Intermittency and dissipative structures of ISM turbulence

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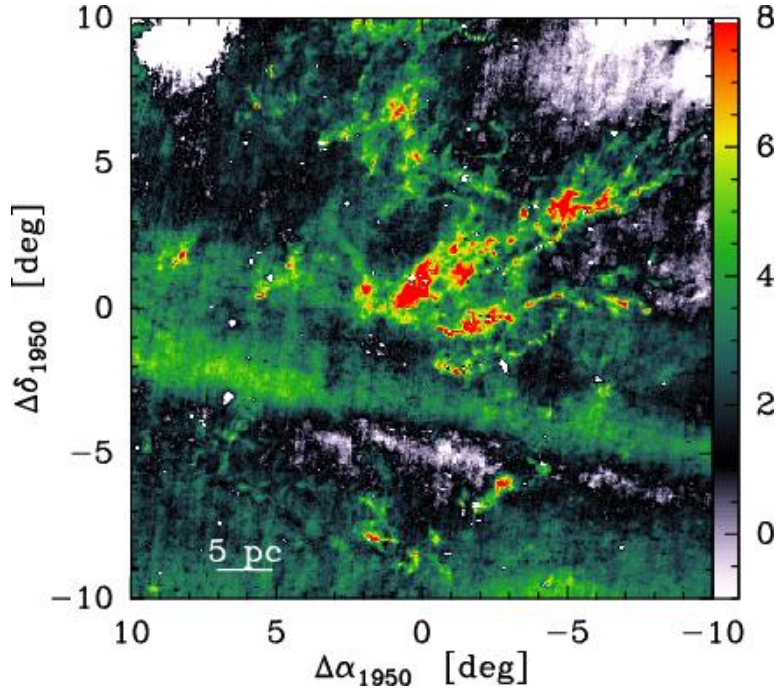
- What is intermittency?
- Compared statistical & structural properties of extrema of line Centroid Velocity Increments (CVI) in two different environments
- Why dissipative structures?

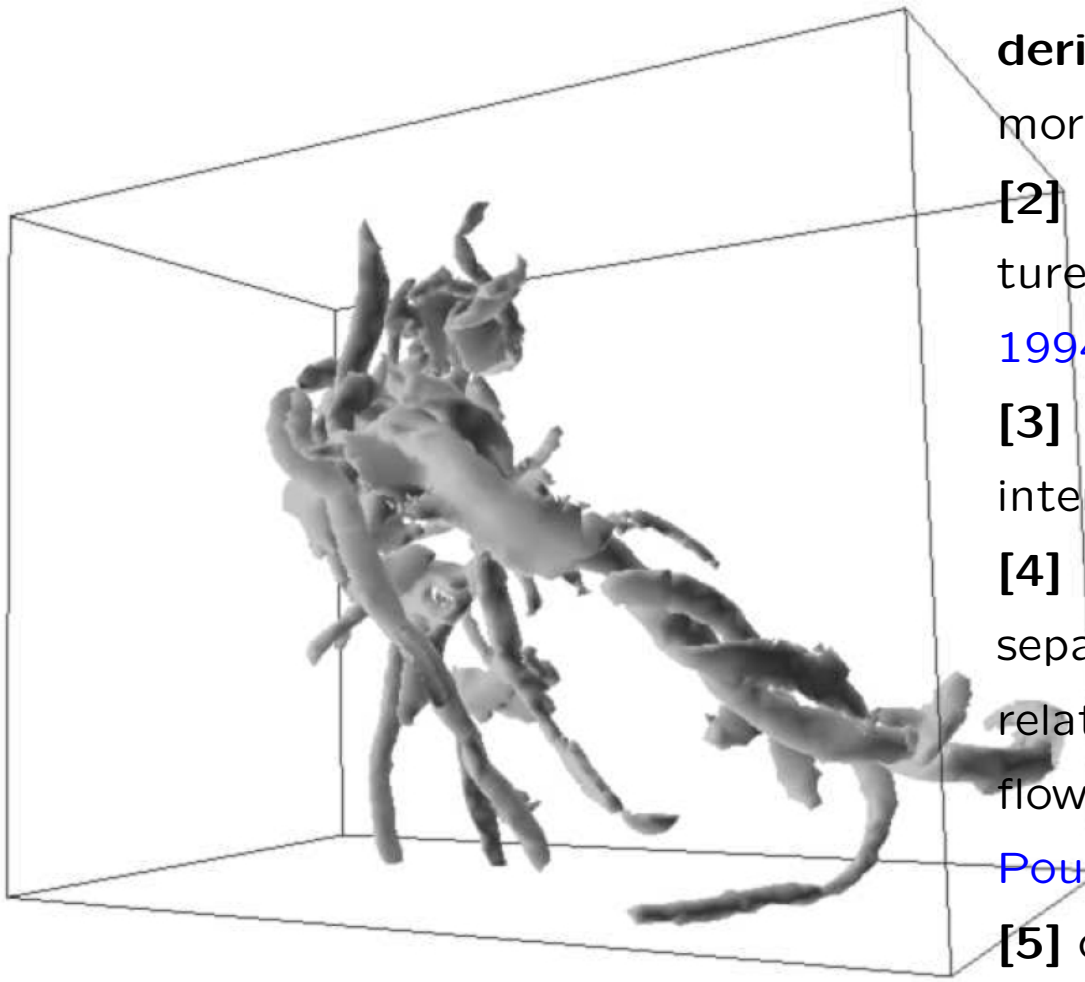
"Star formation, Then and Now", Santa Barbara, 13-17 August 2007

What is the link with star formation?



Taurus-Auriga clouds: cold dust emission Hily-Blant 2004

Intermittency in incompressible and mildly compressible turbulence



Moisy & Jimenez JFM 2004

[1] non-Gaussian statistics of **velocity derivative** signals

more pronounced at small scale

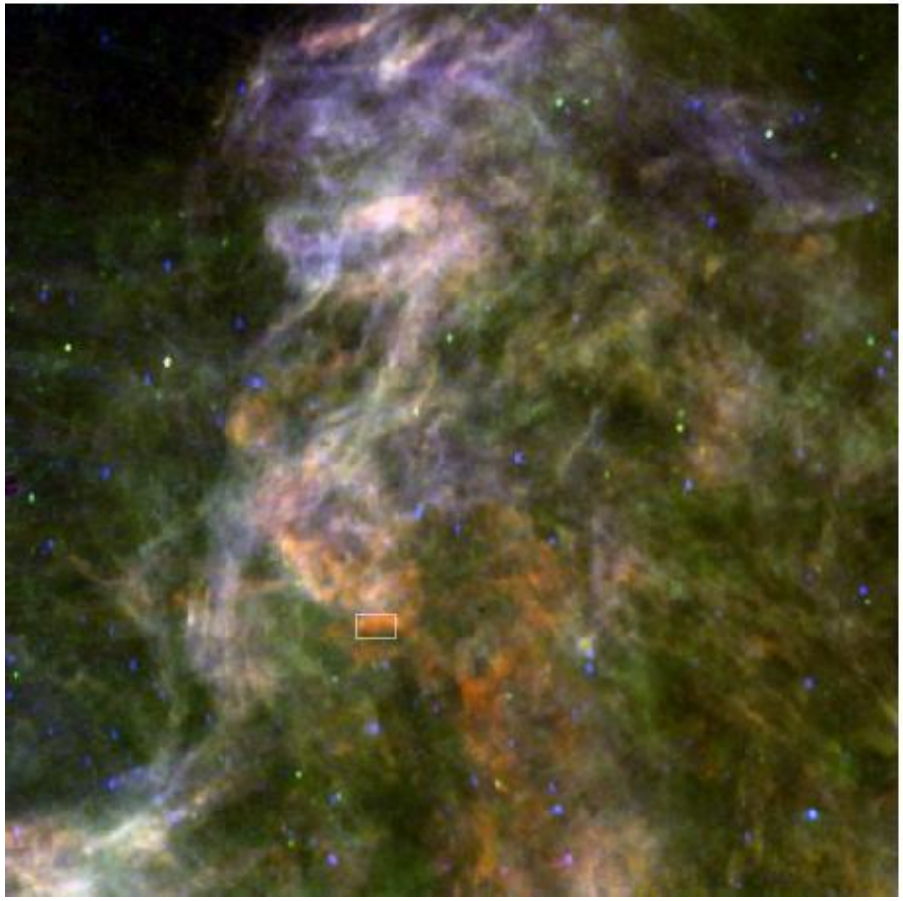
[2] **anomalous scaling** of p^{th} order structures functions $\zeta_p \neq p/3$ She & Levêque 1994

