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Observation of multiple shear layers and long-range transport events on HL-2A tokamak

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Recent flux-driven gyrokinetic computational modeling and theory suggested the existence of an $\boldsymbol{E}\times\boldsymbol{B}$ staircase in the plasma core consisting of a series of m/n=0/0 $\boldsymbol{E}\times\boldsymbol{B}$ shear layers formed at different plasma minor radii via the action of the turbulent Reynolds stress[1,2]. These layers then act as semi-permeable transport barriers and thus regulate the background gradients, causing a localized steepening of the gradient. Recent published experimental work in TORE-SUPRA shows that the turbulent radial correlation length exhibits a number of marked reductions across the minor radius of the device, and data also suggest that the turbulent eddies undergo a reversal of their anisotropic tilting as these minima are traversed.

These observations are consistent with the computational picture of the $\boldsymbol{E}\times\boldsymbol{B}$ staircase. They are, however missing a few important points. First, to date there have been no direct indications of the presence of the $\boldsymbol{E}\times\boldsymbol{B}$ shear layers – their existence has only been indicated by the tilting of the turbulent structures in their vicinity. Second, there have been no published results showing the existence of avalanche dynamics in the region between the shear layers. We note that unpublished work from AUG shows clear evidence for the existence of two spatial scales for the radial correlation length. We also note that earlier experimental work has shown the existence of long-range avalanche-like transport events within the core of DIII-D L-mode discharges[3].

Motivated by these earlier results, a series of experiments have been conducted on HL-2A tokamak in order to investigate the $\boldsymbol{E}\times\boldsymbol{B}$ staircase and long-range transport events together. In this experiment, several solid evidences of multiple shear layers and co-existing long-range transport events have been found:

1. The electron density fluctuation obtained by BES shows several reductions of the radial correlation length of turbulence across the minor radius, as shown in Fig. 1 (a), similar to those reported on TORE-SUPRA;

2. The poloidal phase velocities of turbulence calculated through TDE method show multiple shear layers, even direction reverses at different minor radii in L-mode discharge.

3. The shear layers, where the turbulent eddies are stretched and therefore significantly tilt, coincide with the location of reduction in radial correlation length, as shown in Fig. 1 (a) and (c). The tilt angel of turbulent eddies is defined as $\arctan(k_r/k_\theta)$, where k_r and k_θ are shown in Fig. 1 (b).

4. Multi-channel ECE and FMCW reflectometry data show that there are some corrugations in the background gradient profiles and their radial positions are consistent with those of the shear layers;

5. Moreover, In the region between these shear layers, transport events with long radial distance and small radial wavenumber satisfy the characteristics of avalanche dynamics;

6. A statistical result shows that the weak disturbances terminate at the shear layers while strong disturbances penetrate the shear layers, thus verifies the semi-permeability of the shear layers which is an important feature of $\boldsymbol{E}\times\boldsymbol{B}$ staircases.

In this work, multiple plasma behaviors were studied together to give a thorough view of the $\boldsymbol{E}\times\boldsymbol{B}$ staircase for the first time. The observation of multiple shear layers and long-range transport events provided significant evidence for the existence of EXB staircase and avalanche-like transport in core plasma.

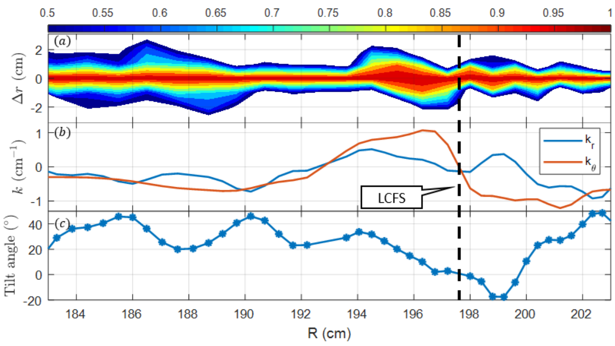

Fig. 1 (a) radial correlation; (b) radial and poloidal wavenumber; (c) tilt angel of turbulent eddies defined as $arctan(k_r/k_\theta)$. The dashed line indicates the position of LCFS.

References

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