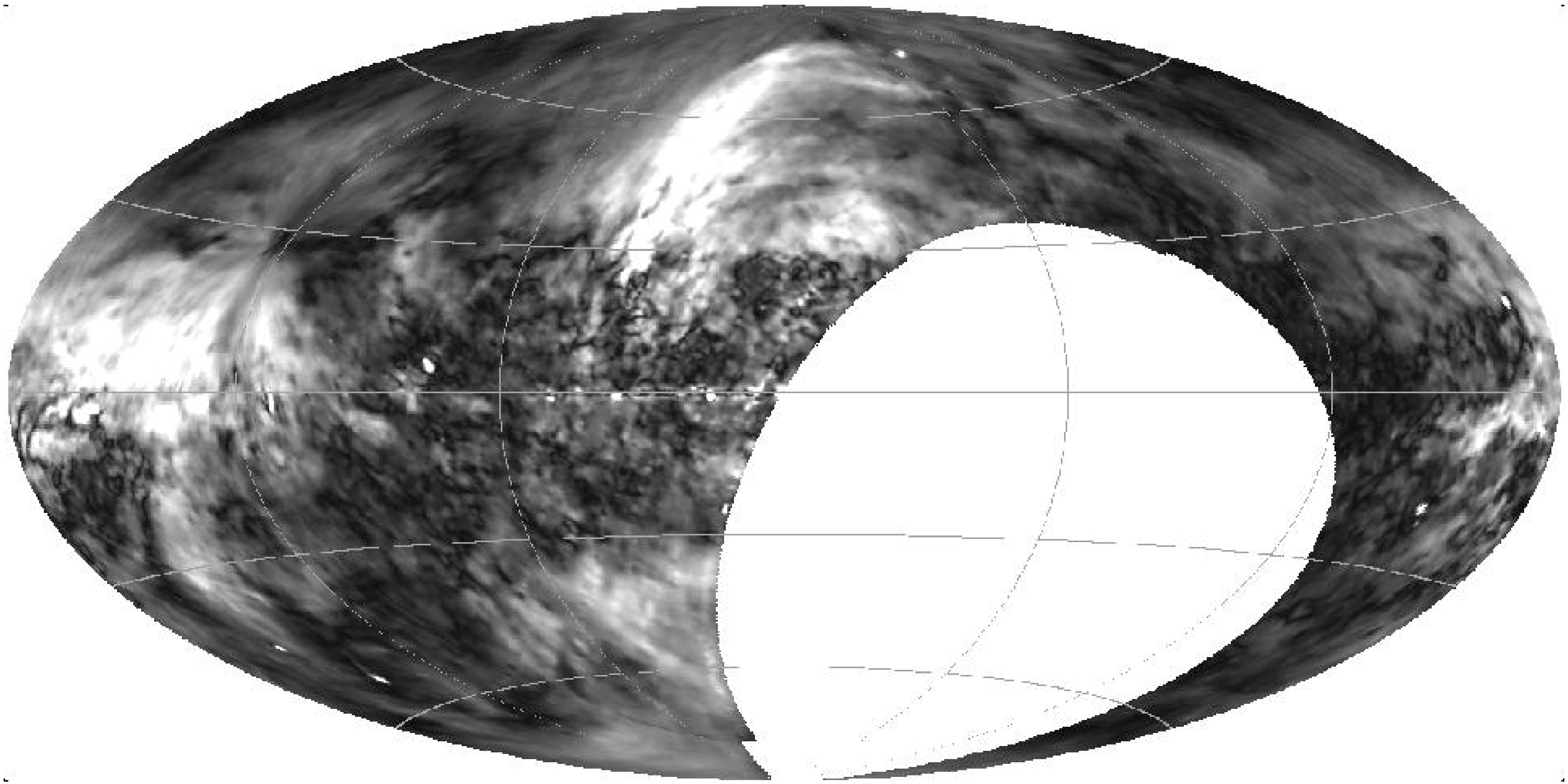


P. Hily-Blant (thèse),
Golsdmith et al. (in prep.)

Summary: B observations in the interstellar medium

- **difficult** (required sensitivity, instrumental biases, sky) but **agreement** between different methods
- large scale **field reversals** at the edge of spiral arms
- interarm field **more coherent** than in spiral arms
- arm & interarm field intensity increases towards the Galactic center
- large range of scales involved, **statistical methods in their infancy**
- field close to **equipartition** with supersonic turbulence in the cold medium
- $B \propto n^{1/2}$ only above a **density threshold**
- some large scale coherence of field direction in molecular clouds

Polarized intensity of the Northern sky at 1.4 GHz



DRAO survey (Canada), resolution 36', Wolleben et al. (2006)

Depolarization structures (dark small spots) $\sim 1^{\circ}$ thick

A few questions connected to LOFAR capabilities

• random component versus regular component of **B**?
- Estimate of $B_\perp$ with Chandrasekhar & Fermi (1953) method:
$B_\perp = Q\sqrt{4\pi\rho}\delta v/\delta\phi$
$\delta\phi = \delta B_\perp / B_\perp$
δv = gas velocity dispersion (provided by linewidths)
$Q \approx 0.5$ from numerical simulations (Ostriker et al. 2001)
- at large scales $B_r \sim B_u$
- $B_r \parallel B_u$ implies field reversals
- RM pulsars $B_r \sim 5\mu$G, $B_u \sim 1.5\mu$G at high galactic latitude

• high energy particles in the cold diffuse medium: confinement? spatial distribution?

• intermittency of magnetic field (large local fluctuations of B intensity)?

• link between ionized & neutral small scale structure (depolarization)?
observed threshold in electrons density fluctuations at $\sim 10^9$ cm (Armstrong, Rickett & Spangler 1995)

Workshop on this issue:

SINS in the ISM

http://astro.berkeley.edu/SINS/program.html

Socorro, May 21-24 2006, deadline registration March 31