[3] existence of **coherent structures** of intense vorticity, shear, rate of strain, ...

[4] non-local interactions between widely separated scales: small scale intermittency related to large scale properties of the flow, in HD and MHD Mininni et al. 2006, Pouquet et al. 2006

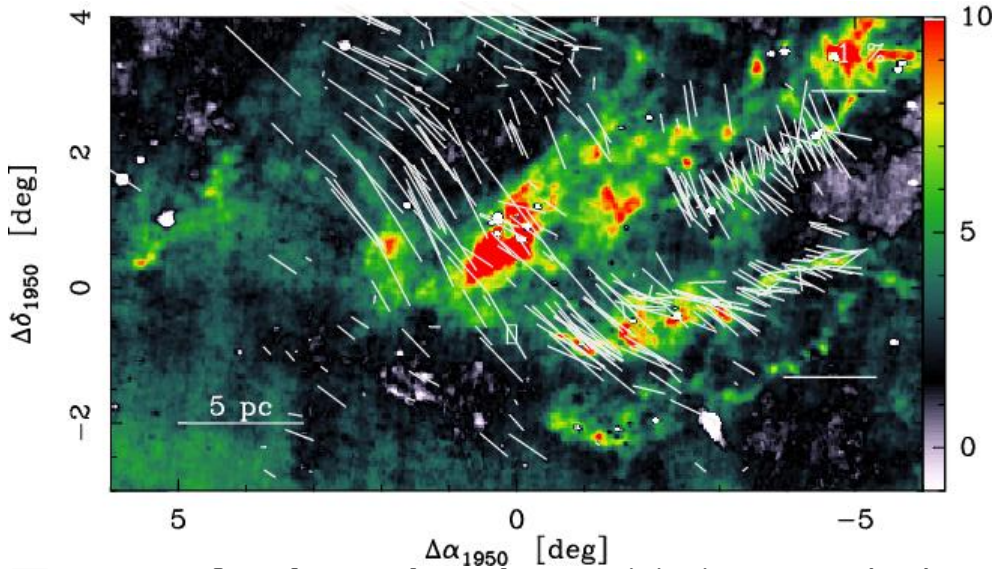
[5] clustering of coherent structures, inertial range intermittency Moisy & Jimenez 2004

Large scale environments: 30-parsec scale



Polaris flare: 27 pc × 27 pc field

100 (red), 60 (green) and 12 μm (blue) reprocessed IRAS maps Miville-Deschênes & Lagache 2005



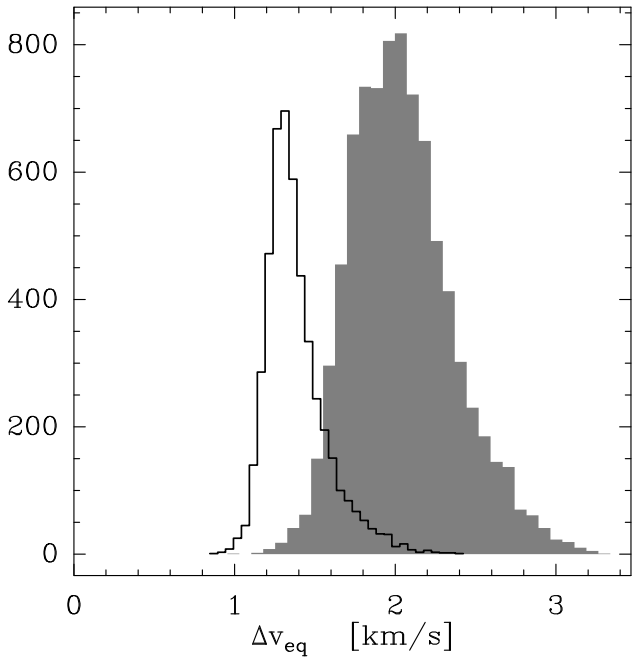
Taurus-Auriga clouds: cold dust emission and $B_\perp$ Heiles 2000

30 pc-scale:

same virial mass, $M_V \sim 4 \times 10^4$ $M_\odot$

- Polaris: $M_{gas}/M_V \sim 0.16$
- Taurus: $M_{gas}/M_V \sim 1$

Compared properties of the two parsec-scale fields



Parsec-scale:

- turbulent

$M \sim 5$ in Polaris,

$M \sim 2$ in Taurus

- translucent

$A_v \sim 0.8$ to 1 mag in both fields

- Polaris: trans-Alfvénic turbulence

dense core environment

- Taurus: cloud edge, no dense core

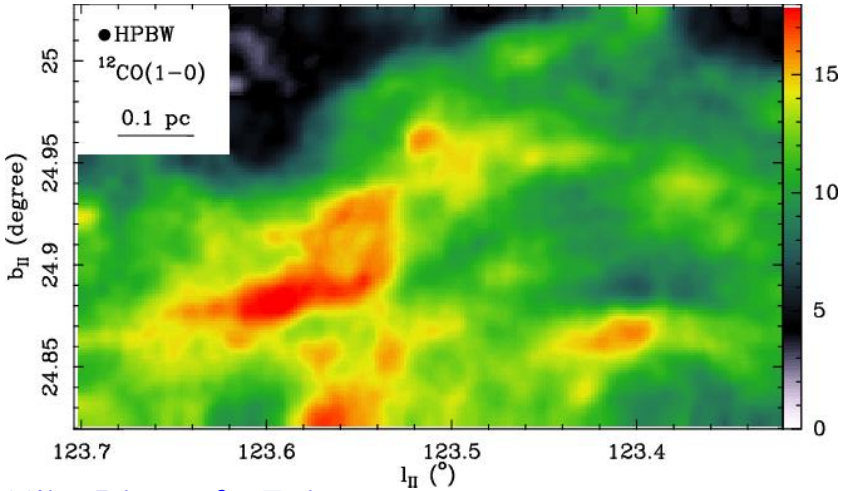
Taurus (left) – Polaris (right)

