Turbulence in the interstellar medium Prospects with SKA/LOFAR

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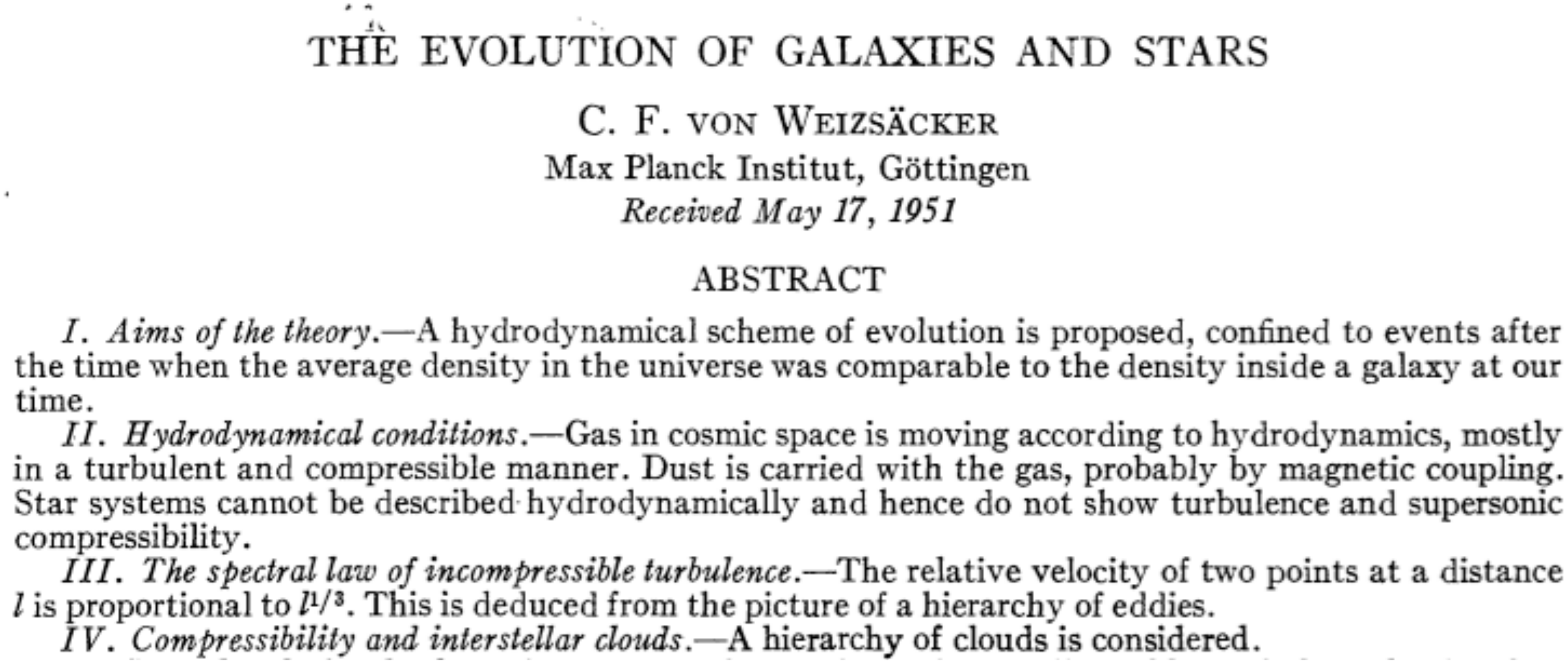
Turbulence in the interstellar medium



THE EVOLUTION OF GALAXIES AND STARS

C. F. von Weizsäcker
Max Planck Institut, Göttingen
Received May 17, 1951

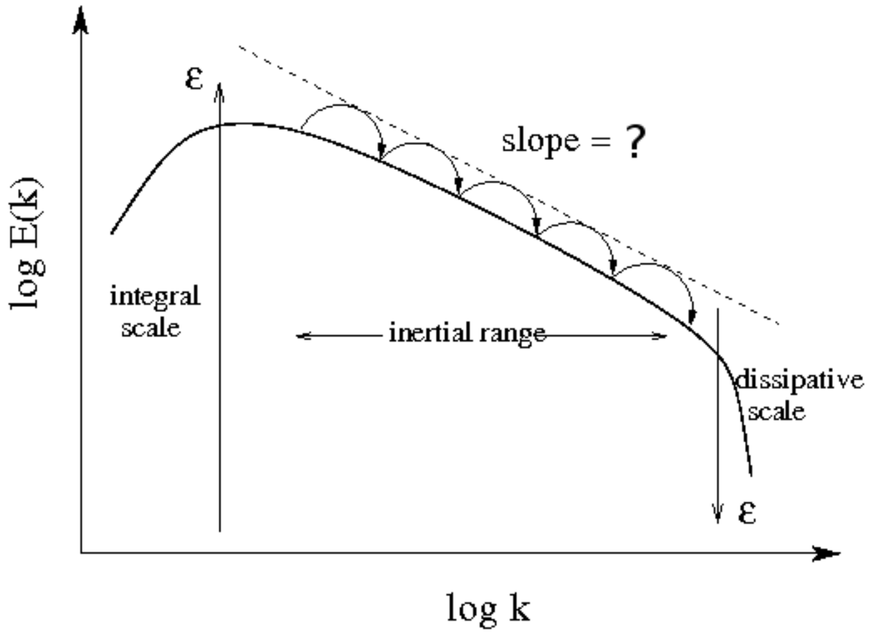
ABSTRACT

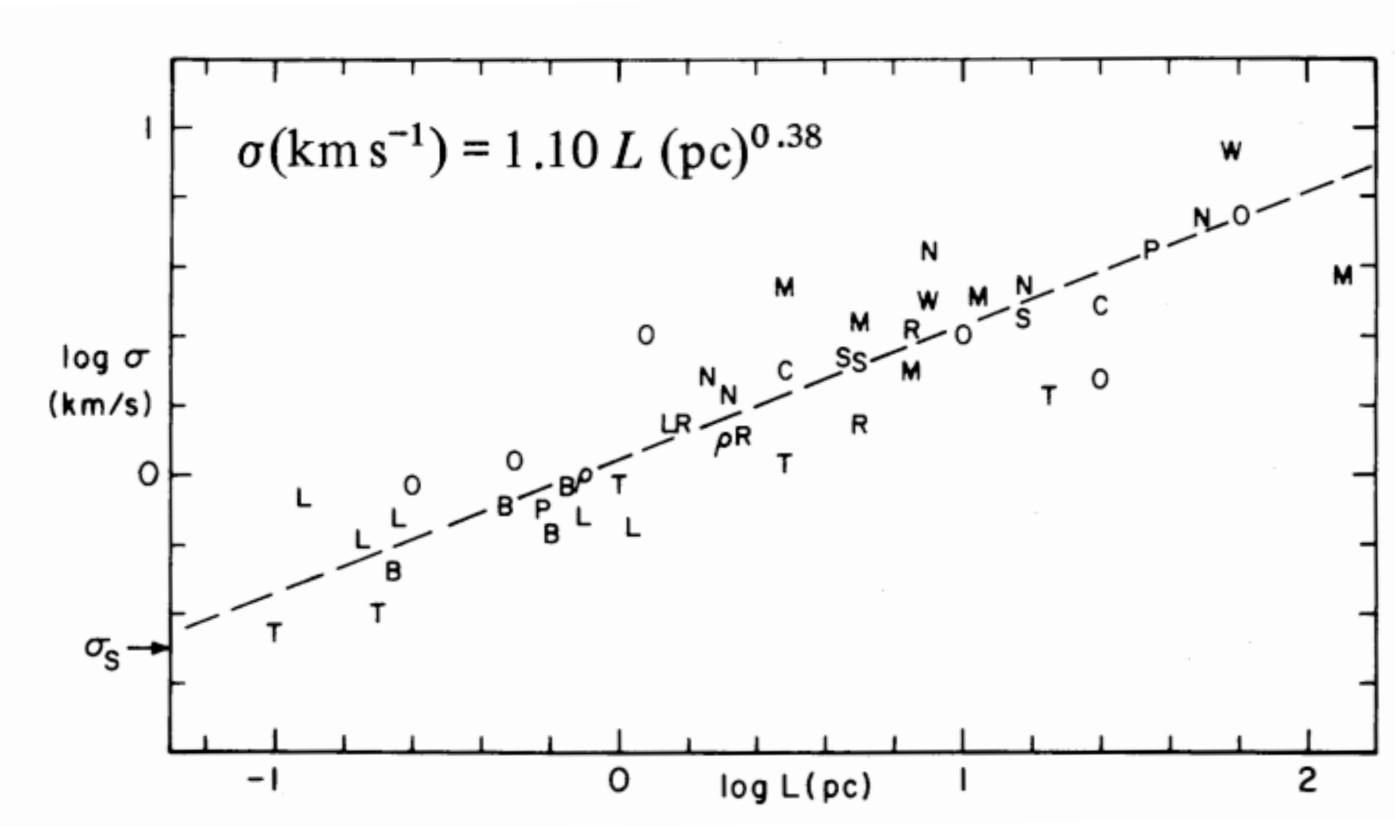
I. Aims of the theory.—A hydrodynamical scheme of evolution is proposed, confined to events after the time when the average density in the universe was comparable to the density inside a galaxy at our time.

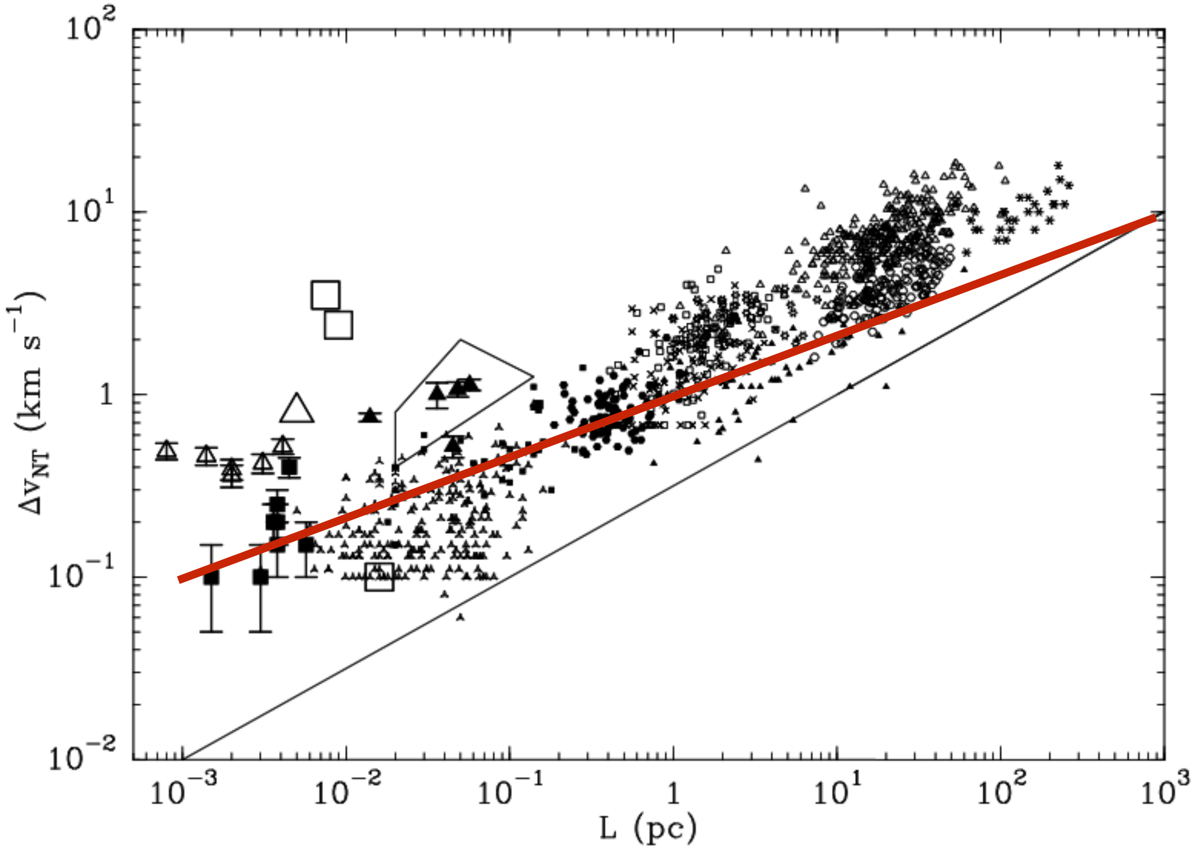
II. Hydrodynamical conditions.—Gas in cosmic space is moving according to hydrodynamics, mostly in a turbulent and compressible manner. Dust is carried with the gas, probably by magnetic coupling. Star systems cannot be described hydrodynamically and hence do not show turbulence and supersonic compressibility.

III. The spectral law of incompressible turbulence.—The relative velocity of two points at a distance l is proportional to $l^{1/3}$. This is deduced from the picture of a hierarchy of eddies.

