Why do we observe a broad distribution of spectral slopes at kinetic scales in solar wind turbulence?

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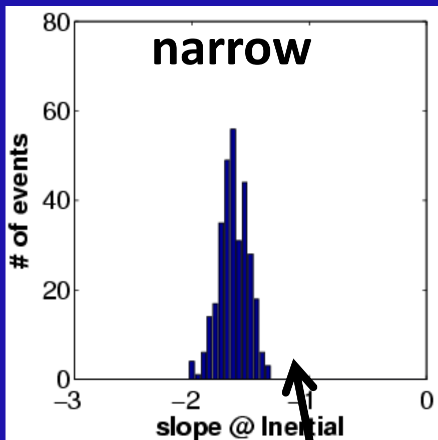
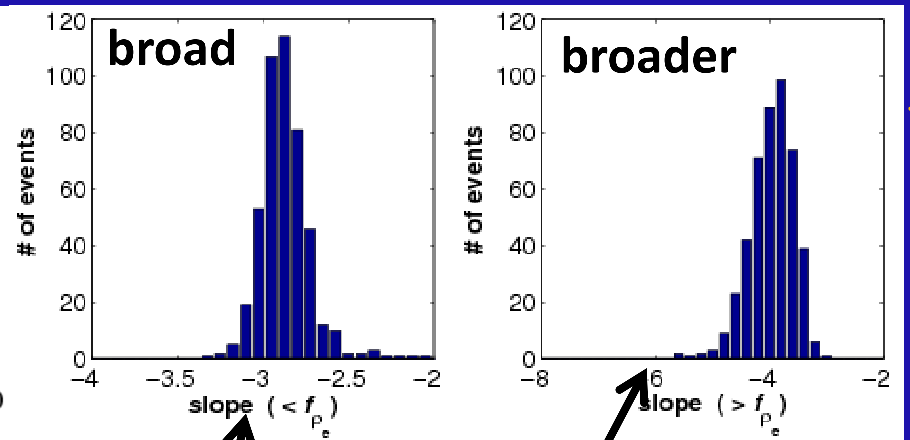
Universality?