The tool: statistics of increments of line centroid velocities

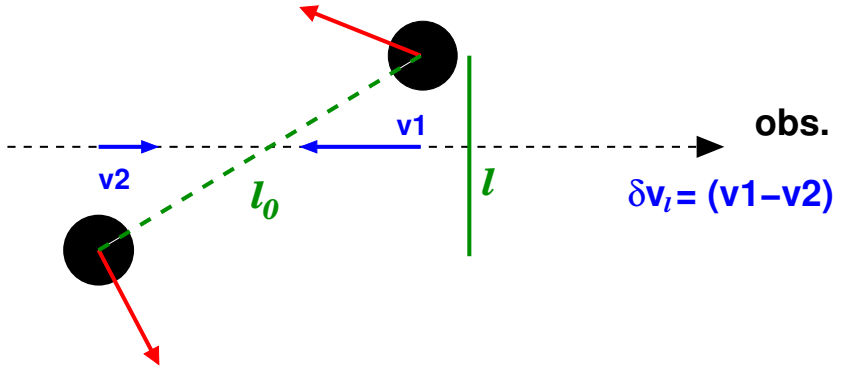
IRAM-30m,

8000 spectra (now 35000, resol 11")

Fully sampled, resolution 20"



Hily-Blant & Falgarone 2007



Line centroid velocity:

$C(\mathbf{r}) = \int T(\mathbf{r}, v_x) v_x dv_x / \int T(\mathbf{r}, v_x) dv_x$

Miesch & Scalo 1999, Pety & Falgarone 2003, Brunt et al. 2003, ...

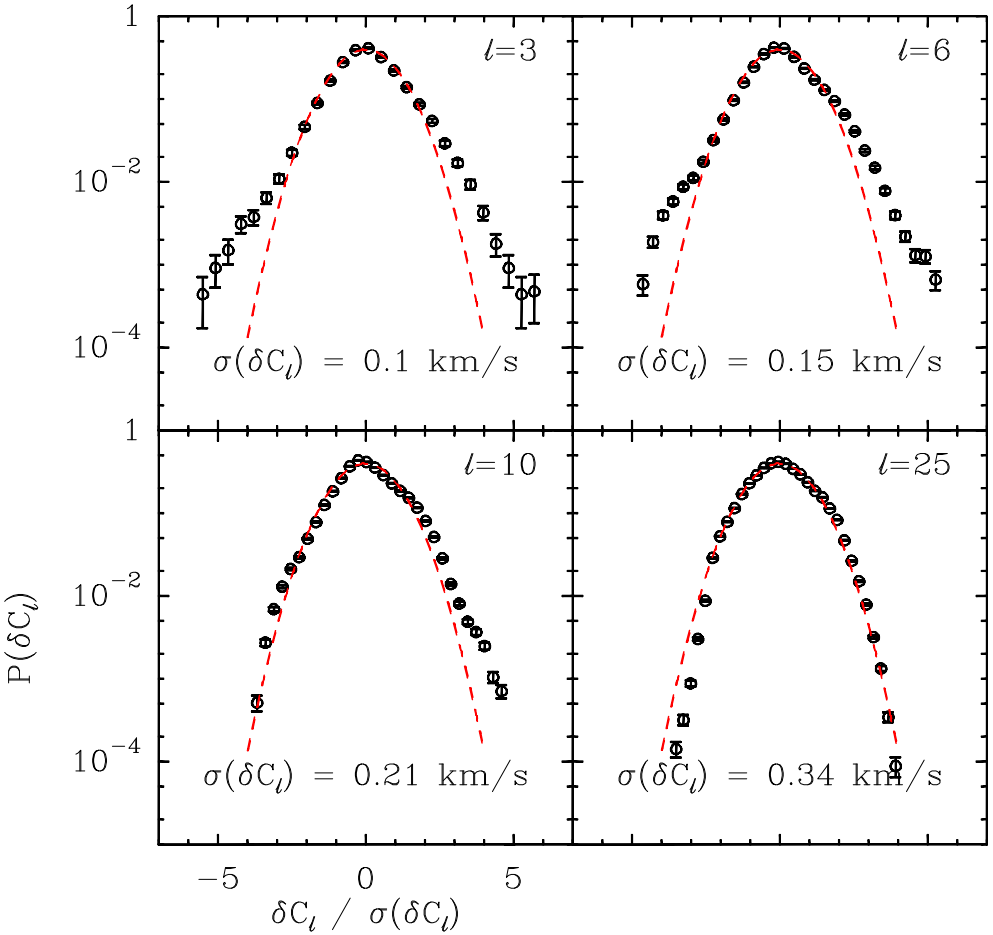
Extrema of line centroid increments trace extrema of

