Recent observations of space plasma turbulence and open questions

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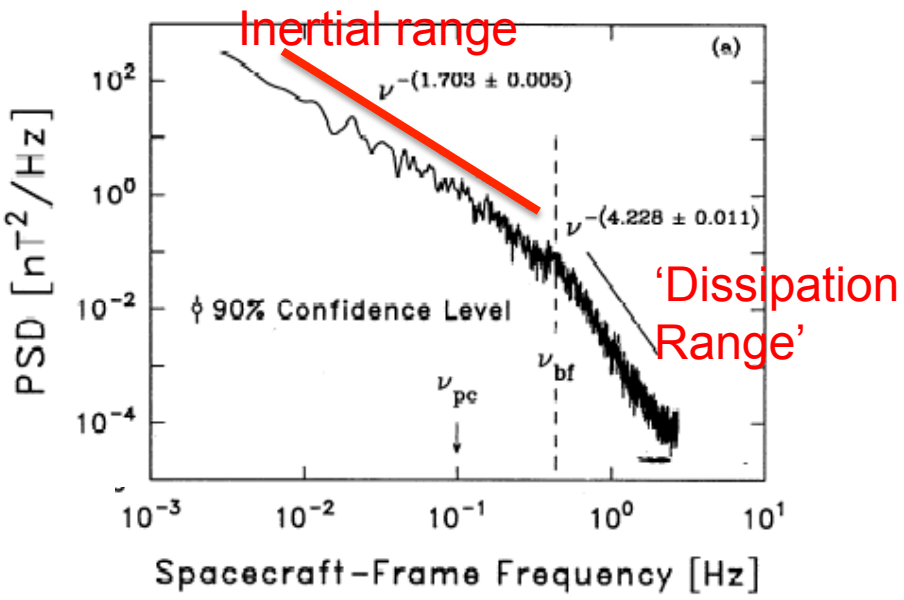
Space plasma turbulence

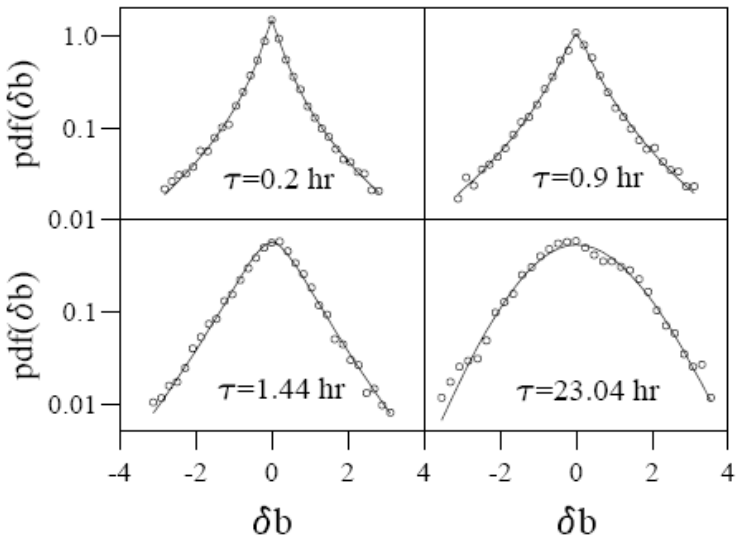
- Magnetic field $B_0 \Rightarrow$ anisotropy
- Characteristic scales and frequencies
- no collisions $\Rightarrow$ dissipation ?
- Linear waves or NL fluctuations ?

Solar wind magnetic turbulence before Cluster



[Leamon et al,1998]

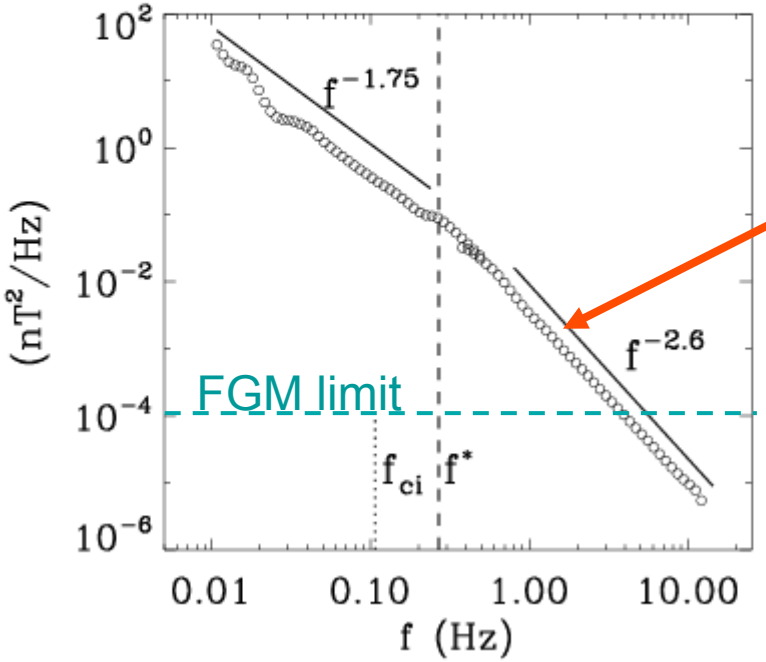
Intermittency

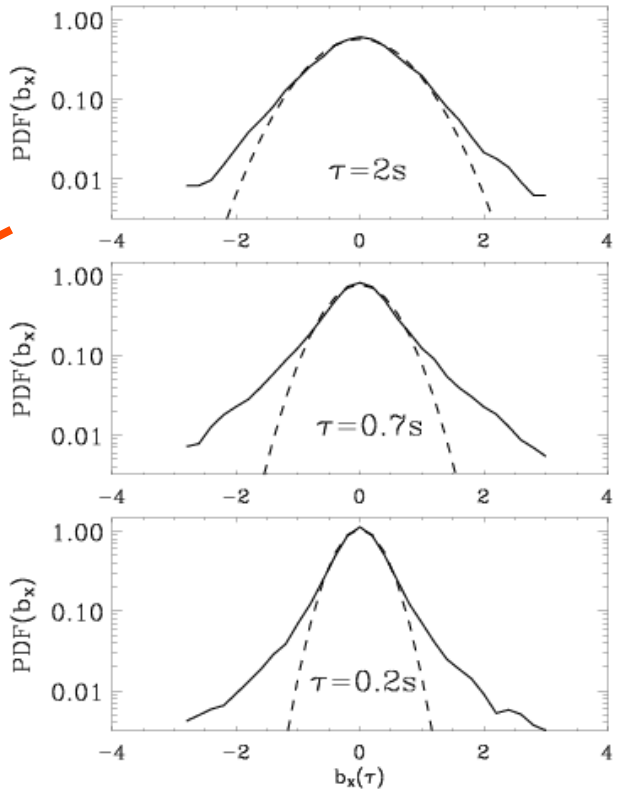


[Sorriso-Valvo et al,1999]