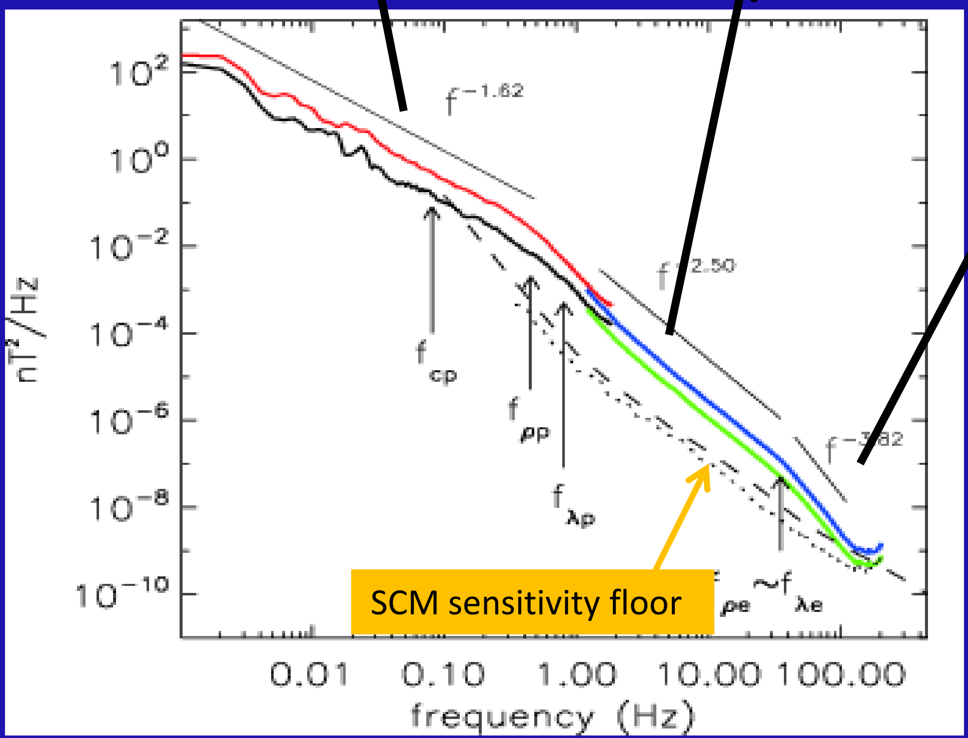
Huang+, 2015

Sahraoui+, ApJ,2013

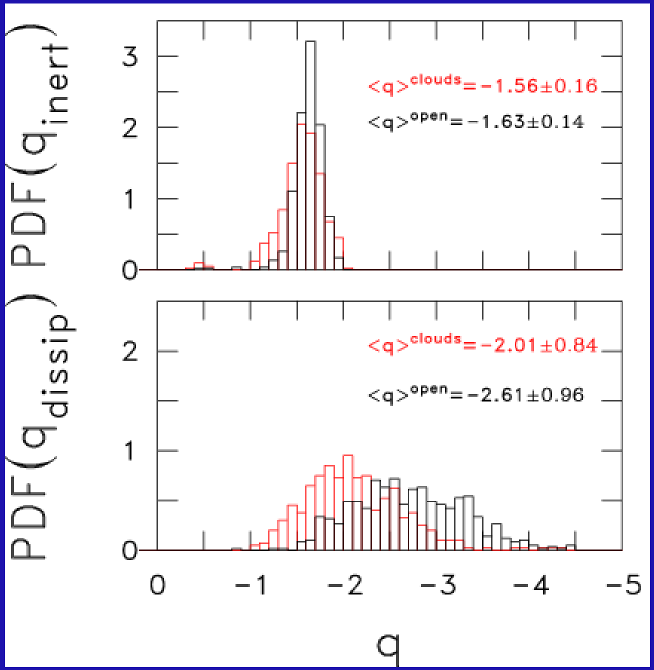




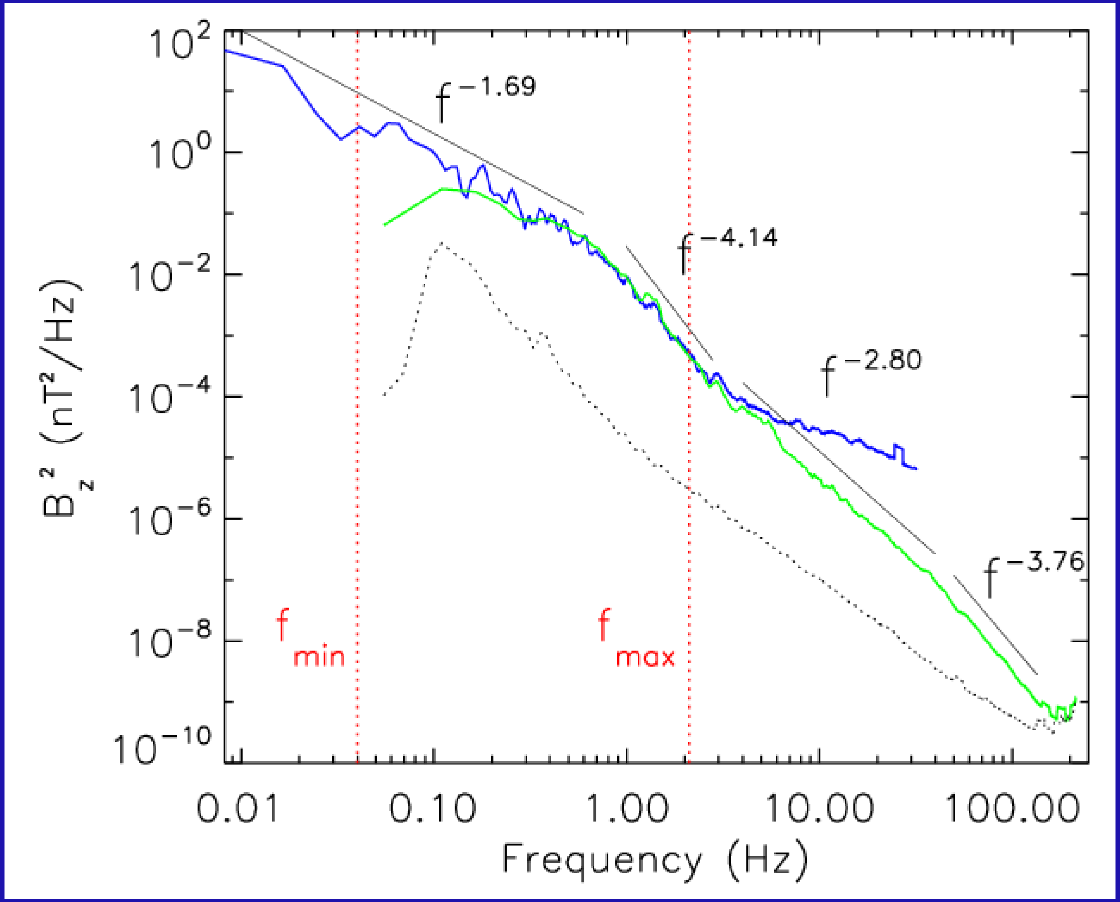
The broadening remains unexplained (no role of β, …)



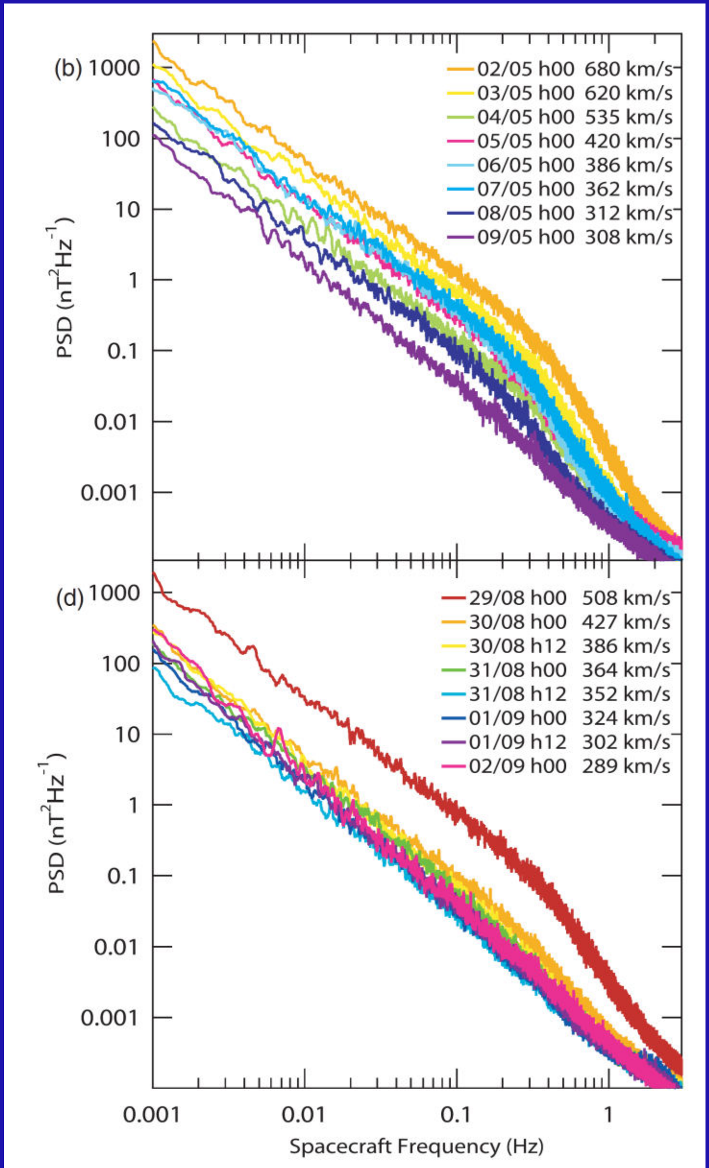
Smith+, ApJ,2006



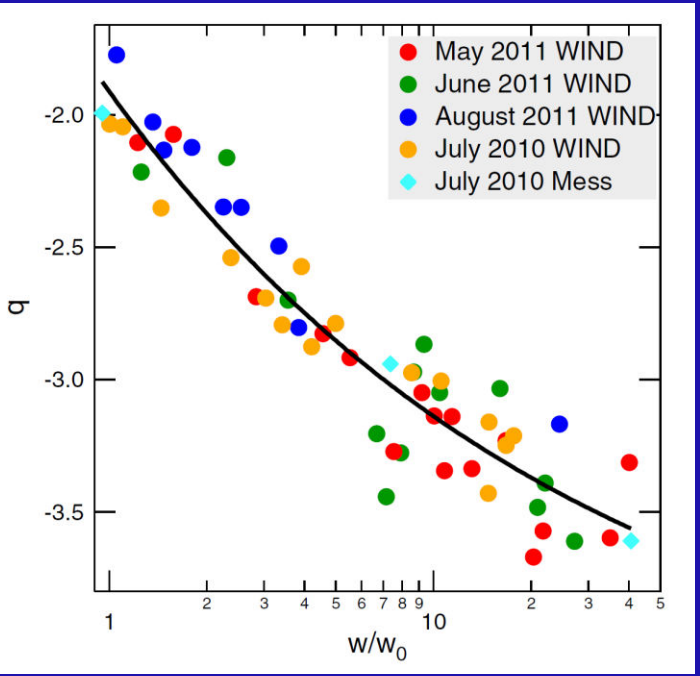
The transition range



Explanation: Dependence on dB/B?