$(\langle\omega_y\rangle^2 + \langle\omega_z\rangle^2)^{1/2}$

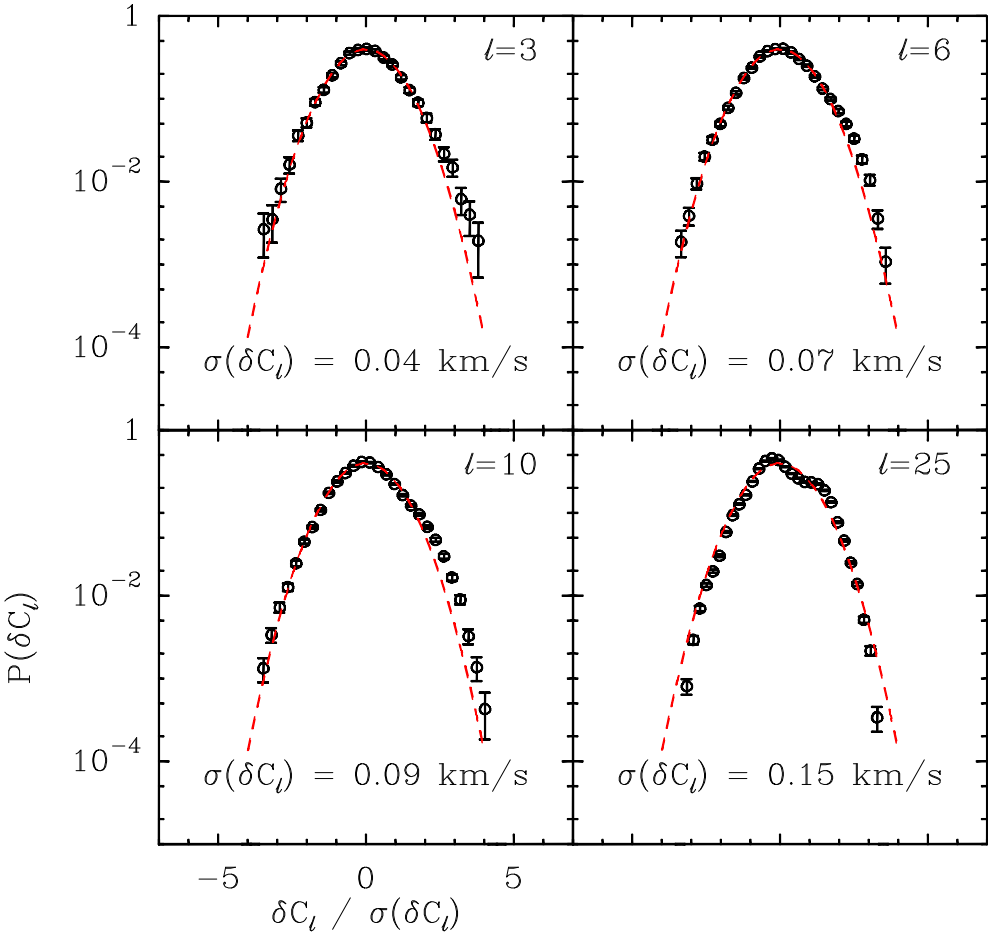
Lis et al. 1996

PDFs of Centroid Velocity Increments with variable lags

Polaris

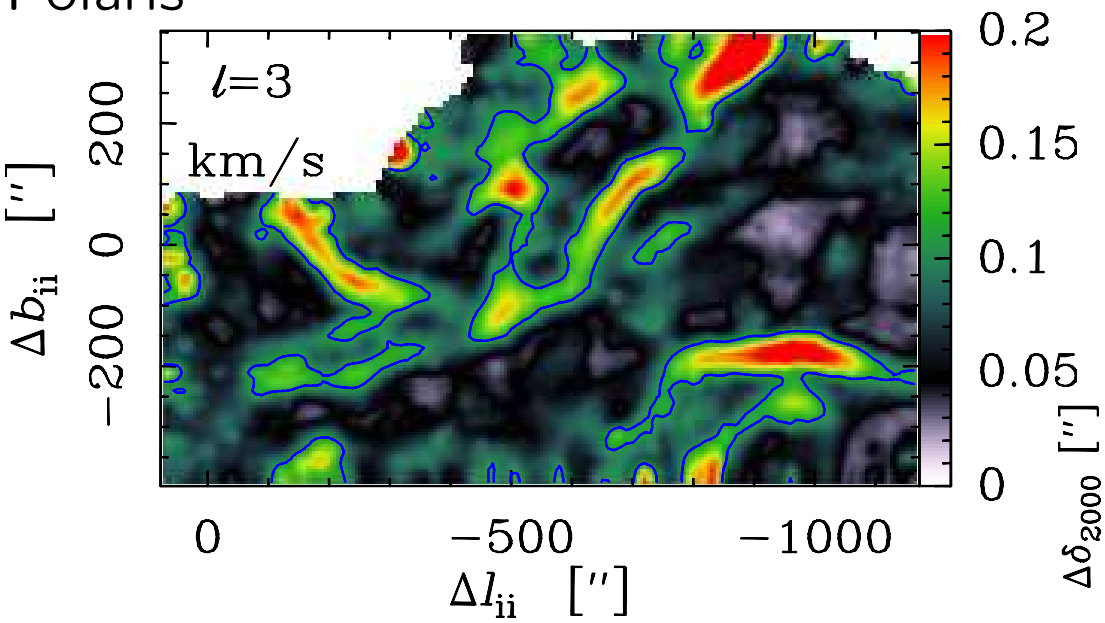


Taurus

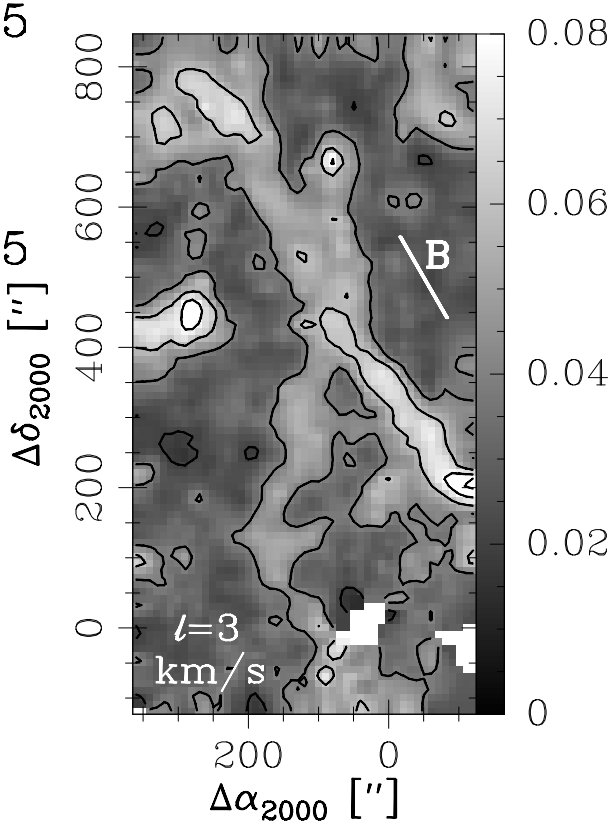


