Characterization of MHD and kinetic turbulence in near-Earth space plasmas using the Cluster data

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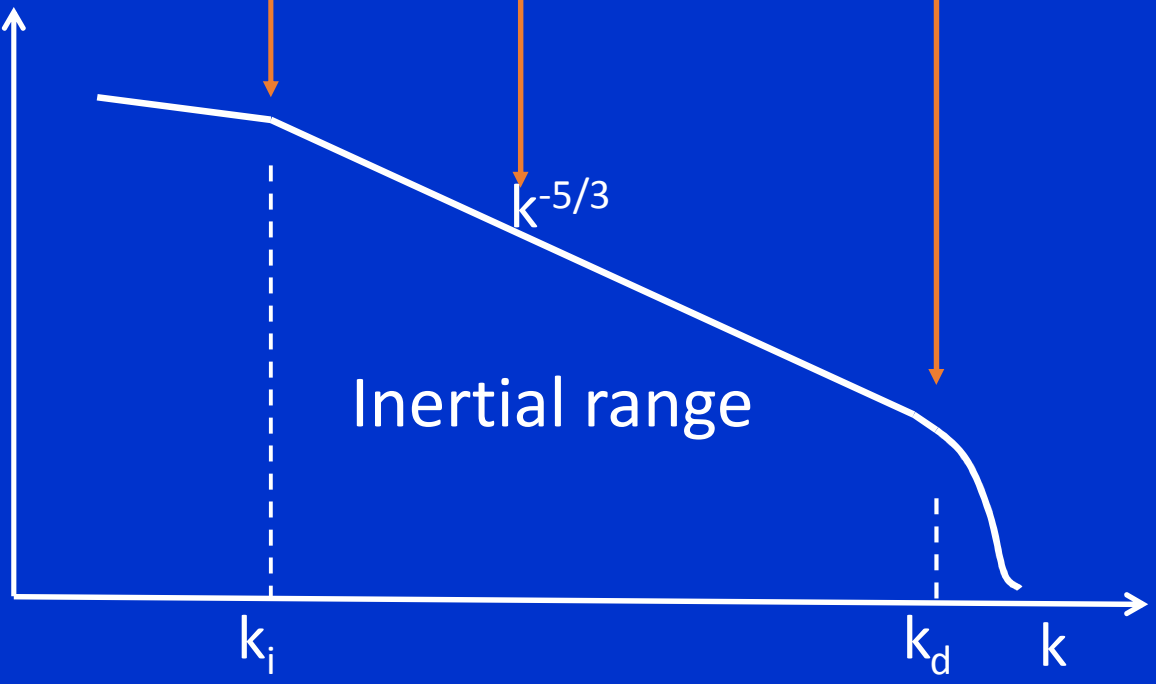
Outline

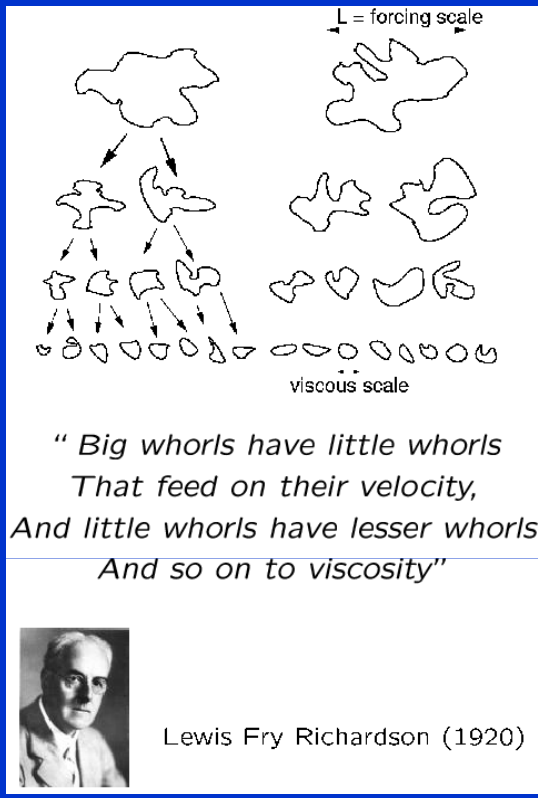
- Universality of turbulence properties?
- MHD scales: f^{-1} & Kolmogorov $f^{-5/3}$ spectra in planetary magnetosheath: Saturn & Earth
- Electron scales: solar wind & magnetosheath
- Summary

Phenomenology of turbulence

NS equation:

$$\partial_t \mathbf{V} + \mathbf{F_i} = -\mathbf{V}.\nabla\mathbf{V} - \nabla P + \nu\nabla^2\mathbf{V}$$



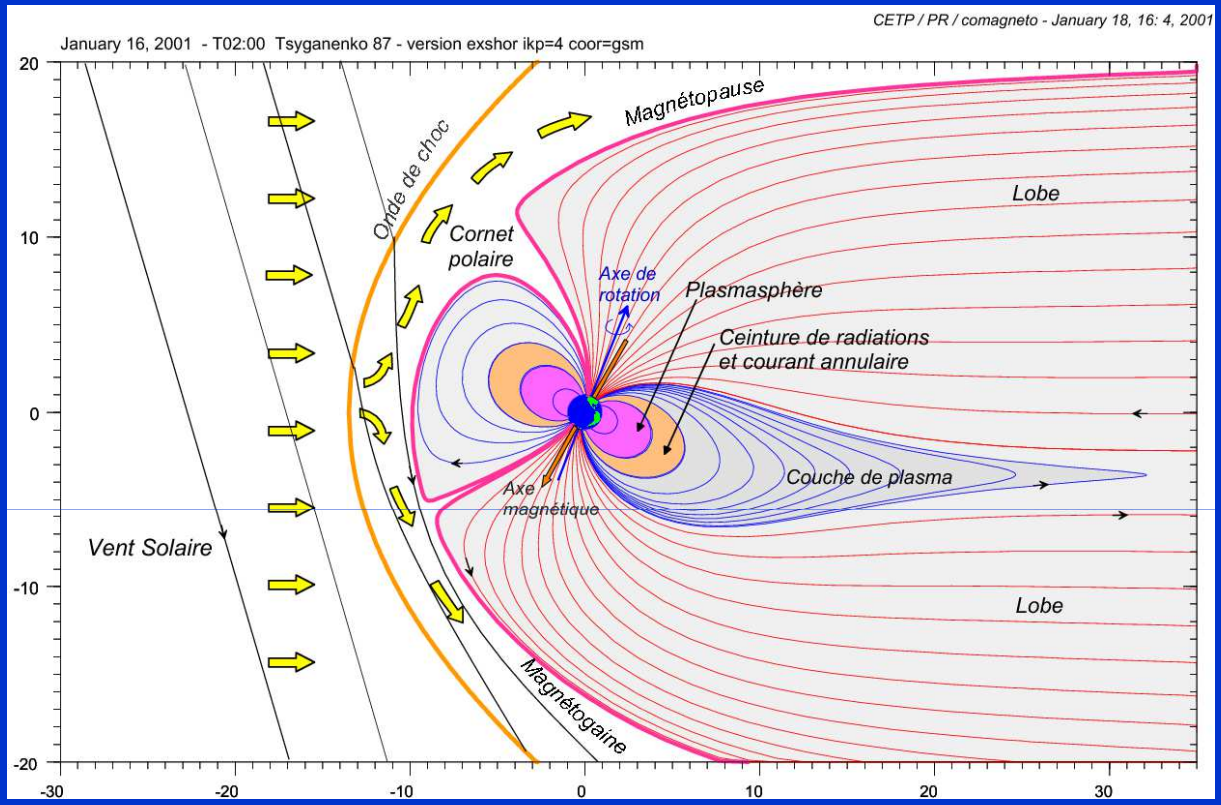


Courtesy of A. Celani

- Hydro: Scale invariance down to the dissipation scale $1/k_d$
- Collisionless Plasmas: - Breaking of the scale invariance at $\rho_{i,e}$ $d_{i,e}$

