On the location of the low frequency break of magnetic field power spectrum within slow speed solar wind

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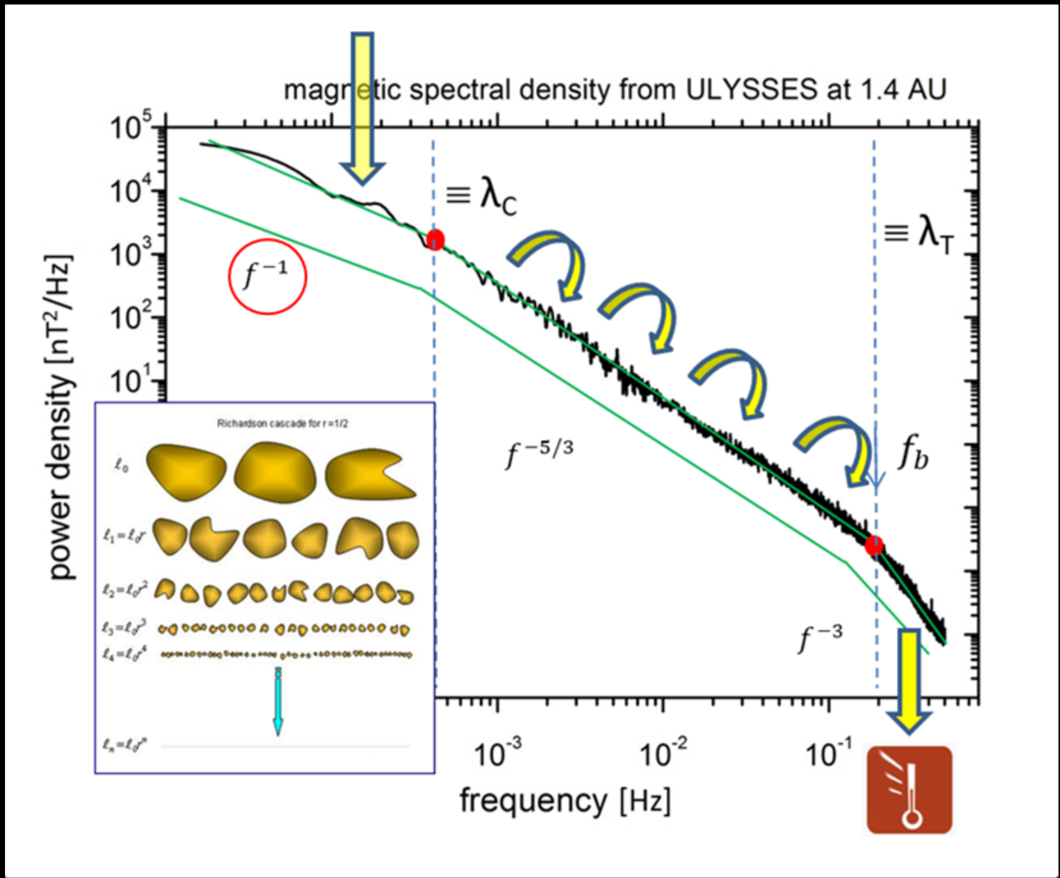
Dynamical Processes in Space Plasmas
Israel, 22-29 April 2018

Interplanetary magnetic field power density spectrum



Suggestions about origin of f^{-1}

- Superposition, within the Alfvénic radius, of uncorrelated samples of solar surface turbulence whose correlation lengths are lognormally distributed

  [Matthaeus and Goldstein, 1986]

- Upward traveling low frequency waves at coronal base are capable of self-generating *1/f* spectrum in density and B
- *1/f* not present in similar hydrodynamics simulations (role of magnetic field)

  [Dmitruk et al., 2002-2004]

- 1/*k* spectral region was found in photospheric observations
- Possible link between the structured surface of the sun and *1/f* scaling in IMF

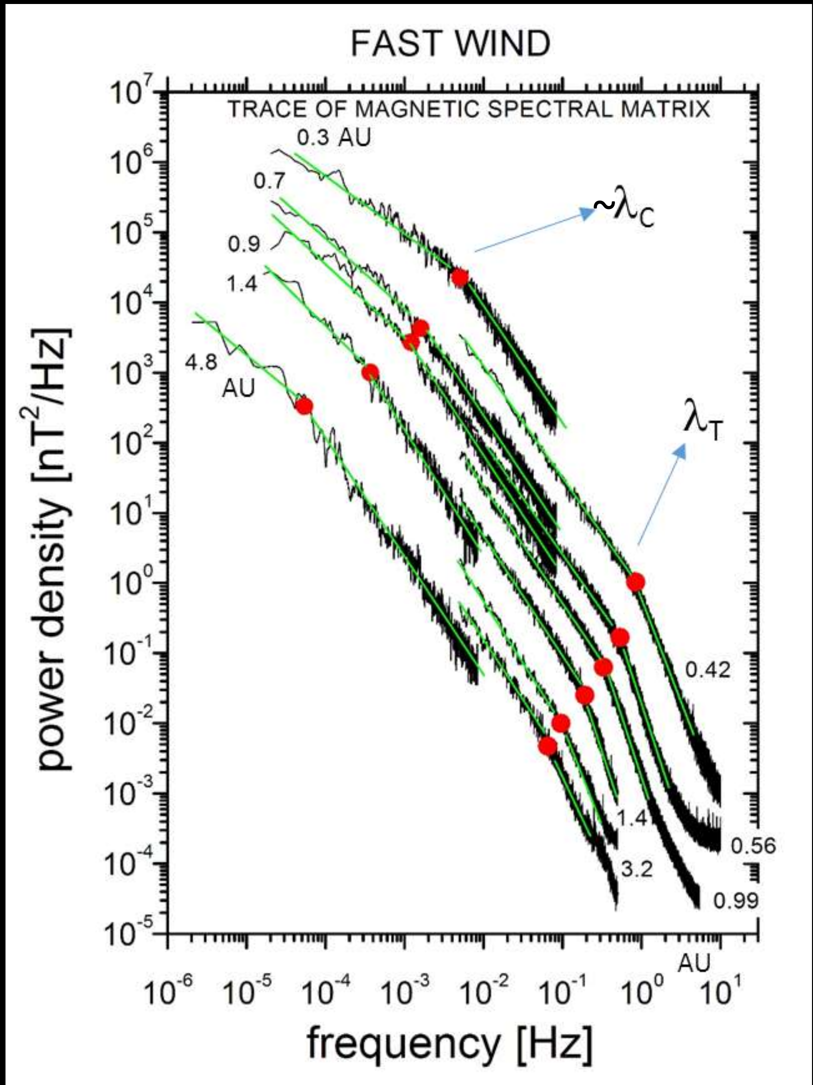
  [Nakagawa & Levine, 1974]

- Reflection of outward modes by large-scale gradients to interact non-linearly to produce a turbulent cascade with a spectrum scaling 1/f already within the sub-Alfvénic solar wind

  [Velli et al., 1989; Tenerani and Velli, 2017]

- etc...

