Spectral shape of magnetic fluctuations in the solar wind at ion scales

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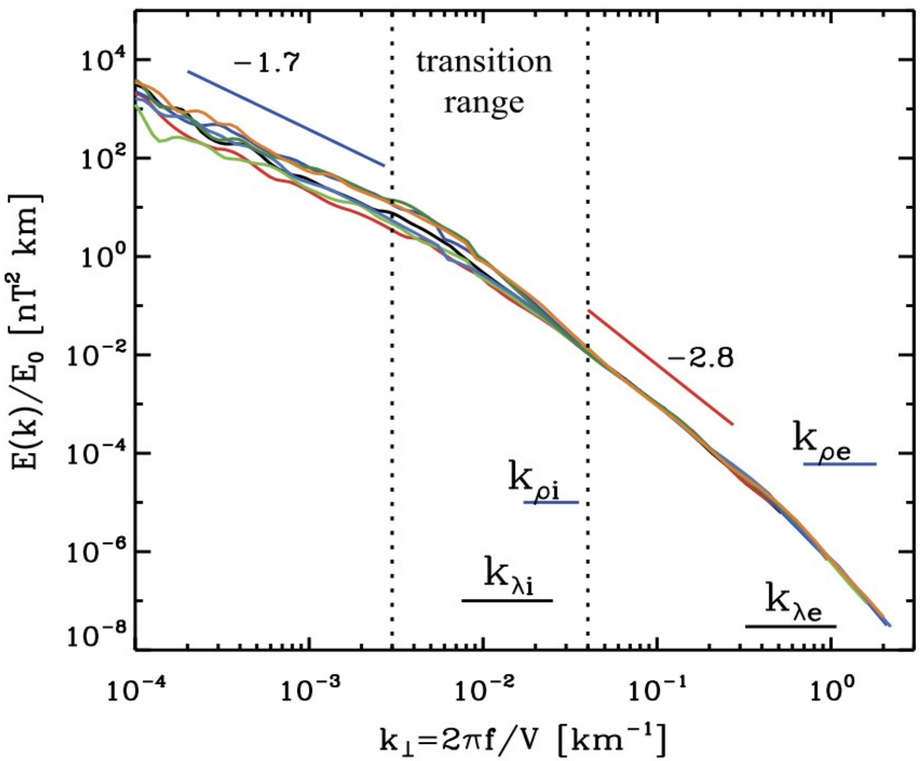
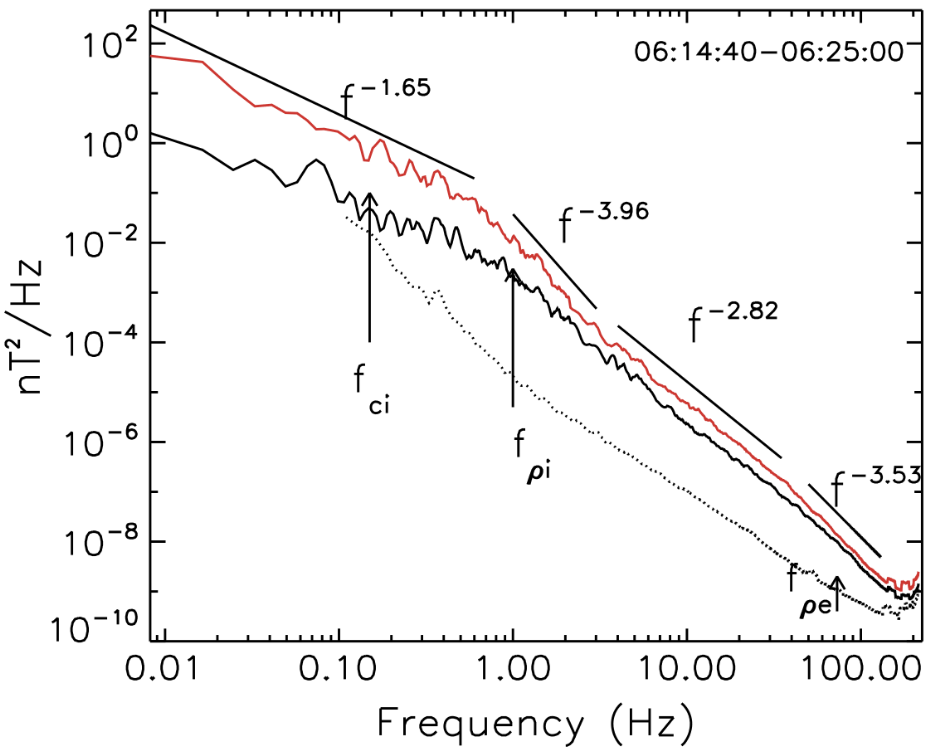
Context : turbulence at ion scales



[Alexandrova et al. 2013]



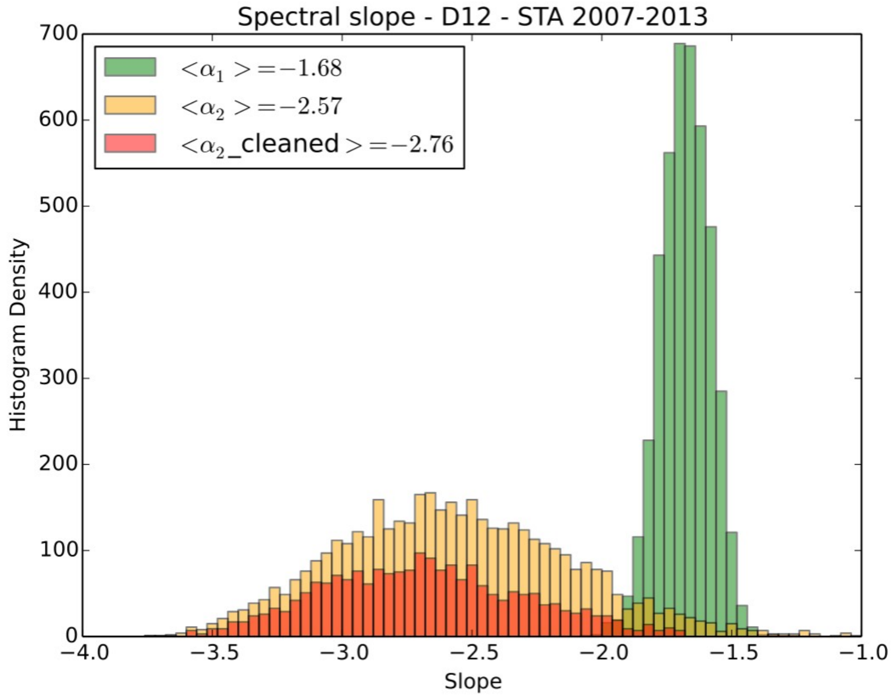
[Sahraoui et al. 2010]

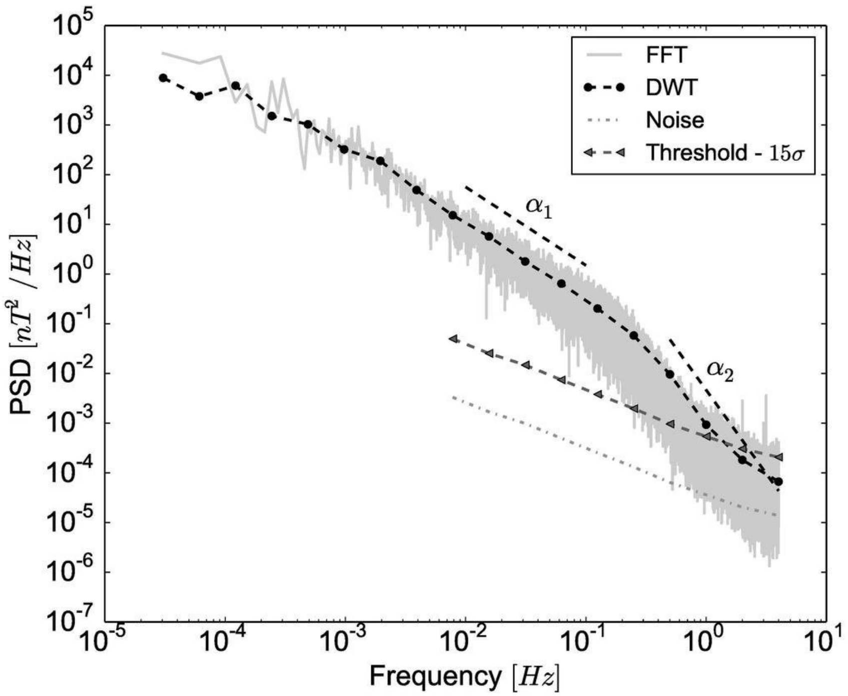
- FGM+STAFF-SC/CLUSTER data : spectra in both inertial and kinetic range
- The spectrum suddenly changes at ion scales
- Two power laws continually observed :
  - -5/3 [0.01, 0.2] Hz
  - -2.8 [3, 30] Hz
- The shape of the spectrum is variable from one example to another in the ion transition:

  => No universal behavior?

