Turbulence and Magnetic Fields in molecular clouds : from 100 pc to mpc-scales

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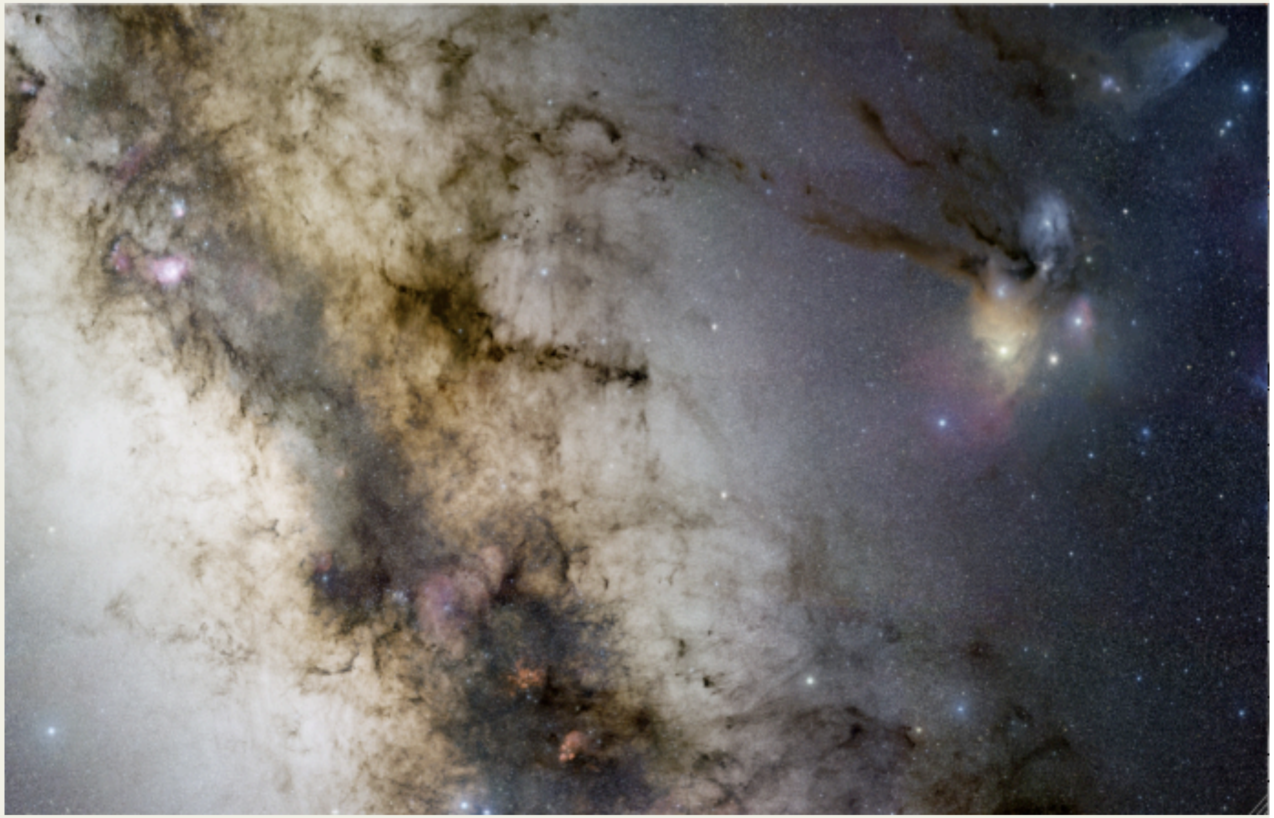
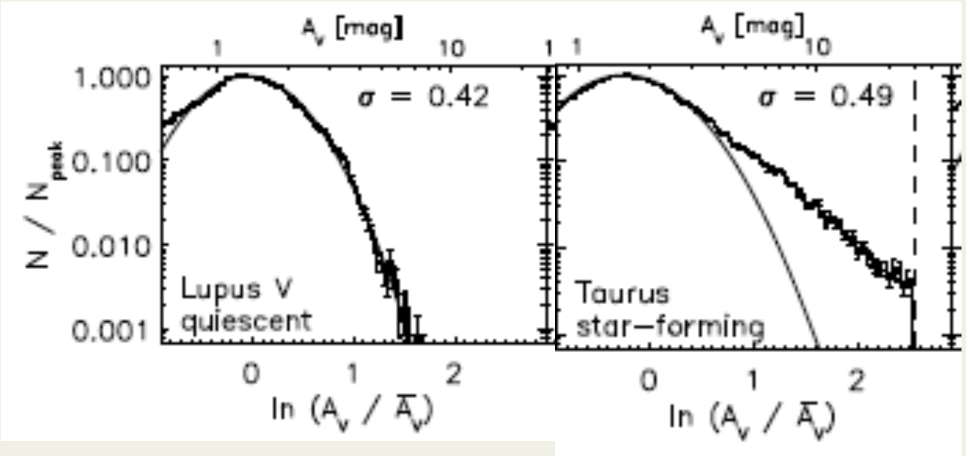
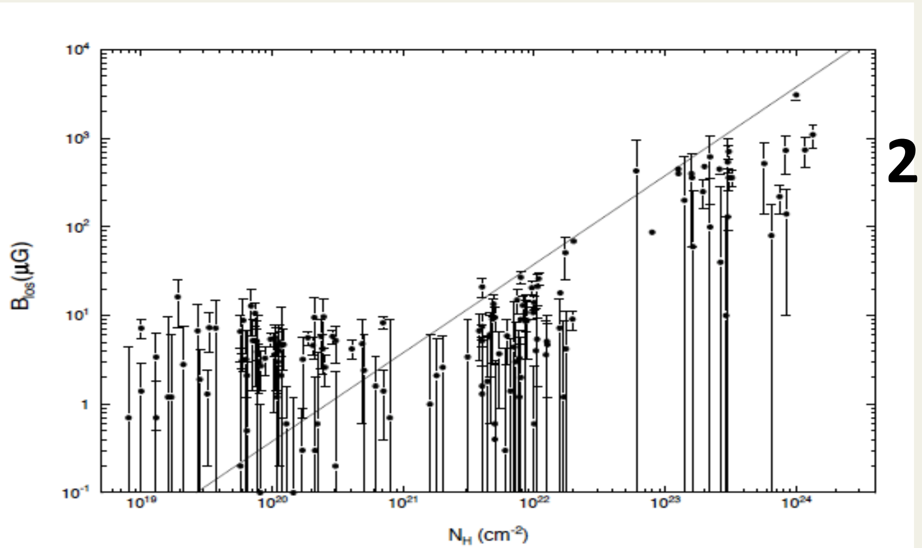


Magnetic Fields in the Universe III,
Zakopane, Poland, 22-25 August 2011

A bird-eye view of molecular clouds (I)



K-extinction, 2MASS, Kainulainen et al 09



HI, OH and CN Zeeman effect, Crutcher et al. 2010

1) Total gas column density

- A_V < a few mag

Log-normal distribution

Turbulence

- A_V > 3 - 5 mag

Power-law tail

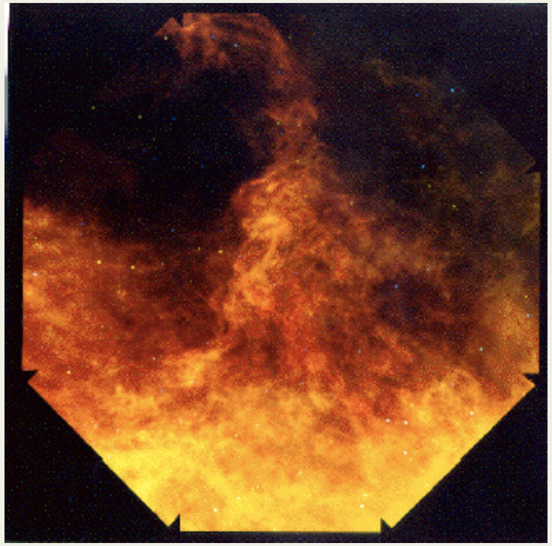
Self-gravity

2) Statistically uniform magnetic field

up to $N_H \sim 5 \times 10^{21}$ cm^{-2} ~ 3 mag

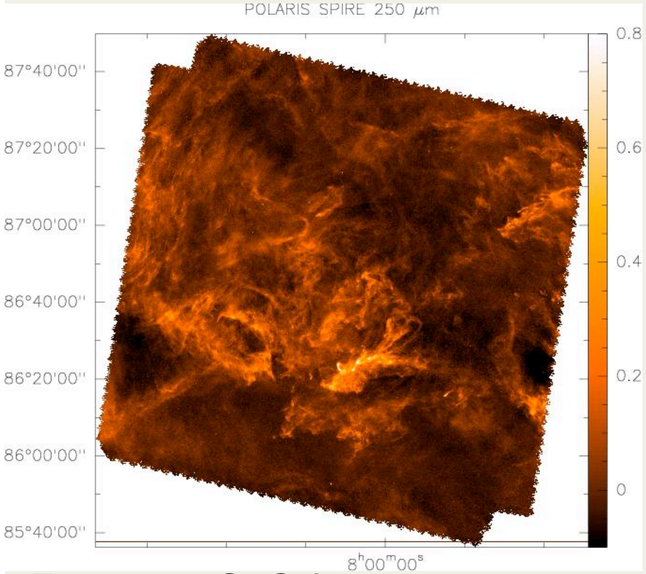
$B_{diff} \sim 6$ μG

A bird-eye view of molecular clouds (II)



