Magnetic fields and turbulence in molecular clouds : observations from 30-parsec to milliparsec scales

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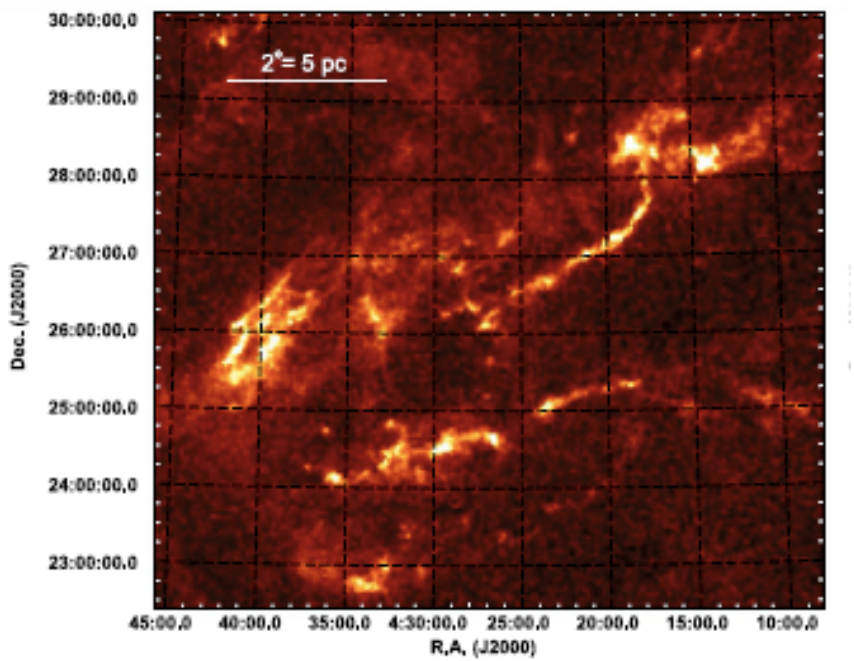
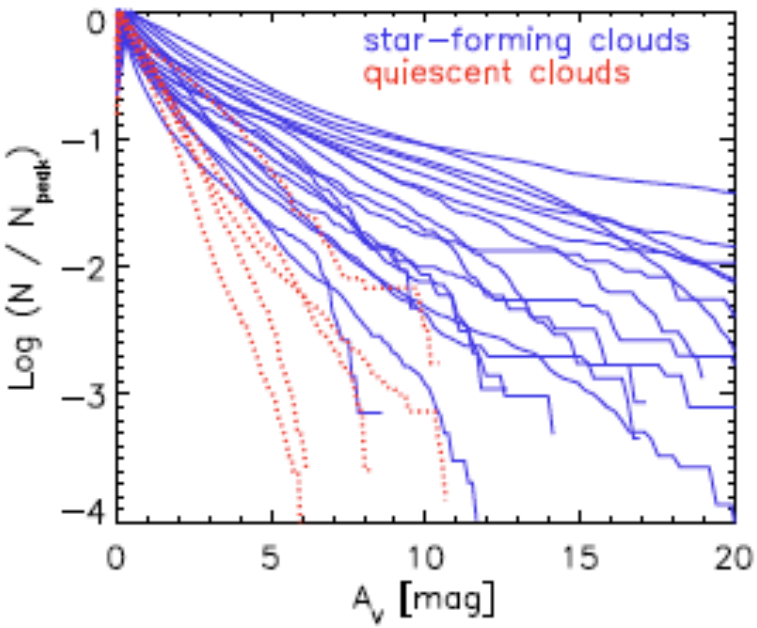
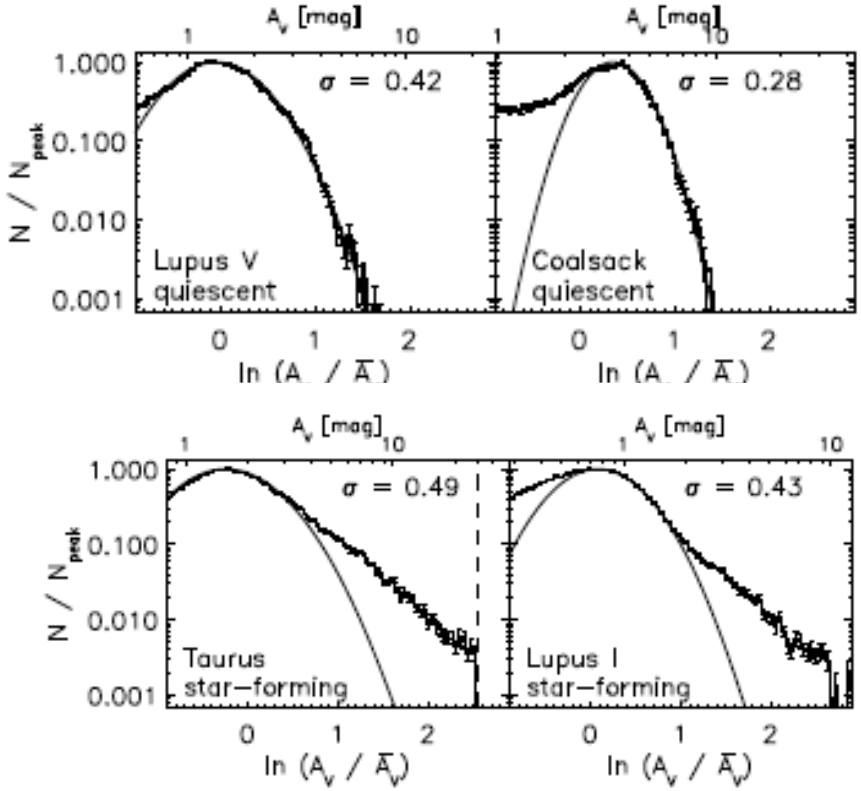
Bimodal distribution of gas column densities in molecular clouds





Kainulainen et al 2009



Av < 3 – 5 mag : turbulent + B dominated

Av > 3 - 5 mag : gravity + B + ?

Outline

- Statistics of B_{POS} orientation at the 30-pc scale
- B_{POS} and intense velocity-shears at the pc scale
- B_{POS} and shear-layers at the mpc-scale
- $B_{//}$ intensity from diffuse medium to dense cores

Tools :

- Starlight polarization
- Spectro-imagery at high spectral and spatial resolution in the CO rotational lines
- Zeeman effect observations in the HI, OH and CN(1-0) lines