  - Absence of the viscous dissipation scale $1/k_d$

Universality of turbulence

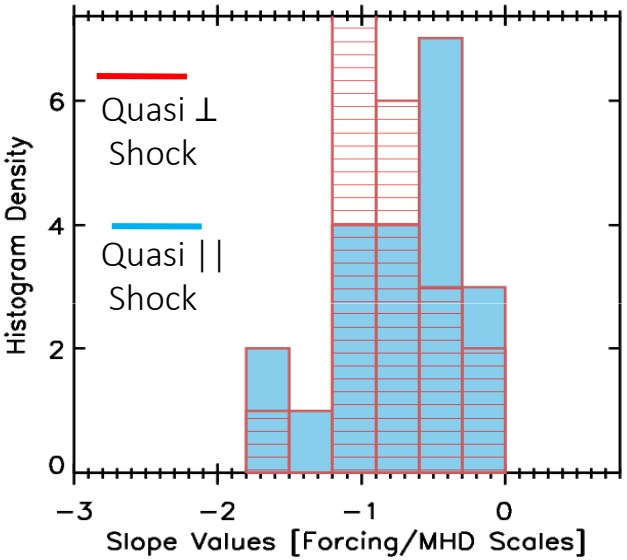


What differences and similarities exist between turbulence in the solar wind and in the magnetosheath?

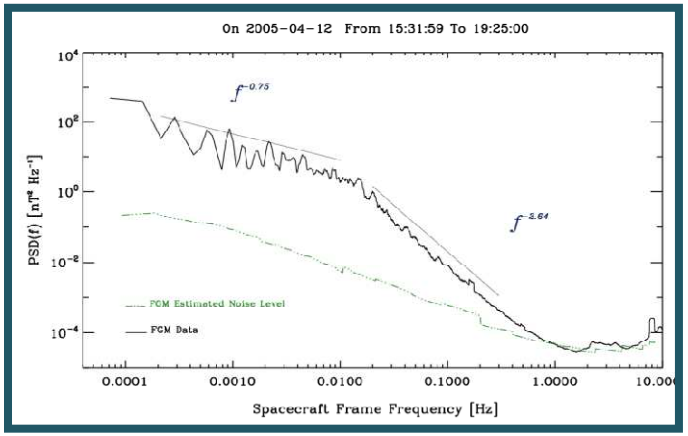
MHD scale turbulence
Saturn & Earth

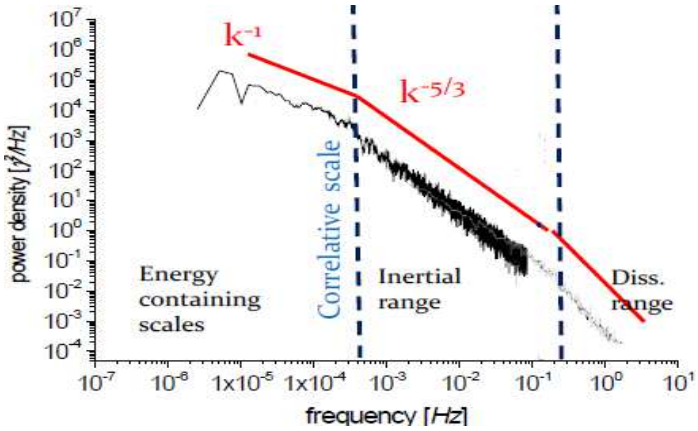
Cassini observations

Statistics on the scaling: 38 magnetosheath crossings (2004-2007)