IV. Compressibility and interstellar clouds.—A hierarchy of clouds is considered.





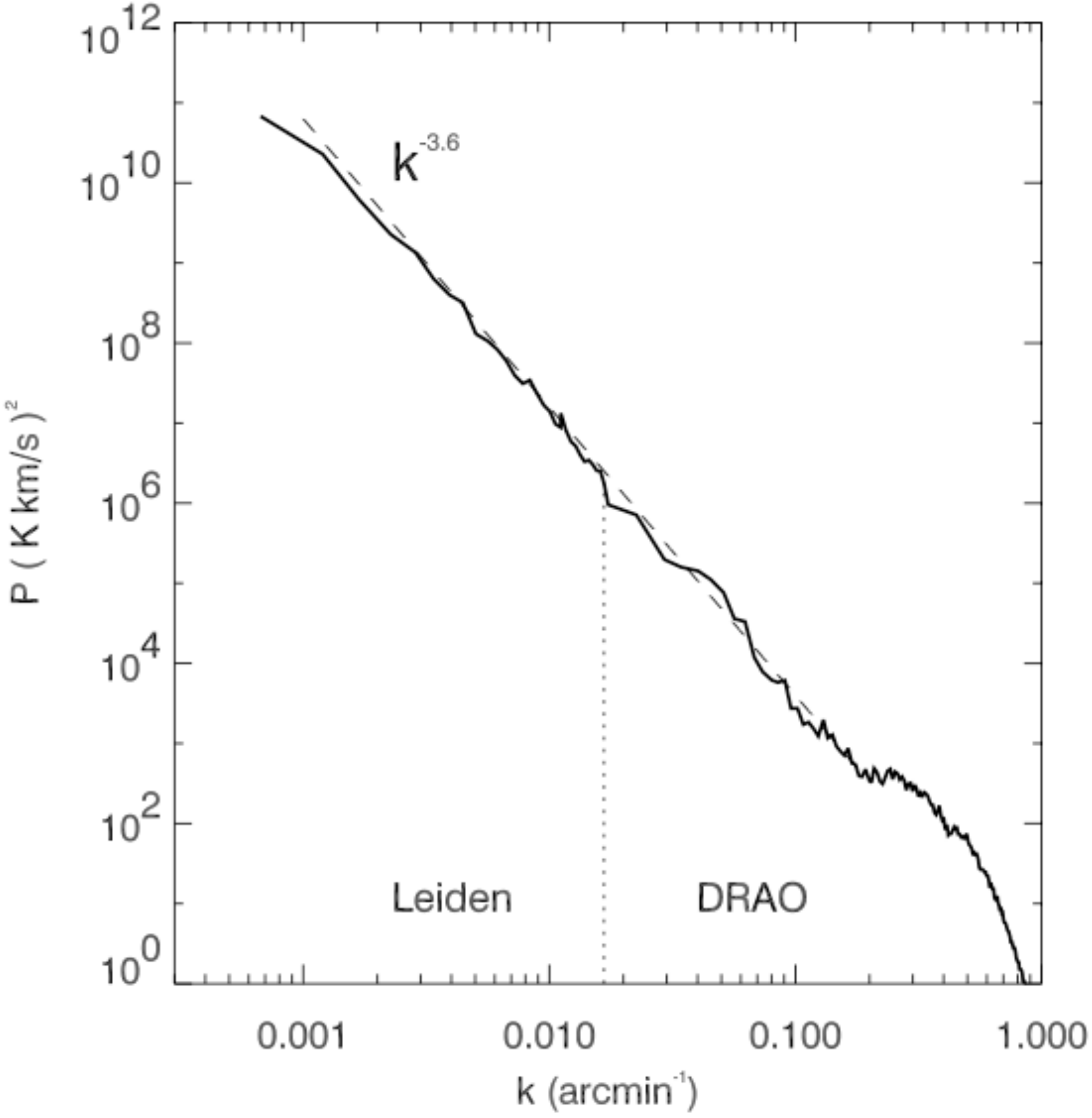


Larson, 1981

Falgarone et al., 2009

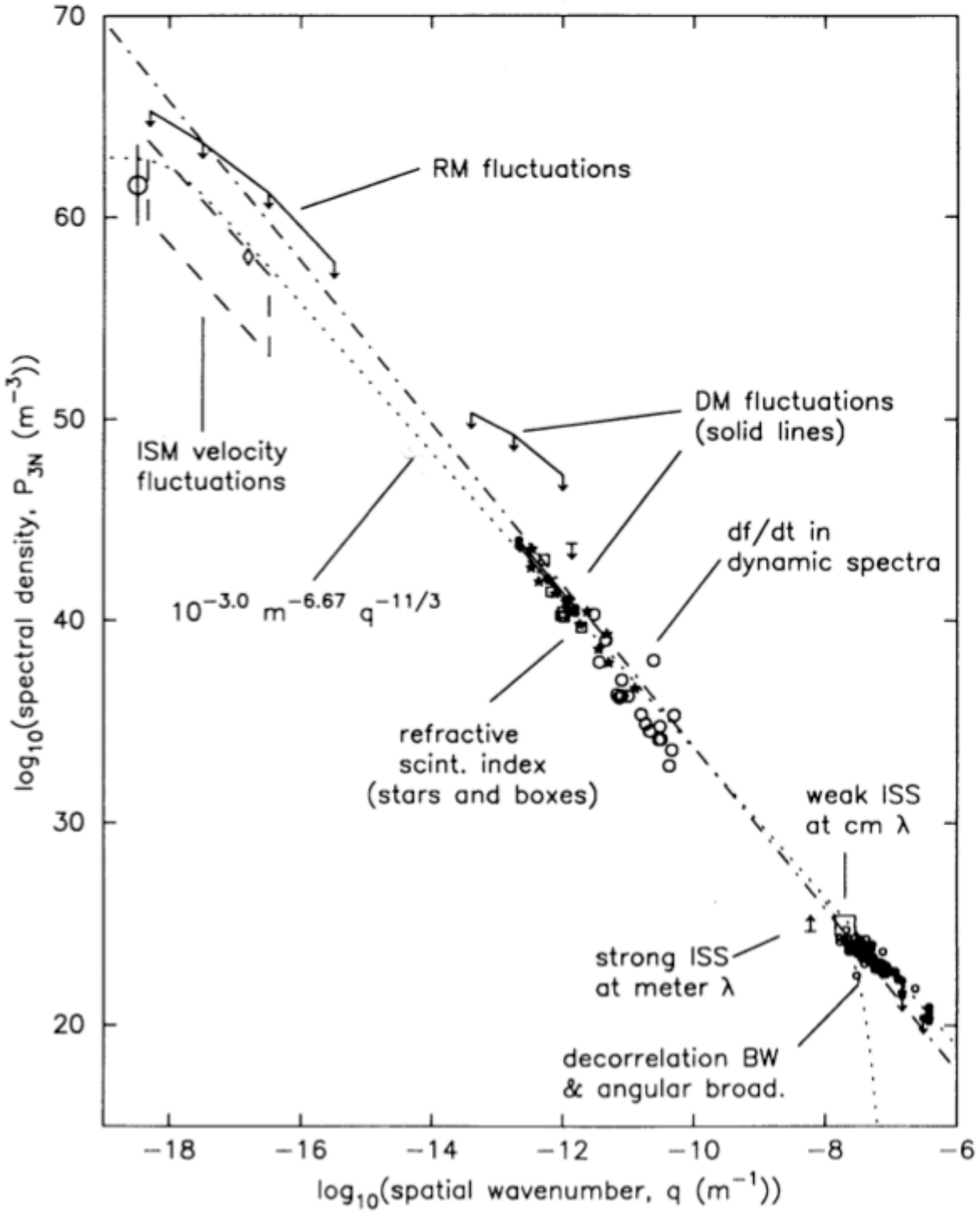
Power spectra in various phases

HI gas in Ursa Major



Miville-Deschênes et al., 2003

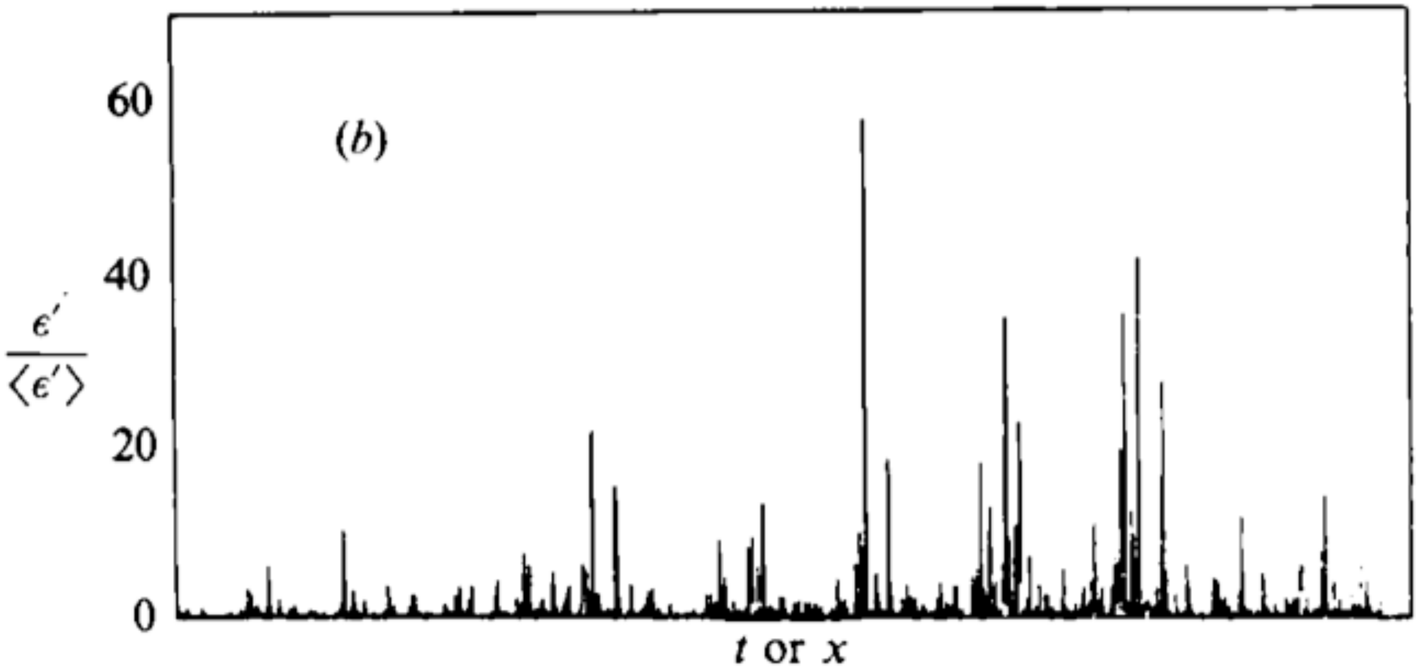
Electron density in local ISM



Armstrong et al., 1995

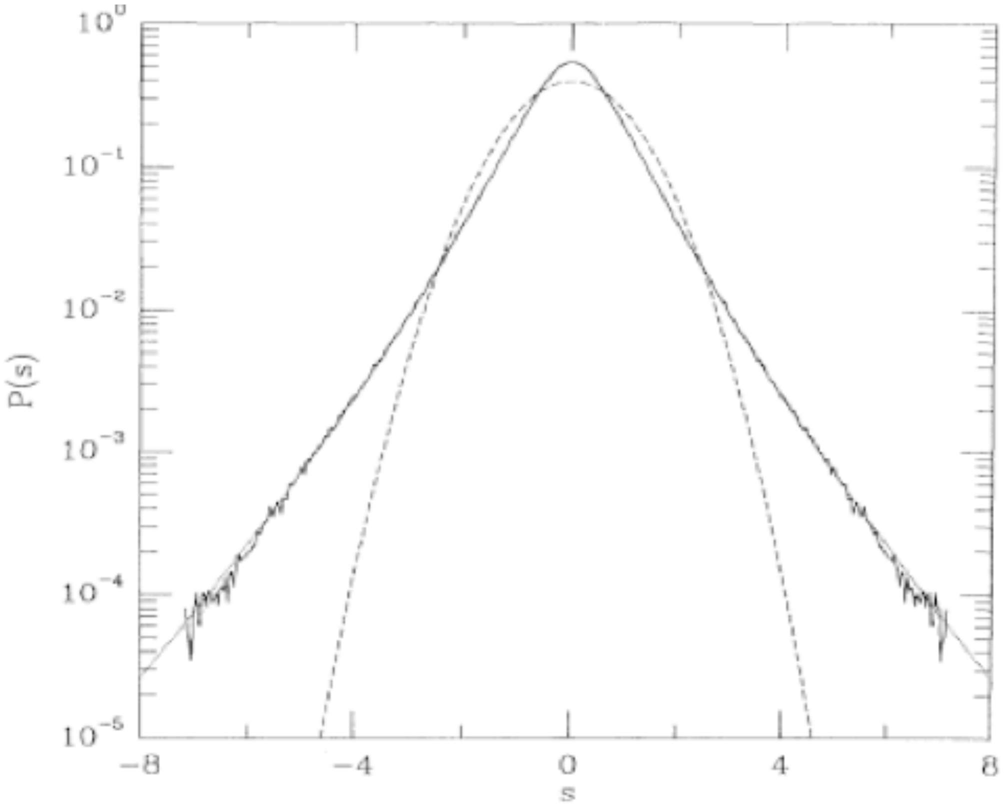
Intermittent dissipation of turbulence

Temporal series of the dissipation rate



Meneveau & Sreenivasan, 1991

