Experimental observation of streamer-like structure enhancing turbulent transport in scrape-off layer of HL-2A tokamak

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The scrape-off layer (SOL) width is generally recognized to be governed by the competition between cross-field and parallel transport, which sets the divertor heat load in fusion devices [1]. Thus the study of physical mechanism determining the SOL width has attracted enormous interest in magnetically confined plasmas. Many theoretical works indicate that edge turbulence [2] and the related secondary structures, such as blobs [3], steamers [4], could enhance the SOL transport. Theoretical evaluation [5] shows that the streamer-induced radial transport is significant, and it is also supported by the JT-60U experiment [6]. Recently, the long-radial correlation structure, or streamer-like structure, has been widely observed in DIII-D [7], KSTAR [8] and HL-2A [9]. The streamer flow is highly expected to be an alternative candidate to control SOL width. However, the fundamental characteristics of streamer and its influence on the SOL transport together with divertor heat flux has not yet well understood.

In this work, we report the experimental observation of streamer-like structures enhancing SOL turbulent transport together with a corresponding decrease of parallel transport toward the divertor target in the HL-2A tokamak. In this experiment, the basic discharge parameters are as follows: plasma current I_p =160 kA, chord-average density $\bar{n}_{e,l} = (1.5 - 2.7) \times 10^{19}\, m^{-3}$, and the toroidal magnetic field B_t = 1.3 T in the clockwise toroidal direction. Figure 1(a) shows the time trace of divertor D_α emission, where the L-H transition occurs at t = 835ms. As shown in figures 1(b) – (c) are the time evolution of the frequency spectra of poloidal Mirnov and density fluctuations ($\tilde{n}_e$) measured by beam emission spectroscopy (BES) at ρ~0.97, indicating that the observed coherent structure with a central frequency of approximately 17.6 kHz has the electromagnetic characteristics. Moreover, the coherent structure displays distinct behaviours in L-mode and H-mode. In L-mode, they appear intermittently with a relatively small amplitude, just after the L-H transition the intermittent activity disappears, and the amplitude increases significantly. Figures 1(d) and 1(g) present the time evolution of the frequency spectrum of density fluctuations in the far-SOL and the local particle flux, as measured by the Langmuir probe installed at the first wall. Figures 1(e) – (f) show

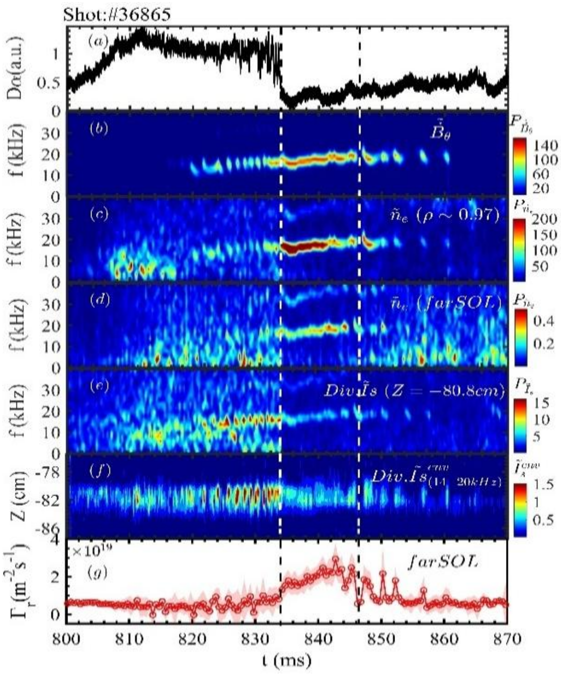

Figure 1. Streamer-like increase cross-filed transport in SOL and decrease parallel transport in divertor. (a) Divertor D_α emission, (b) time-frequency spectrum of the poloidal Mirnov signal, (c) the BES signal (ρ ~0.97), (d) the floating potential in the far scrape-off layer (SOL), (e) the divertor saturation ion current at Z=−80.8 cm, (f) the divertor saturation ion current filtered in the range of 14-20 kHz and (e) particle flux (Γ_r) of far-SOL.

