EGU General Assembly 2020
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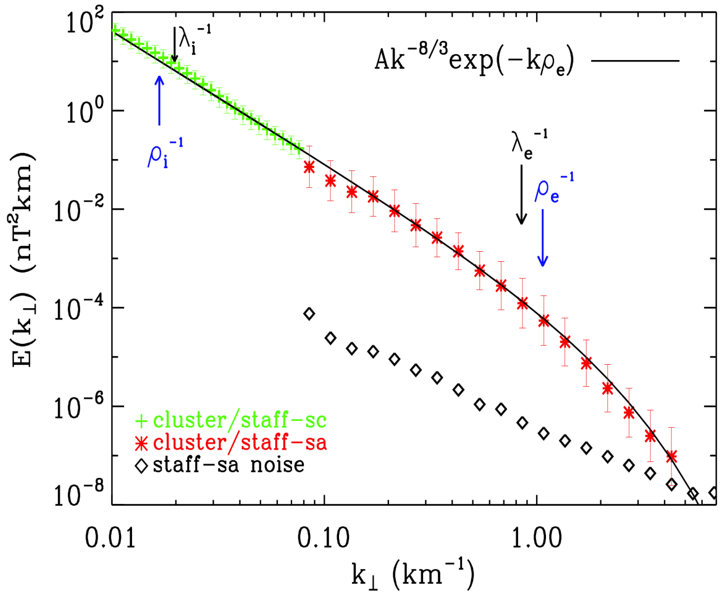
Laboratoire d'Études Spatiales et d'Instrumentation en Astrophysique

# Solar Wind Turbulence at Kinetic Scales in the Inner Heliosphere

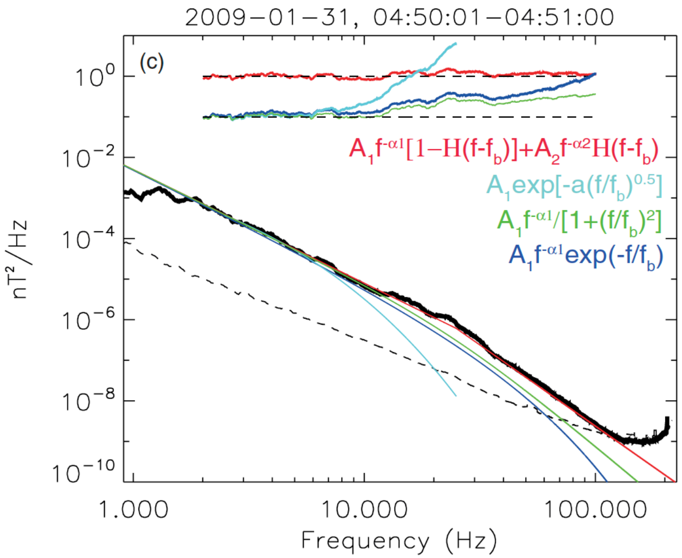
Olga Alexandrova[1], Vamsee Jagarlamudi[2], Milan Maksimovic[1], Petr Hellinger[3], Yuri Shprits[4] and Andre Mangeney[1]

*[1]LESIA, Observatoire de Paris, France; [2]LPC2E, Orleans, France*
*[3]IAP, Prague, Czech Republic; [4]GFZ, Potsdam, Germany*

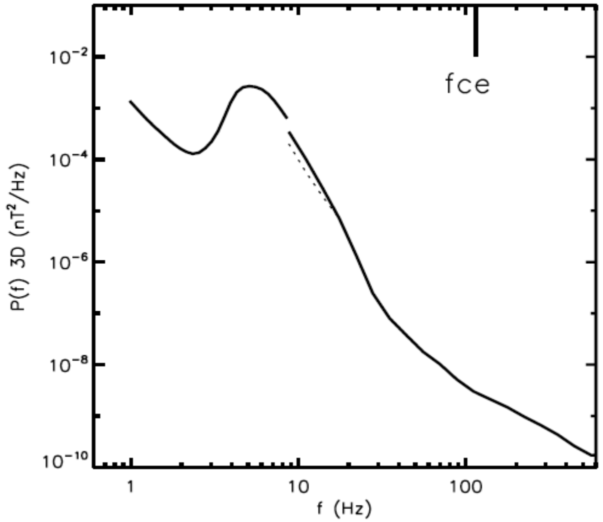
# (1) Do the turbulent fluctuations at kinetic scales form a universal spectrum?




[Alexandrova et al. 2009, 2012]



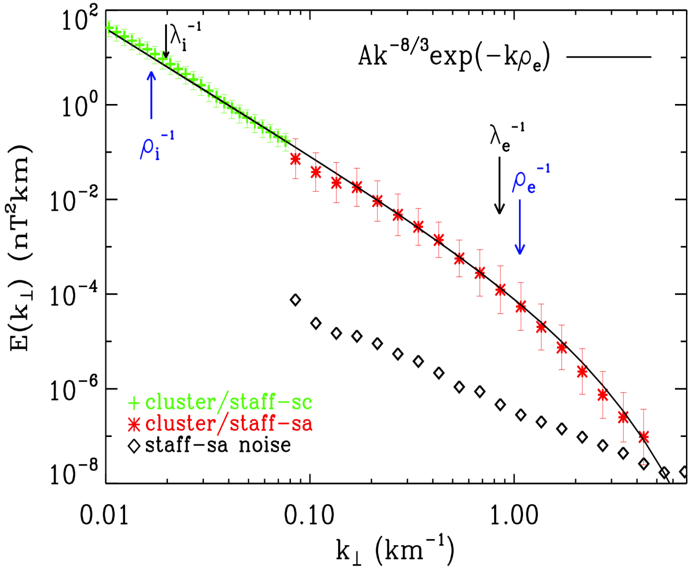

[Sahraoui et al., 2009, 2013]