100 pc to 0.2 pc

IRAS 100 µm

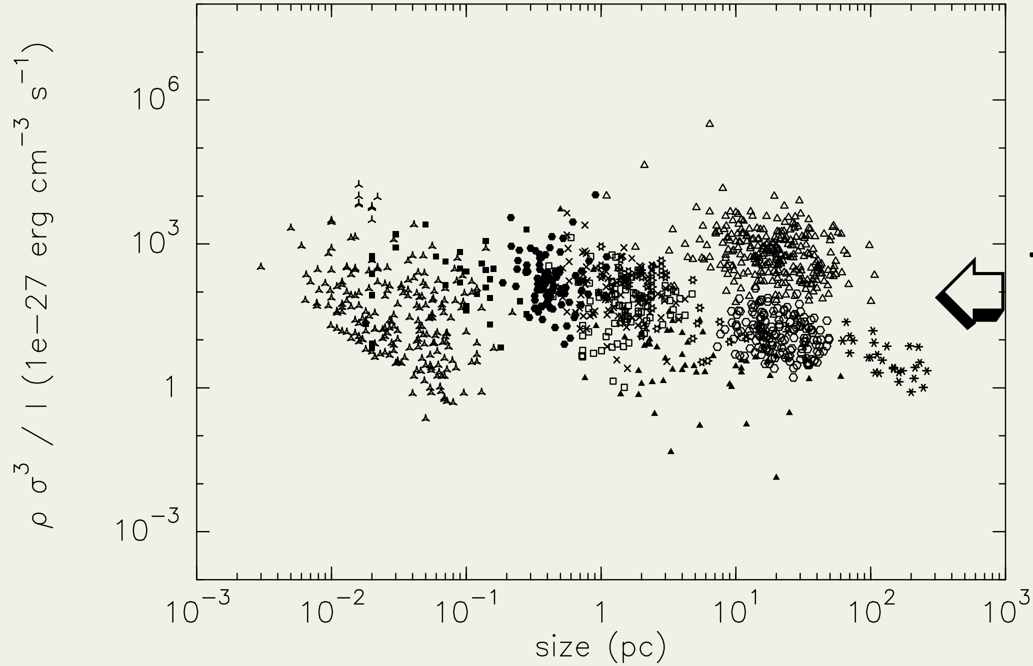


5pc to 0.01 pc

Herschel/SPIRE 250 µm

Men'shchikov et al 2010

3) Transfer rate of turbulent kinetic energy

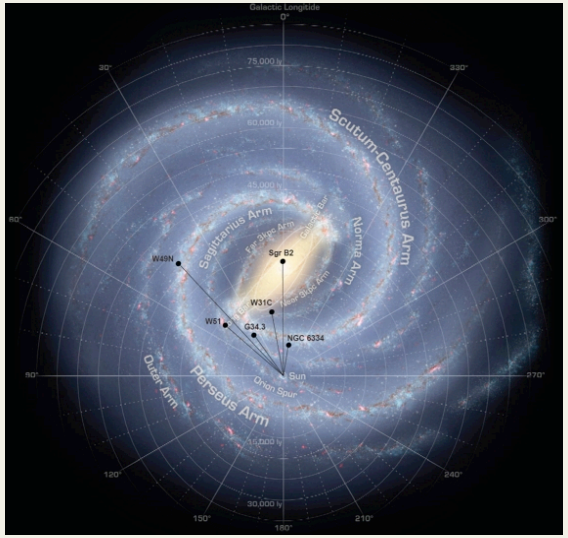


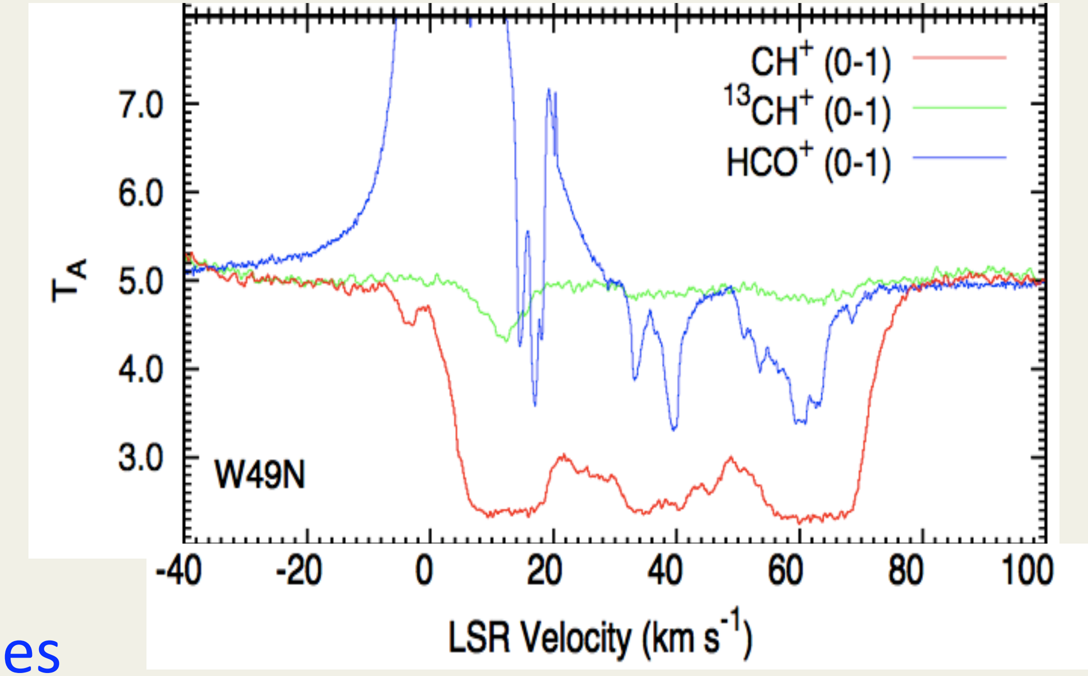
rate in the HI Turbulent cascade

Diffuse molecular gas traced by $^{12}CO(1\text{-}0)$ line emission.

References of data sets in Falgarone et al. (2009)

Puzzle 1 : large CH^+ and SH^+ abundances



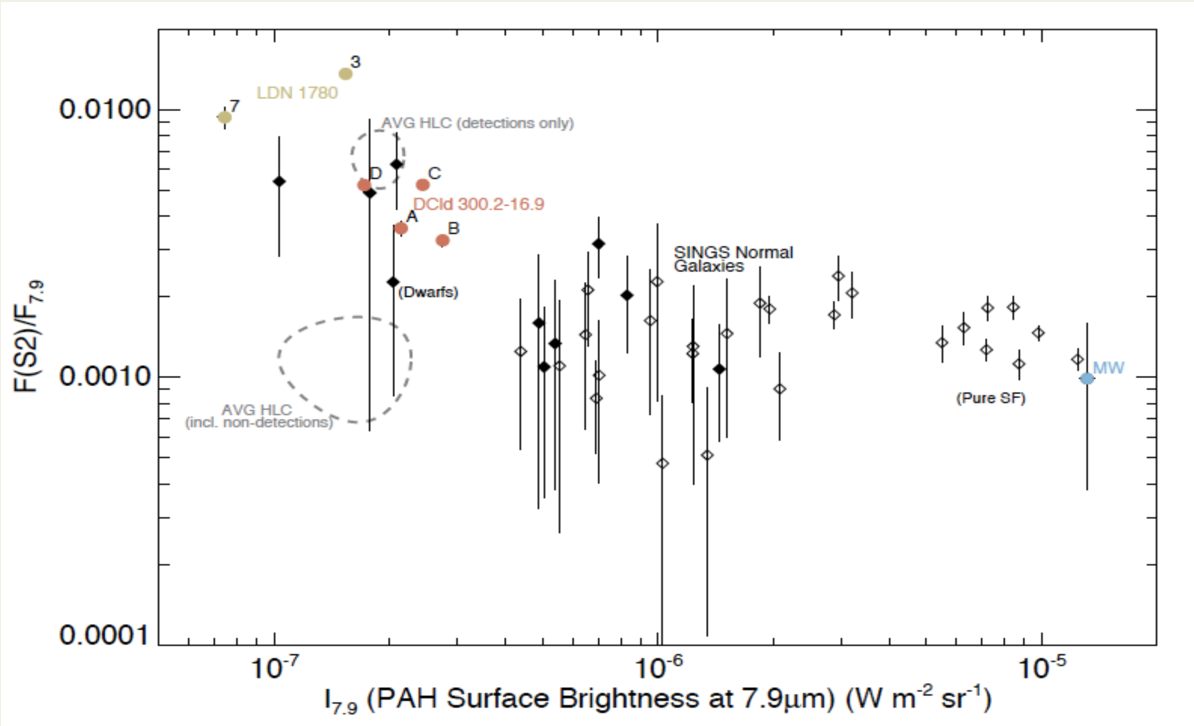


Herschel/HIFI absorption lines

Falgarone + 2010

- High endothermicity of formation (CH^+ : 4640 K, SH^+ : 9860 K)
- CH^+ rapidly destroyed by collisions with H_2