Spatial distribution of largest CVIs

Polaris



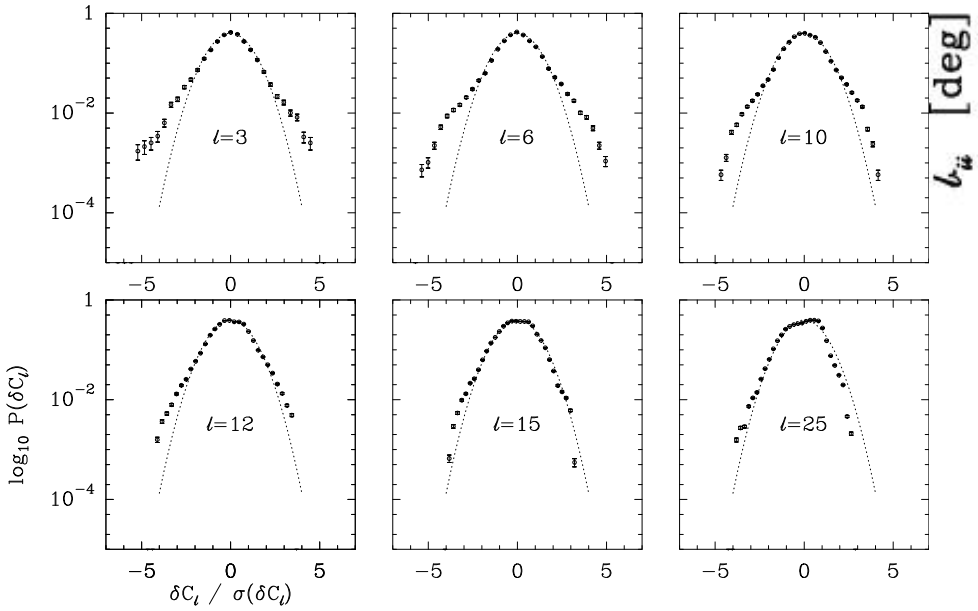
Taurus

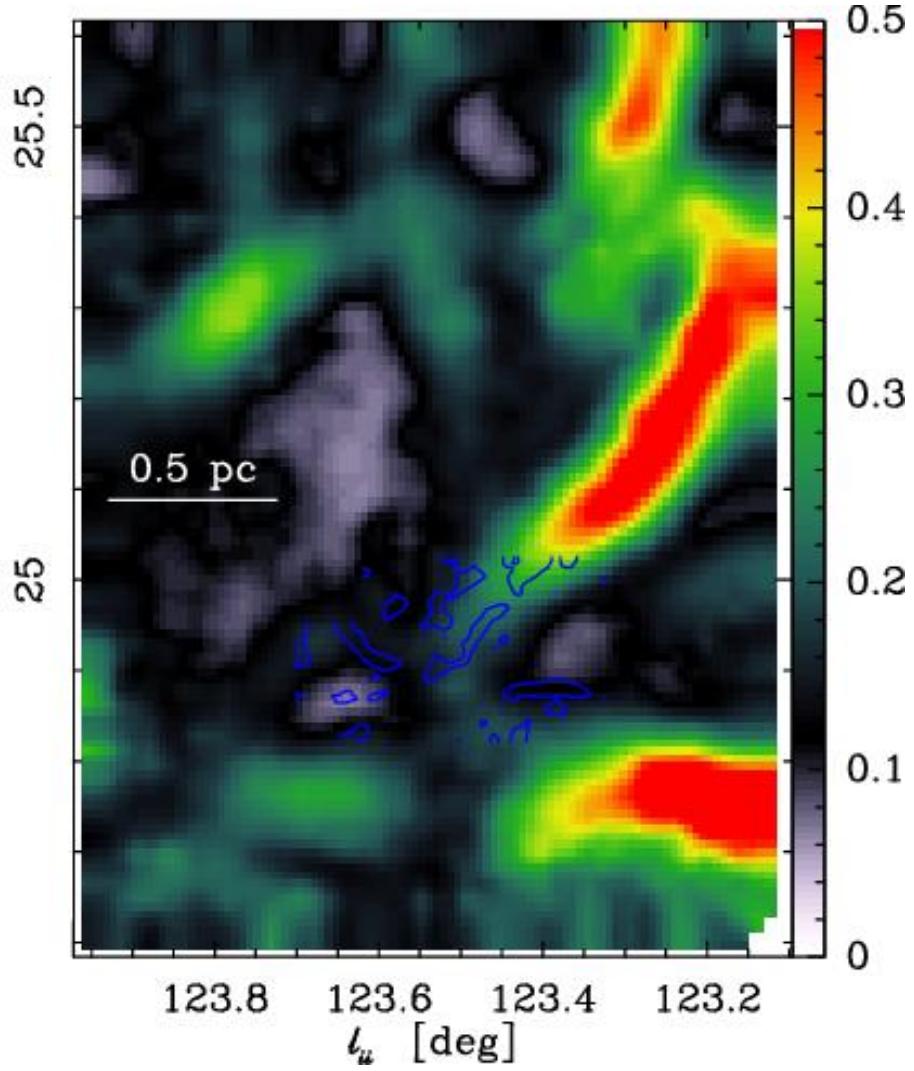


- Elongated structures of thickness $\leq$0.03 pc
- Taurus: parallel to $B_\perp$,
- Polaris: rms orientation of 30°
- CVI_{max} in Polaris $\sim$ 3 CVI_{max} in Taurus