1 – Turbulent and magnetic energy at the 30 pc- scale

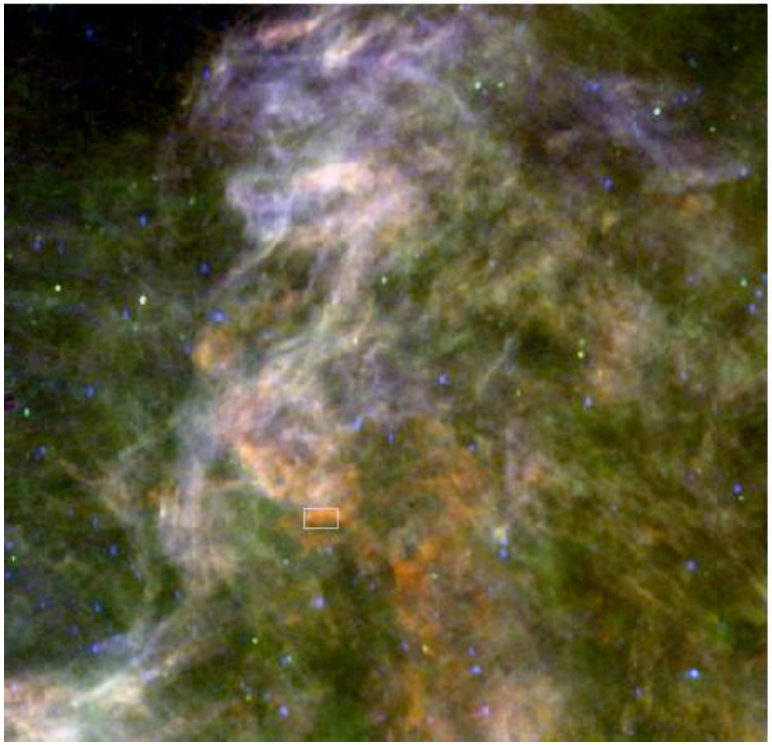
- Comparison of virialized (Taurus Complex) and non-virialized (Polaris Flare) fields
- Chandrasekhar-Fermi method :

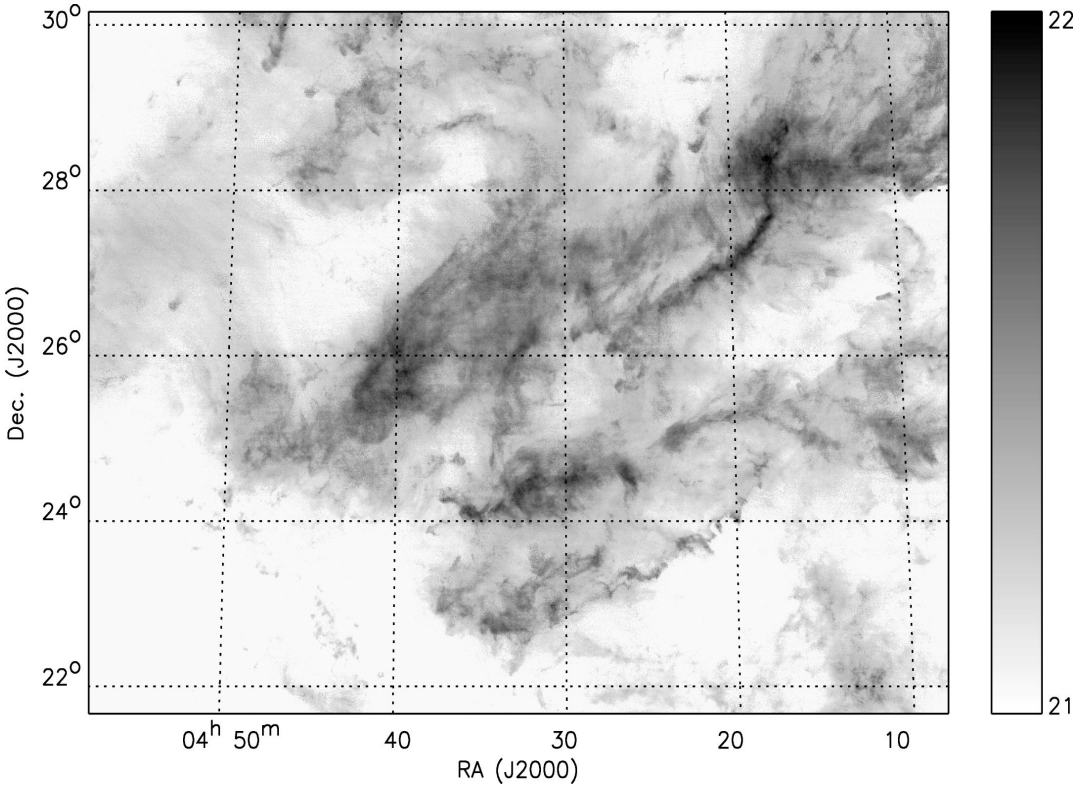
$$B = 6.6\, n_H^{1/2}\, (\Delta v / \delta\phi)\ \mu G$$

$$E_{mag} / E_{turb} = (38^o / \delta\phi)^2$$

Valid for $\delta\phi < 25^o$ (MHD simulations Ostriker et al. 01)

Two 30-pc scale fields :





Polaris Flare

FIR map Miville-Deschênes et al.

Δv =4.8 km/s

Taurus-Auriga complex

$N(H_2)$ map Goldsmith et al. 08

Δv = 3.8 km/s

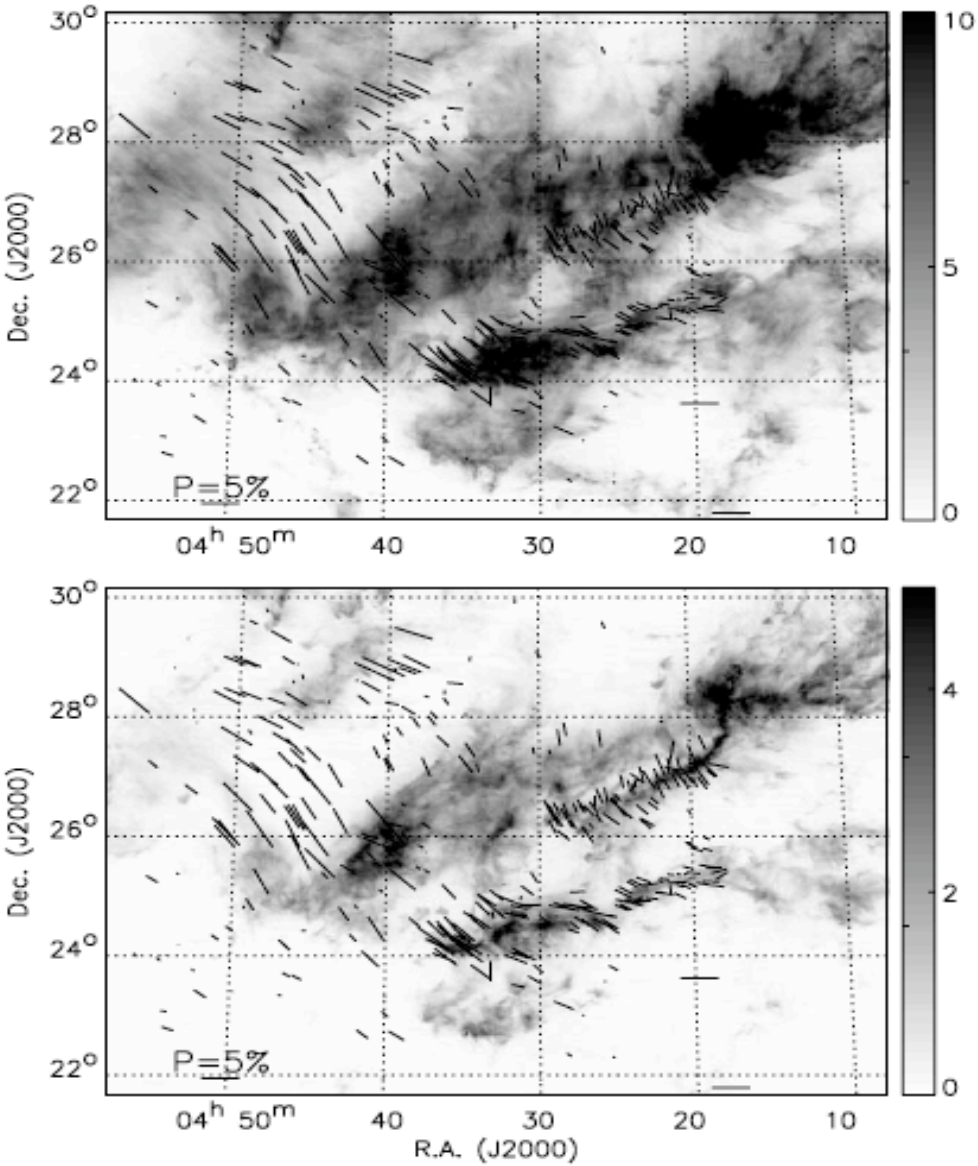
Comparable virial masses @ 30pc : $M_V = 4.4 \times 10^4\ M_{sun}$