Statistical study with STEREO spacecraft

- 9h Spectra – from 2007 to 2013



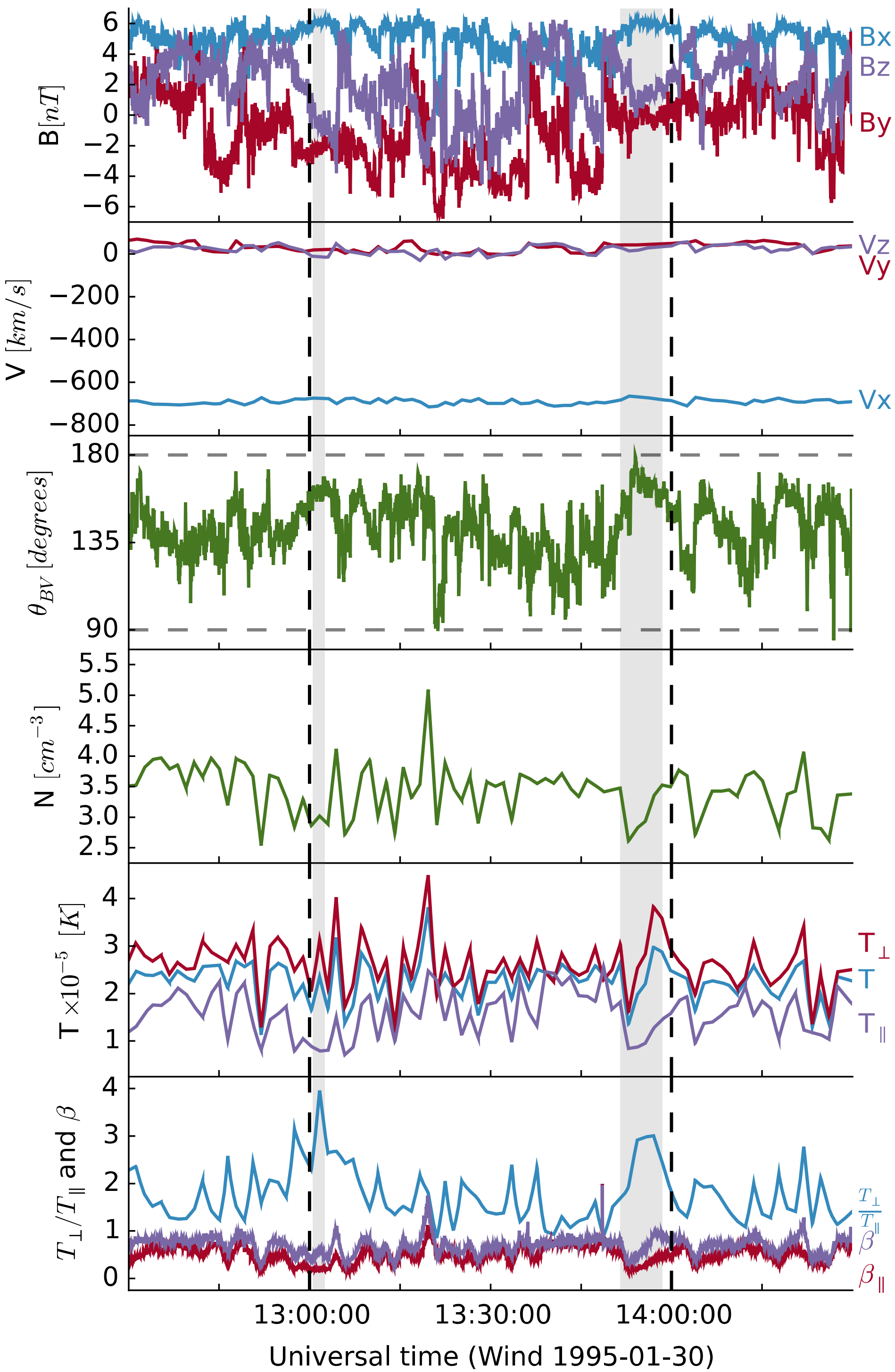


- Not always well defined transition
  - Slope in transition and inertial range too close
  - Smooth transition

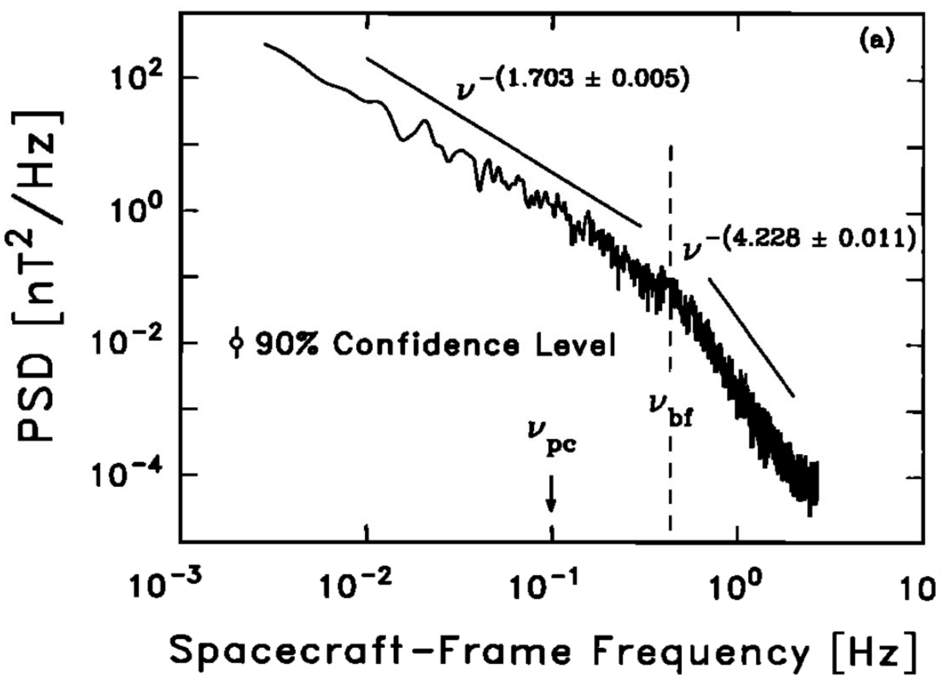
=> Difficult to identify a meaningful break frequency

- Broad slope distribution at high frequency => High variability of the spectrum (even on 9h)

A typical example of ion transition?



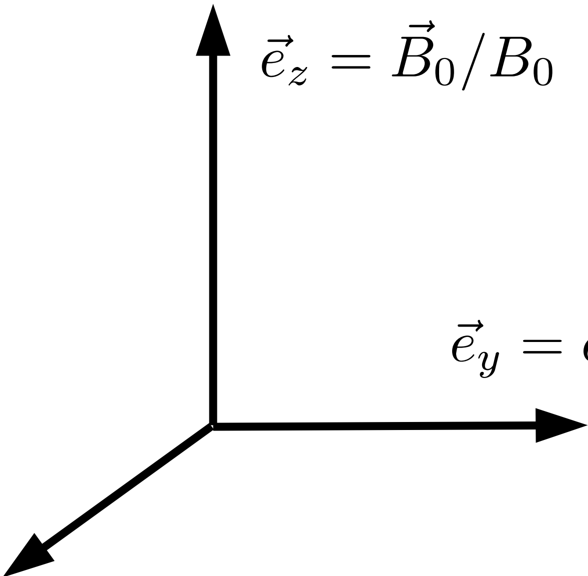
[Lion et al, 2015, to be submitted]



[Leamon et al., 1998]

- Central interval: same as in Leamon et al. 1998
- $V \simeq 700\ km/s$
- $T_\perp > T_\parallel$

Reference frame



- BV reference frame :

  Separation of perpendicular and parallel to B_0 fluctuations

  $P_{\|} = (\vec{e}_z, \vec{e}_x)$

  $P_{\perp} = (\vec{e}_x, \vec{e}_y)$

Relative phasing

- Local phase is obtain from complex wavelet coefficients :

$$\phi_x(f,t) = arg(W_x(f,t))\ [2\pi]$$

- Relative phasing between Bx and By is given by :

