Information theory approach to measure long-memory in experimental plasma turbulence time series

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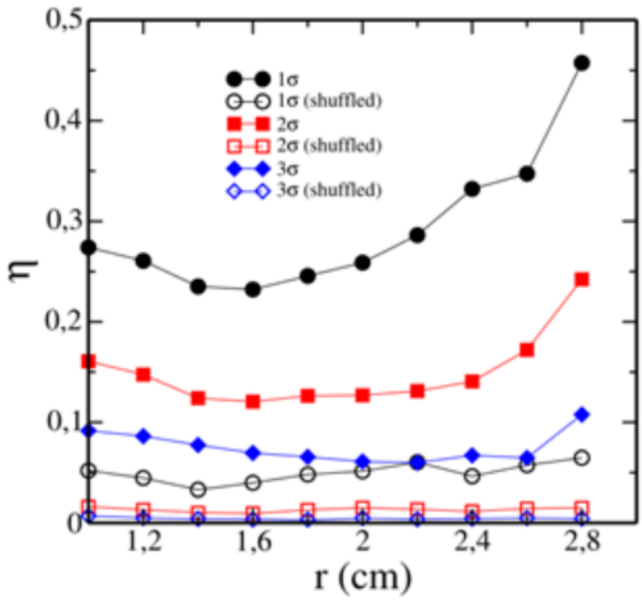
The nature of intermittency in turbulent plasma transport—whether avalanches occur as independent events or exhibit memory—is a fundamental question with direct implications for confinement prediction and control. Conventional analysis based on autocorrelation functions and power spectra is primarily sensitive to linear correlations and Gaussian statistics, yet plasma fluctuations are strongly intermittent, non-Gaussian, and dominated by bursty avalanche events.

Here we employ information-theoretic tools—block entropy, excess entropy, complexity index, and mutual information—to systematically probe temporal correlations in fluctuation-induced particle flux time series from the Santander Linear Plasma Machine. Experimental data are first converted into binary avalanche sequences via thresholding. Analysis of block entropy reveals that the complexity index grows with block length and remains unsaturated for the outermost radial positions, indicating significant temporal memory and structure. At the plasma edge, mutual information decays slowly and remains detectable over many consecutive avalanche events, indicating that information propagates across the avalanche sequence far into the future. This provides a direct evidence that edge plasma turbulence exhibits non-renewal, long-range memory in avalanche occurrence: the timing of each avalanche contains predictive information about avalanches many events ahead. The complexity index and quiet-time mutual information together offer sensitive, model-free, quantitative markers of proximity to marginal stability and confinement regime transitions.



Complexity index $\eta(k = 13)$ up to length $k = 13$ at different radii (solid symbols). Results for avalanches above 1σ, 2σ and 3σ thresholds are shown. In view of Fig. 3 the complexity index at $k = 13$ for the outermost radii has to be seen as a lower bound, being the actual value much higher. A random shuffle of the data (empty symbols) destroys temporal memory and complexity drops to nearly negligible values showing the complexity index is measuring information in the form of temporal patterns.