Solar wind turbulence at ion kinetic scales

FGM+STAFF-SC/CLUSTER



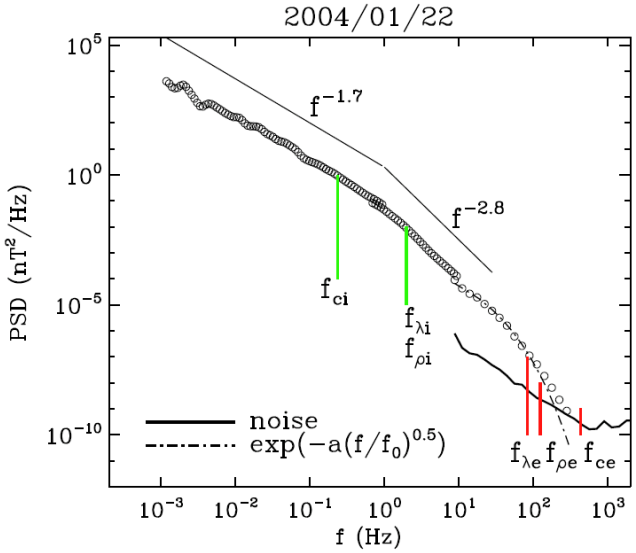


- Spectrum ~ power law
- Intermittency increases toward smaller scales

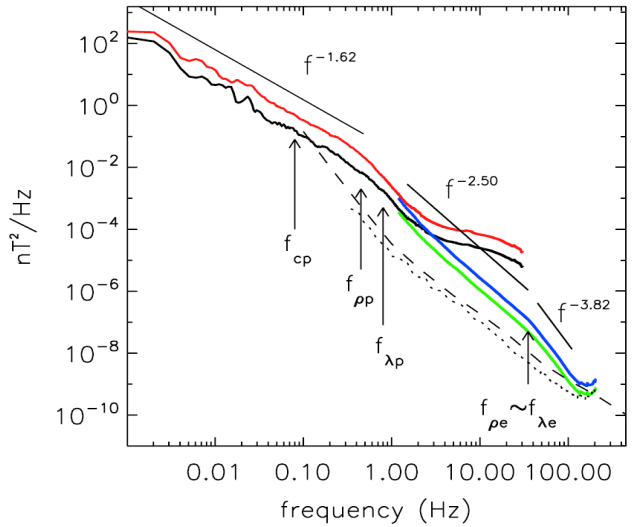
Turbulent cascade ! [Alexandrova et al., 2008, ApJ]

Where does the magnetic turbulent cascade end?

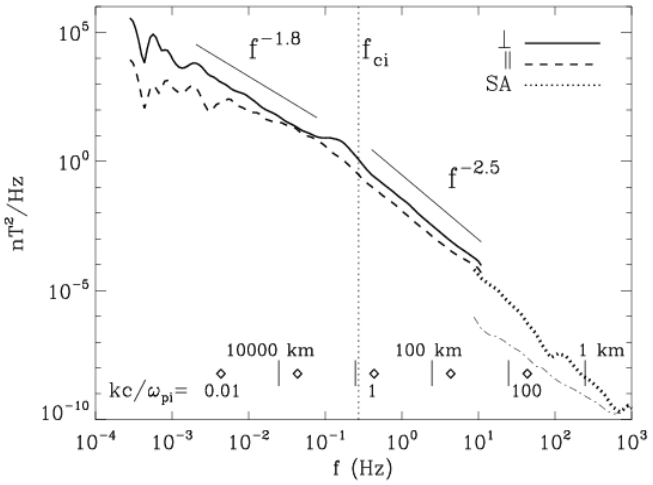
Turbulent spectra from MHD to electron scales seen by CLUSTER in different regions



Solar wind [Alexandrova et al.,2009]



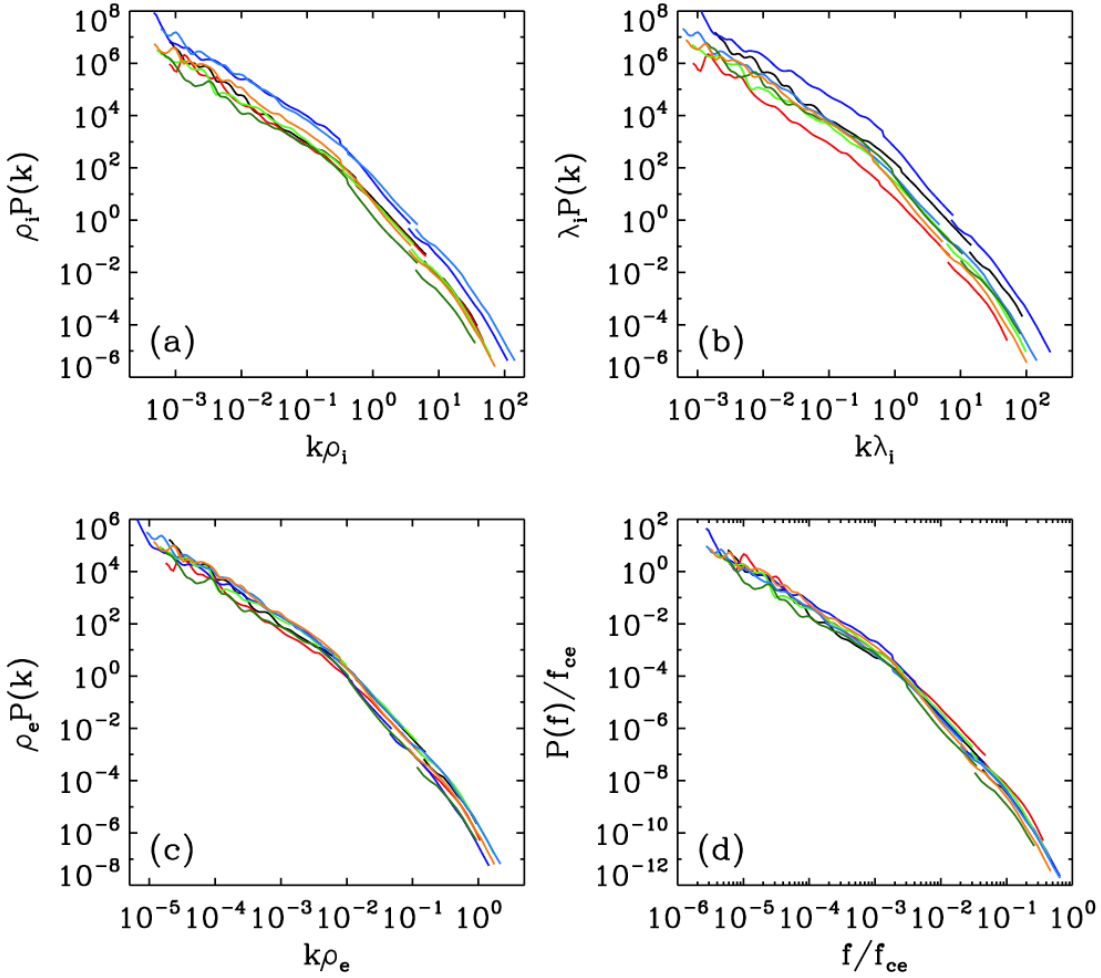
Foreshock [Sahraoui et al.,2009]