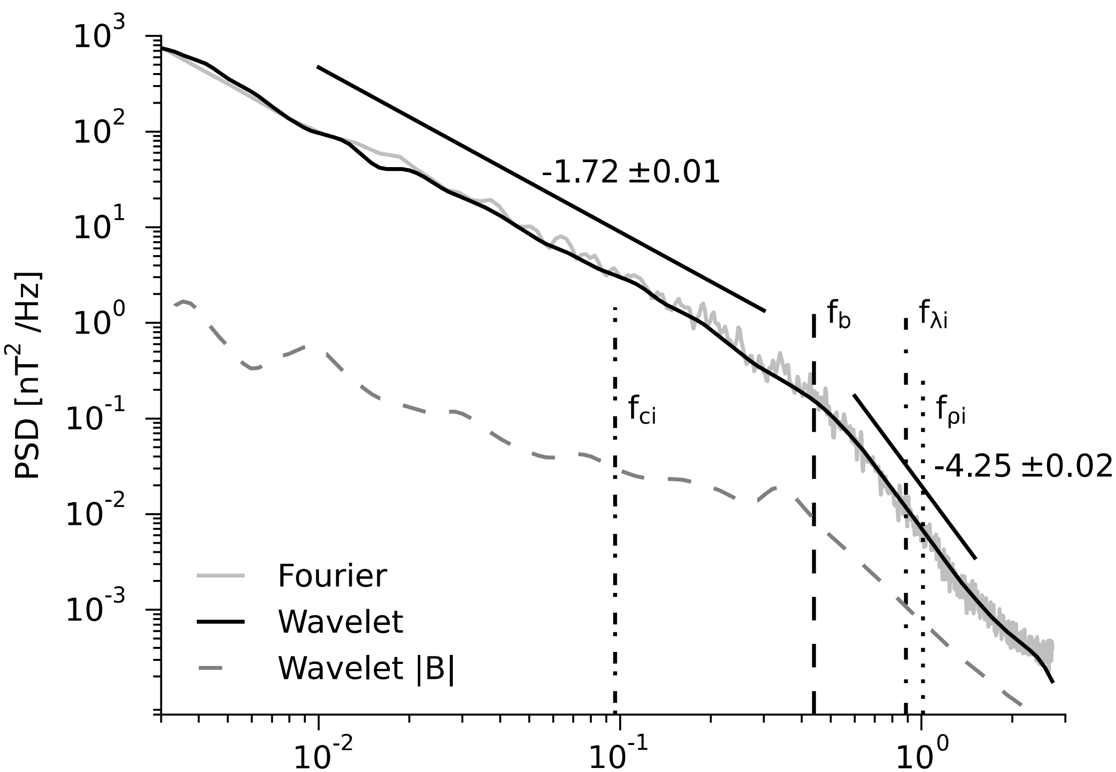
$$\Delta\phi_{xy}(f,t) = \phi_x(f,t) - \phi_y(f,t)$$

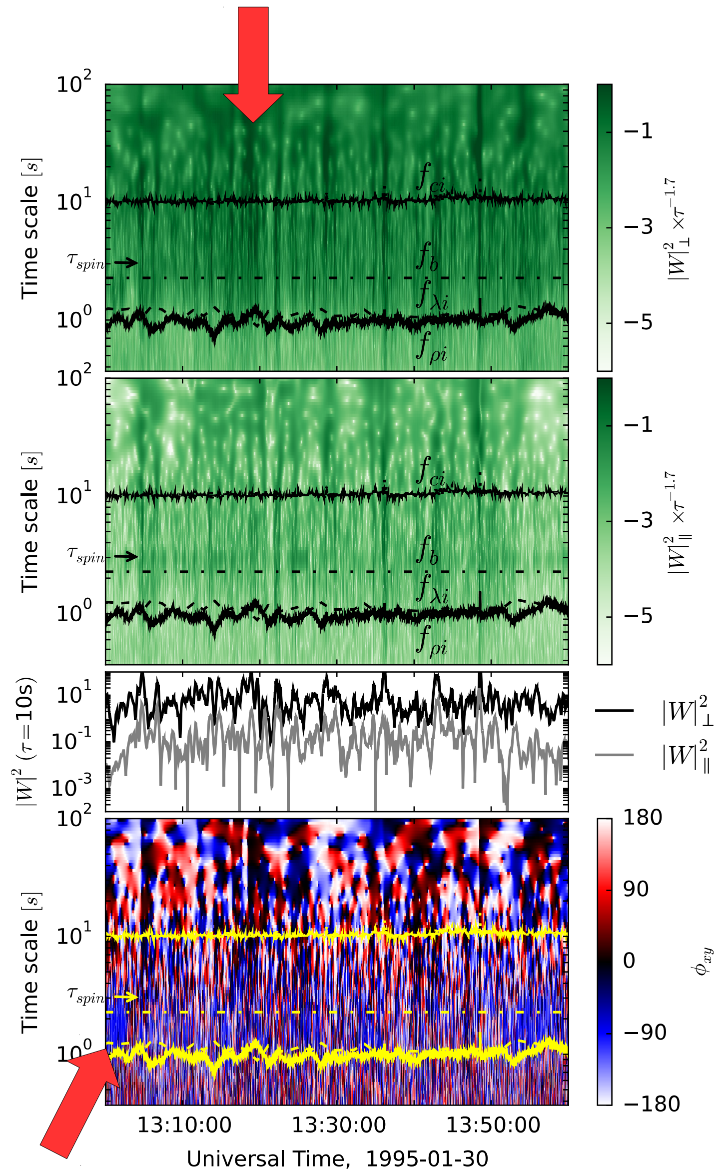
$$\Delta\phi_{xy}(f,t) = \begin{cases} \pi/2 & [2\pi] \rightarrow \text{right handed} \\ 0 & [\pi] \rightarrow \text{linear} \\ -\pi/2 & [2\pi] \rightarrow \text{left handed} \end{cases}$$

[Grinsted et al. 2004]

Time evolution of magnetic fluctuations

- No direct correspondence between ion scales and the break frequency
- Coherent structures everywhere in this interval
- Polarized signal at the beginning and the end of the interval

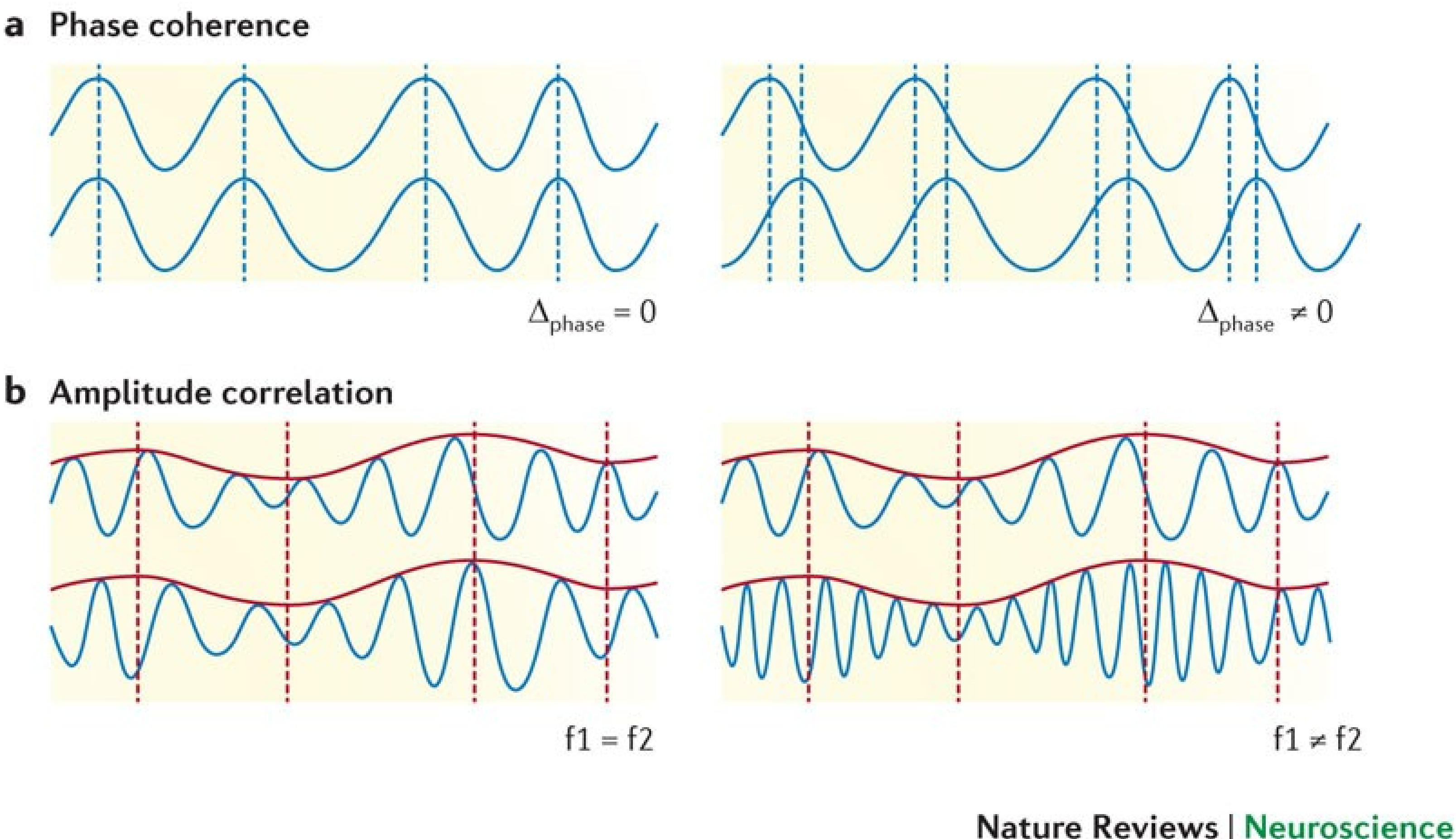




[Lion et al, 2015, to be submitted]