Puzzle 2: H_2 pure rotational emission



Ingalls et al. 2011

Four detections at high latitude (*Spitzer*/IRS):

- ➪ UV pumping not sole source of excitation
- ➪ H_2 brigthness per H ~ constant

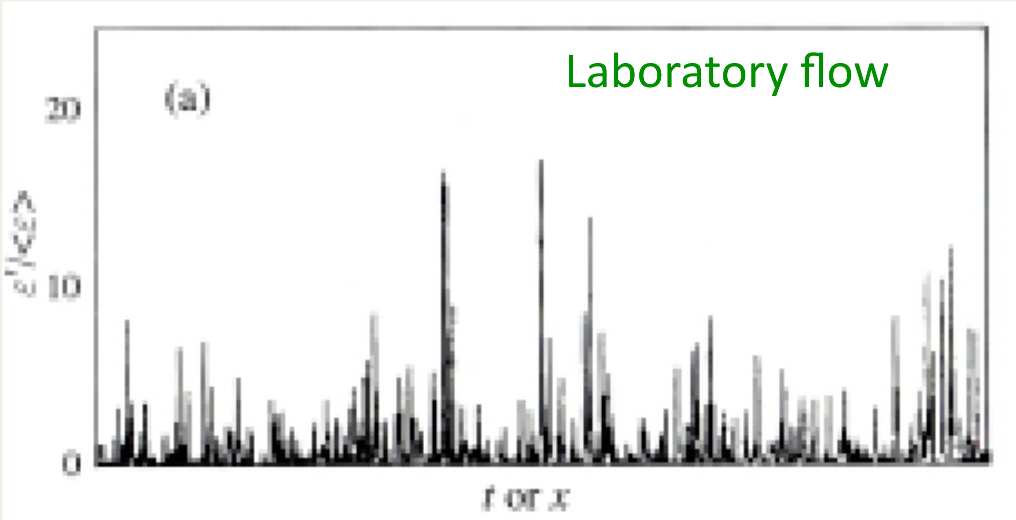
It is turbulent dissipation that, in this cold, transparent and turbulent medium

- ➯ locally and temporarily heats the gas,
- ➯ drives the first steps of chemistry in the ISM,
- ➯ seeds structure formation

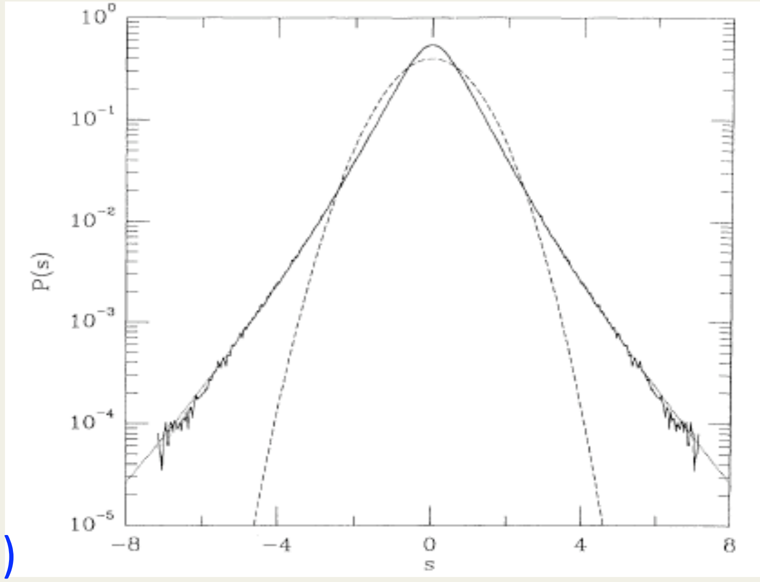
Outline :

- Observed signatures of turbulent dissipation : multiscale shear-layers and magnetic field
- Models of turbulent dissipation regions

Turbulent space-time intermittency



Méneveau & Sreenivasan (1991)



- Dissipation bursts

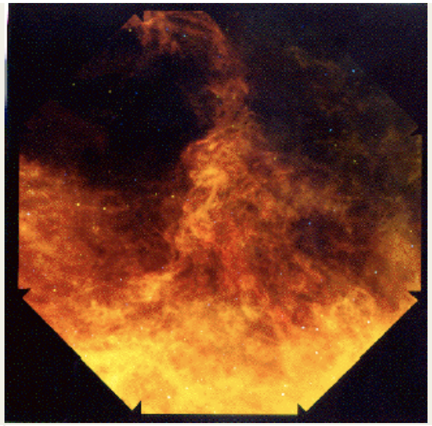
- Non-Gaussian PDF of velocity increments

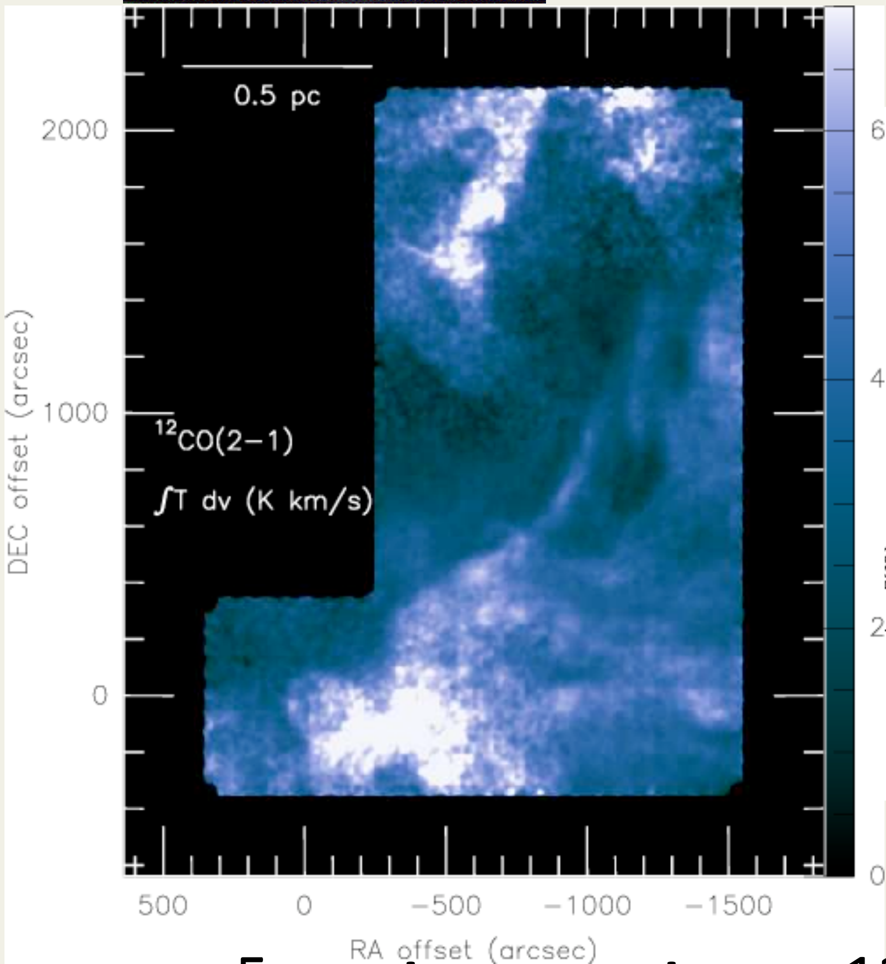
She 1991

Dissipation rate :