Magnetosheath [Alexandrova et al.,2008]

Electron scales – end of magnetic turbulent cascade…

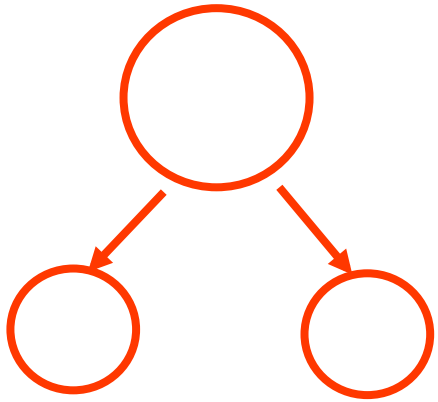
Dissipation scale: electron Larmor radius



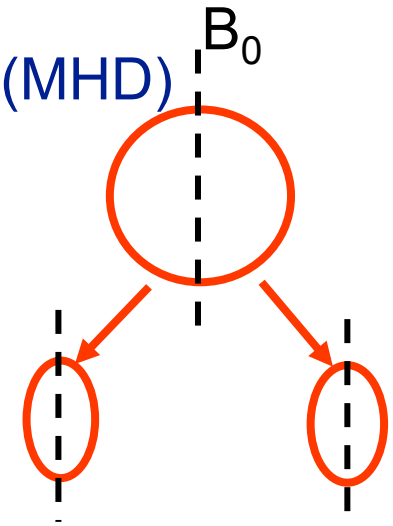
Spectra collaps better when they are normalized on e-larmor radius (or f_ci,f_ce)
[Alexandrova et al., 2009, PRL]

Anisotropy

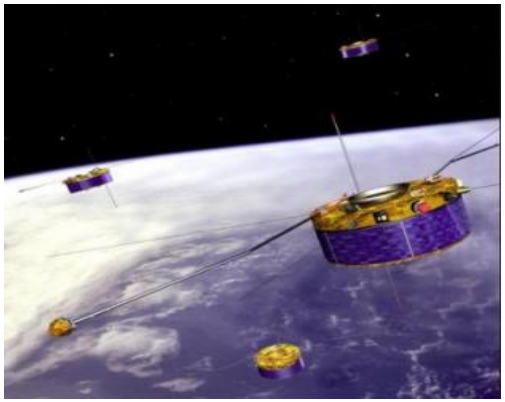
hydrodynamics



plasma (MHD)

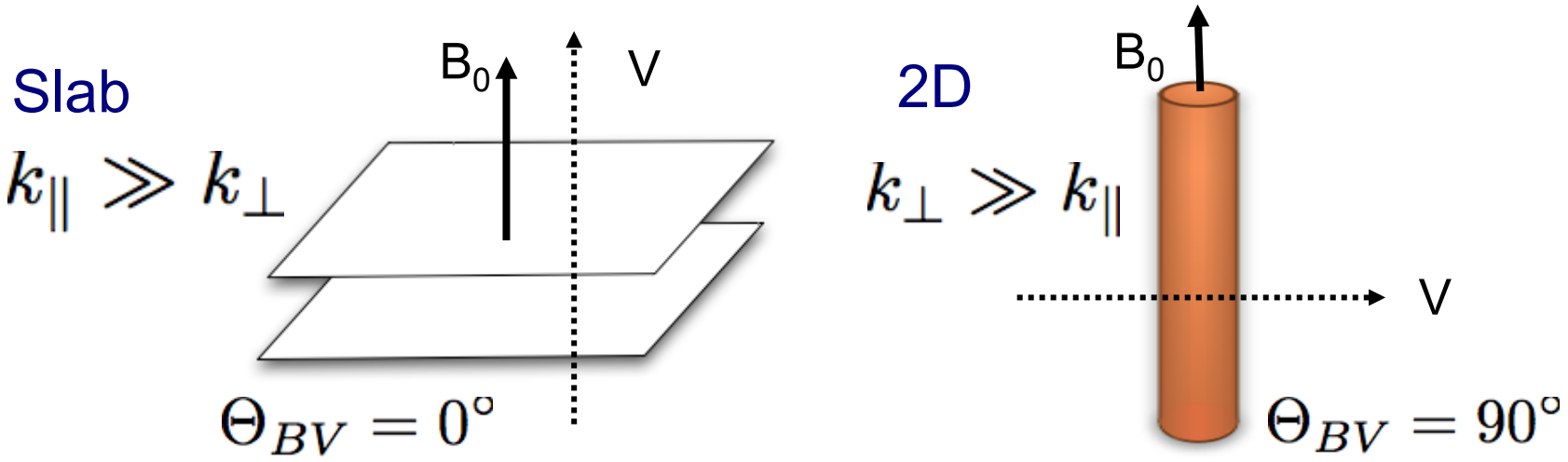


Presence of a mean magnetic field B_0 leads to an anisotropy of turbulent fluctuations