Phase coherence

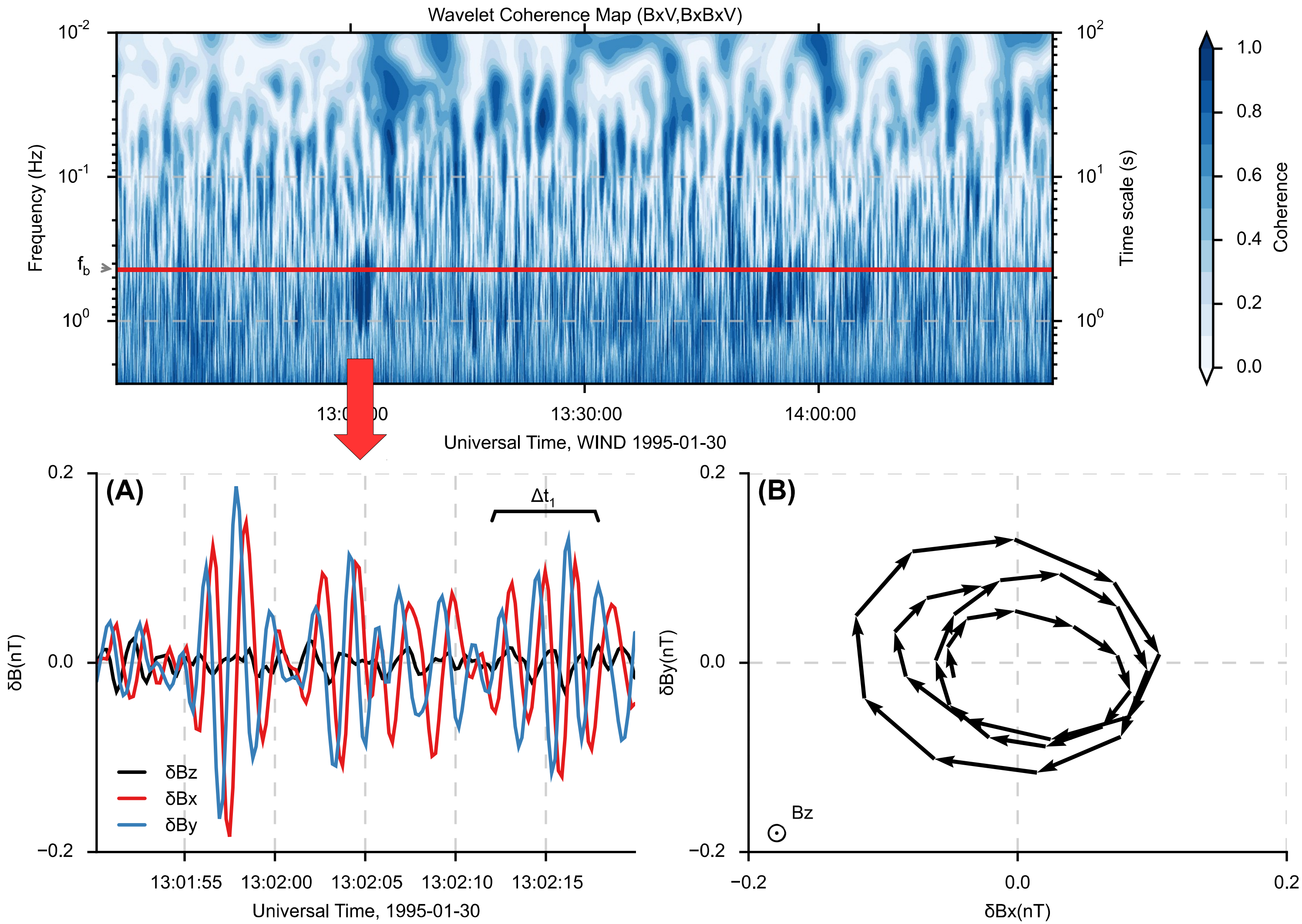
- Definition:
  - Coherence is a measure of the variability of time differences between two time series.
  - Two signals are considered coherent if they maintain a fixed phase relationship.



Markus Siegel, Tobias H. Donner & Andreas K. Engel

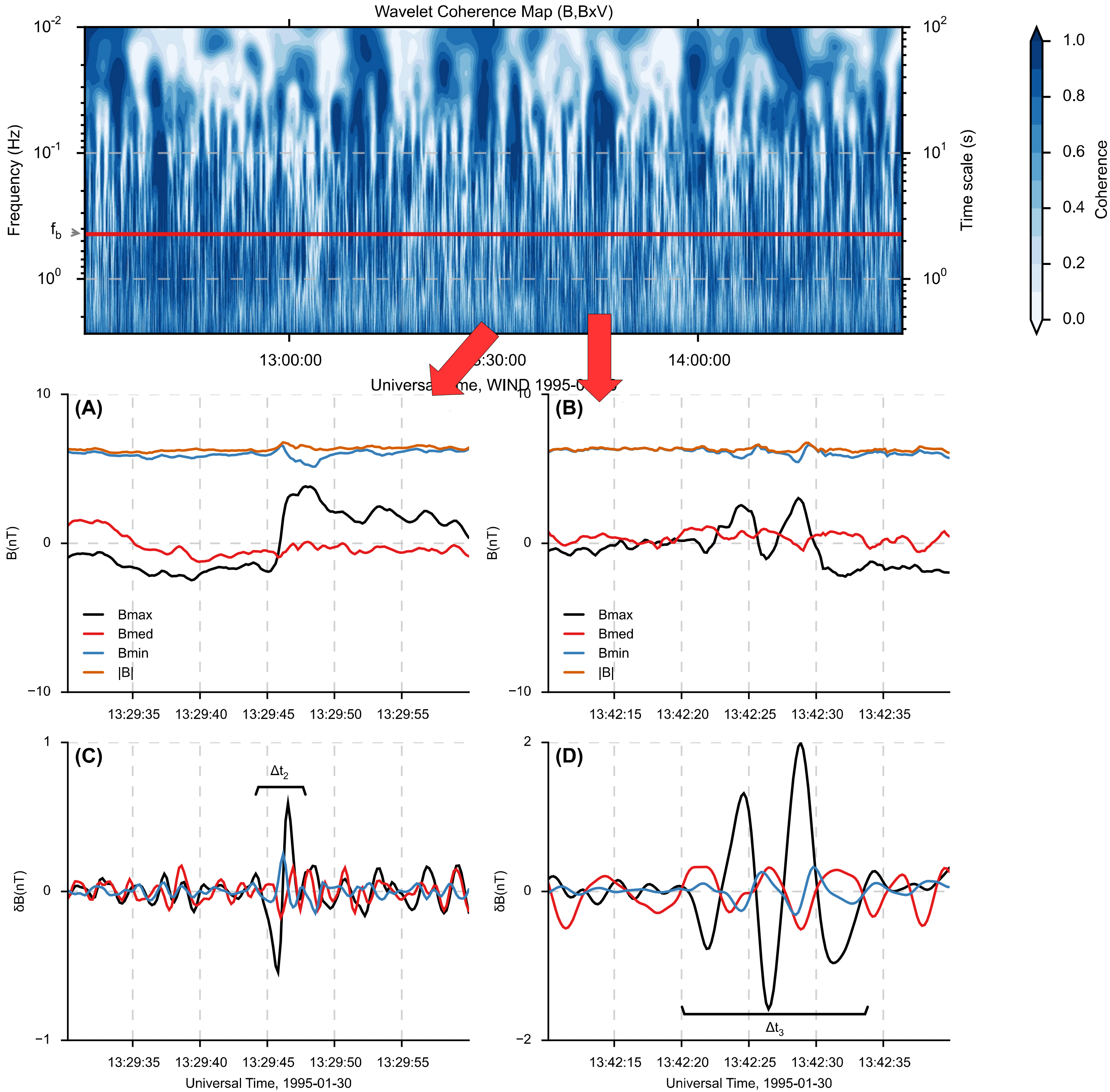
Nature Reviews Neuroscience 13, 121-134 (February 2012)

