A mechanism for the formation of 1/f spectrum in the Heliosphere

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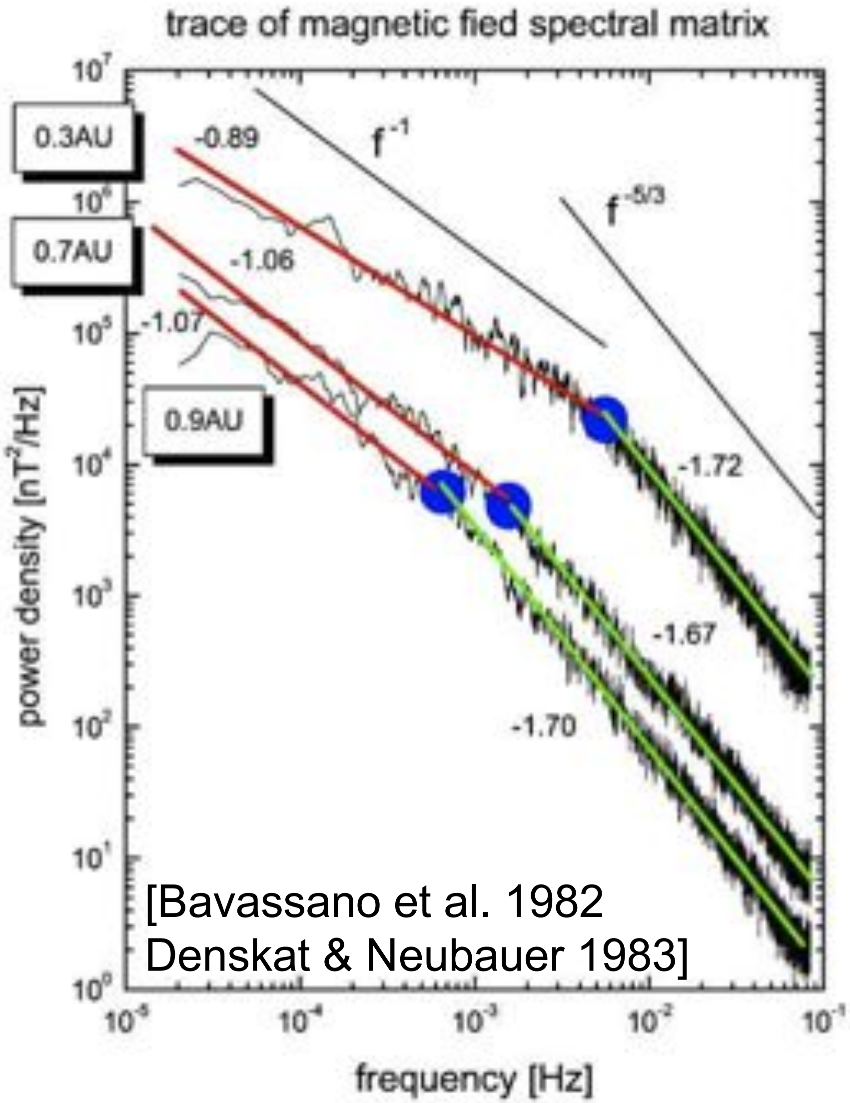
Helios, fast streams

[Bruno & Carbone 2005]



[Bavassano et al. 1982
Denskat & Neubauer 1983]

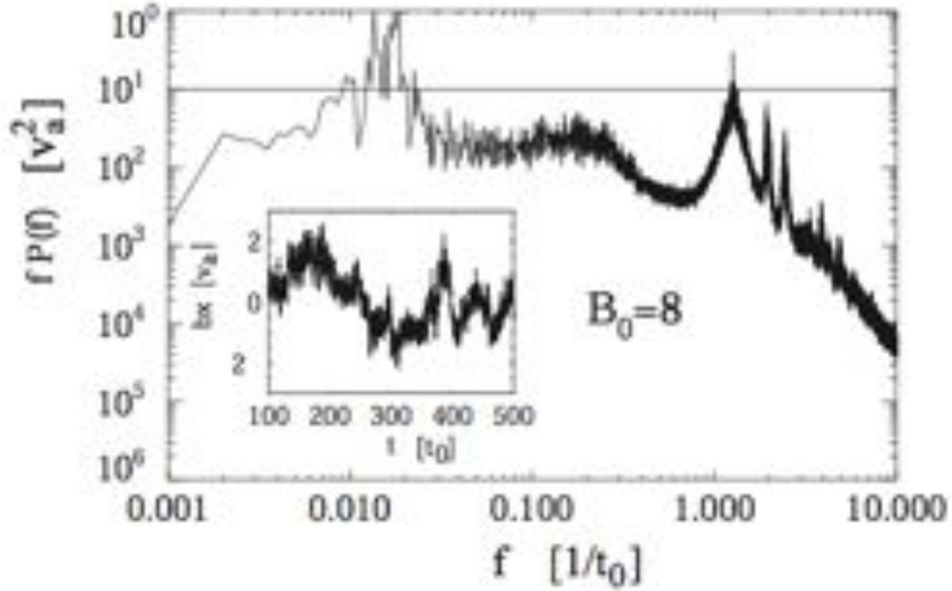
- 1/f part:
  WKB evolution, freezed spectrum
  [Bavassano et al. 1982, Marsch & Tu 1990]

- Evolution with distance:
  turbulence and expansion
  [Tu et al. 1984, Tu 1988, Tu & Marsch 1995]

Origin of 1/f?

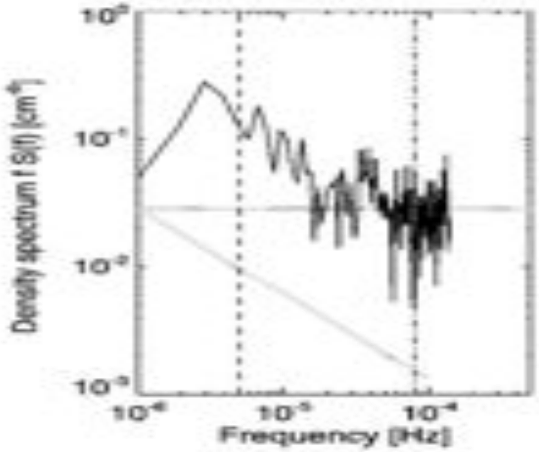
MHD turbulence

[Dmitruk et al. 2007,2011]



Phot. or corona B

[Matthaeus & Goldstein 1986,
Close et al. 2004 Matthaeus et al. 2007]



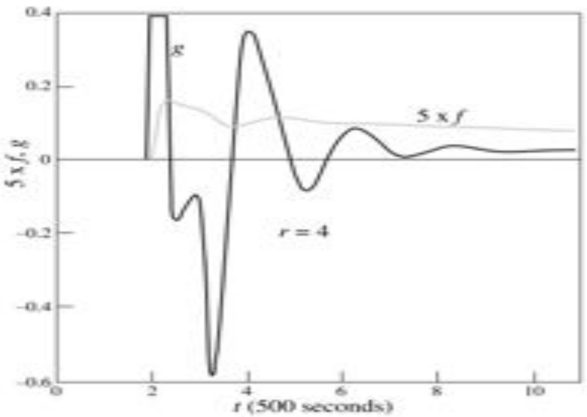
Turbulence + expansion

[Velli et al 1993]

$$\mathbf{z}^{\pm} = \mathbf{P}^{\pm}(\epsilon t, \epsilon \mathbf{r}) \exp(i\mathbf{k}\cdot\mathbf{r} + i\phi^{\pm}) + \epsilon \mathbf{S}^{\pm}(\epsilon t, \epsilon \mathbf{r}) \exp(i\mathbf{k}\cdot\mathbf{r} + i\phi^{\mp}),$$

Ringing in Sub-Alfvénic SW

[Hollweg & Isenberg 2007]



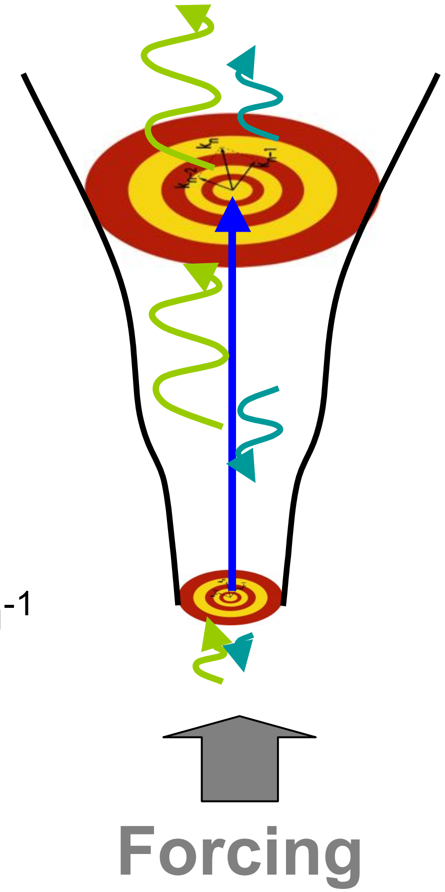
Turbulence in Coronal holes

- **Assigned <u>radial</u> U, rho, B**
  - No back reaction
- **Inject AW (Z_+^0) from below**
  - Reflection creates Z- : **Z- > Z+**

=> **2D turbulence develops** (in ⊥ plane)

  - Shell-RMHD model (scalar model Re~10^4-10^5)

Coronal hole≡flux tube



Wave/turbulence parameters

$\mathbf{Z_+^0, k_\perp^0, T_{cor}^0}$ $\quad (t_{NL}^0 = 1/k_\perp^0 Z_+^0)$ $\left\{ \begin{array}{l} z_+^0 = 10 \text{ km/s}, \\ k_\perp^0 = 2\pi/16 \text{ Mm}^{-1} \\ T_{cor}^0 = 600 \text{ s} \end{array} \right.$