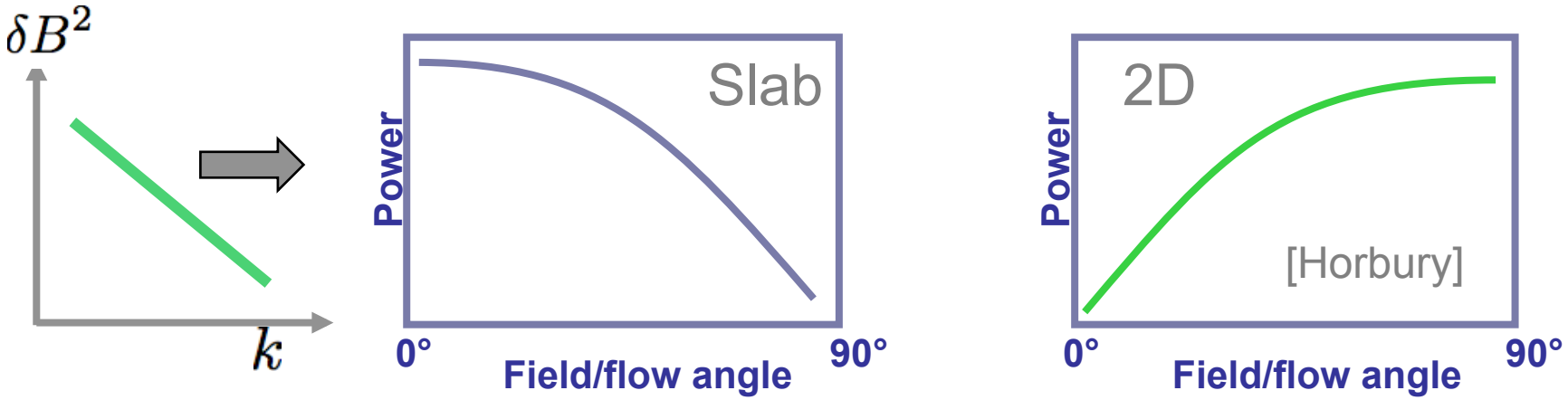


- 3D vision at scales around CLUSTER separations (~1 decade)
- But cascade covers more than 7 decades => monosatellite studies

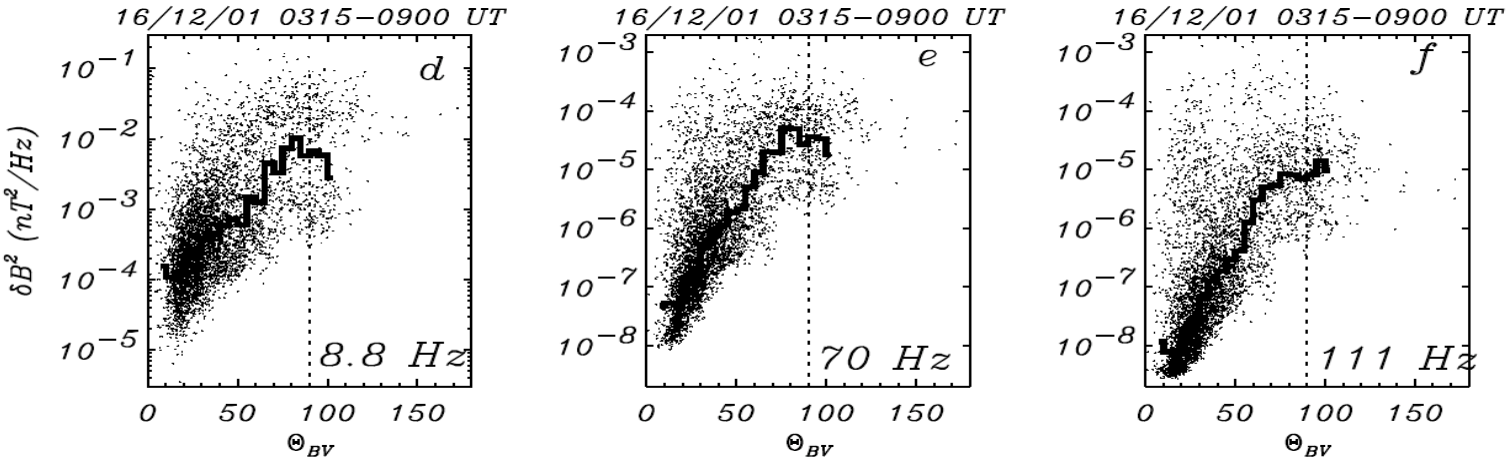
Anisotropy of turbulent fluctuations



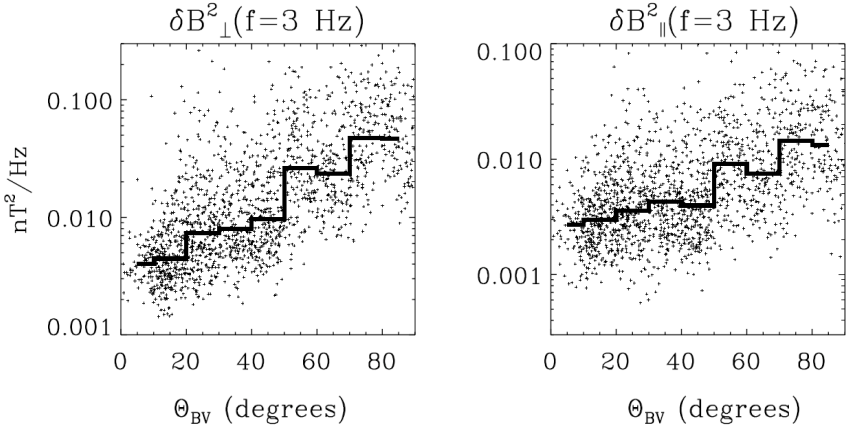
If Taylor hypothesis (V_{φ}«V) is verified ⇒ variation of field-flow angle allows to resolve slab fluctuations while V is || to B and 2D fluctuations while V is ⊥ to B.
[Bieber et al., 1996; Horbury et al., 2008; Mangeney et al., 2006]



Evidence of 2D cascade at ion and electron scales

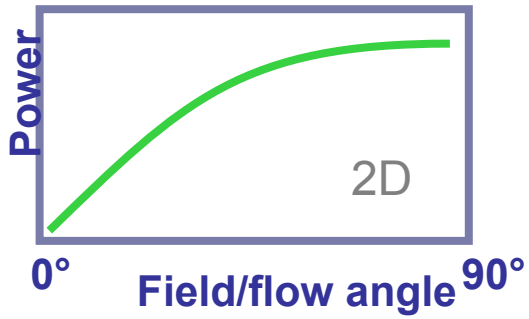


Electron scales [Mangeney, Lacombe et al.,2006]