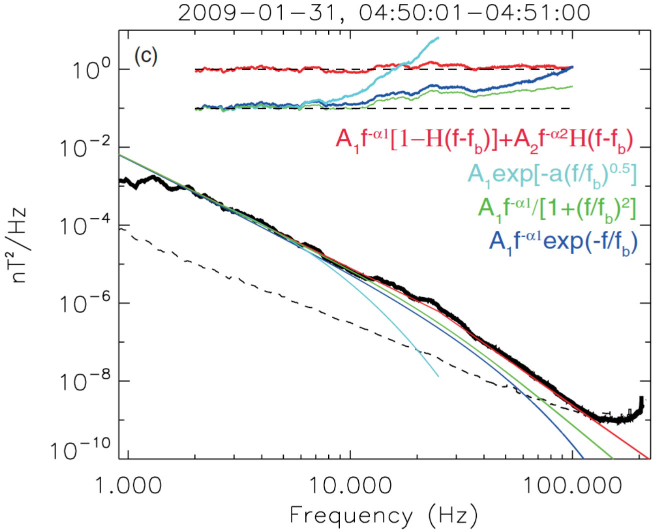


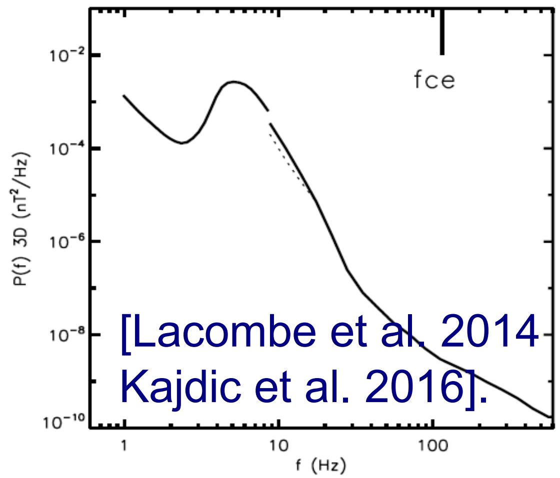

[Lacombe et al. 2014]

**It seems that the answer is 'No', the spectra can be very different…**

# (1) Do the turbulent fluctuations at kinetic scales form a universal spectrum?

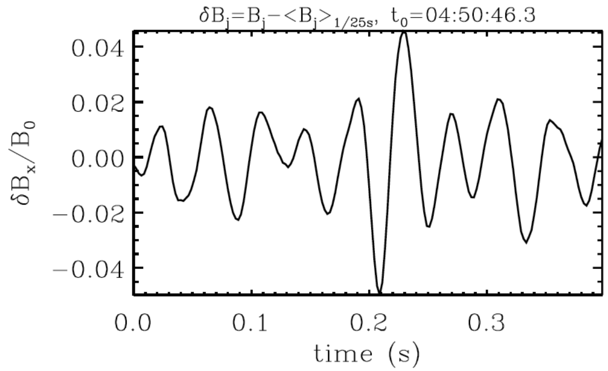


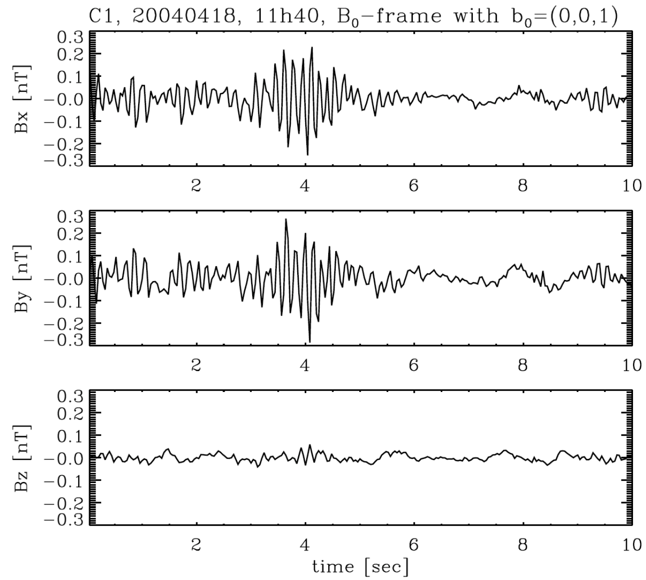




[Lacombe et al. 2014 Kajdic et al. 2016].

Background turbulence with $\mathbf{k}\perp\mathbf{B_0}$ and f≃0 [Lacombe et al. 2017].