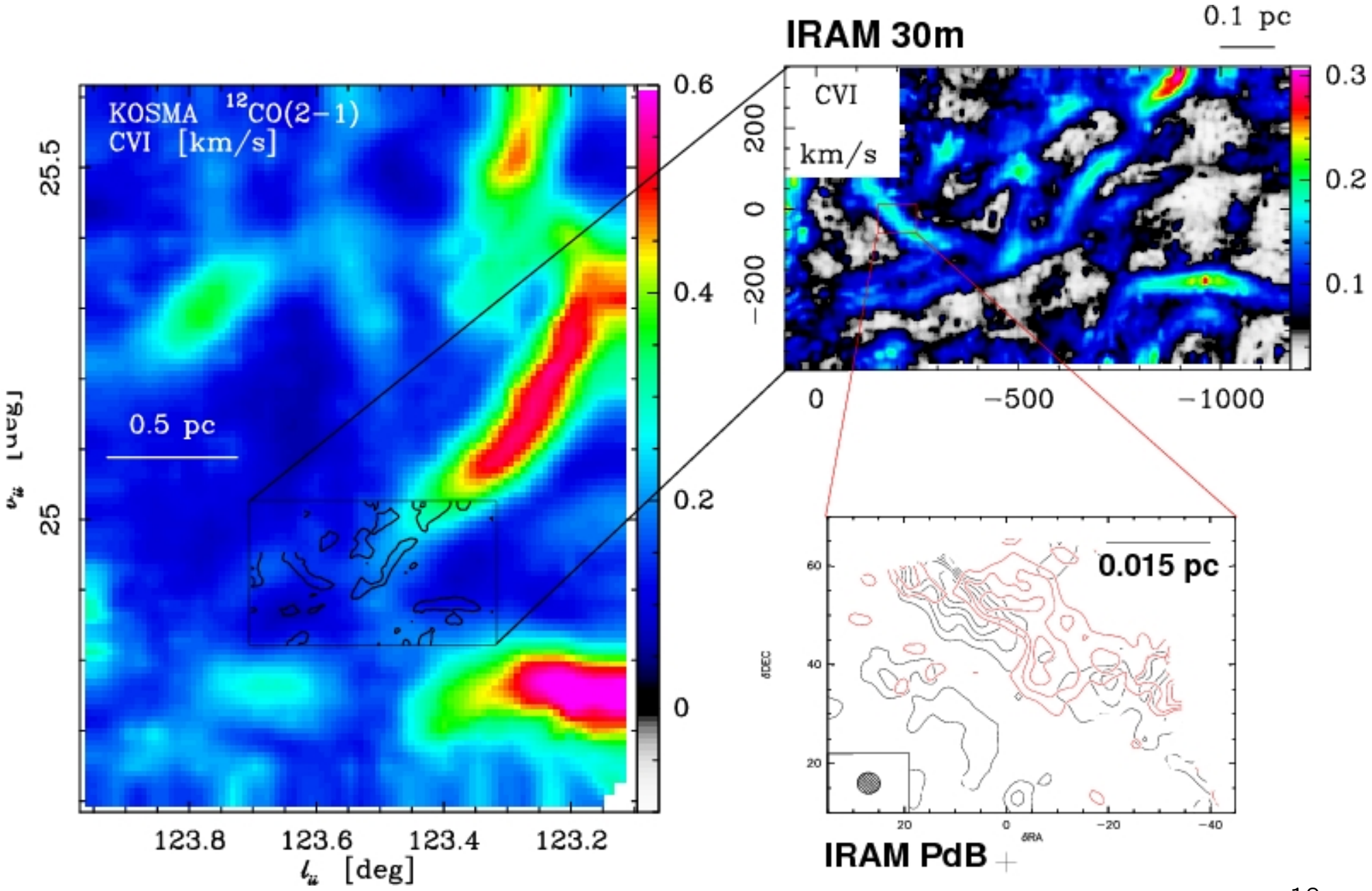
Self-similarity of PDFs of CVIs

Polaris large scale (5 pc)
KOSMA data, resolution 120”,
Bensch et al . 2001



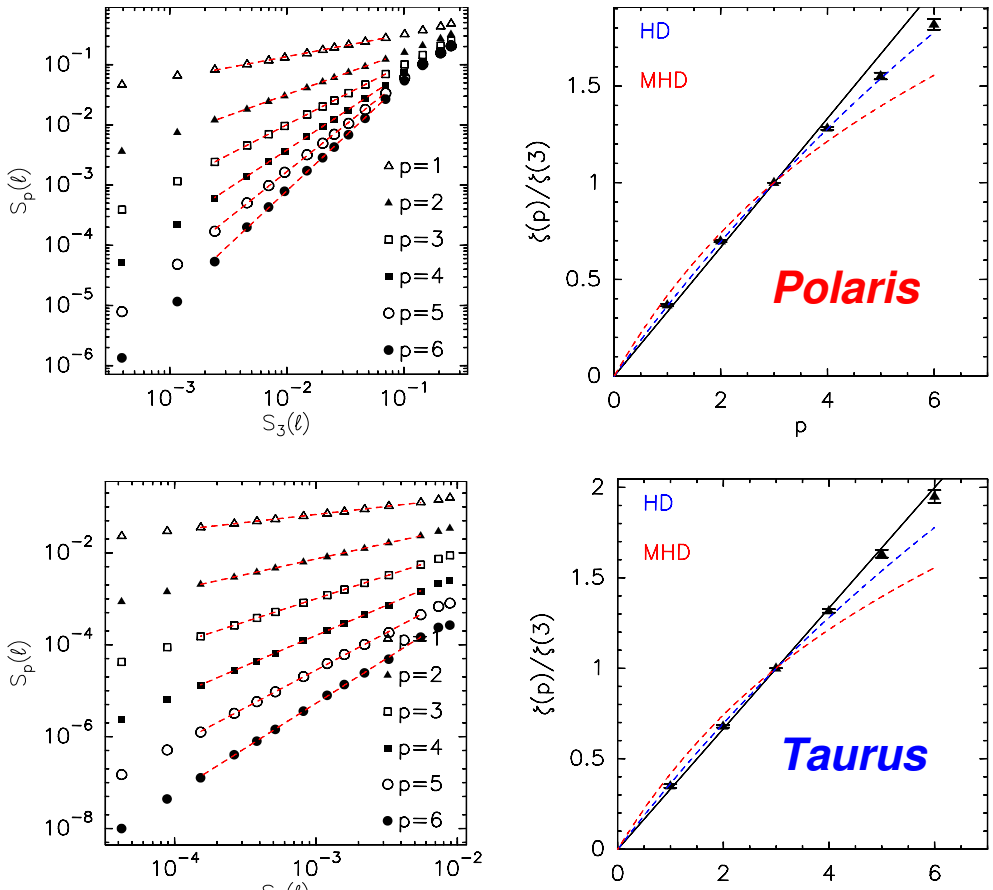


From 7 mpc to 3 pc



Scaling of CV p^{th}-order structure functions with p

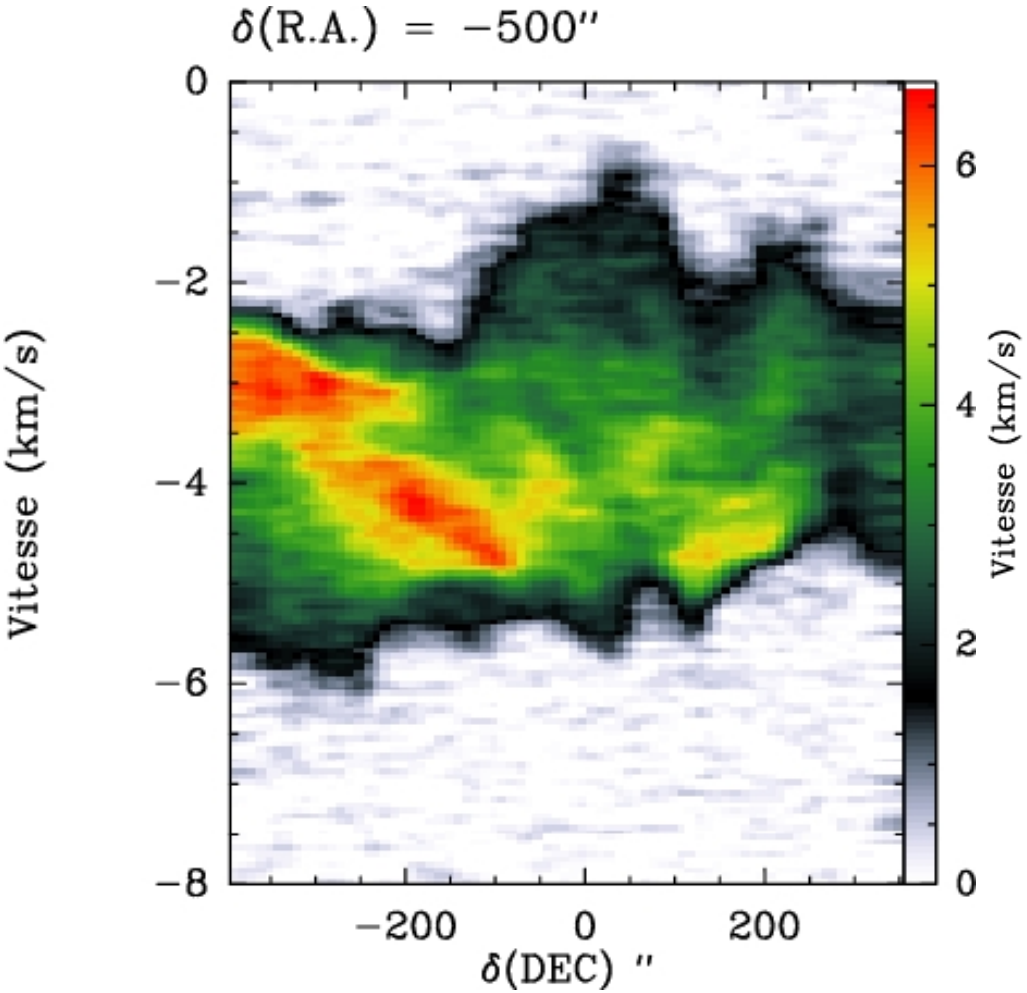
Extended Self-Similarity exponents Benzi et al. 1993



HD scaling: She & Lévêque 1994, $\theta = 1/3$, $D = 1$, $\beta = 2/3$

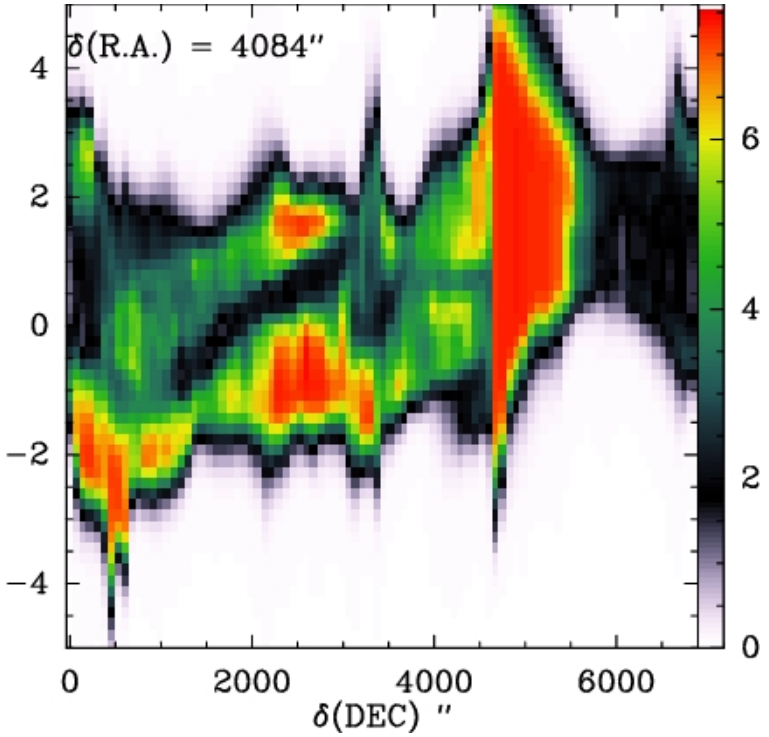
MHD scaling: Boldyrev et al. 2002, $\theta = 1/3$, $D = 2$, $\beta = 1/3$