Ion scales

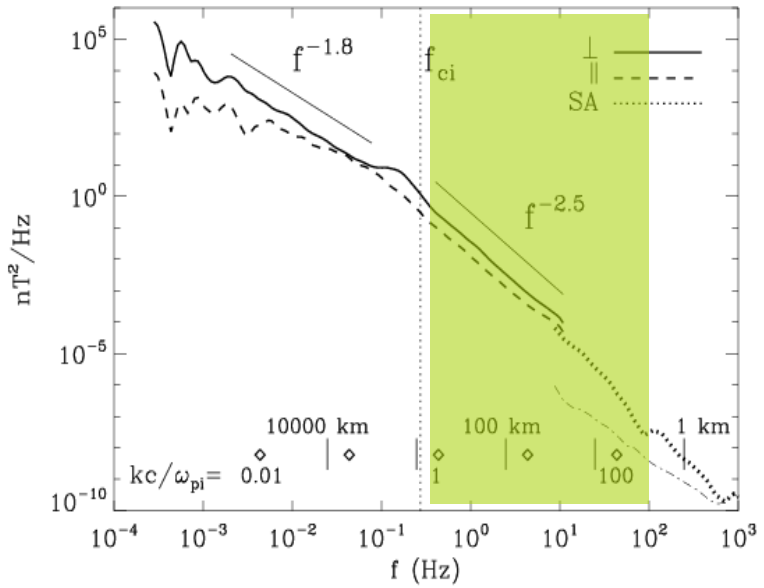
[Alexandrova, Lacombe, Mangeney, 2008]

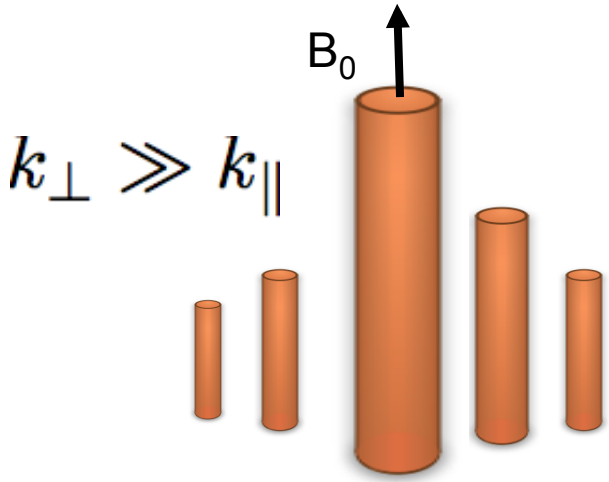


2D turbulence at ion and electron scales

[Mangeney et al. 2006; Alexandrova et al., 2008]

STAFF-SA & FGM/Cluster



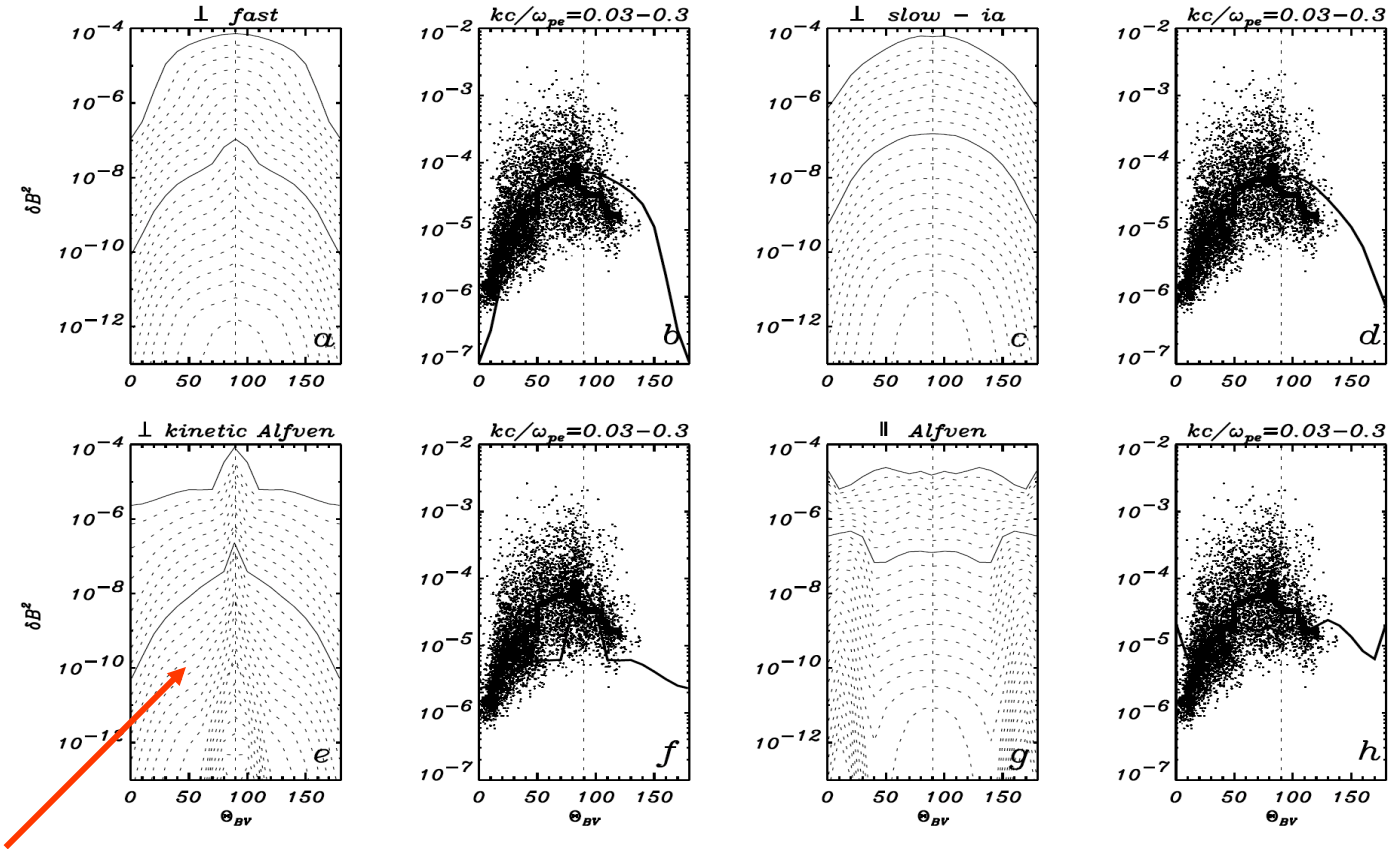


- [Mangeney et al. 2006] = 1st and only evidence of 2D cascade at electron scales.

- Interpretation : zero frequency structures with $k_\perp >> k_{||}$

2D magnetic turbulence : interpretation ?