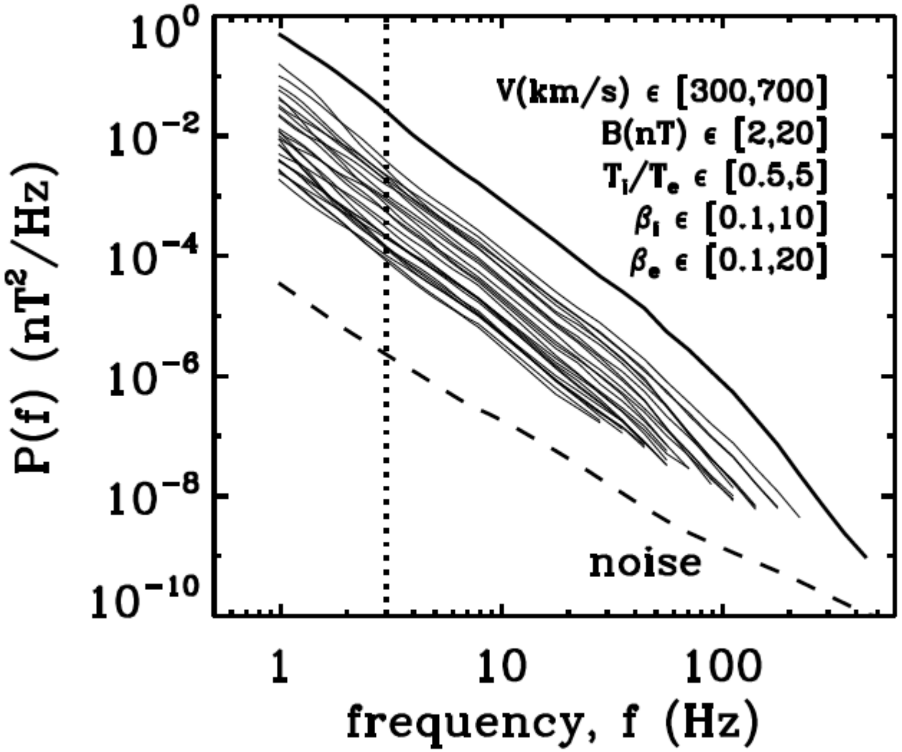



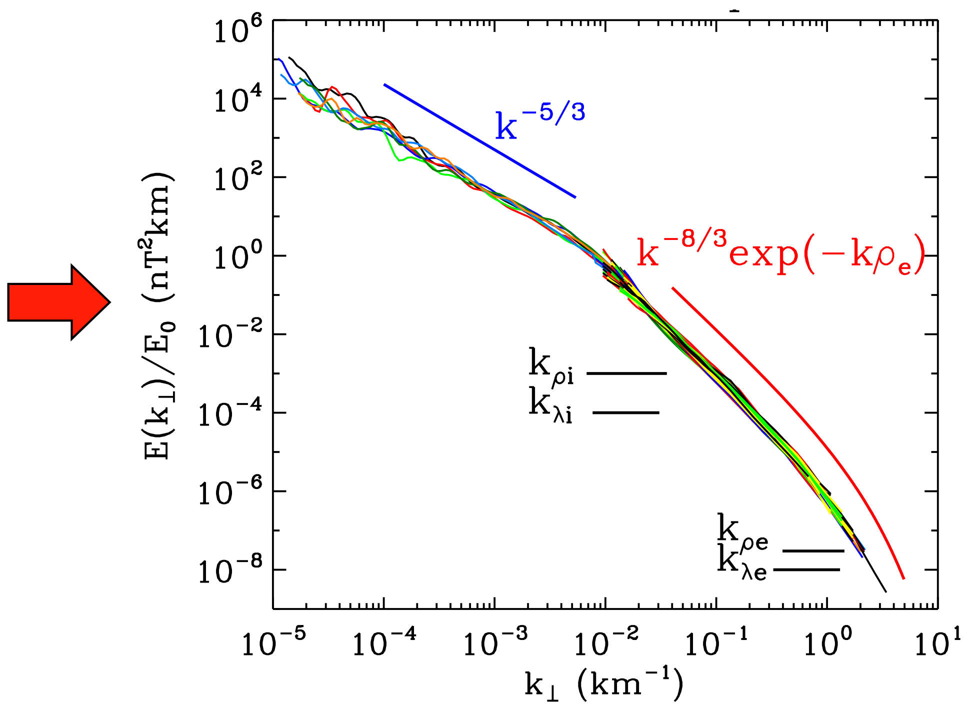

Whistlers with $\mathbf{k}\parallel\mathbf{B_0}$ and f ≃ fraction of $f_{ce}$ [Lacombe et al. 2014,Roberts et al. 2017]

In the plasma frame, turbulence (with $\mathbf{k}\perp\mathbf{B_0}$ and f≃0) is well separated from whistlers. Let us focus now on the background turbulence without whistlers.

# Kinetic spectrum of background turbulence at 1 AU

[Alexandrova et al. 2012, APJ]

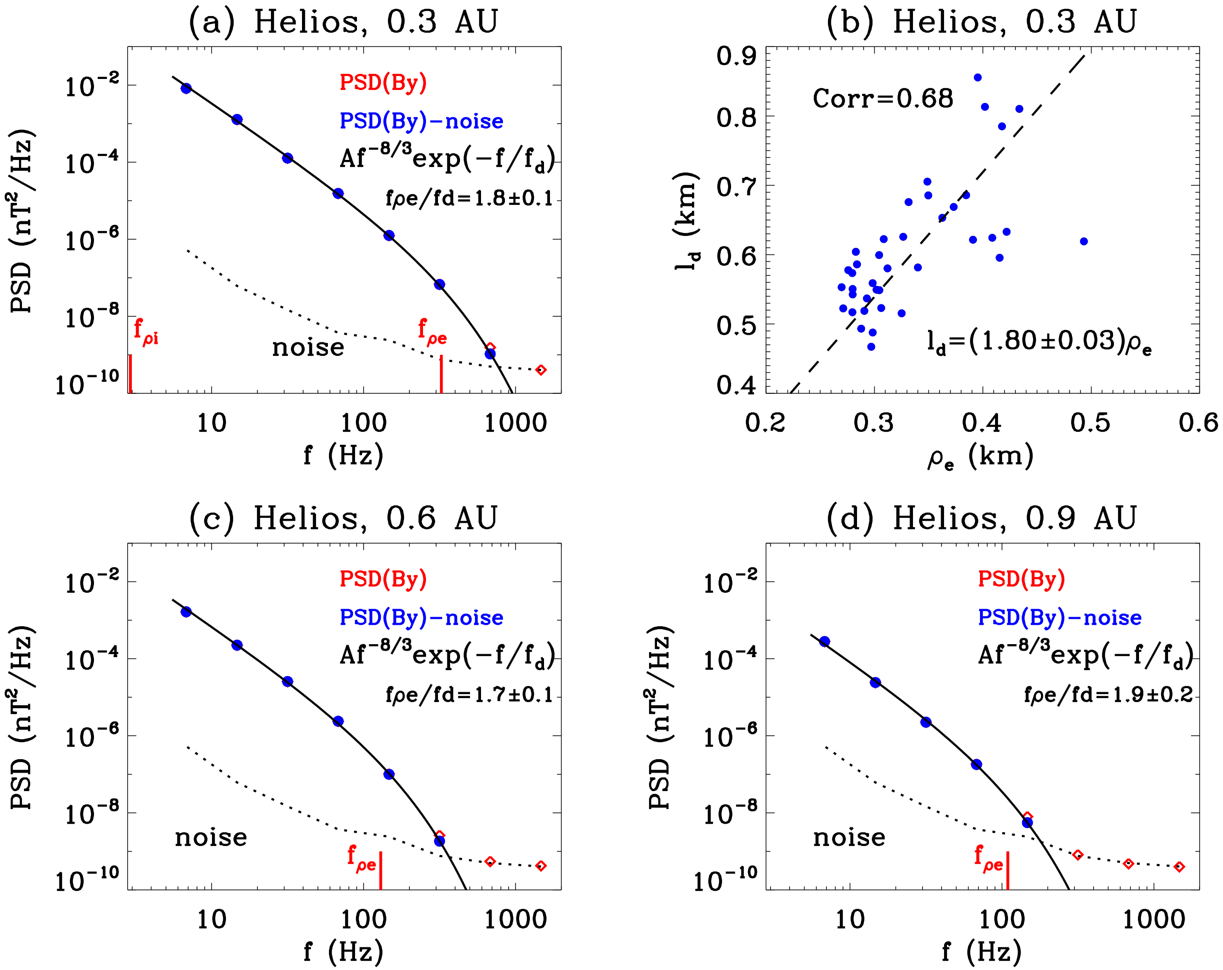



- Spectra normalized ($f \rightarrow k_\perp = 2\pi f/V$) and collapsed in amplitude ⇒ general shape at 1 AU (while no signatures of parallel whistlers).

- Closer to the Sun?