Energy containing scales



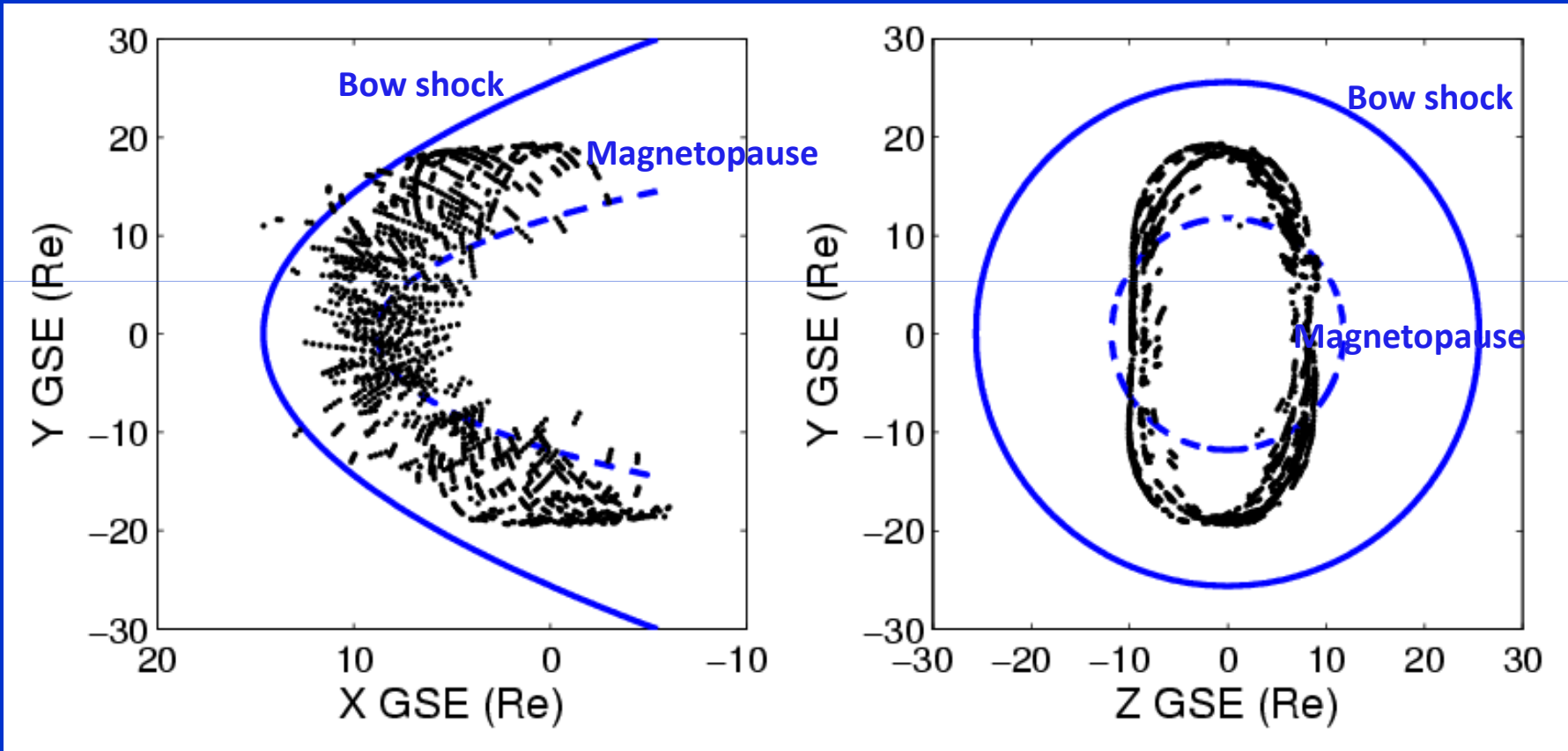


Solar wind observations

No Kolmogorov spectrum is observed at MHD scales over ~40 events

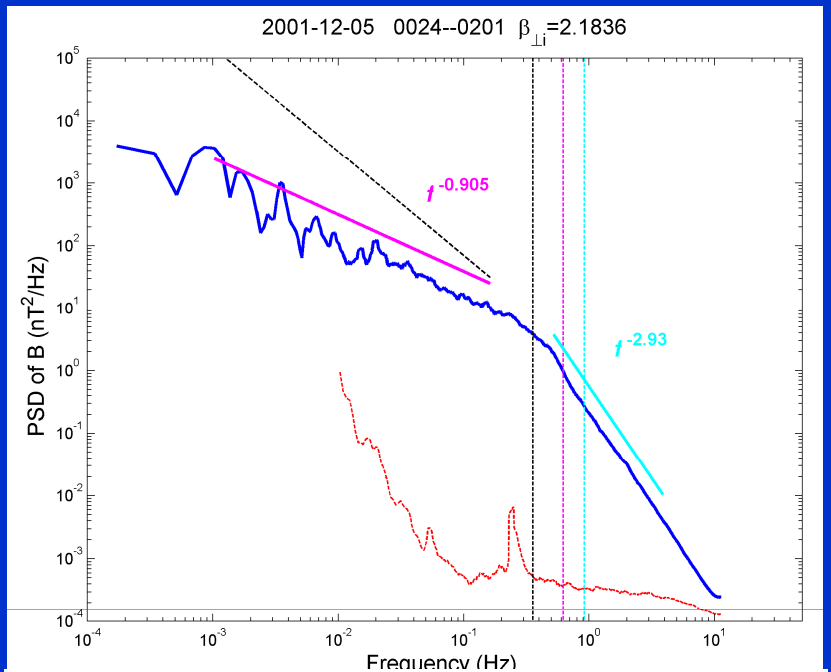
Cluster observations of MHD turbulence in the magnetosheath

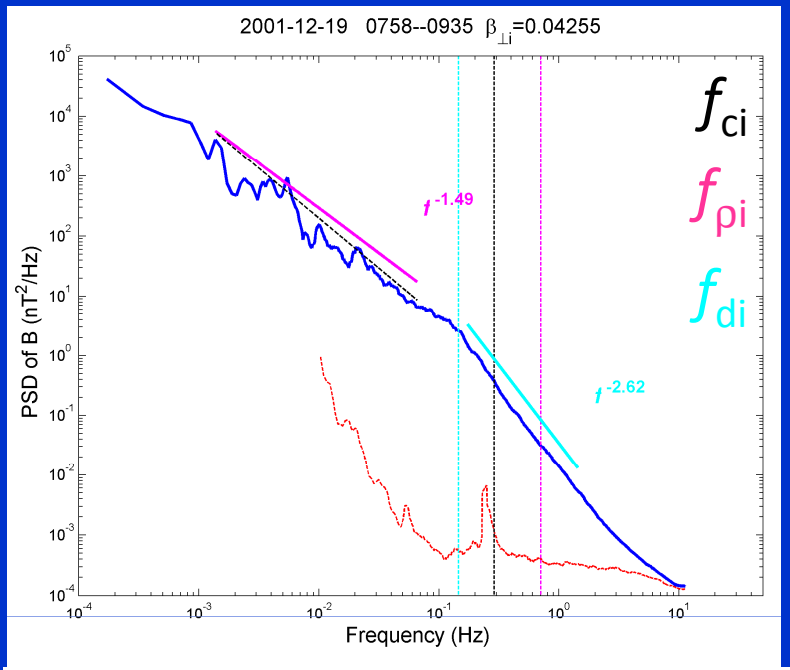
Database: 2001-2003

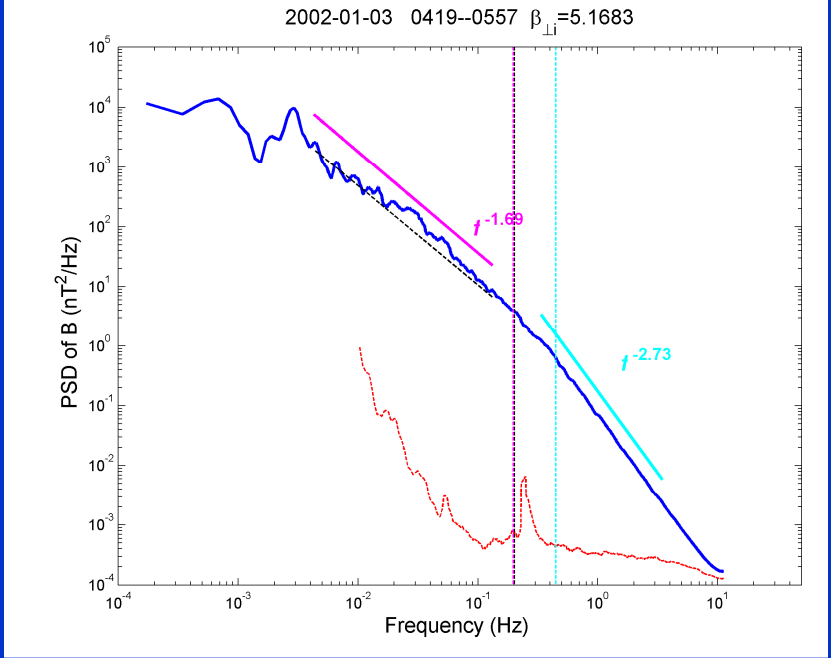


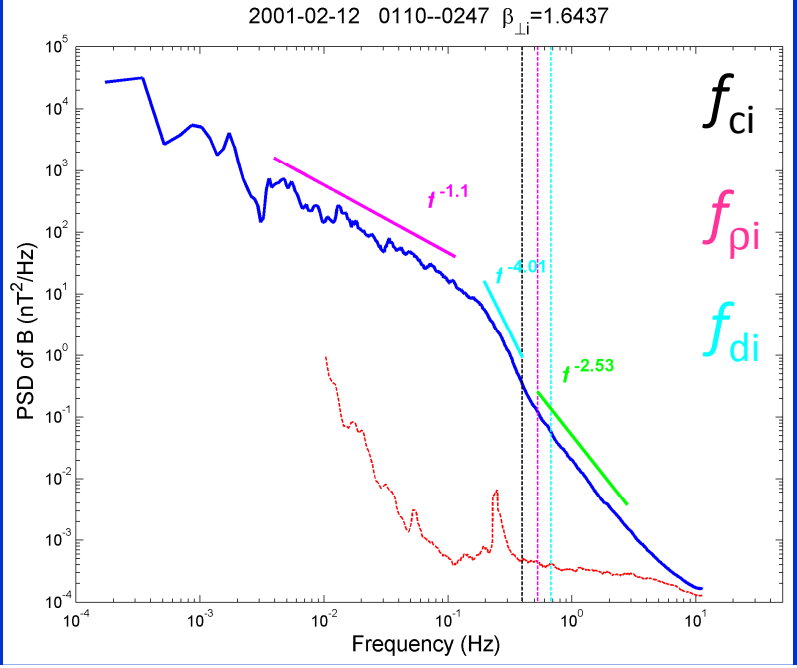
The trajectories of SC3 when it is in the magnetosheath