Bruno+, ApJL 2014

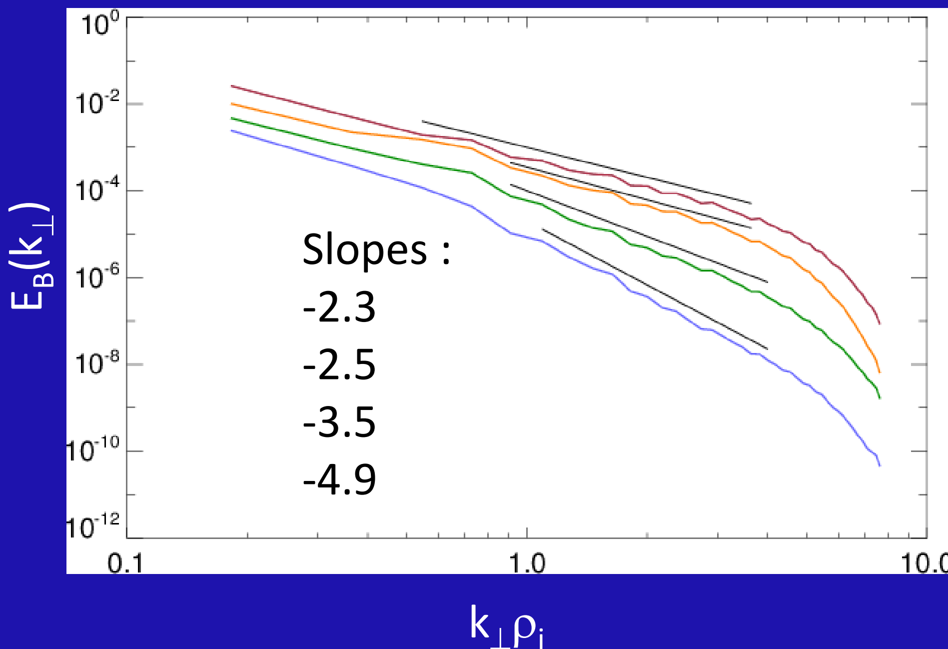


More power, steeper spectra

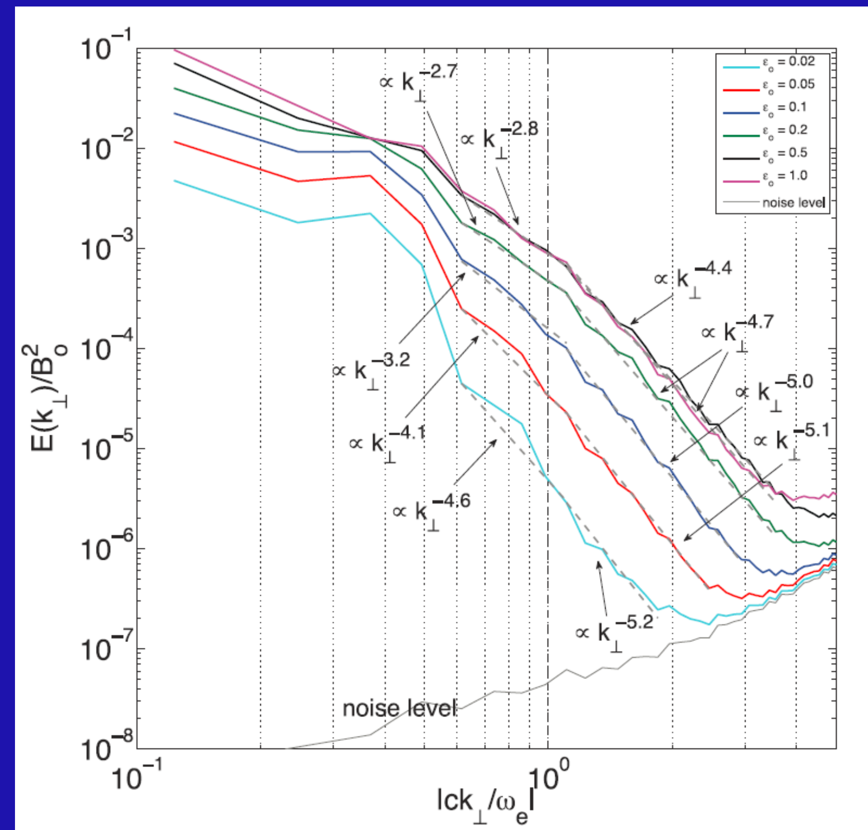
See also Smith+, ApJ, 2006

Simulations

3D Landau-fluid simulations [see Sulem's talk]



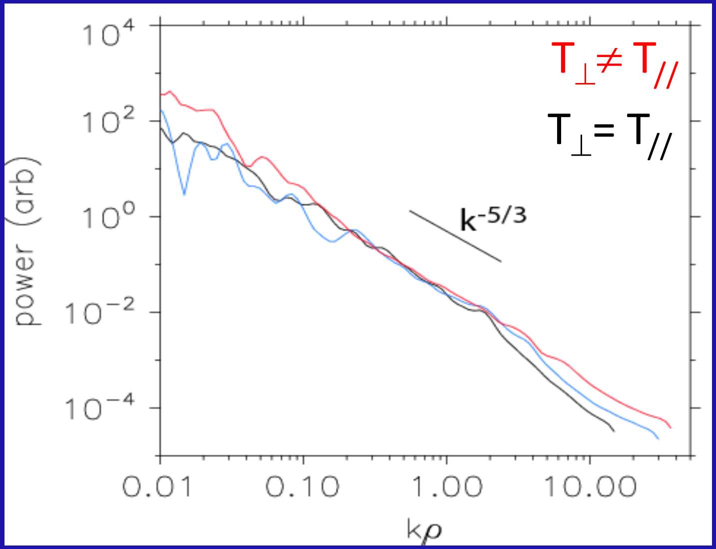
3D PIC code [Gary+, ApJ 2012]



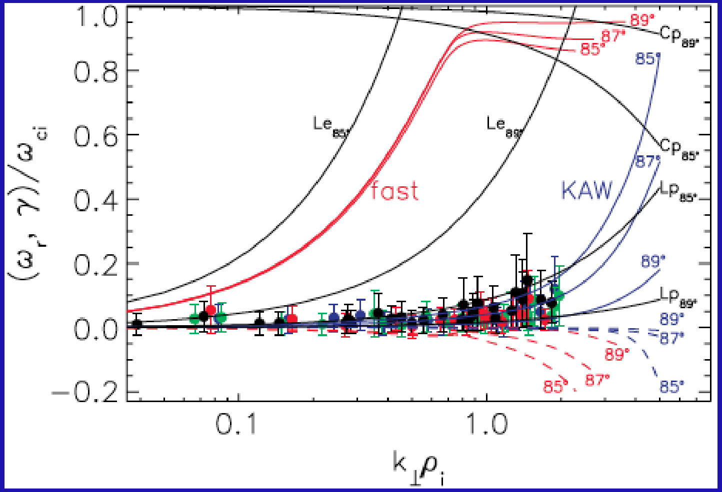
More power, flatter spectra!

