The energy transfer rate of coherent structures in the kinetic and inertial ranges of solar wind turbulence

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Abstract

Solar Orbiter observations are used to investigate coherent structure prevalence in turbulent solar wind flows in situ from ~ 1-0.4 au. Magnetic field fluctuations are obtained by wavelet decompositions which preferentially resolve either signatures of coherent structures or wave-packets. We find a single fluctuation threshold in each of the kinetic and inertial ranges above which coherent structures typically dominate. It is insensitive to plasma parameters or solar distance, that is, different states of the turbulence, suggesting a ubiquitous constraint on the turbulent phenomenology.

Bendt, A. & Chapman, S.C. Ubiquitous threshold for coherent structures in solar wind turbulence. PRResearch. (2025) DOI: 10.1103/PhysRevResearch.00.003000

1) Identification of the PVI threshold

- above the PVI threshold fluctuations may be coherent structures
- compensated Quantile-Quantile (QQ)-plots of fluctuation pdfs typically have a core and tail at time scales of the crossover and the inertial range [2]
- the PVI threshold is the transition point of core to tail of fluctuation pdfs
- for the KR only intervals at distances $R < 0.4$ au have a clear core-tail transition [2]

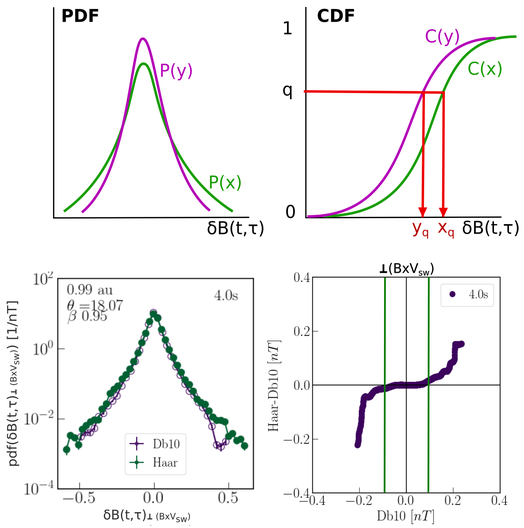

Figure 3: Fluctuation pdfs and compensated QQ-plots of pdfs obtained from Haar and Db10 wavelet decompositions in the crossover range at 4s.

2) PVI threshold in the kinetic range

- the PVI threshold (back line) is located where PVI distributions typically depart from each other
- the PVI threshold is at PVI= 2.2 on average, $(2.1 - 2.7)$
- PVI tails at $R < 0.4$ au follow one trend, consistent with coherent structures
- PVI tails at distances > 0.4 au depend on conditions

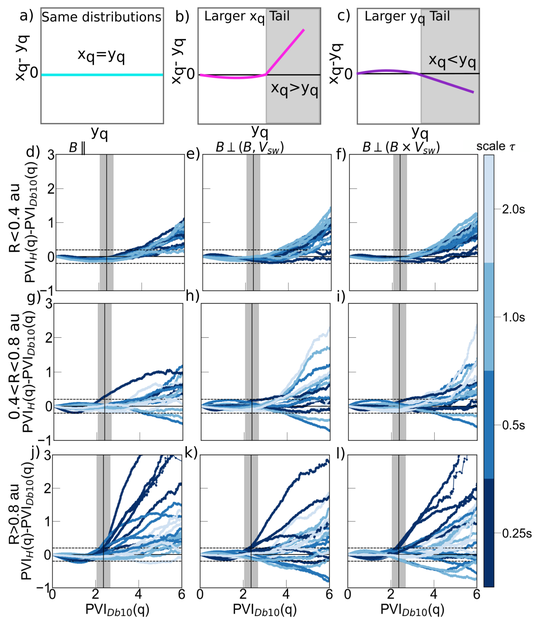

Figure 4: Compensated QQ-plots of the PVI pdfs obtained from the Haar and Db10 wavelet decompositions in the kinetic range.

Introduction

The inertial range (IR) is intermittent, possibly due to coherent structures which may dissipate energy in the kinetic range (KR) to heat the solar wind. The Partial Variance Increment (PVI) identifies coherent structures [1].

$$PVI = \frac{|\delta B(t,\tau)|}{\sqrt{\langle |\delta B(t,\tau)|^2 \rangle}}$$

We compare PVI obtained from Haar and 10th-order Daubechies (Db10) wavelet decompositions to identify a PVI threshold.

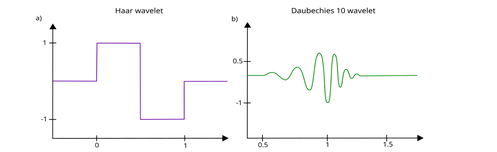

Figure 1: Schematic of the Haar and Db10 wavelets.

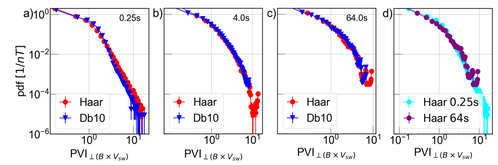

Figure 2: Comparison of PVI distributions obtained from Haar and Db10 wavelet decompositions.

3) PVI threshold in the inertial range

- PVI threshold (back line) is PVI= 2.5 on average $(1.7 - 3.3)$
- detailed trend of the PVI tail depends on plasma conditions

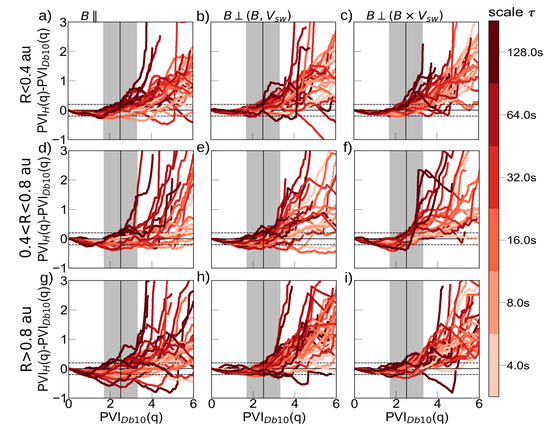

Figure 5: Compensated QQ-plots of the PVI pdfs obtained from the Haar and Db10 wavelet decompositions in the inertial range.

4) Conclusions

- a single ubiquitous PVI threshold for each IR and KR
- "critical boundary" at ~ 0.4 au where turbulence evolves differently
- ~ 3% of fluctuations in the IR & ~ 4% in the KR PVI tail

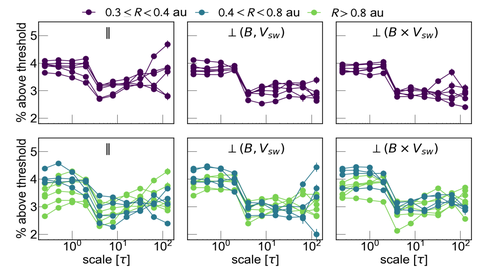

Figure 6: Percentage of fluctuations above PVI threshold.

A single PVI threshold value may operate as universal constraint on different processes mediating the turbulent cascade.

References

(1) A. Greco, P. Chuychai et al., *Geophys. Res. Lett.*, 2008, **35**, DOI: 10.1029/2008GL035454.

(2) A. Bendt, S. Chapman et al., *Astrophys. J.*, 2024, **971**, 179.

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