Examples of magnetic spectra in the magnetosheath



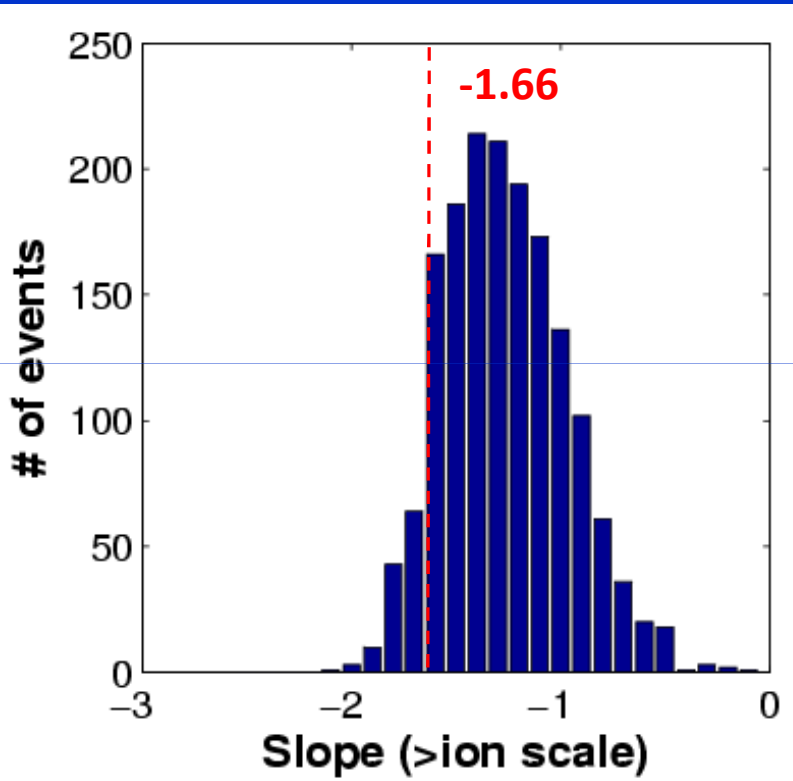






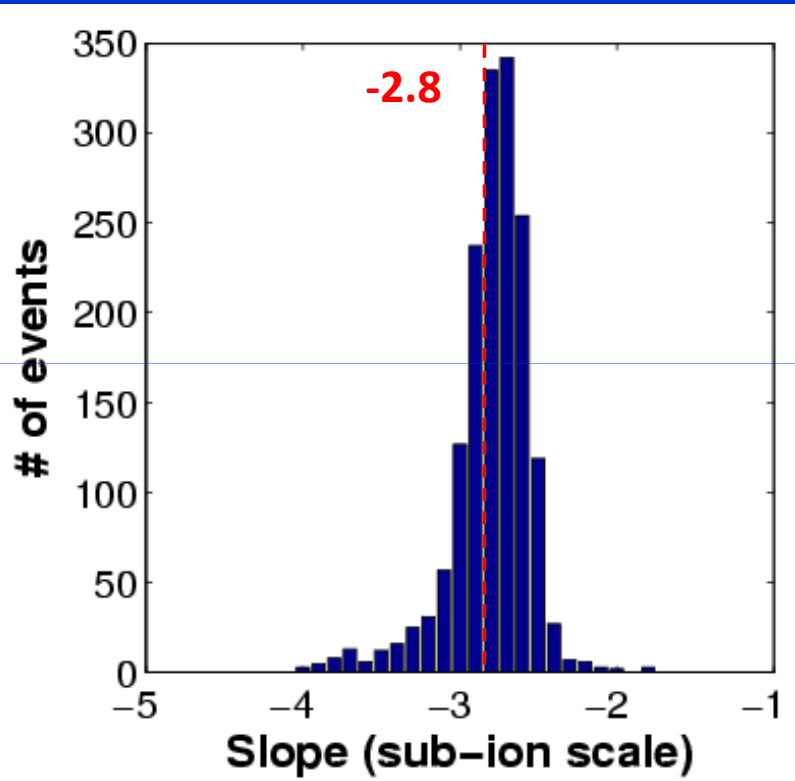
Statistical results of the spectra slopes

