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Non-diffusive turbulence spreading and its relation to intermittent convective fluctuation events

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Edge plasmas are usually strongly turbulent, and manifest intermittency in linear plasma devices and toroidal fusion devices [1]. Generally, turbulence spreading refers to the spatial propagation of turbulence intensity or energy due to nonlinear interactions. Spreading can decouple the intensity field from the local instability growth rate [2]. Numerous theoretical and simulation works have explored the spreading models. But most studies of turbulence spreading are based on a presumed diffusion model [3], where the turbulence intensity flux is given by the product of diffusivity and intensity gradient, i.e. $\Gamma = -\chi_I \partial_r I$. There is a lack of research on the non-diffusive characteristic of turbulence spreading.

In this report, we present comprehensive experimental studies of turbulence spreading dynamics at the tokamak plasma edge [4]. We focus on the non-diffusive characteristics of turbulence spreading and their relation to intermittent convective density fluctuation events (blobs/holes). Turbulence spreading is significantly enhanced at high collisionality or low adiabaticity. Characterizing turbulence spreading as a Fickian diffusion yields an extremely large or singular diffusivity (as shown by Figure 1(a)), which is found to depart radically from the turbulent particle diffusivity. Turbulence spreading manifests non-diffusive characteristics and thus the usual models are dubious. The turbulence spreading speed (named "mean jet velocity") correlates linearly with the skewness of density fluctuations, as shown by Figure 1(b). Spreading induced by positive density fluctuation events is outward toward larger radii, and spreading induced by negative density fluctuation events is inward toward smaller radii, as shown by Figure 1(c). Increasing symmetry breaking between outgoing blobs and incoming holes causes enhanced turbulence spreading, as shown by Figure 1(c). These results are essential to understand the basic physics of turbulence spreading and to build a foundation for the prediction and interpretation of turbulence transport behaviors.

To summarize, we conduct an in-depth experimental study of turbulence spreading in edge plasmas and its relation to intermittent convective density fluctuation events (i.e. blobs and holes) for the first time. Turbulence spreading is demonstrated to be strongly non-diffusive. The results highlight the importance of intermittent convective events in conveying the spreading of turbulence, and constitute a fundamental challenge to existing diffusive models of spreading. These are essential to build a foundation for the prediction and interpretation of turbulence transport behaviors. The findings can stimulate new insights into the research on the role of non-diffusive turbulence spreading in the performance of magnetic fusion devices, such as its significant influence on the pedestal structure and the divertor heat load width broadening.

References

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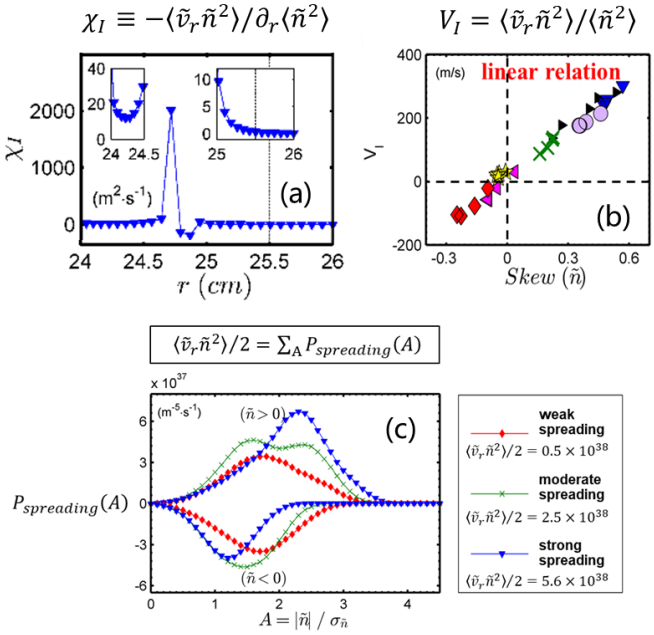

Figure 1. (a) Characterizing turbulence spreading as a Fickian diffusion yields an extremely large or singular diffusivity; (b) Turbulence spreading speed correlates linearly with the skewness of density fluctuations; (c) Spreading induced by positive (negative) density fluctuation events is outward (inward), and increased symmetry breaking between blobs and holes causes enhanced turbulence spreading.