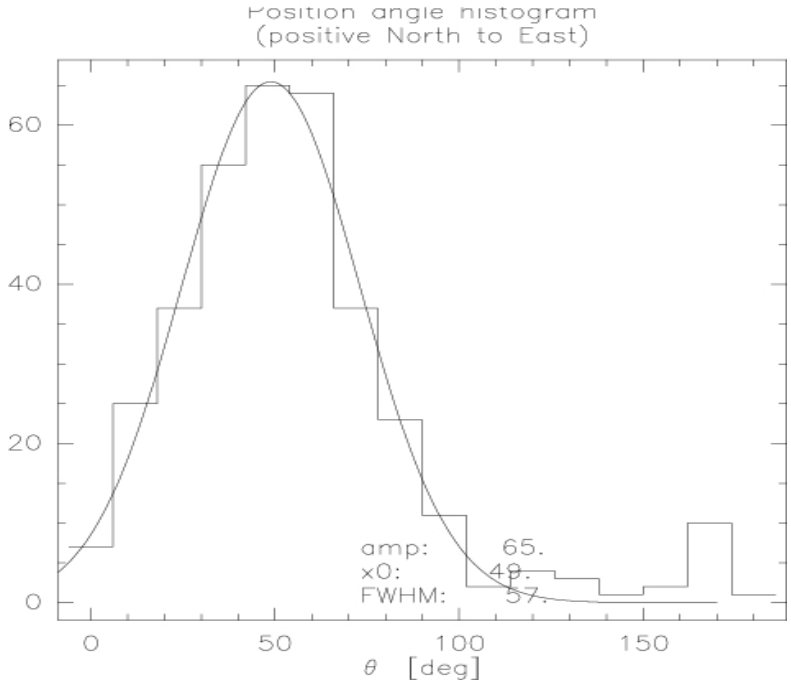
Taurus Complex : $M_{gas} \approx M_V$

Polaris Flare : $M_{gas} = 5 \times 10^3\ M_{sun} = M_V/6$

^{12}CO(1-0) (top)
^{13}CO(1-0) (bottom)