CONTROL PARAMETER: $\mathbf{T_{cor}^0/t_{NL}^0 \sim 1}$

Equations

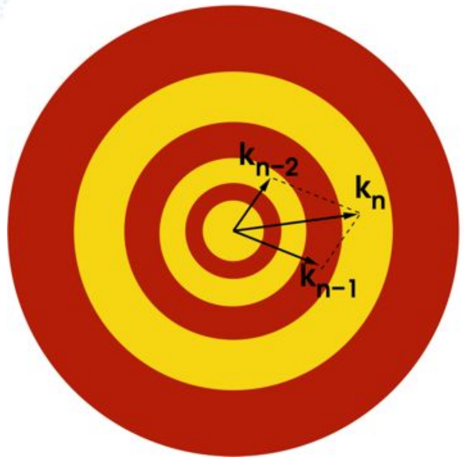
$$\frac{\partial z_n^{\pm}}{\partial t} + (U \pm V_a) \cdot \nabla z^{\pm} + z^{\mp} \cdot \nabla (U \mp V_a) + \frac{1}{2}(z^{-} - z^{+}) \nabla \cdot \left(V_a \mp \frac{1}{2} U \right) =$$

$$-\frac{1}{\rho} \nabla \left(p^T - \langle p^T \rangle \right) - \left[z^{\mp} \cdot \nabla z^{\pm} - \langle z^{\mp} \cdot \nabla z^{\pm} \rangle \right]$$

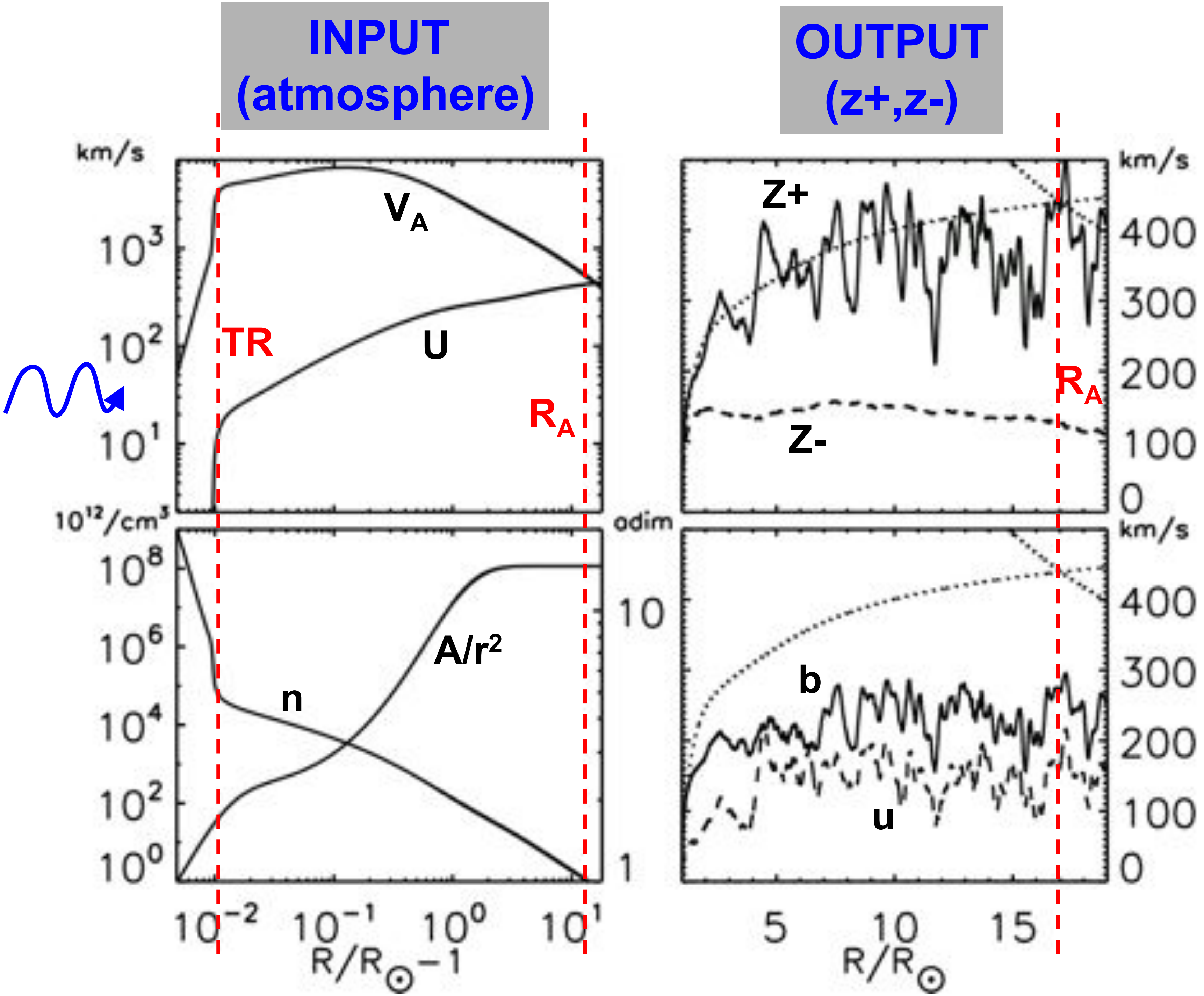
$$\frac{\partial z_n^{\pm}}{\partial t} + (U \pm V_a) \frac{\partial z_n^{\pm}}{\partial r} - \frac{1}{4}(U \mp V_a) \left(\frac{1}{\rho} \frac{d\rho}{dr} \right) z_n^{\pm}$$

$$+ \frac{1}{4}(U \mp V_a) \left(\frac{1}{\rho} \frac{d\rho}{dr} + 2 \frac{1}{A} \frac{dA}{dr} \right) z_n^{\mp} = T_{\mathrm{npq}}^{\pm} - \nu k_n^2 z^{\pm},$$

$$T_{npq}^{\pm} \simeq k_n z_p^{\pm} z_q^{\mp}$$



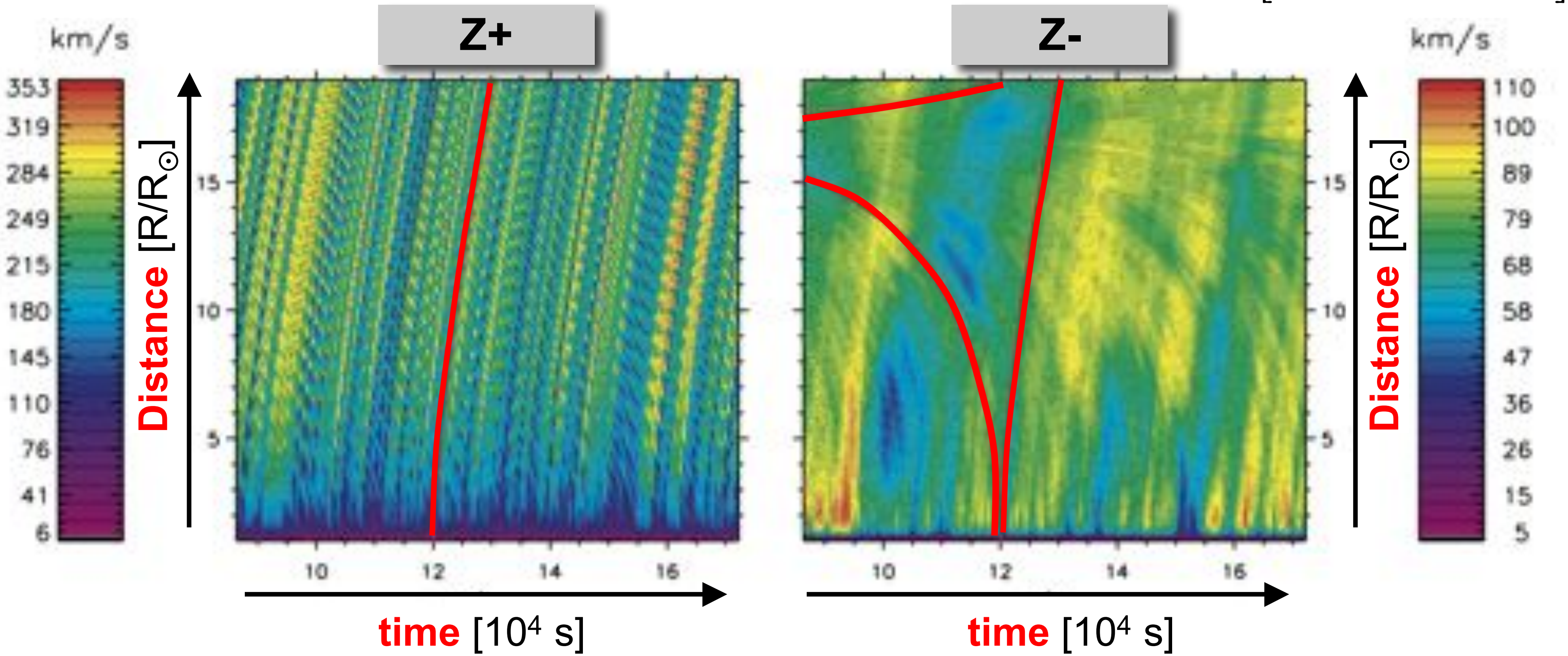
$k_n = k_0 2^n \quad k_0 = k_0 / A(r)$



INPUT
(atmosphere)
OUTPUT
(z+,z-)
km/s
V_A
TR
U
R_A
10^12/cm^3
n
A/r^2
adim
R/R⊙−1
Z+
Z-
b
u
R/R⊙

