8th Asia-Pacific Conference on Plasma Physics, 3-8 Nov, 2024 at Malacca

Long radial coherence of electron temperature fluctuations in non-local transport in HL-2A plasmas

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One of the perplexing phenomena observed and extensively studied worldwide is non-local transport, which has been investigated in various tokamaks and stellerators [1-3]. These experiments have consistently revealed a peculiar long-range transient temperature response triggered by pulsed interventions. These observations suggest that disturbances at the plasma's edge can perturb the deeper plasma equilibrium, challenging the conventional understanding of transport governed by local parameters and the gradient-flux relation. To a certain extent, non-locality remains an enigma within the domain of heat transport. This perplexity arises from the challenges in deciphering thermal fluctuations within the turbulence. These fluctuations are characterized by their low amplitude within the core region, their propensity for long-distance effects, and the formidable obstacles posed by localized measurements. Notably, the turbulence and its electron thermal fluctuation (referred to as $\widetilde{T_e}/T_e$) present formidable detection and measurement challenges. A notable development on this front occurred with the deployment of a correlation electron cyclotron emission system (CECE)[4] in the HL-2A tokamak. This advancement has played a pivotal role in shedding light on the profound physics underlying the non-local phenomenon.

In this work, the dynamics of long-wavelength ($k_\theta <$ 1.4 cm^{-1}), broadband (20 kHz – 200 kHz) electron temperature fluctuations of plasmas in gas-puff experiments are observed in HL-2A tokamak [5]. In a relatively low density ($n_e(0)$ = 0.91 - 1.20 × 10^{19} m^{-3}) scenario, after gas-puffing the core temperature increases and the edge temperature drops. On the contrary, temperature fluctuation drops at the core and increases at the edge. Analyses show the non-local emergence is accompanied with a long radial coherent length of turbulent fluctuations. While in a higher density ($n_e(0)$ = 1.83 - 2.02 × 10^{19} m^{-3}) scenario, the phenomena are not observed. Furthermore, compelling evidence indicates that $E \times B$ shear serves as a substantial contributor to this extensive radial interaction. This finding offers a direct explanatory link to the intriguing core-heating phenomenon witnessed within the realm of non-local transport. This work is supported by the Innovation Program of Southwestern Institute of Physics (Grant No. 202301XWCX001), the Sichuan Science and Technology Program (Grant Nos. 2023ZYD0014), the National Natural Science Foundation of China (Grant No. 12175055).

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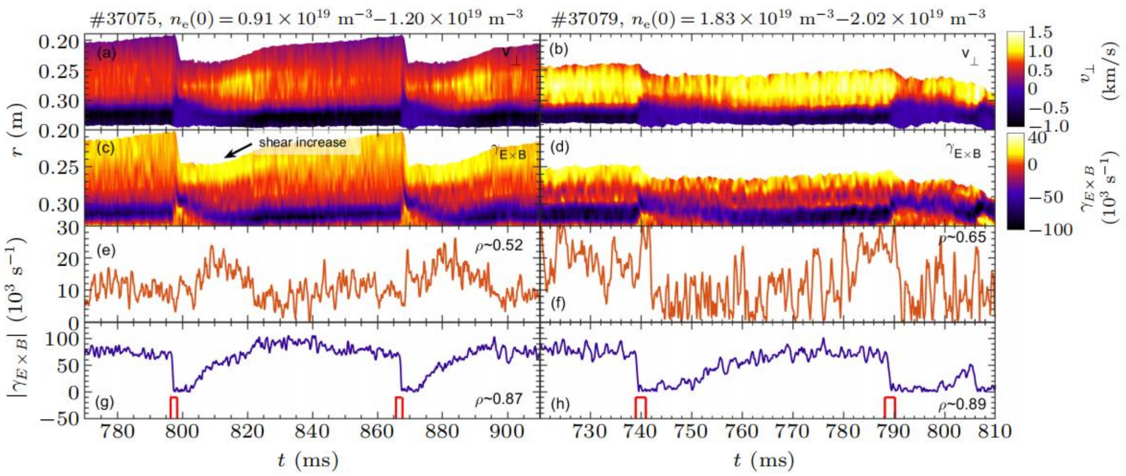

Figure 1. Spatio-temporal plots of (a) and (b) perpendicular velocities $v_\perp$, (c) and (d) $E \times B$ shear rates $\gamma_{E\times B}$ and (e)–(h) absolute values of $\gamma_{E\times B}$ with core T_e increasing (nonlocal phenomenon) in the low density ($n_e(0)$= (0.91 ~ 1.20) × 10^{19} m^{-3}) scenario and without core Te increasing in the high density ($n_e(0)$=(1.83 ~ 2.02)×10^{19} m^{-3}) scenario. The plus or minor value of $v_\perp$ represents the ion or electron diamagnetic drift direction, respectively. The shearing rates increase abruptly inside inverse region in the non-local scenario.