Probing turbulence from MHD to kinetic scales in space plasmas: electric and magnetic field spectra in Earth's magnetosheath

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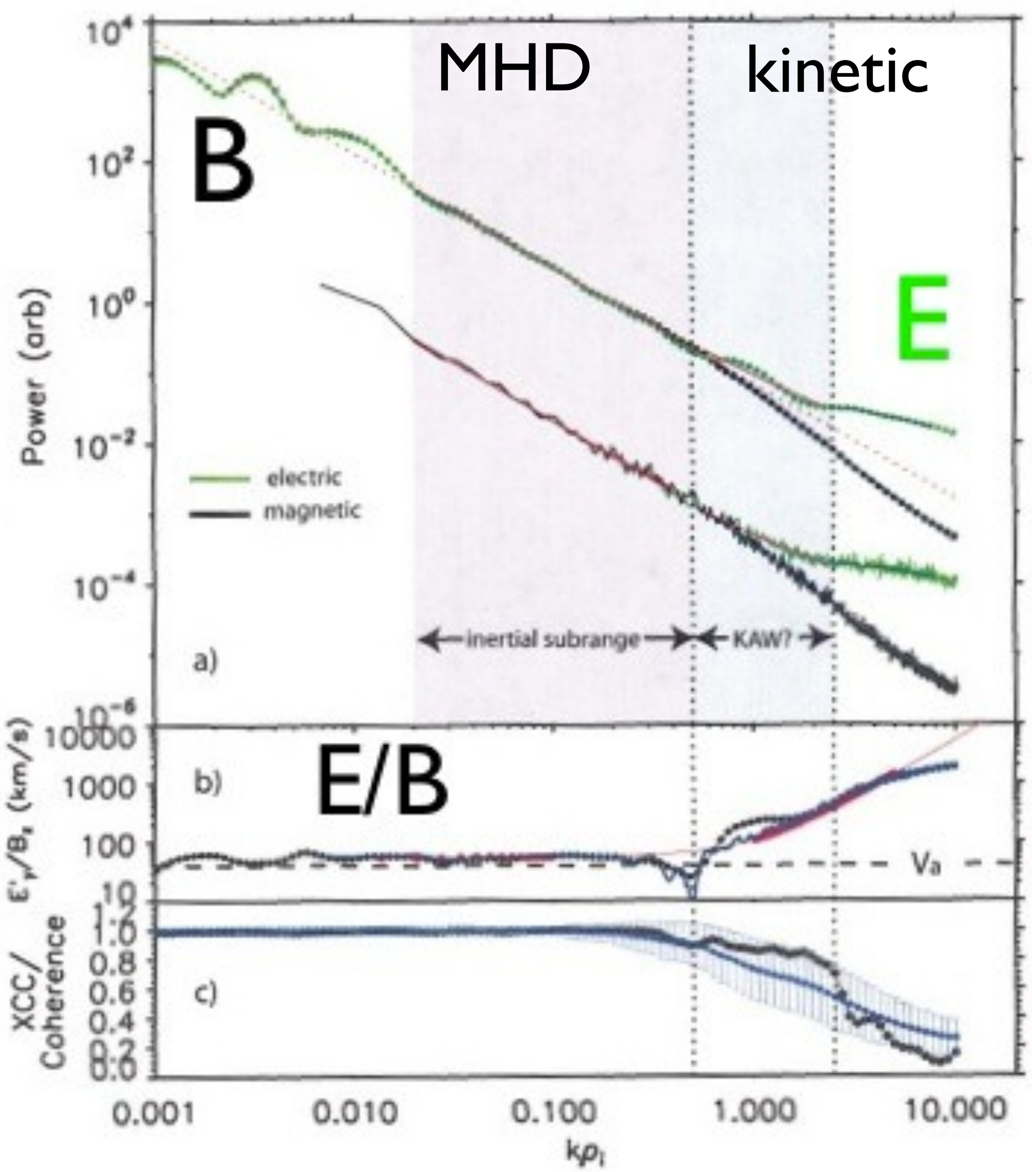
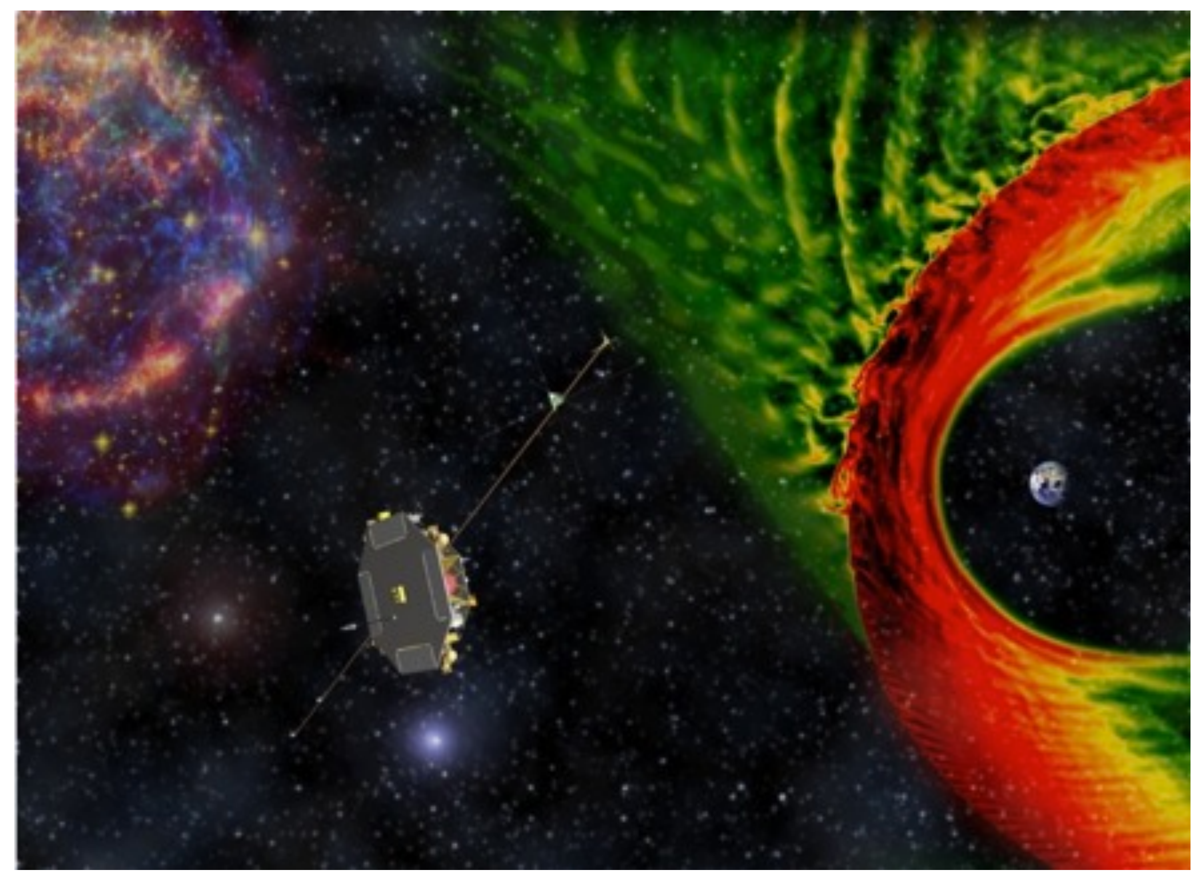
Motivation

The study of electric fields at kinetic scales is crucial for the understanding of particle energization in plasmas



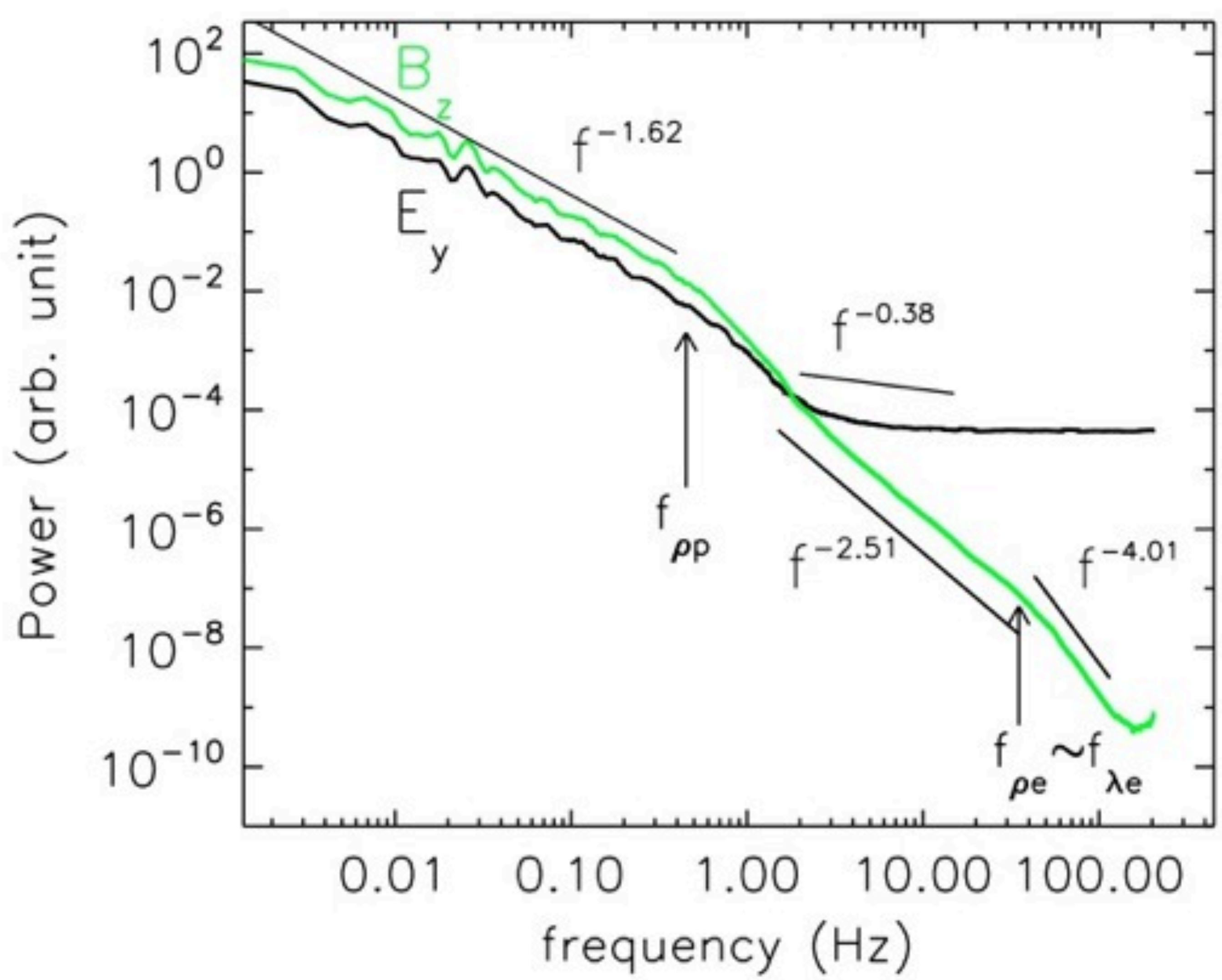
Bale et al. PRL 2005

THOR

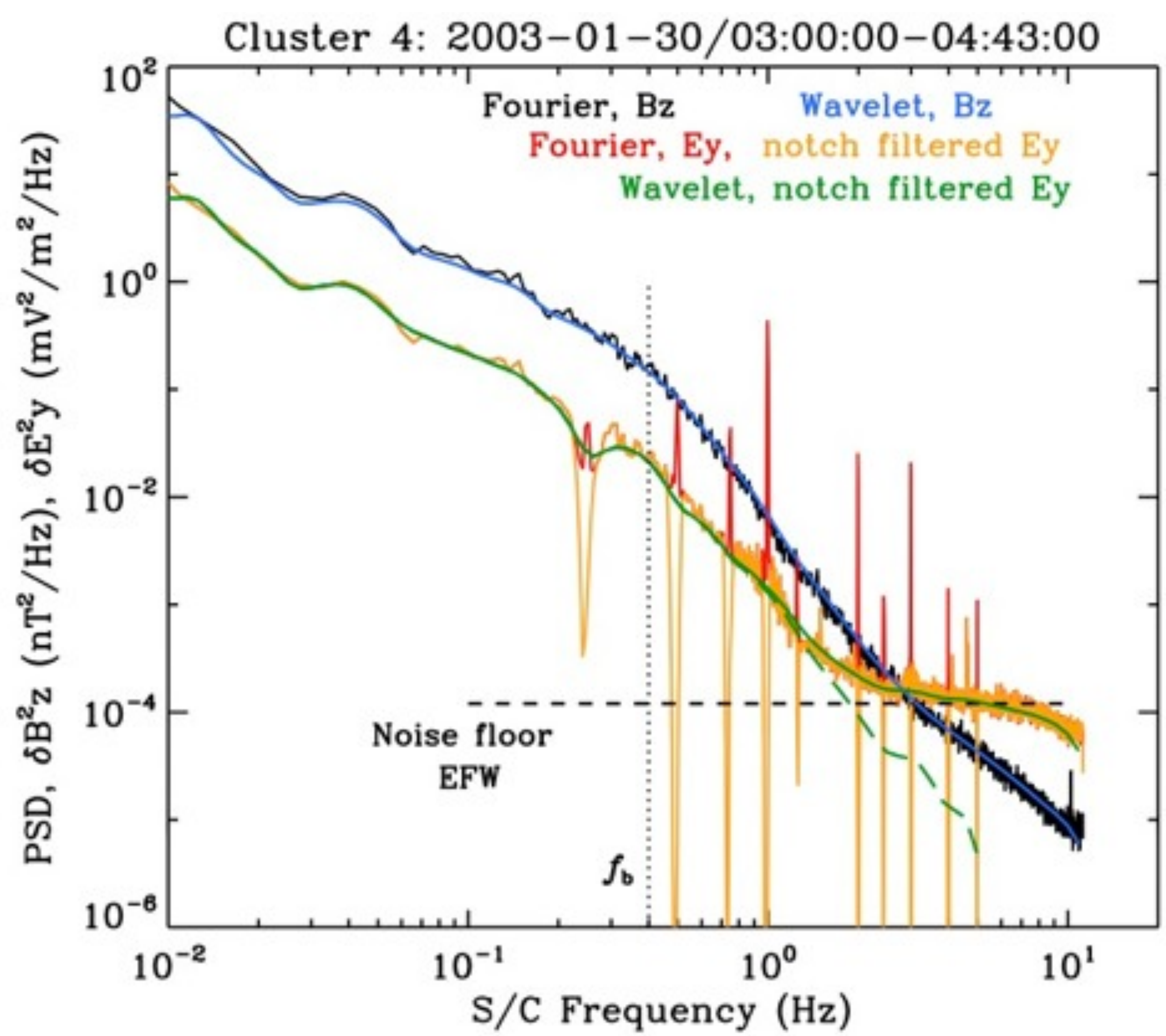


Electric field measurements in SW

While it is possible to follow the turbulent cascade down to electron scale with magnetic field observations, the same is not possible with electric field data due to current instrument limitations