Space-time diagram

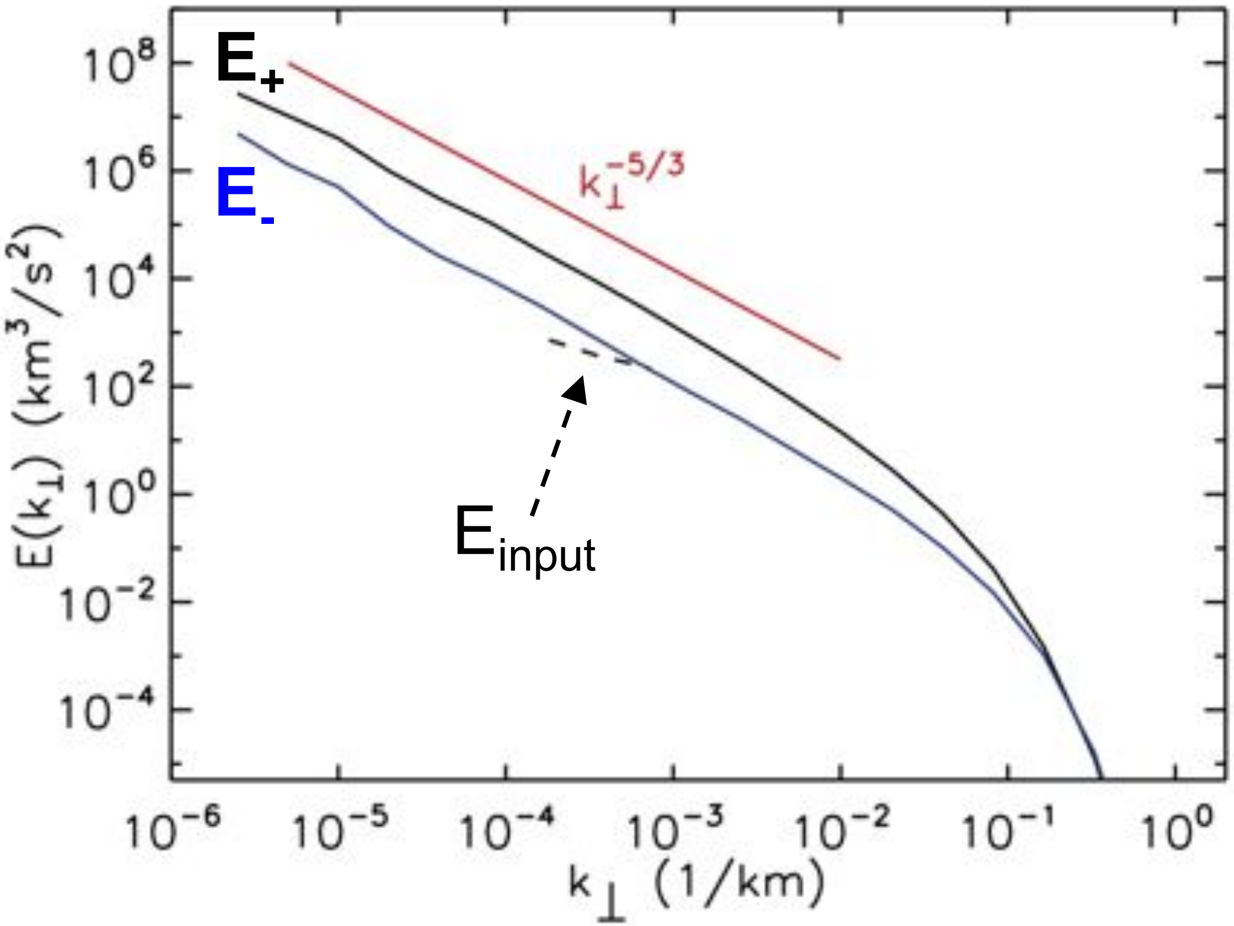
[Verdini et al. 2009]



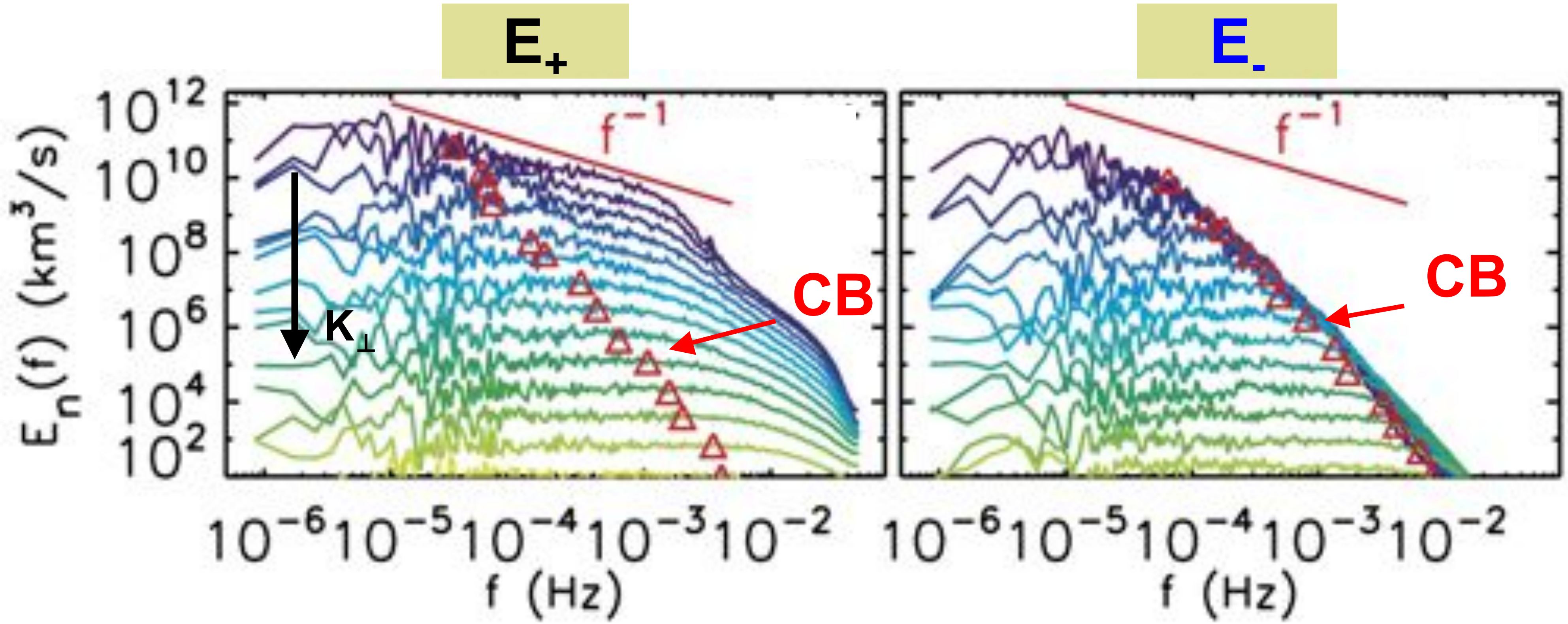
Z- is smoother then Z+ and **Z- ~ 1/3 Z+**

Z- has both proper and forced component

Time averaged PERP. SPECTRA at $R=19R_\odot$ ($>R_A$)



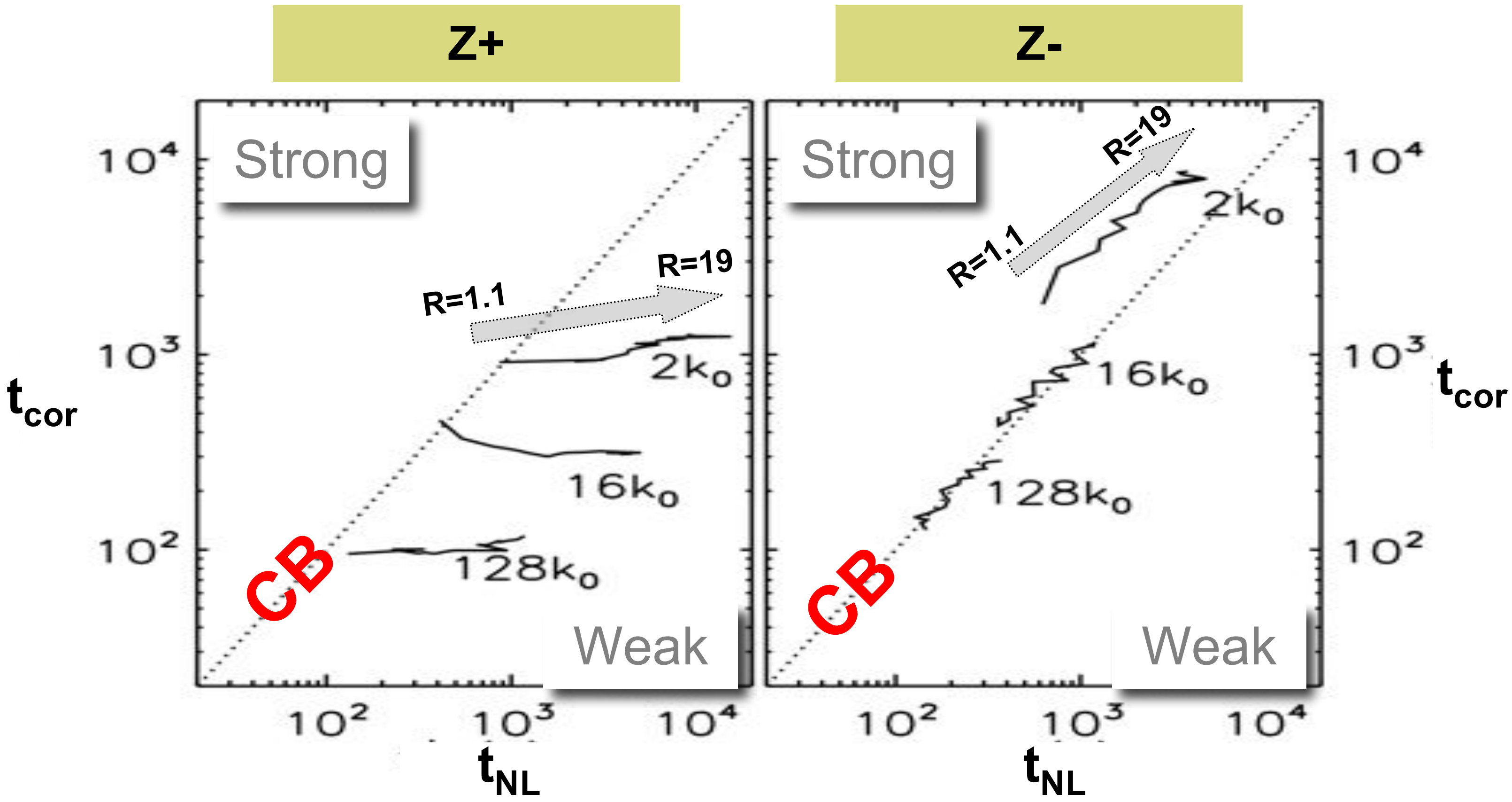
Freq. SPECTRA at R=19$R_\odot$



[Verdini et al. 2012]