Taurus complex

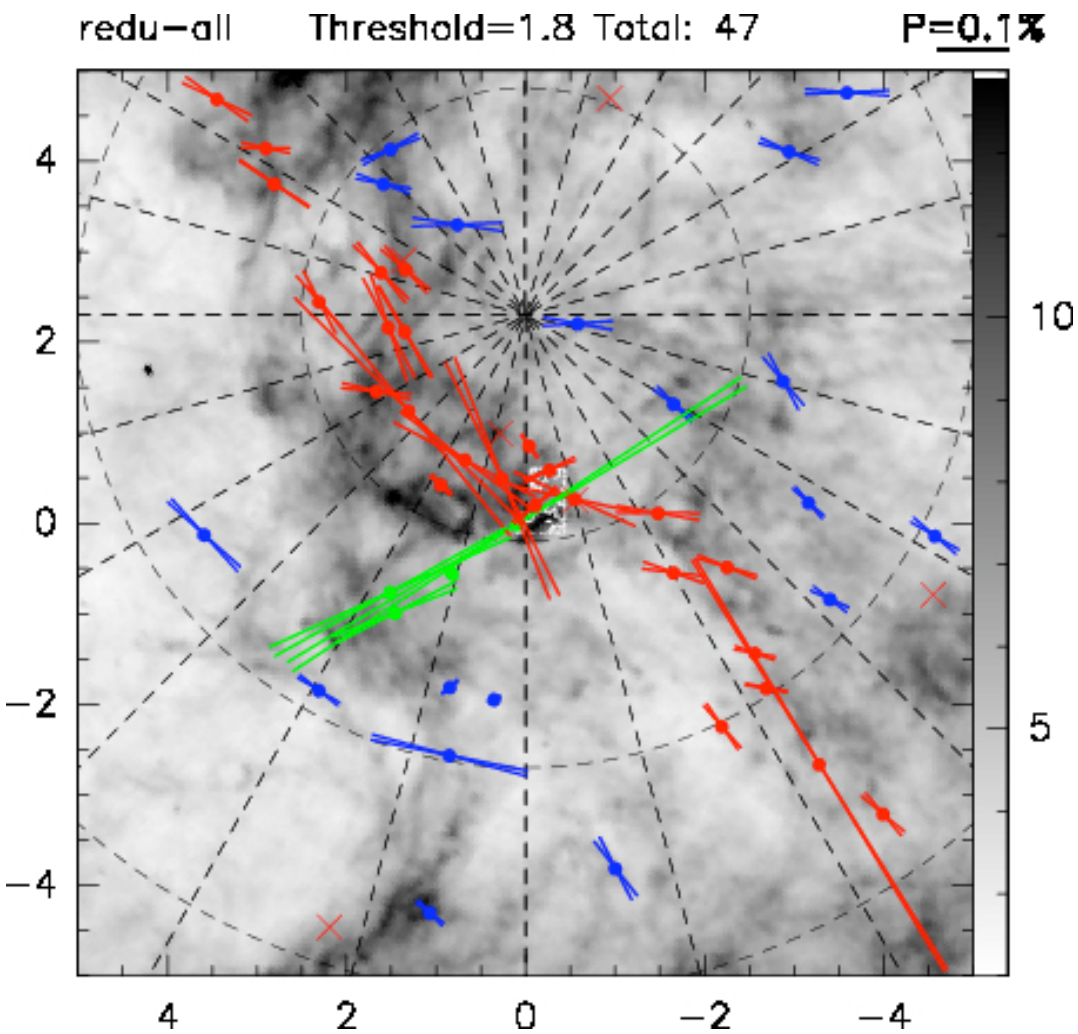




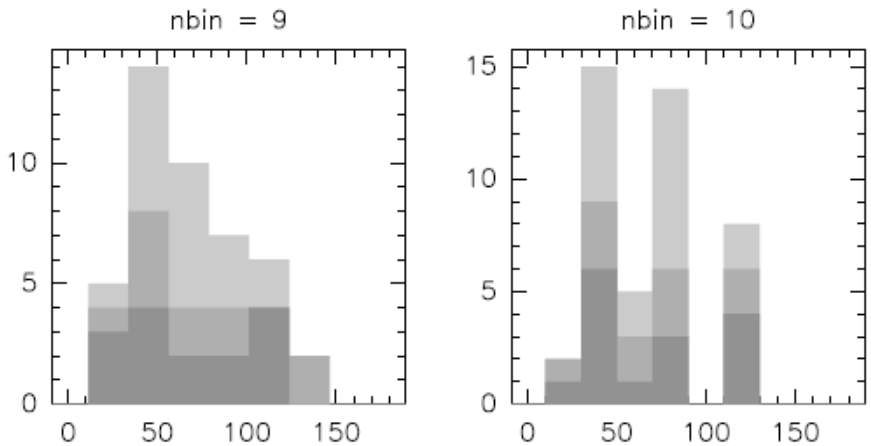
$\delta\phi = (24 \pm 5)^{o}$

$E_{mag}/E_{turb} = 2.5$

Polarisation measurements Heiles 2000



Polaris Flare



$\delta\,\phi = 19^{o}$

Non Gaussian PDF: 3 more common PA

$E_{mag} / E_{turb} \approx 4.0$

Hily-Blant et al.
in preparation

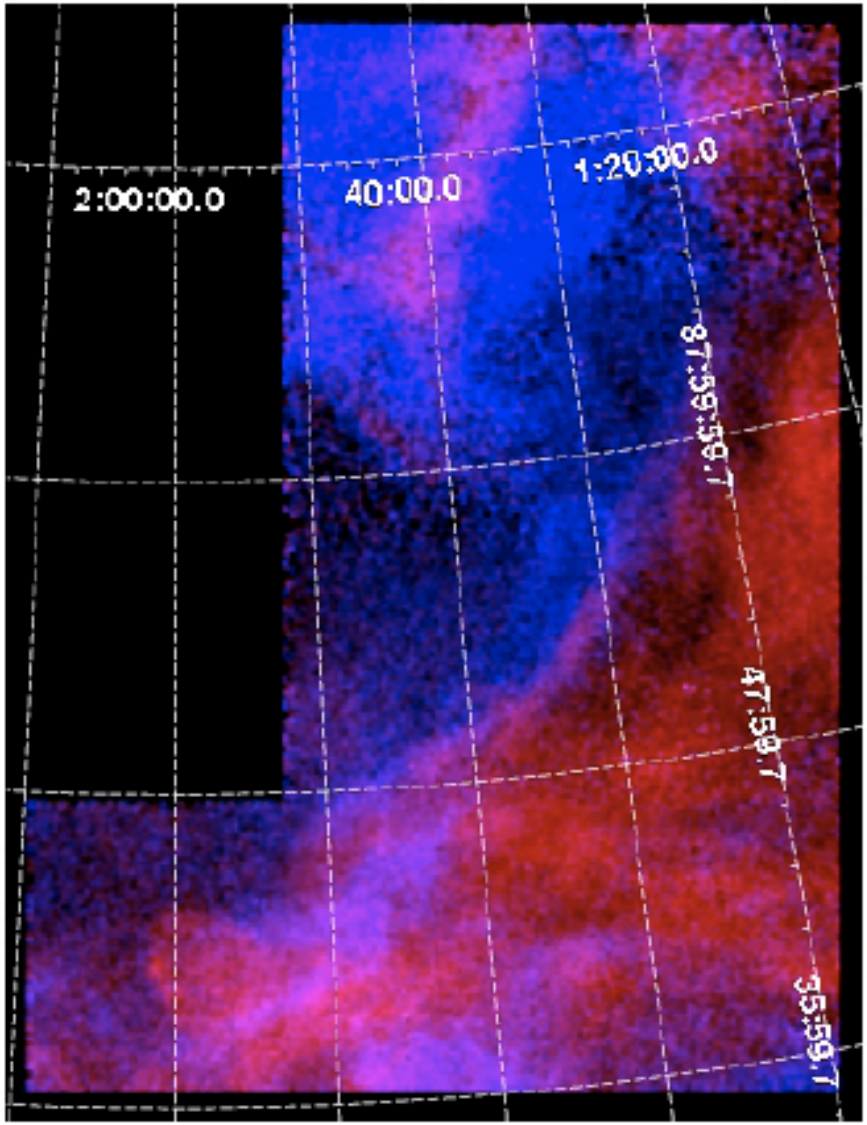
At 30 pc-scale , $E_{mag} > E_{turb} \geq E_{grav}$

2 – B_{POS} and velocity-shears at the parsec-scale

- Statistics on velocity field based on CO line-centroid-velocity (CV) in translucent fields
- Departure from Gaussian statistics
- Comparison of plane-of-sky projection of magnetic fields B_{POS} and locus of extreme CV increments (E-CVI) : extrema of Ω_{POS}

  Hily-Blant & Falgarone 09

Parsec-scale field in the Polaris Flare



Hily-Blant & Falgarone 2009

IRAM-30m, HERA mosaic,
On-The-Fly + FS mapping,

Polaris Flare
$A_v = 0.6$ to 0.8 mag
^{12}CO(2-1) line

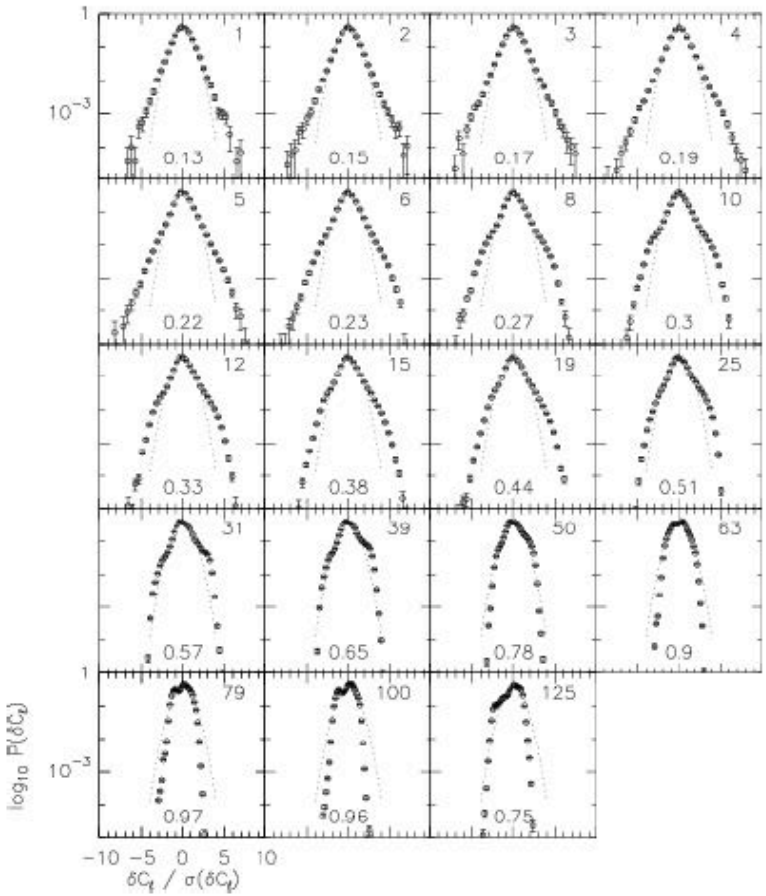
1.5 million spectra,
$\sim 10^5$ independent spectra,