# Helios/SCM @ 0.3, 0.6 & 0.9 AU




(a,c,d) Kinetic spectra at 0.3, 0.6, 0.9 AU and fitting with the 3-parameter model ($A,\alpha,f_d$):

$$Af^{-\alpha}\exp\left(-f/f_d\right)$$

(b) Fitting of the most intense spectra at 0.3 AU with the 2-parameter model ($A$, $f_d$):

$$Af^{-8/3}\exp\left(-f/f_d\right)$$

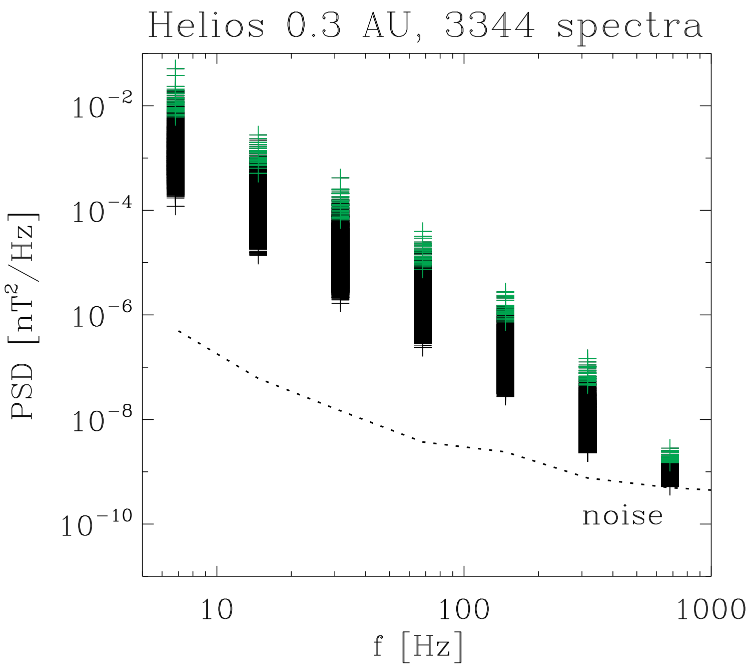
$$\ell_d = V/(2\pi f_d)$$

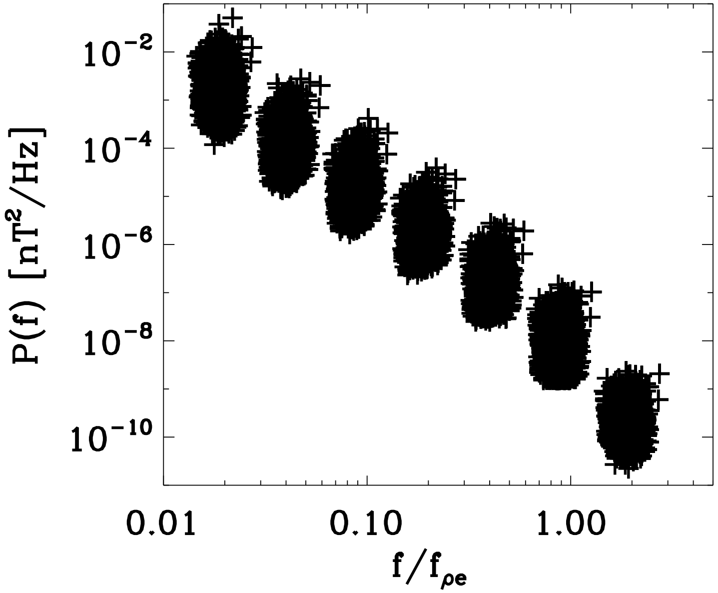
There is a correlation between the dissipation scale $\ell_d$ and the electron Larmor radius $\rho_e$.

$$Af^{-8/3}\exp\left(-1.8f/f_{\rho e}\right), \quad f_{\rho e} = V/(2\pi\rho_e)$$

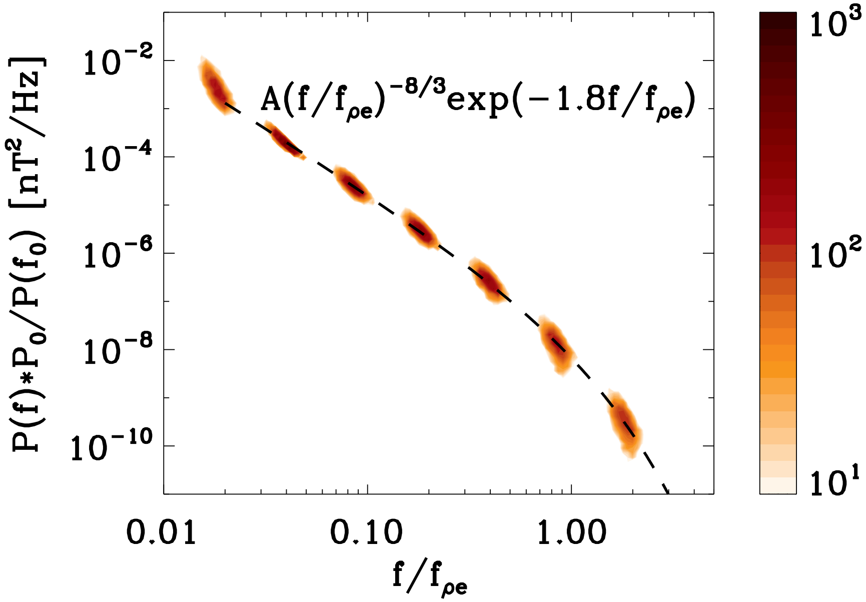
- We end-up with one-free-parameter (A) model.
- How well does it describe all available spectra at 0.3 AU ?

# Helios/SCM @ 0.3 AU




- Spectra cleaned from the noise, normalised ($f/f_{\rho e}$) and collapsed in amplitude.

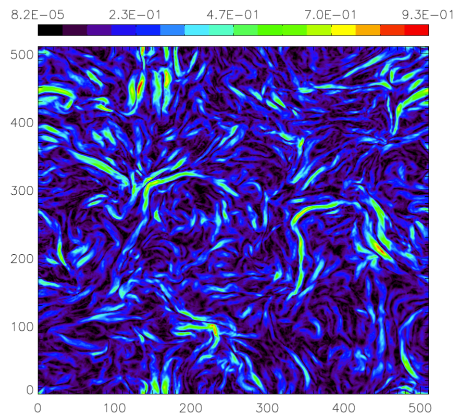


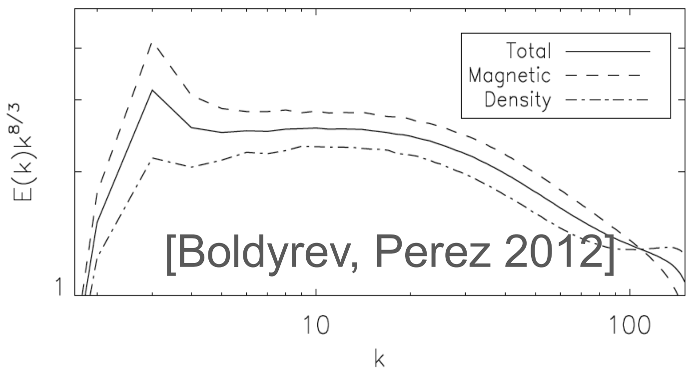

- General spectrum similar to the one @1AU. One-parameter model passes through the data without any particular adjustment.