Fast wind:
during the wind expansion (i.e. elapsed time) ⇒ low and high frequency breaks shift to lower frequencies



- Larger and larger scales are involved in the cascade process
- High frequency break $\propto R^{-1.1}$ (Bruno and Trenchi 2014)
- Low frequency break $\propto R^{-1.5}$ (Bruno and Carbone 2005)

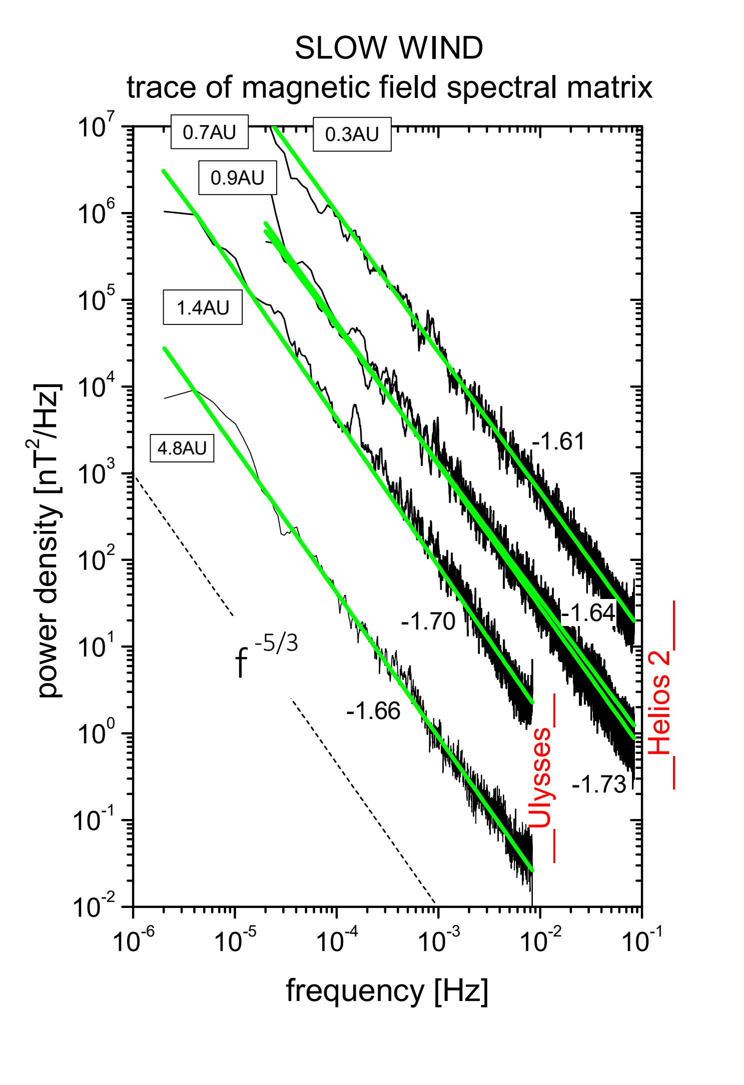
$$\mathrm{Re}_m^{eff} = \left(\frac{\lambda_C}{\lambda_T}\right)^2$$

<u>Effective Reynolds number</u>
(rough estimate from breaks locations)

(0.85/0.005)^2 = ...3E4	.3-.4 AU
(0.53/0.0015)^2 = ...1.1E5	.6-.7 AU
(0.38/0.001)^2 = ...1.5E5	.9-1 AU
(0.192/0.00034)^2 = ...3.2E5	1.4AU
(0.065/0.00005)^2 =..... 1.7E6	4.8-5.3AU

[Matthaeus et al., 2005: 2.3E5 1.AU]

Slow wind:
spectra from Helios and Ulysses do not show any low frequency break



- f^{-1} possibly located at lower frequencies wrt fast wind

⇩

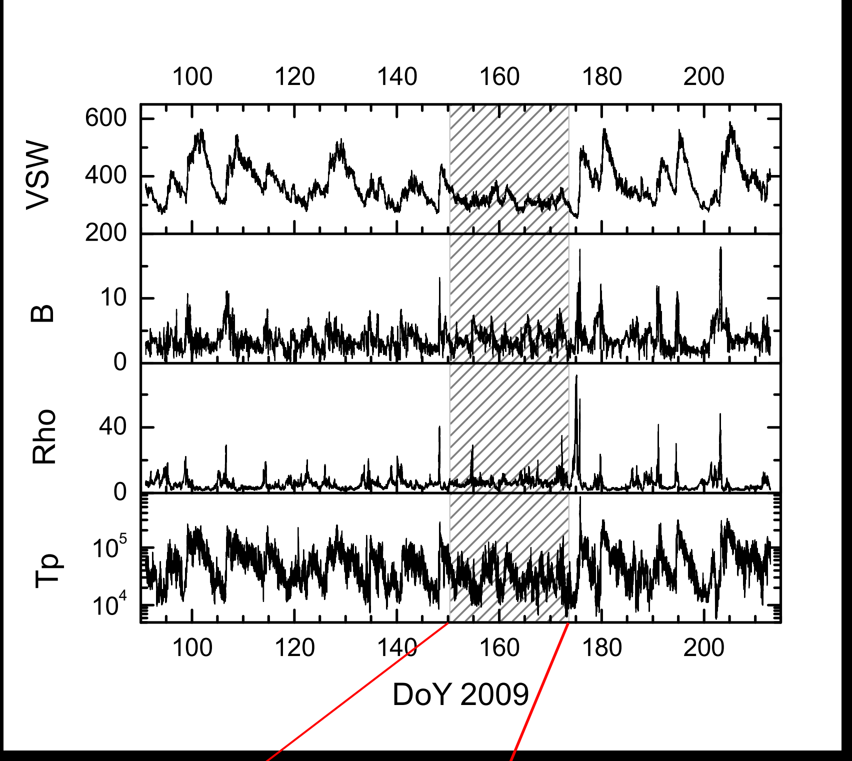
- turbulence would be older than in fast wind

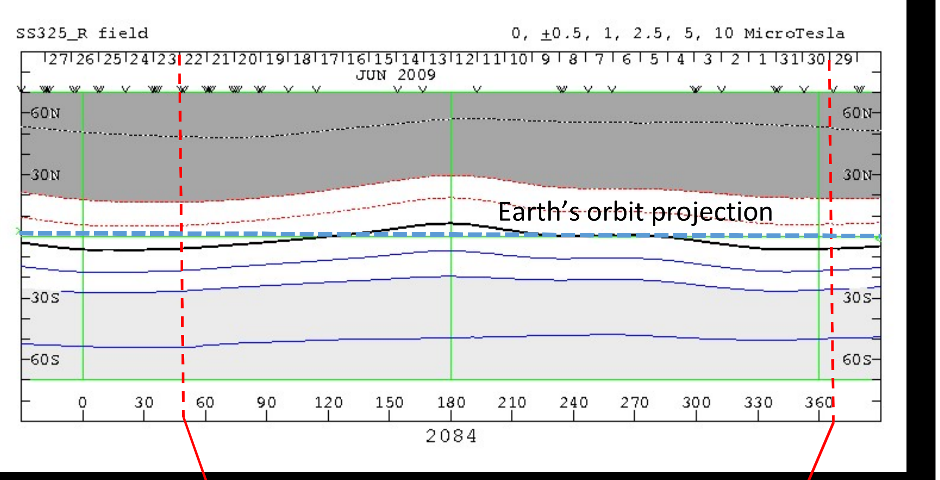
⇩

- need to search long enough intervals of slow wind to detect a clear f^{-1} scaling

- Systematic search in WIND data for very long (>7days) and quiet slow wind time intervals not perturbed by strong transient events
- Slow Alfvénic wind [D'Amicis and Bruno, 2015] not included
- Analysed epoch: 2005 – 2016
- 47 intervals identified