Space-velocity slices: observations and MHD simulations



^{12}CO(1-0) l-v slices

in Polaris Flare, across a large-CVI structure



SuperAlfvénic MHD turbulence and radiative transfer

(Padoan & Juvela, private communication)

CVIs extrema as tracers of "intermittency"

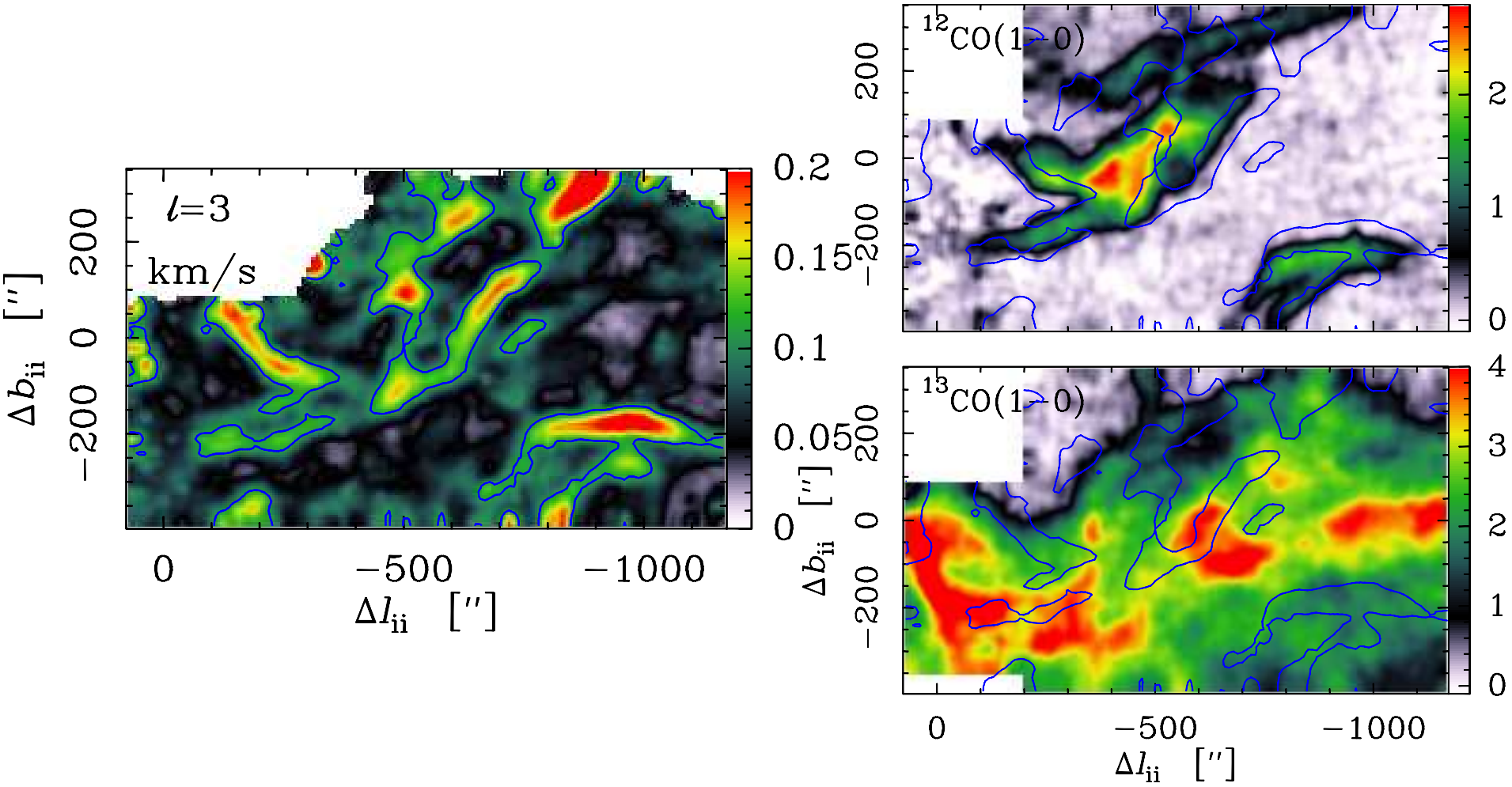
Same statistical and structural properties as intermittency of **velocity field** in incompressible or mildly compressible turbulence, magnetized or not:

- non-Gaussian wings of PDFs increase at small lags **[1]**
- anomalous scaling of CV structure functions **[2]**
- thin (0.02 pc) elongated structures of CVIs extrema, coherent over $>$ 1pc **[3]**
- CVIs extrema trace intense velocity shears (PdBI data: velocity shear $\sim$ 200 km s^{-1} pc^{-1} over 7 mpc) **[1]**

not associated with density/column density peaks

- most turbulent field at large scale (Polaris) is most intermittent at small scale **[4]**

CVIs extrema as tracers of local enhanced dissipation: CO emission

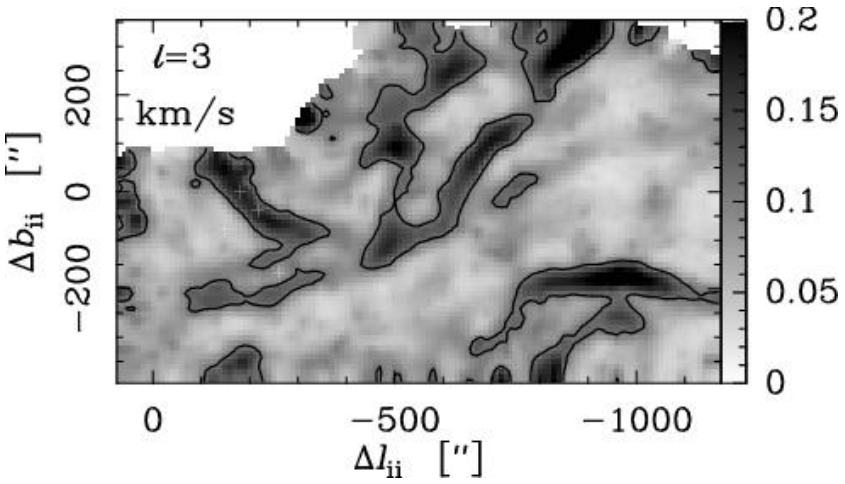


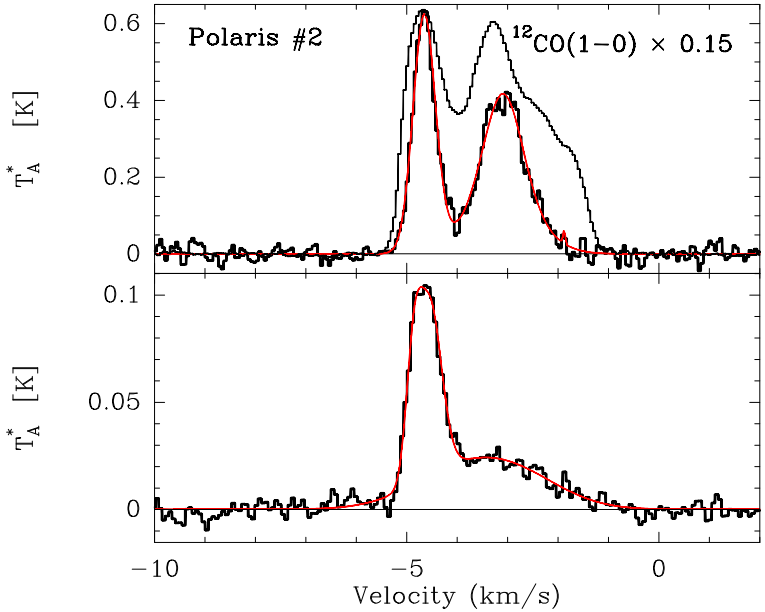
Optically thin ^{12}CO(1-0) emission: $[^{12}CO]/[^{13}CO] > 35$