Experimental PDF of velocity increments

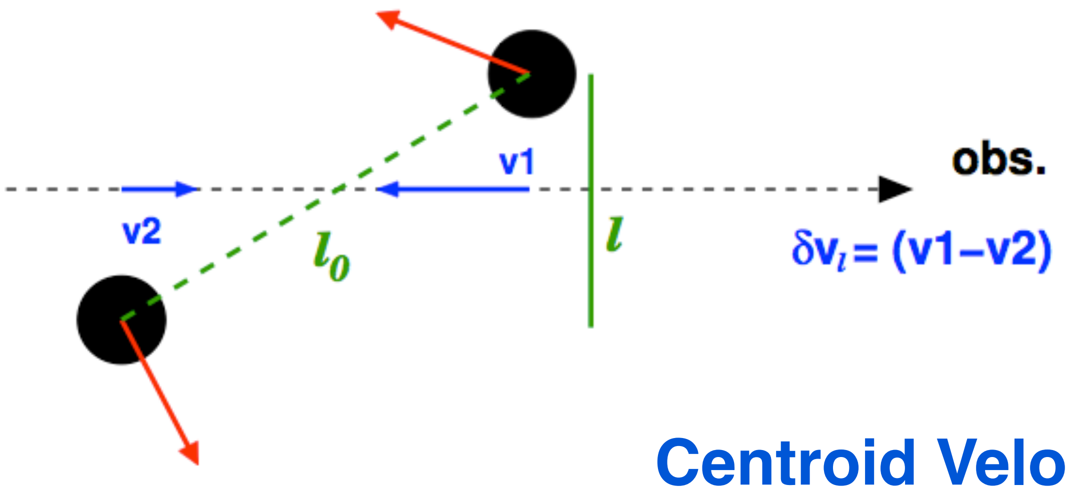


She 1991, Belin et al., 1996

Viscous dissipation rate $\langle \epsilon_d \rangle = \nu \left| \nabla \times \boldsymbol{v} \right|^2$

Problem : we cannot trace the vorticity ! $v_z(x, y)$

Kinematic signatures of turbulent dissipation



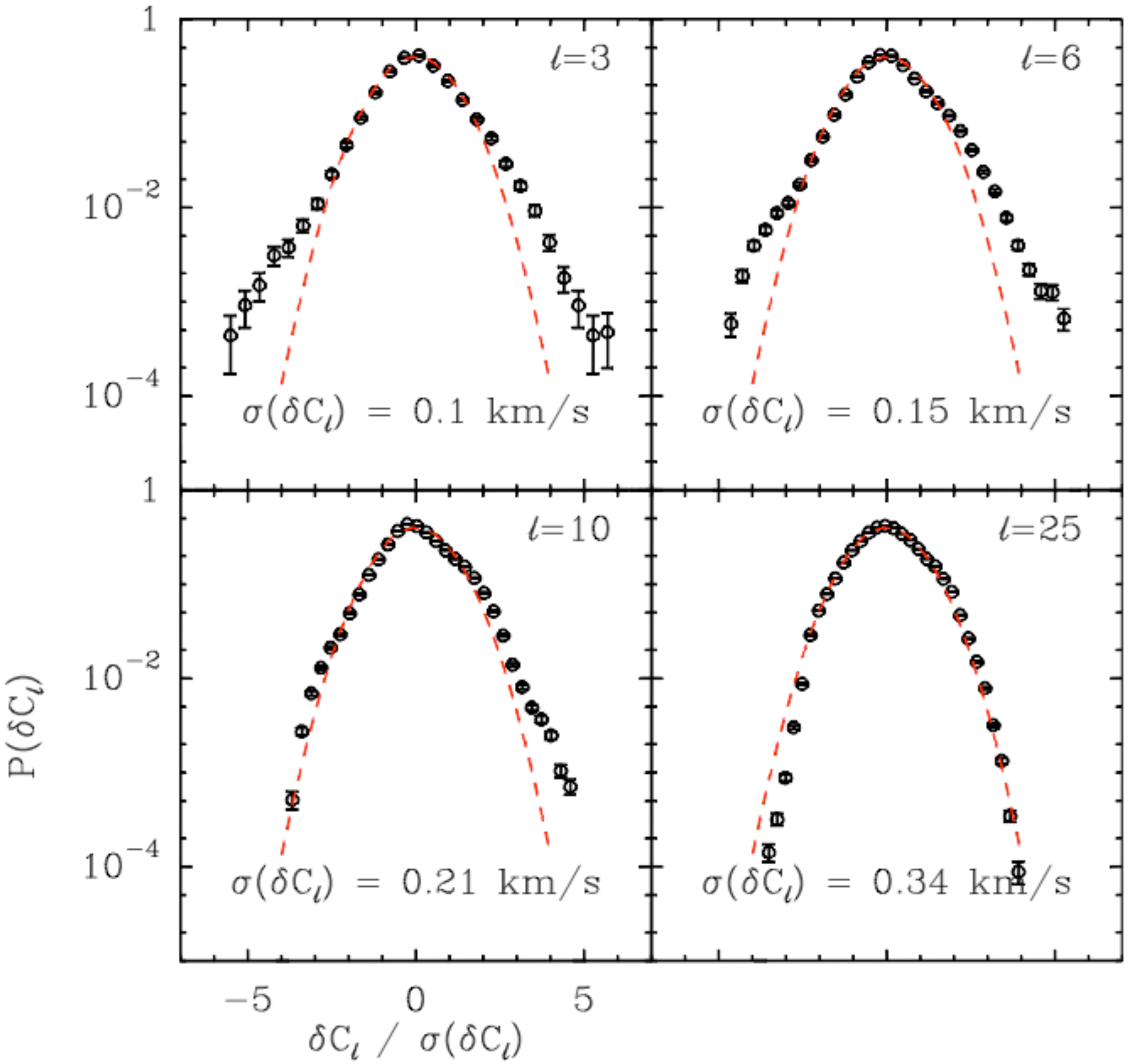
Line centroid velocity:

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

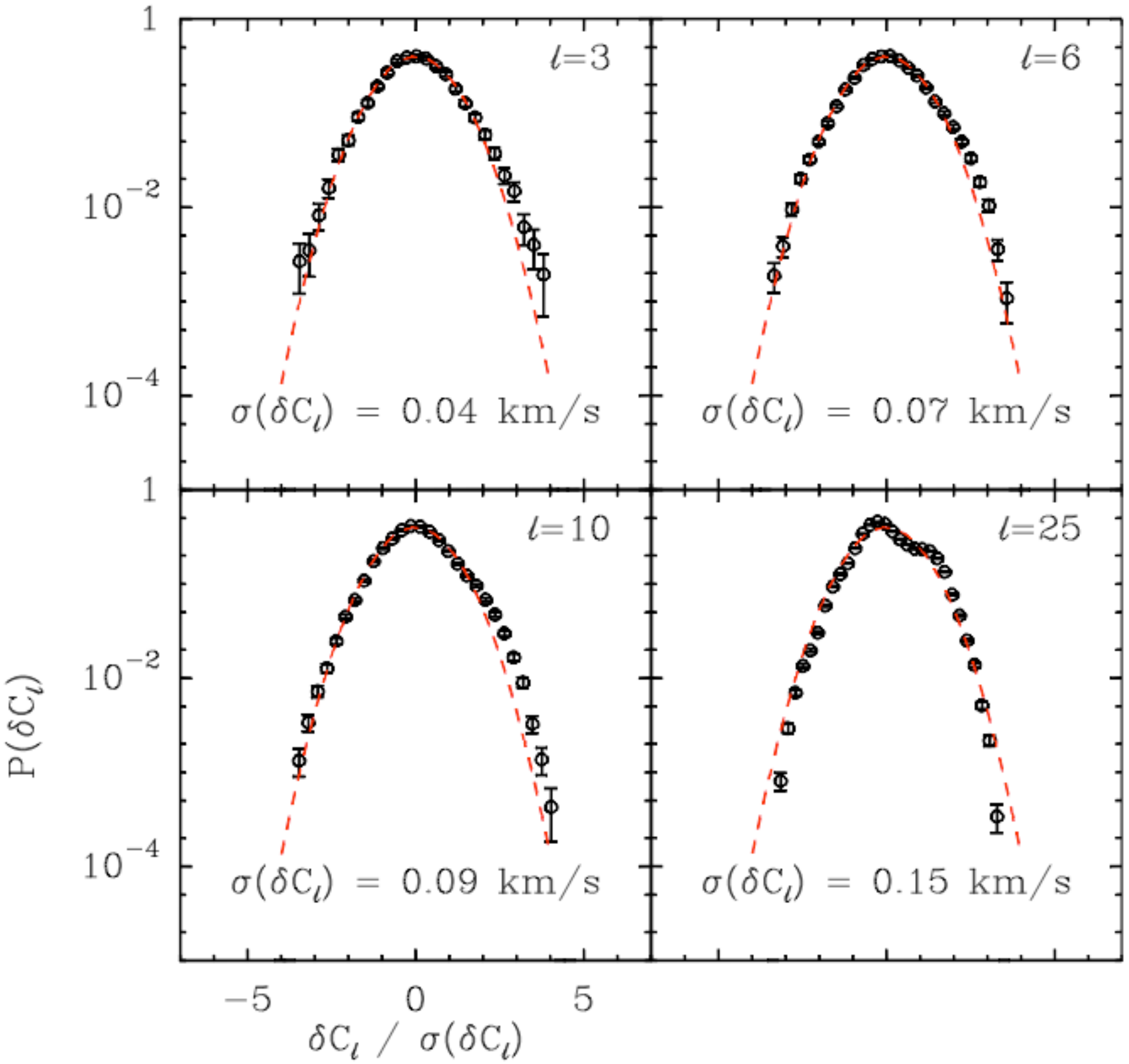
Miesch & Scalo 1999, Pety & Falgarone 2003, Levrier 2004

Centroid Velocity Increments (CVI)