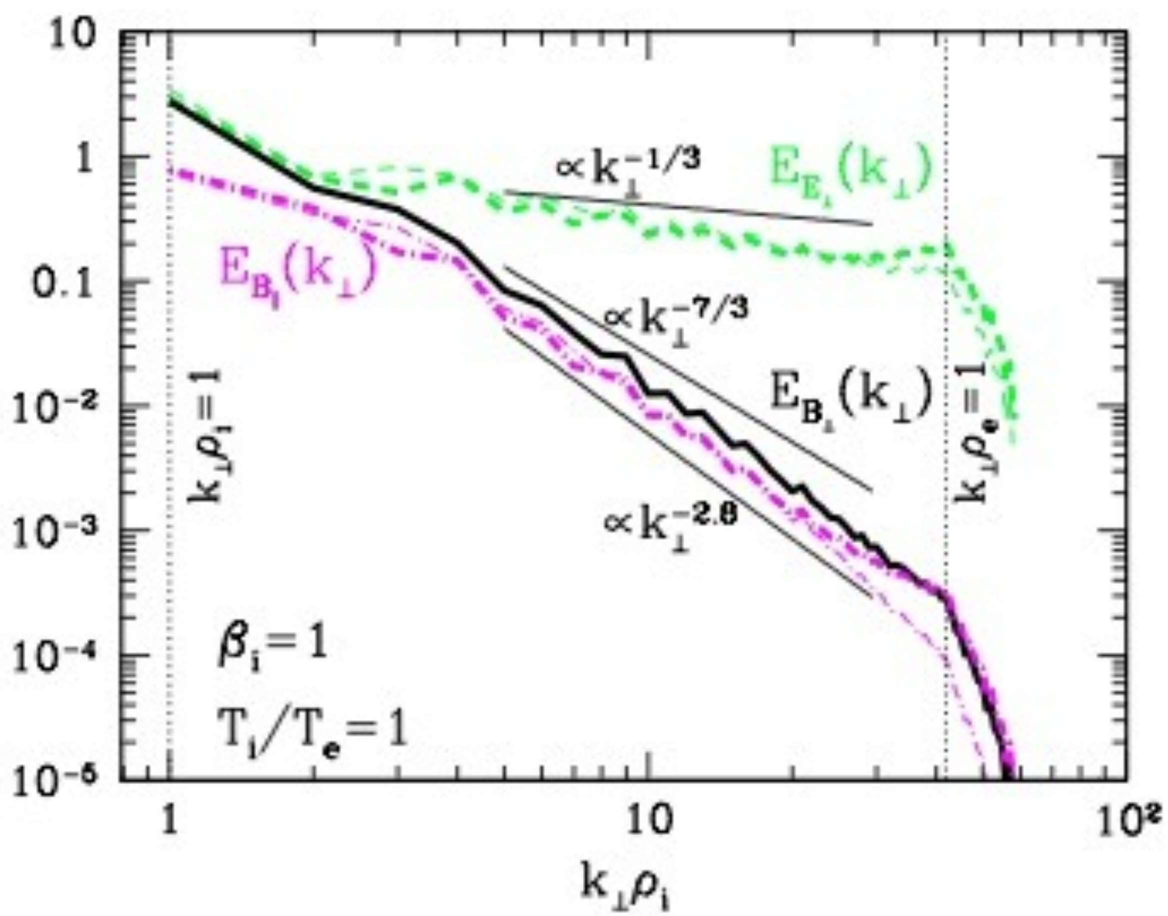
Sahraoui et al. 2009



Salem et al. 2012

Theoretical prediction

A shallower than magnetic electric field spectrum is observed in turbulence simulations of sub-ion scales



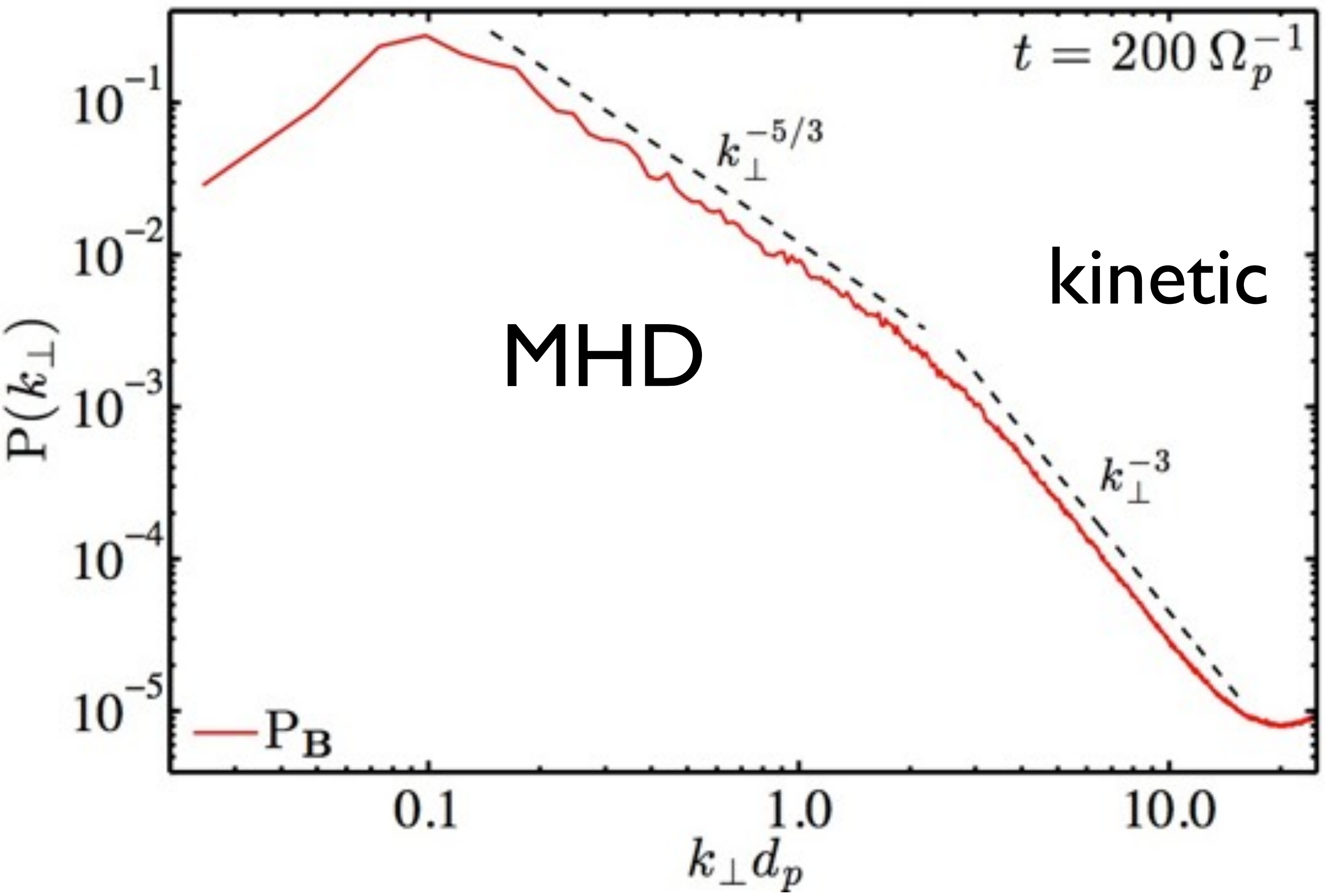
After ion scale: $\delta E^2 \propto k^2 \delta B^2$

Gyrokinetic simulations
Howes et al. PRL 2011

Analogous behavior also observed with other modeling:
Hall-MHD (*Matthaeus et al. 2008*)
Landau-Fluid (*Passot et al. 2014*)
Hybrid-Vlasov (*Valentini et al. 2014, Cerri et al. 2016,...*)
Hybrid-PIC (*Franci et al. 2015a,b*)

Electric field - Generalised Ohm's law

$$\boldsymbol{E} = \underbrace{-\boldsymbol{u} \times \boldsymbol{B}}_{\boldsymbol{E}_{\mathrm{MHD}}} + \underbrace{\boldsymbol{J} \times \boldsymbol{B}/n}_{\boldsymbol{E}_{\mathrm{Hall}}} \underbrace{-\boldsymbol{\nabla}\mathrm{p}_e/n}_{\boldsymbol{E}_{\mathrm{pe}}} + \underbrace{\eta\,\boldsymbol{J}}_{\boldsymbol{E}_\eta}$$



Franci et al. ApJ 2015

See also Poster of Luca Franci on ion break dependence on plasma beta

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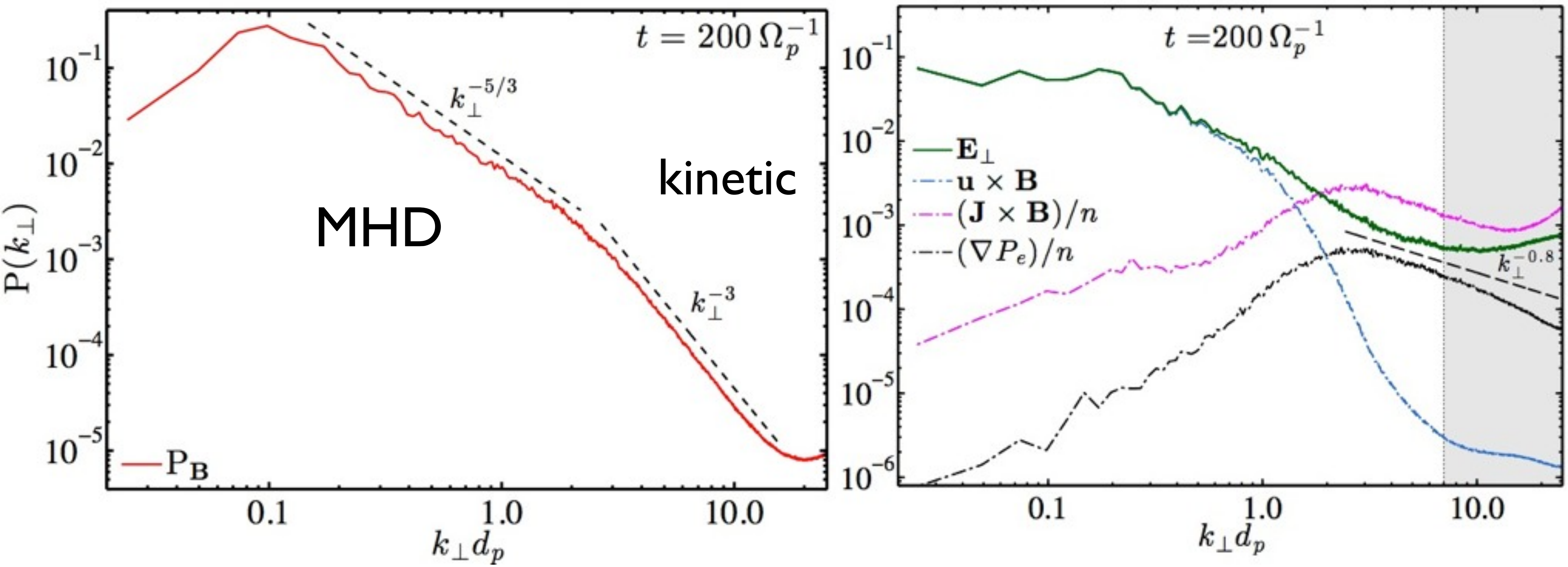

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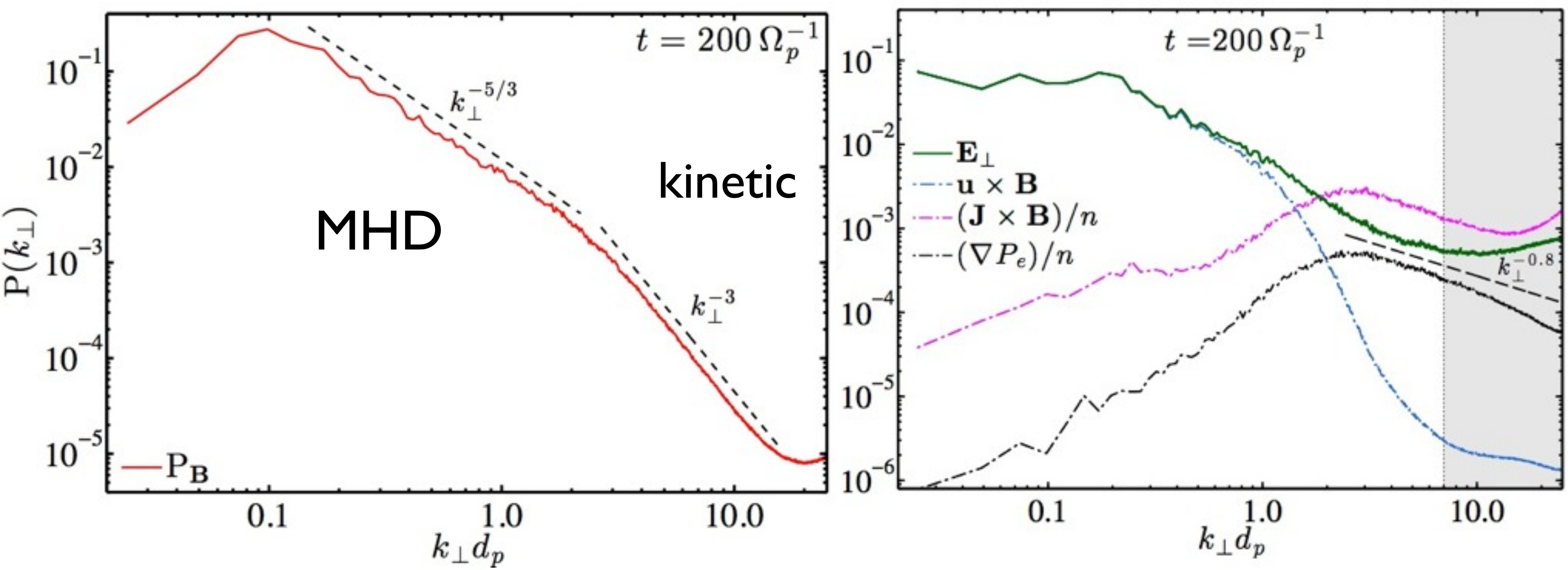