# Interpretation of the solar wind kinetic spectrum?

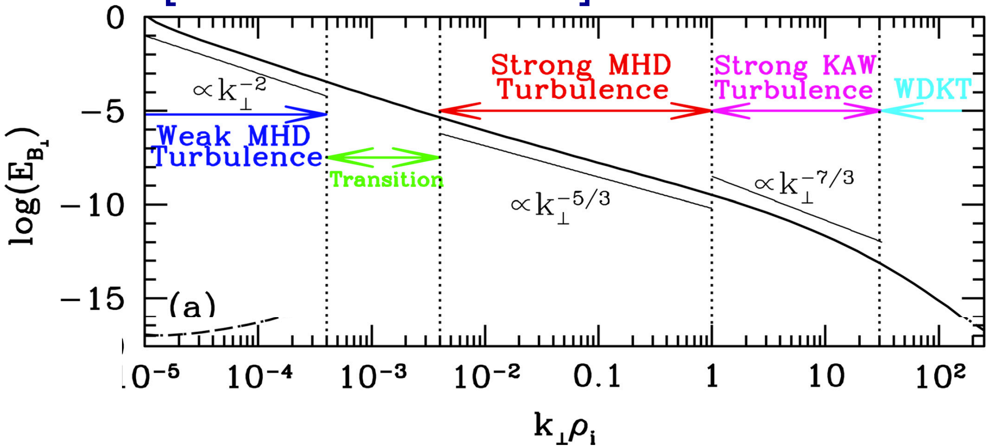
$$\boxed{E(k) = Ak^{-8/3}\exp(-k\rho_e)}$$

Compressible NL KAW fluctuations have -8/3 spectrum between ion and electron scales [Boldyrev and Perez 2012]:



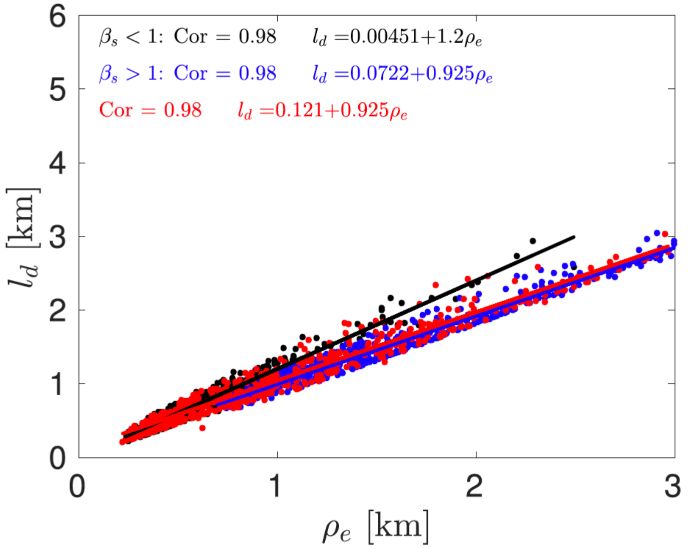

[Howes et al. 2011]




In gyrokinetic simulations, dissipation via linear Landau damping gives ~exp spectrum at electron scales [Howes et al. 2011]

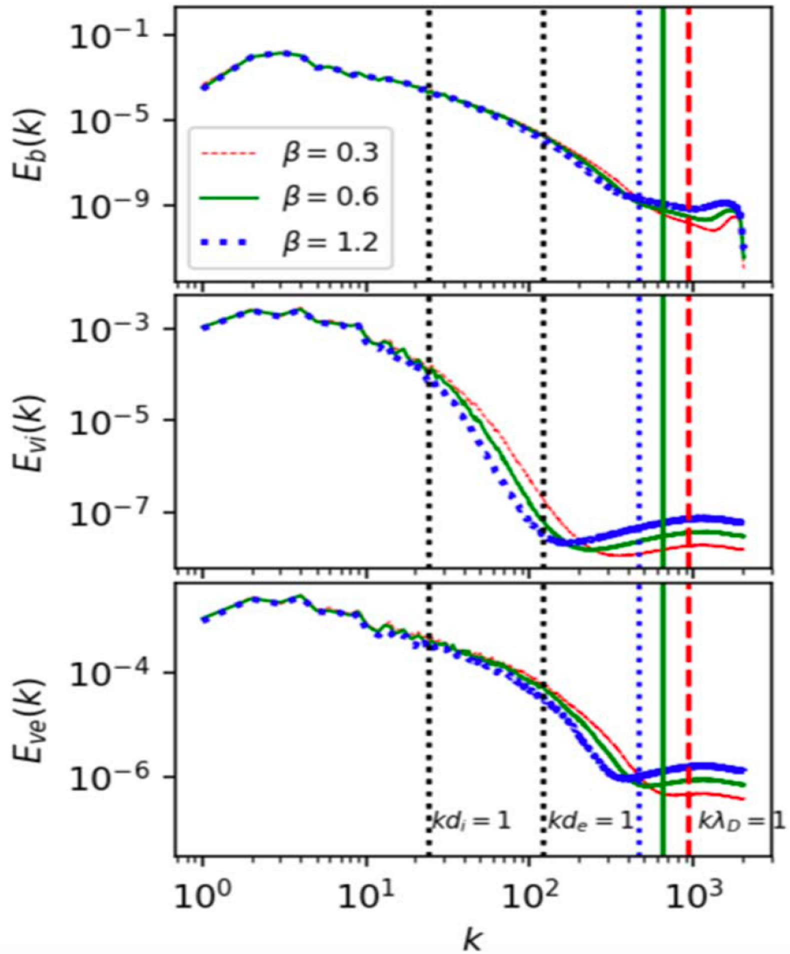
# Interpretation of the solar wind kinetic spectrum?