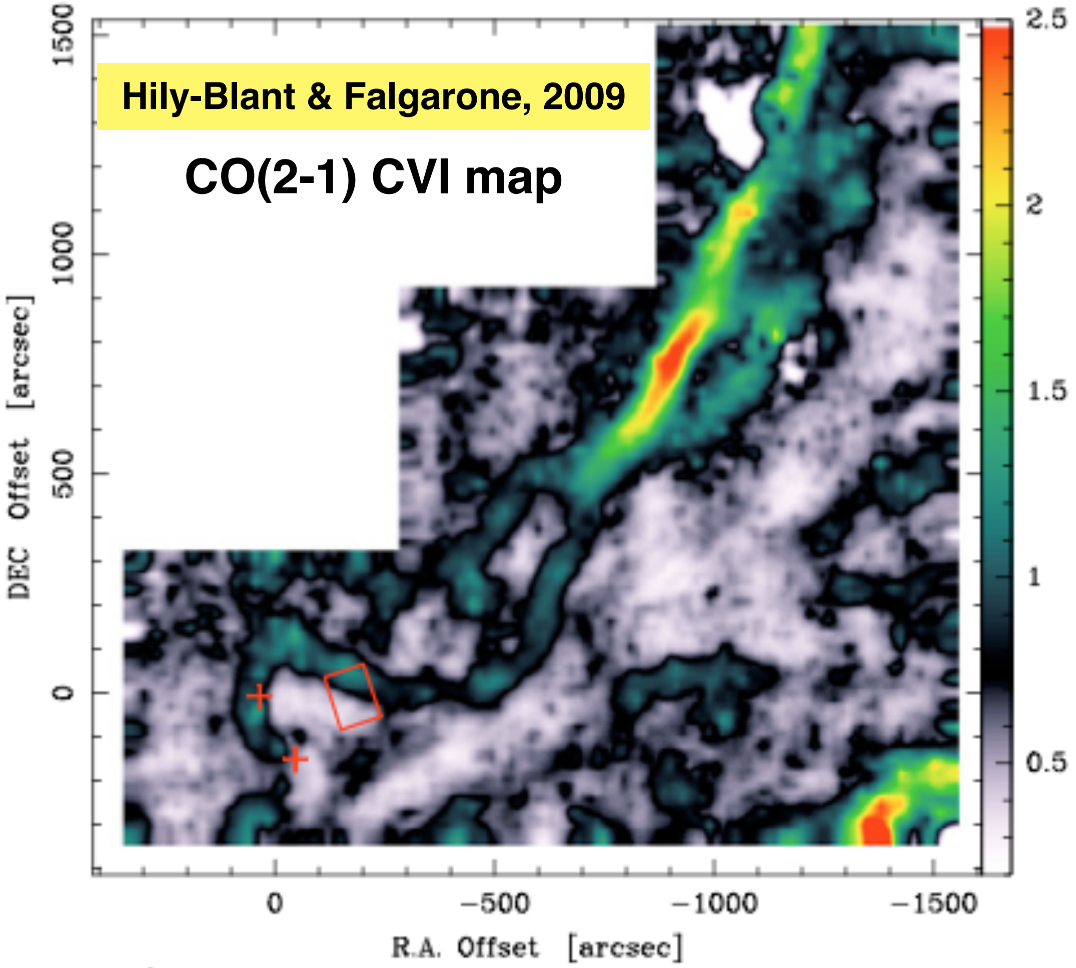
Polaris



Taurus

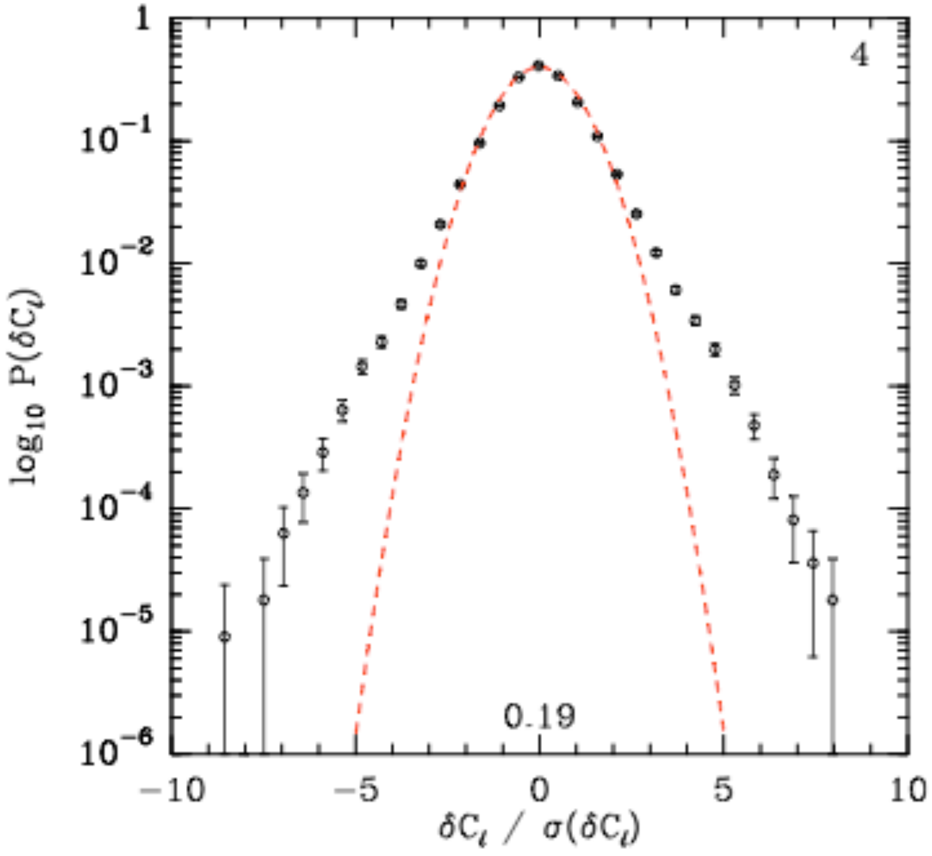


Loci of extreme CVI

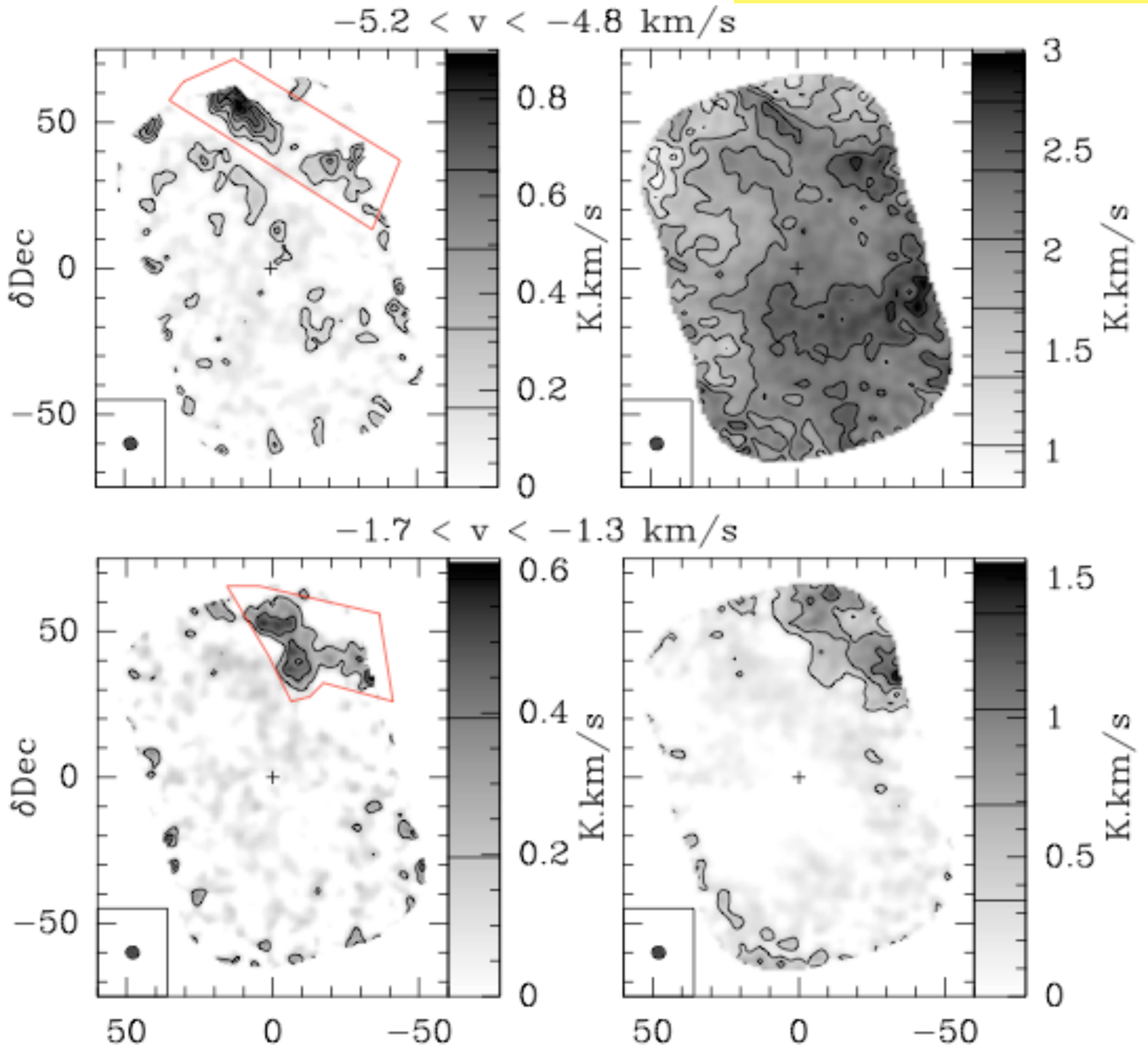


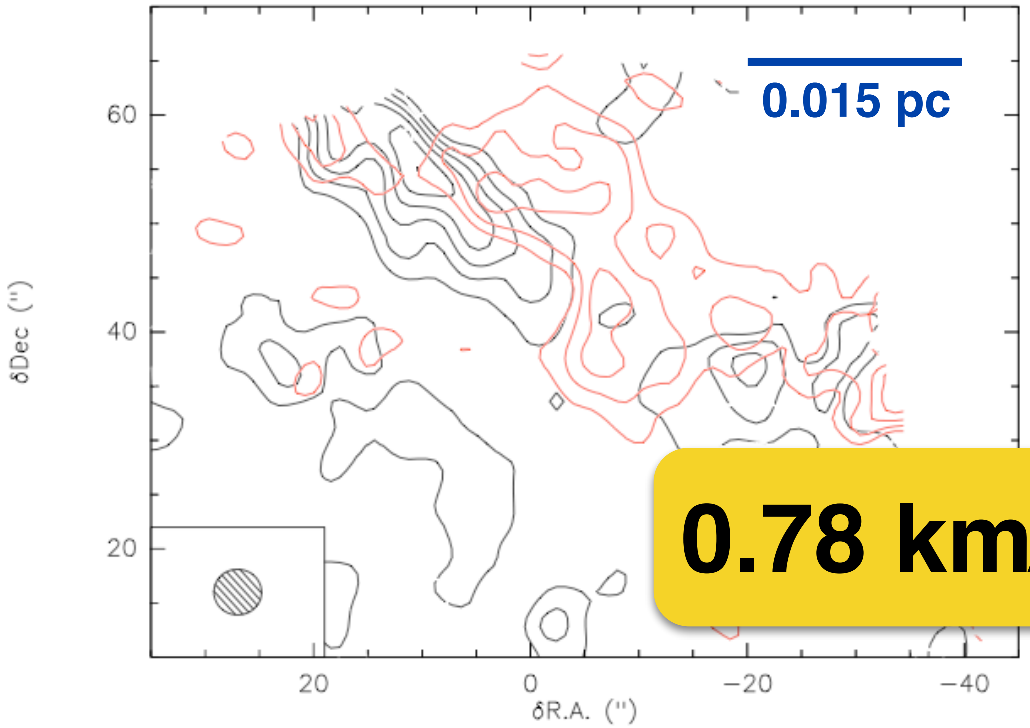
Hily-Blant & Falgarone, 2009

CO(2-1) CVI map



Falgarone, Pety & Hily-Blant, 2009

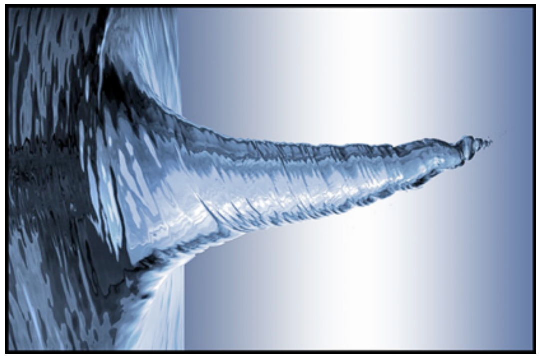




0.78 km/s/mpc

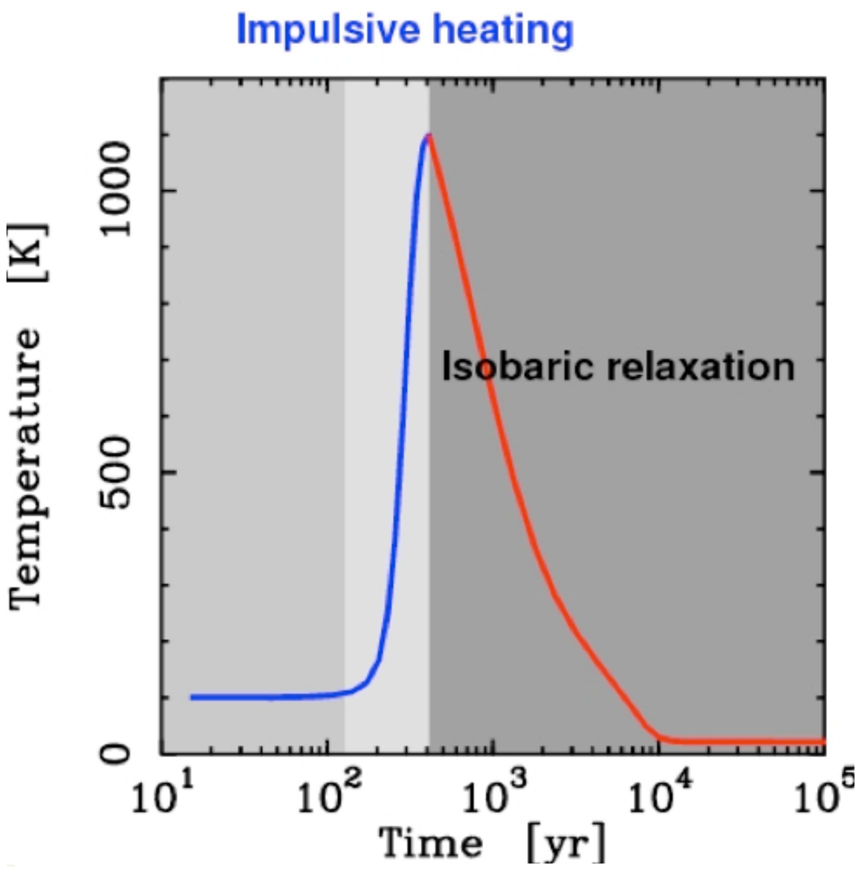
Chemical signatures of turbulent dissipation