CB: $t_{cor}=t_{NL}$ => In the figure $\triangle=1/t_{NL}$

Correlation and NL time at different coronal heights



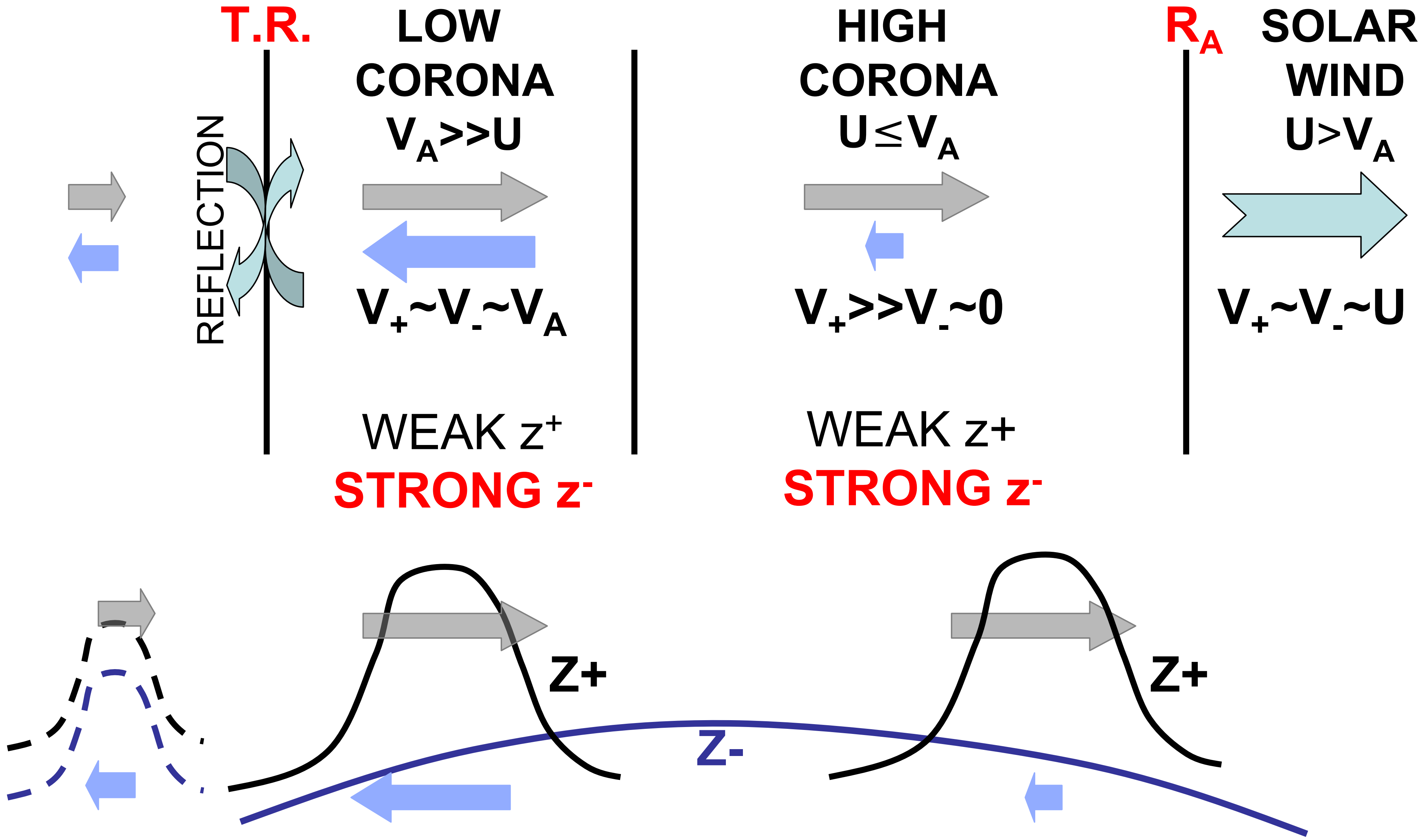
Weak turbulence (Z+)

t_{cor}~const => Δf~const

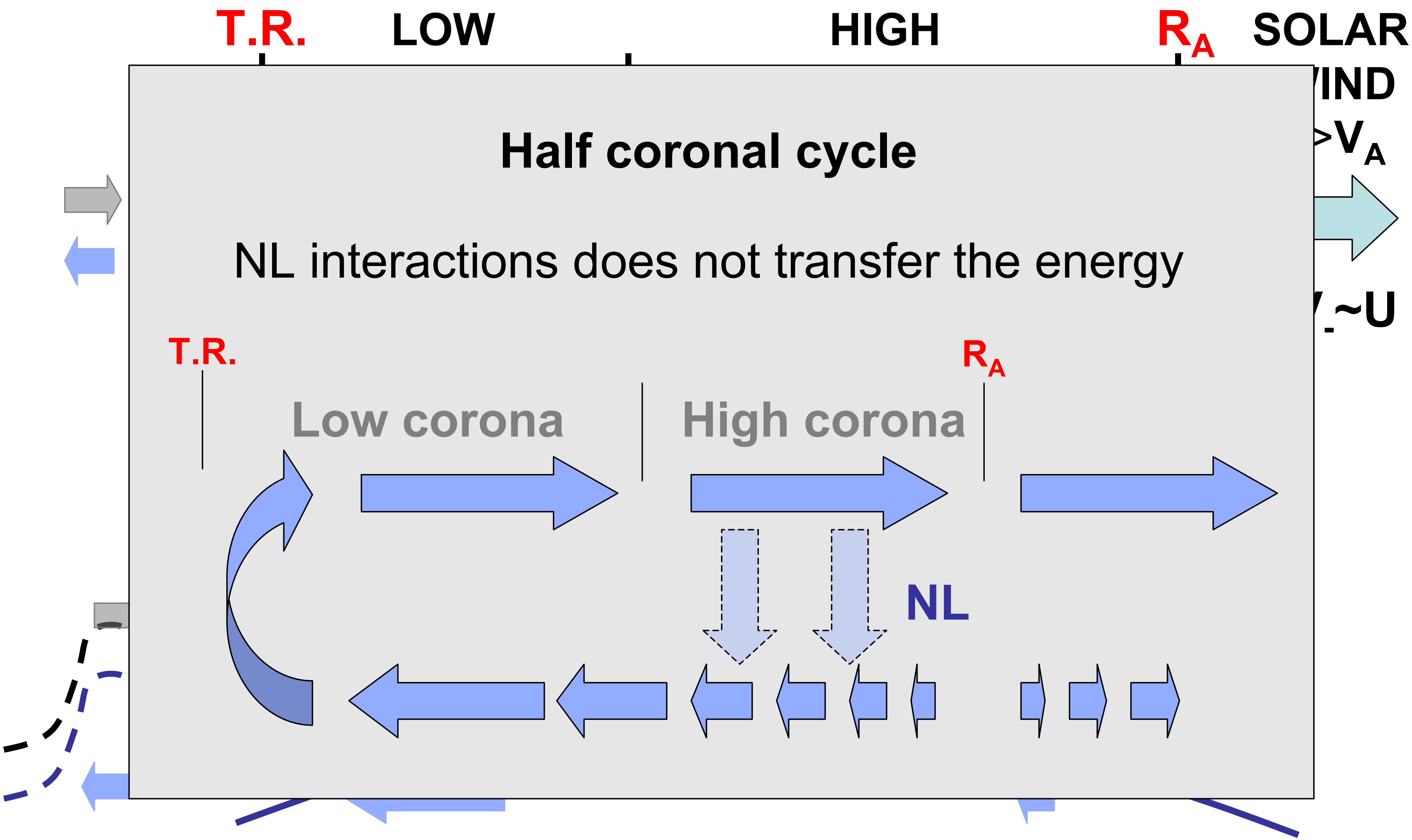
Strong Turbulence (Z-)