Other possible explanations

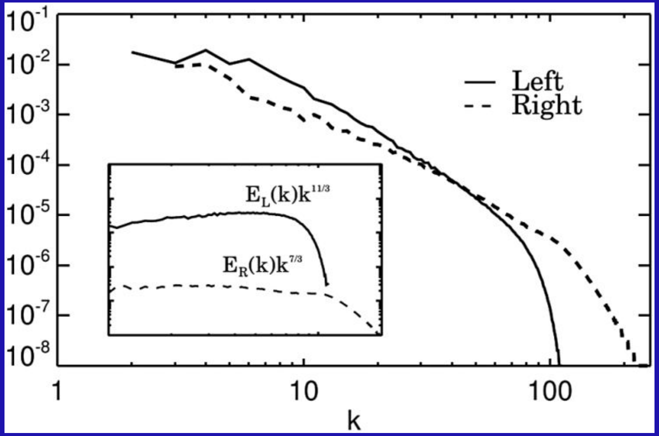
Kinetic instabilities
[Bale +, PRL, 2009]

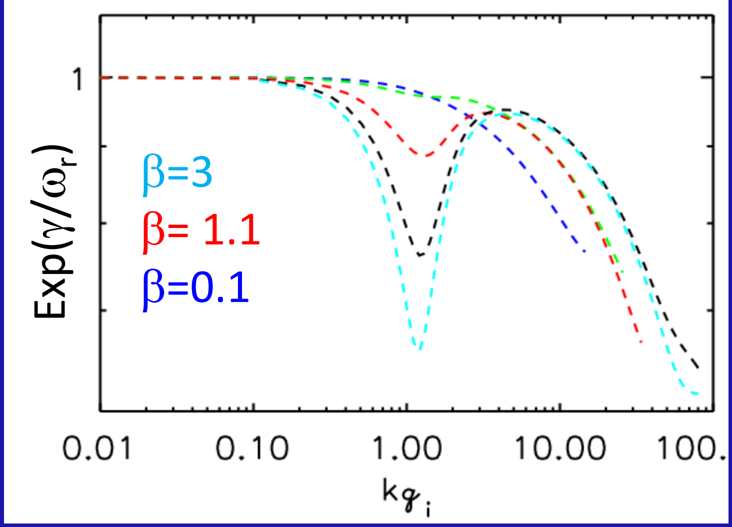


Ion Landau damping of KAW
@ $k\rho_i$~1



Polarized fluctuations : IMHD vs EMHD
[Meyrand & Galtier, PRL, 2012]