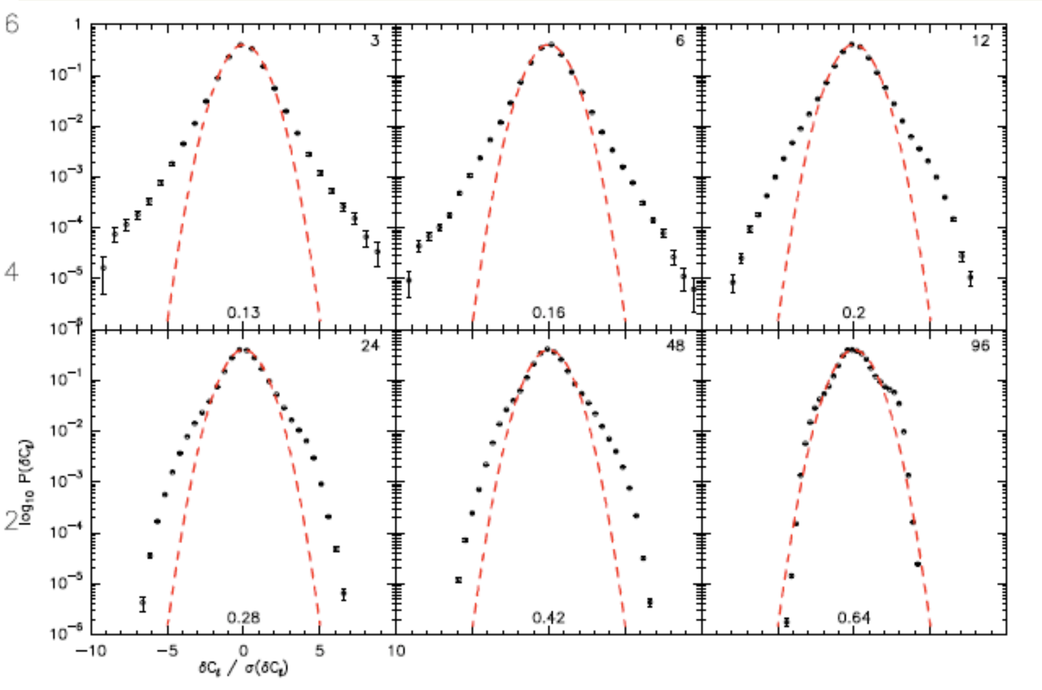
$\varepsilon \propto (\nabla \times u)^2$ and $(\nabla . u)^2$

Non-Gaussian statistics of line centroid velocity increments





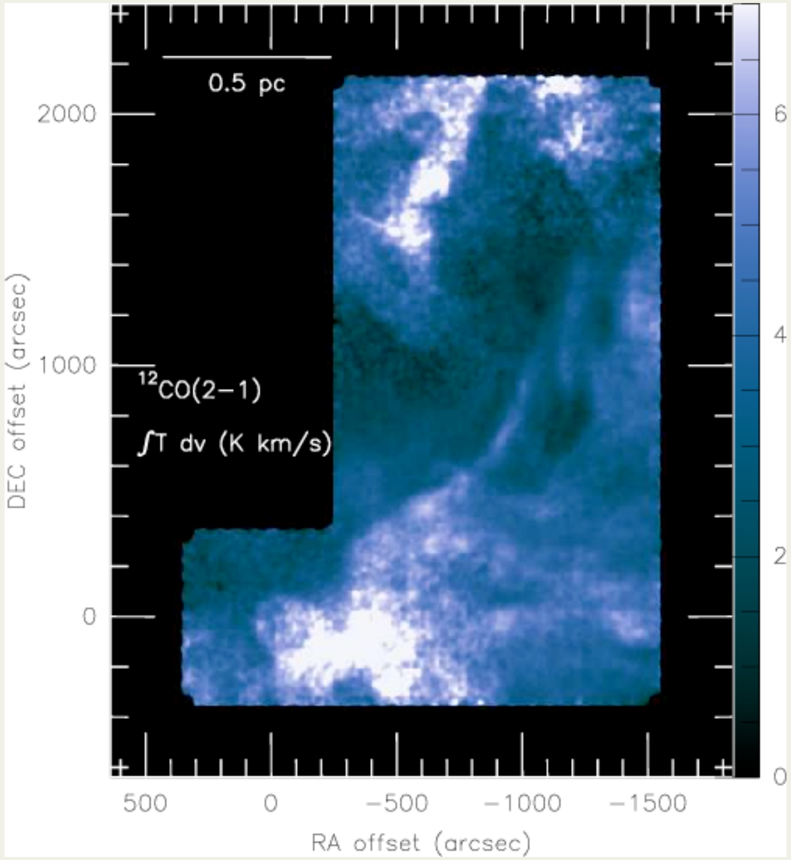
smallest lags →

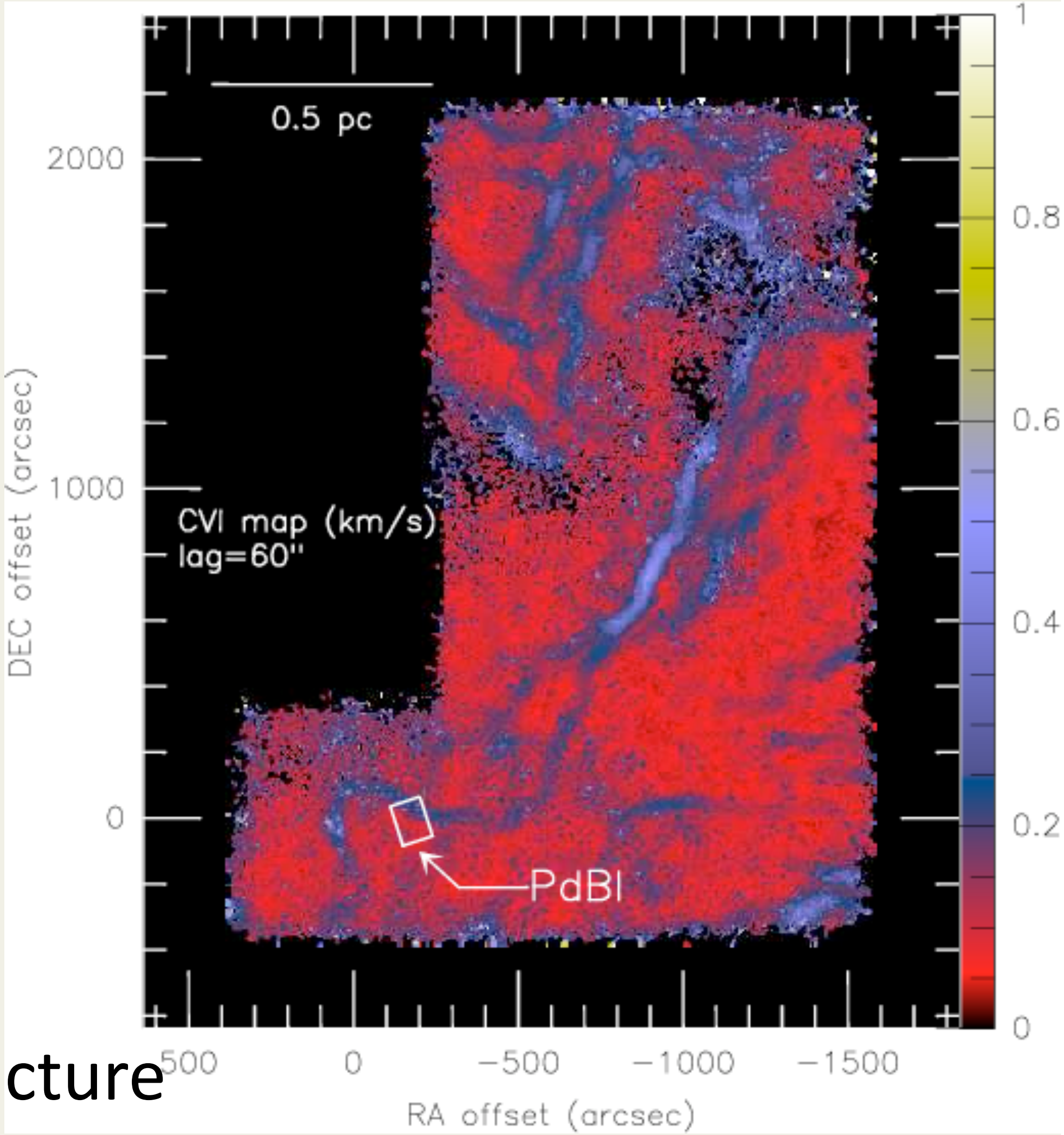


←largest lags

~ 10^5 independent ^{12}CO(2-1) spectra

Extreme velocity increments...