$t_{cor} \propto t_{NL}$ (CB) => Δf~$1/t_{cor}$

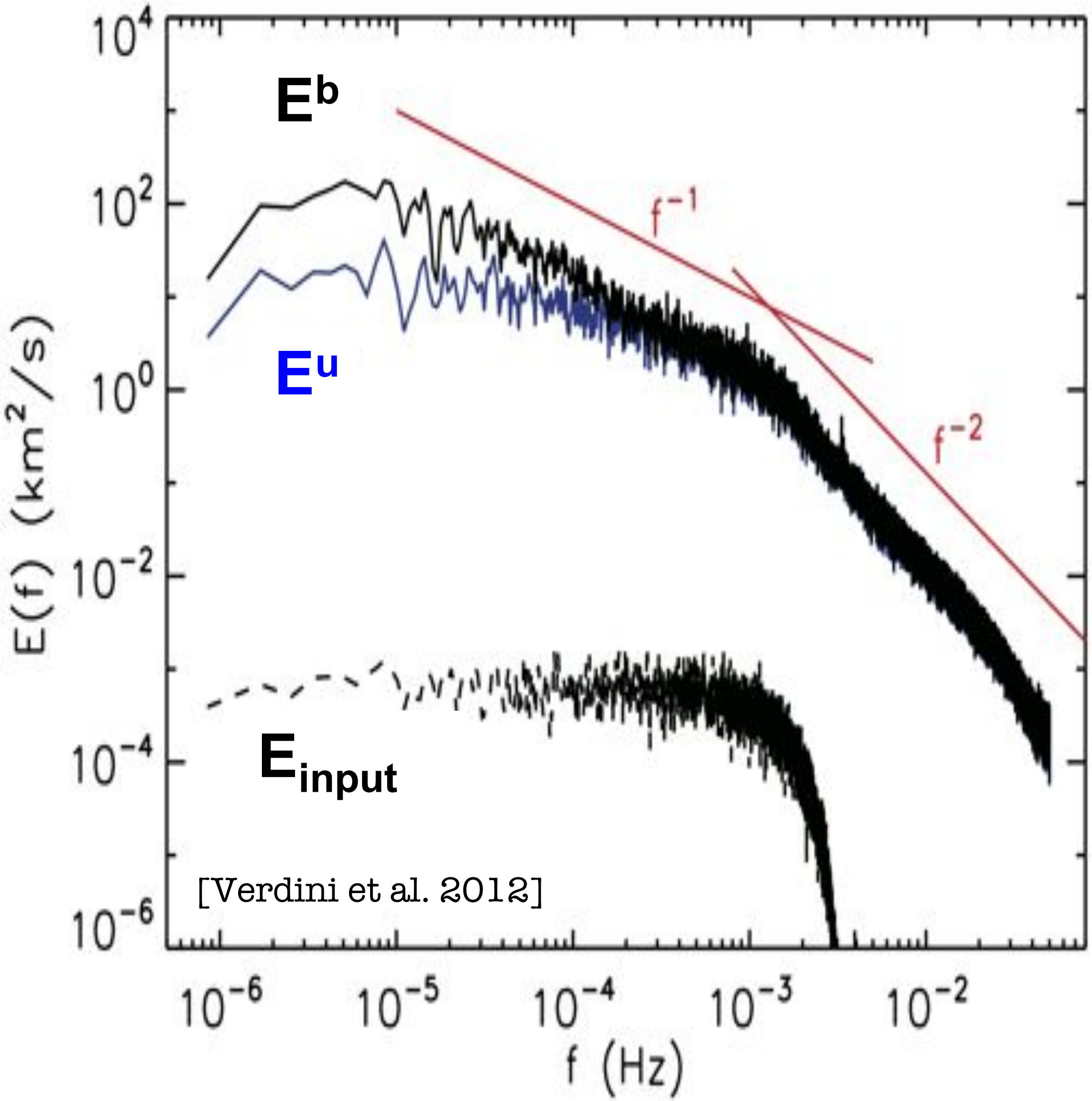
Reflection driven cascade



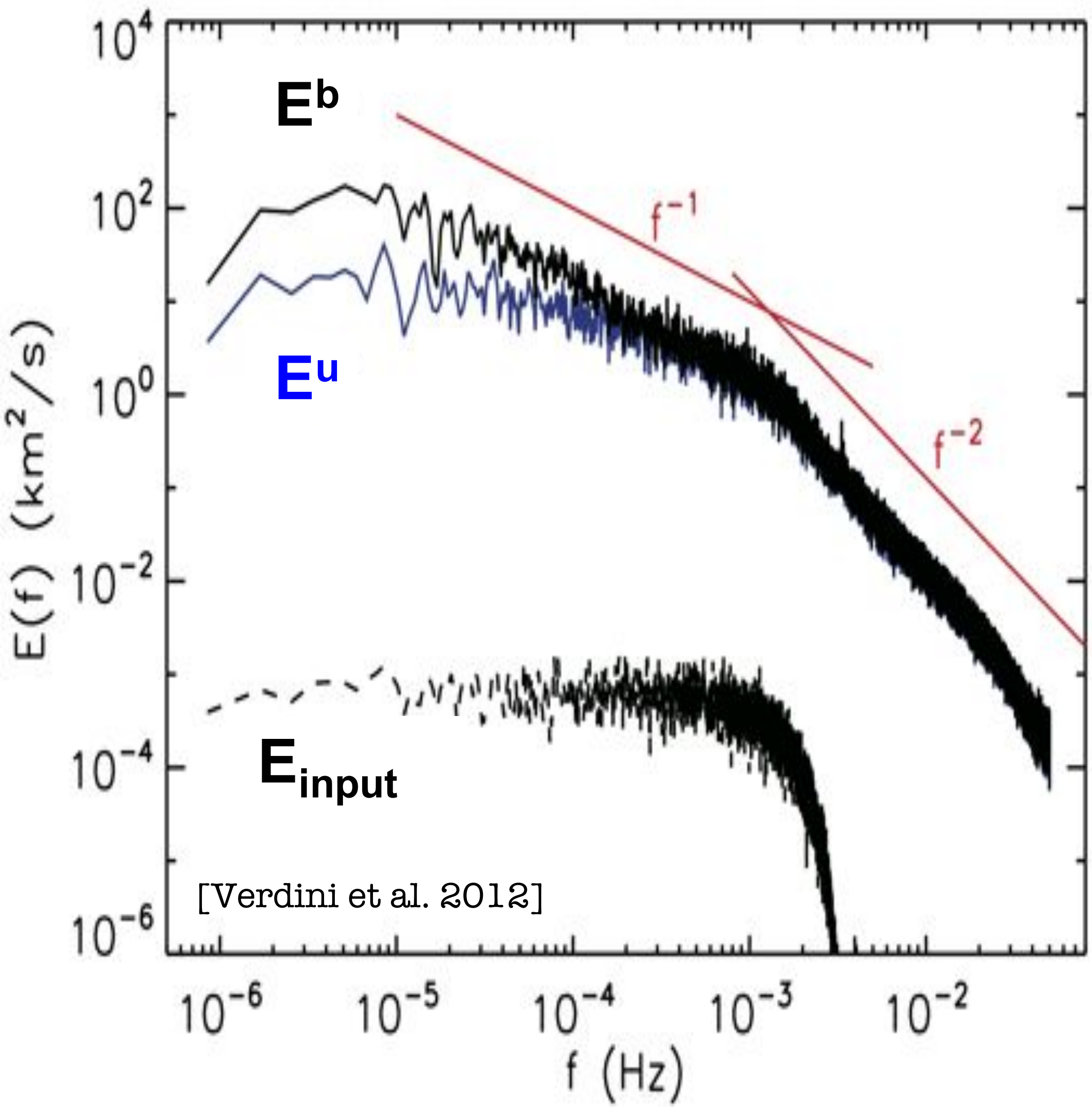
Reflection driven cascade



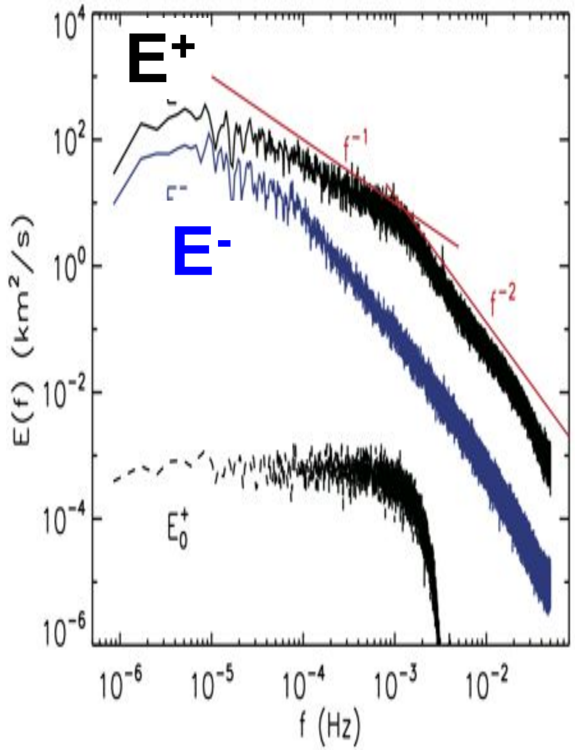
Freq. Spectrum @ R=19R$_\odot$



Freq. Spectrum @ R=19R⊙



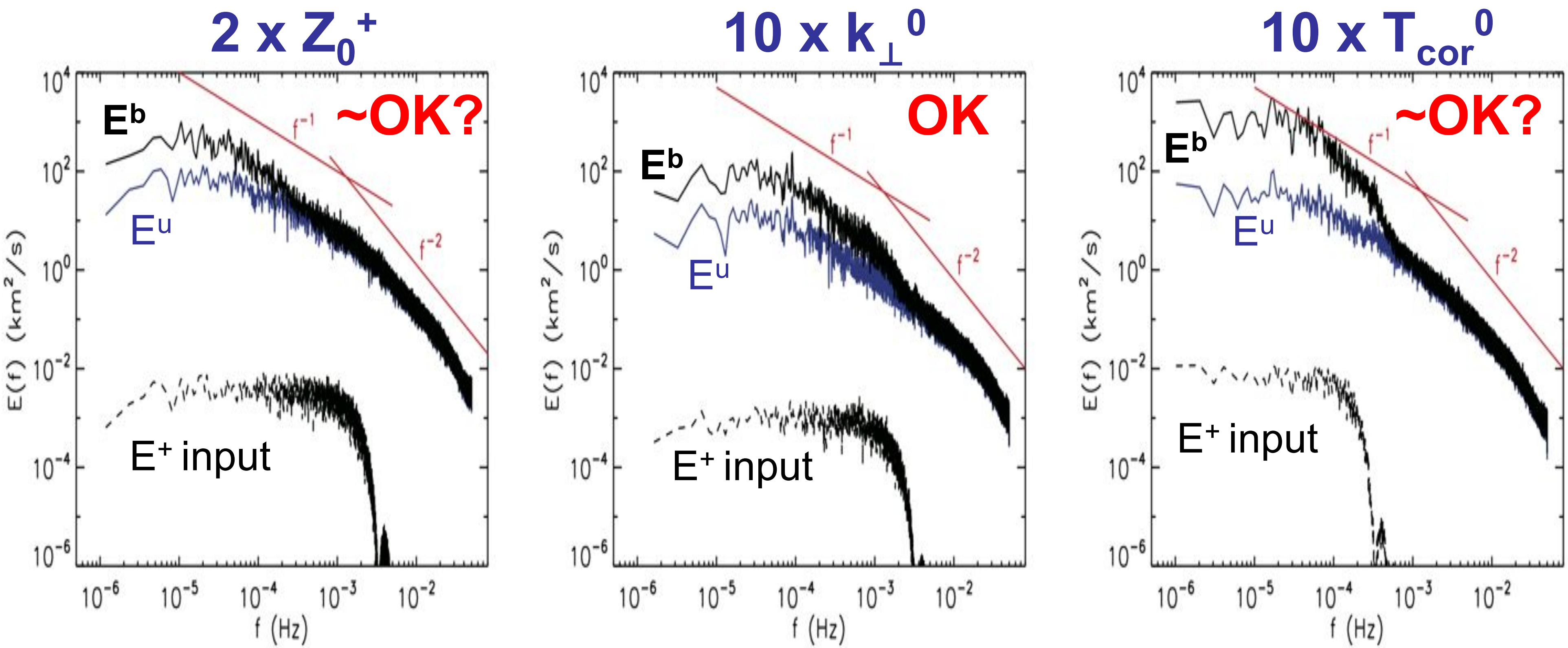
f<10^-4 Strong Z- cascade
+reflection
f>10^-4 Weak Z+ cascade