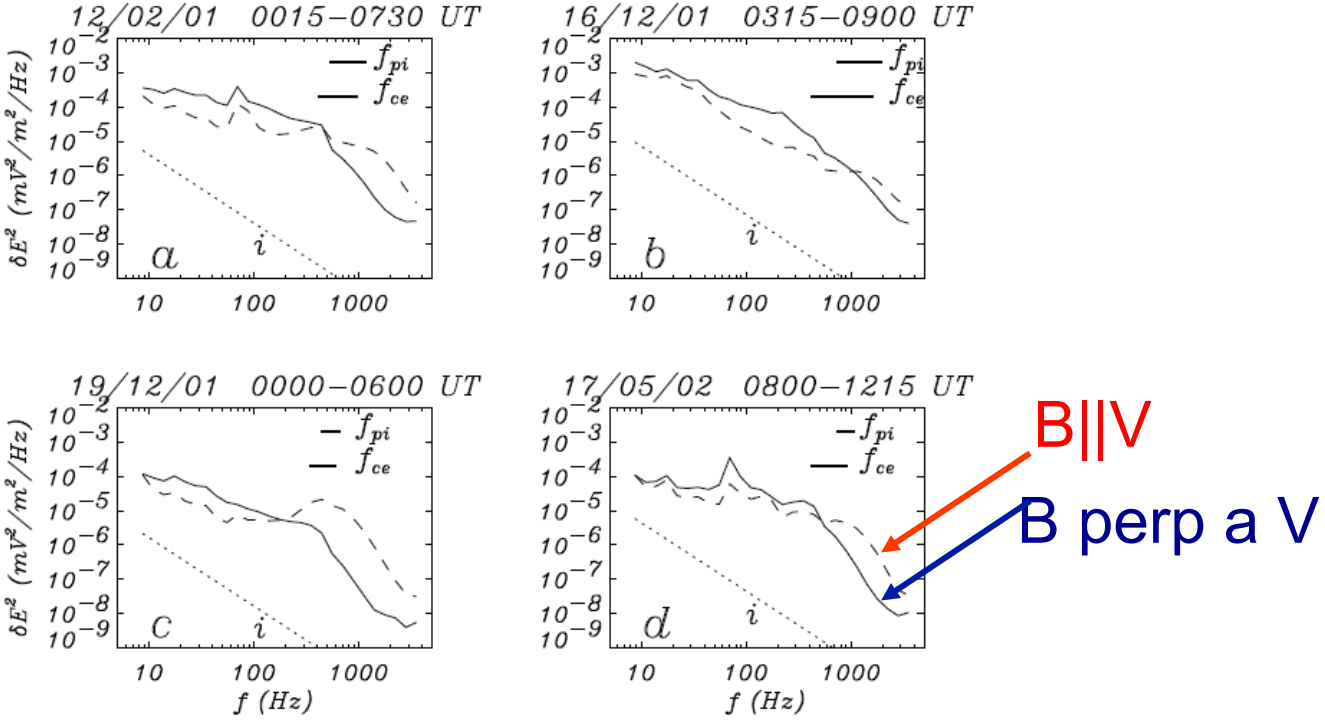
Magnetosheath 2D turbulence at electron scales
[Mangeney, Lacombe, et al., 2006]



Model of $B^2(\Theta_{BV})$ for the 27 frequencies of STAFF-SA (supposing 2D-k and power-law for k) for different dispersion relations (fast waves, KAW, slow, parallel AW) => zero frequency fluctuations with k⊥ (not KAW, fast, ||AW)

Spectra and anisotropy of electric field fluctuations in the magnetosheath

[Mangeney, Lacombe, et al., 2006]