Field size: 43′× 33′, ∼ 2 pc
Pixel size: 7.5 mpc

Small spatial overlap of the two velocity components

PDF of centroid velocity increments with variable lags

Polaris



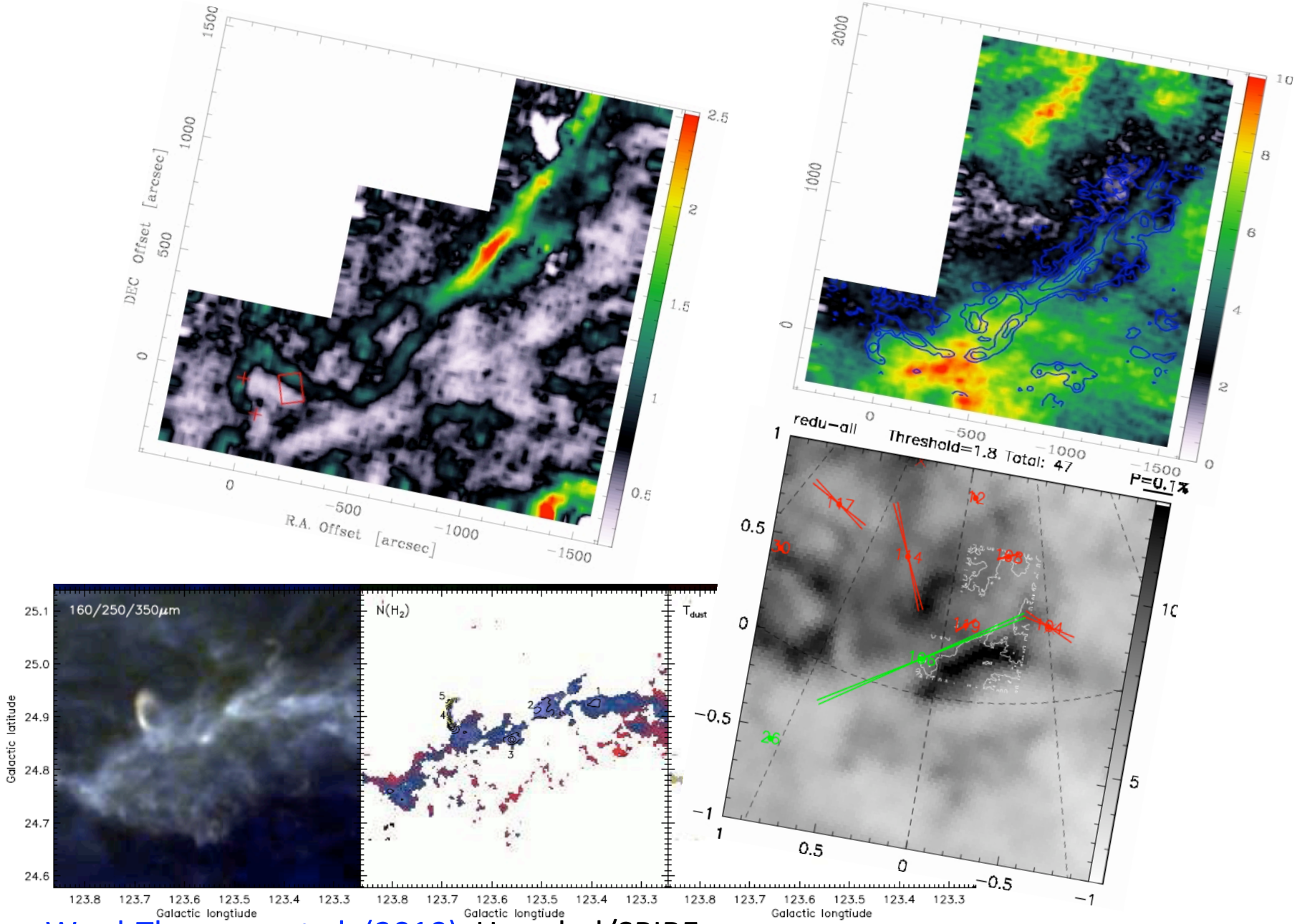
- Non-Gaussian tails increase at smaller lags : more and more rare events
- Locus of these events :

E-CVIs ~ extrema of Ω_{POS} (Lis et al 1996)

- Intermittency of turbulence

Hily-Blant, Falgarone, Pety 2008

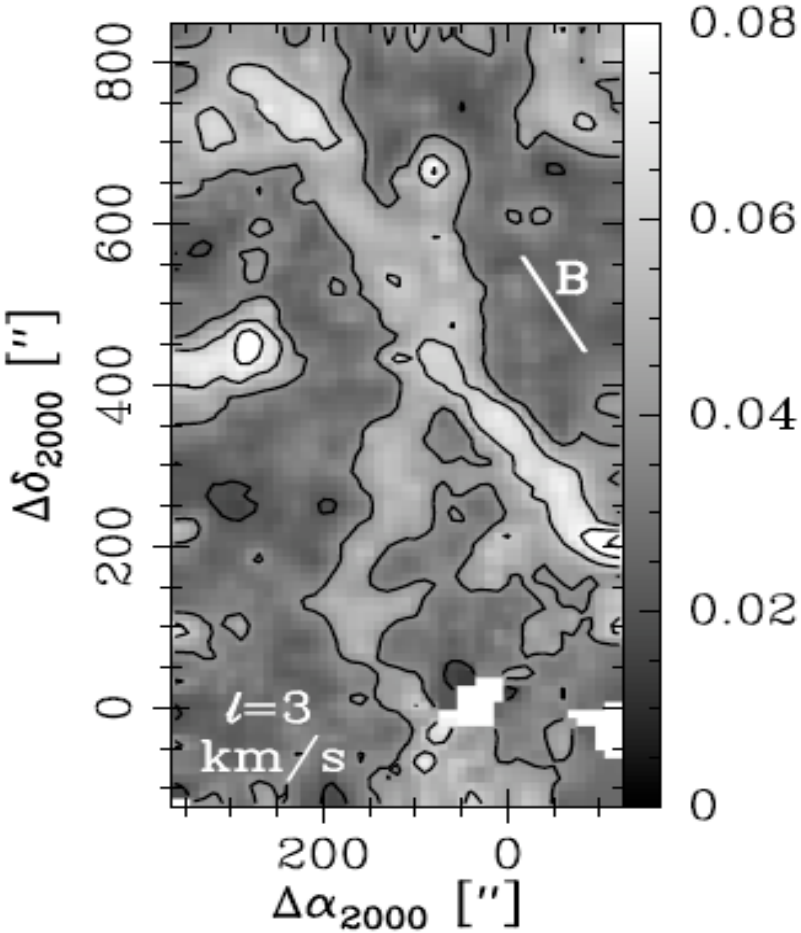
Spatial distribution of extreme CVIs (1)



Ward-Thomson et al. (2010) Herschel/SPIRE

Spatial distribution of E-CVIs (2)

Taurus edge



Taurus edge :

B_{POS} // Ω_{POS} : one close measurement

Polaris Flare :