[Schreiner & Saur, 2017]




Theoretical model of strong KAW turbulence + Landau Damping – explains nicely the observations [Schreiner & Saur, 2017]

[Parashar et al. 2018, APJL]

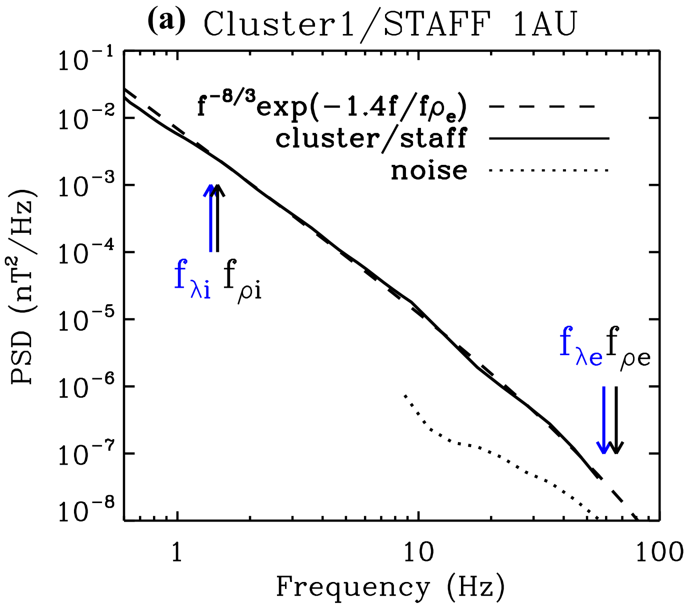


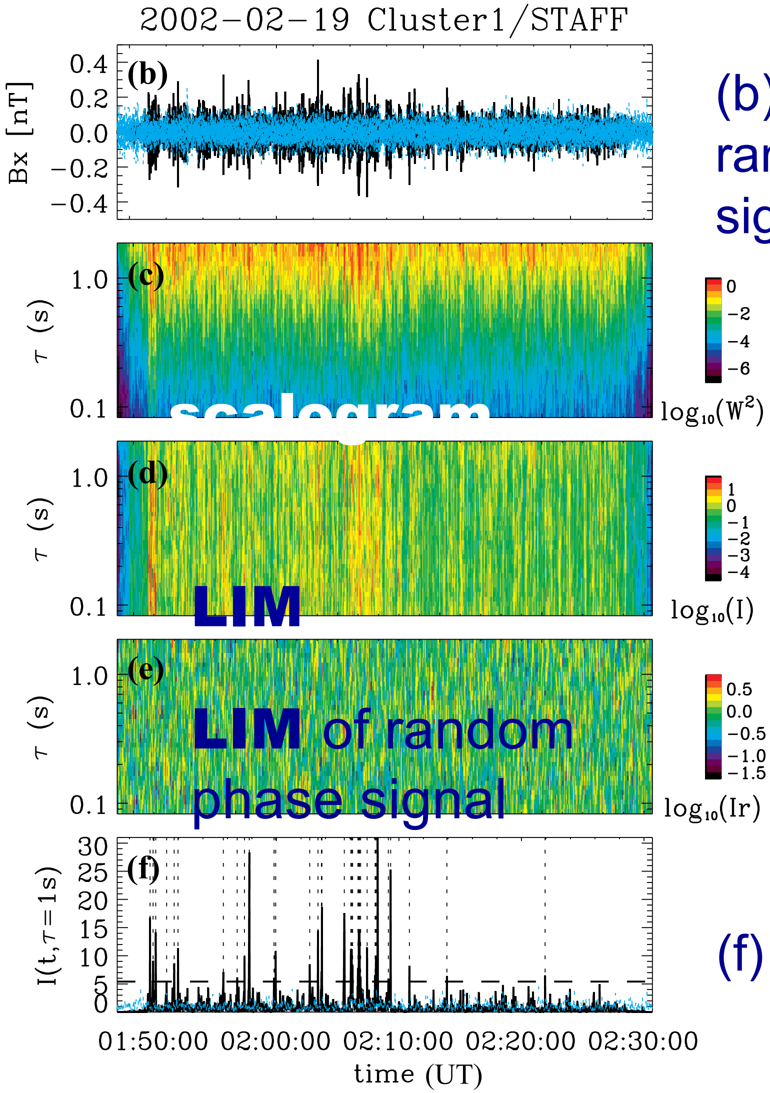

Parashar 2018, 2D PIC simulations: the magnetic PSDs decrease faster for larger electron beta/gyroradius in a qualitative agreement with $l_d \sim \rho_e$.

$$\beta_e = \frac{nk_BT_e}{B^2/2\mu_0} = \frac{\rho_e^2}{\lambda_e^2}$$

# (2) What is ‘behind the spectrum’ ?

# Signatures of coupled phases in WT-Scalogram & in Local Intermittency Measure (LIM)




(b) Observed (black) & random phase (blue) signals.