MHD scales range



Peak ~ -1.45

Sub-ion scale

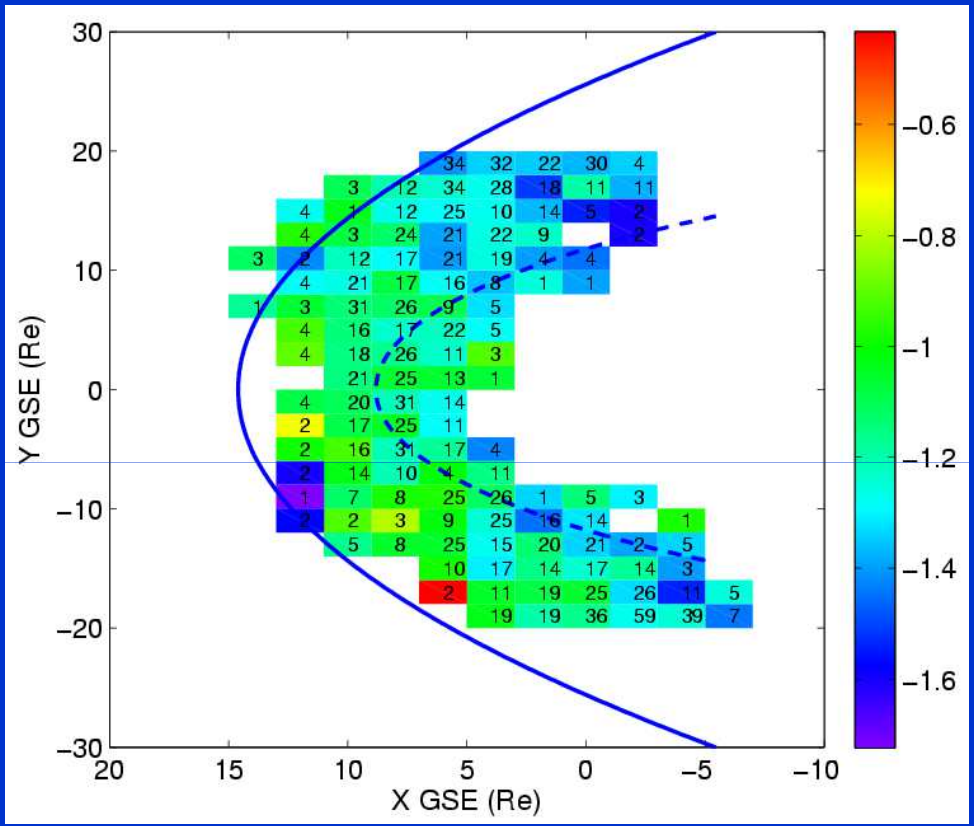


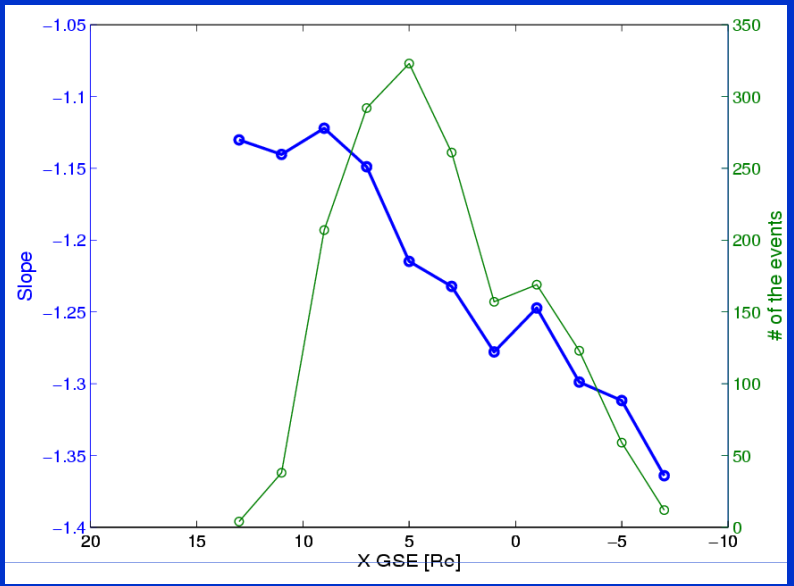
Peak ~ -2.6

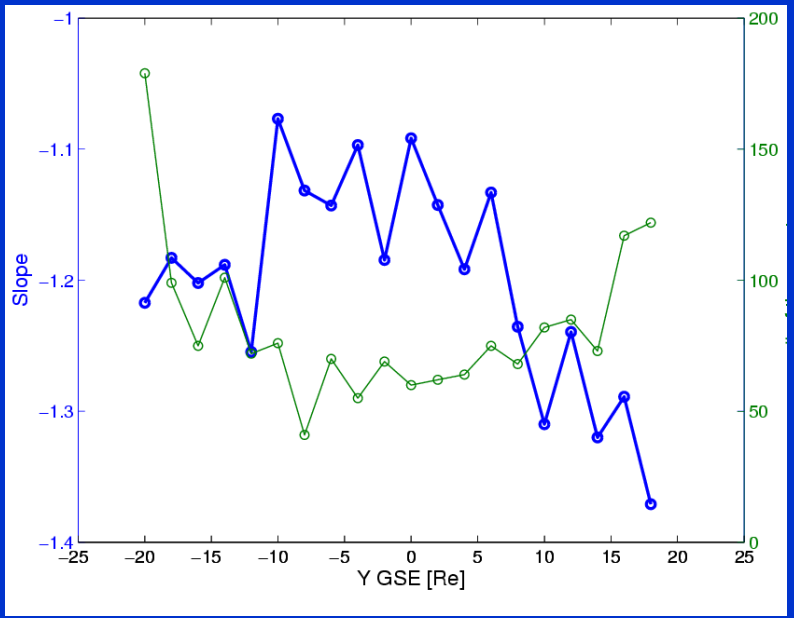
Most of events do not show an inertial range!
Breaking of the universality of the Kolmogorov spectrum?

The distributions of the slopes at MHD scales

Slopes at MHD scales

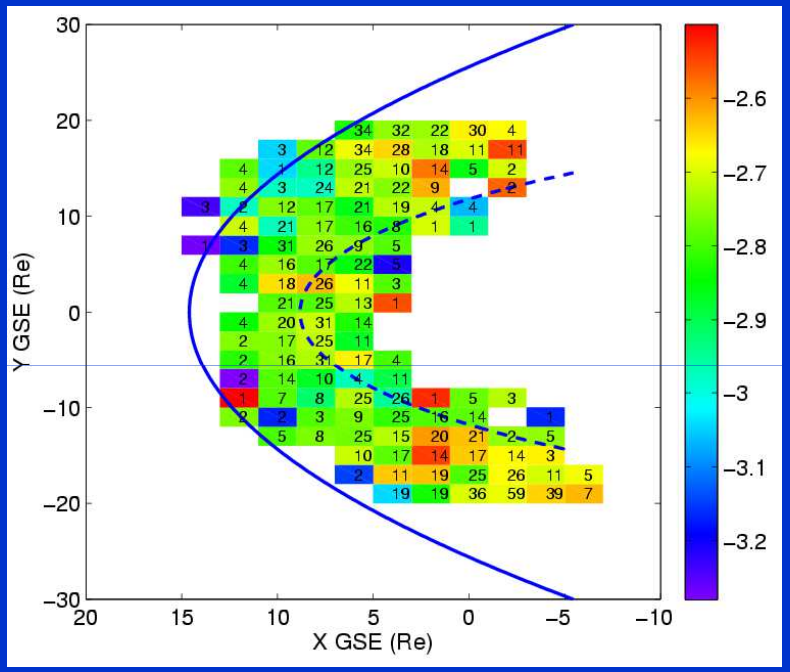


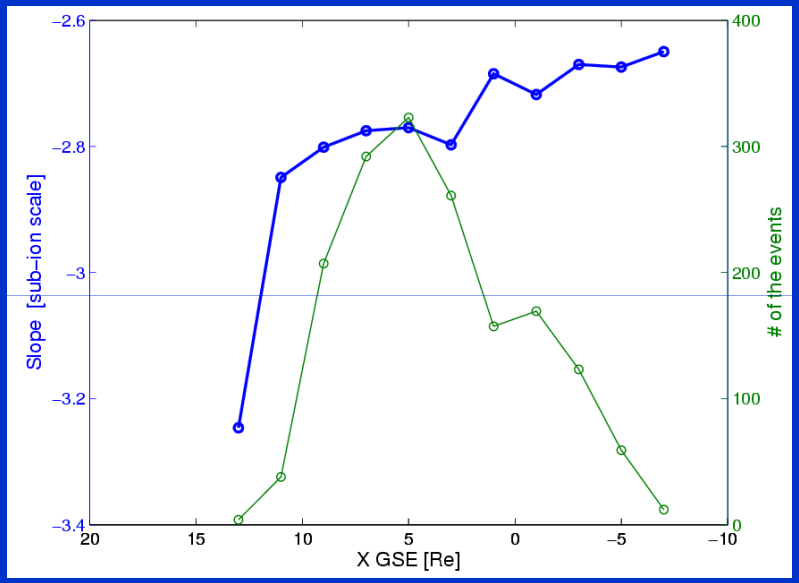




The inertial range is observed only in the magnetosheath flanks, away from the bow shock

The distributions of the slopes in at sub-proton scales





No clear dependence on the location within the magnetosheath -

→ Small scale turbulence (~<10^2km) seems to "ignore" large scale driving (~10^5 km)

Turbulence in the Earth magnetosheath

Magnetosheath turbulence evolves in a "confined" space limited by the bow shock and the magnetopause; these boundaries may influence the anisotropy of the turbulence

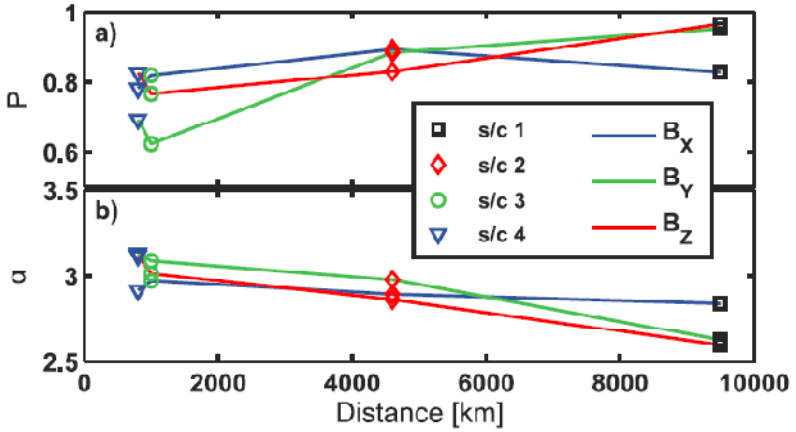
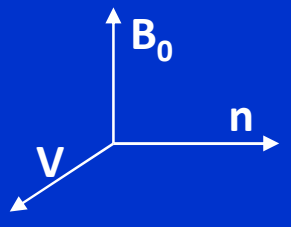
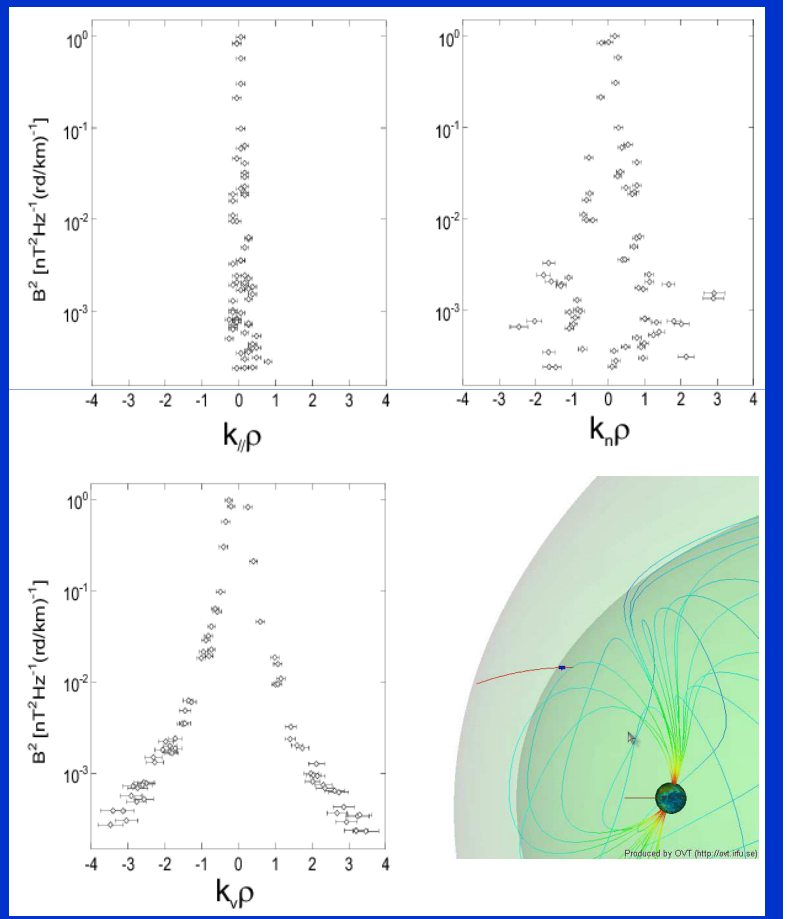