Phase coupling in the perpendicular to B_0 plane



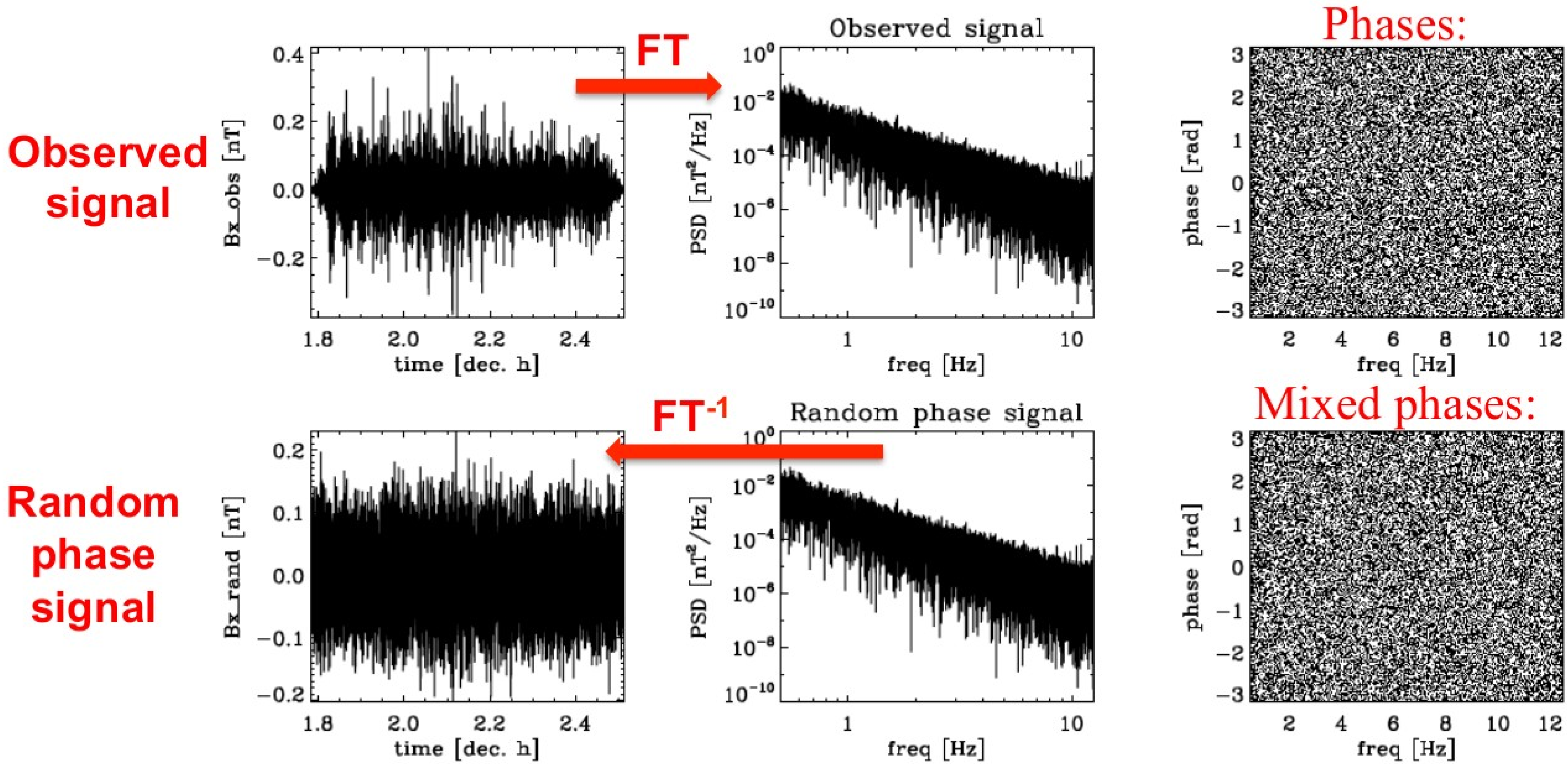
[Lion et al, 2015, to be submitted]

... And in the parallel to B_0 plane



Surrogate data

Cluster-1/STAFF-SC measurements, 2002-02-19

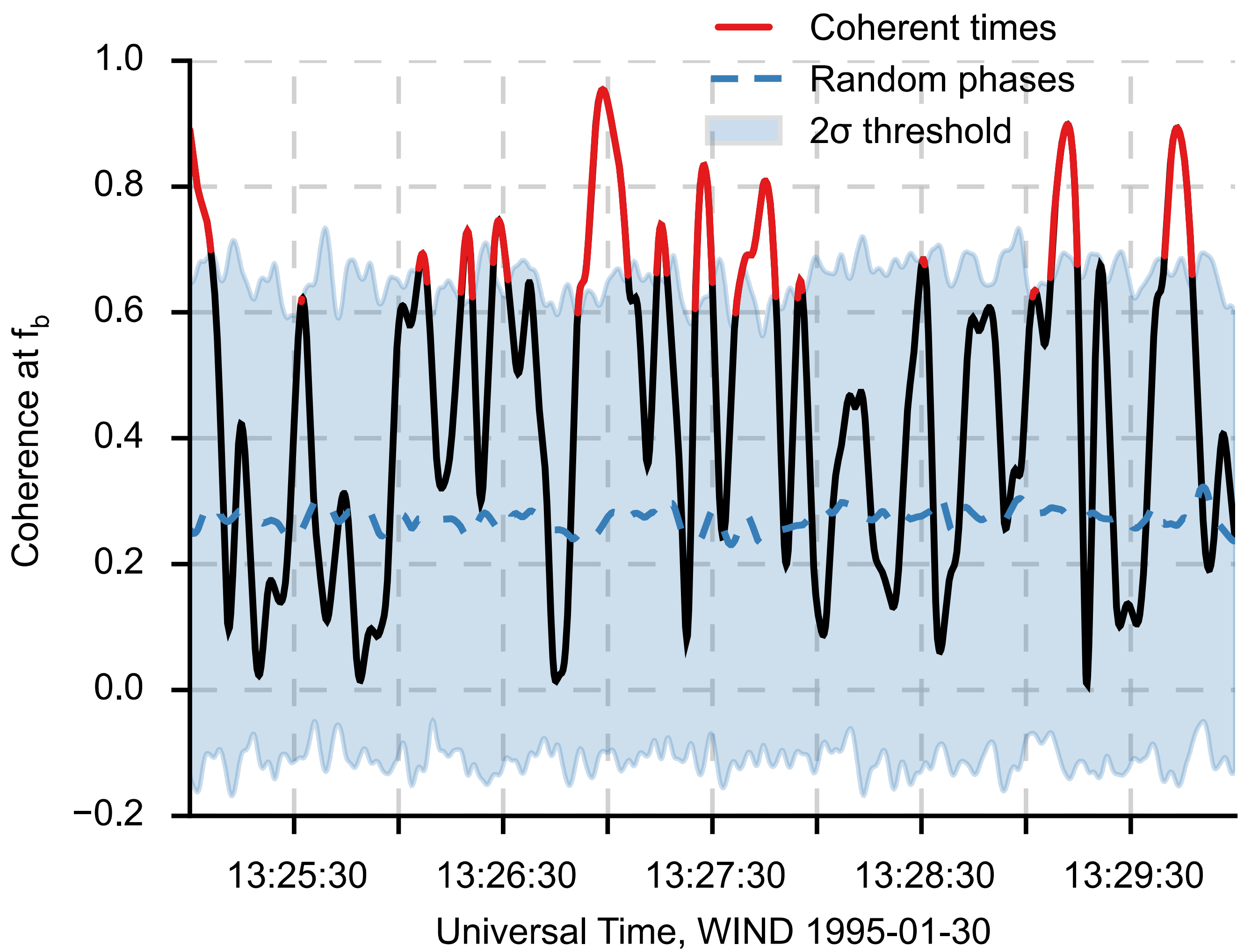


From the observed signal we construct a signal with random phases but with the same spectrum.

[Rossi, Tesi di Lauria, 2011; Hada et al. 2003; Koga & Hada, 2003; Sahraoui, 2008]

