The Evolution of the 1/f Range Within a Single Fast-Solar-Wind Stream Between 17.4 and 45.7 Solar Radii

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Introduction

Turbulence is a nonlinear phenomenon that allows transfer of energy between different scales.

The power spectrum of magnetic-field fluctuations in the fast solar wind (V_{SW} > 500 km s^{-1}) at magnetohydrodynamic (MHD) scales is characterized by two different power laws on either side of a break frequency f_b.

- The range $f < f_b$, is called the "energy-containing range", and α_B is often $\simeq -1$, especially in the fast solar wind
- The range $f > f_b$, is called "inertial range", and α_B is approximately −5/3 to −3/2.

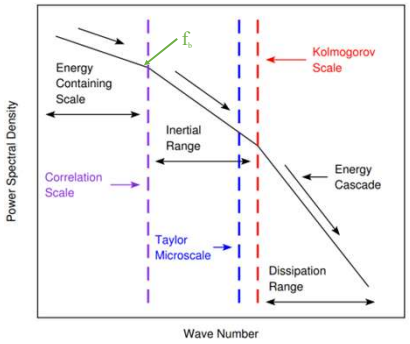

Figure 1: Generic picture of energy cascade in solar wind turbulence (Gurgiolo et al. 2013).

Fast Solar Wind Stream

Data from Nov. 17-20, 2021 from PSP Encounter 10 is analyzed. The magnetic-field data used from the outboard flux magnetometer (MAG) (Bale et al., 2016) had a resolution of ~0.22 s. The velocity data was derived from Solar Wind Electrons Alphas and Protons measurements (Kasper et al., 2016) at a resolution of ~3.49 s.

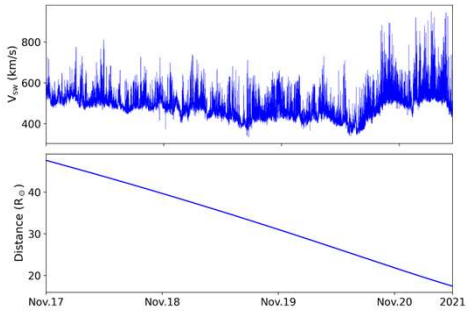

Figure 2: (top) Radial solar wind velocity (bottom) Heliocentric distance of PSP.

- Fast solar wind stream, with $V_{SW} > 500$ km/s most of the time
- PSP orbit decreases from ~46 to ~17 $R_\odot$

Parker Solar Probe Encounter 10

- Heliographic location varied by < 10° in Carrington longitude.
- Field line mapping places the source region of solar wind near the center of the same coronal hole for the entire period.
- Time interval excludes both coronal mass ejection and any crossings of heliospheric current sheet.

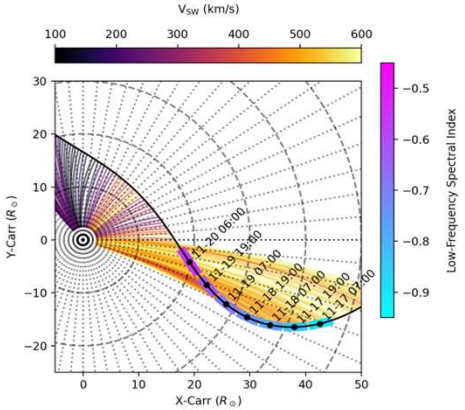

Figure 3. Orbit of PSP Encounter 10 and encountered solar wind.

This time interval provides a nearly radial scan of the same fast solar wind stream from 17.4 to 45.7 $R_\odot$

The angle θ_{VB} between running one-hour averages of B and the spacecraft-frame velocity V is defined as:

$$\cos\theta_{VB} = \frac{\vec{V}.\vec{B}}{|V||\vec{B}|}$$

- Most of the time $160^\circ \lesssim \theta_{VB} \lesssim 180^\circ$.
- $\sin(\theta_{VB})$ is small
- The frequency spectra at $f < f_b$ corresponds approximately to the $k_\parallel$ spectra of the low-frequency fluctuations.

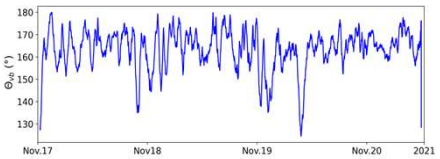

Figure 4. Variation of the angle between the mean magnetic field and mean velocity field in the spacecraft frame

This fast solar wind stream's evolution towards a f^{-1} spectrum is similar to the nonlinear evolution of the PDI that takes place when slow waves are significantly dampened.

In Situ Development of the f^{-1} Spectrum

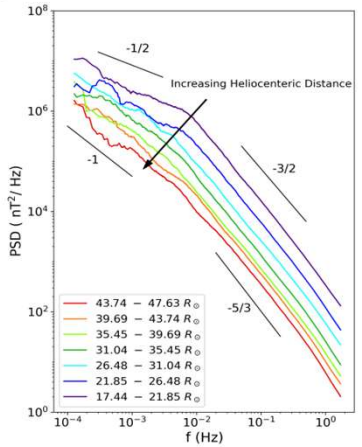

Figure 5: Magnetic field power spectrum for different heliocentric distances, with several power-law slopes marked for reference.

- As heliocentric distance increases, power levels decrease
- Total power decrease exceeds an order of magnitude over the range of distances considered
- This behavior is due to the expansion of the solar wind and the turbulent cascade.

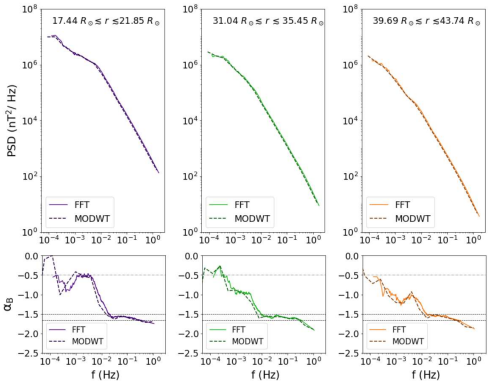

Figure 6: (top) Magnetic field power spectra (bottom) Local spectral index with horizontal lines for α_B = -1/2, -3/2, and -5/3.

The power spectrum in the low frequency, inertial range gradually steepens towards a f^{-1} *in situ* as heliocentric distance increases

Radial Evolution of Spectral Index

- As heliocentric distance r increases from 17.4 to 45.7 $R_\odot$, the spectrum steepens, α_B decreases from -0.61 to -0.94
- The breakpoint frequency f_b decreases as r increases

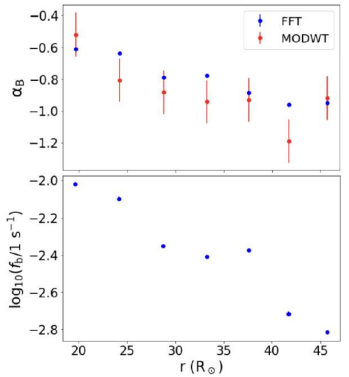

Figure 7: (Top) Variation of α_B, and (Bottom) f_b with r.

- Possible physical mechanisms: (1) nonlinear interactions in reflection-driven Alfv́en-wave turbulence or (2) nonlinear evolution of the parametric decay instability

Summary and Future Work

Key Points:

- α_B decreases from about -0.61 to -0.94 at $f < 10^{-3}$ Hz as r increases from 17.4 to 45.7 $R_\odot$s.
- Observations suggest that 1/f is not produced at sun, but develops in situ, at least within fast wind.

Future Work:

- Revisit this behavior with further analysis of more solar-wind streams
- Investigate the physical mechanism(s) behind this behavior

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