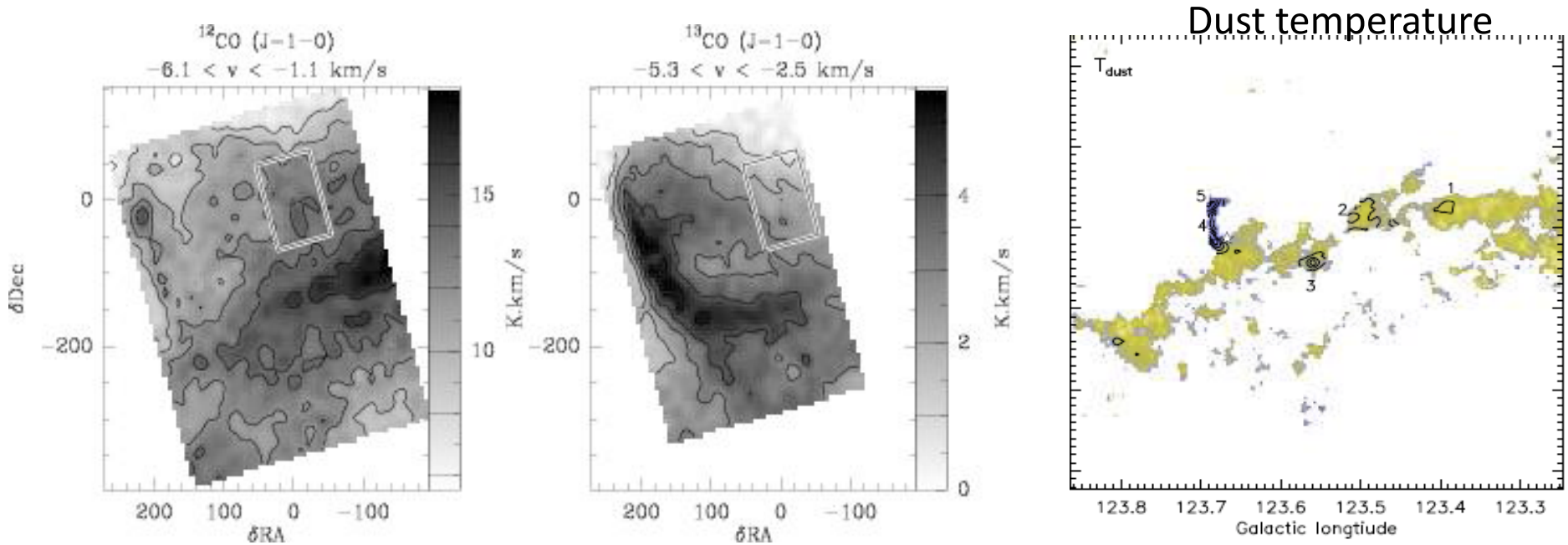
Specific orientations of B_{POS}

Sharp PA changes

No close measurement

Ω_{POS} //B_{POS} at parsec-scale

3 – B_{POS} and shear-layers at milliparsec scales



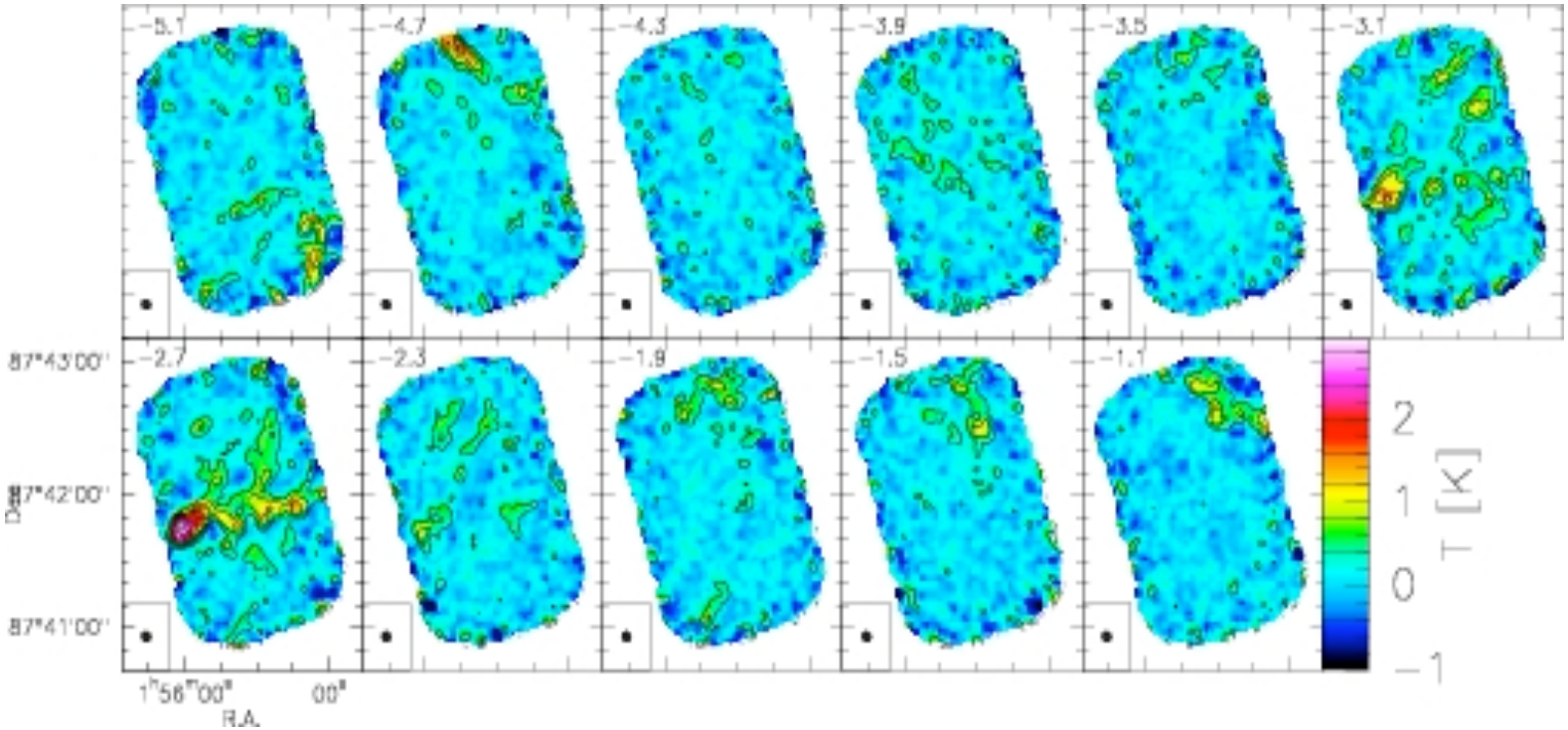
IRAM-PdBI CO(1-0) line. Mosaic of 13 fields, 180 hours integration

Pixel size : 3mpc (4 arcsec)