A. Verdini On the origin of the 1/f spectrum

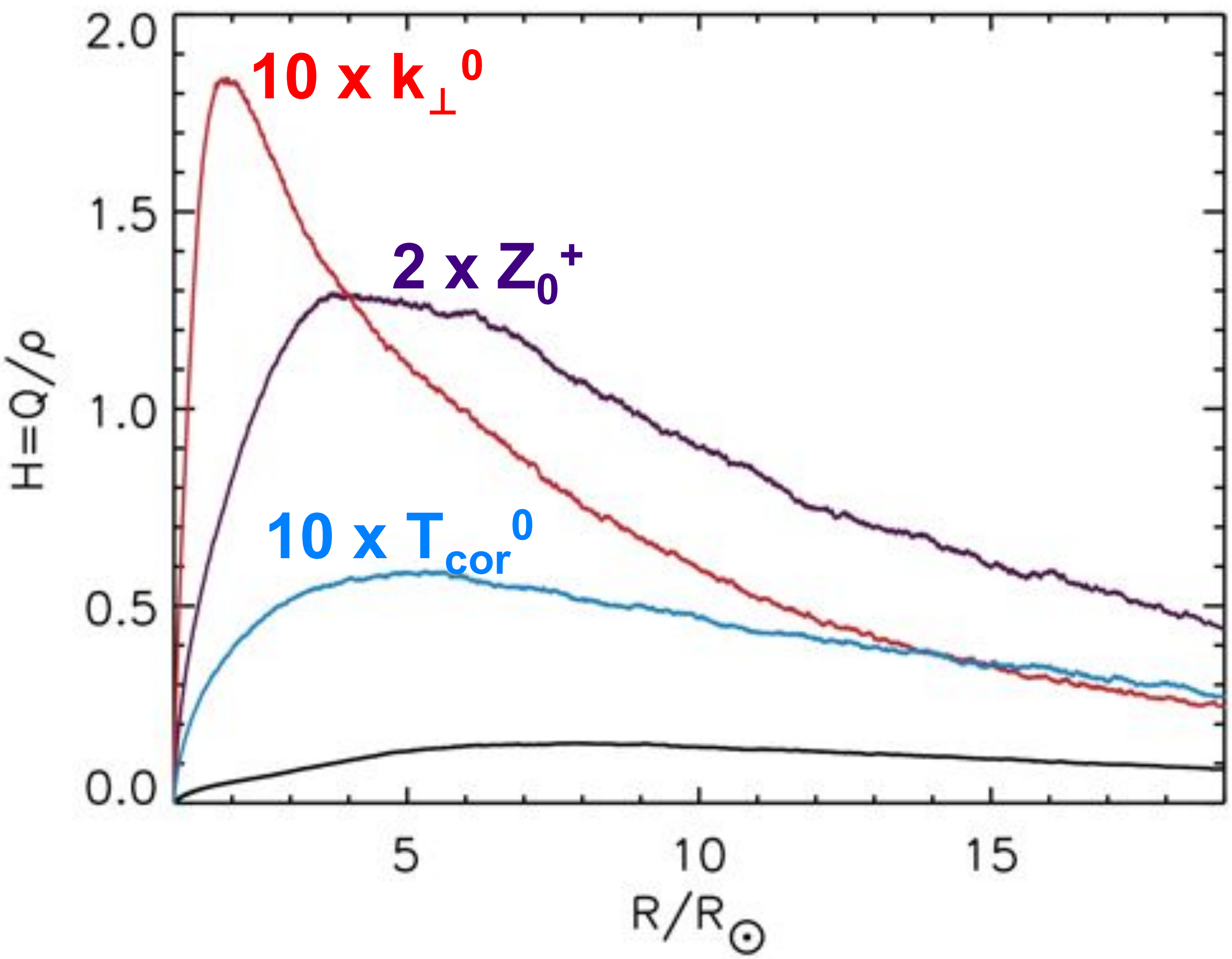
Increasing Turb. Strength

Increasing T_{cor}^0/t_{NL}^0, the f^{-1} is partially lost



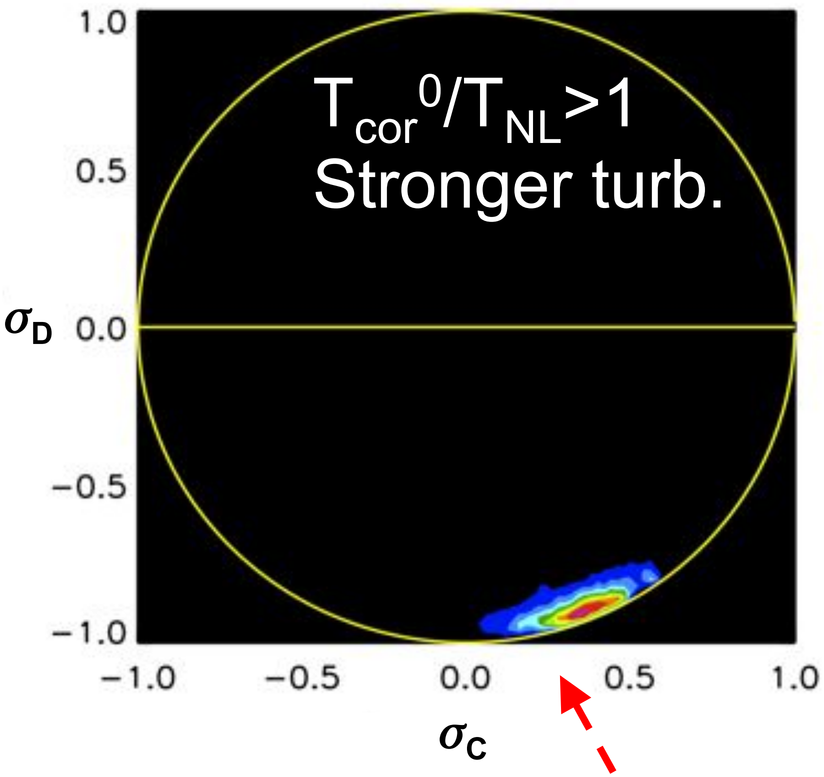
Increasing Turb. Strength

...but high heating rates and 1/f are not incompatible

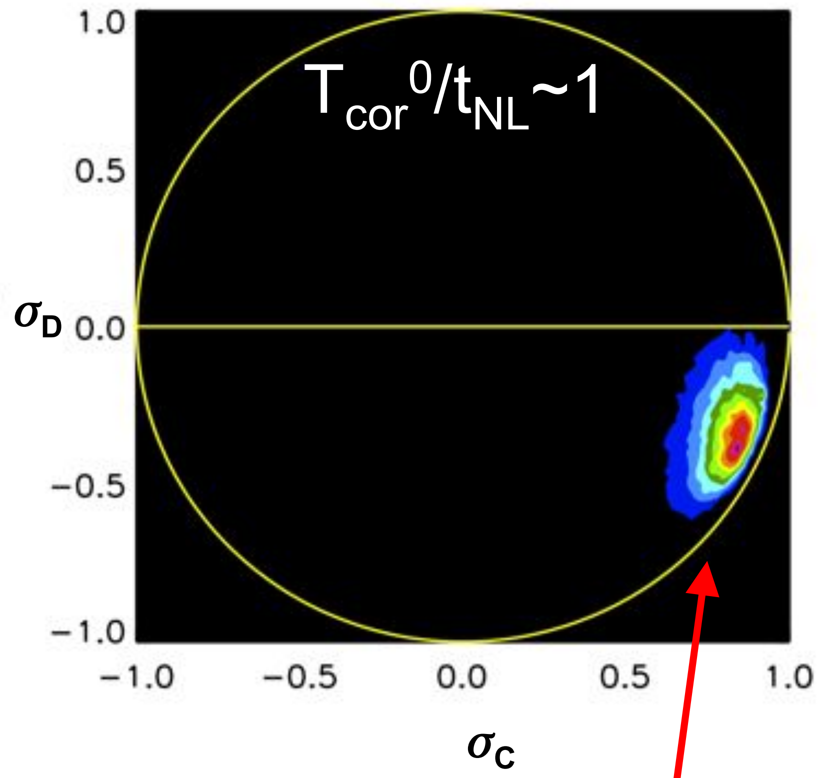


Shell-RMHD model

T_{cor}^0= 1.5h @ 0.1 AU



T_{cor}^0= 10min @ 0.1 AU



$$\sigma_C = \frac{E^+ - E^-}{E^+ + E^-}$$

