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Turbulence spreading and flow shearing dynamics in high density operation

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Turbulence spreading generally refers to the spatial propagation of turbulence energy due to nonlinear interactions[1]. It plays a significant role in the comprehensive performance of magnetic fusion devices. It is related to the breaking of gyro-Bohm scaling[2,3]. It is also important in the core-boundary coupling to affect the pedestal structure as well as the divertor heat load width[4-6]. Recent studies show that, the density limit can be regarded as a state linked to the breakdown of turbulence self-regulation[7-9]. In this report, we present the recent experimental study about the dynamics of turbulence spreading and shear flow in the high density operation on the J-TEXT tokamak.

It is found that as collision rate increases, turbulence spreading flux $\langle \tilde{v}_r \tilde{n}^2 \rangle/2$ increases. Turbulence spreading power $\mathcal{P}_S = -\partial_r \langle \tilde{v}_r \tilde{n}^2 \rangle/2$ increases significantly in the region just inside the last close flux surface (LCFS). The normalized turbulence spreading power $\mathcal{P}_S/\mathcal{P}_I = (-\partial_r \langle \tilde{v}_r \tilde{n}^2 \rangle/2)/(-\langle \tilde{v}_r \tilde{n} \rangle \partial_r \langle n \rangle)$, a measure of turbulence internal energy increments due to the turbulence spreading relative to the local turbulence production, increases with the normalized collisionality $v_i^* \equiv \frac{v_{ii}/\varepsilon}{\varepsilon^{1/2} v_{th,i}/(qR)}$, as shown in Figure 1. The enhanced edge turbulence spreading plays an important role in the edge cooling approaching the density limit. This is strongly associated with the interaction between the $E \times B$ shear flow and the turbulence random scattering.

For high Greenwald fraction $\bar{n}/n_G$, a region of $\Delta r \sim l_{cr}$ is observed at the edge, where the turbulence intensity flux $\langle \tilde{v}_r \tilde{n}^2 \rangle/2$ is large but the turbulence intensity gradient $\partial_r \langle \tilde{n}^2 \rangle$ is near zero. This implies the breakdown of Fick's law of local flux-gradient formulation. Besides, the "mean jet velocity" of turbulence spreading $V_I = \langle \tilde{v}_r \tilde{n}^2 \rangle / \langle \tilde{n}^2 \rangle$ shows the linear positive correlation with the skewness of density fluctuations and presents an increasing trend with the auto-correlation time of density fluctuations, as shown in Figure 2(a-b). It is also found that the increasing symmetry breaking between positive and negative density fluctuations (especially blobs and holes) coincides with the enhanced turbulence spreading.

References

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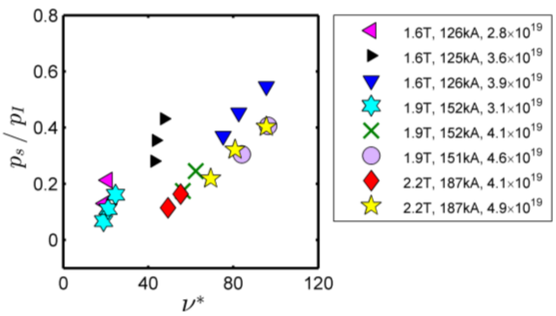

Figure 1. The normalized edge turbulence spreading power VS the collisionality.

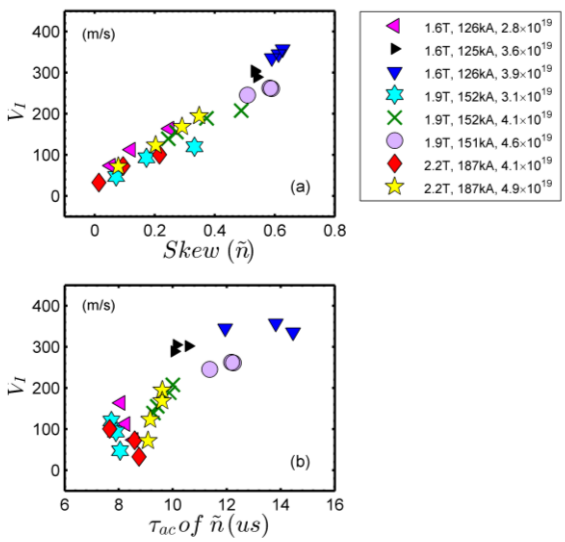

Figure 2. The "mean jet velocity" of turbulence spreading VS (a) the skewness of density fluctuations and (b) the auto-correlation time of density fluctuations.