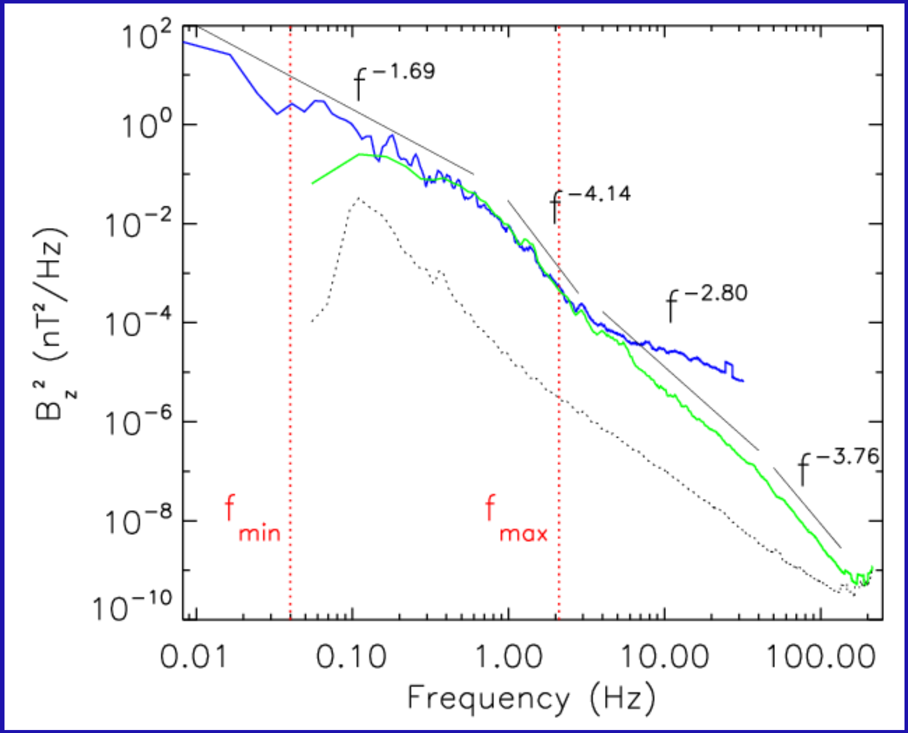


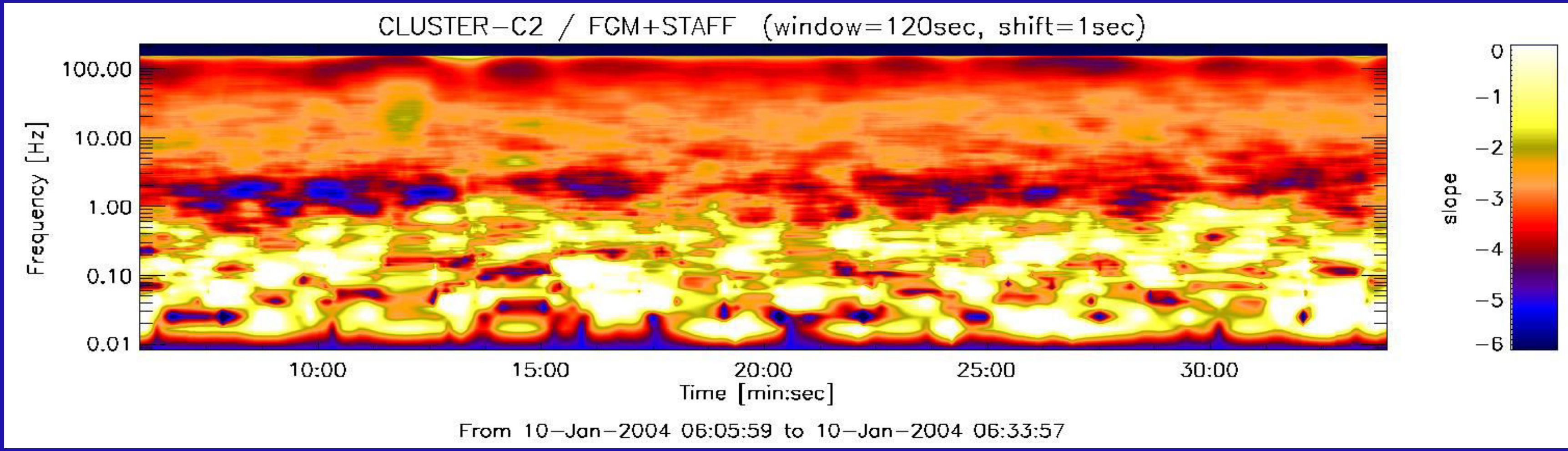


Sahraoui+, PRL, 2010; ApJ, 2013

Very local fluctuation in the slopes

Sahraoui+, 2015





The Taylor frozen-in-flow assumption in the solar wind

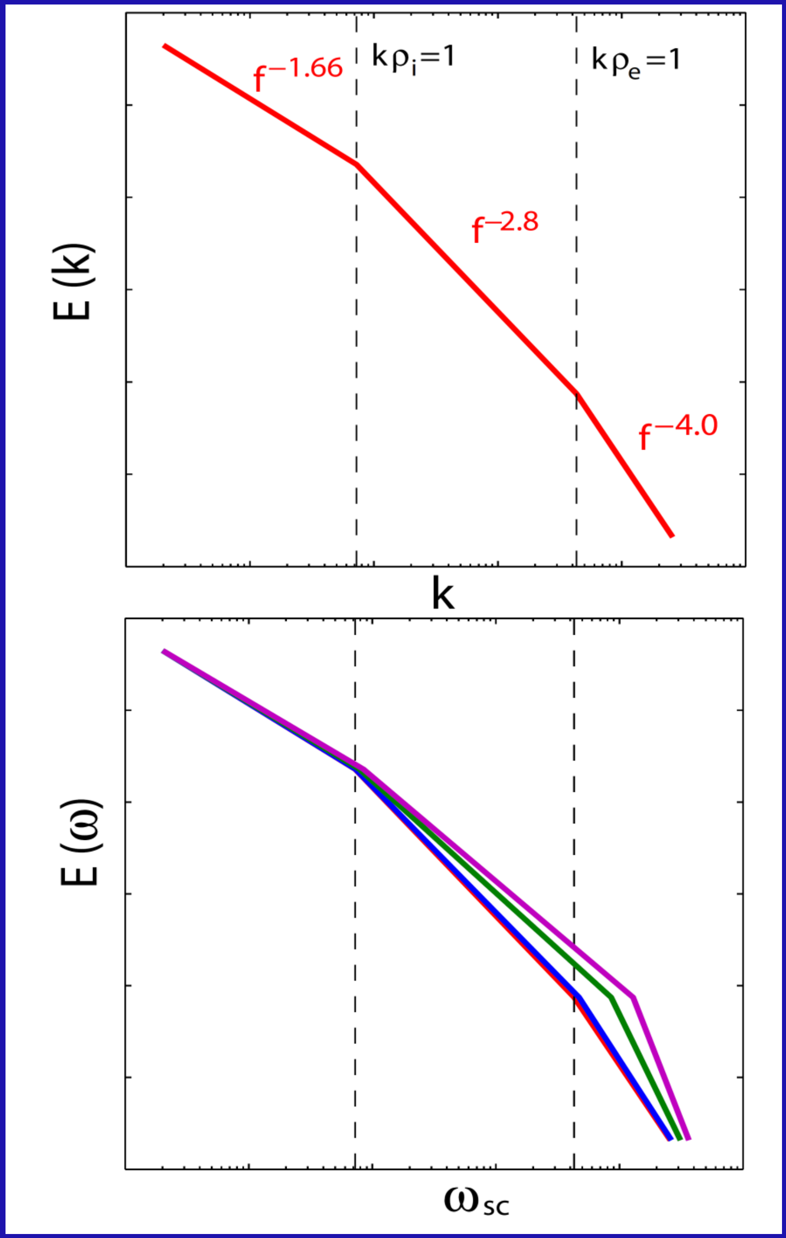
1. MHD scales: the Taylor's hypothesis can be valid.

High SW speeds: $V \sim 600\text{km/s} \gg V_\varphi \sim V_A \sim 50\text{km/s} \Rightarrow$

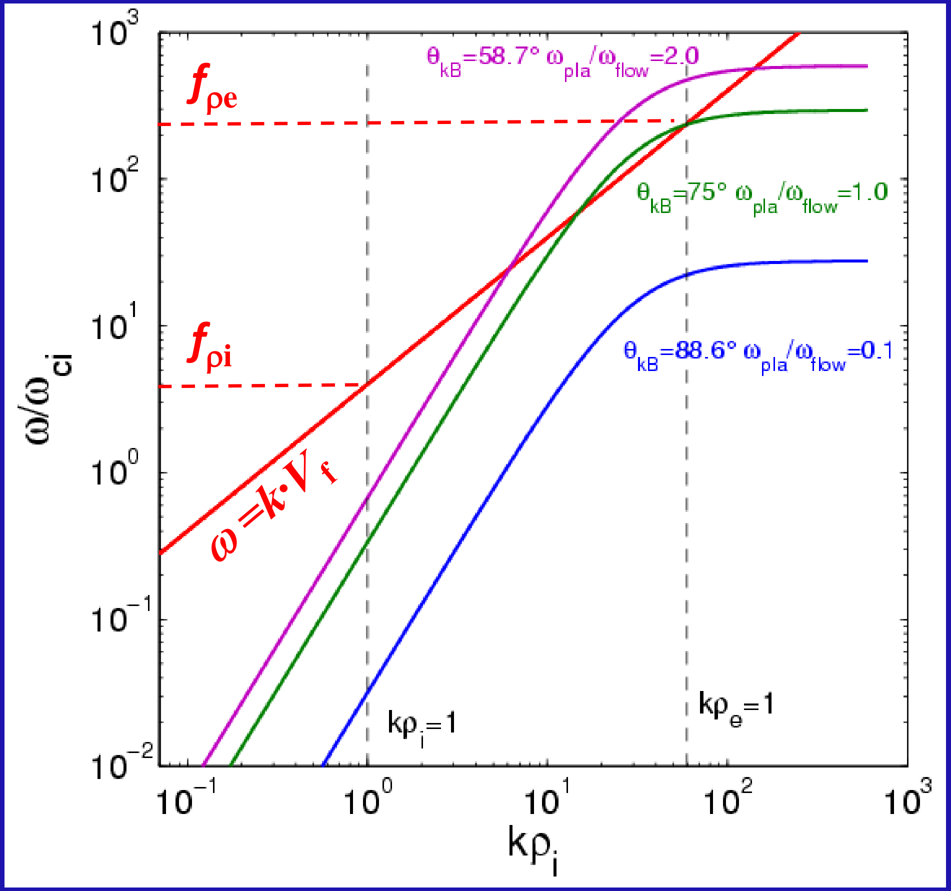
$$\boxed{\omega_{spacecraft} = \omega_{plasma} + \mathbf{k.V} \approx \mathbf{k.V} = k_V V}$$

