Edge plasma transport in three-dimensional magnetic topology

S.C. Liu[1], Y. Liang[1], P. Drews[2], N. Yan[1], M. Jia[1], G.S. Li[1], Y. Sun[1], L. Wang[1], G.S. Xu[1], X. Gao[1], X.Z. Gong[1] and EAST Team

[1] Institute of Plasma Physics, Chinese Academy of Sciences; [2] Forschungszentrum Jülich GmbH

E-mail: Shaocheng.liu@ipp.ac.cn

In tokamaks, the edge transport barrier collapses during the eruption of edge localized mode (ELM); simultaneously, a large amount of heat and particles ejected into the scrape-off layer (SOL) could lead to extremely high instantaneous heat flux on divertor target. This is a critical challenge for the first-wall materials in ITER and fusion reactors. As demonstrated by many tokamaks, resonant magnetic perturbation (RMP) is an effective method to control ELMs. Understanding of edge plasma transport during the application of RMP is crucial for the interpretation of ELM control physics, because edge transport could directly impact the plasma confinement and divertor heat load. To investigate the common physical mechanism of edge plasma transport in 3D magnetic topology, a series of experiments are conducted in EAST tokamak and W7-X stellarator. In the plasma conditions close to the ITER Q=10 scenario in EAST, ELMs are fully suppressed by $n = 4$ RMP, exhibiting clear existences of low-frequency turbulence (<30 kHz) and an electromagnetic mode at 120 kHz. The former propagates in the ion diamagnetic drift direction with $k_\theta \rho_s \approx$ 0.1-0.35 and contributes to most of the outward heat and particle fluxes; the latter propagates in the electron diamagnetic drift direction with $k_\theta \rho_s \approx$ 0.01-0.035 and contributes to weak outward transport. A set of CGYRO simulations suggests that the 120 kHz mode is the MTM and the low-frequency turbulence is the ITG mode, which is consistent with the experimental fingerprints. When ELMs are strongly mitigated by $n = 1$ RMP, broadband turbulence (<50 kHz) dominates the outward particle flux and helps to maintain the ELM mitigation. In the island divertor configurations of W7-X, the radial turbulent heat and particle fluxes strongly depend on the local magnetic topology and electron density, revealing two distinct transport patterns: a broadband turbulence dominant region in the island and a low-frequency dominant region in the inner SOL. From the findings in EAST and W7-X, turbulence could drive significant radial transport in 3D magnetic topology, and the dominant turbulence depends on the local magnetic topology and plasma profiles, which provides a physical means to control the cross-field transport and divertor heat flux actively.

References

[1] Liu S. C. *et al* 2023 Nucl. Fusion 63 042003;
[2] Liu S. C. *et al* 2020 Nucl. Fusion 60 082001;
[3] Liu S. C. *et al* 2019 Nucl. Fusion 59 066001;
[4] Liu S. C. *et al* 2020 Phys. Plasmas 27 122504.

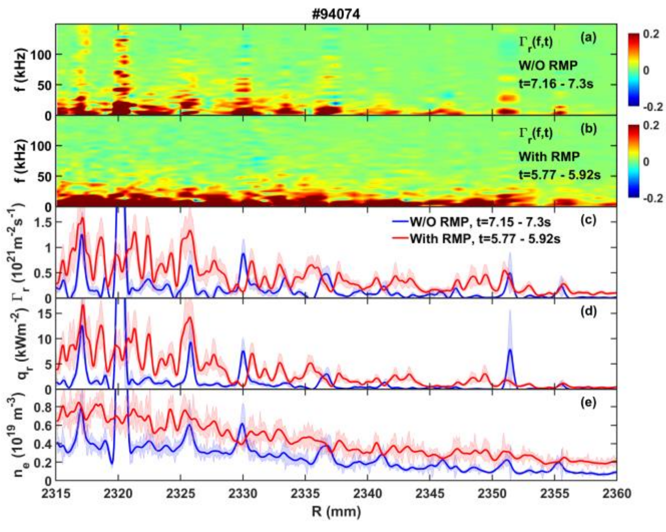

Figure 1. Radial turbulent particle flux in the frequency space for the ELMy phase (a) and ELM suppression phase with $n = 4$ RMP (b) at the outer midplane; (c) radial turbulent particle flux; (d) radial turbulent heat flux; (e) SOL electron density. The positive Γ_r signifies the outward particle flux, while the negative value means the inward particle flux. The shaded regions in (c), (d) and (e) denote the standard deviation of particle flux and electron density, respectively.