Wilcox Solar Observatory
Source Surface Synoptic Charts





2009-05-30_2009-06-22

surfing on the heliomagnetic equator

<VSW>=316 km/s

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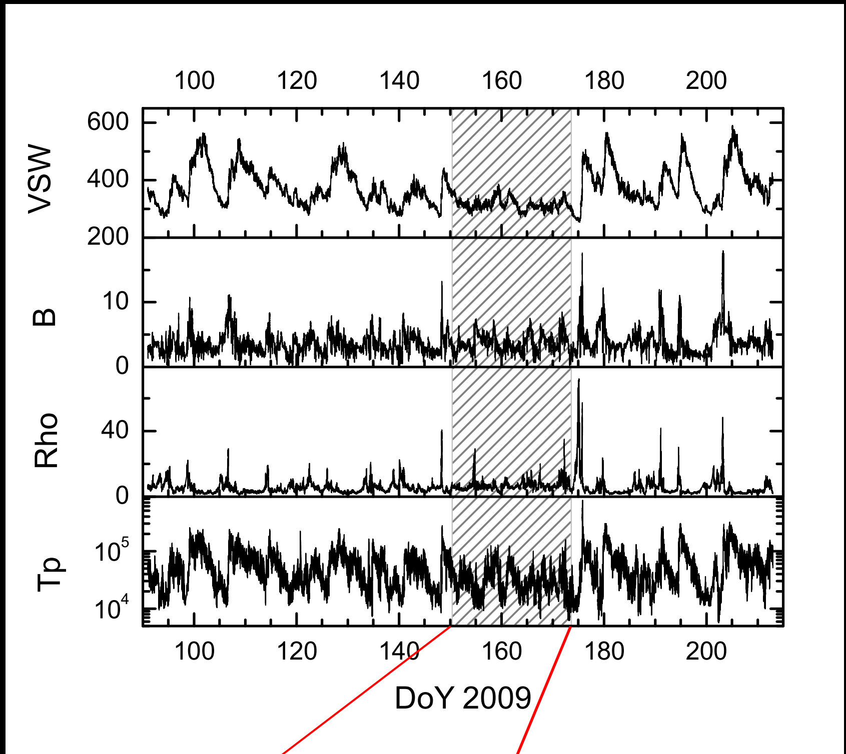