2. Electron scales: the Taylor's hypothesis might be invalid

Effect on spectral slopes



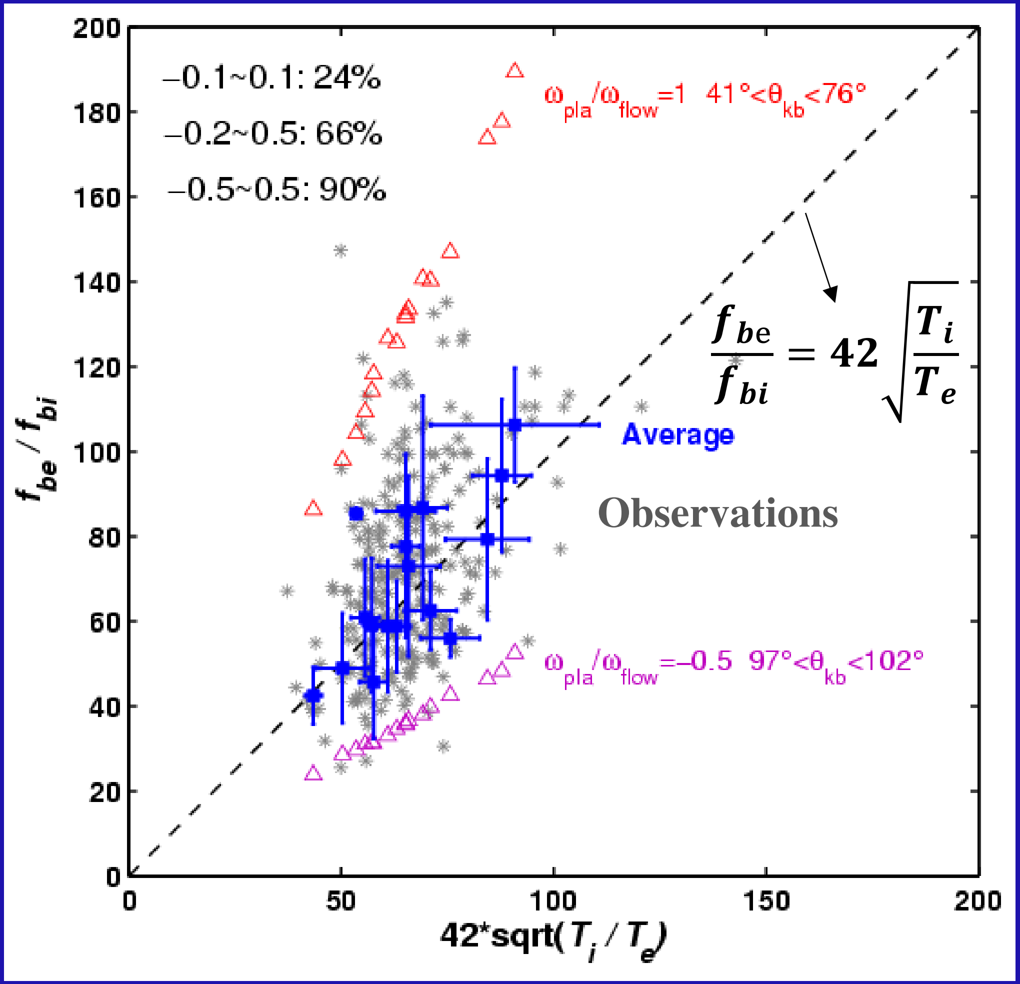
General formula: $\omega_{sc} = \omega_{pla} + k \cdot V_f$

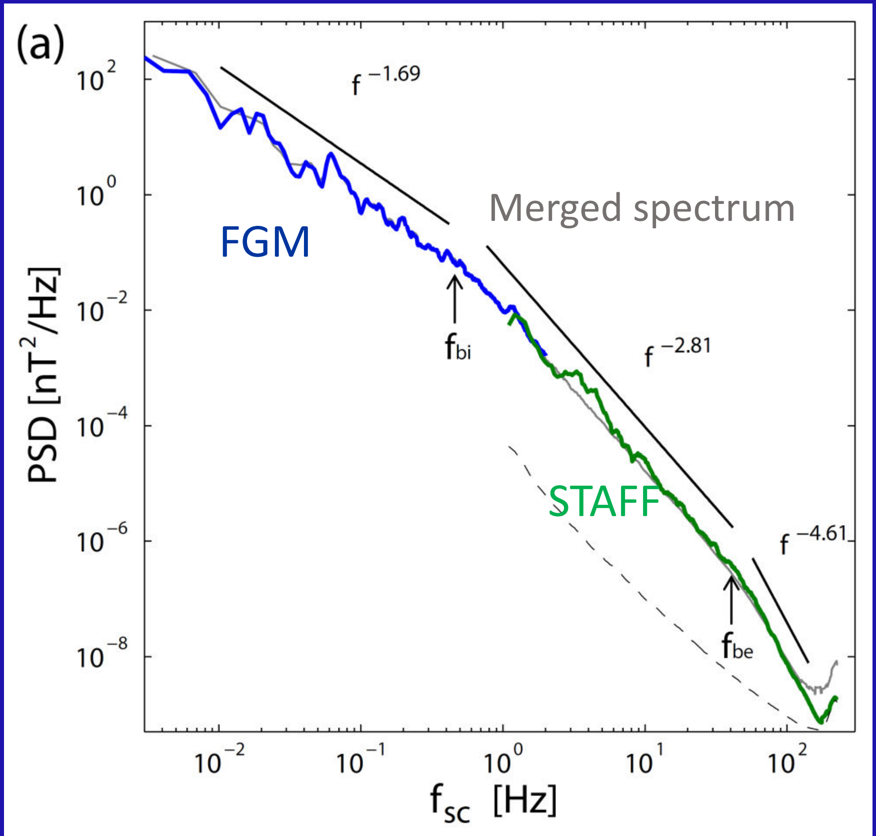


$$\frac{f_{be}}{f_{bi}} = 42\sqrt{\frac{T_i}{T_e}}$$

Sahraoui+, ApJ, 2012

Test of the Taylor hypothesis





Solar wind turbulence does not strictly satisfy the Taylor hypothesis at electrons scales [Huang+, 2015a]

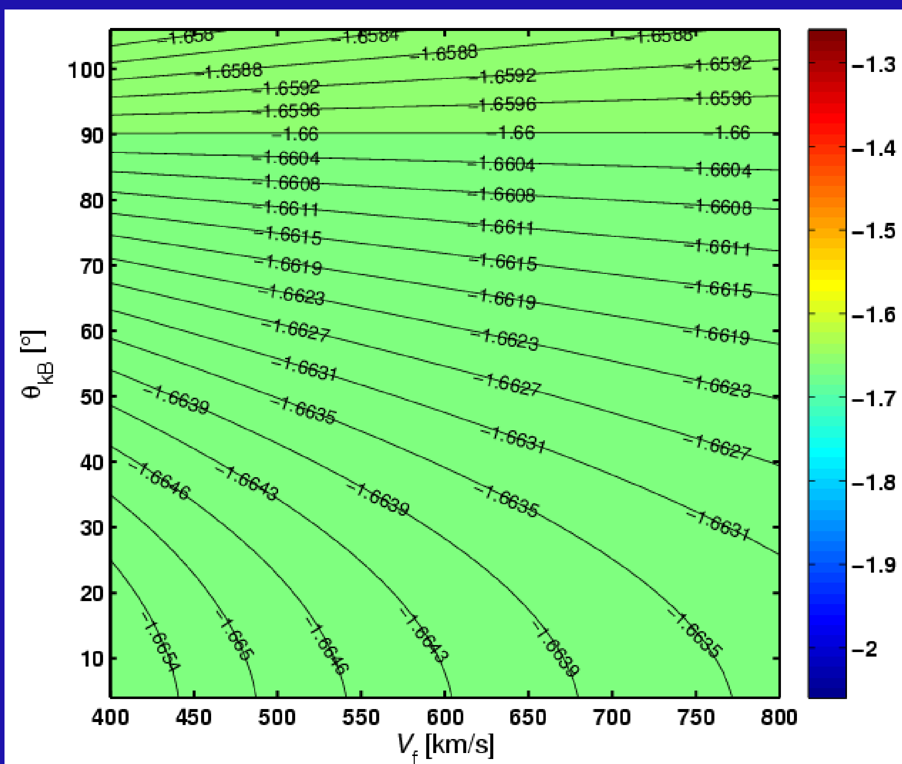
[See also Howes +, ApJ, 2014]