$$\sigma_D = \frac{E^u - E^b}{E^u + E^b}$$

Flux tube component

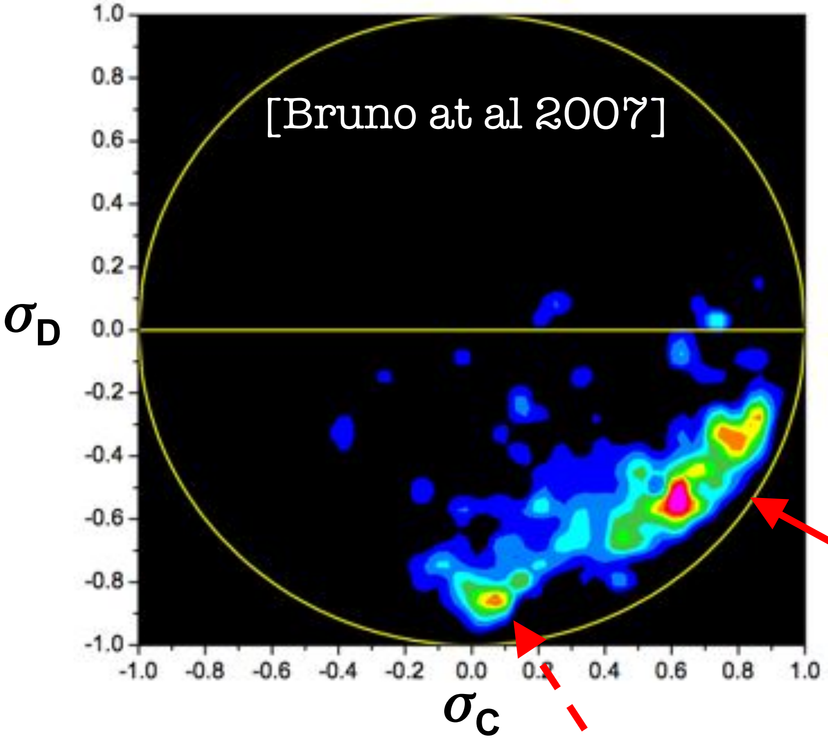
$\sigma_D \sim -1$ => b >> u
$\sigma_C \sim 0$ => Z+ ~ Z-

Alfvénic component

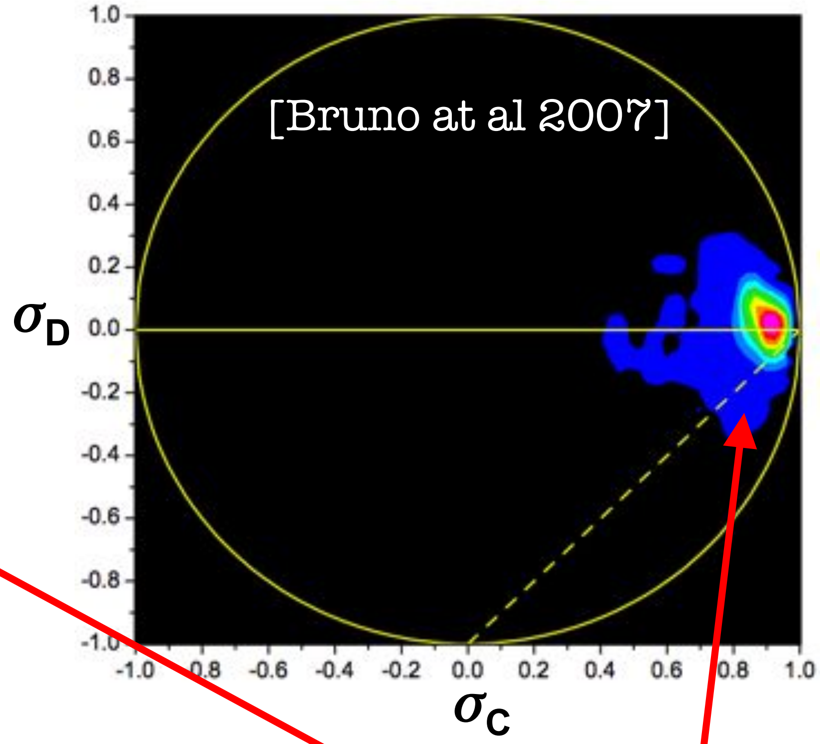
$\sigma_D \sim 0$ => b~u
$\sigma_C \sim 1$ => Z+>>Z-

Observations

SLOW WIND @ 0.29AU



FAST WIND @ 0.29AU



$$\sigma_C = \frac{E^+ - E^-}{E^+ + E^-}$$

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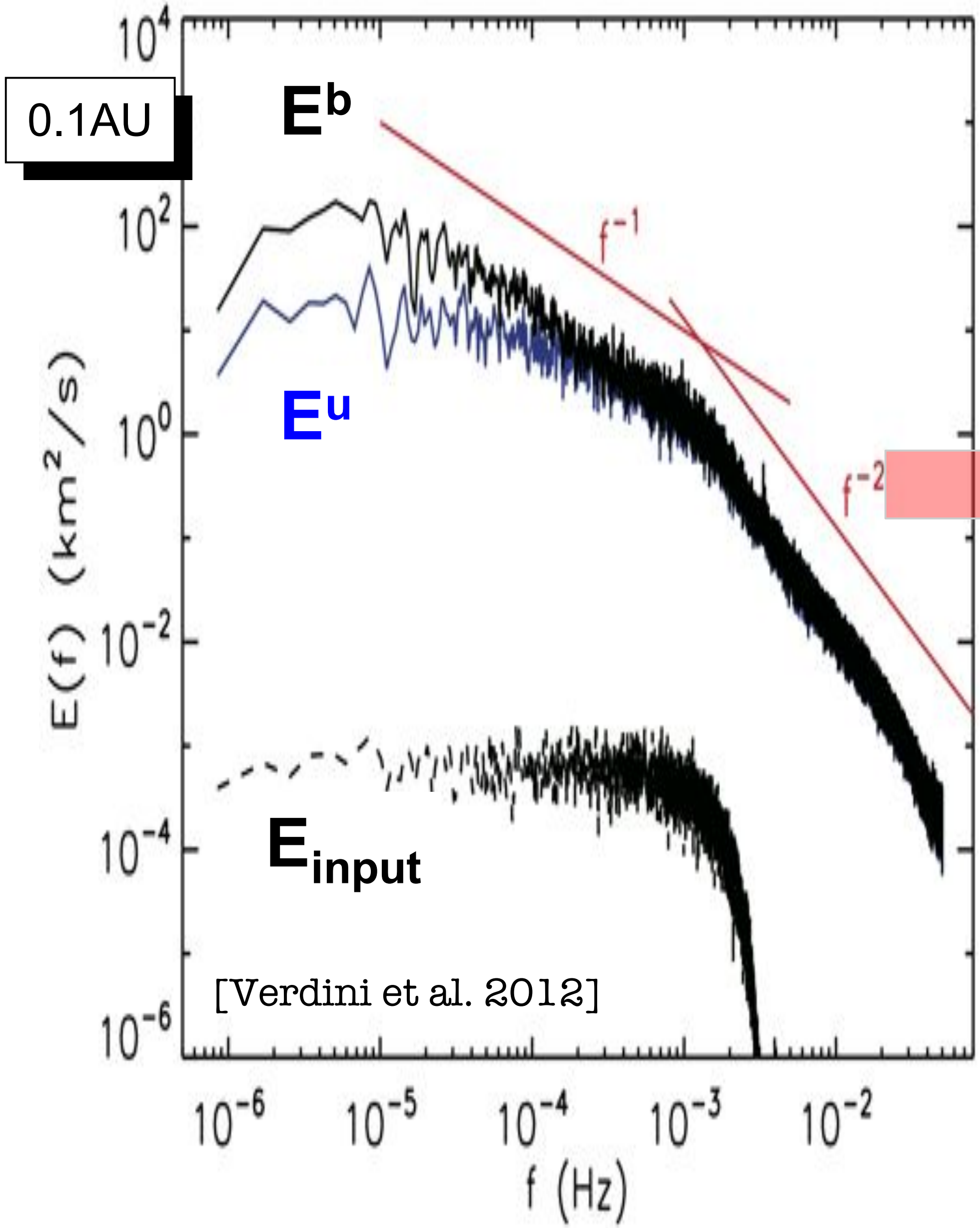
Flux tube component