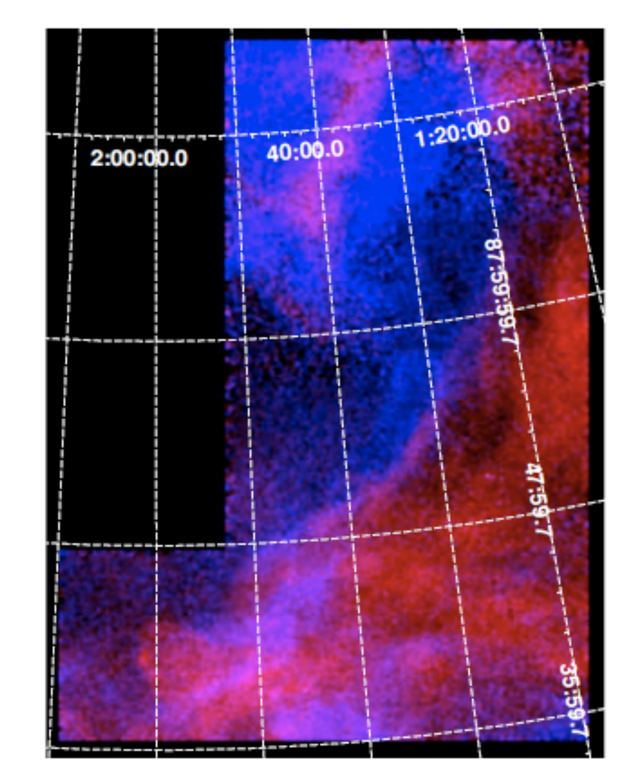


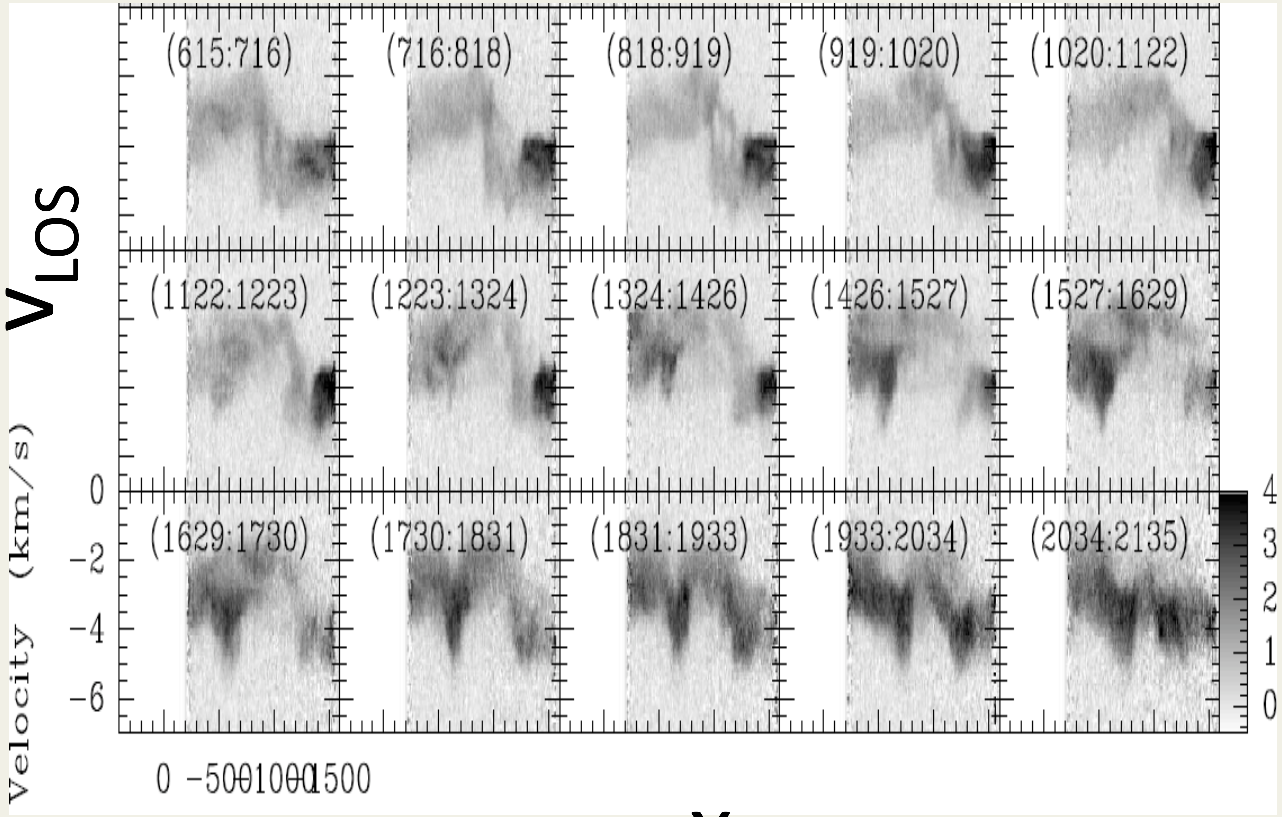


- not randomly distributed
- parsec-scale coherent structure

Hily-Blant et al 2008

… are intense velocity-shears $\Delta v_{LOS} / \Delta x_{POS}$



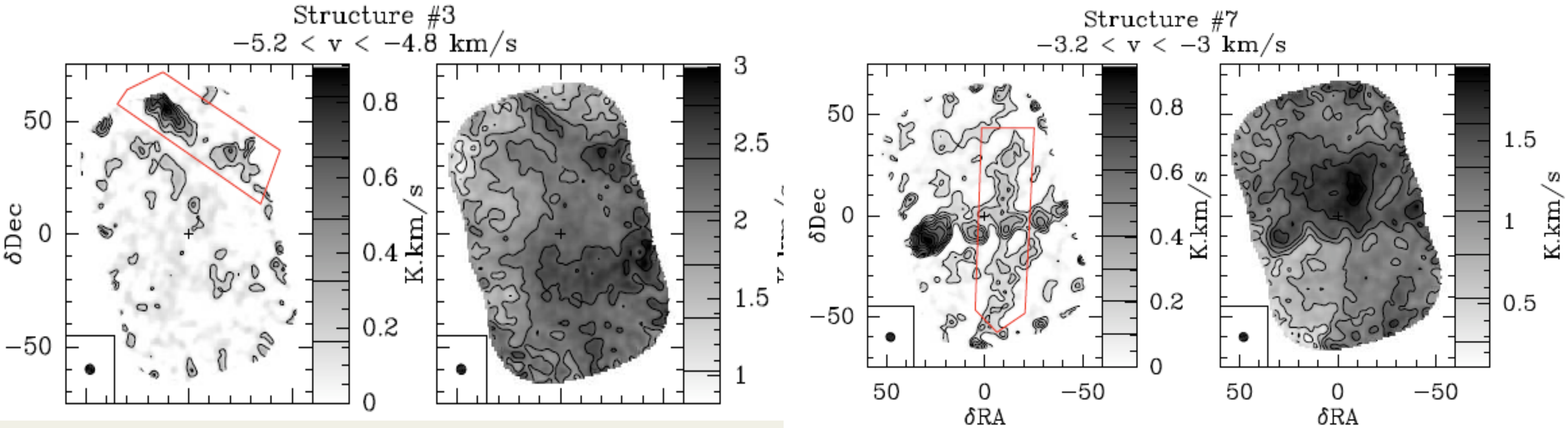


Unresolved overlap of different velocities
➩ CO layers not 3D volumes

max shear ~ 40 km s^{-1} pc^{-1}

IRAM-PdBI CO(1-0)mosaic : 3 mpc resolution

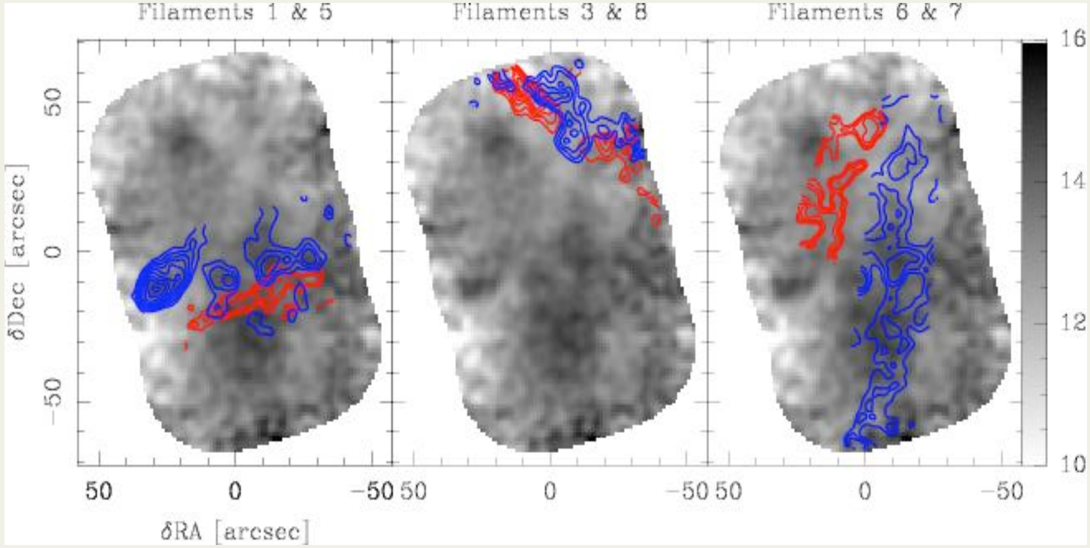
- 8 elongated and almost straight structures
- not filaments : sharp edges of thin sheets of CO emission
- N(CO) in the range 10^{14} to 10^{15} cm^{-2}
- 6 out of 8 are pairs at different velocities