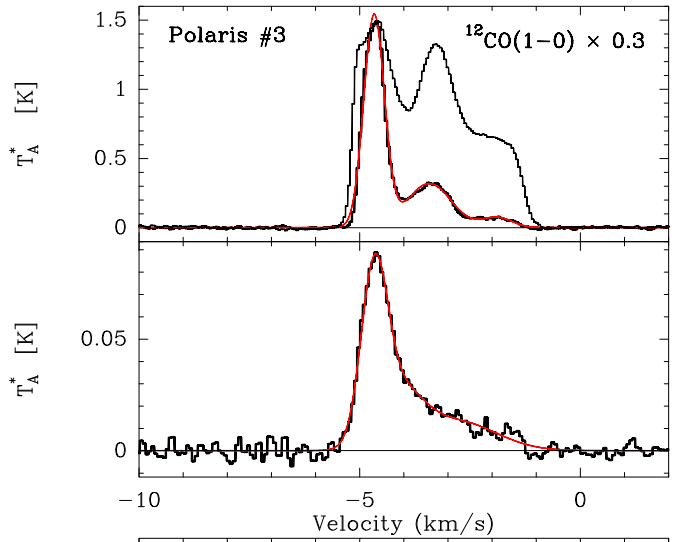
LVG analysis and translucent constraint :

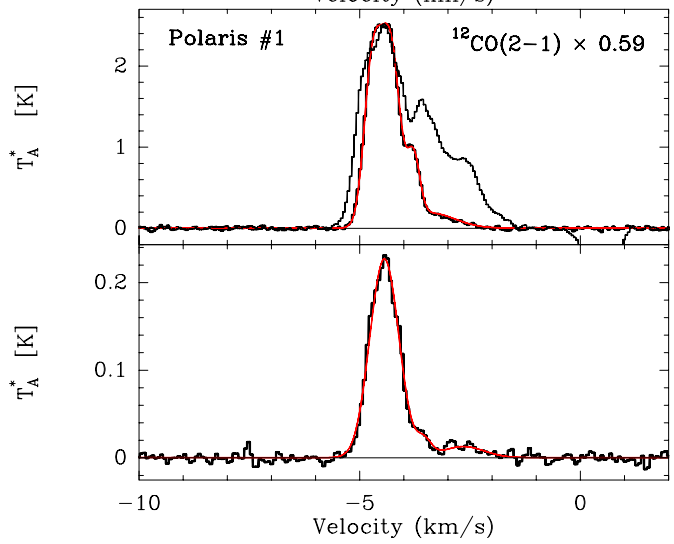
dense and cold solutions ruled out: $n_{H_2} < 10^3\,cm^{-3}$, $T_k > 25K$

CVIs extrema as tracers of local enhanced dissipation: HCO^+(1-0)





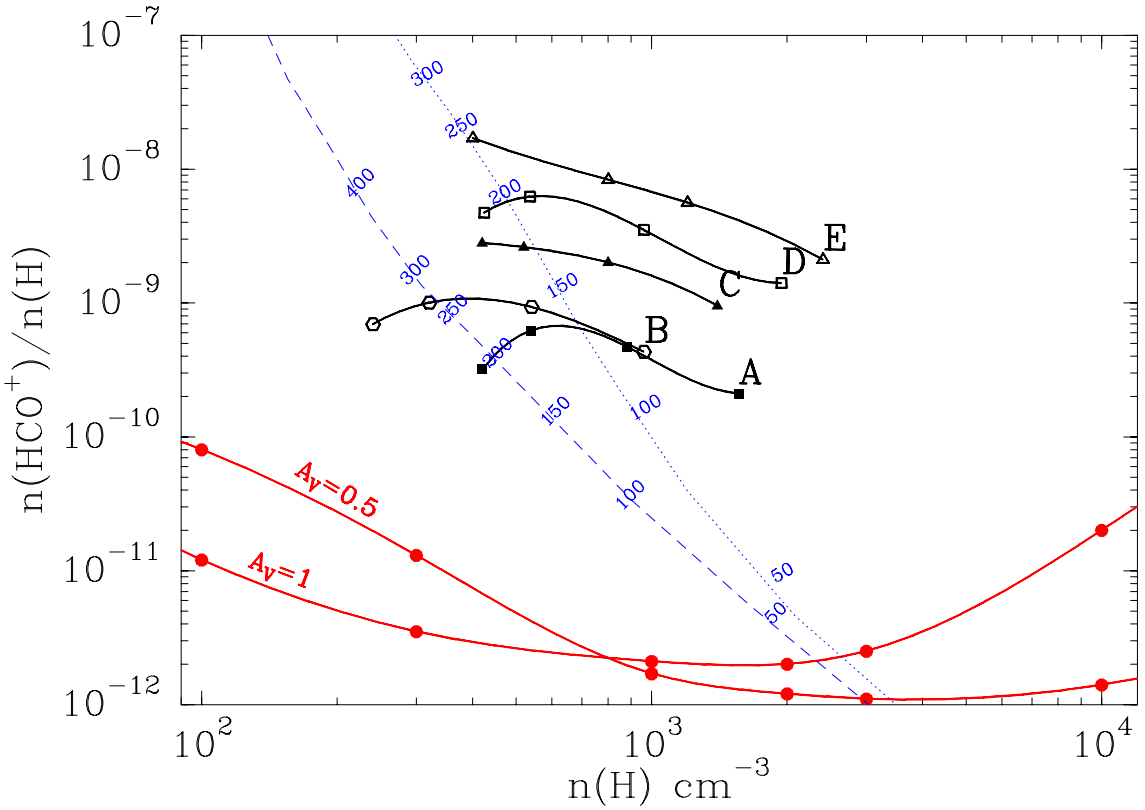




Observed HCO^+ abundances are **more than one order of magnitude** above predictions of **steady-state chemical models**: non-equilibrium chemistry

Falgarone, Pineau des Forêts, Hily-Blant & Schilke 2006

Relaxation tracks versus observed HCO^+ abundances



Cooling tracks for same initial density and two different UV shieldings, $A_v = 0.5$ and 1 mag.

Observations meet models in the range $T = 100$–200 K, $n = 200$–$10^3\,\mathrm{cm}^{-3}$

Conclusions and Open Questions

In translucent molecular gas:

• intermittency of velocity field similar to that of incompressible/mildly compressible turbulence

• intermittency more pronounced in most turbulent field at large scale

• observed intermittent structures: thickness: $\leq$ 0.02 pc, down to 7mpc, coherent over $\sim$ 3pc or more

• signposts of turbulence dissipation (thermal, chemical, radiative)

Open questions:

- nature of these structures, unlikely to be shocks
- role of magnetic fields
- actual smallest scale (ALMA) and radiative cooling rate
- observable helicity?