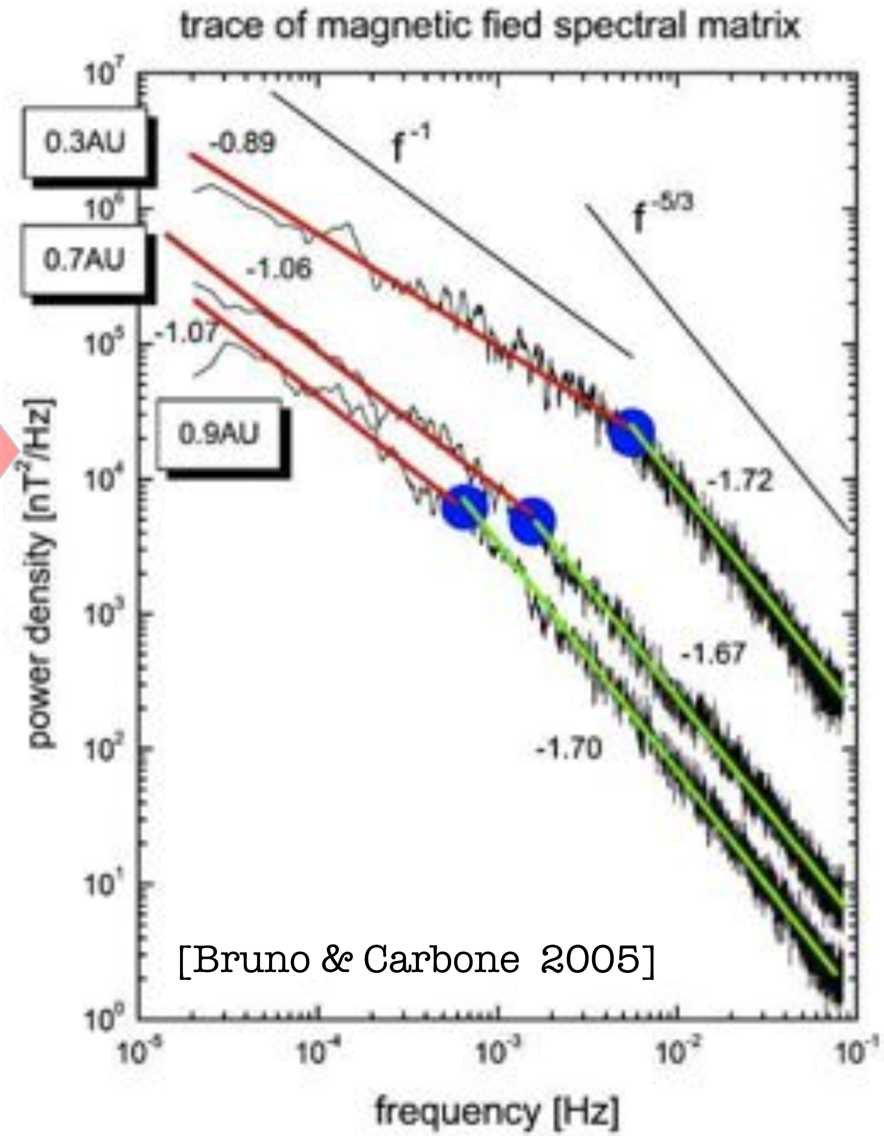
σ_D **~-1** => b >> u
σ_C **~ 0** => Z+ ~ Z-

Alfvénic component

σ_D **~ 0** => b~u
σ_C **~ 1** => Z+>>Z-

Following evolution ?



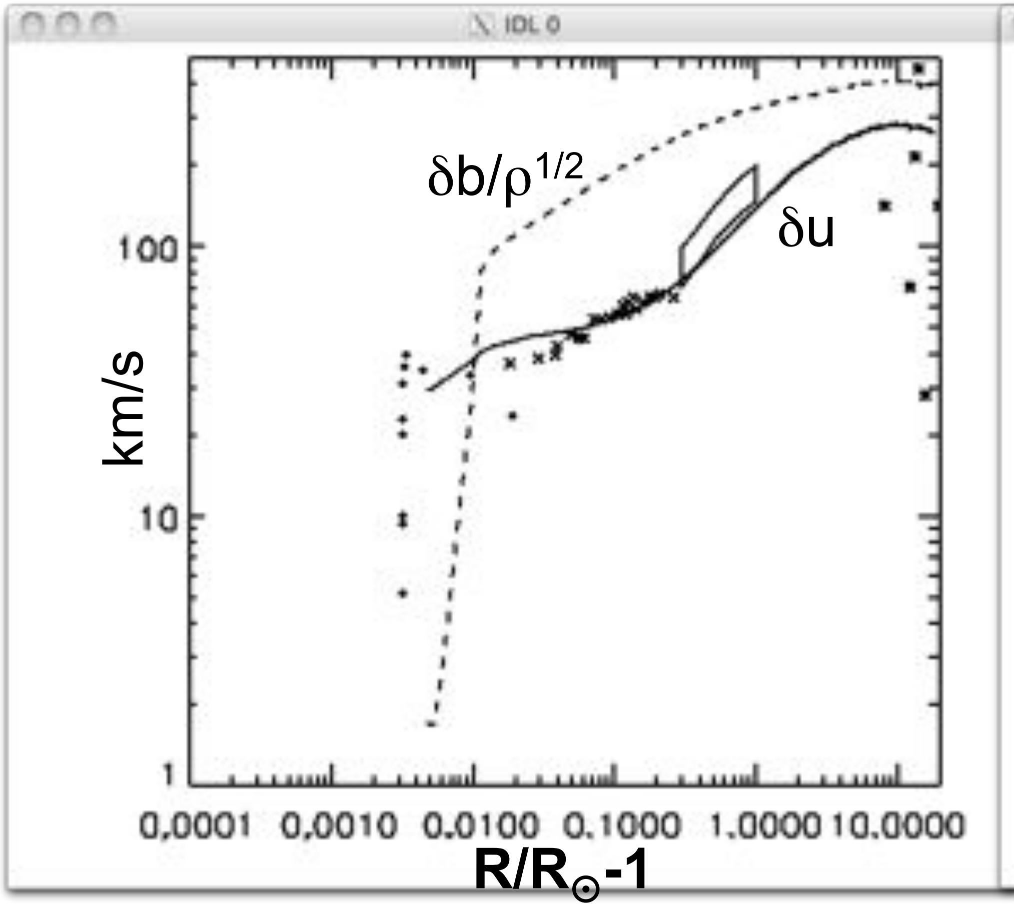


Conclusion

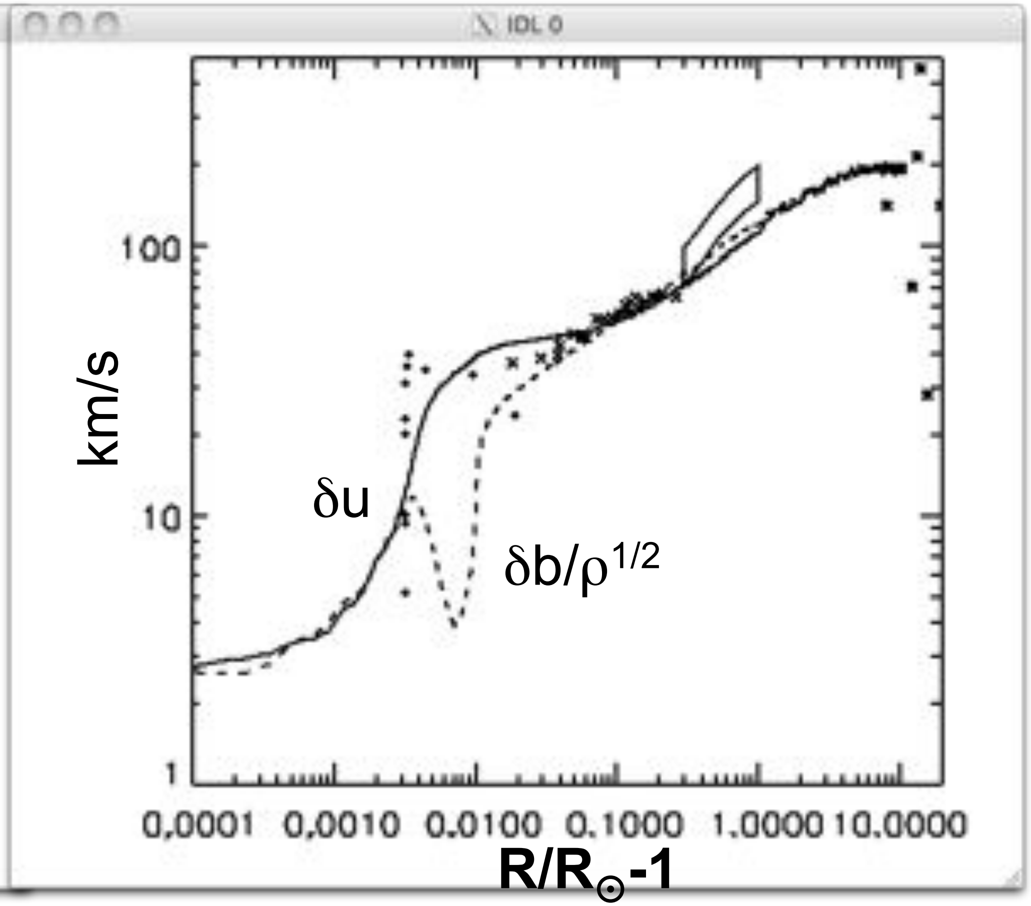
- The **1/f spectrum** can be generated by **turbulence** in the sub-Alfvénic solar wind if turbulence is **weak** enough
- Weak means $\mathbf{T_{cor}^0/t_{NL}^0 \approx 1}$ (small wave amplitude and wide frequency spectra at the photosphere): the expected conditions at the surface
- **Reflection** at the photosphere, **different SW** profiles or **self consistency** may change the spectrum
- **In the heliosphere**:
  - Expansion partially freezes the $E^{\pm}$ spectra that evolve self-similarly
  - B_0 turns, the observed break could result from a superposition of parallel and perpendicular spectra (work in progress)

Amplitudes (SW & FW)

Slow Wind ($2xZ_0$)



Fast Wind



E^+, E^- outside X_A and Lin sol.