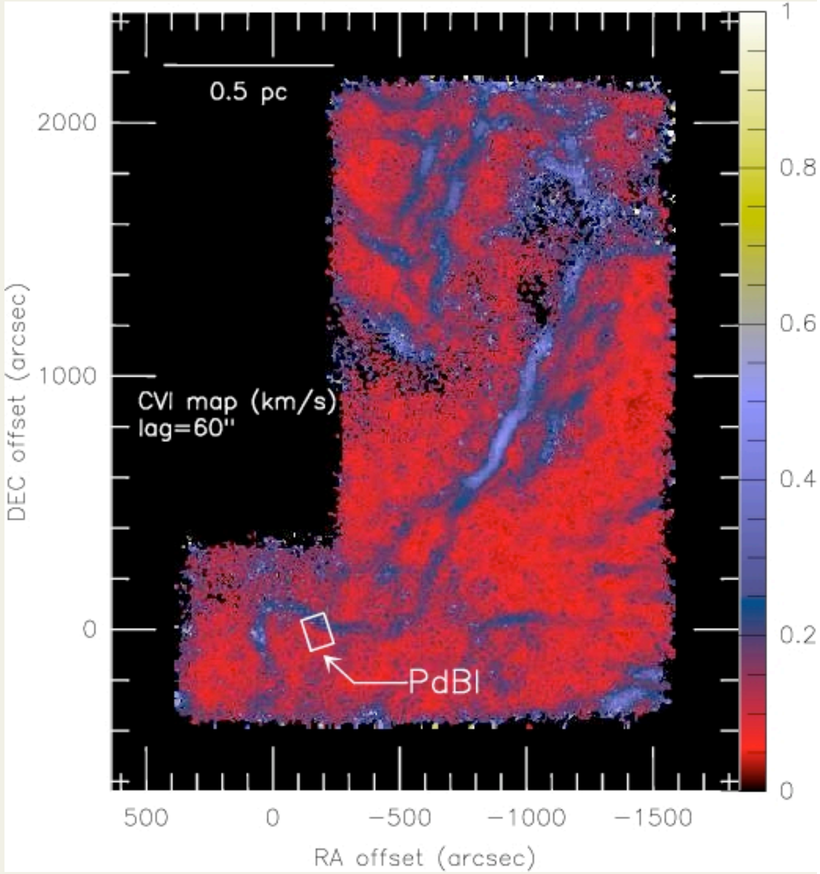


CO emission IRAM-PdBI (left) and merged with short spacings (right)

Falgarone + 2009

From pc to mpc scales





15mpc

➯ Orientation of shear-layers is preserved

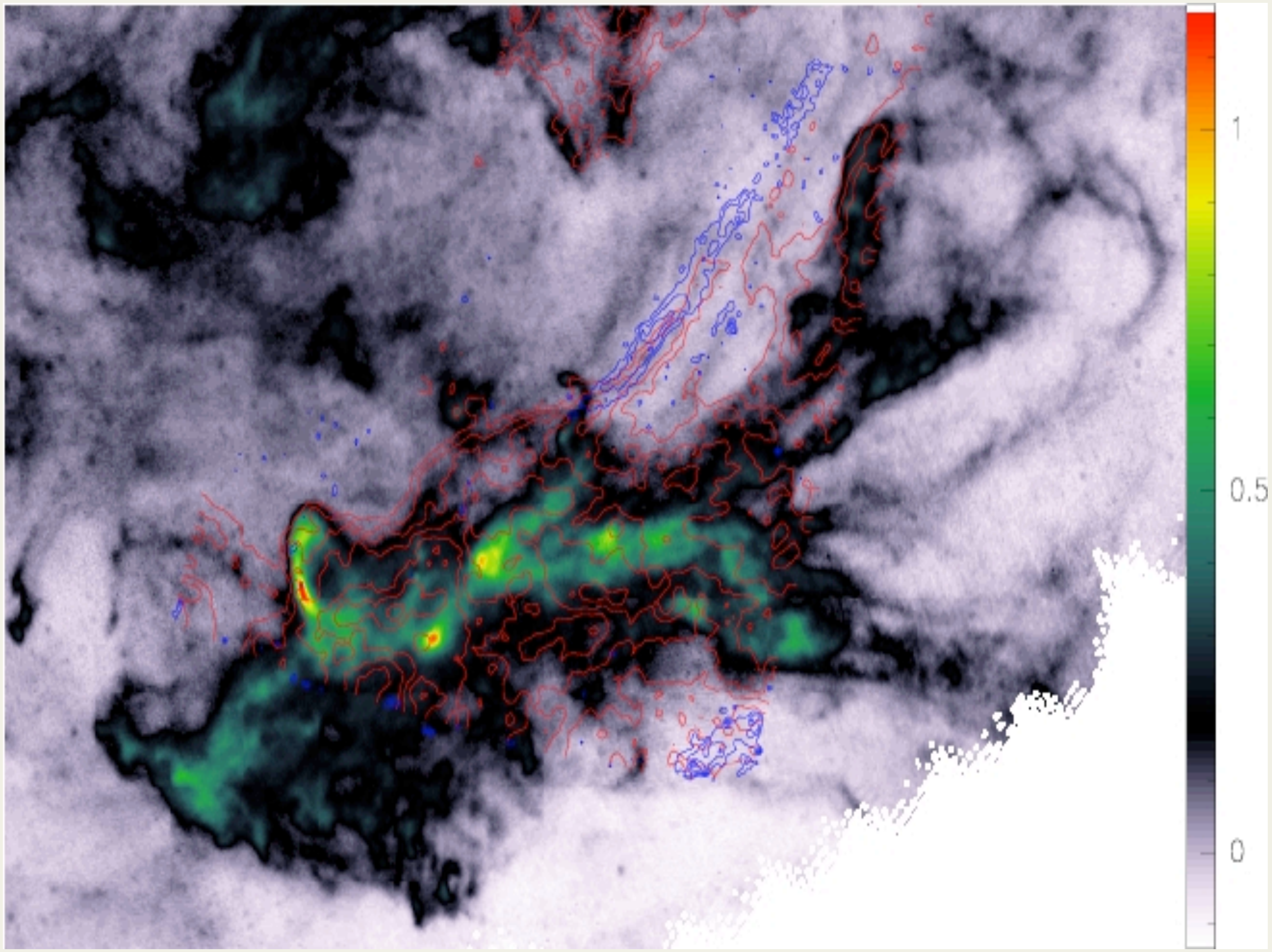
➯ As at pc scales, sharp CO-edges are pairs

Velocity-shears : up to 700 km s^{-1} pc^{-1}

➯ Chemically active shears: CO seeds

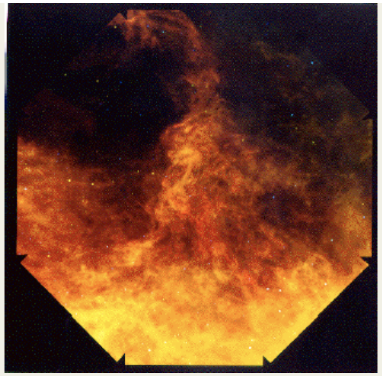
Seeds of structures:

dust 250μm, CO(2-1) (red), extreme velocity-shears (blue)

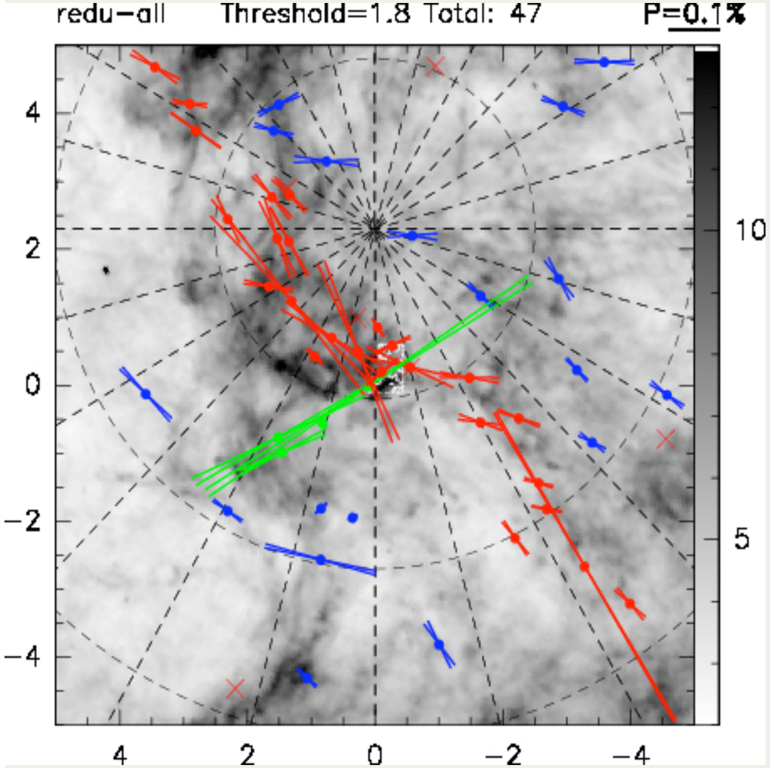


Herschel/SPIRE 250μm map (André et al. 2010)