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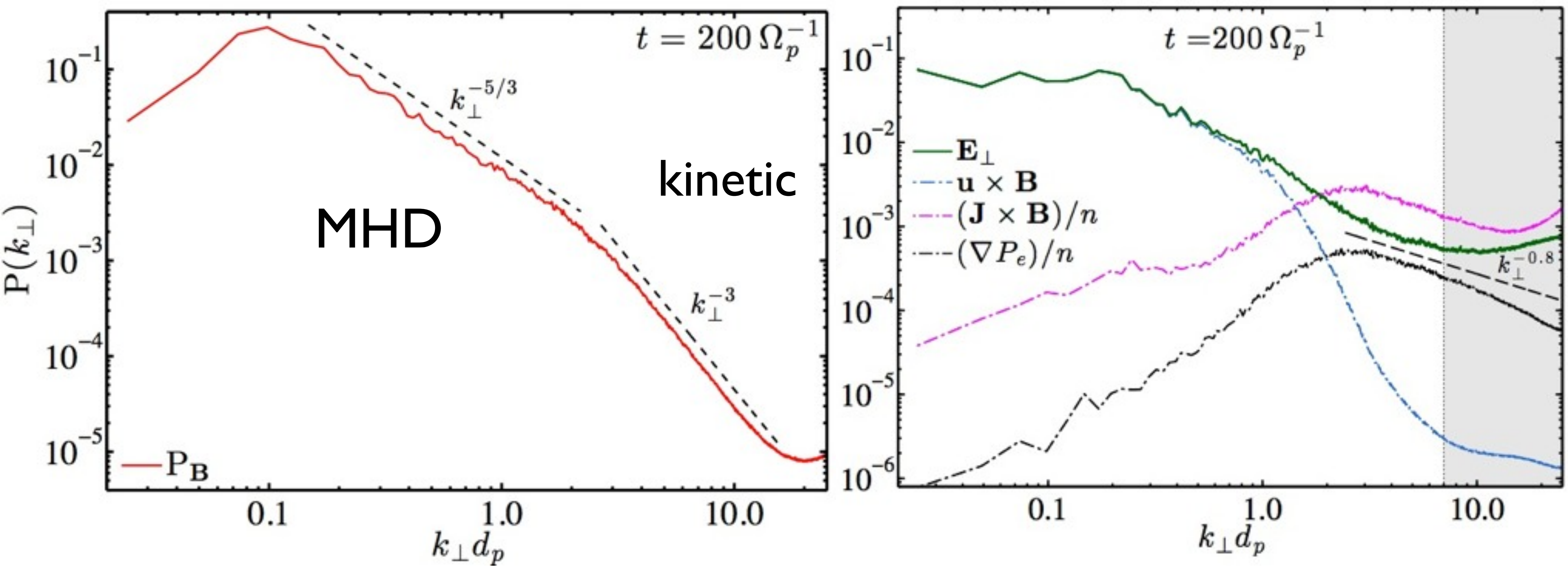

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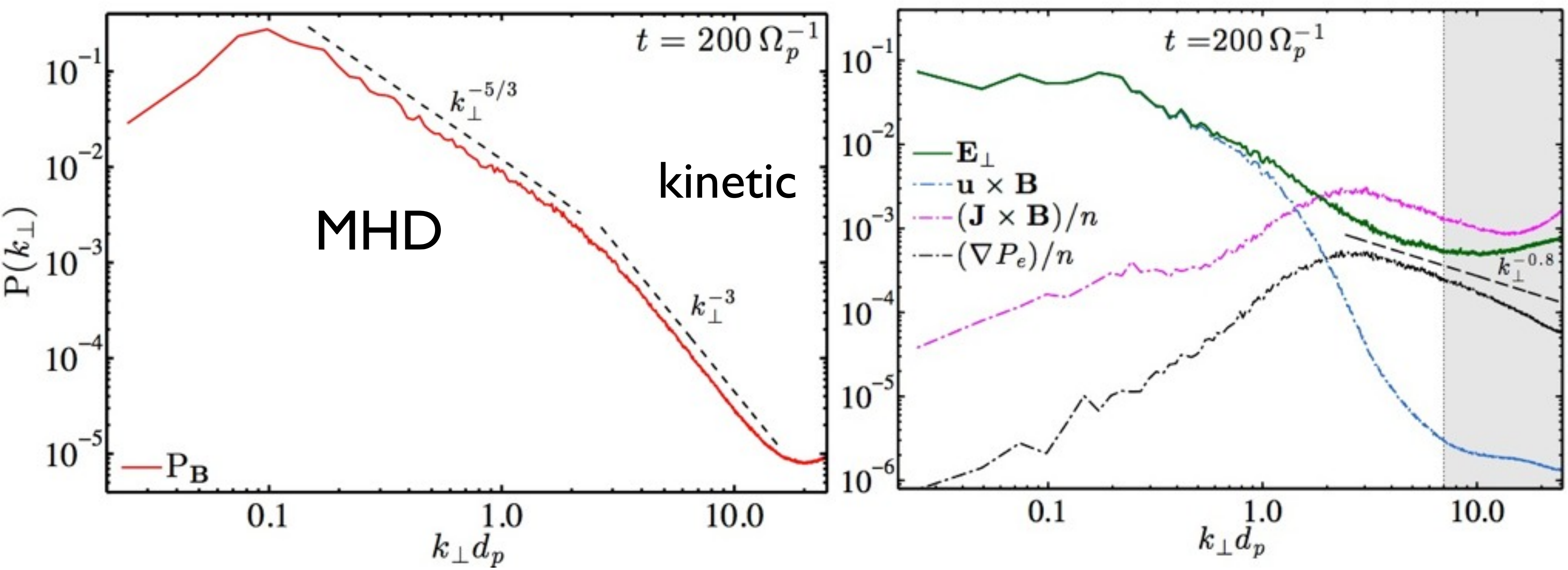

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A simple scaling at sub-ion scales

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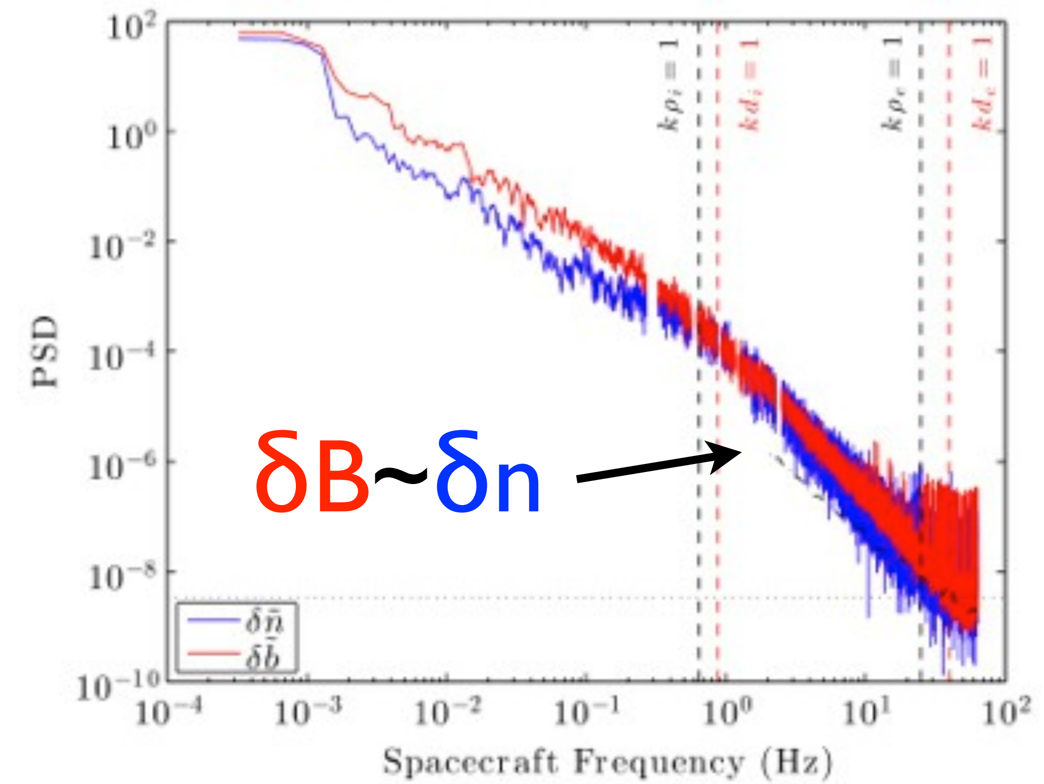

Chen et al. 2013

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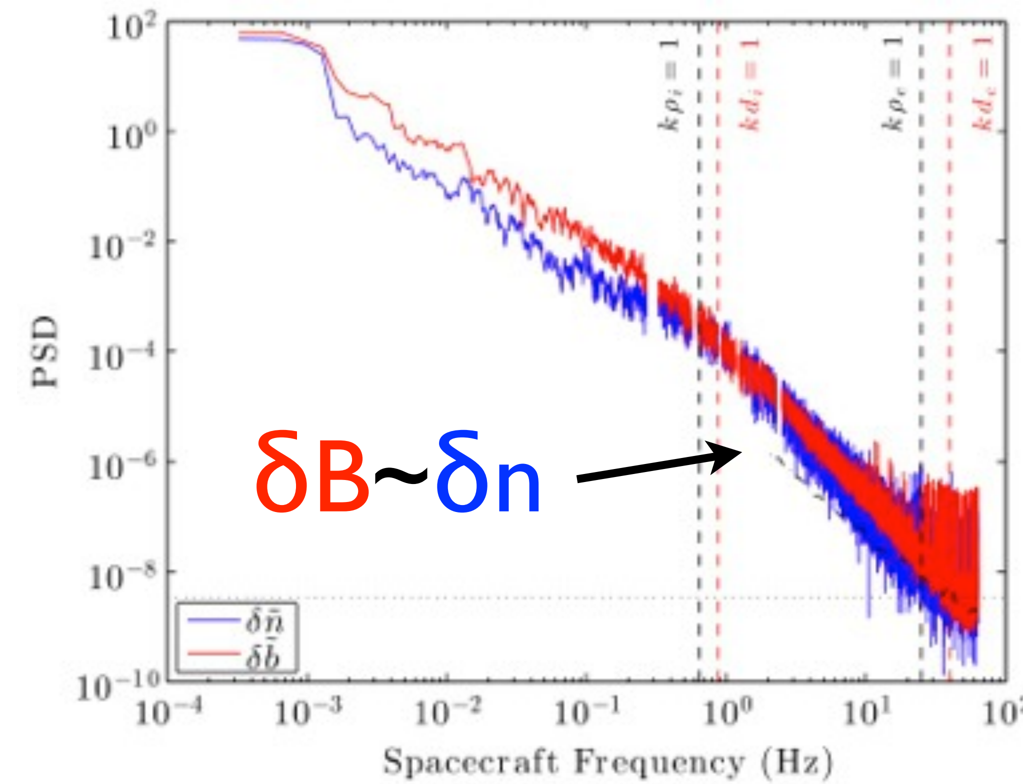

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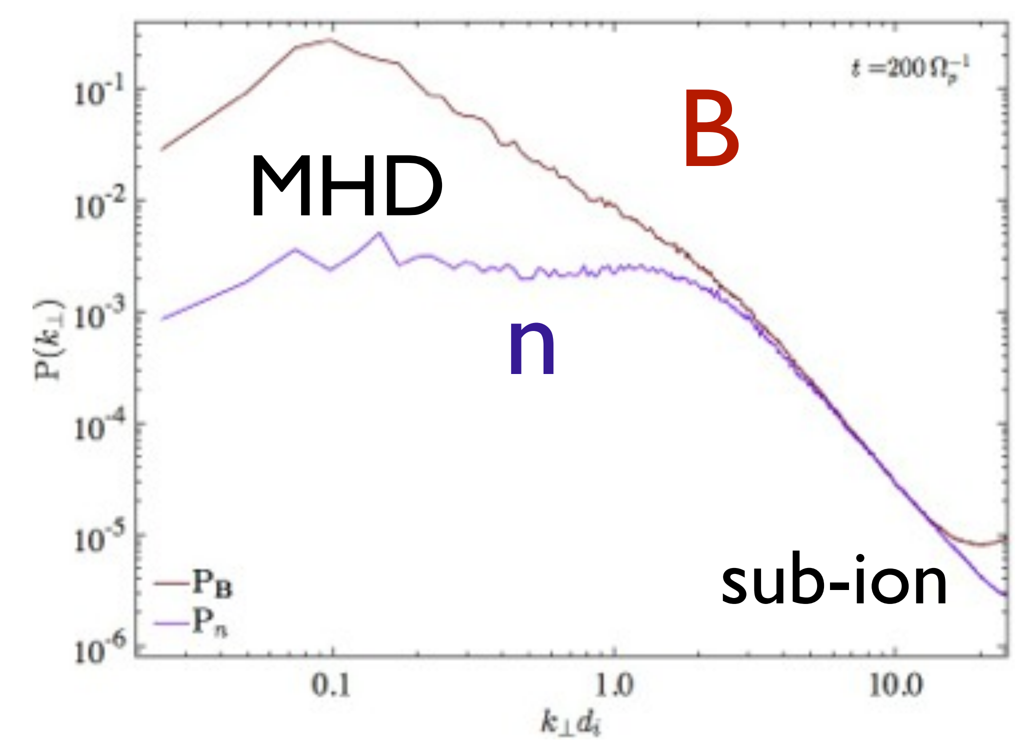

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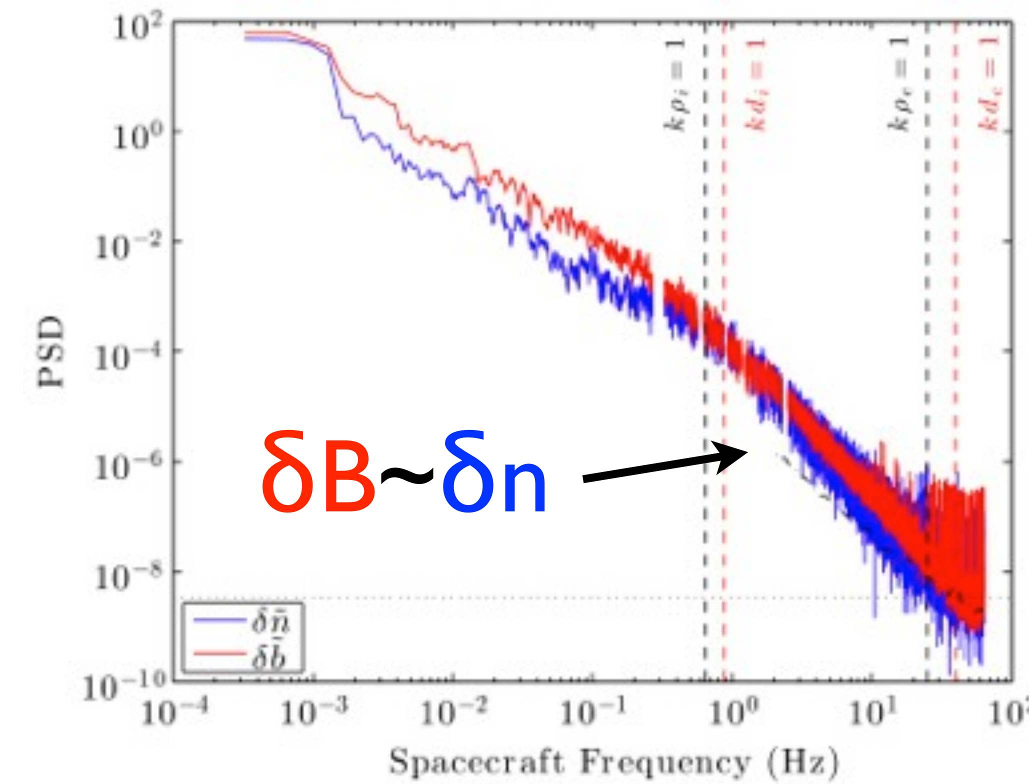