Field size : 0.09 pc x 0.045 pc

Translucent field with no structure visible at 0.01 pc resolution

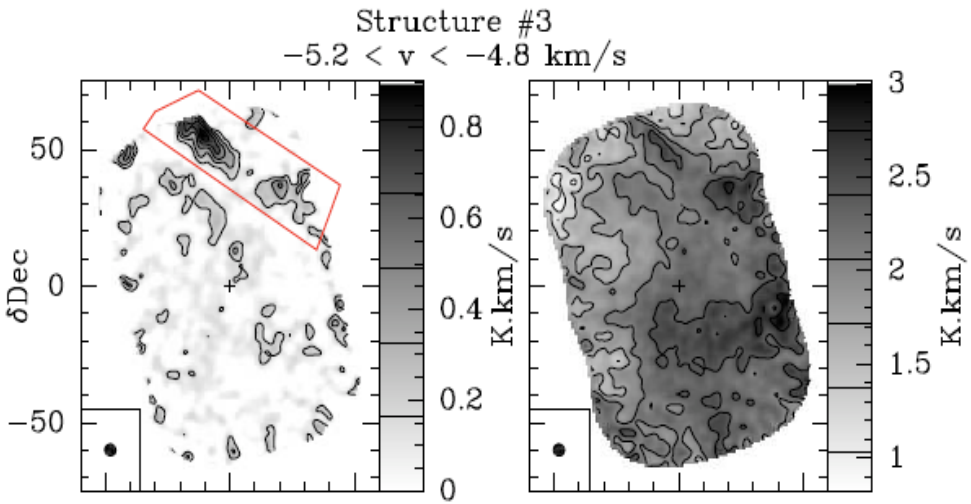
Structure at the milliparsec scale

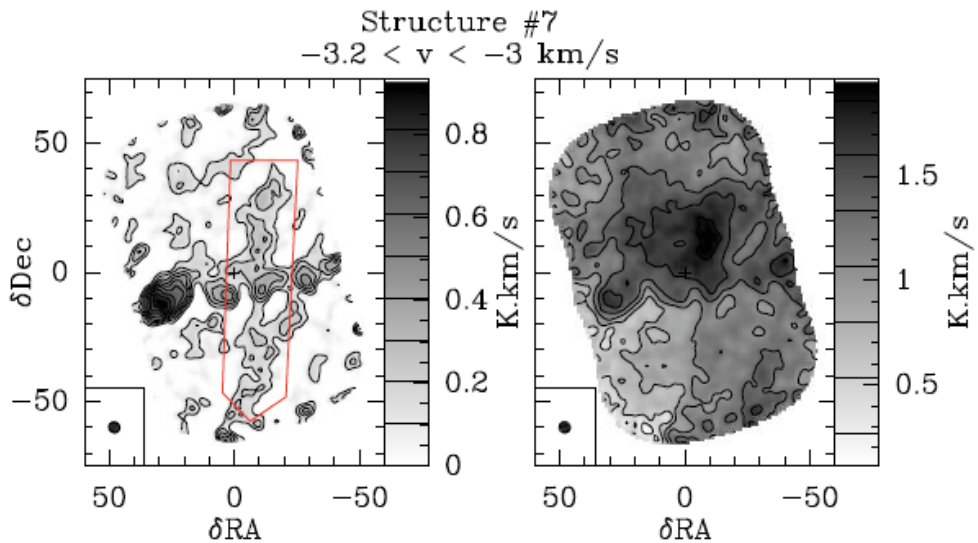


- 8 straight structures detected, thickness 3 to 11 mpc
- Specific PA
- Specific velocities (empty channels)

Falgarone, Pety, Hily-Blant 2009

Not filaments : sharp edges of thin extended sheets of CO emission

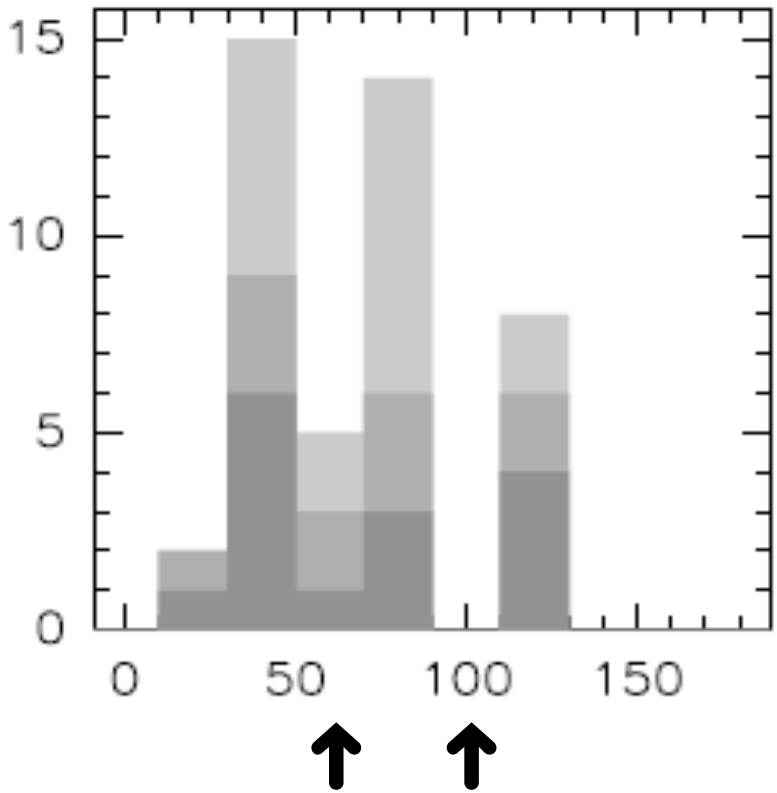


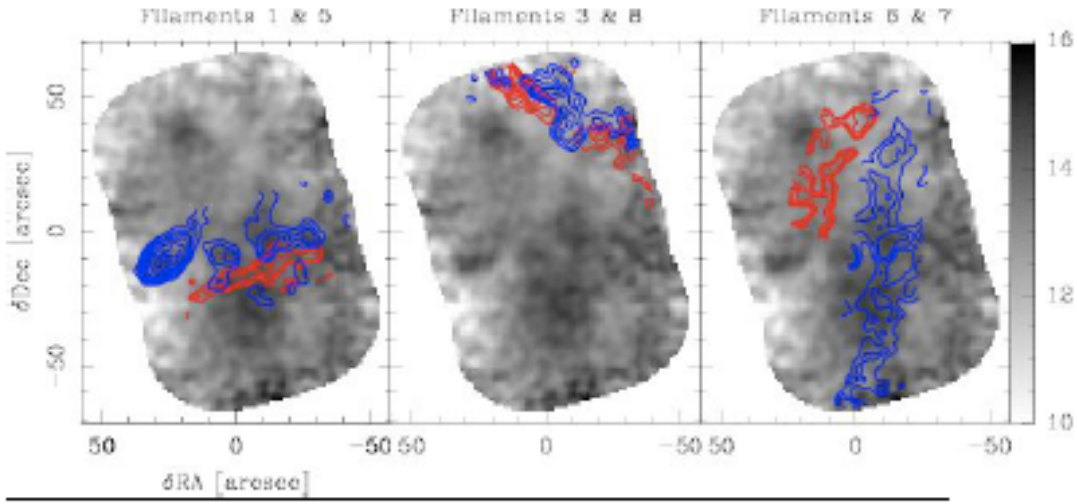


CO emission in 2 velocity ranges : seen by the IRAM-PdB interferometer (left) and merged with short spacings from IRAM-30m (right)

4 edges form pairs of parallel structures of high velocity shear : milliparsec scale shear-layers