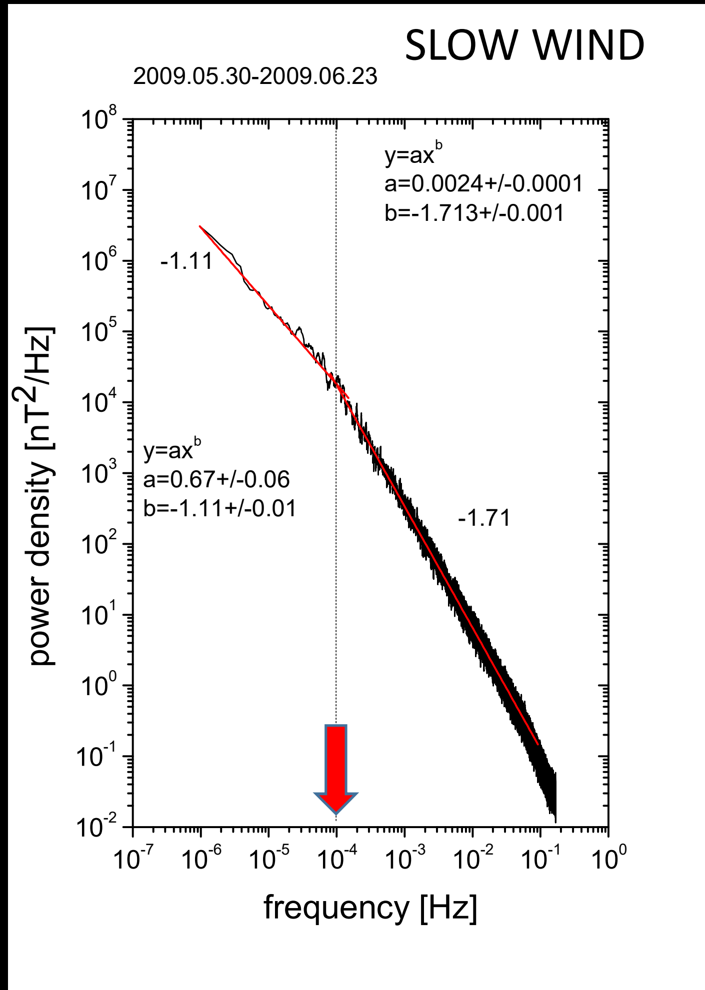

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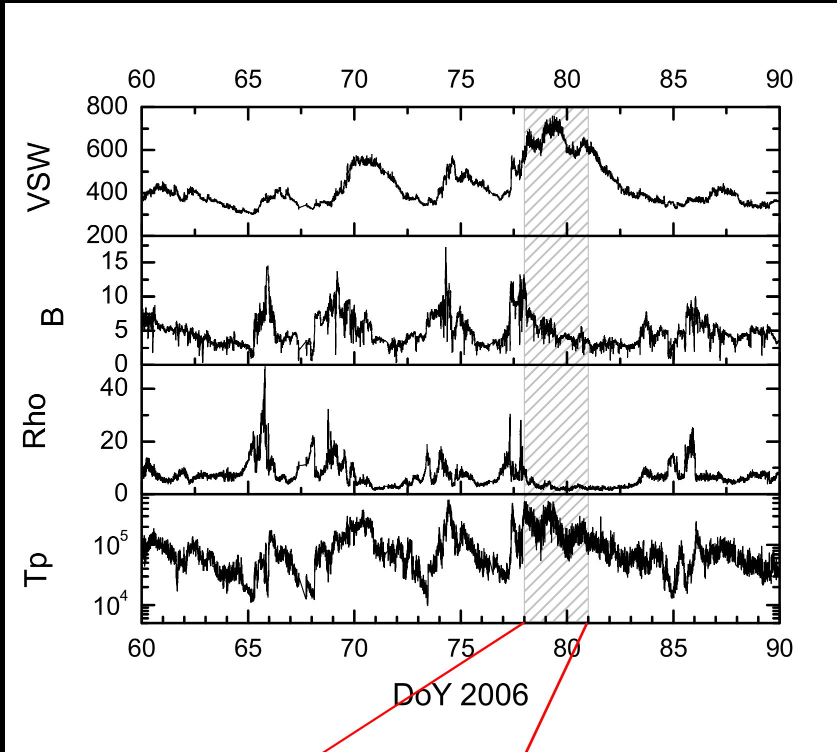
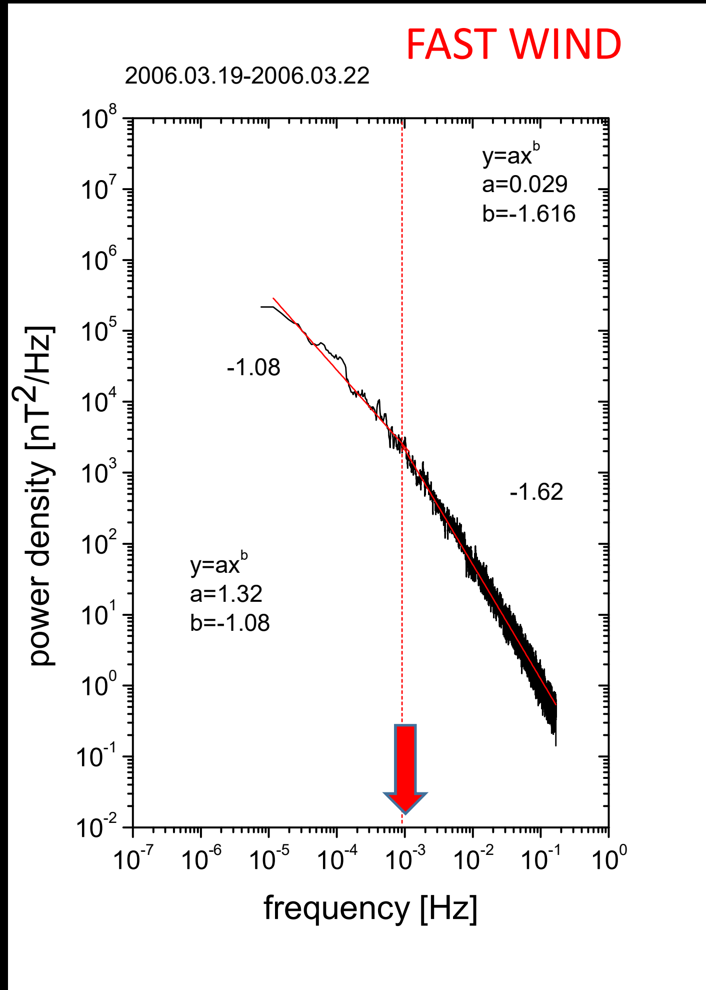
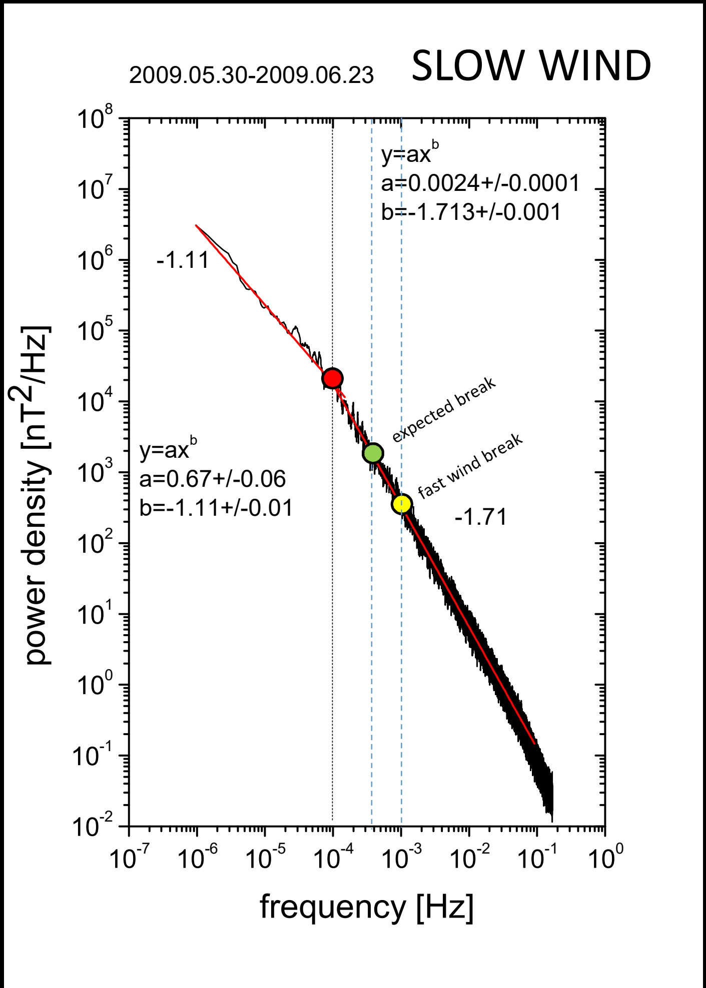




<VSW>=640 km/s

Predicting the break location for slow wind using its radial dependence



	<Vsw>[km/s]	measured f_b [Hz]
Fast wind	640	~1E-3
Slow wind	316	~1E-4

lower flow speed

longer transport time

older turbulence at 1AU

longer transport time ≡ larger radial distance (for $V_{slow}=V_{fast}$)

use frequency break radial dependence $f_{R2}=f_{R1}(R2/R1)^{-1.5}$

expected $f_{slow}=1E\text{-}3 \times (640/316)^{-1.5} = 3.5E\text{-}4$ Hz

Roberto Bruno,
Isradynamics 2018
Dead Sea, 22-29 April 2018

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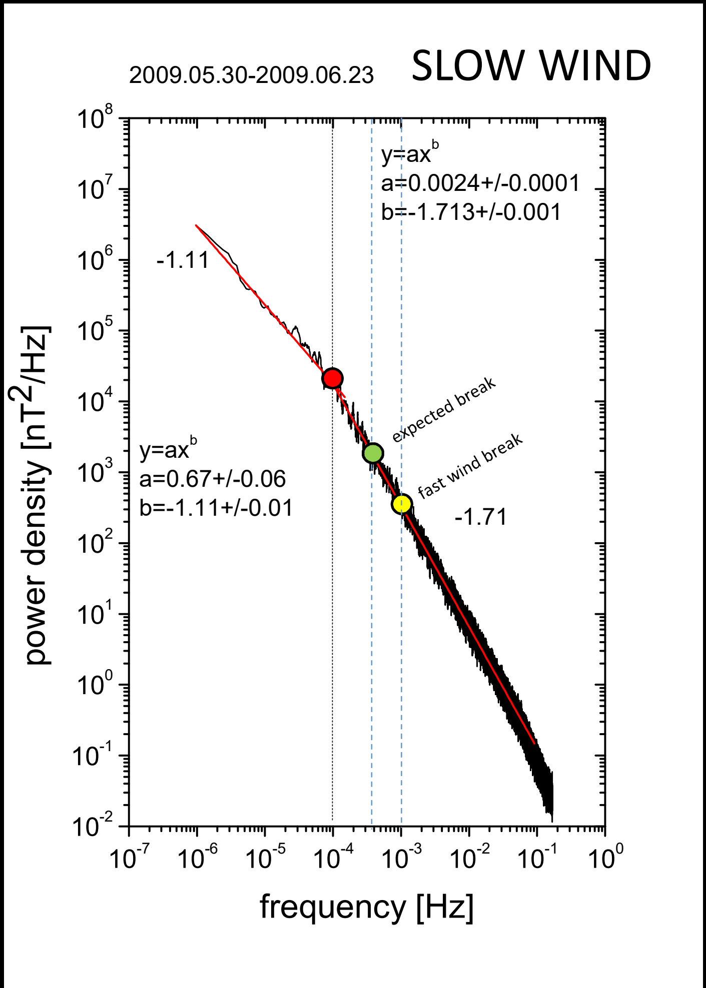