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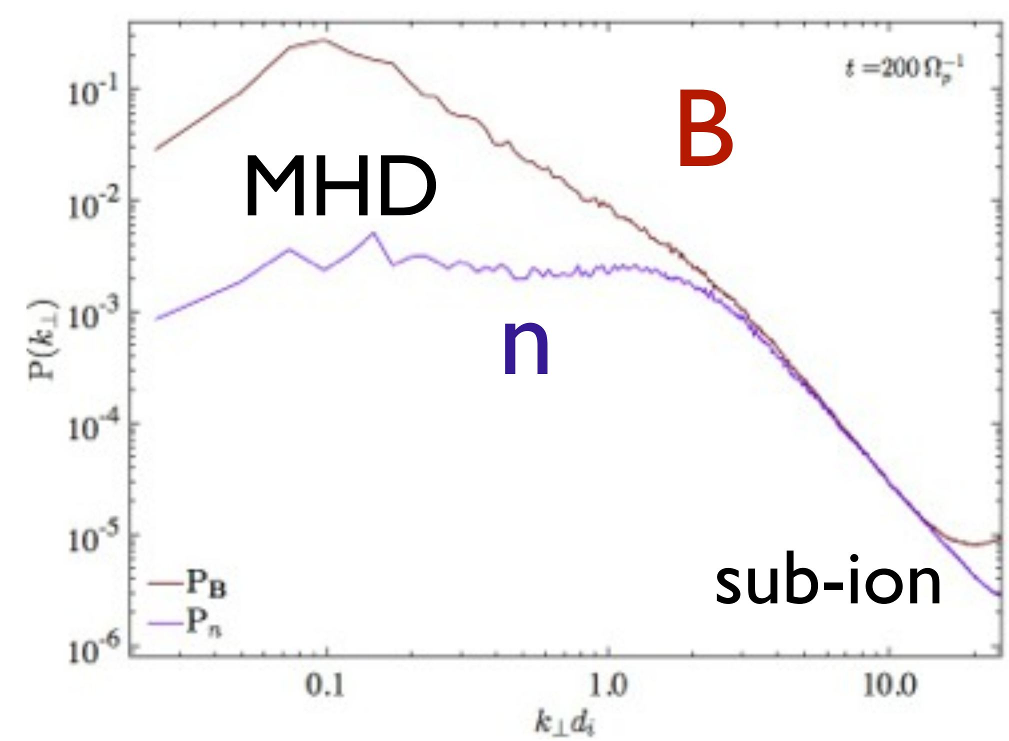

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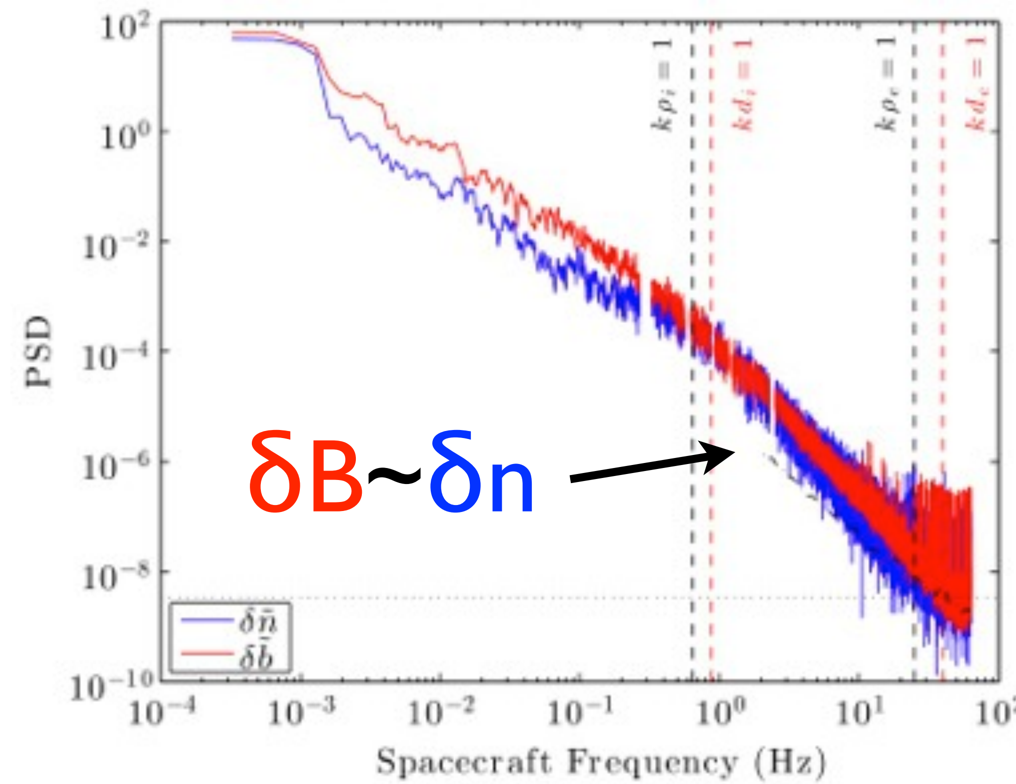
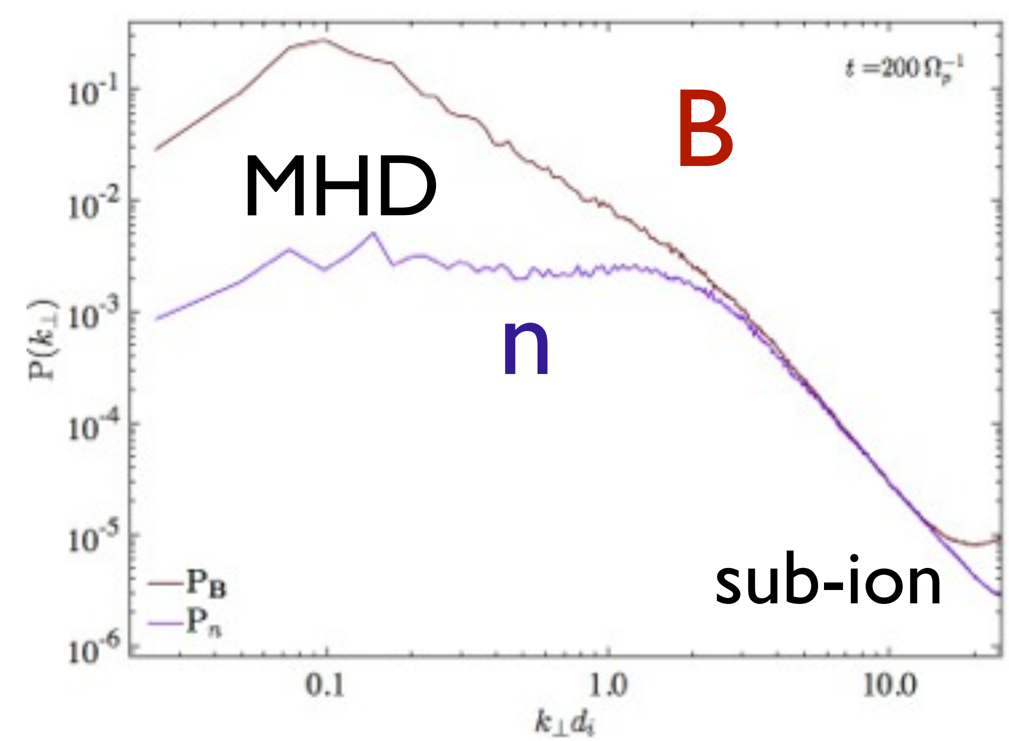


Chen et al. 2013

E/B ratio vs. k :

$$\frac{\delta E^{kin}}{V_A} \propto k\rho_i\delta B$$



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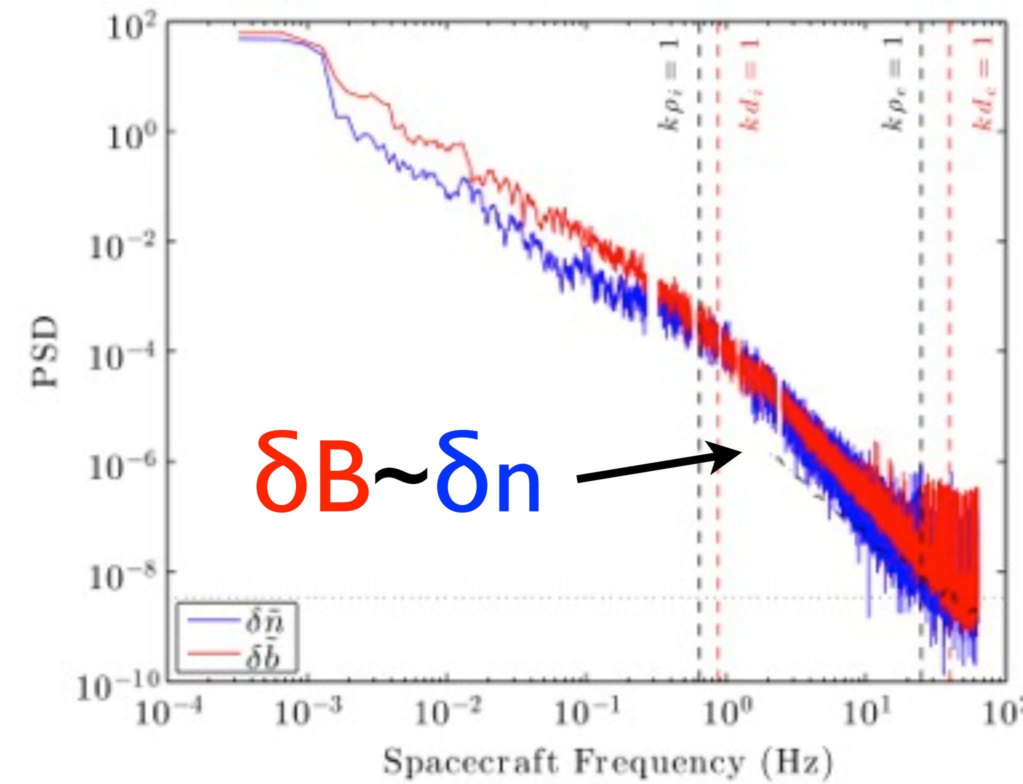

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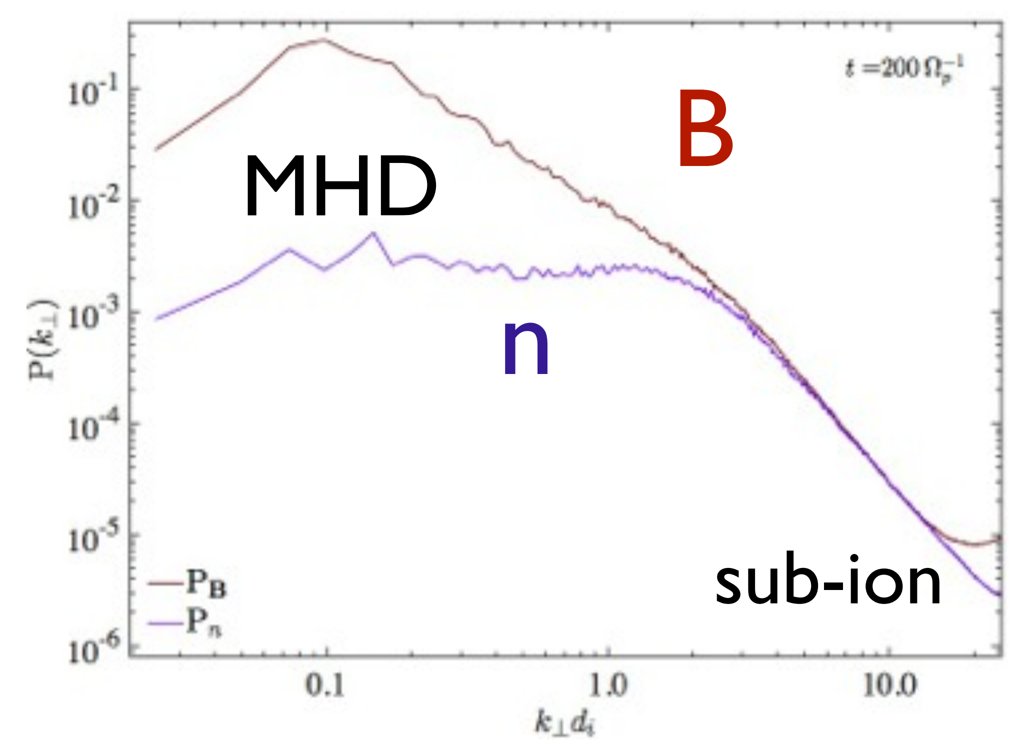

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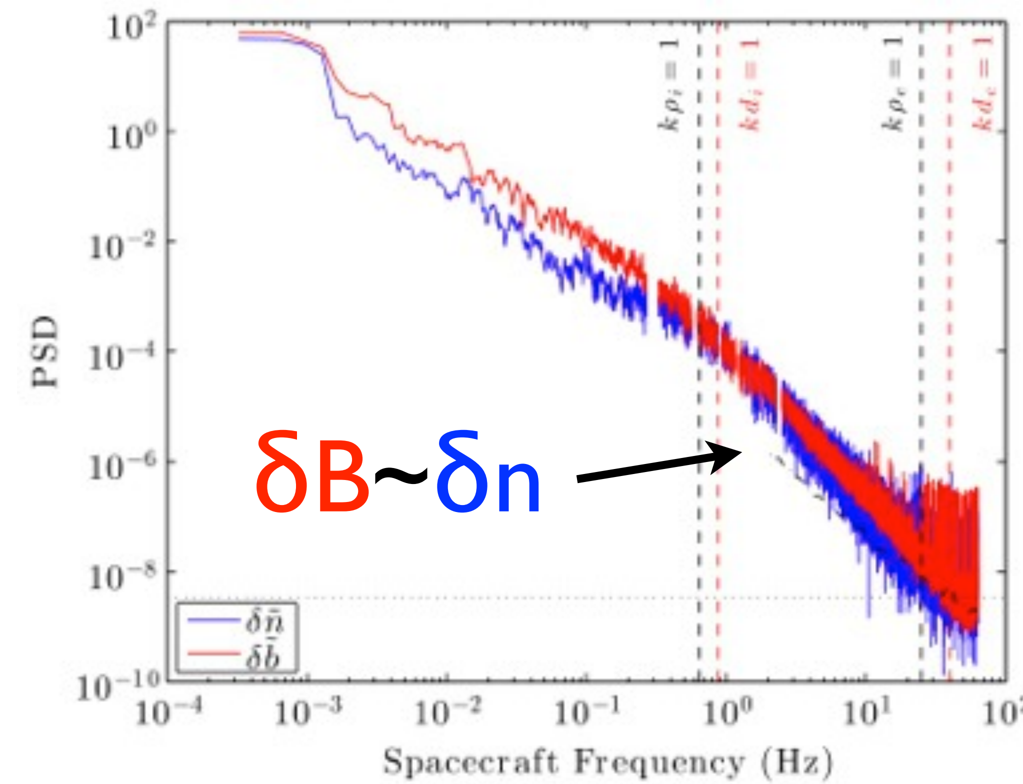
E/B ratio vs. k :