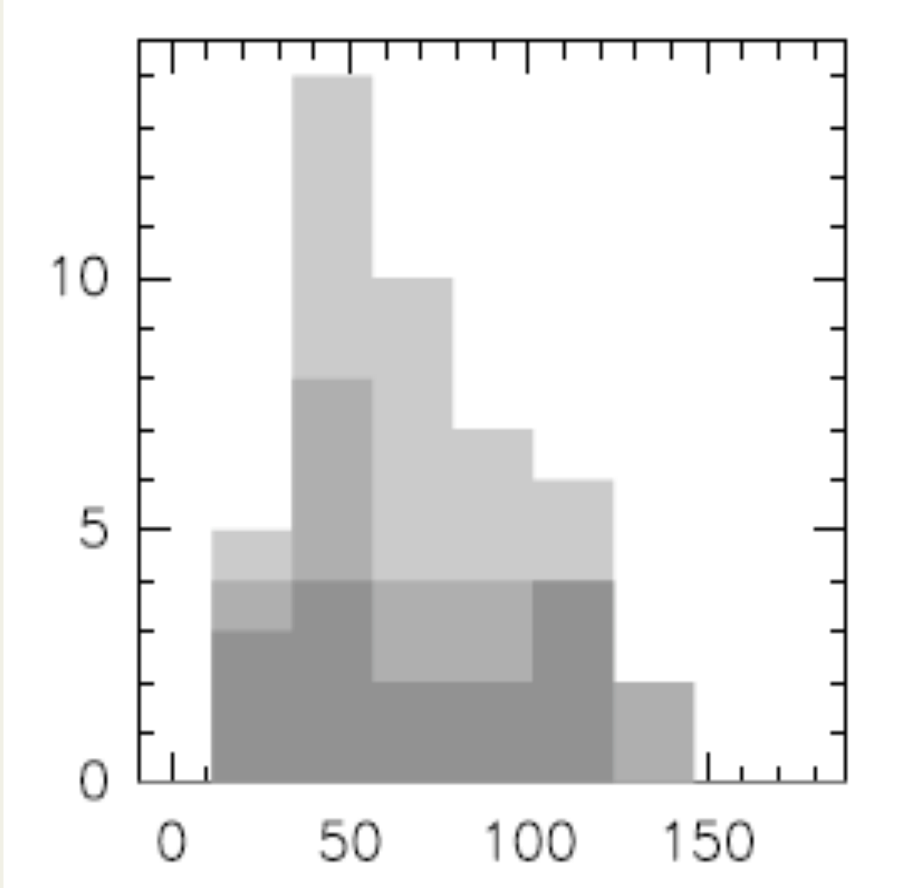
Magnetic field : B_{POS} direction



Polaris Flare : 30 pc scale



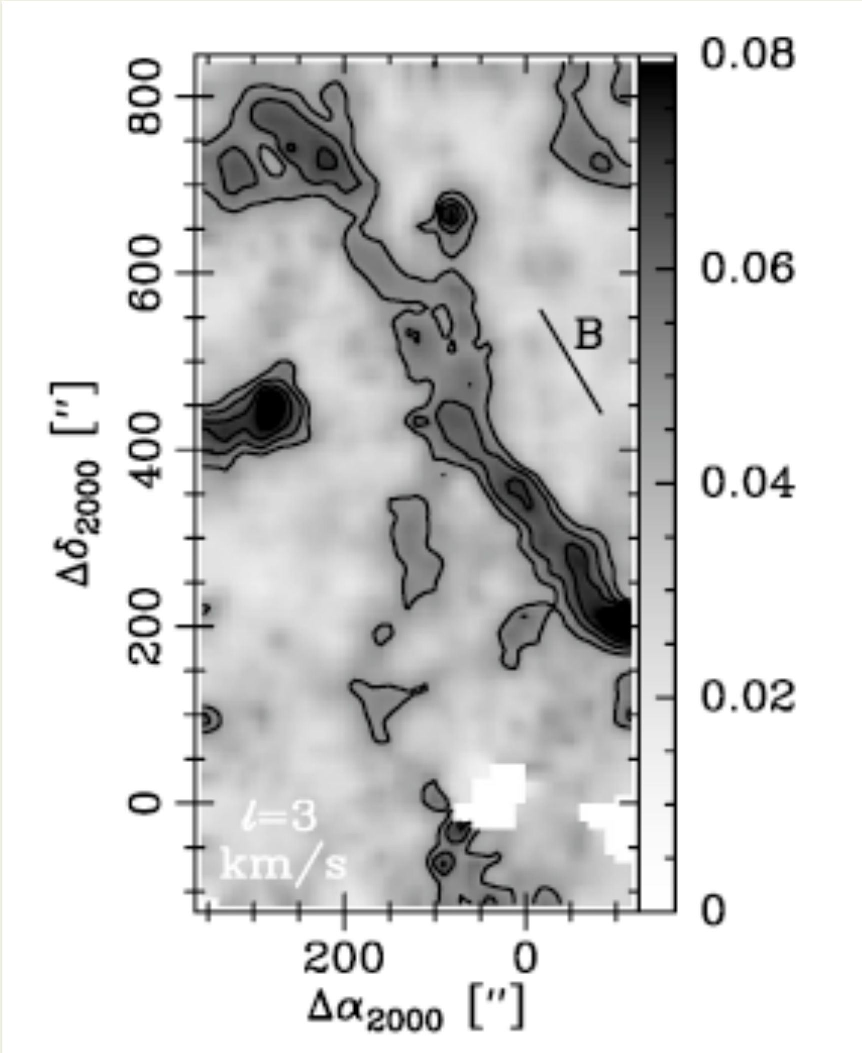
Mohan et al.
in preparation



PA B_{POS}(deg)