Comparison with B_{POS} orientations at the 30-pc scale





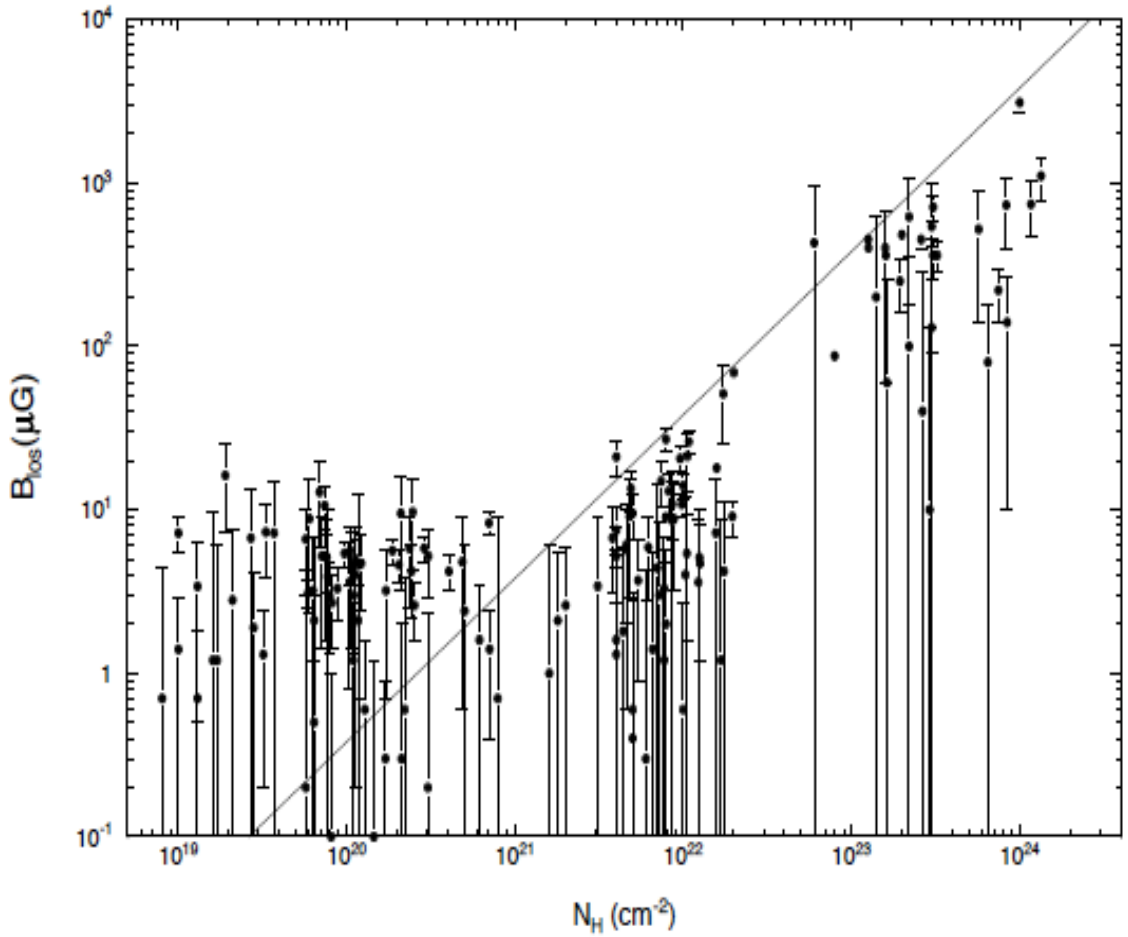
Pair	$\Delta v_{los}/\Delta l_{pos}$ km s^{-1} pc^{-1}	PA °
1, 5	264	109-91
3, 8	465	62-59
6, 7	6	161-173

The lessons of the milliparsec scales

- Layers of most intense velocity-shears at mpc-scales and **B** lie in parallel planes : quasi-parallel projections on the plane-of-sky → B_{POS} // Ω_{POS}
- Coherence of orientations across scales
- Velocity increments in shear-layers at mpc-scales of same order as rms velocity of large scale turbulence (2 to 4 km s^{-1}) → wide scale separation
- Largest observed velocity-shear: 3.5 km s^{-1} over 7 mpc or 500 km s^{-1} pc^{-1} or equivalent timescale ≈2000 yr

  → short timescales

4 - HI, OH, CN Zeeman measurements (1)

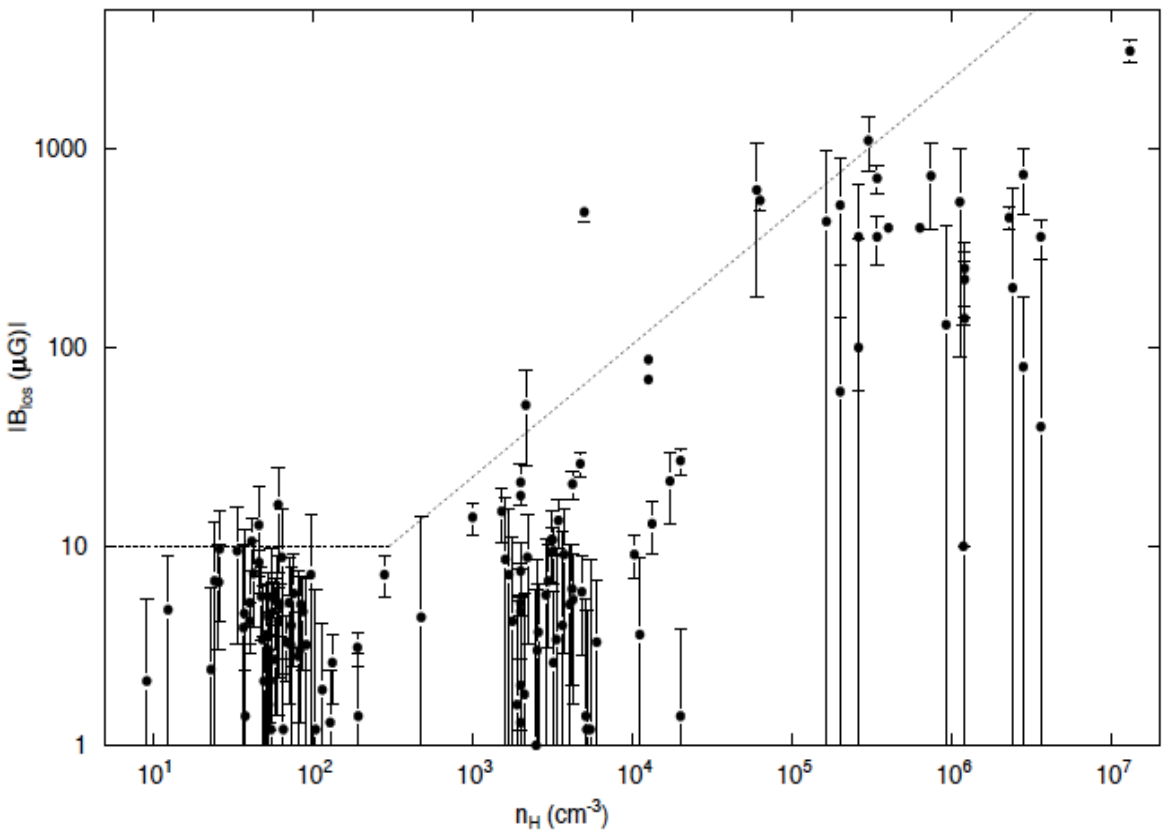


Crutcher et al in prep.

Line :
$M/\Phi=(M/\Phi)_{critical}$

No evidence for subcritical dense cores

HI, OH, CN Zeeman measurements (2)



Crutcher et al in prep.

Bayesian analysis :

$n < 300$ cm^{-3}

$B_{max} = 10$ μG

B not compressed by turbulence

$n > 300$ cm^{-3}

Uniform distribution of B_{TOT} between ≈0 and $B_{max} \propto n^{2/3}$

Weak B in dense cores

Summary and Openings (1)

- At 30 pc scales, magnetic > turbulent energy
- Coherent structures of vorticity/shears parallel to B_{POS} from parsec to milliparsec scales
- Wide scale separation

- Diffuse medium : B not compressed by turbulence
- No evidence for subcritical dense cores

Summary and Openings (2)

- Turbulence (and its property of intermittency) possibly at the origin of the loss of magnetic flux of matter

- Ion-neutral ambipolar drift in the diffuse medium required to explain its rich chemistry : Herschel/HIFI results Falgarone et al. 2010
- Models of warm chemistry in cold gas Godard et al 2009