	B	E
$\dfrac{\delta E^{kin}}{V_A} \propto k \rho_i \delta B$	-7/3	-1/3
sub-ion spectra:	-8/3	-2/3
$\delta E^2 \propto k^2 \delta B^2$	-2.8	-0.8



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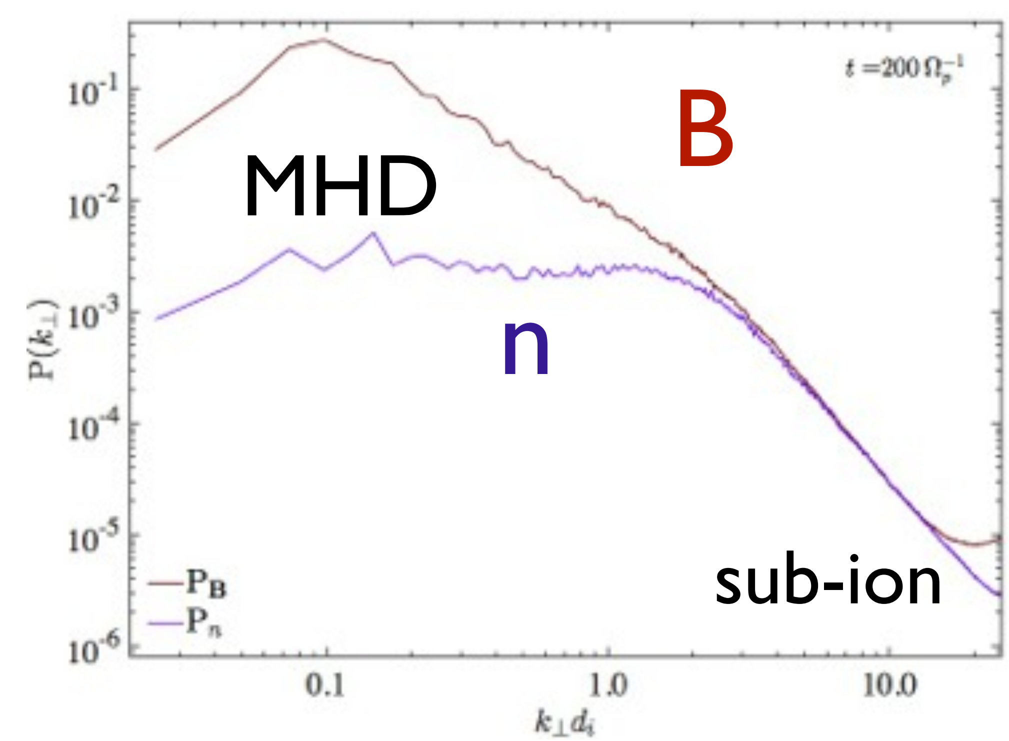

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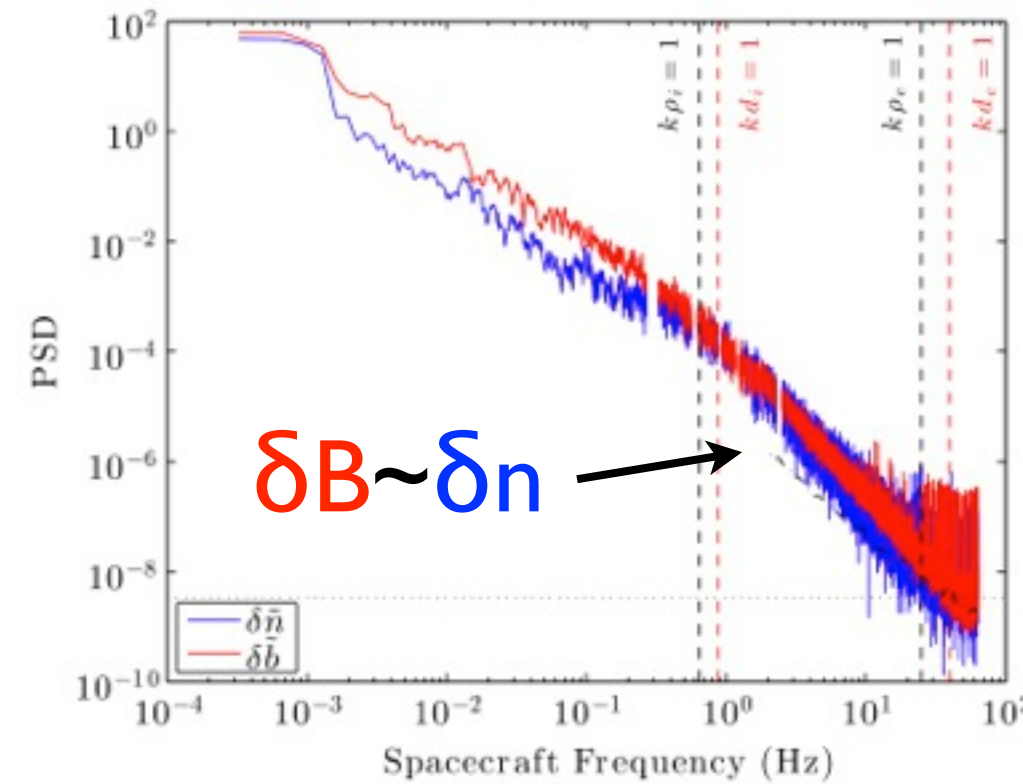

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B	E
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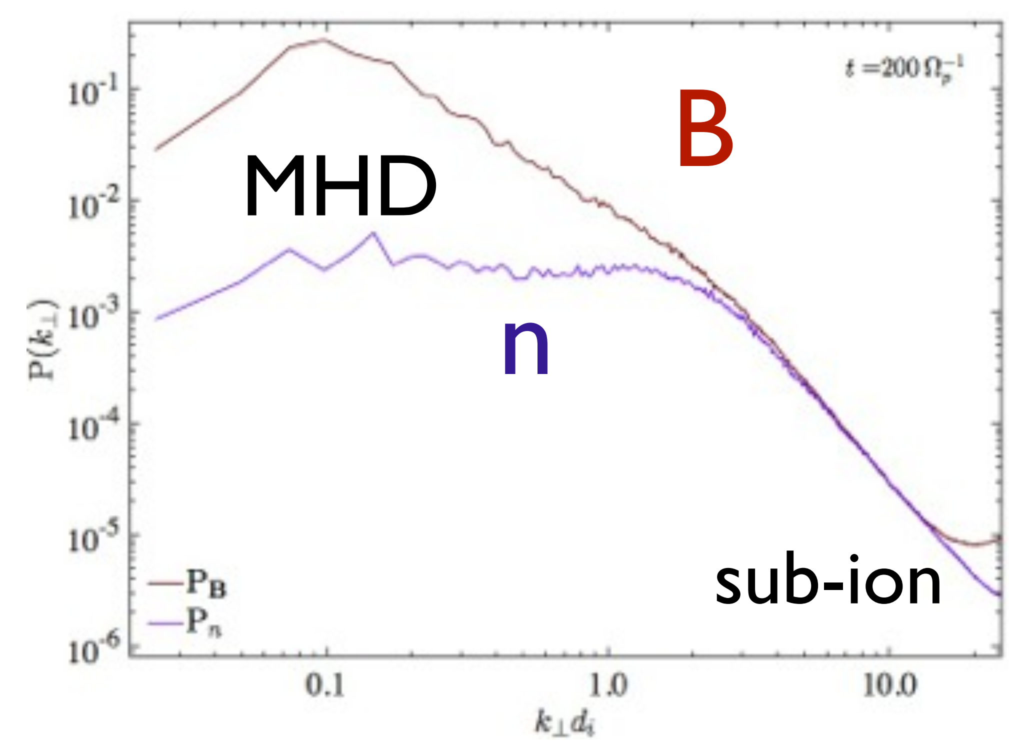
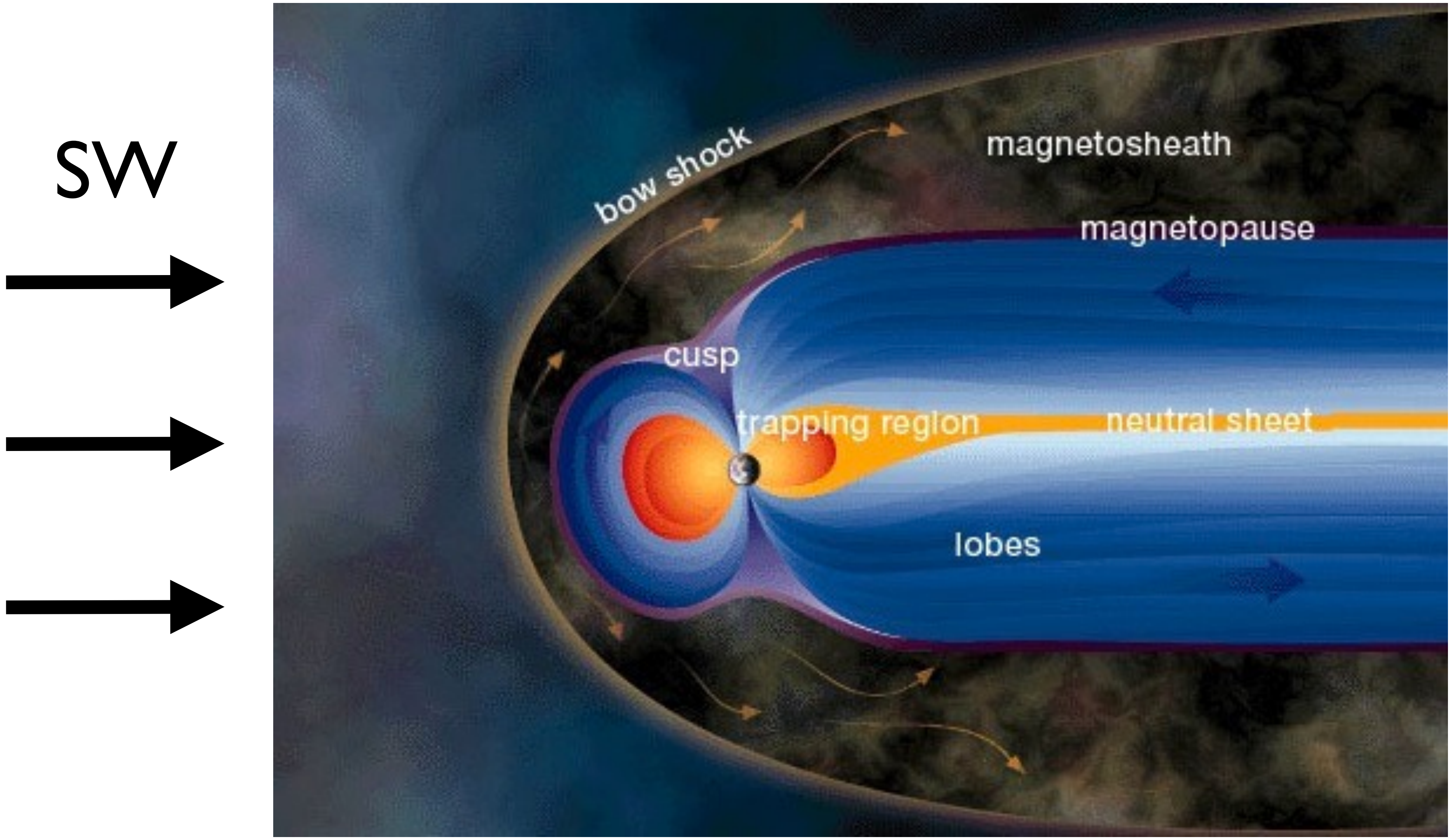


Franci et al. 2015a,b

Earth's Magnetosheath

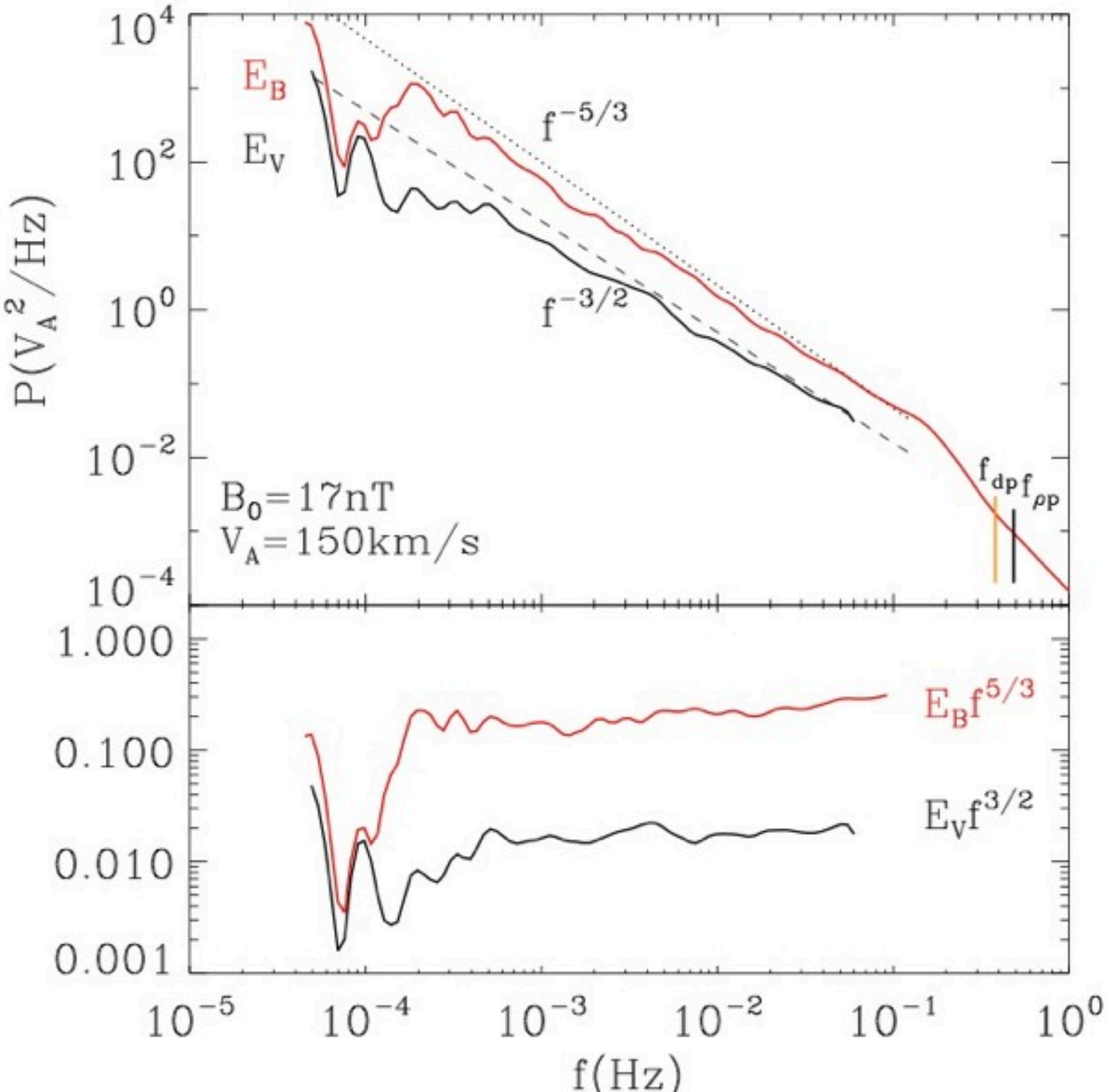
Downstream of Earth's bow shock, the turbulence has a higher power than in the solar wind