FIG. 4 (color). Intermittency parameter P (panel a) and spectral slope α (panel b) as functions of the BS distance. The colors represent the magnetic field components—B_X (blue), B_Y (green), and B_Z (red), with the spacecraft symbol in color for each P estimation.

[Yordanova et al. 2008].



(v,n) ~ 104°
(v,B_o) ~ 110°
(n,B_o) ~ 81°

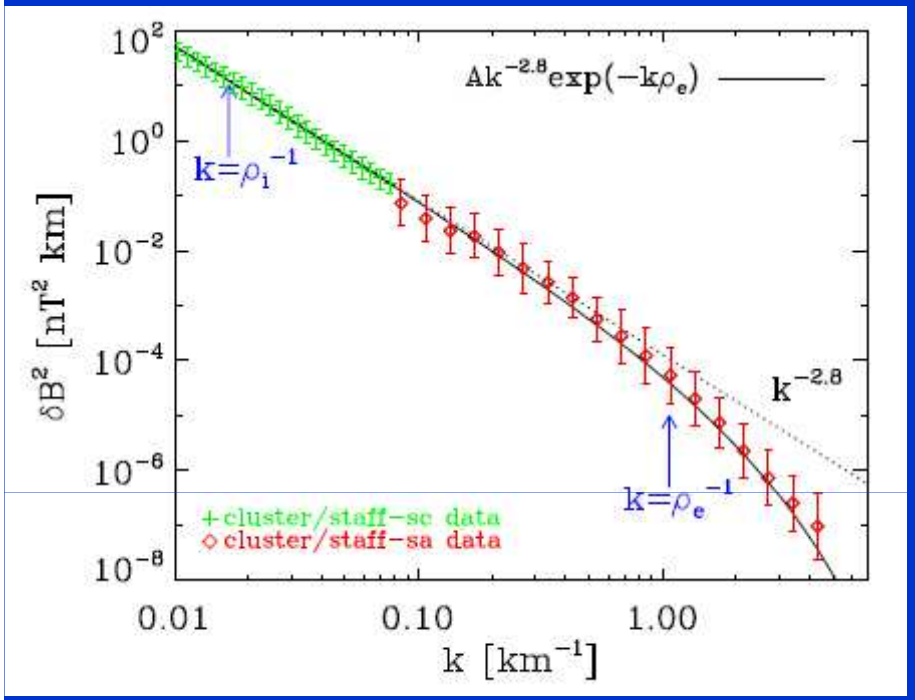


The magnetopause controls the turbulence anisotropy [Sahraoui et al., PRL, 2006]

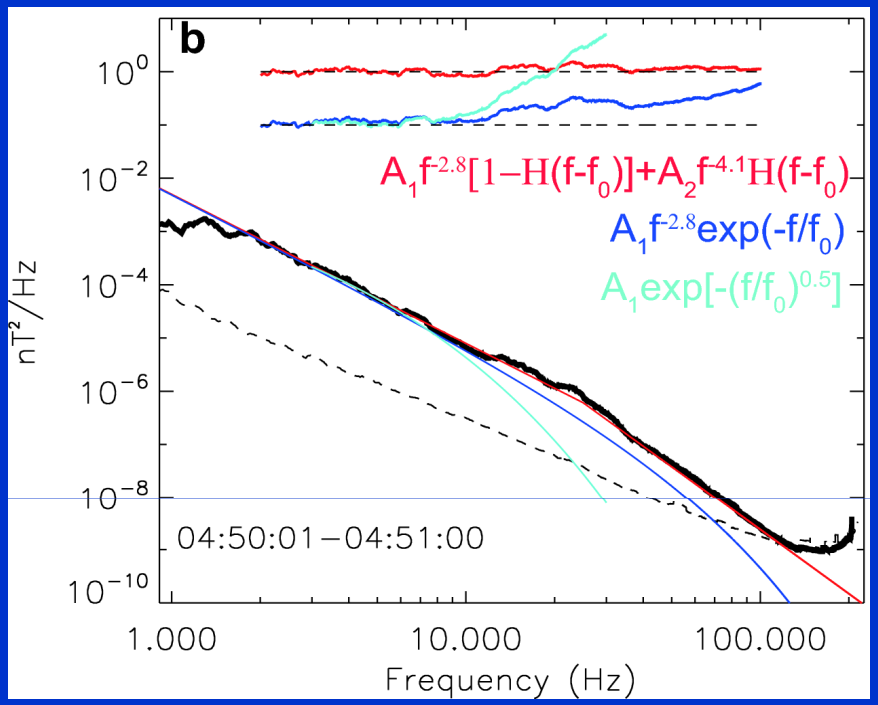
Electron scale turbulence
Earth & solar wind

Cluster observations of electron scale turbulence

***Alexandrova et al., 2009;* 2012**

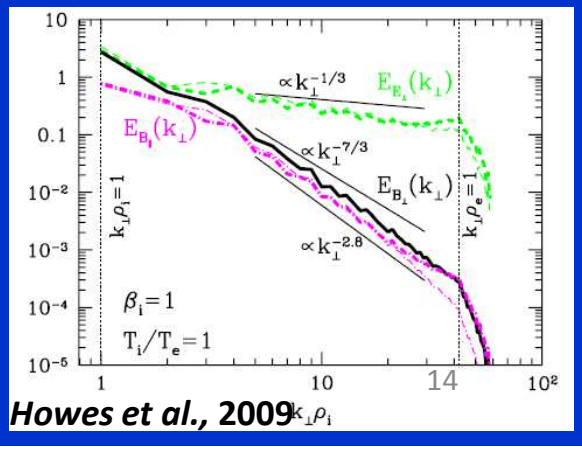


***Sahraoui et al.*, 2009, 2013**



Exponential or power-law dissipation?
Open question … **Voir la mission M4/THOR**