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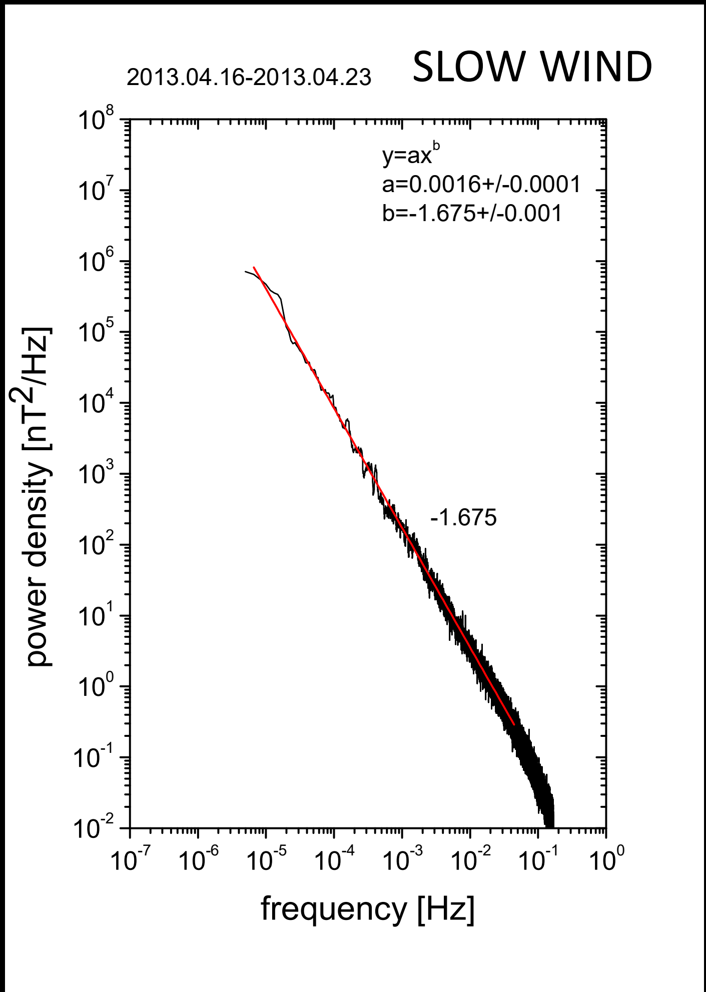
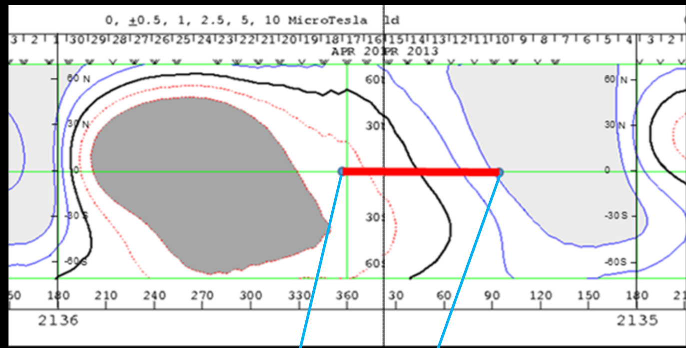
the longer transit time is unable to explain the observed break location and, consequently, slow wind turbulence appears to be “older” than it should be

Not all slow wind samples show a frequency break





Wilcox Solar Observatory
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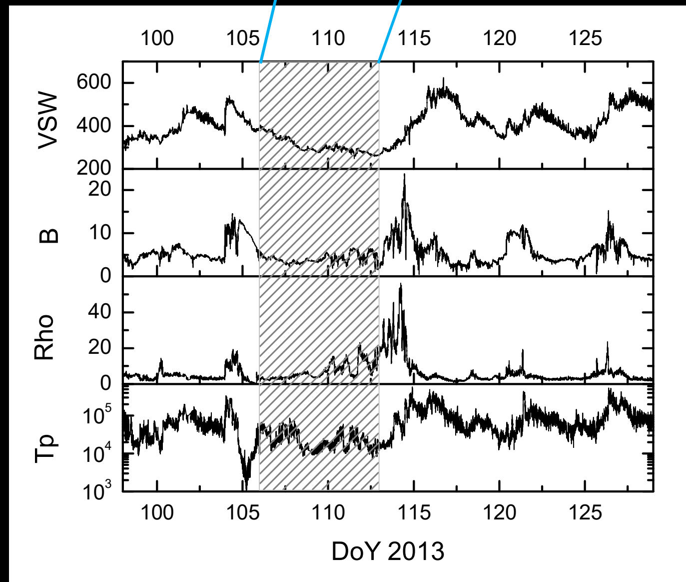
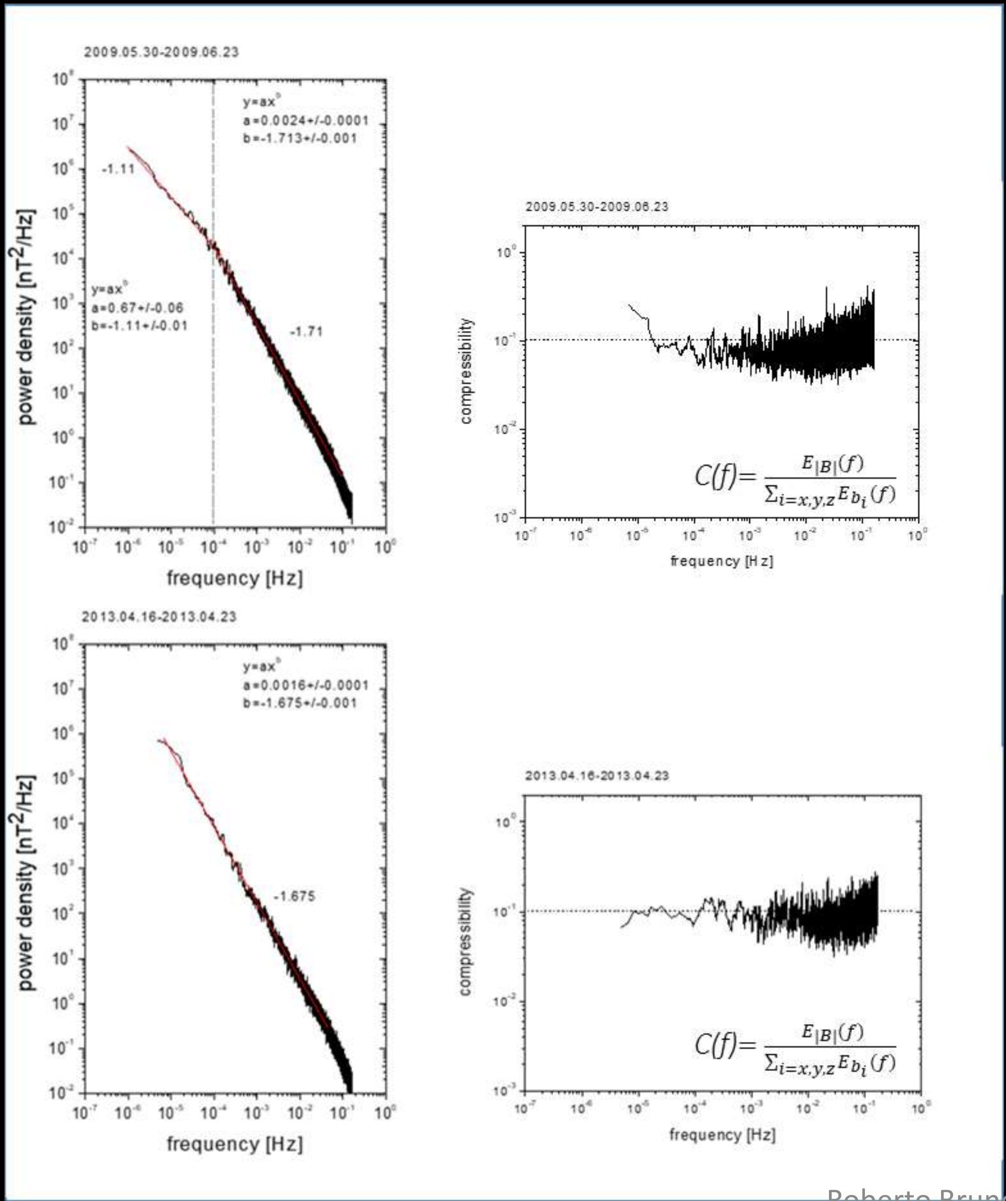
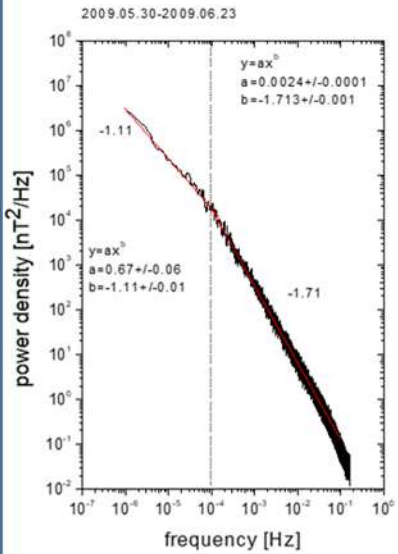