Cluster (STAFF-SA) can measure magnetic AND electric field at sub-ion scales in the magnetosheath (*Mangeney et al. 2006, Lacombe et al. 2006*)

Spectra in the Magnetosheath

fluid-MHD scales (FGM data)



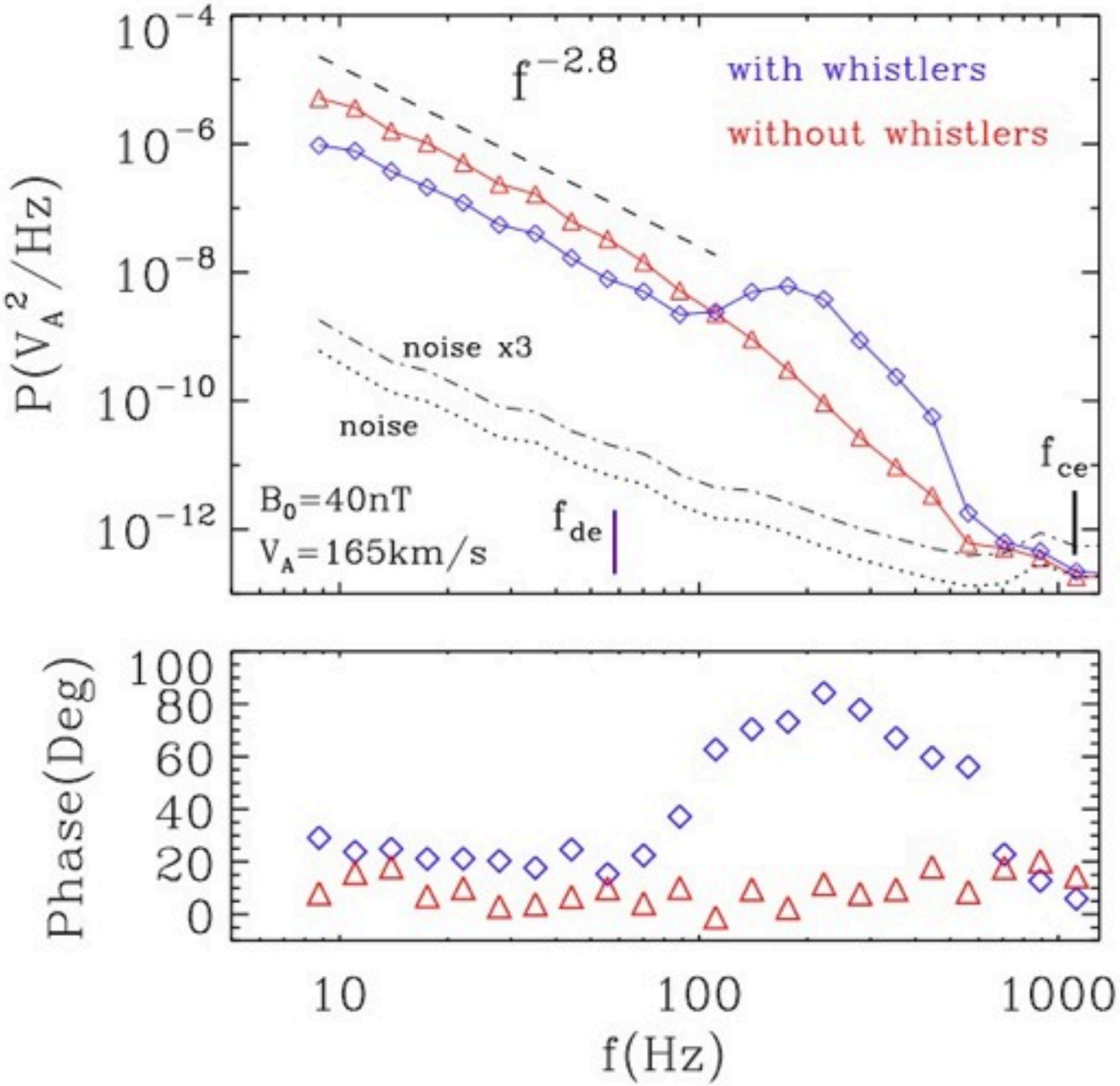
Well defined inertial range before ion break

Different spectral index in V and B, as often observed in solar wind

Matteini et al., to be submitted

Whistler waves at small scales

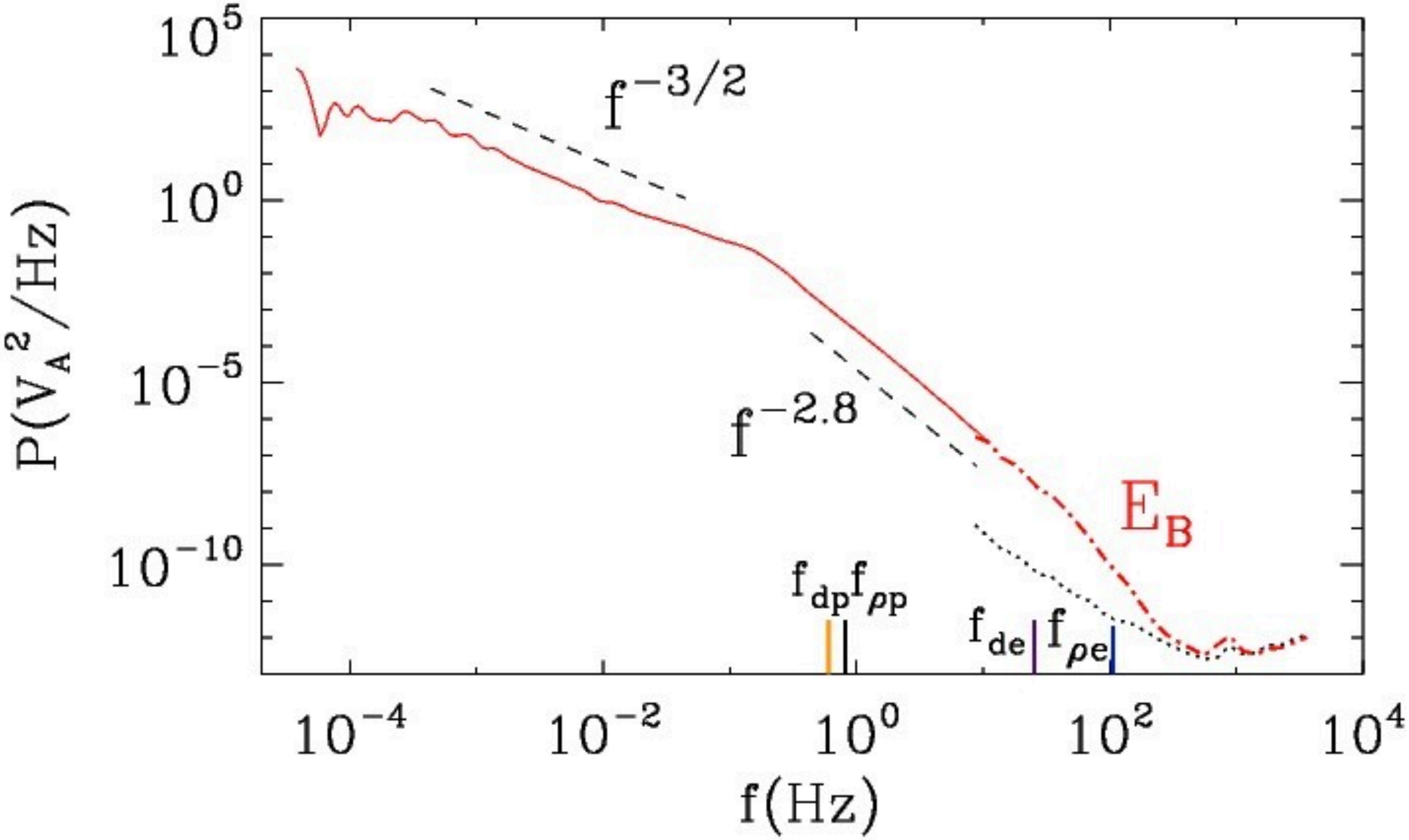
Small scale wave contribution to spectra has been removed by removing periods with whistler signatures (circular polarization)



In SW whistlers are associated with heat flux (carried by strahl electrons)
see *Lacombe et al. ApJ 2014*

Electric and magnetic spectra

FGM/EFW (solid) + STAFF-SA (dash-dotted)



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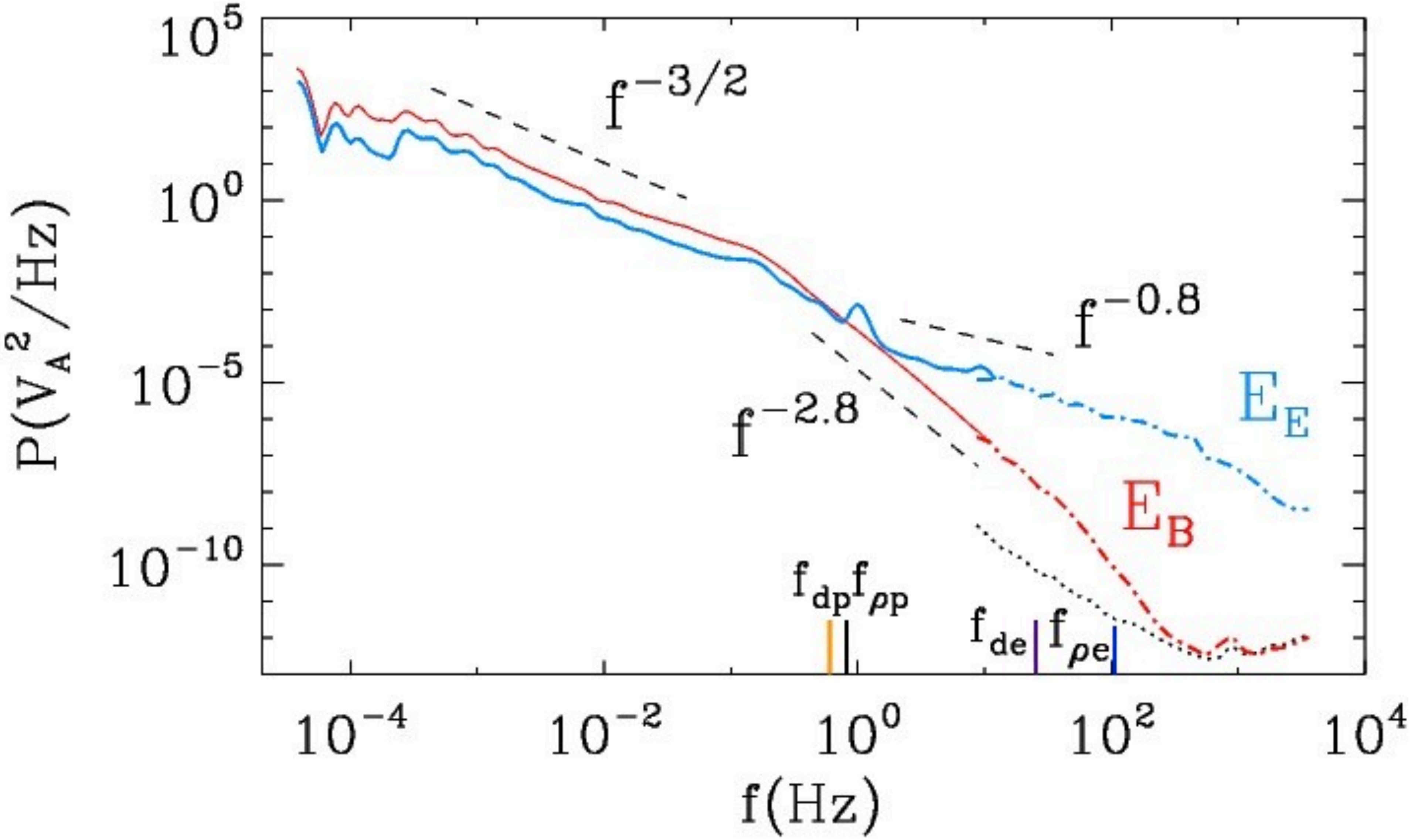

sub-ion spectra:

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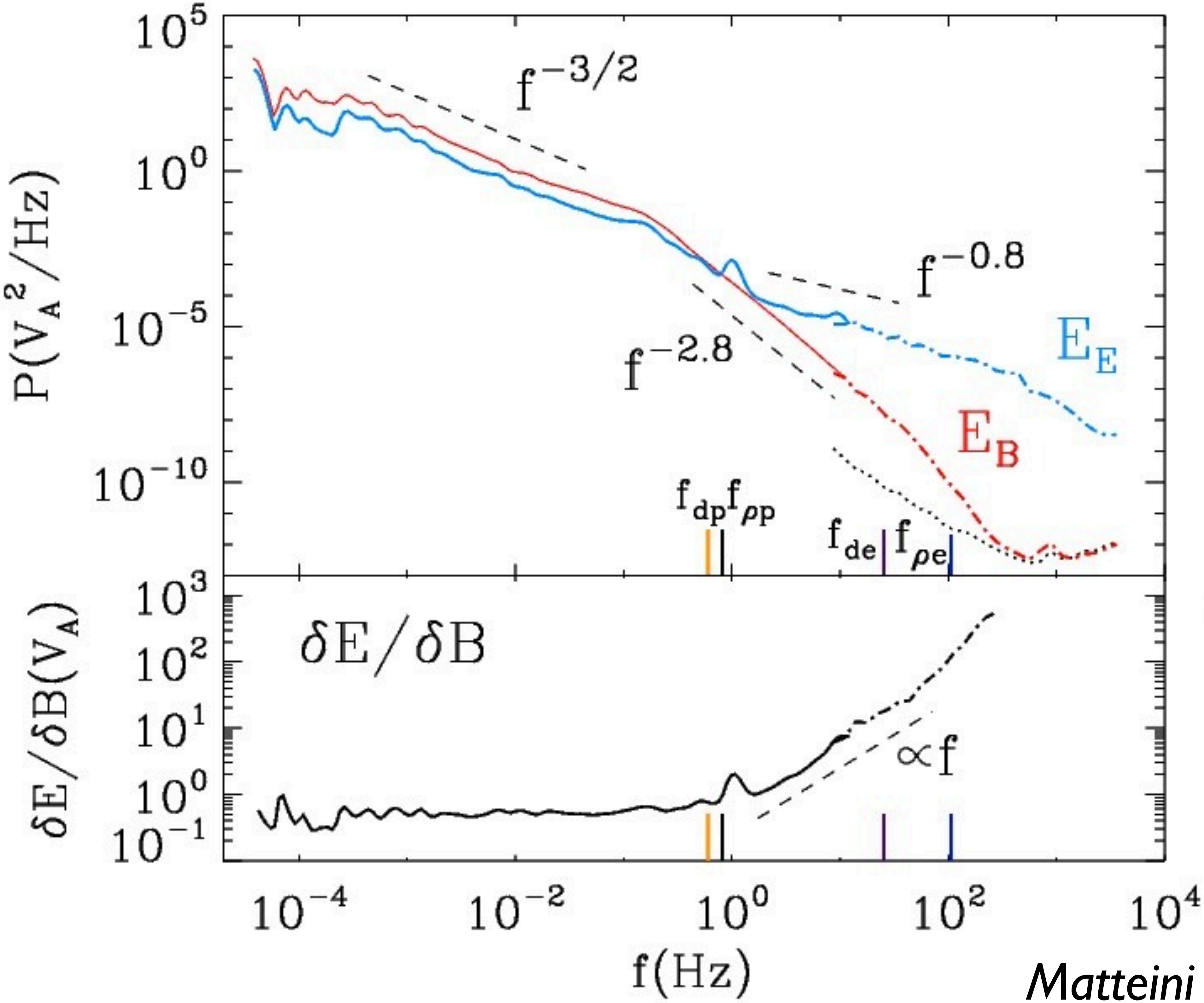

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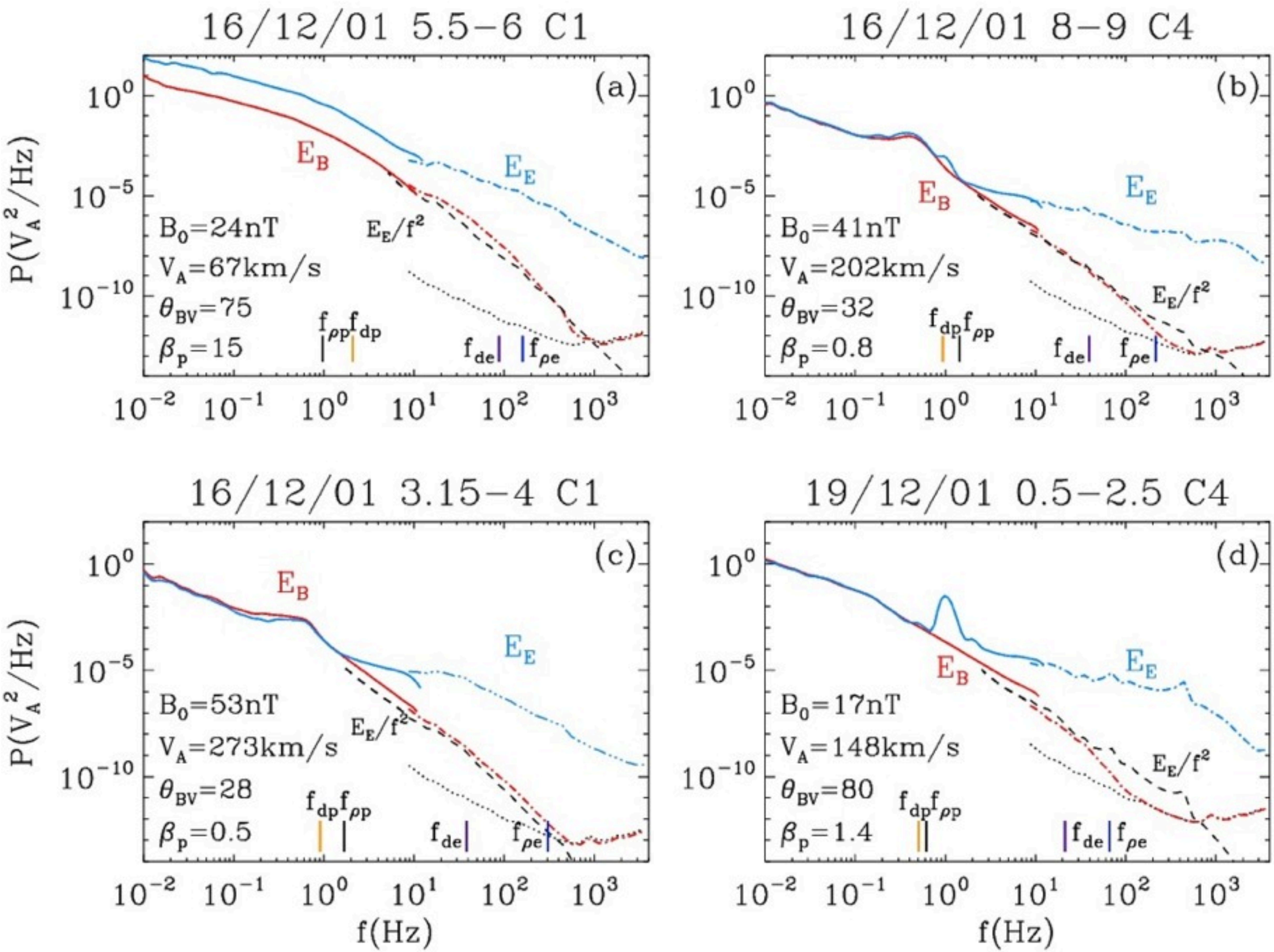
More examples at various beta and BV angle



Conclusion

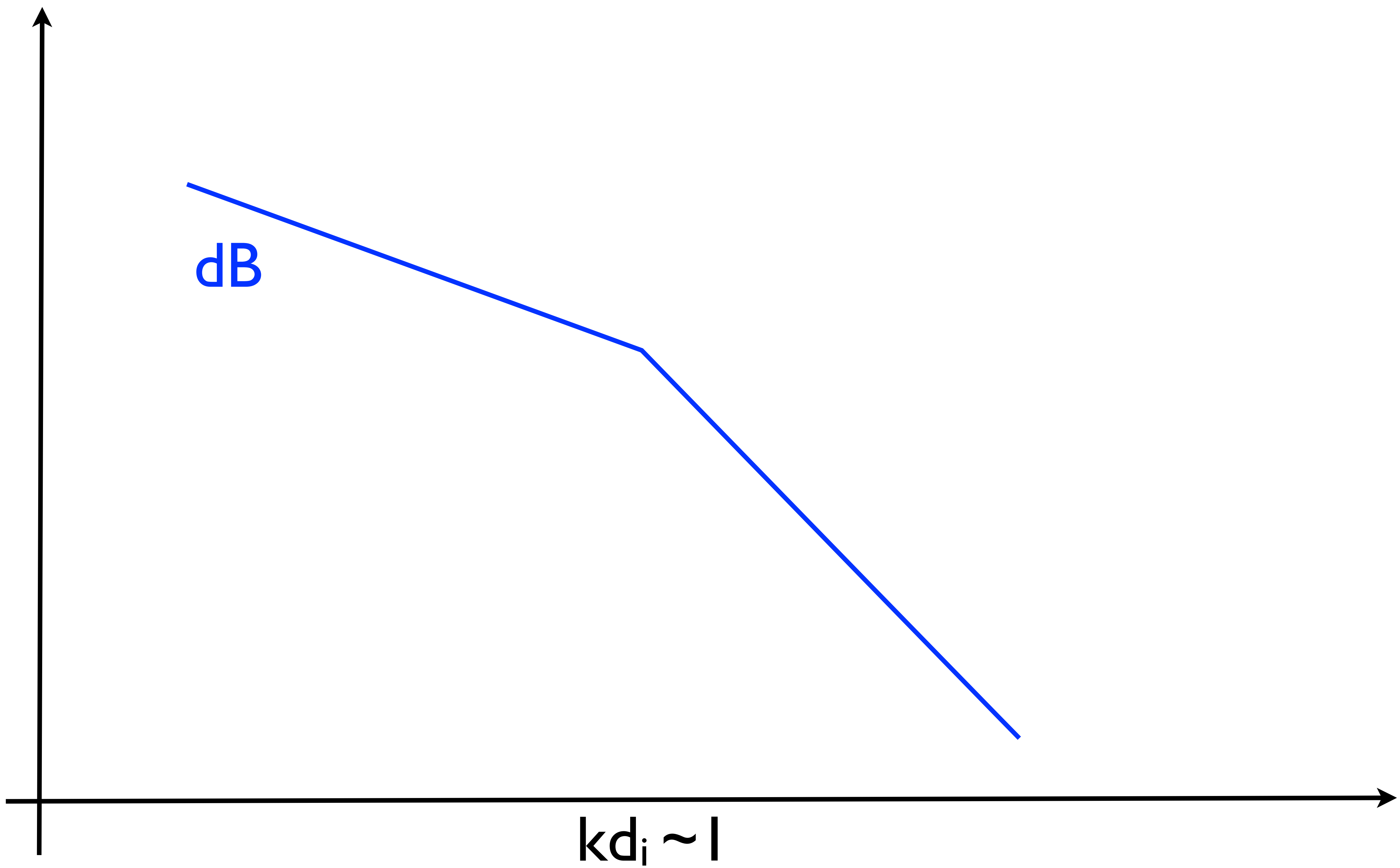
- First analysis of E and B spectra from MHD to electron scales in space plasmas. Spectrum of E is shallower than B after ion scale ($\delta E \sim k \delta B$). NB. this is s/c frame E, however at small scales it is the same as the real plasma frame E !

- At present, this can not be tested in SW (next future: SPP, Orbiter) However, such an investigation is possible in the magnetosheath (Cluster)

- Between ion and electron scales turbulent spectra are well described by the generalized Ohm's law:
  - fluid description of electrons in the cascade
  - turbulent fluctuations are electromagnetic in this range
  - Fluctuations in E, B and plasma are in equilibrium (self-consistent): at this stage, no clear excess of E for plasma heating!

- THOR will need to measure departures from this scaling of the background turbulence in order to capture energy dissipation and particle energization

Plasma vs. Spacecraft frame electric field



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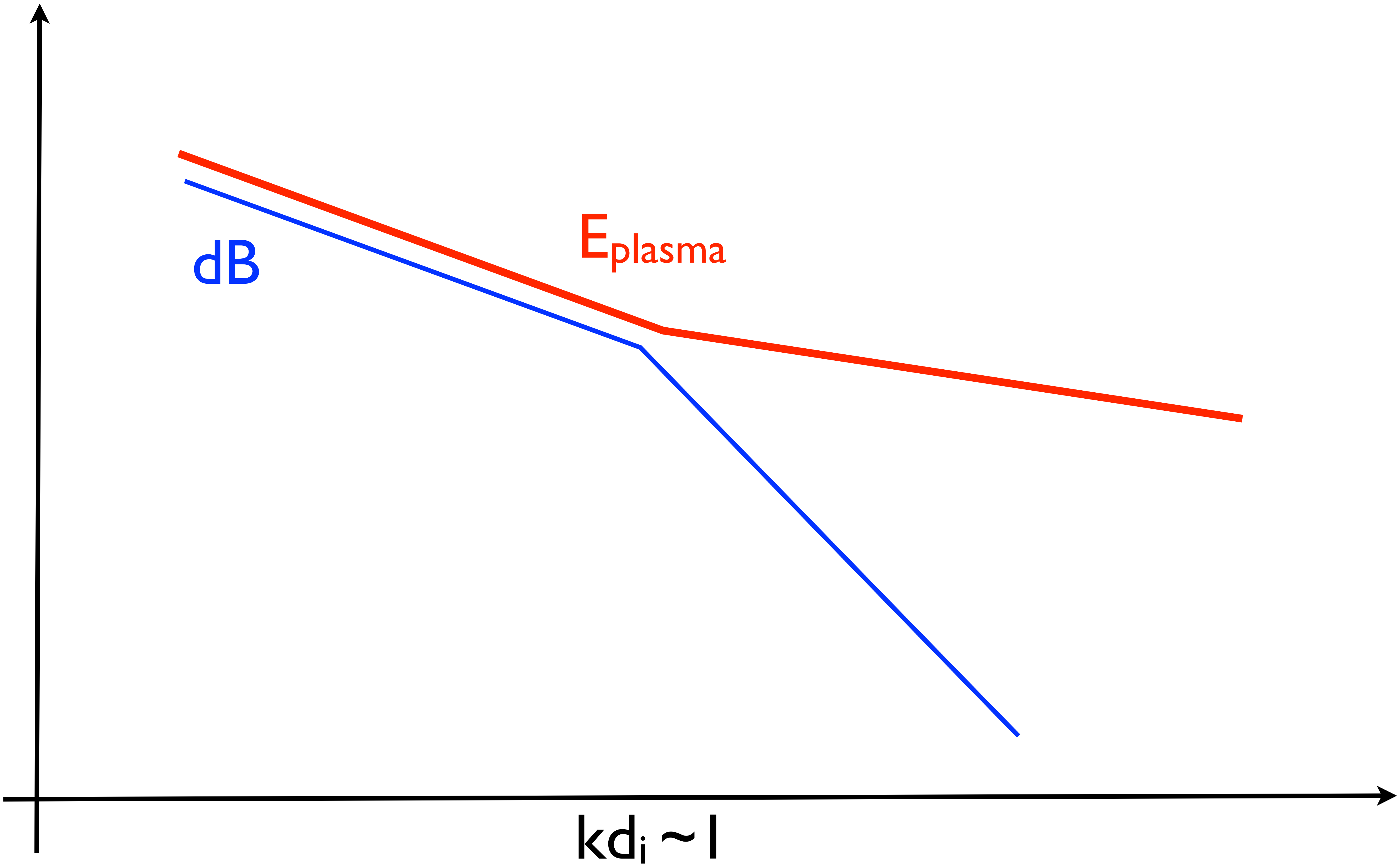