PA shear-layers
at mpc-scale

Magnetic field : B_{POS} direction
Taurus edge at pc-scale

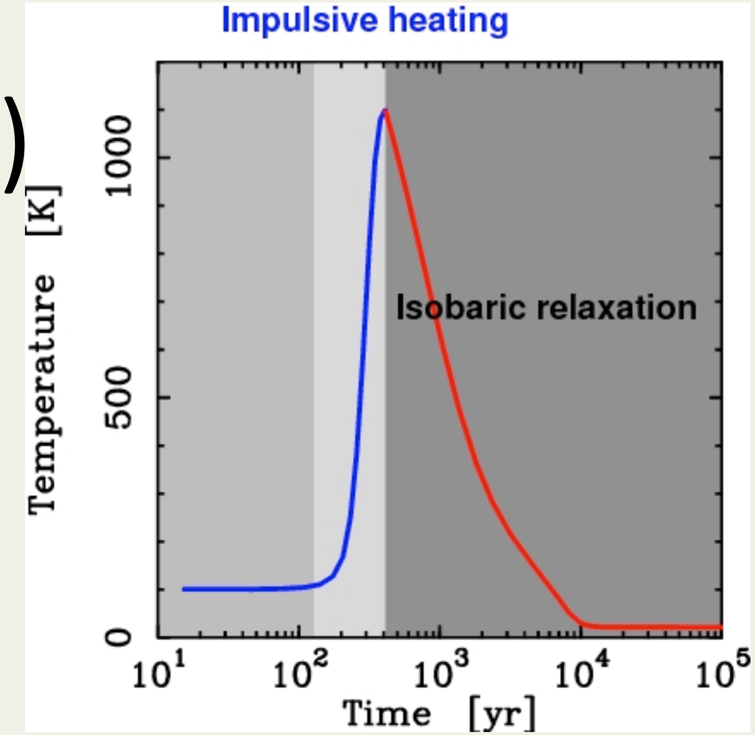


Polarisation measurements Heiles 2000

$\Omega_{POS} // B_{POS}$

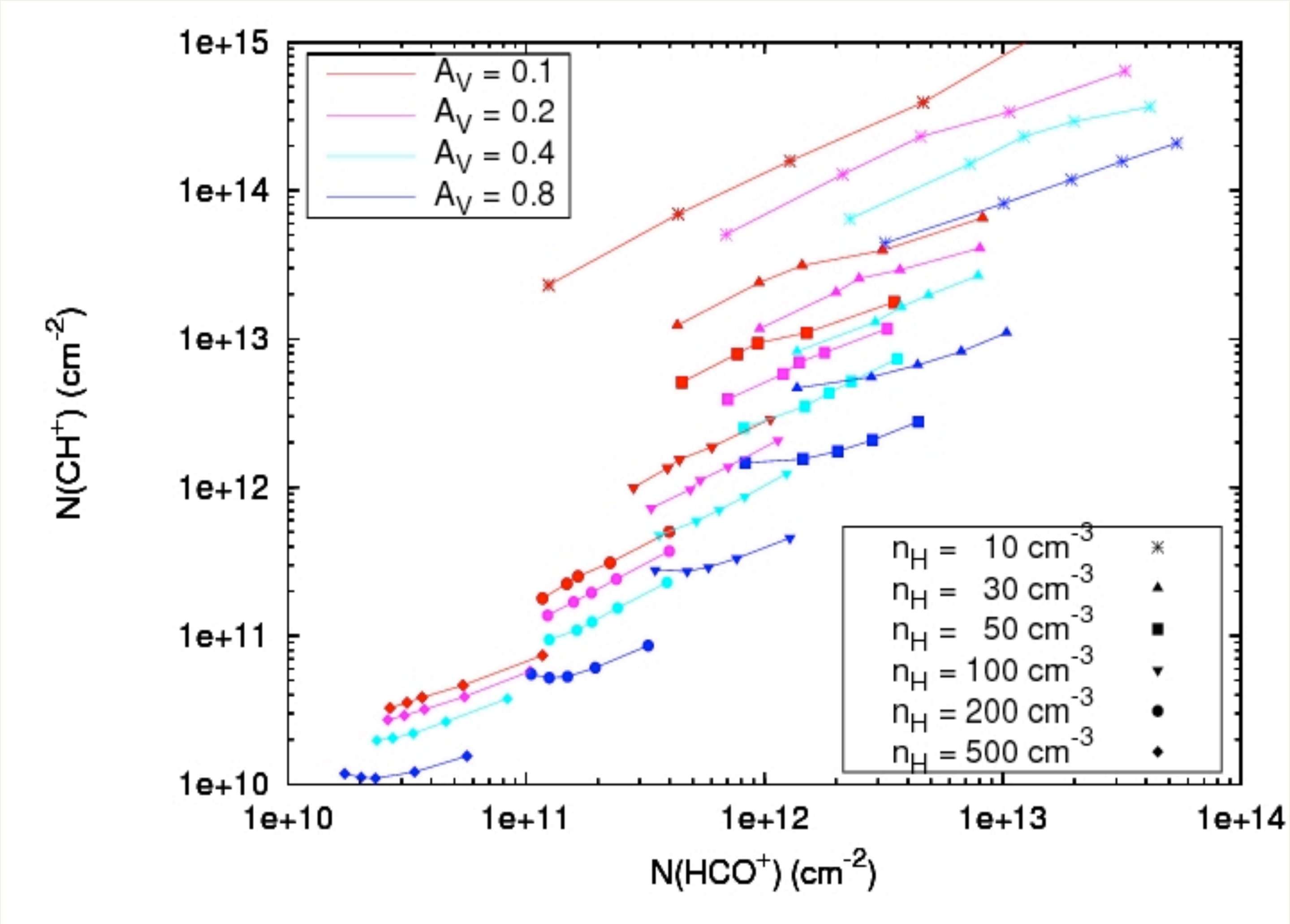
Models of Turbulent Dissipation Regions (TDR)

- Magnetized vortices
  ~ 50 AU, ~ 100 yr
- Dissipation :
  viscous + ion-neutral friction
  → **warm chemistry**
- Thermal and chemical relaxation :
  up to 4 x10^4 yr
- **Few free parameters** :
  rate of strain a, n_H, A_v
- **3 phases :** active and relaxation phases (a few %) + ambient medium



Joulain et al. 1998;
Godard et al. 2009

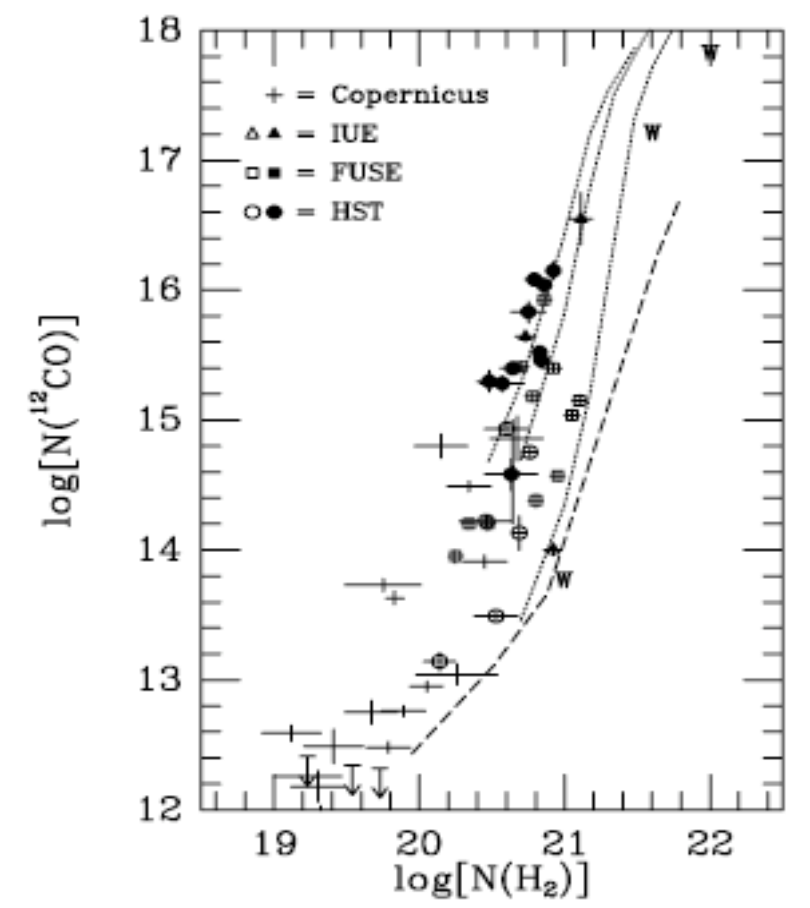
CH^+ and HCO^+

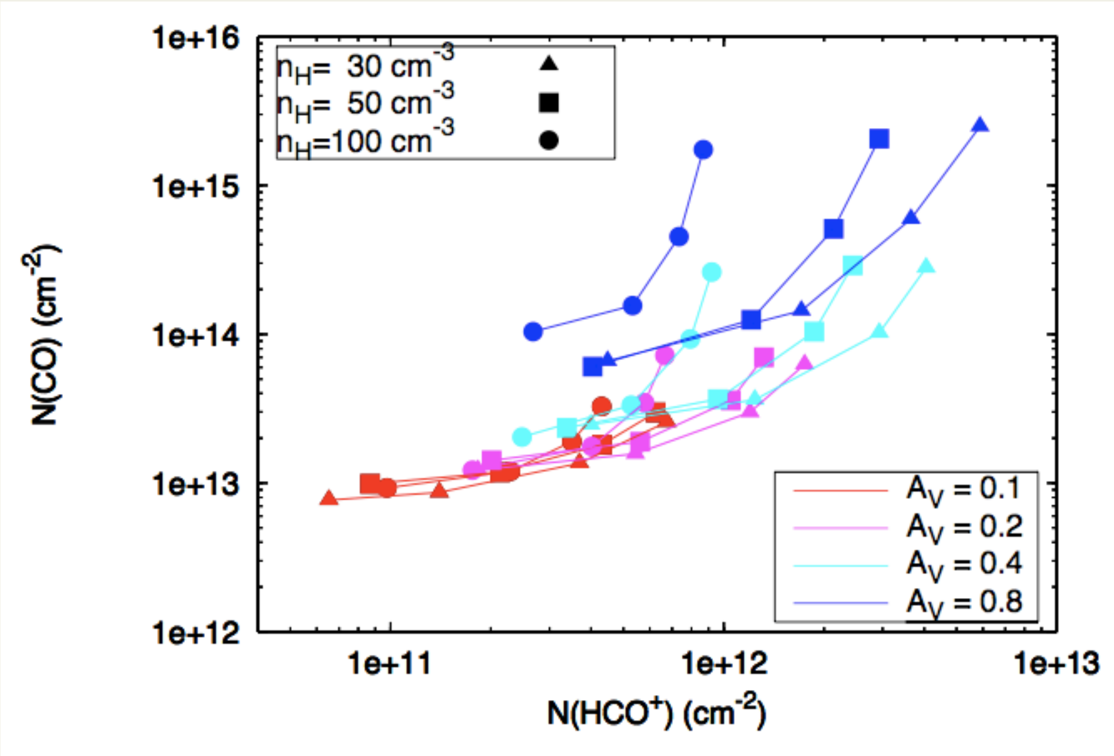


Observed ranges per magnitude

Free parameter along each curve :
rate of strain , a

CO and HCO^+





Sonnentrucker et al 07

Summary and Openings

- Coherent structures of vorticity/shears // B_{POS} from pc to mpc
- Wide scale separation : orientation preserved
- Only a few % of warm gas needed to reproduce observations
- Warm chemistry dominated by ion-neutral drift favored by observations

➪ What are these structures?

➪ Link still missing at 100 AU scale : targets for ALMA?

➪ Other sources of supra-thermal energy : B, cosmic-rays?

➪ Role of structures of intense velocity-shear in the formation of dense filaments?