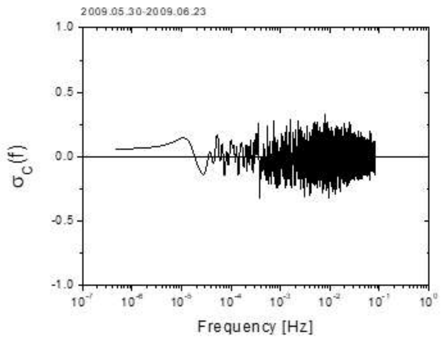


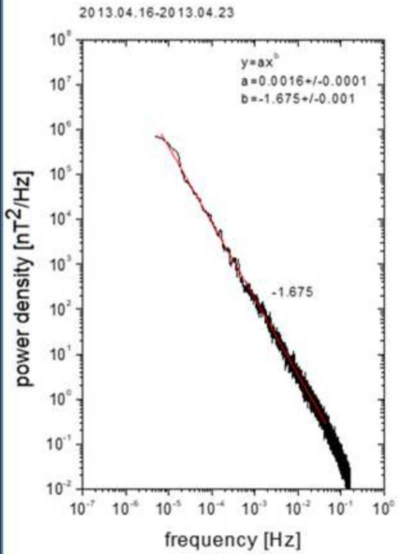
What is the difference between break and no-break slow wind samples?

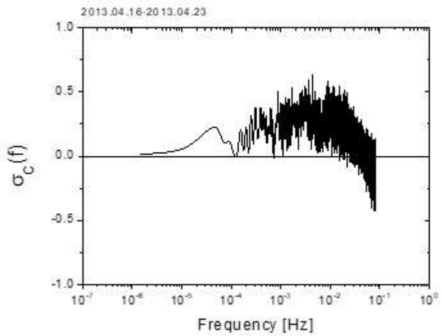
- ❑ compressibility does not play a relevant role

$$\sigma_C(f) = \frac{2H_C(f)}{E(f)}$$









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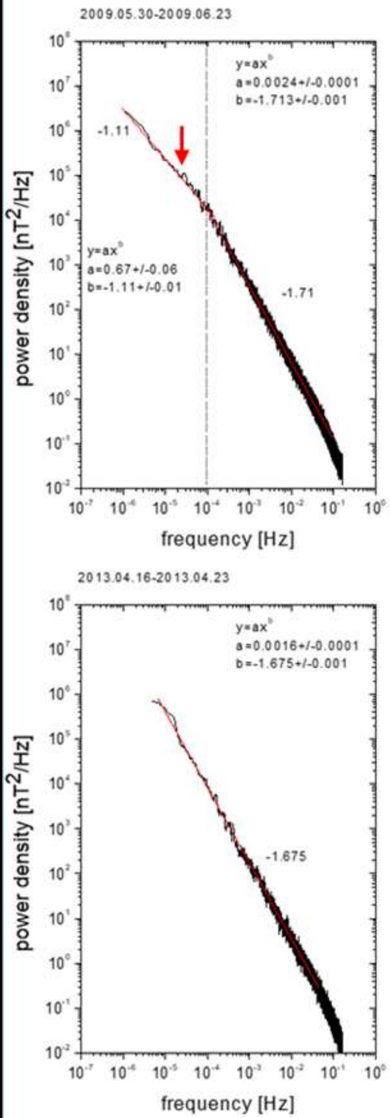