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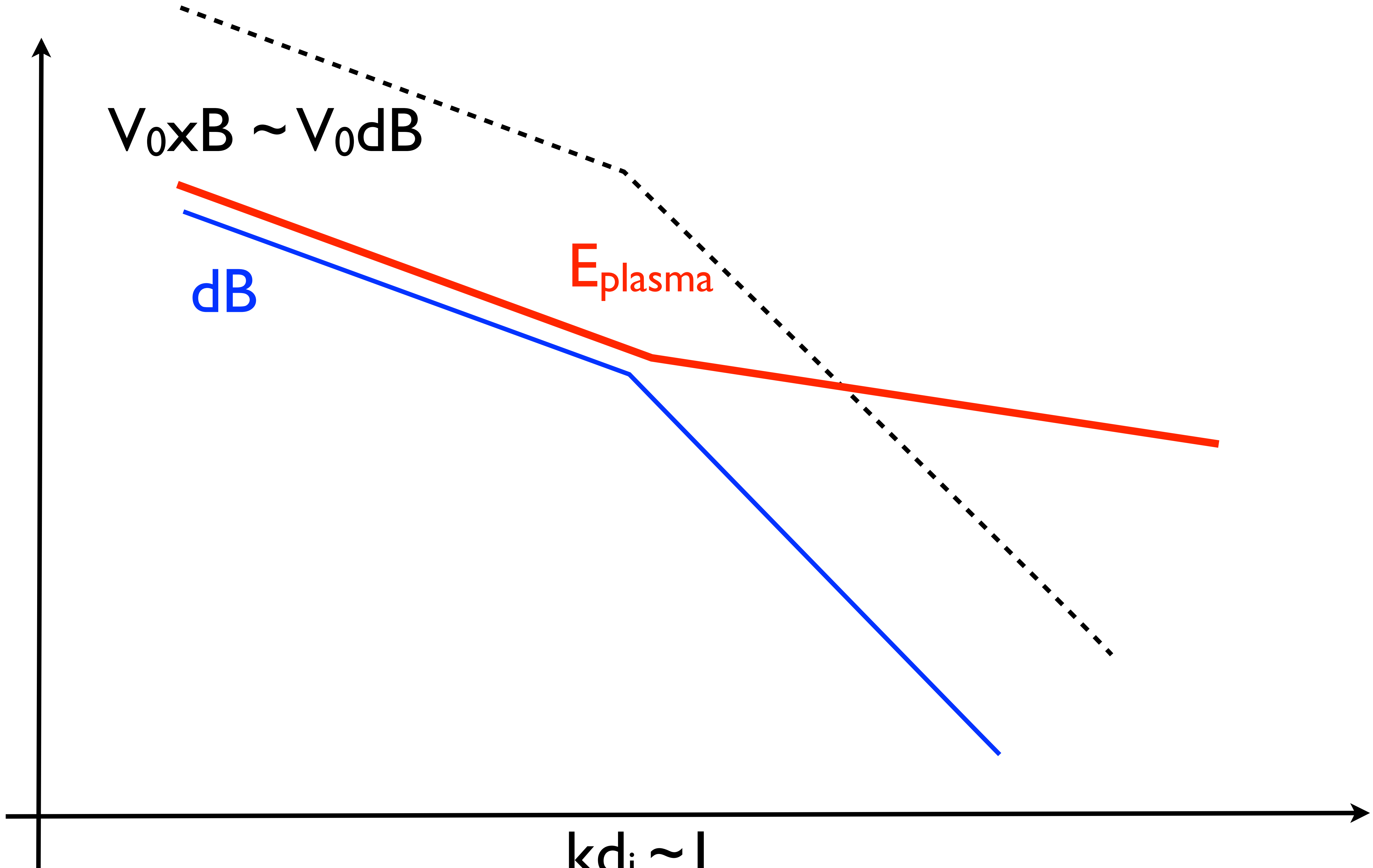

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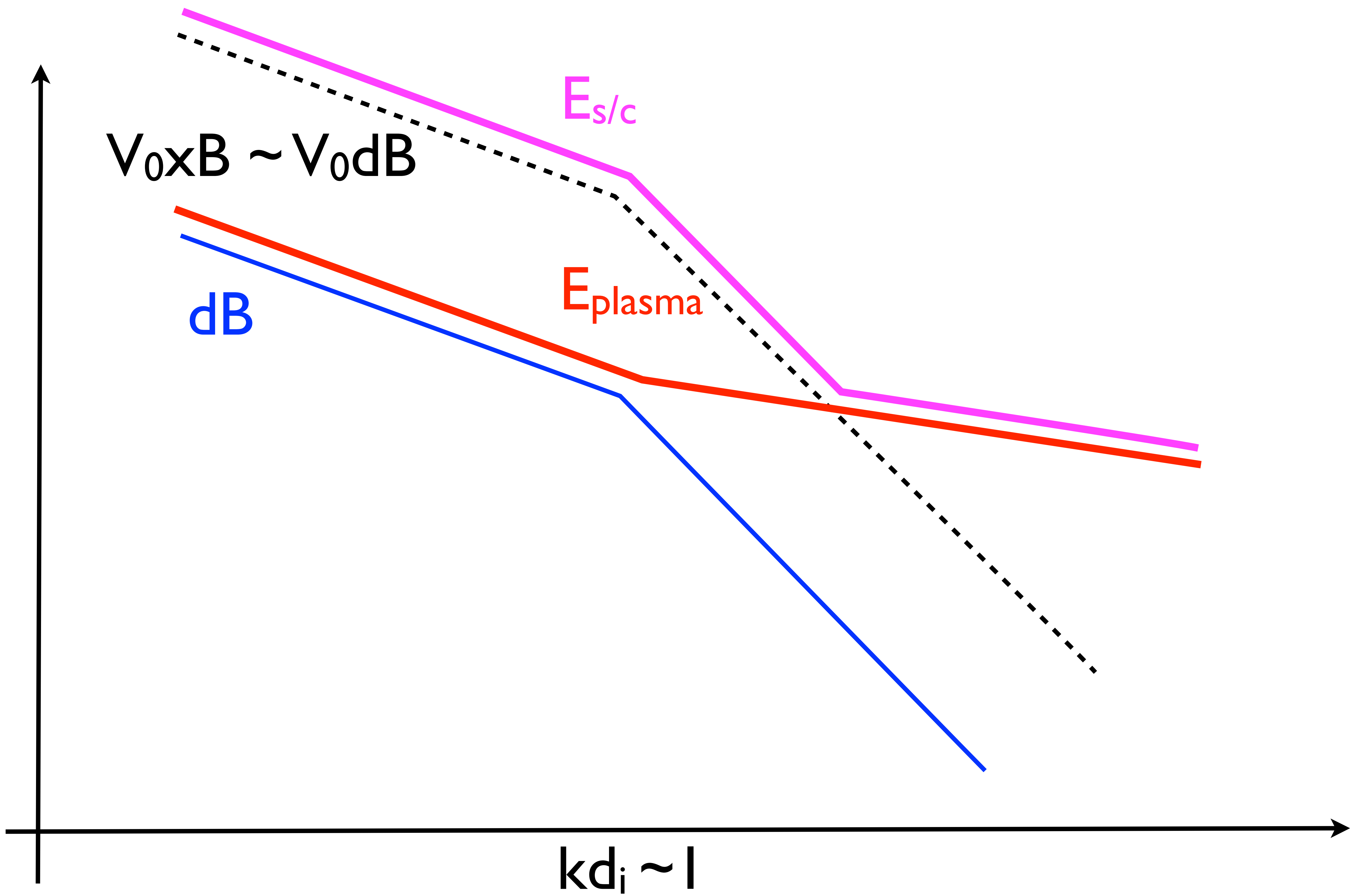

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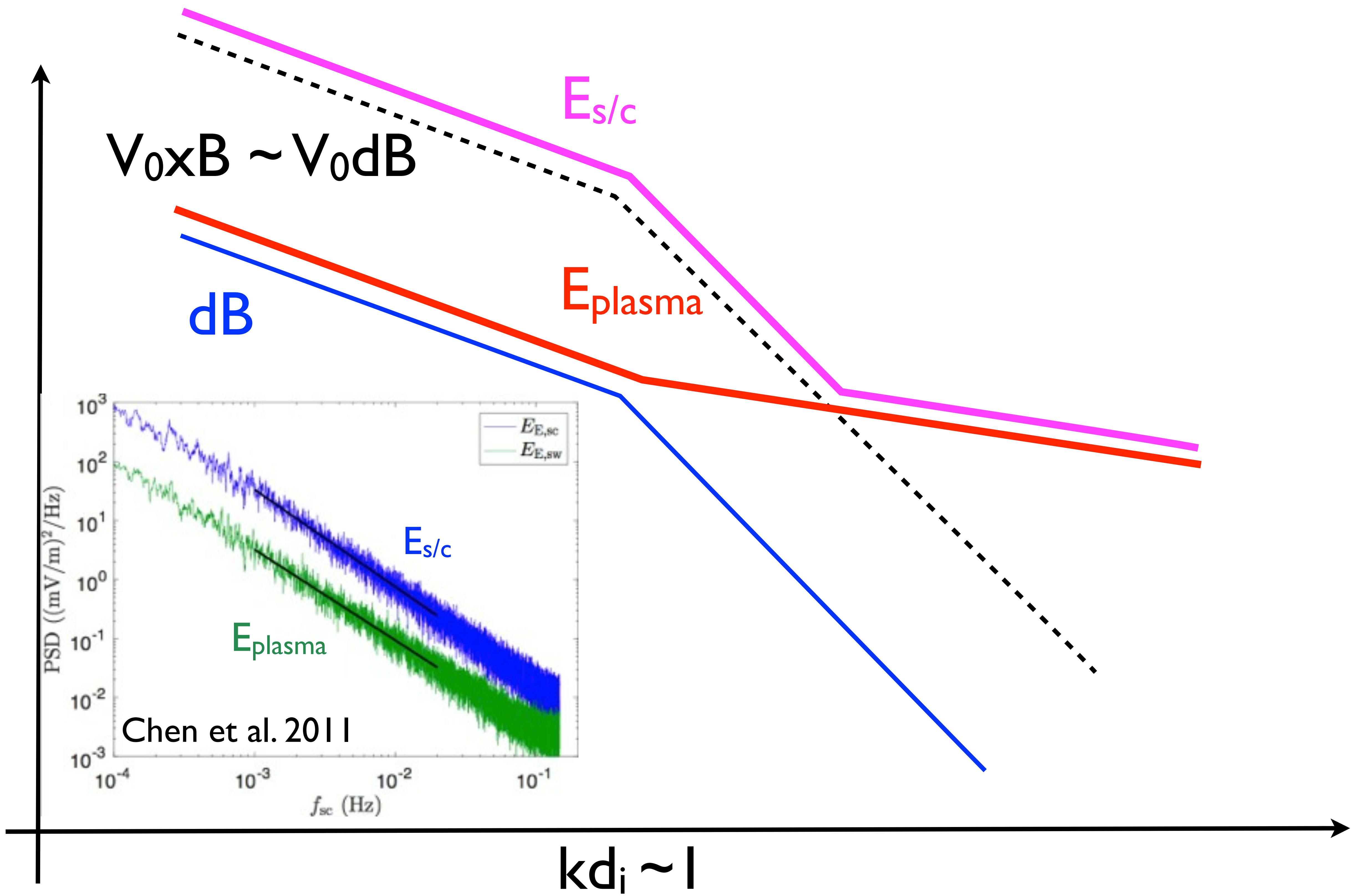

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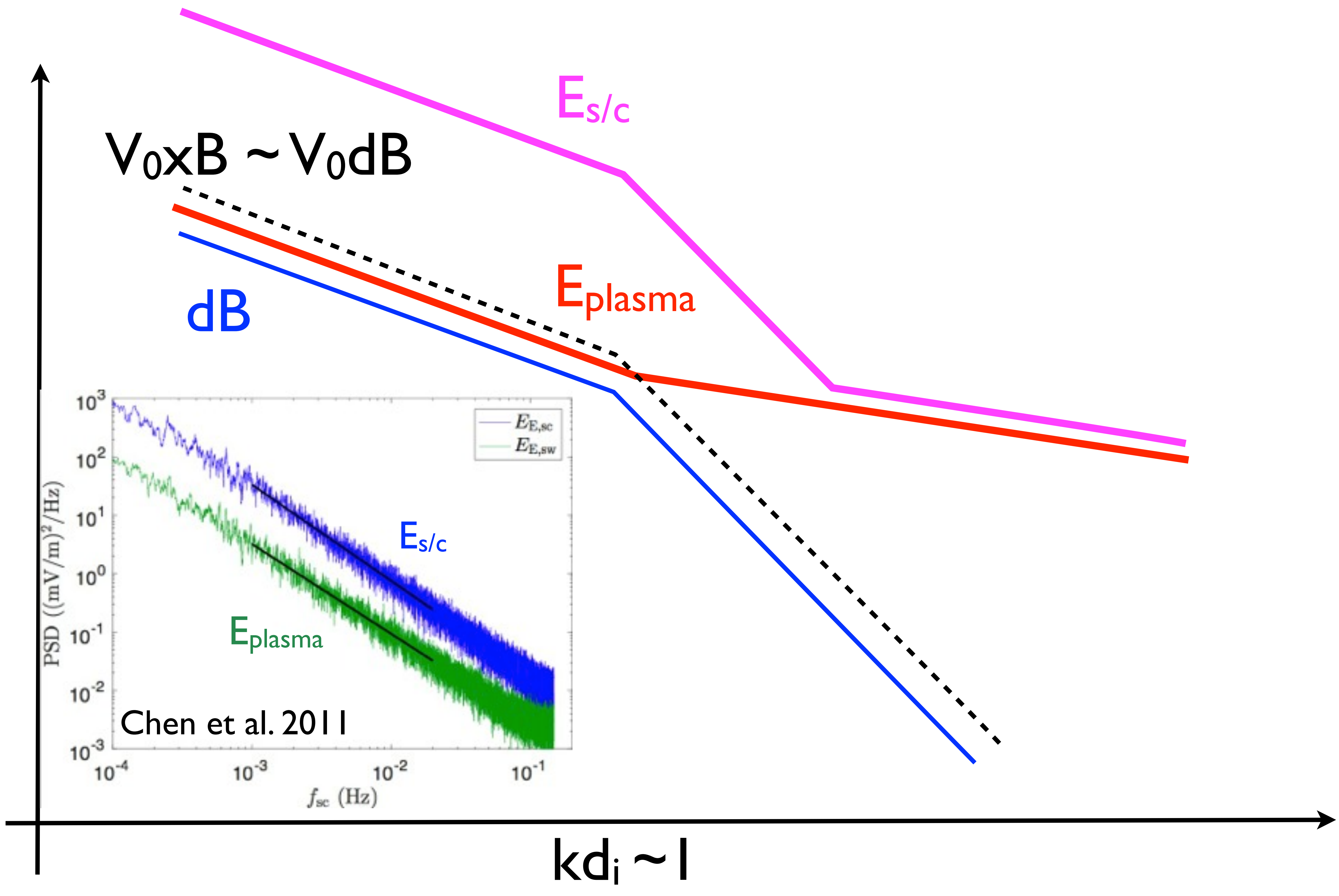

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