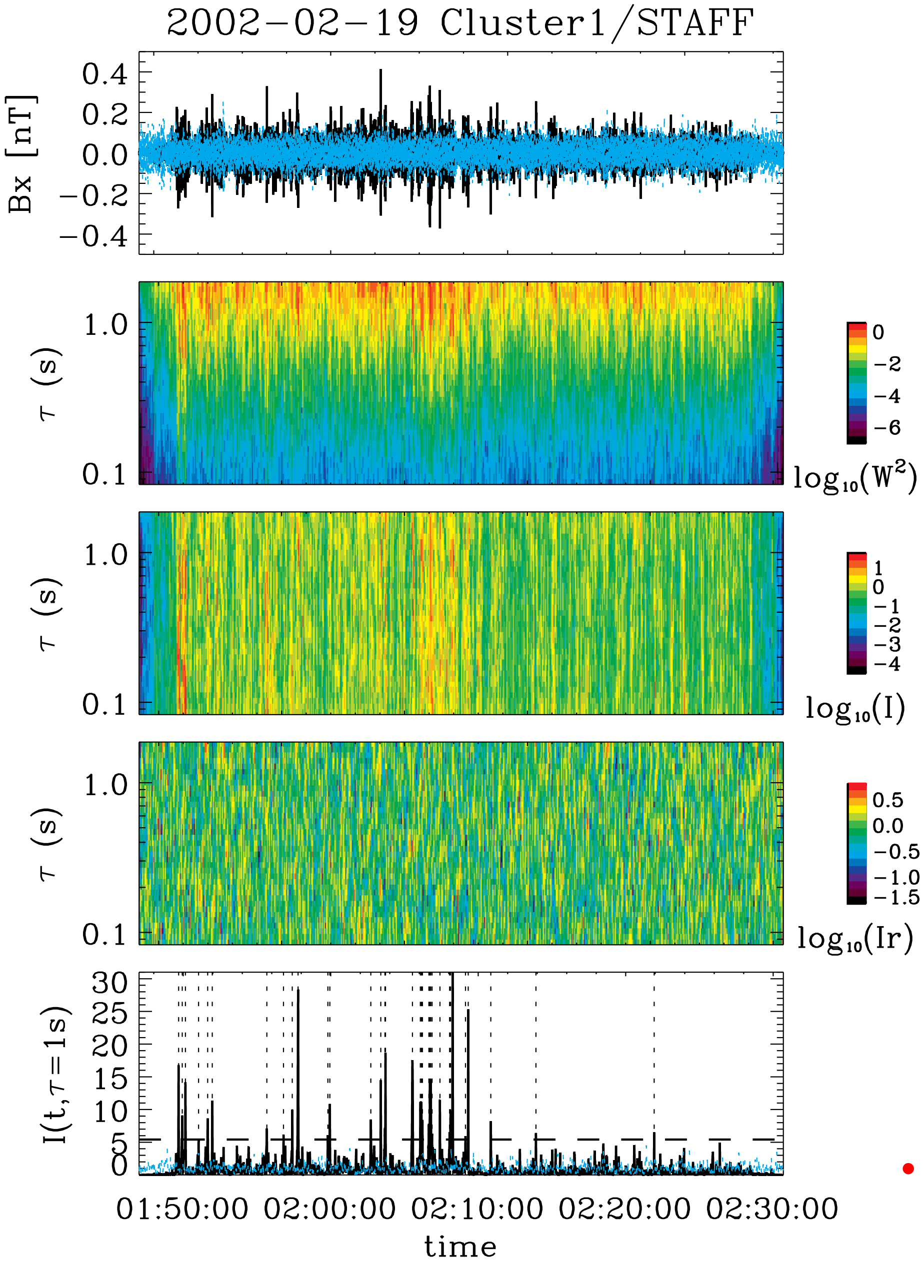
**LIM [Fange, 1990]:**

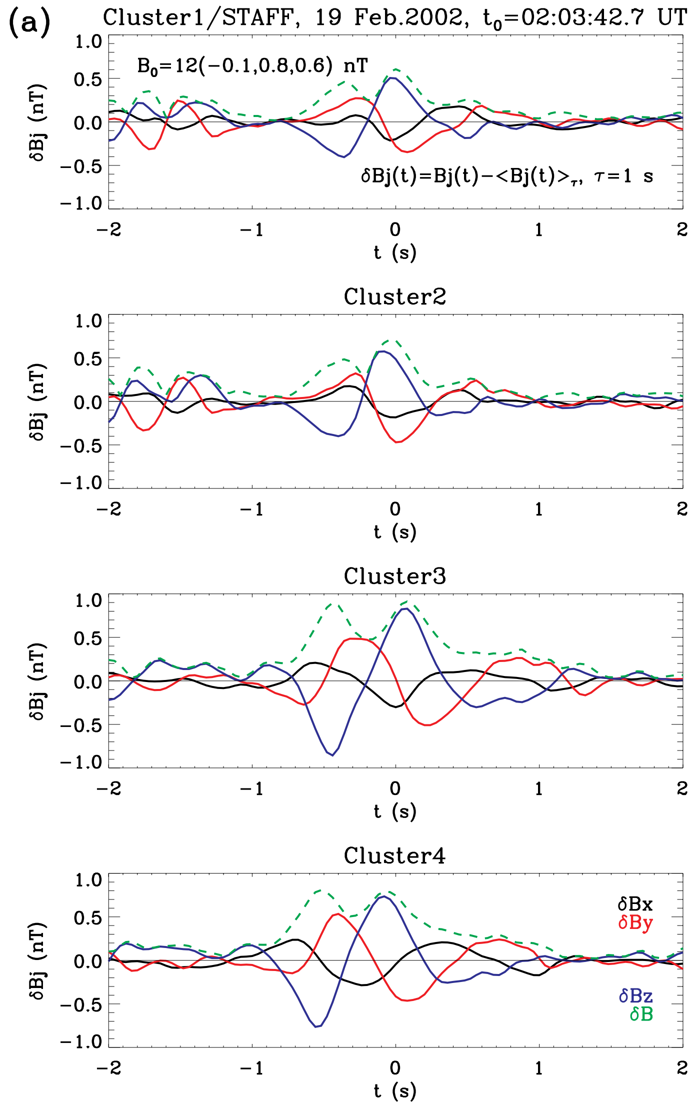
$$I(t,\tau) = \frac{|W(t,\tau)|^2}{\langle |W(t,\tau)|^2 \rangle_t}$$

(f) Cuts of LIM's at $\tau$=1s.

Observed signal: non-homogeneous energy distribution in time-scale plane, energy enhancements ~vertical lines: coupled phases across all scales.