Magnetized modified Burgers vortex



$$\omega_z(r) = \omega_0 \cdot \mathrm{e}^{-\frac{a}{4\nu\beta}\left[1-\mathrm{e}^{-\beta r^2}\right]}$$

a : **Turbulent rate of strain**



Joulain et al., 1998, Godard et al., 2009

Magnetized vortices:
~ 50 AU
~ 100 years lifetime

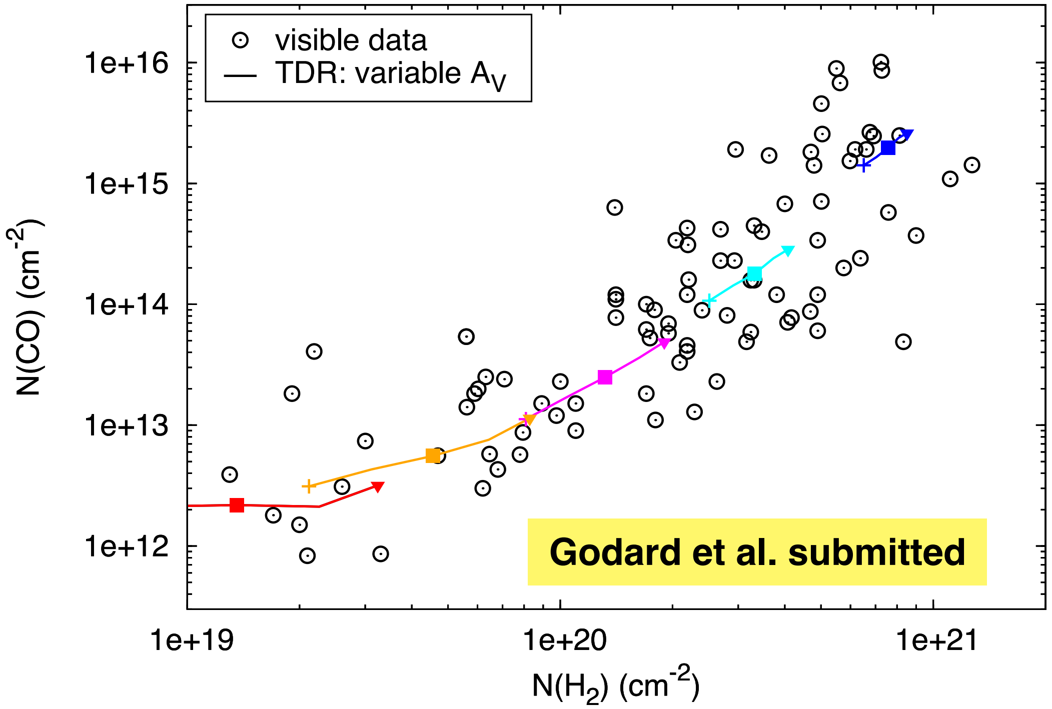
Dissipation leads to warm chemistry

Thermal and chemical relaxation last up to 4.10^4 years

Free parameters a ; $n_{\rm H}$; $A_{\rm V}$

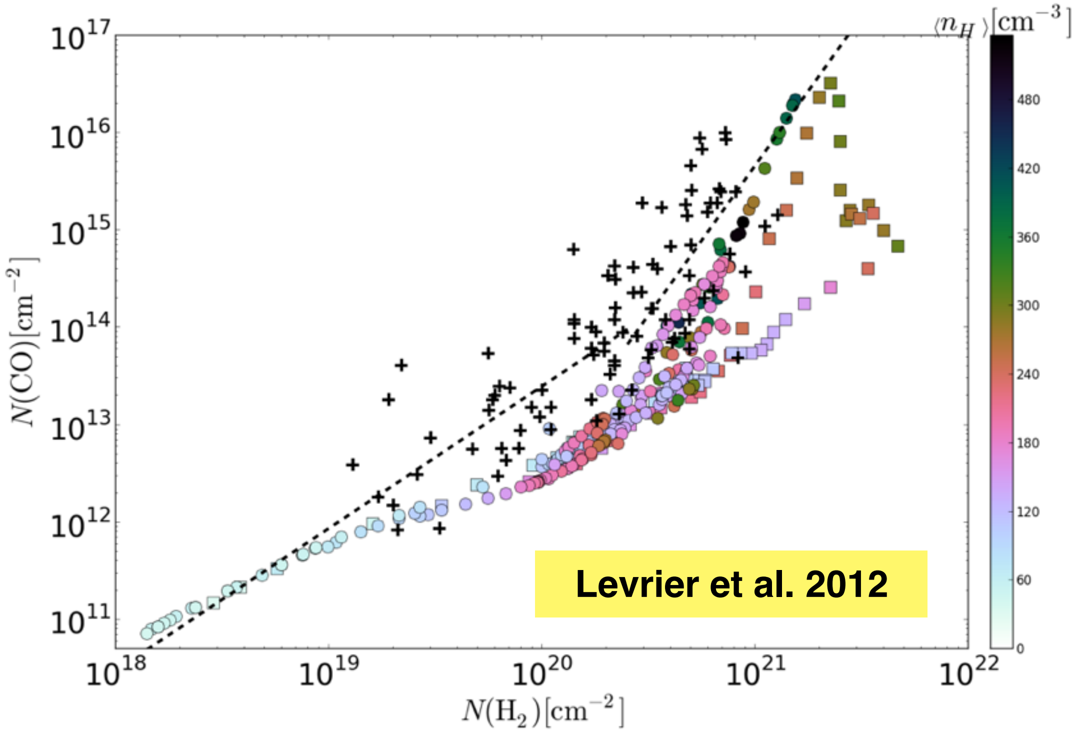
3 phases : active and relaxing vortices, ambient medium