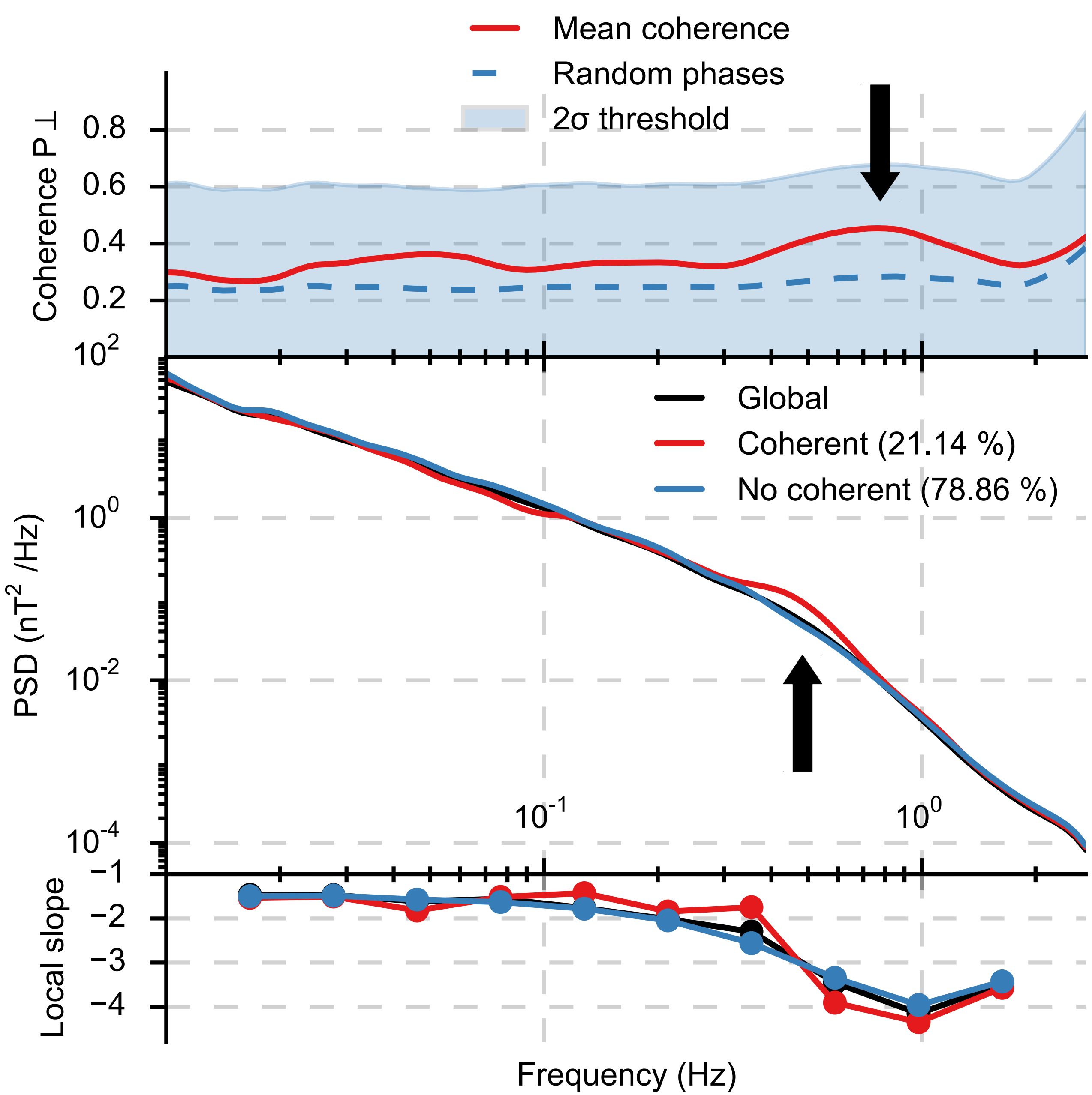
Coherent times

- 100 realization of surrogate data are used in order to compute a threshold (mean and standard deviation)



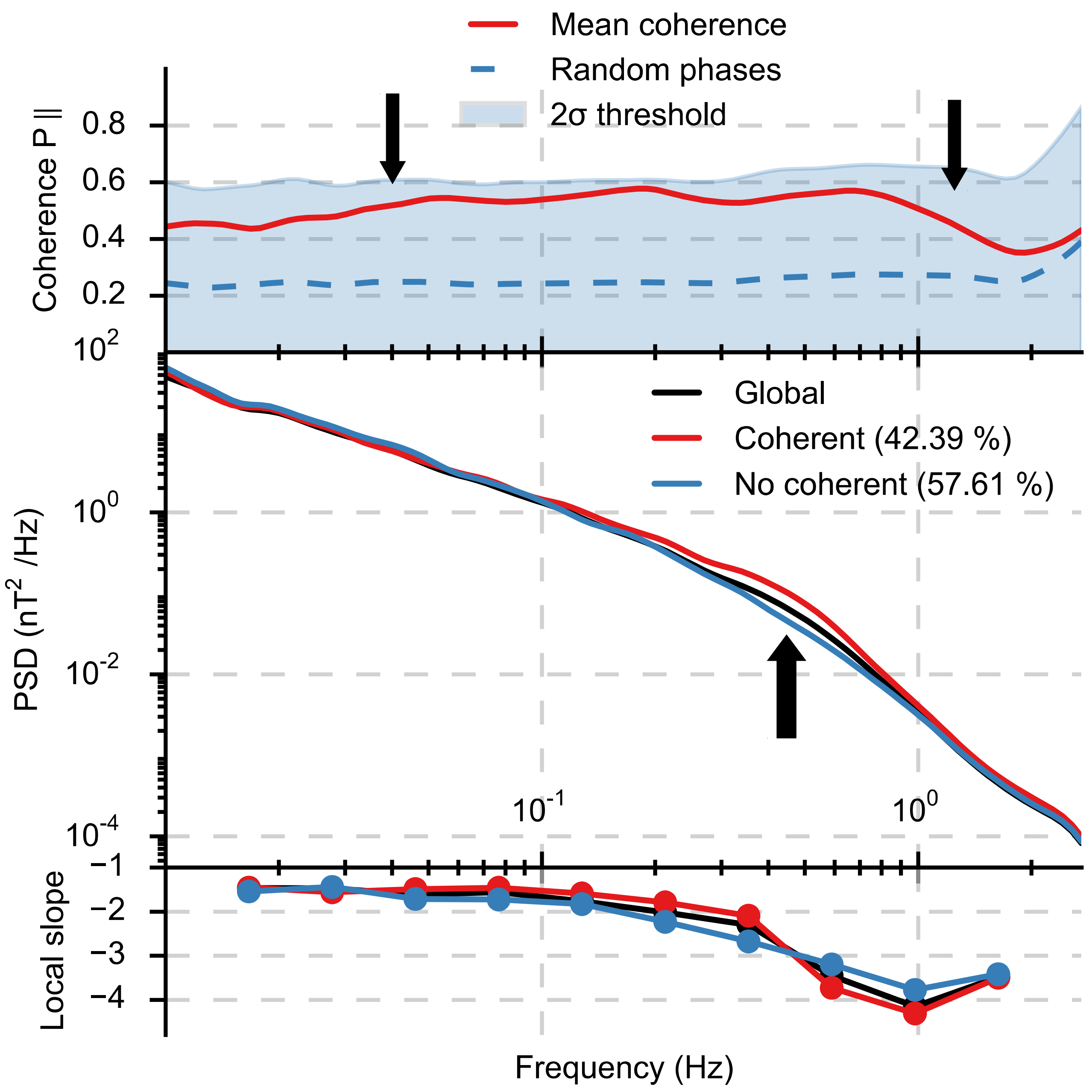
- Coherent times (red) are times where coherence is above the threshold (blue)

Perpendicular Plane



- Mean coherence is higher for frequencies just above fb
- Filtering mainly affects the spectrum around fb