Model and simulated results

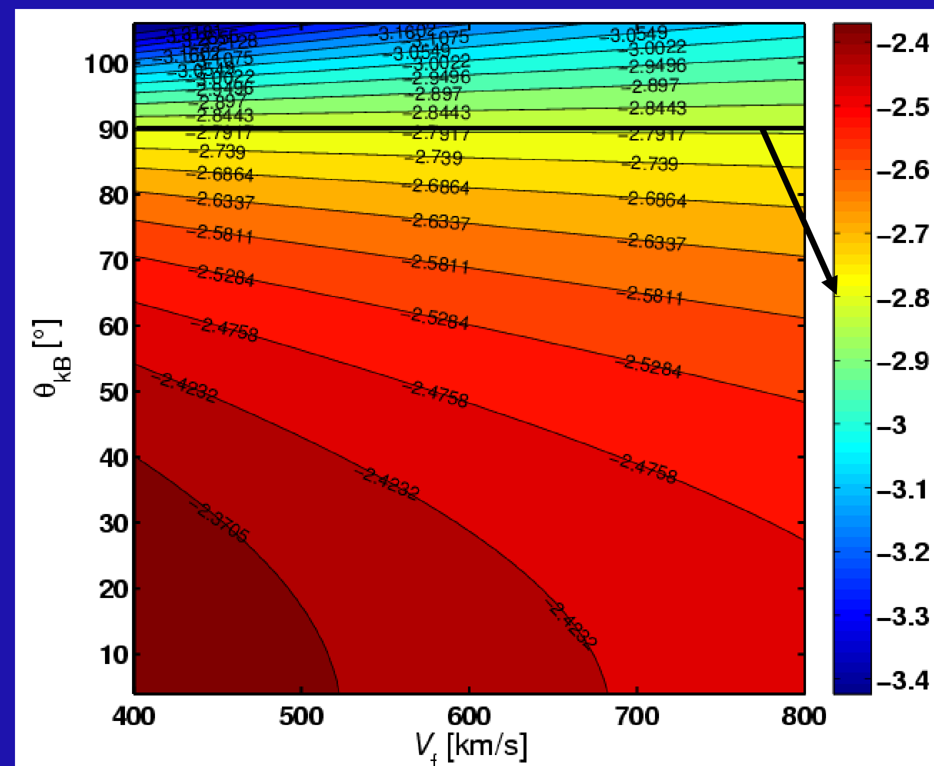
$$\omega_{sc} = kV_f cos\theta_{kv} + \frac{k^2 cos\theta_{kB}\, c^2/\omega_{pe}^2}{1 + (1+\sqrt{\beta_e})(k^2\, c^2/\omega_{pe}^2)}\,\omega_{ce}$$

Doppler shift **Whistler term**

Energy conservation $\int E(k)\, dk = \int E(\omega_{sc})\, d\omega_{sc}$ ➡ $E(k) = E(\omega)\dfrac{d\omega_{sc}}{dk}$