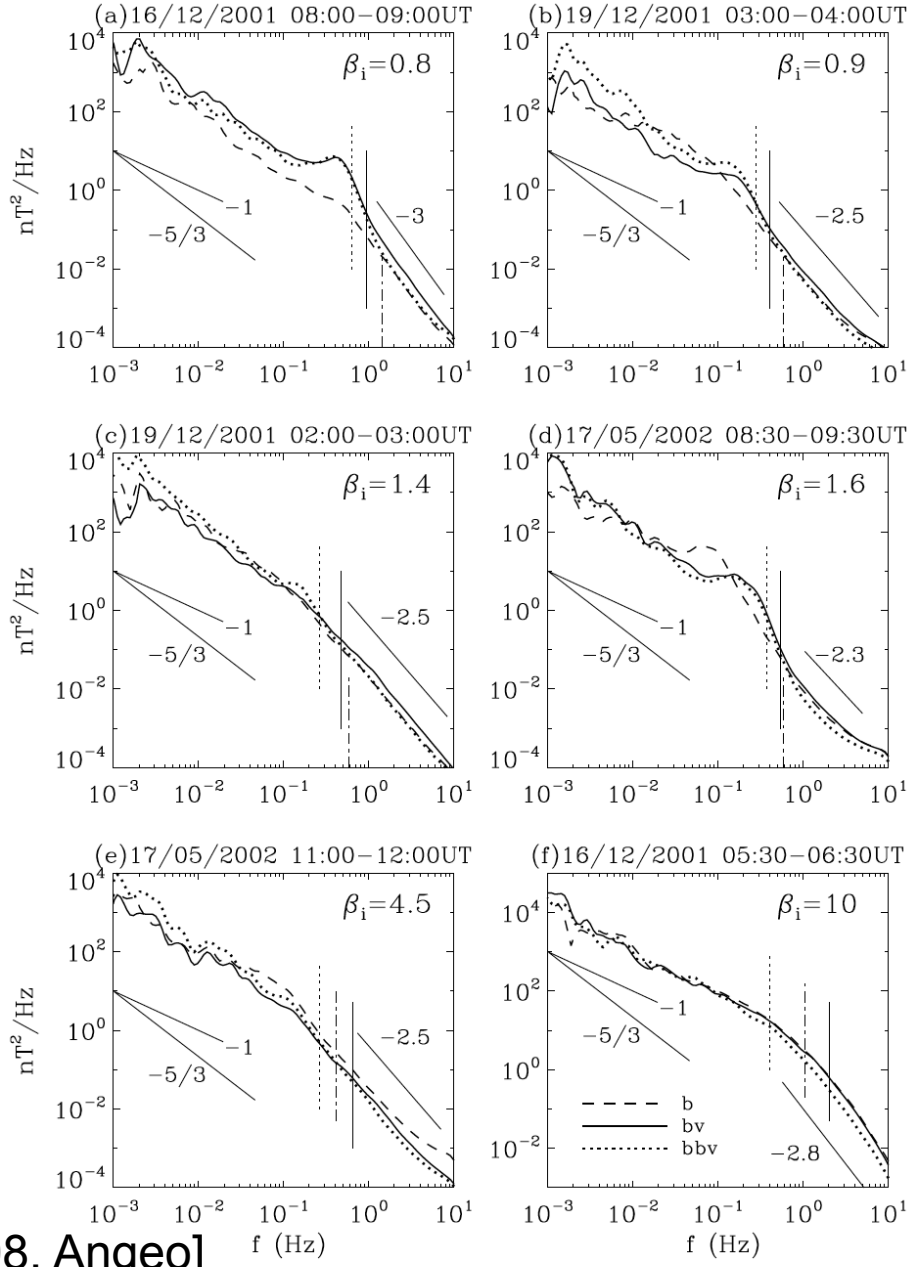


$k_\perp >> k_{||}$ for f<100 Hz

$k_\perp << k_{||}$ for f>400 Hz

Magnetosheath turbulent spectra under different plasma conditions:

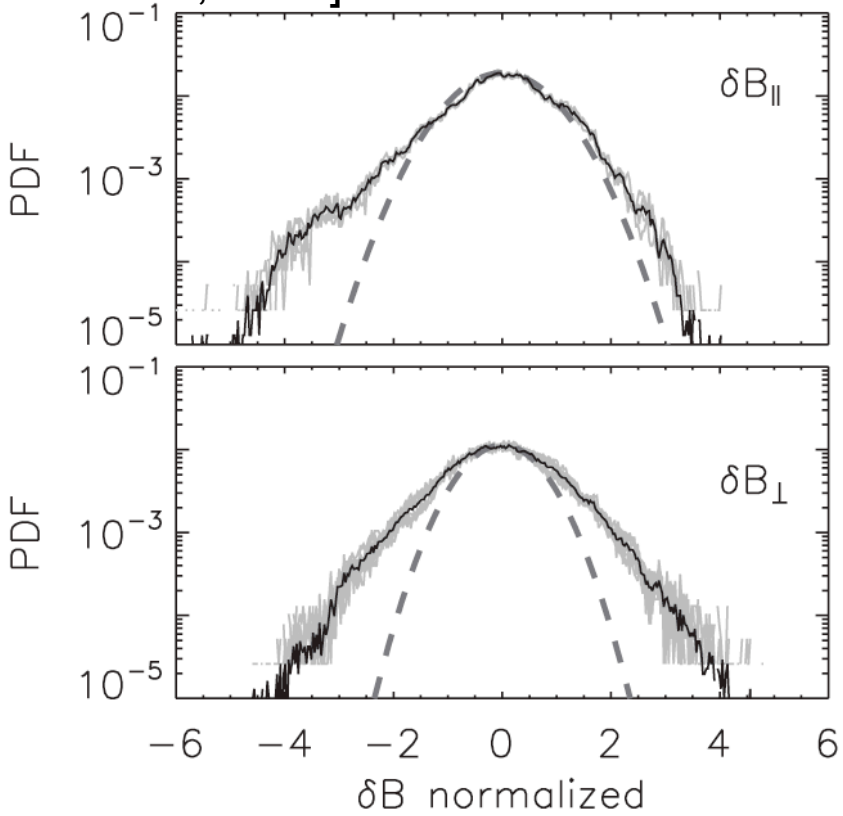
-Kolmogorov spectrum at MHD scales
-Break at ion scales as in the solar wind
-Steeper power-law at smaller scales



[Alexandrova, Locombe, Mangeney, 2008, Angeo]

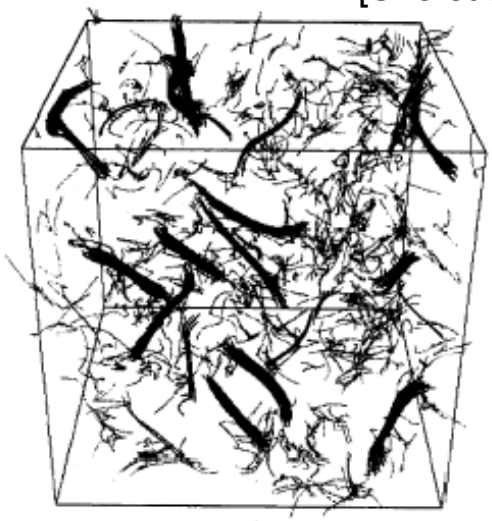
Intermittency = coherent structures

Example Cluster: foreshock [Narita et al., 2006]



In HD turbulence intermittency corresponds to appearance of coherent structures:

[She et al., 1991]

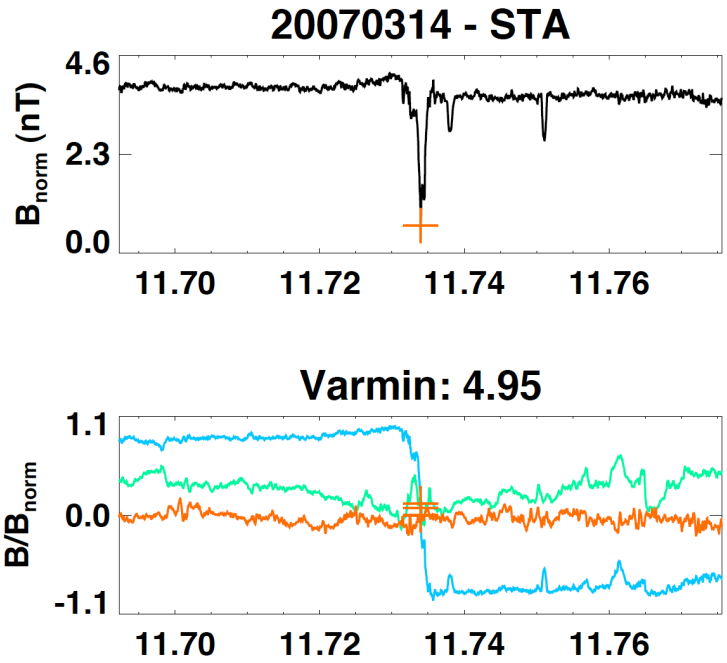


3D Simulations HD : filaments of vorticity with cross-section ~ $L_{dissipation}$, and length ~ $L_{injection}$