the time evolution of the frequency spectrum of the ion-saturated current near the strike point and the spatial distribution of the filtered (14 – 20 kHz) ion-saturated current ($Div.I_{s\,(14-20kHz)}^{env}$) on the outer divertor plate, where 14-20 kHz represents the full width at half maximum (FWHM) of the spectral peaks. The results indicate that the coherent structure significantly enhances the ion-saturated current at the divertor target during the L-mode phase (t=820-835 ms), whereas the less particle flux could reach the far-SOL region, suggesting that parallel transport dominates the particle transport in L-mode. While after the L-H transition (835 – 850 ms), the amplitude of the coherent structure increases significantly, leading to a remarkable reduction in the ion-saturated current at the divertor, while enhancing particle flux in the far-SOL, which demonstrates that cross-field transport becomes the dominant channel for particle transport in this phase, accompanying with the enhancement of the coherent structure amplitude. To further analyse the spatial characteristics of the coherent structure, figures 2(a) and 2(b) illustrate the radial evolution of the frequency spectrum from 12-channel BES signals and the corresponding envelope amplitudes filtered in 14–20 kHz, respectively. A distinct coherent mode at 17.6 kHz is observed across multiple radial positions, exhibiting a spatial extension of approximately 10 cm, which is an indicator of theoretically-predicated streamer structures [10]. The profile of amplitude peaks in the edge region and gradually diminishes toward the core. To further elucidate the influence of streamer-like structure on SOL transport, we present the spatial characteristics of density fluctuations together with particle fluxes measured in the far-SOL during Δt = 837.7–838.2 ms, as shown in figure 2(c) and 2(d). It is clearly seen that the presence of streamer-like structure is accompanied by enhanced particle fluxes in the far-SOL, whereas their disappearance correlates with a significant reduction in particle flux.

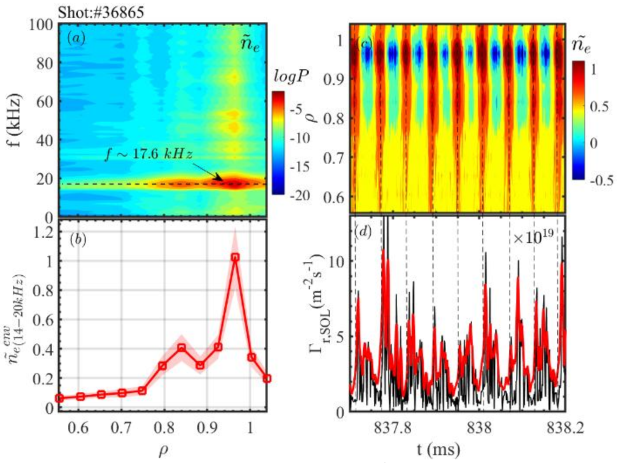

Figure 2. Experimental observation of streamer-like. (a) The frequency spectra of radial row of 12-channel BES signals, (b) the envelope amplitude of radial 12-channel BES signals in the filtering range is 14-22kHz, and (c) the contour plot of the radial density fluctuation signal and (d) the corresponding particle flux of the far scrape-off layer.

In summary, the streamer-like structure can play a key role enhancing cross-field transport and reducing the parallel transport. This insight offers valuable guidance for the development of advanced divertor heat load mitigation strategies. Detailed experimental results will be reported in this conference.

Acknowledgements

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References

[1] A. Loarte et al. *Nucl. Fusion* 47 (2007)
[2] T. S. Hahm et al. *Plasma Phys. Control. Fusion* 46 A323 (2004)
[3] D. A. D'Ippolito et al. *Phys. Plasmas* 18 060501 (2011)
[4] G. Manfredi et al. *Plasma Phys.Control.Fusion* 43 (2001)
[5] Y. Kosuga et al. *Contrib. Plasma Phys.* e201900141 (2020)
[6] F. Kin et al. *Nucl. Fusion* 63 016015 (2023)
[7] J. R. Hong et al. *Nucl. Fusion* 63 104001 (2023)
[8] M. J. Choi et al. *Nucl. Fusion* 59 086027 (2019)
[9] J. Cheng et al. *Nucl. Fusion* 60 046021 (2020)
[10] W. Dorland et al. *Phys. Rev. Lett.* 85 5579 (2000)