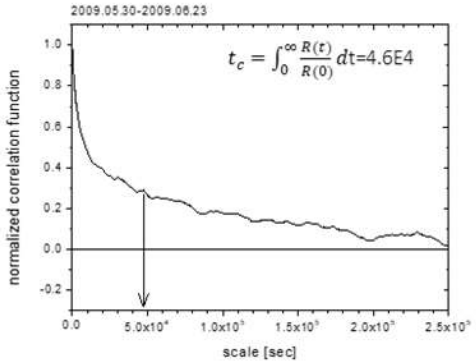

f_b=1/4.6E4=2.2E-5 Hz

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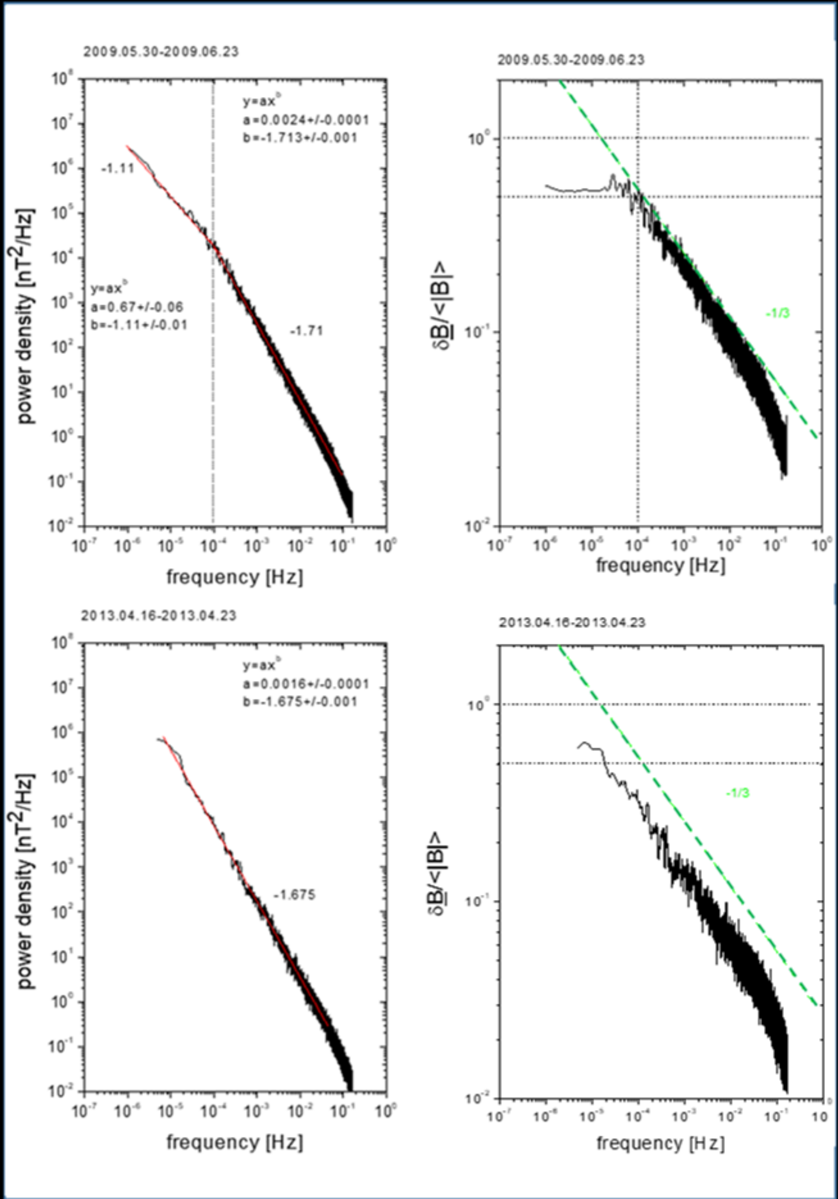
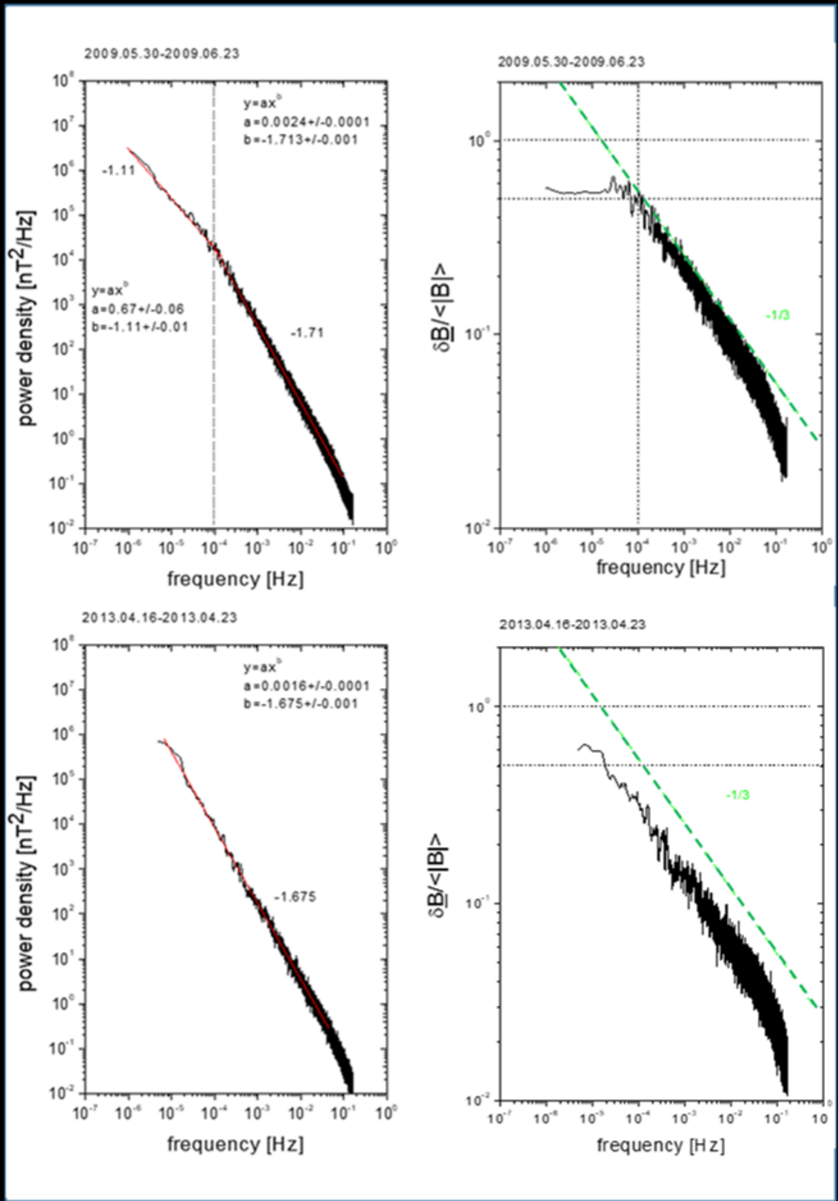
- ❑ Alfvénicity not relevant for the break
- ❑ CL not clearly related to break location **(related in fast wind)**



What is the difference between break and no-break slow wind samples?

- compressibility does not play a relevant role
- Alfvénicity not relevant for the break
- CL not clearly related to break location (related in fast wind)
- Remarkable difference in the relative amplitude of the fluctuations
- The flattening of dB/<|B|> roughly corresponds to the f^{-1} spectral region



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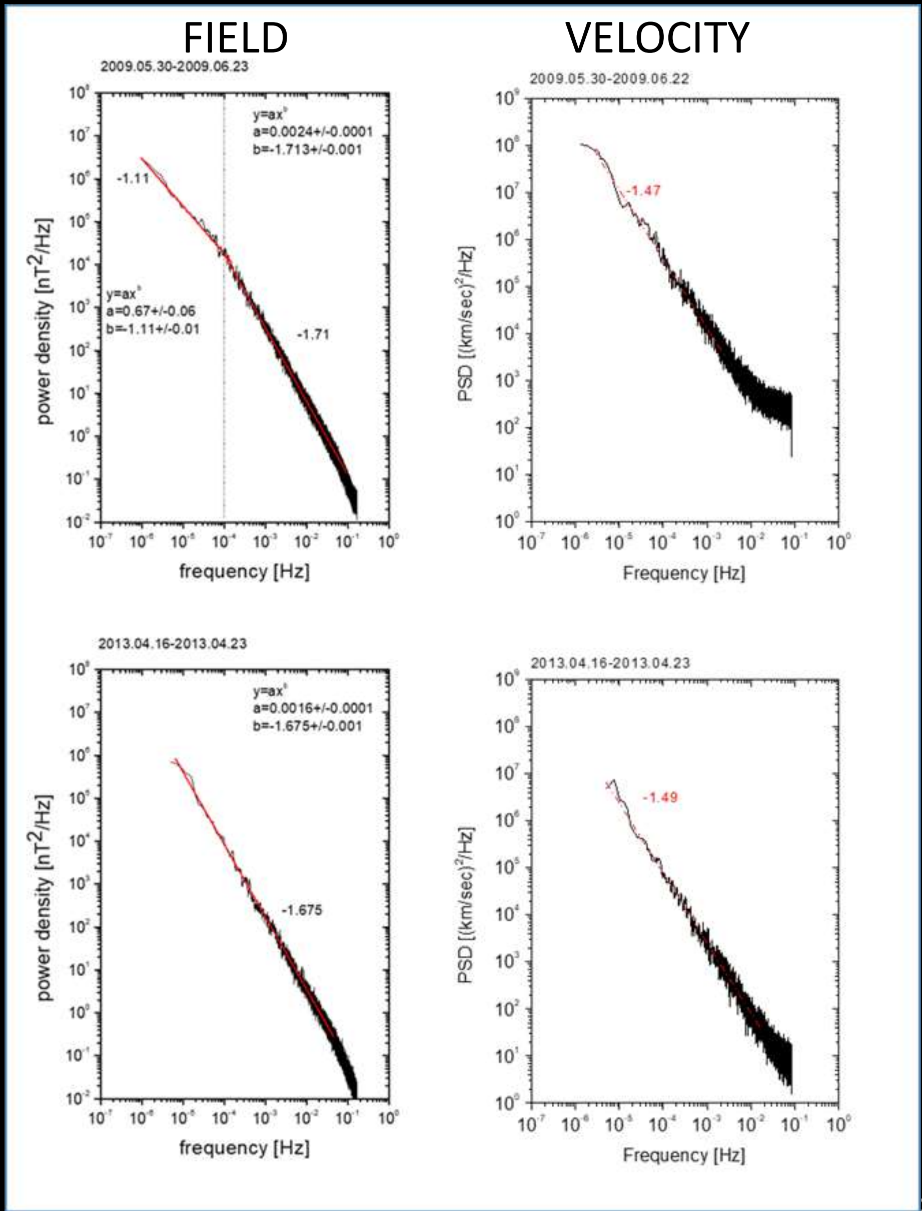
Saturation of fluctuations?
[Matteini et al., 2018]