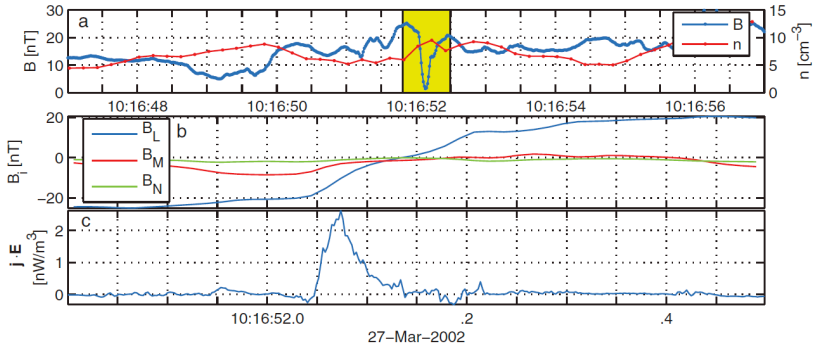
Important for dissipation

Coherent structures in space plasmas

1. Magnetic holes and current sheets in SW and Q||-magnetosheath (1D structures)



Cluster & STEREO observations
[Briand, Soucek, et al., 2010, JGR]

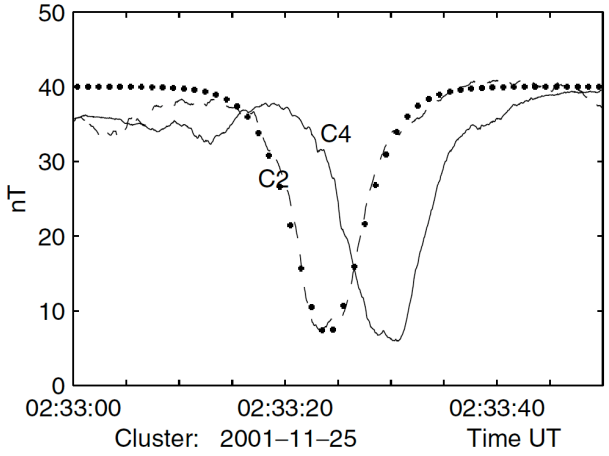


Cluster observations
[Retino et al., 2007, Nature,
Sundkvist et al., 2007, PRL]

2. Magnetic dips and peaks (mirror modes)

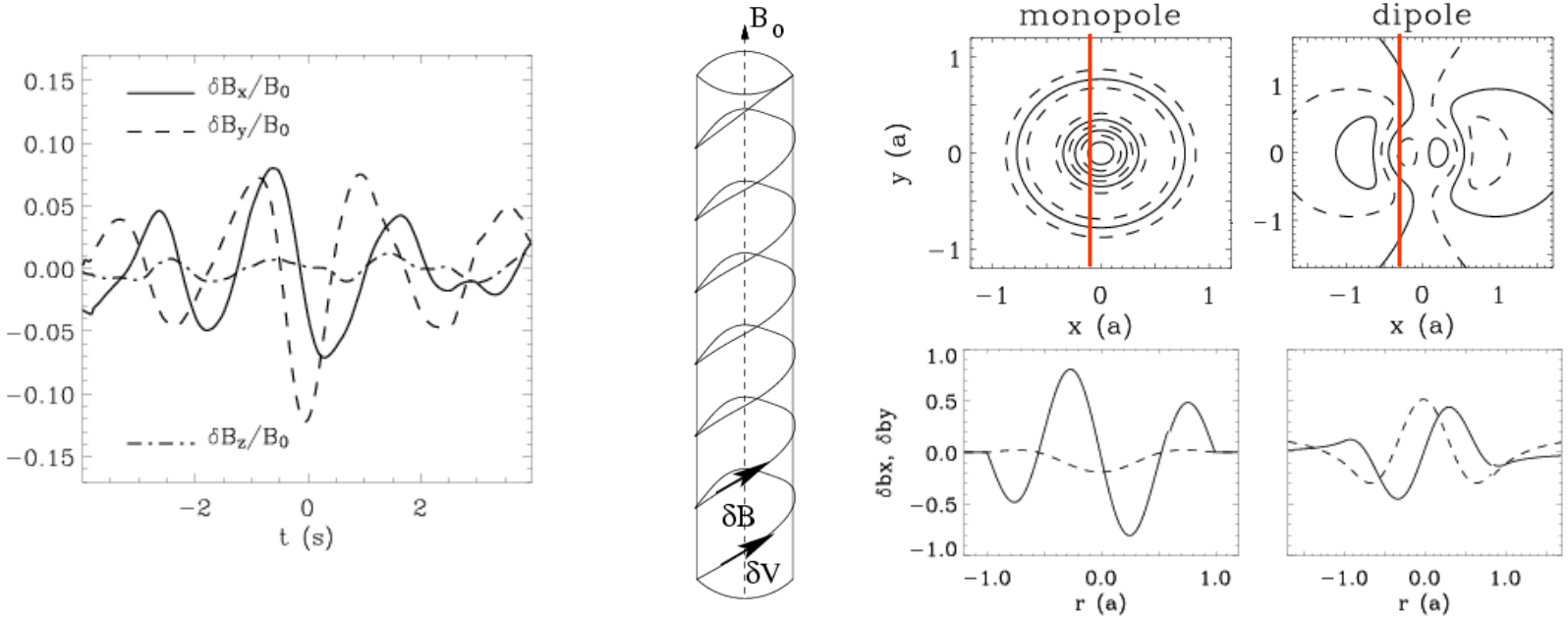
[Soucek et al., 2008; Genot et al., 2008]

3. Slow m/sonic solitons at magnetopause [Stasiewicz et al, 2003]



Coherent structures in space plasmas

4. Alfven Vortices in the Earth's and Saturn's Qperp-magnetosheathes, Earth's cusps (2D structures)



[Alexandrova et al. 2004, 2006, Alexandrova & Saur, 2008, Sundkvist, et al., 2005, 2008]

Open questions (small scales)

- Dissipation of turbulent energy in collisionless plasmas
  - ✓ role of coherent structures? Stability and generation of the structures?
  - ✓ measurements of waveforms at different plasma scales are needed (MMS electron scales,X-Scale)
  - ✓ measurements of ion and electron distribution functions with “better” time resolution are needed

- Temperature anisotropy and q-lin. instabilities

Open questions (all scales ☺)

- Cascade model?
- Wave/strong turbulence?
  - ✓ How can we measure NL time/life time of the fluctuations?

- Radial evolution of turbulence and particles distribution functions with heliospheric distance
  - ✓ BepiColombo
  - ✓ Solar Orbiter
  - ✓ Solar Probe
  - ✓cruise phase of Uranus mission