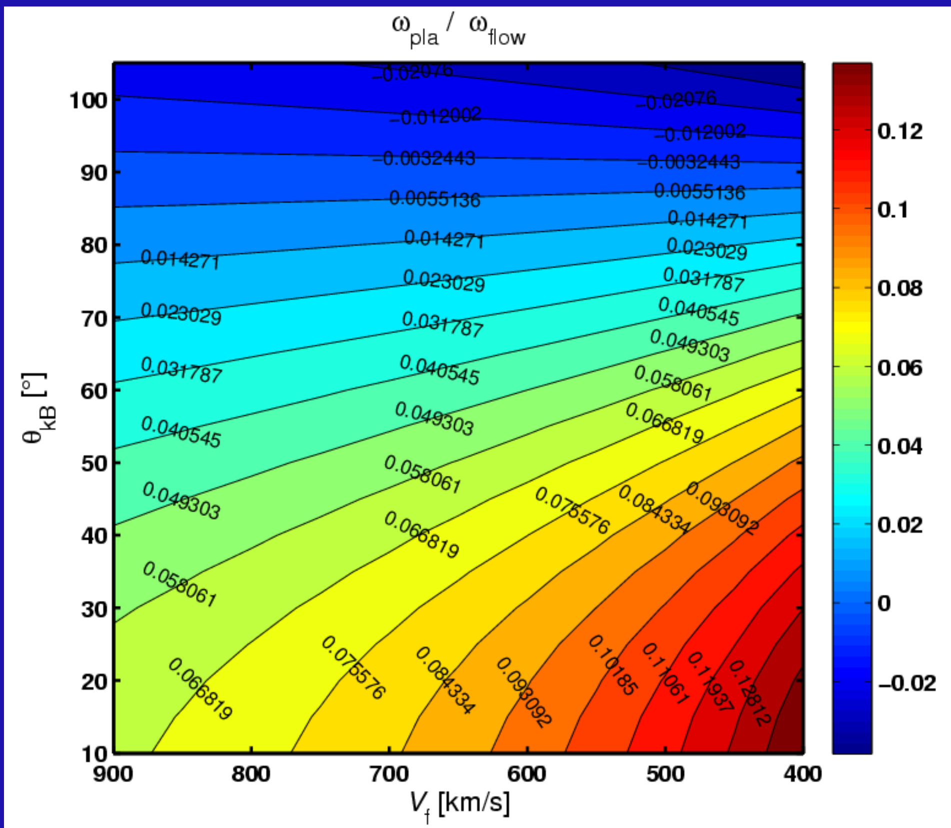
Inertial range



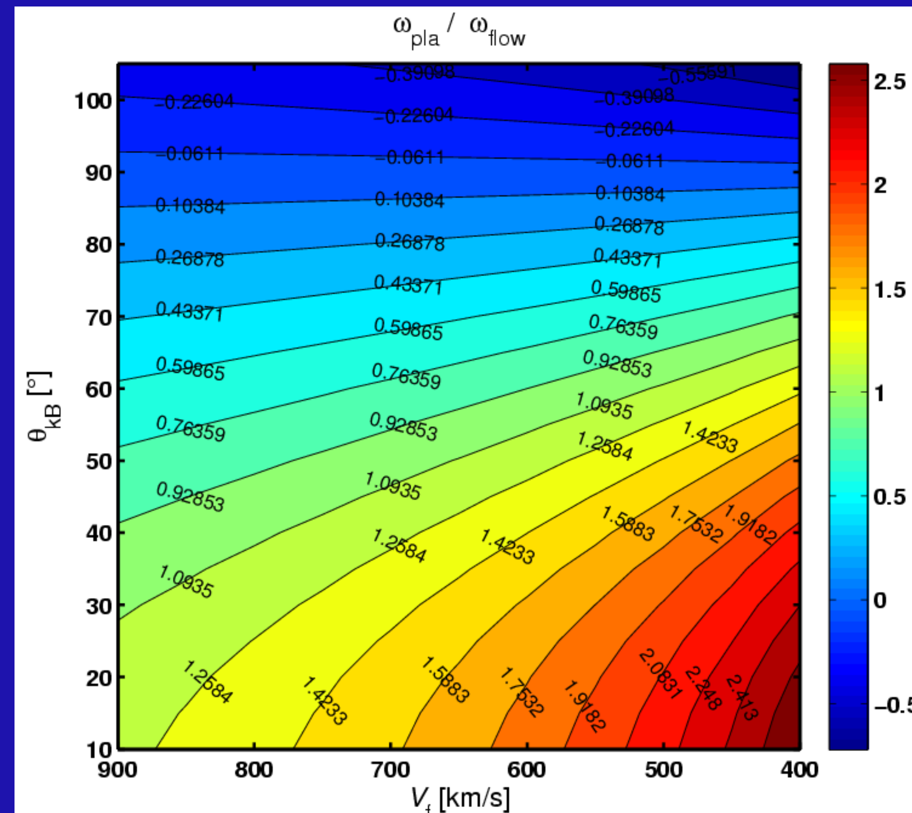
Sub-ion scales

Estimated Doppler shift

Inertial range

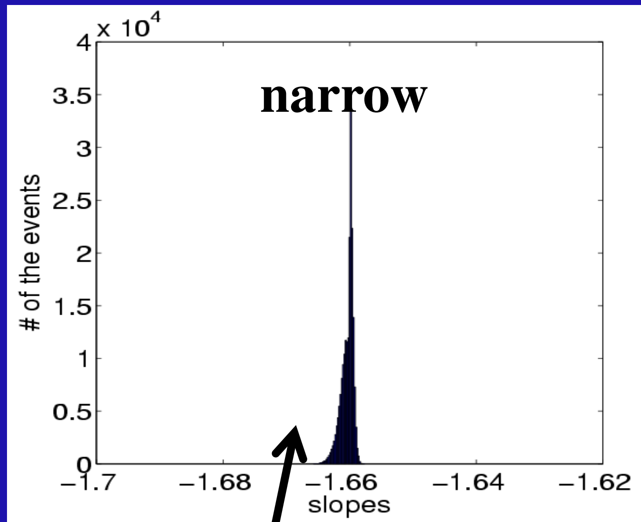


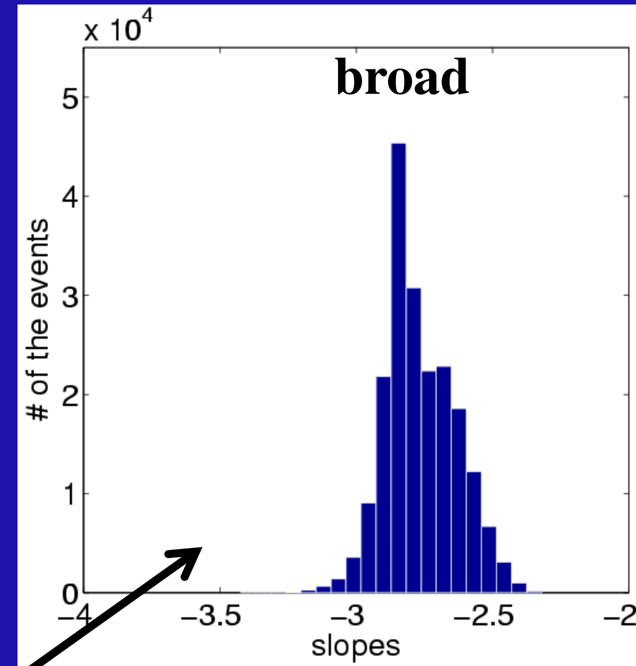
Sub-ion scales

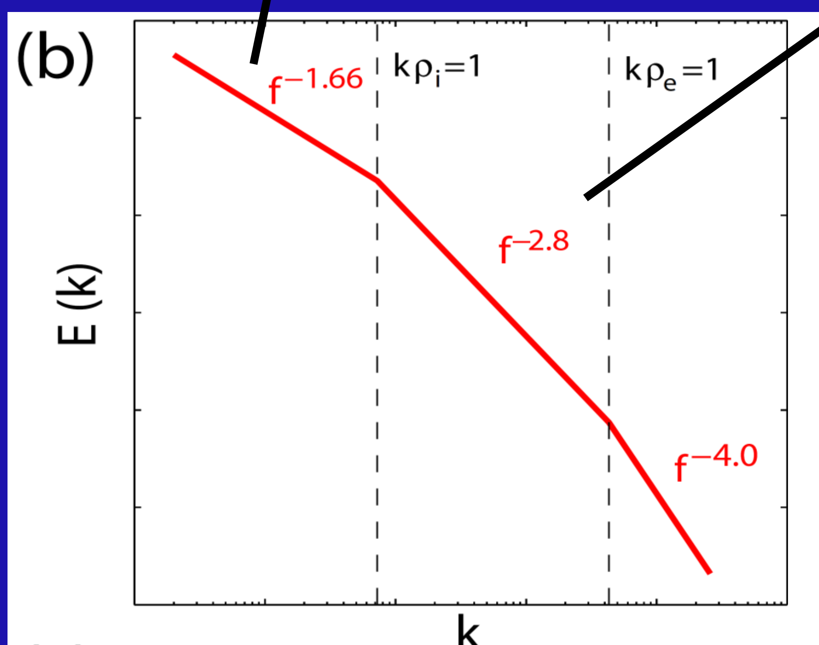


[Huang+, 2015b, submitted

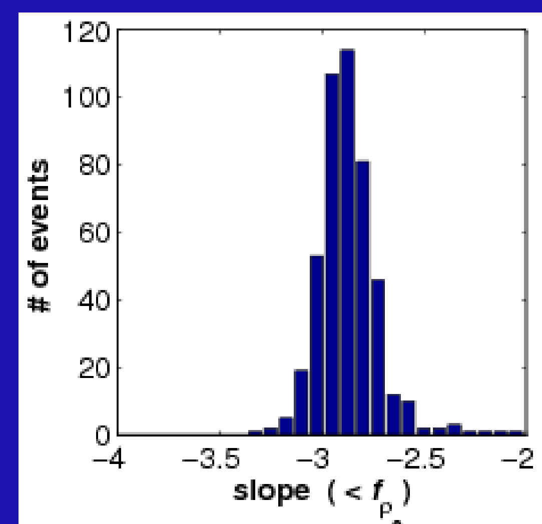
Simulated slopes







SW Observations



Conclusions

- **Solar wind turbulence does *not rigorously satisfy Taylor hypothesis at electron scale*: *dispersive waves may exist in the solar wind turbulence* with their frequencies in the plasma rest frame (ω_{pla}) comparable to the Doppler shift near ρ_e**

- **Our model based on the *variations of propagation angles and flow velocity* can explain the *broad distribution* of the slopes between ion and electron scale.**