TDR model



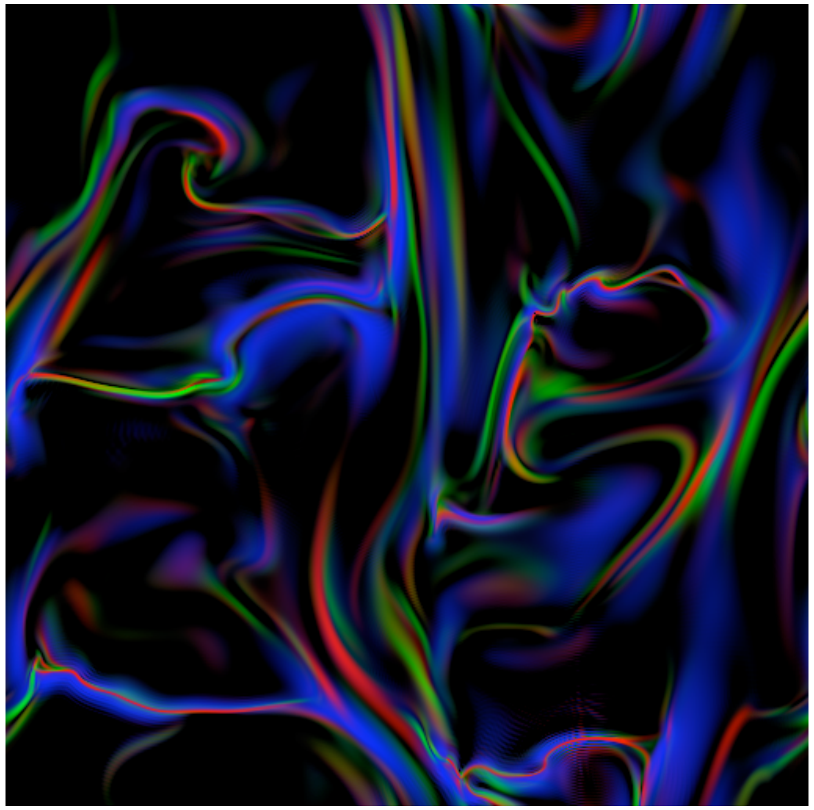
Godard et al. submitted

MHD+PDR model



Levrier et al. 2012

Dissipation processes



2D cut through a 512^3 incompressible turbulence simulation with the ANK code

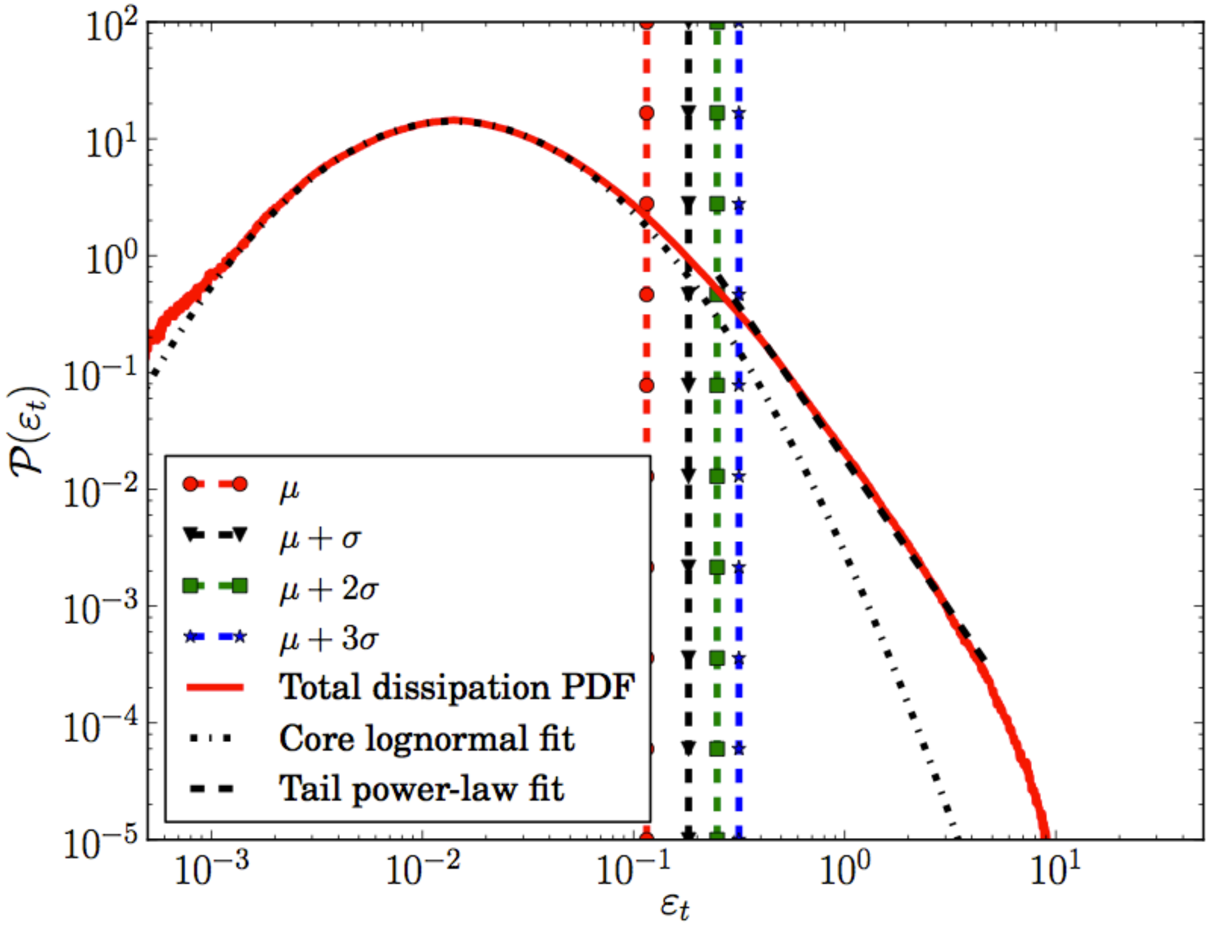
🟩 **Viscous heating**

🟥 **Ohmic heating**

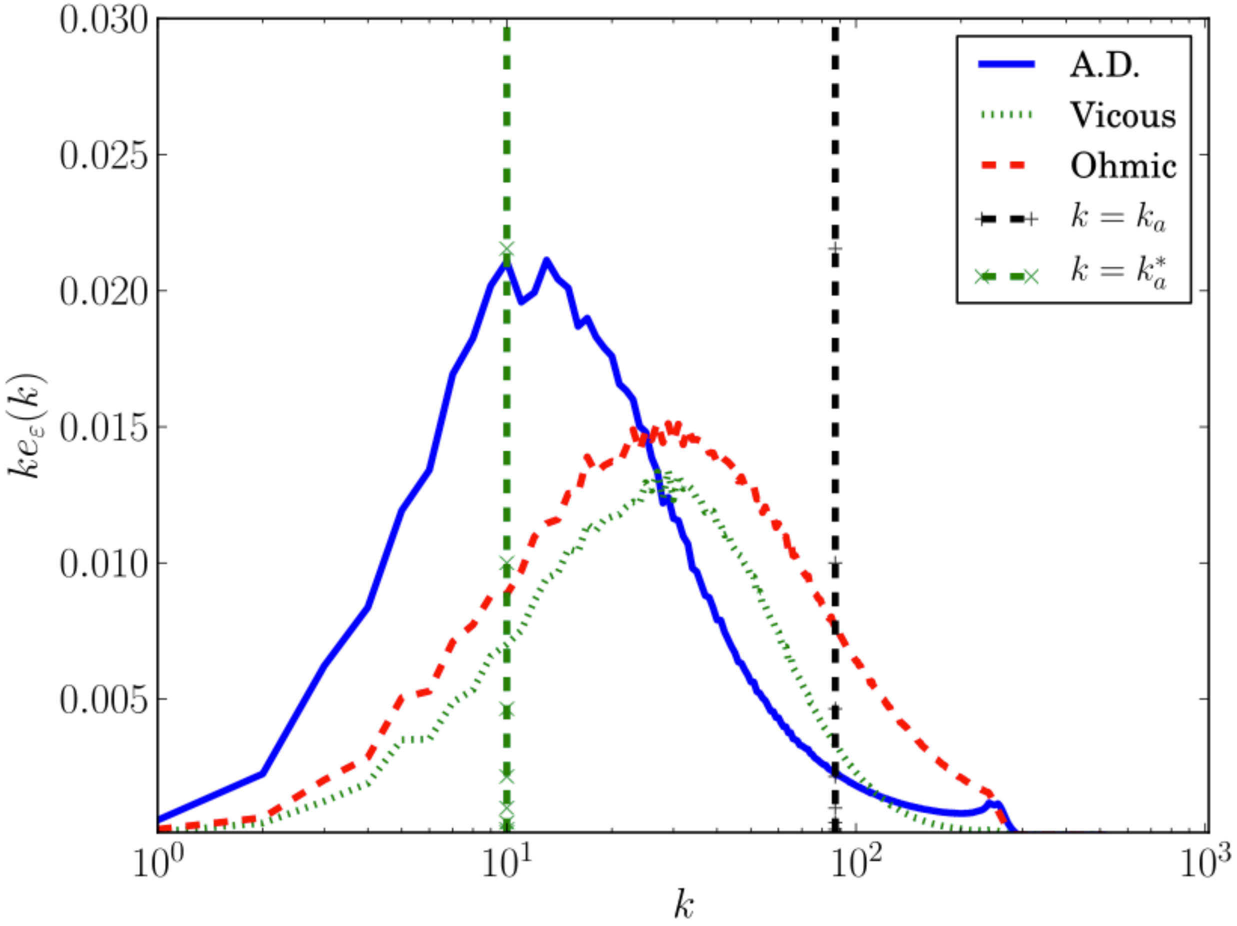
🟦 **Ambipolar diffusion heating**

Momferratos et al., accepted.

PDF of the dissipation rates



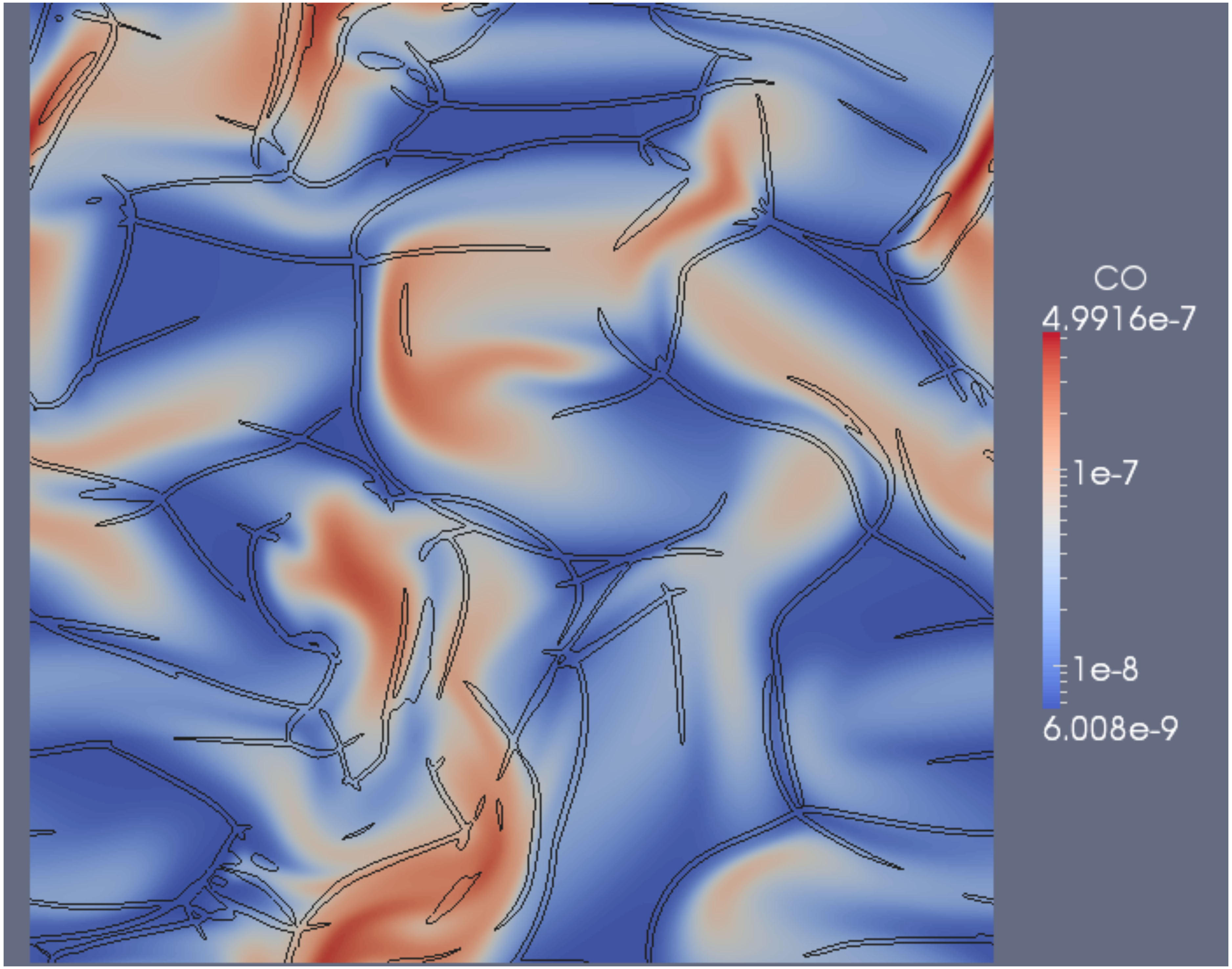
Compensated dissipation spectra



Chemical enrichment in the wakes of shocks

2D decaying turbulence simulation with chemical coupling

- Colour scale : CO abundances
- Contours : Regions of high viscous heating

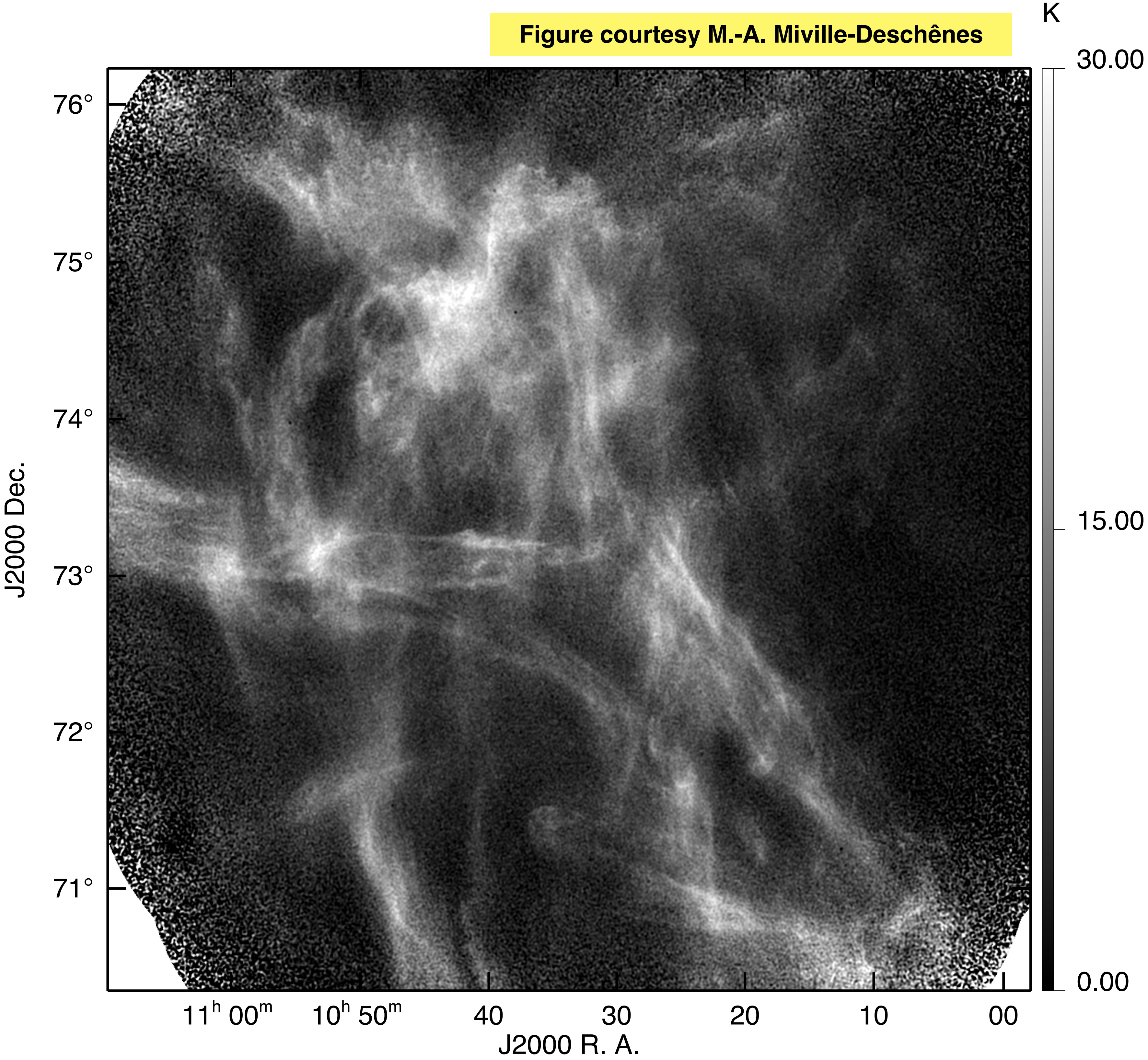


Lesaffre et al., in prep

HI kinematics at small scales

HI 0.4 km/s velocity channel with DRAO in the Spider

Figure courtesy M.-A. Miville-Deschênes



HI kinematics at small scales with the SKA

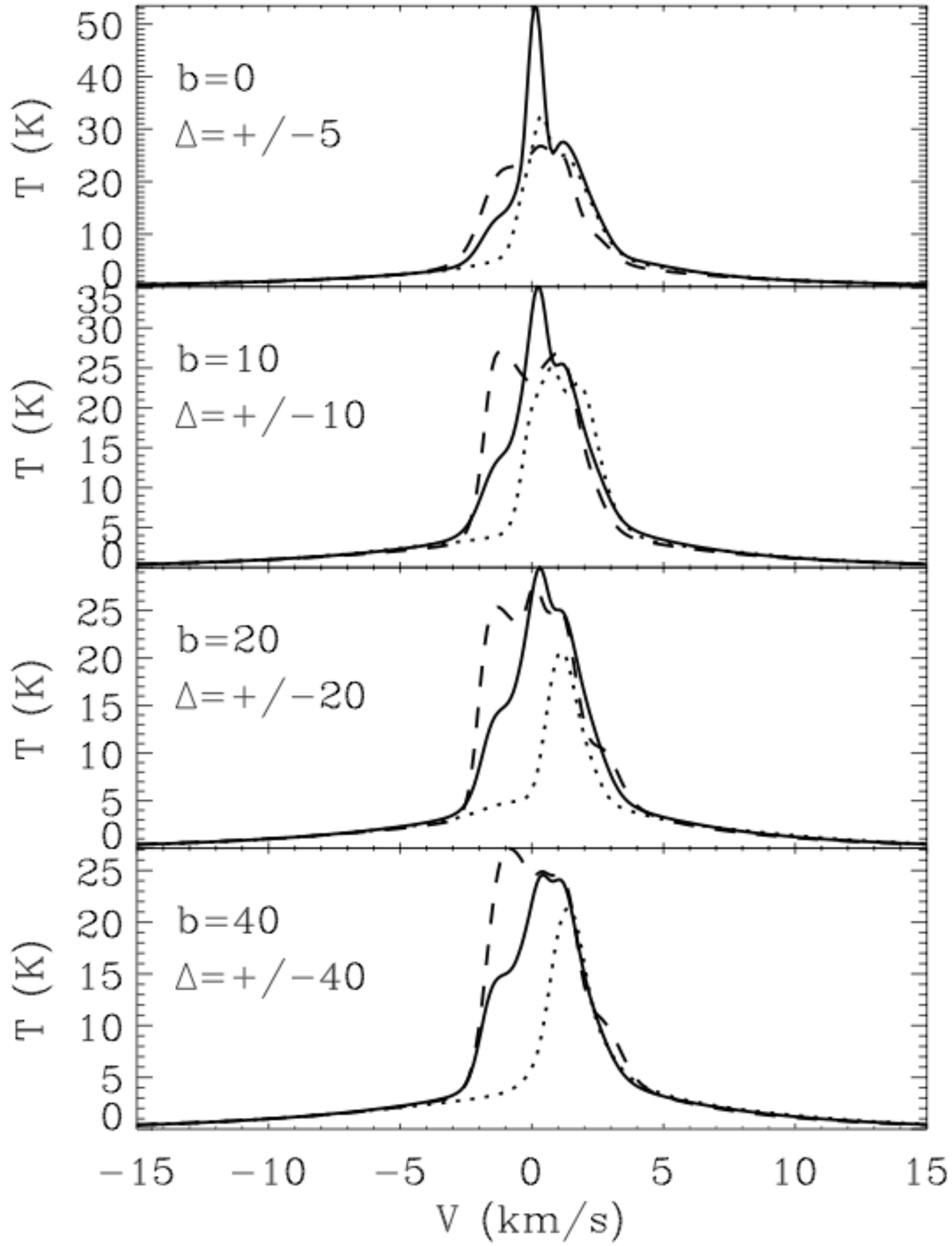
	Core	*Full*
Baselines	5 km	3000 km
Angular resolution	10''	0.018''
Spatial resolution at 150 pc	8 mpc	2.5 AU