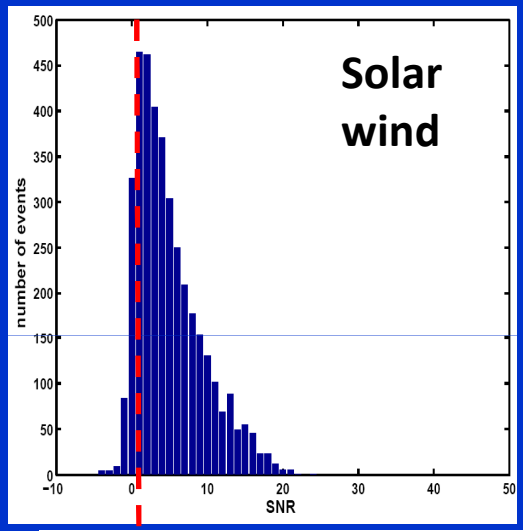
Can magnetosheath data help us to go further while waiting for … **THOR ?**

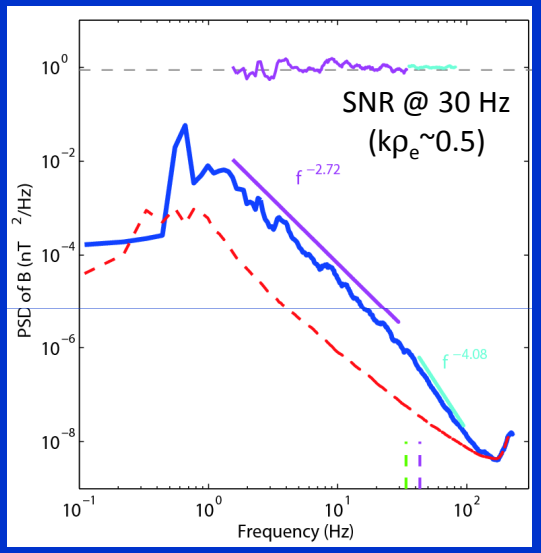


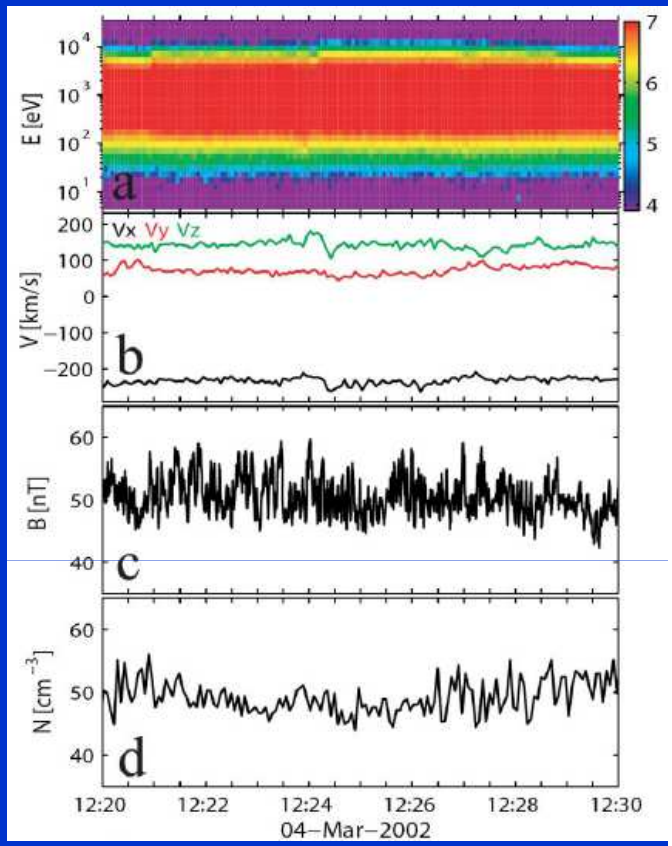
***Howes et al.*, 2009**

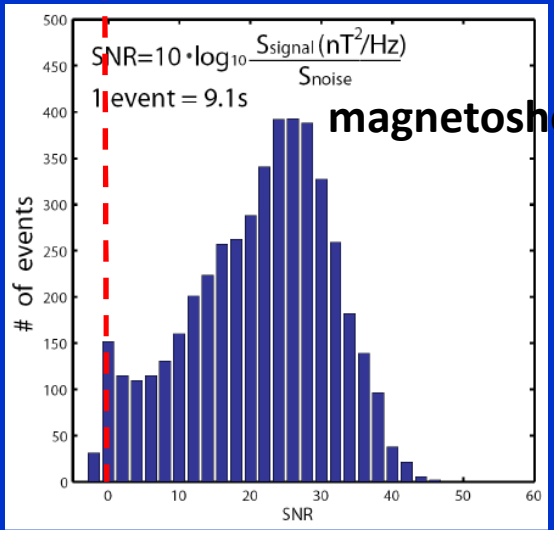
Cluster observations of electron scale turbulence in the magnetosheath

Higher SNR than in he solar wind





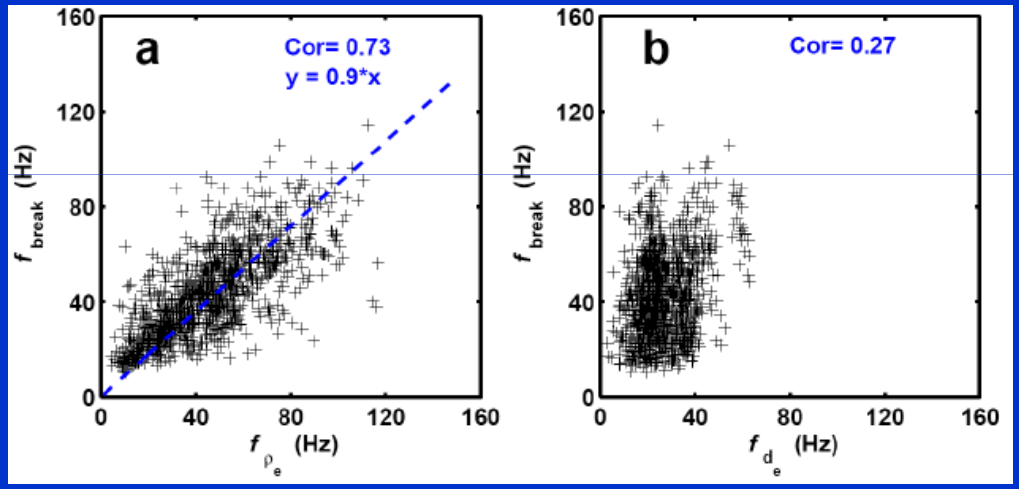


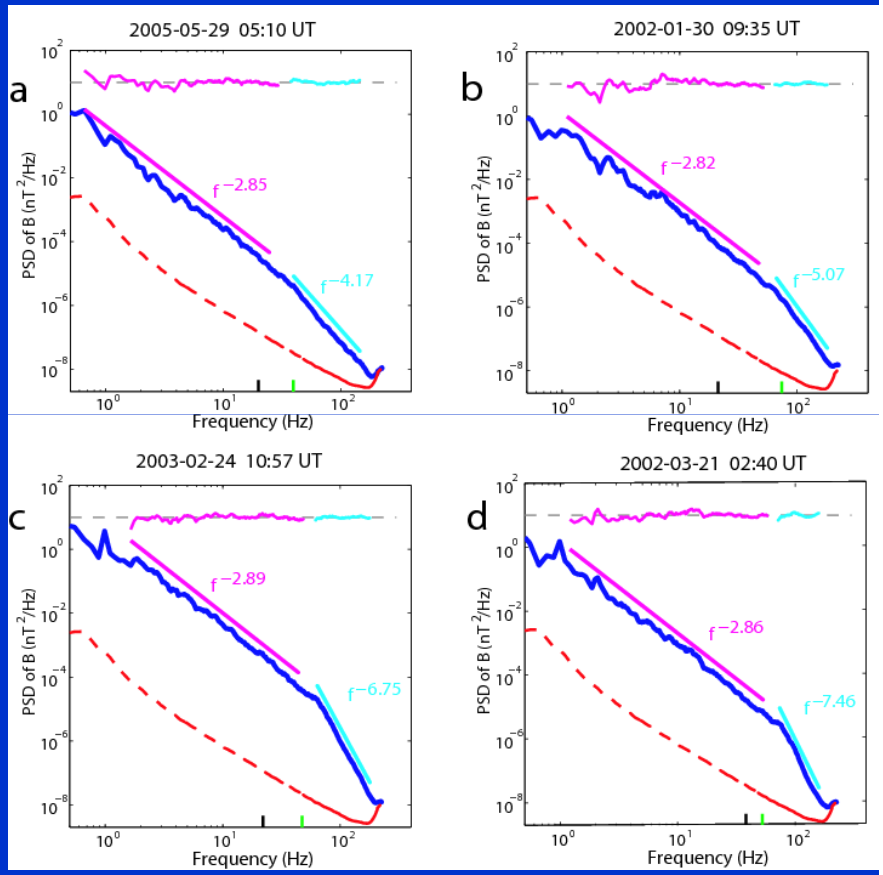


71 time intervals of 10 min in BM (2002-2007) data.