Selected long lasting slow wind intervals from 2005 to 2016
(WIND magnetic field observations @3sec)

- Break appears for increasing level of dB(f)/<|B|>
- f^{-1} establishes when dB(f)/<|B|> saturates around 0.5

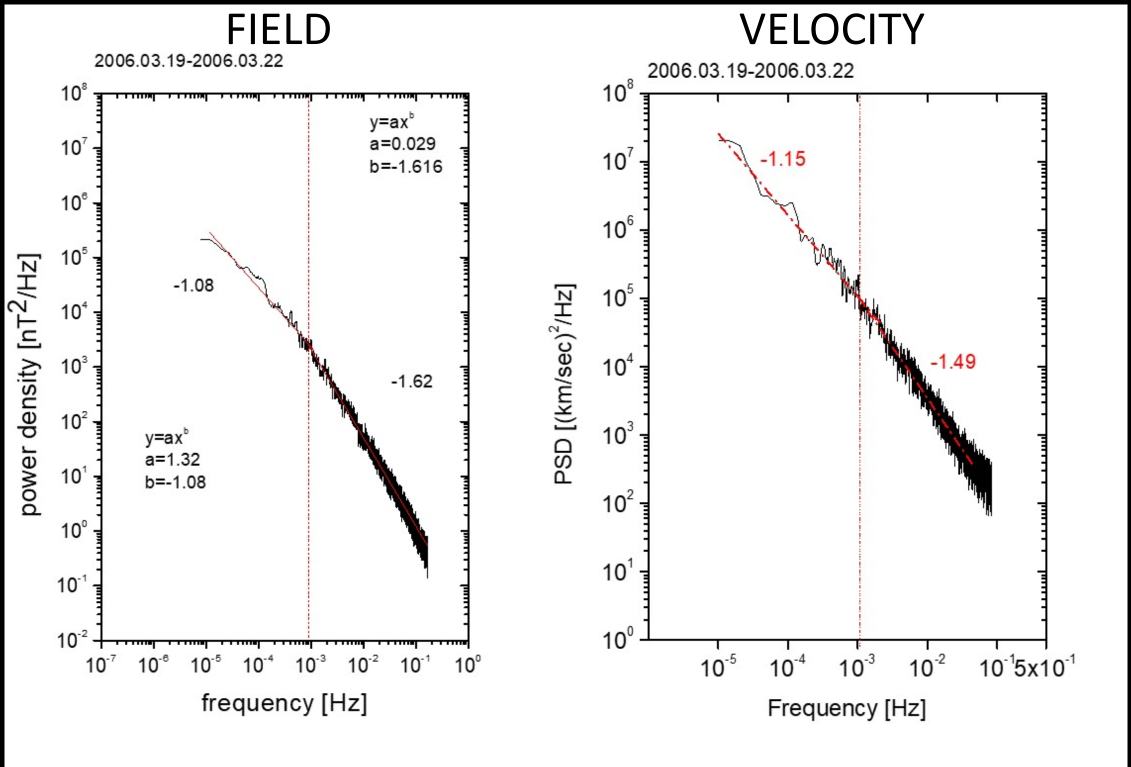
Click here to start the movie

SLOW WIND



- ❑ Velocity spectra do not behave like magnetic field spectra
- ❑ No break in velocity spectra

FAST WIND



- Velocity spectra behave like magnetic field spectra
- break present roughly at the same location

the major difference wrt slow wind is that this interval is Alfvénic

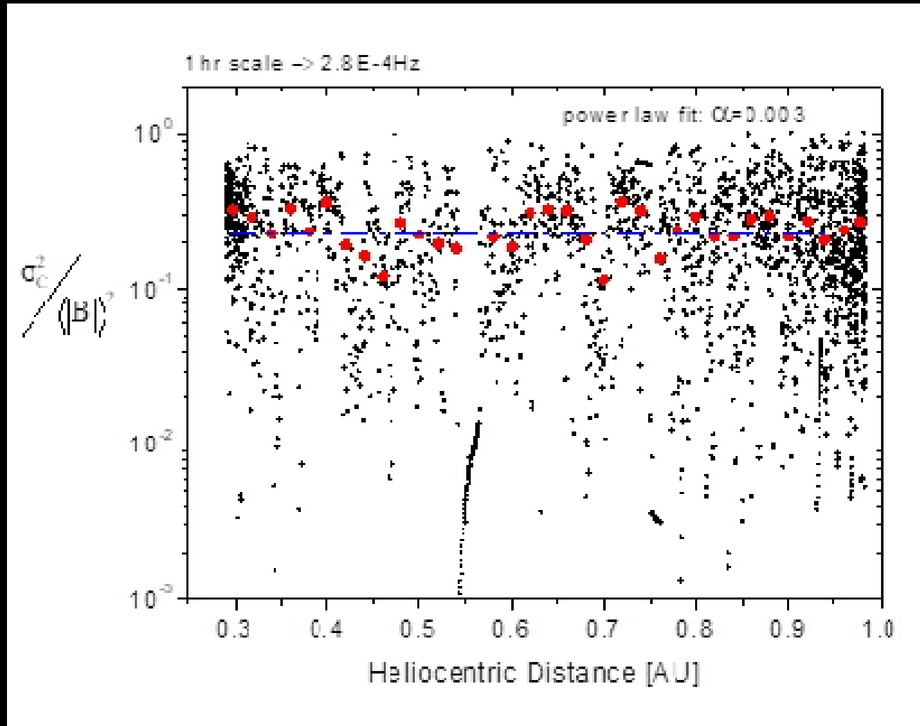
About saturation

Early studies about the radial dependence of magnetic field variance, based on Helios observations, suggested that fluctuations could be saturated (Mariani et al., 1978, Behannon, 1978, Villante, 1980, Villante and Vellante, 1982)

Saturated fluctuations ⇒ σ^2/B^2 would not change during wind expansion

As a matter of fact:

- ❑ $B^2(r) \rightarrow \sim r^{-3}$
- ❑ $\sigma^2(r) \rightarrow \sim r^{-3}$ at large scales



Summary & Conclusions

- ✓ Selected long time intervals (≥7days) of slow wind, low compression, no transient structures
- ✓ Clear low frequency break found in several intervals but, not in all of them
- ✓ Transit time does not justify break location (lower than expected)
- ✓ Break not related to compressibility or λ_c
- ✓ Break not related to Alfvénicity, Vsw spectra don't show any break
- ✓ Break seems to be related to the spectral level of fluctuations (saturation, Matteini et al., 2018)
- ✓ Analysed time intervals much longer than transit time suggest $f^{-5/3}$ already present at the source region

- ✓ The f^{-1} in slow wind does not seem to be related to the turbulence evolution paradigm

Thank you