FoV 1 square degree
2.6 pc

- **16384 channels with 0.5 km/s resolution**
- **Sensitivity to detect the very diffuse HI (10^{18} cm^{-2}) with the core baselines**

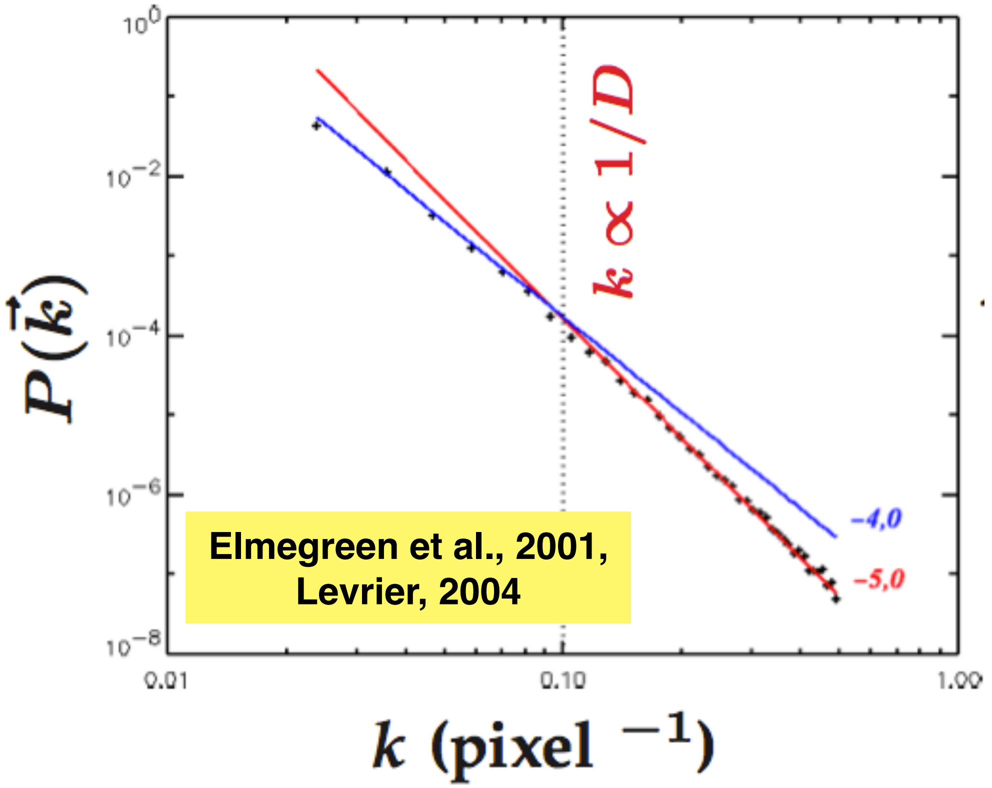
Able to resolve large velocity gradients in the diffuse neutral ISM over a wide instantaneous field-of-view

Hennebelle et al., 2007

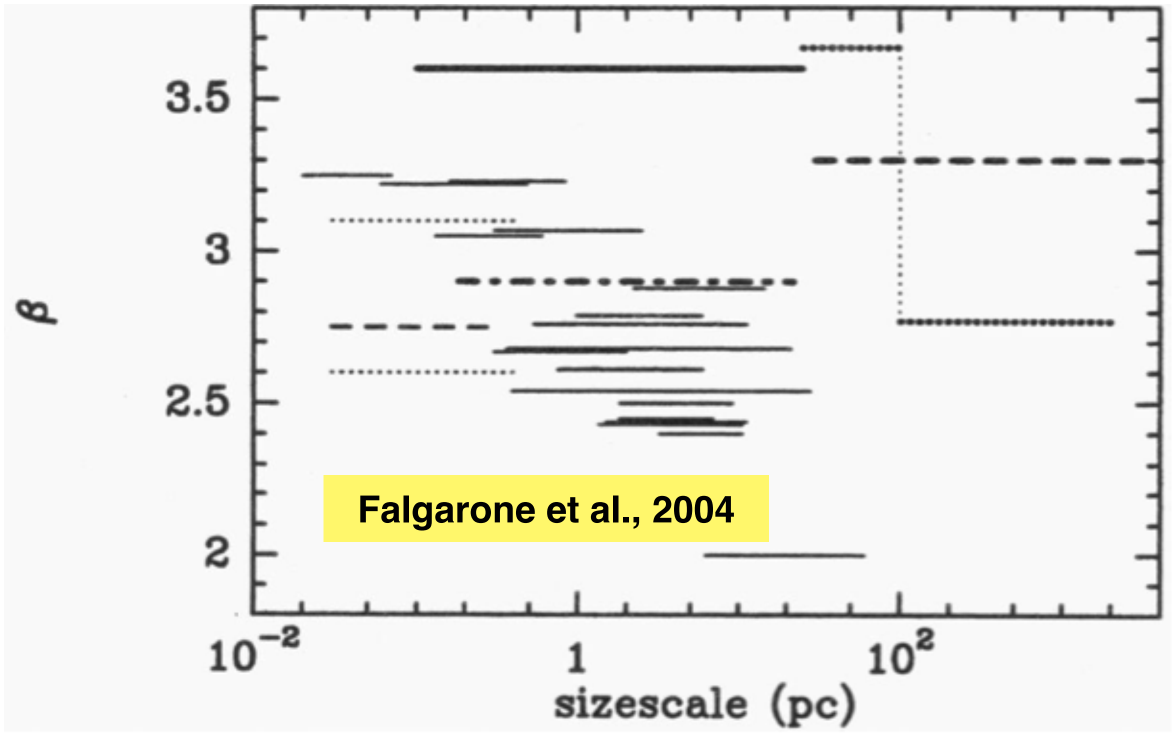


Power spectral analysis

Integrated intensity maps



Elmegreen et al., 2001,
Levrier, 2004



Falgarone et al., 2004

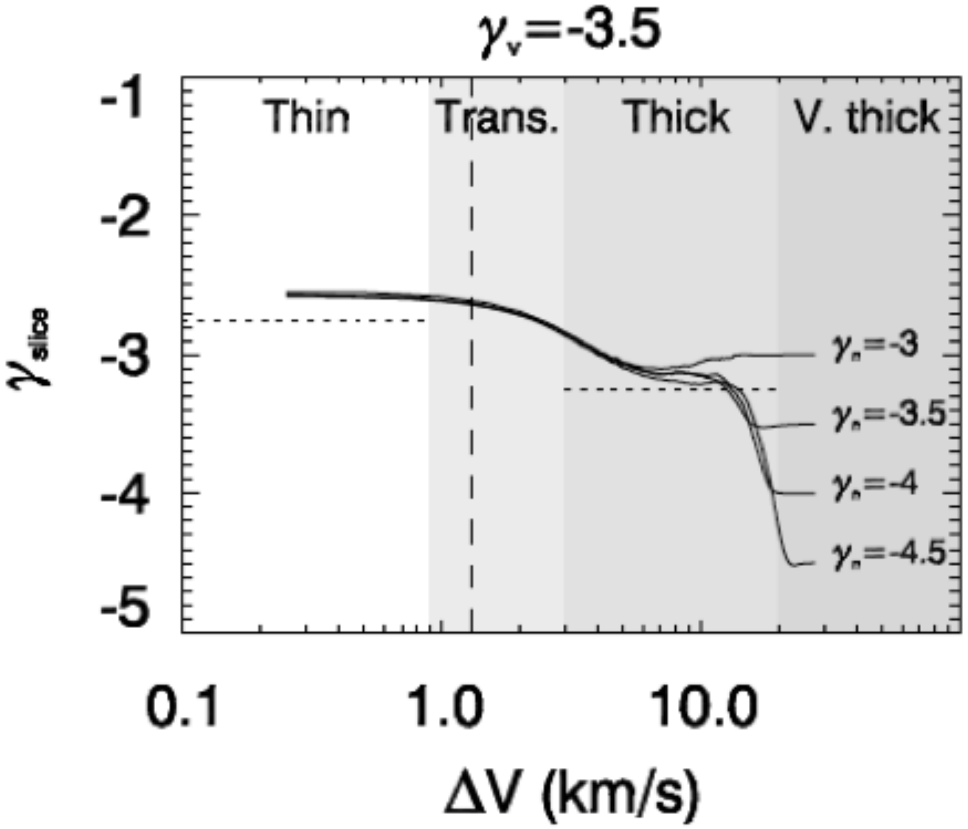
Velocity diagnostics

Velocity Channel Analysis :
Spectral indices of velocity channels of varying width

Lazarian & Pogosyan, 2000

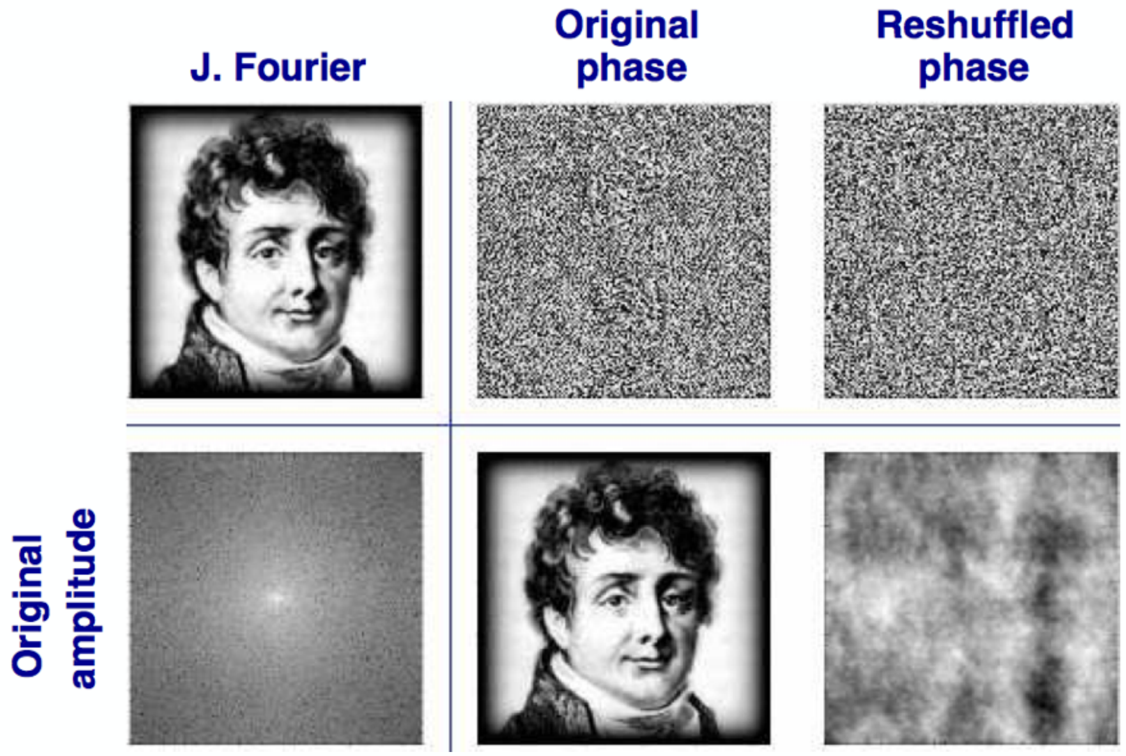
Spectral indices of centroid velocity maps