Examples of observed spectra showing spectral breaks at electron scale

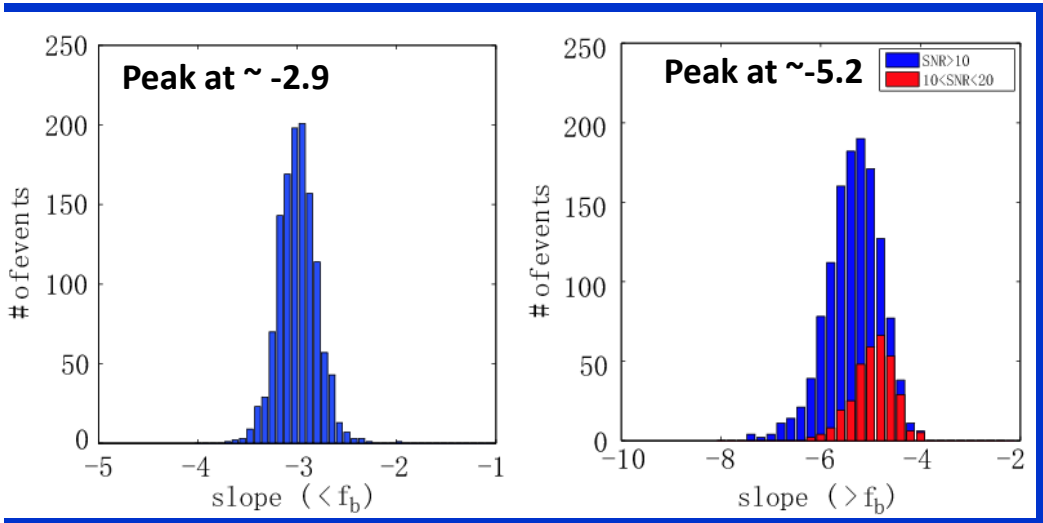
Correlation between the spectral breaks and the Taylor-shifted electron gyroscale ($\rho_e = V_{the}/\omega_{ce}$) and inertial length ($\lambda_e = V_A/\omega_{ce}$)

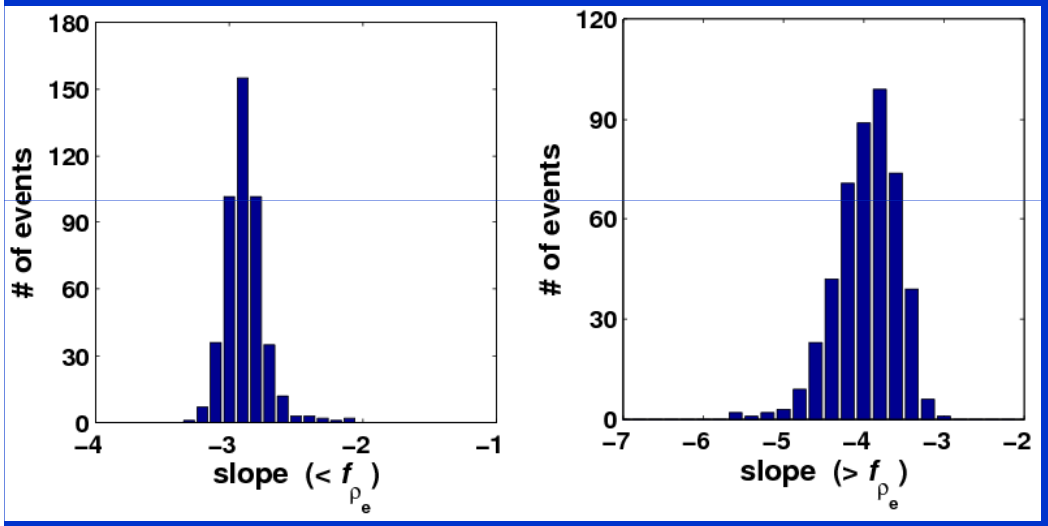




The electron gyroradius plays the role of a dissipation scale as in the solar wind

[Sahraoui et al., PRL2009; Alexandrova et al., ApJ, 2012]





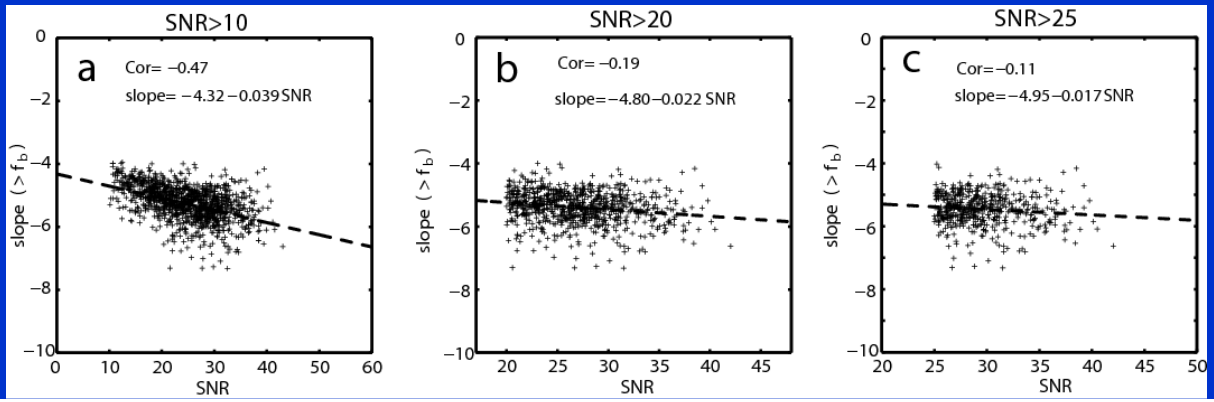
- Sub-ion scales: similar histogram of slopes than in the solar wind [Sahraoui, ApJ, 2013]

- Sub-electron scales: magnetosheath spectra are steeper than those of the solar wind!

Why?

To better investigate turbulence at electron scale, it requires high SNR.

Correlations between observed slopes and SNR



Summary

1. **Violation de l'universalité du spectre de Kolmogorov dans les magnetogaine planétaire (i.e., transition directe du spectre $\sim f^{-1}$ (MHD) vers specrtre $\sim f^{-2.8}$ (cinetique) → différence avec le SW**

2. **"Universalité" des spectres aux échelles cinétiques (i.e., similaire au vent solaire)**

3. **Beaucoup de questions théoriques restent ouvertes:**
   - nature de la turbulence quand le spectre de Kolmogorov est observé (Alfvénic? Compressible?)
   - nature de la turbulence et processus de dissipation aux échelles cinétiques (KAW? Whistler? Autre?)
   - et plein d'autres …