# Vertical lines in LIM: coherent structures

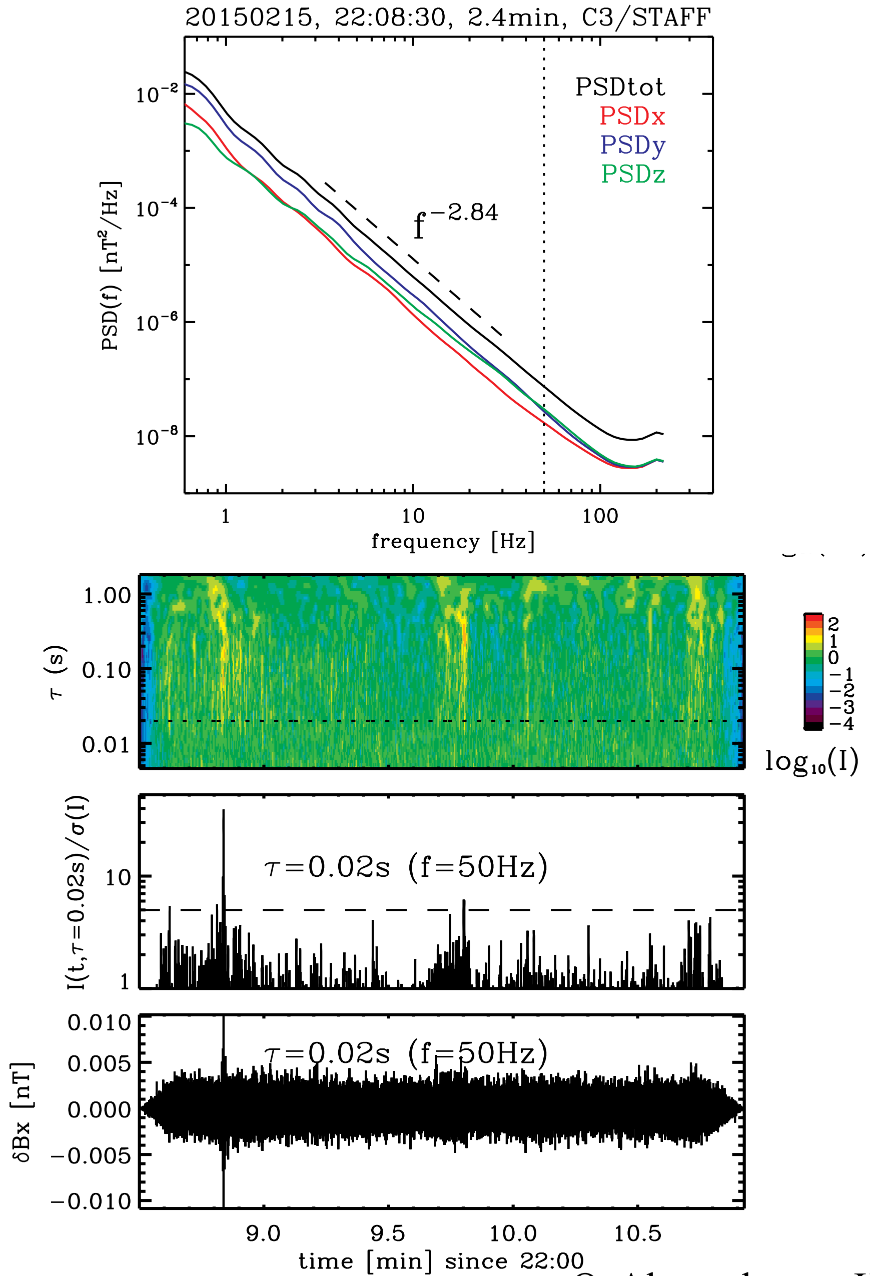


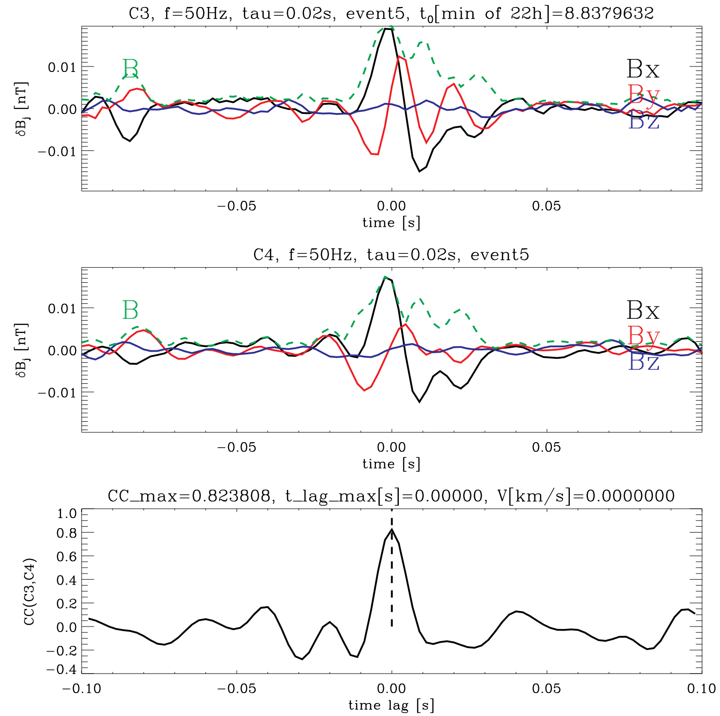




O. Alexandrova - Kinetic turbulence @EGU20

- Magnetic vortex at scales starting at ion scales and covering sub-ion scales.
- Jovanovic et al. 2020, APJ: vortex model in large-β plasma (fluid and ion scales).

# Magnetic vortices at electron scales

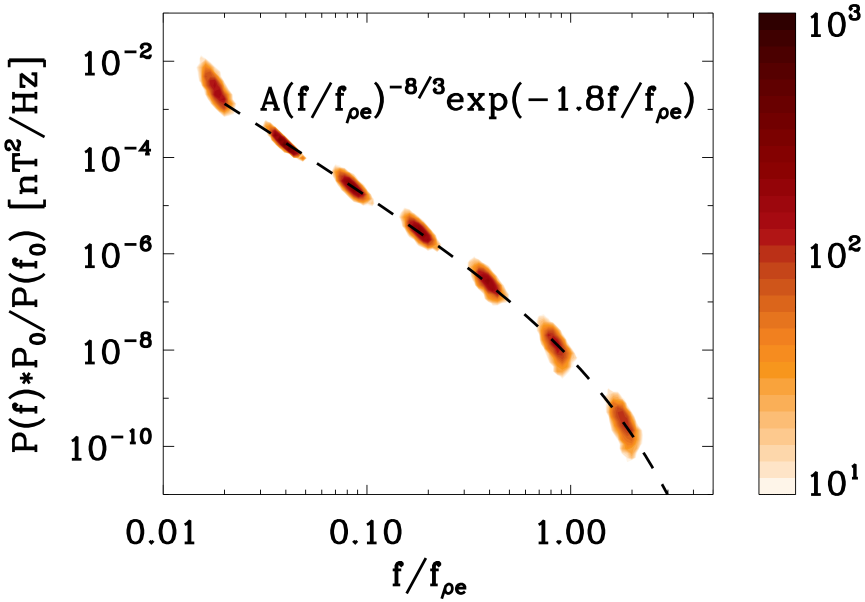


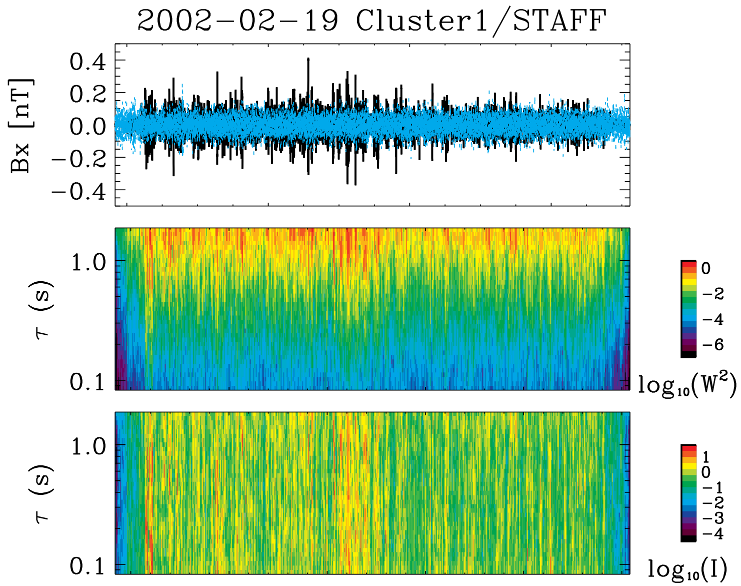




- Cluster GI 2015 data: C3-C4 at 7 km distance; STAFF in burst mode => electron scales are resolved in time and in space.
- Vortices at ~5 km scale (several $\rho_e$), see the model of Jovanovic et al. [2015].
- Strong turbulence signatures.

# Conclusions

[Alexandrova et al., 2020, arXiv:2004.01102]




- The same general spectrum is observed at 0.3, 0.6, 0.9 and 1 AU.
- Kinetic turbulence is strong in nature: presence of coherent structures all over the kinetic range in the form of magnetic vortices (current sheets are parts of the vortices?).

**to be verified with Parker Solar Probe and Solar Orbiter (work in progress)**