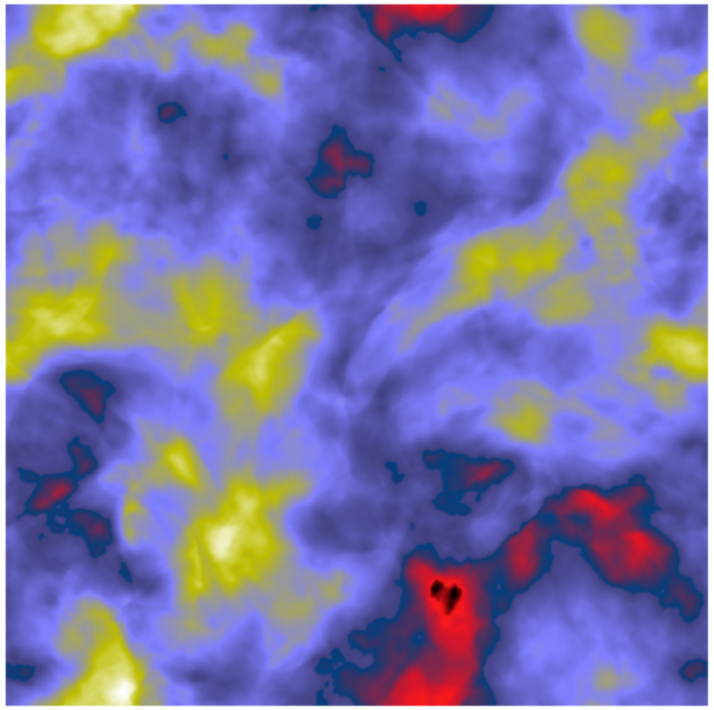
Miville-Deschênes et al., 2003



Fourier phase analysis

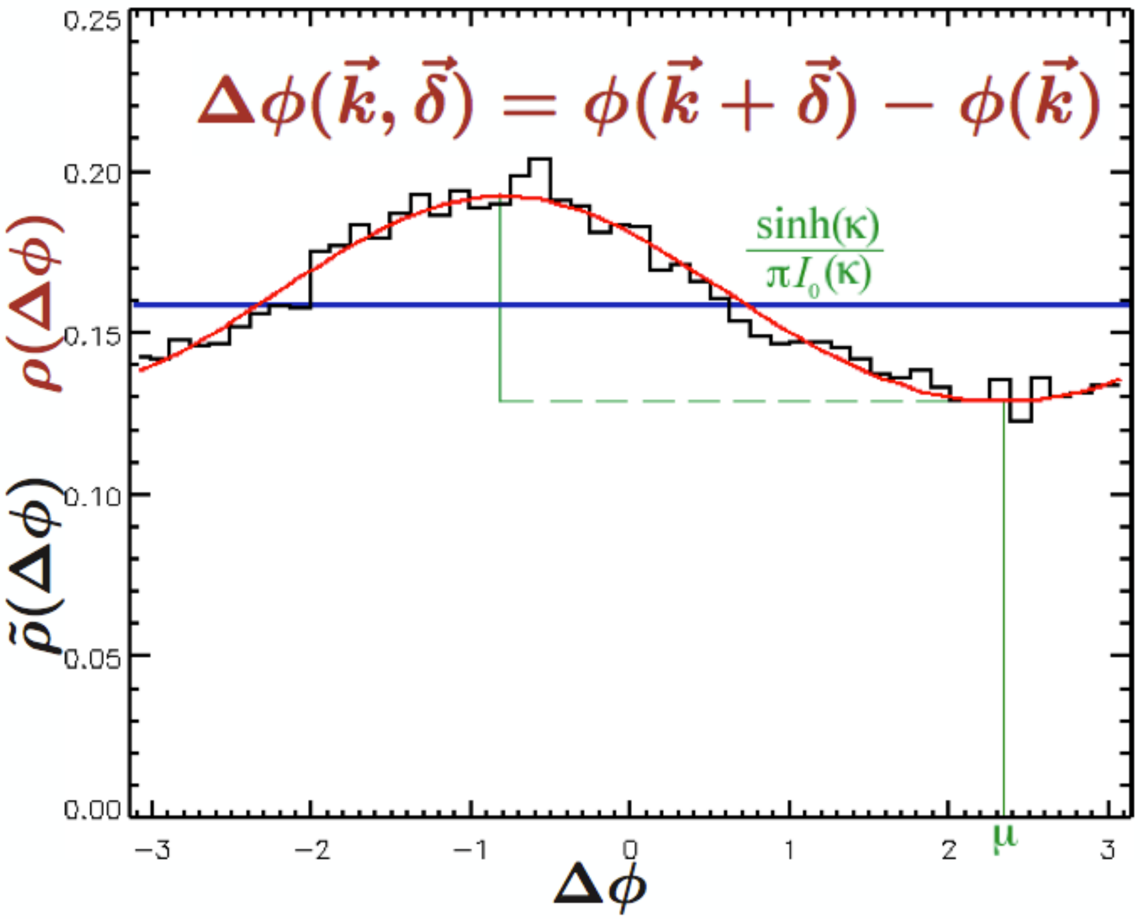
Large number of baselines accessible : Fourier space diagnostics

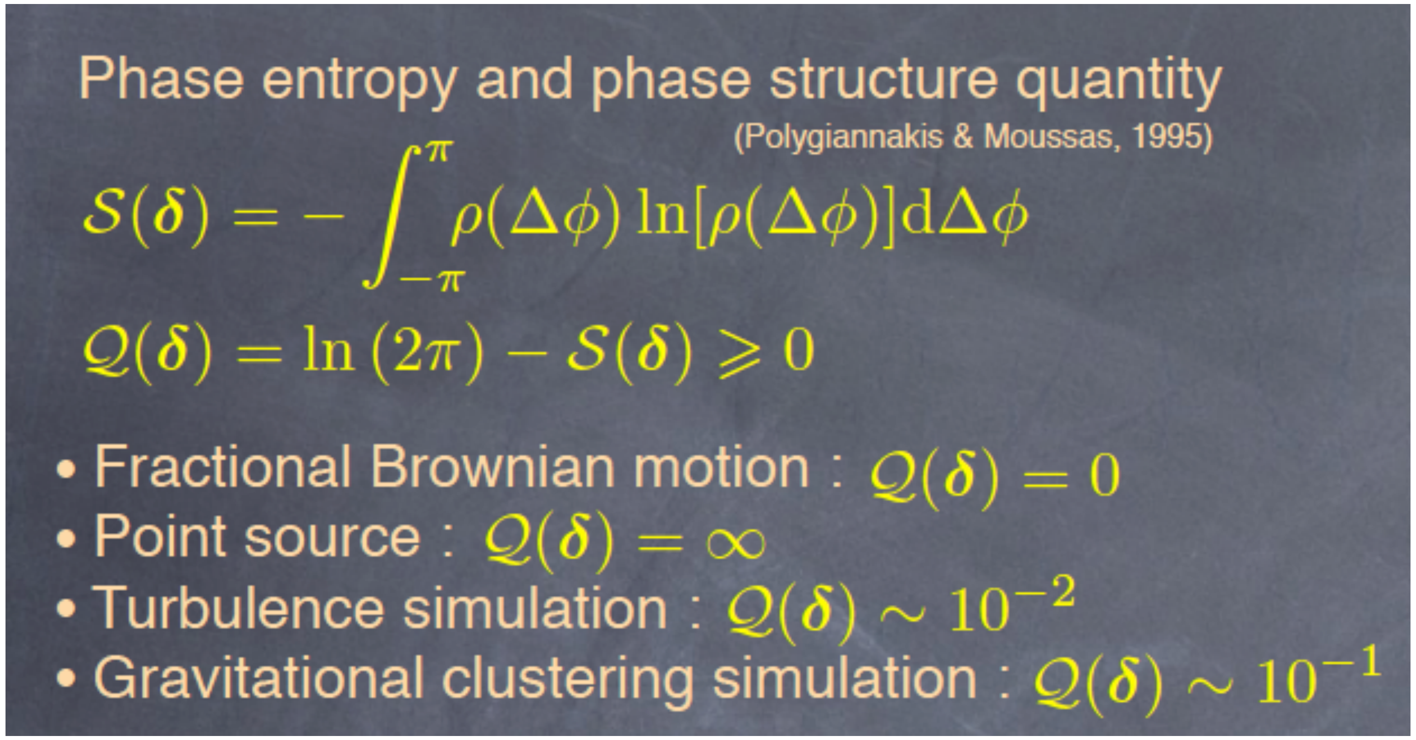




Column density in a compressible turbulence simulation

Porter, Pouquet, Woodward, 1994





Phase entropy and phase structure quantity

(Polygiannakis & Moussas, 1995)

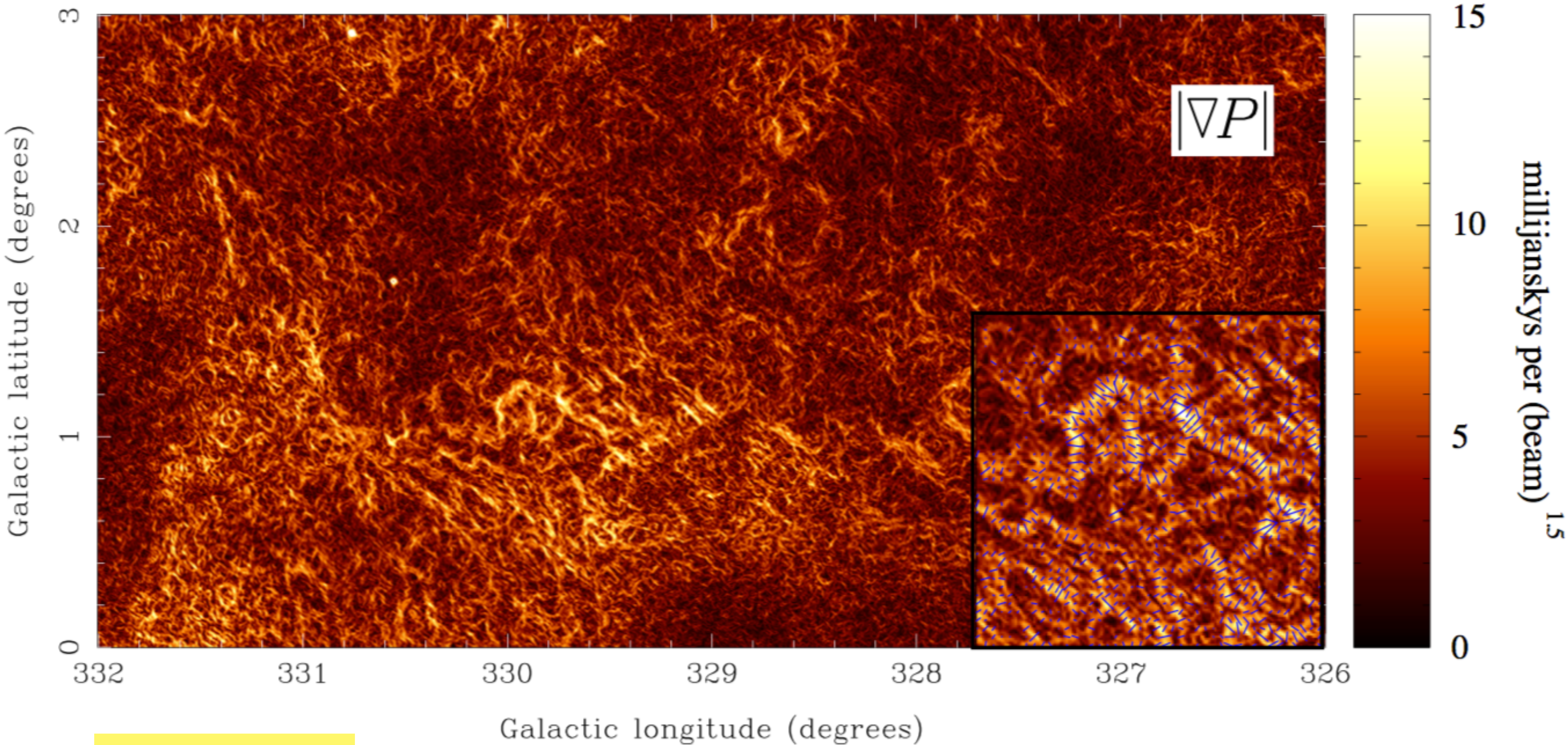
$$\mathcal{S}(\delta) = -\int_{-\pi}^{\pi} \rho(\Delta\phi)\ln[\rho(\Delta\phi)]\mathrm{d}\Delta\phi$$

$$\mathcal{Q}(\delta) = \ln(2\pi) - \mathcal{S}(\delta) \geqslant 0$$

- Fractional Brownian motion : $\mathcal{Q}(\delta) = 0$
- Point source : $\mathcal{Q}(\delta) = \infty$
- Turbulence simulation : $\mathcal{Q}(\delta) \sim 10^{-2}$
- Gravitational clustering simulation : $\mathcal{Q}(\delta) \sim 10^{-1}$

To be performed on velocity channels ?

Turbulence in the ionized ISM



Gaensler et al., 2011

Gradient of the Stokes vector in the continuum at 1.4 GHz with ATCA
Possible target signal for LOFAR/NenuFAR ?

Conclusions

- Observations provide kinematical and chemical clues of the small-scale (mpc) dissipation of ISM turbulence

- This dissipation may be in the form of vortices or low-velocity shocks

- The SKA will be able to resolve large velocity gradients in the diffuse neutral ISM, and do so over a wide instantaneous field-of-view, an essential aspect for statistical analyses (many connected scales)

- New tools are needed to analyse the large amounts of data on interstellar dynamics the SKA will provide, in connection with other instruments at higher frequencies (molecular transitions, dust emission)