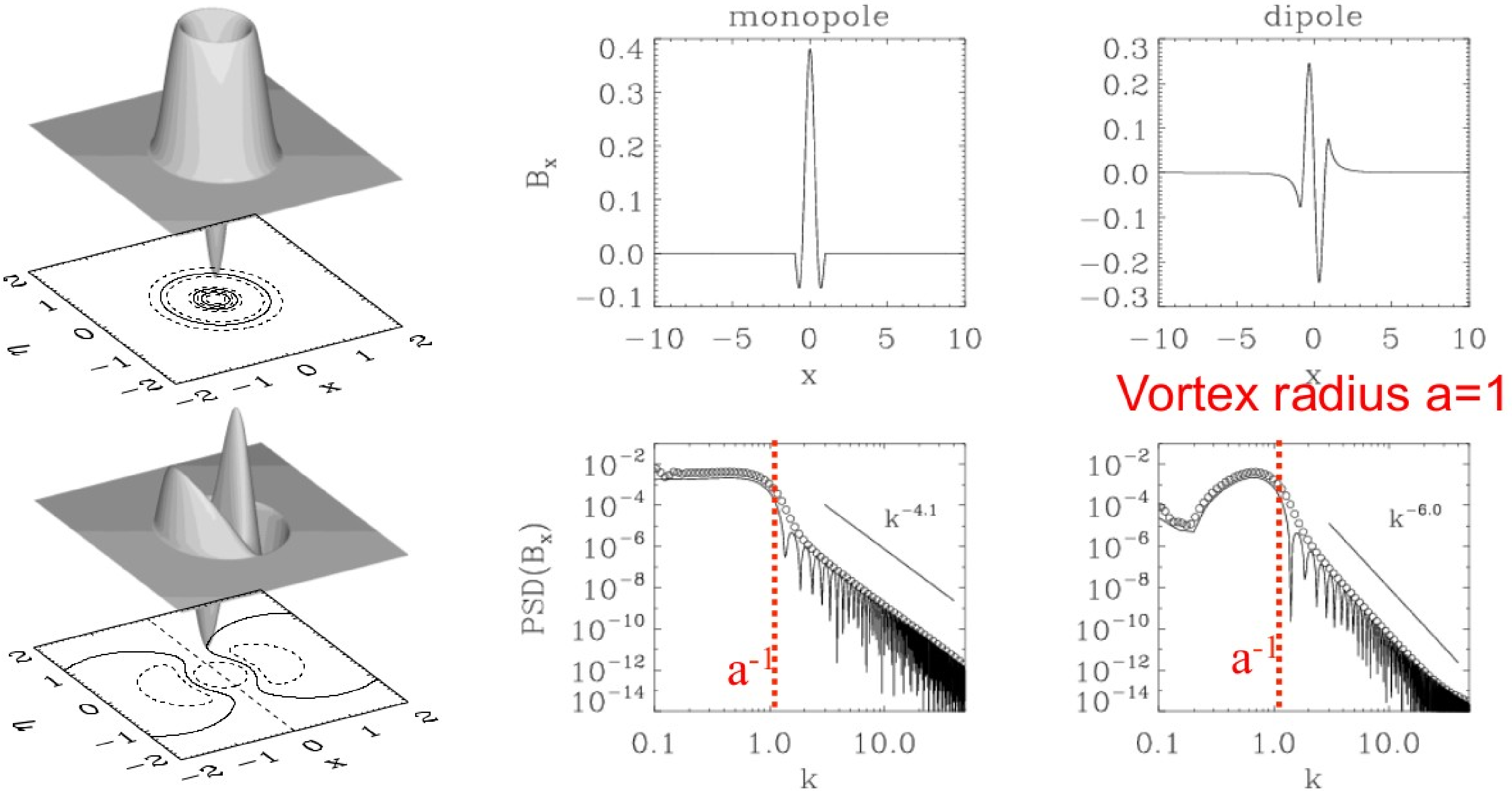
Parallel Plane



- The mean coherence forms a plateau and drops sharply just after fb

Spectral properties of Alfvén vortices

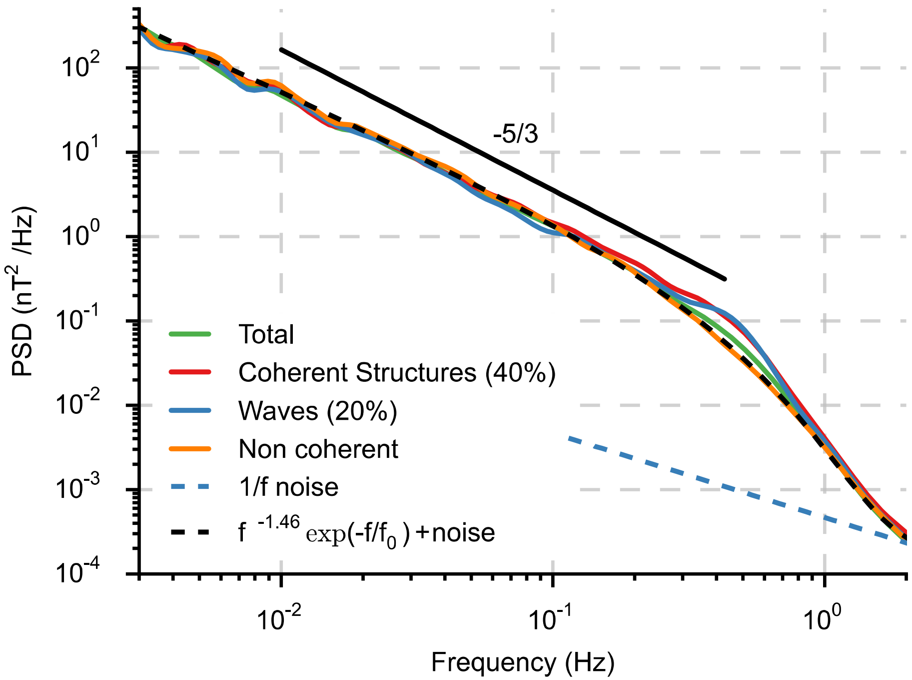
[Petviashvilli & Pokhotelov, 1992]

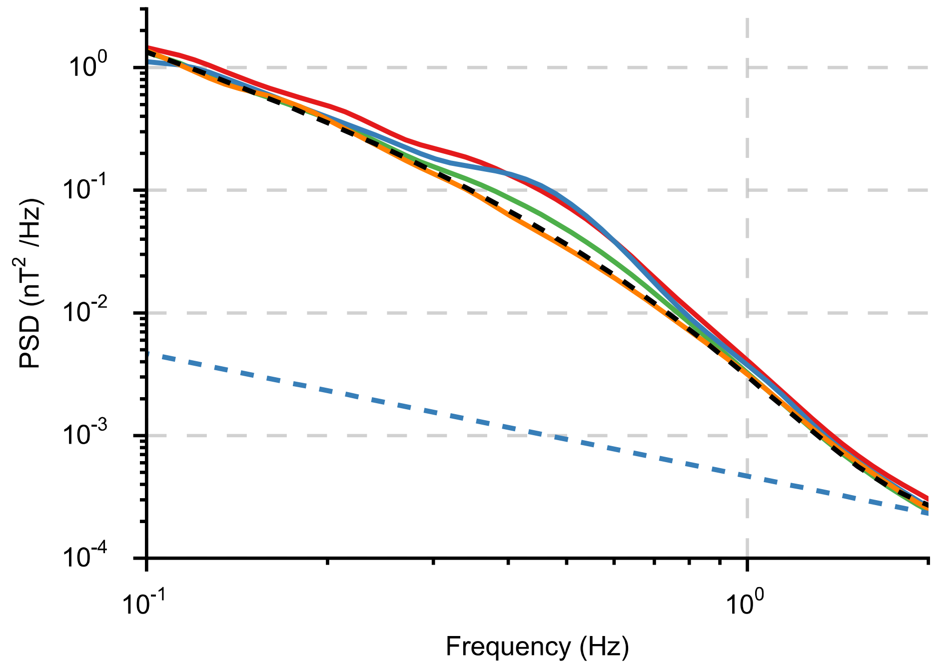


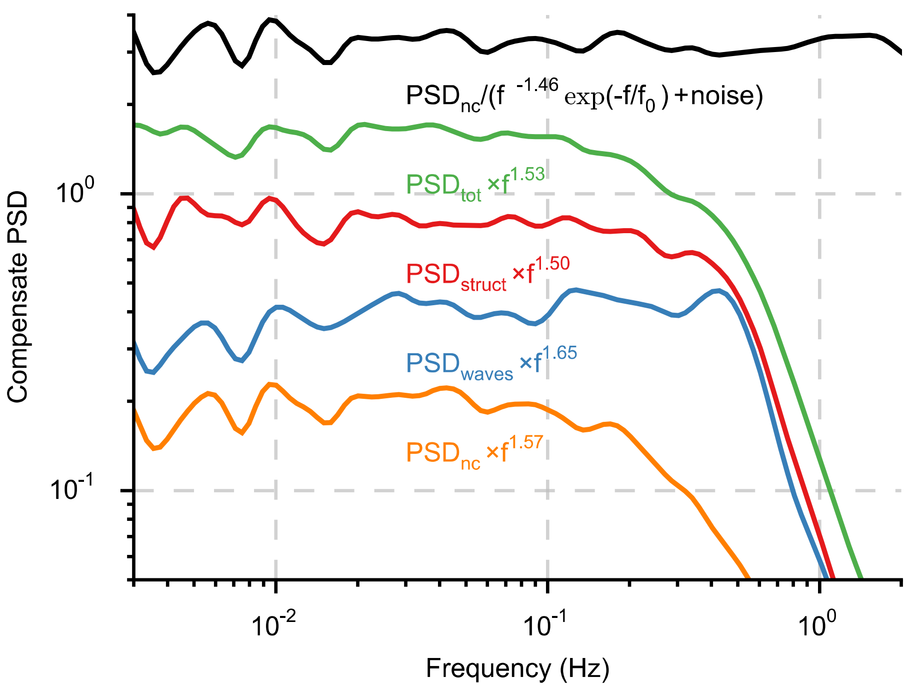
- Spectral knee at k=a ; power law spectra above it
- Monopole => dB ~k^{-4} (due to discontinuity of the current)
- Dipole => dB ~k^{-6} (due to discont. of the current derivative)

[Alexandrova, 2008]

Spectrum decomposition



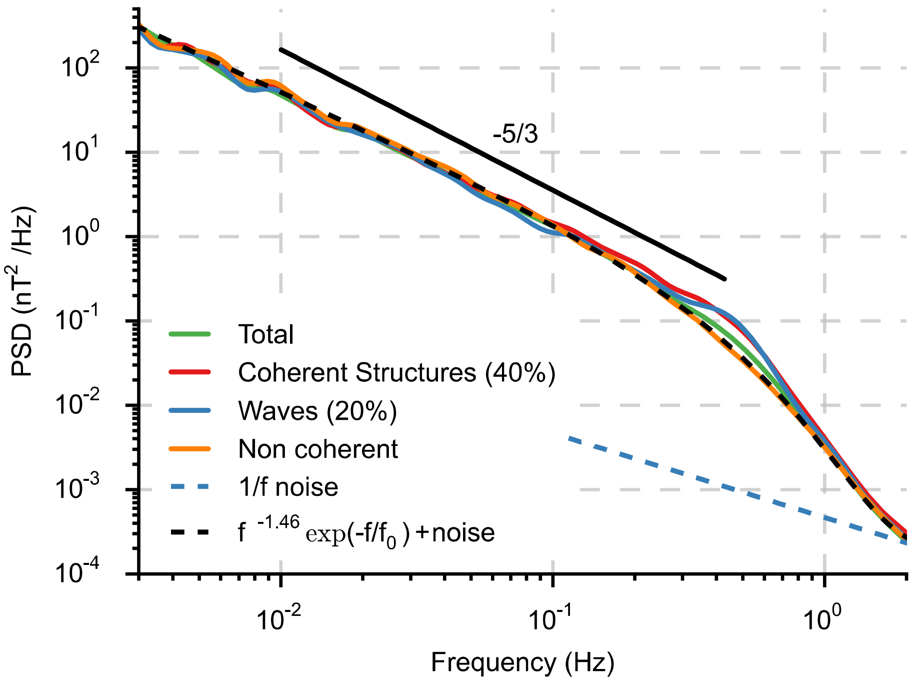


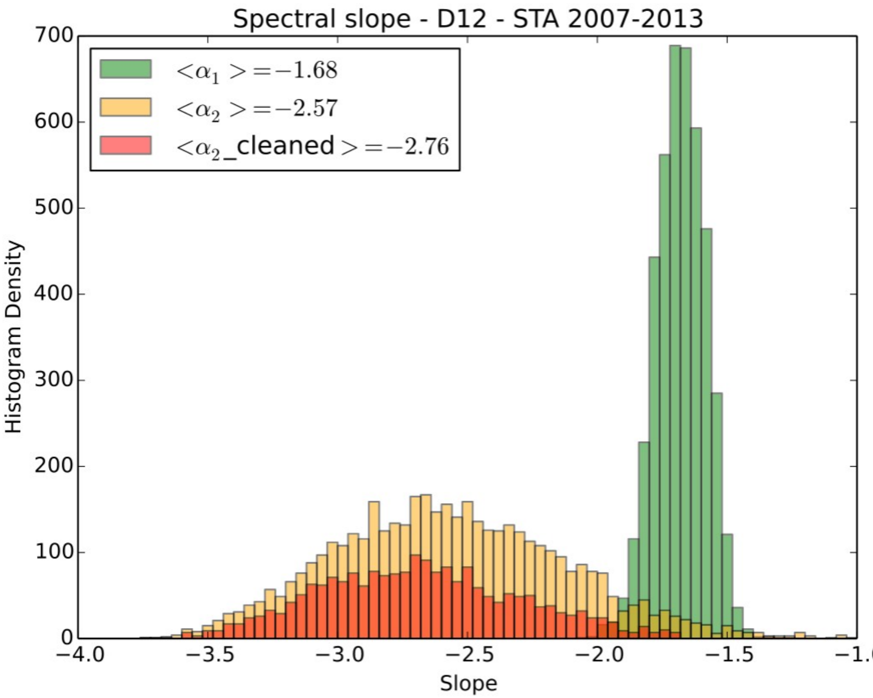


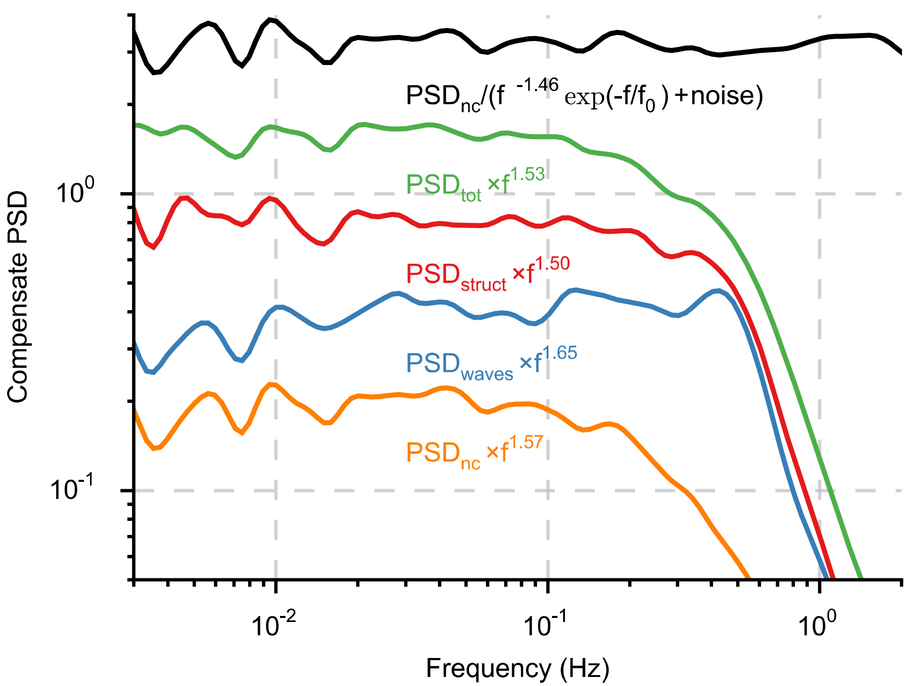
- Alfven waves (20%)
- Coherent structures (40%)
- Non coherent signal (40%), well fitted by :

$$E_B \sim f^{-3/2}\exp(-f/f_0), \quad f_0 = 0.3\text{Hz}$$

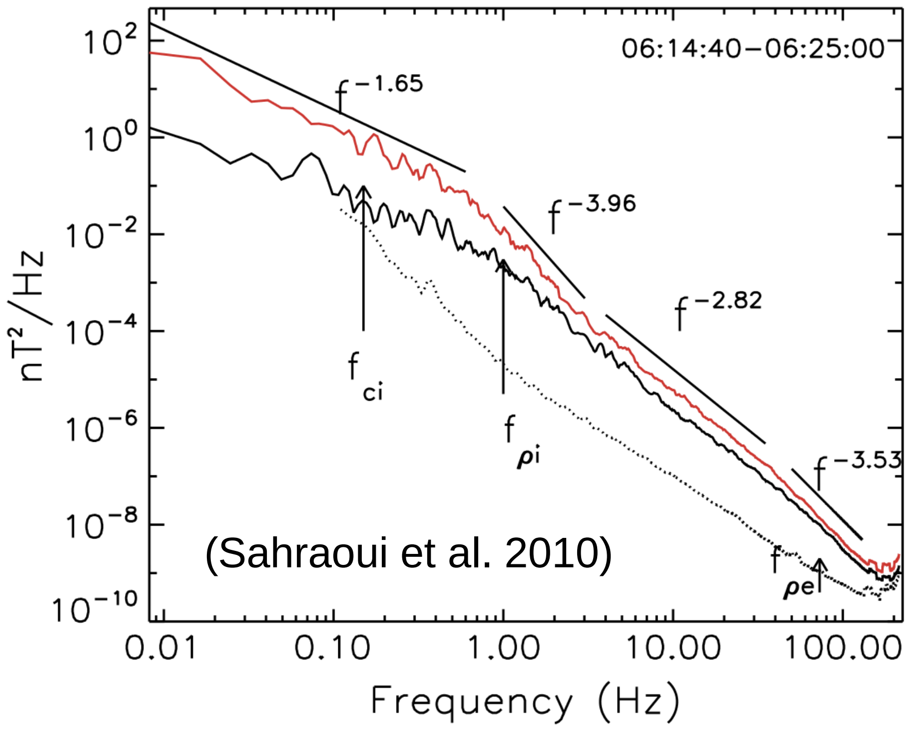
Conclusion

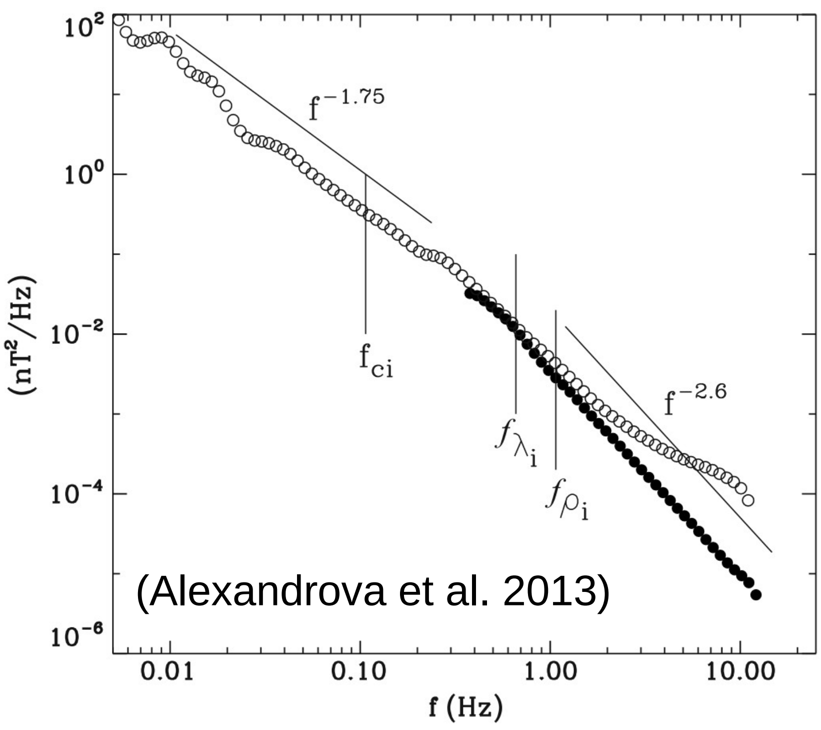






- The total observed spectrum depends on the contribution (percentage) of each event
- Visible power-law scaling at high frequencies : partly due to spectrum of coherent structures





Outlook

- Characterization of the effects of instrumental filters on the signal phase and coherence for frequencies near the Nyquist frequency for FGM
- Use the coherence filtering on FGM + STAFF-SC/CLUSTER data