BOUT++ Simulations on Turbulence Spreading in Small ELM Regimes for Divertor Heat Load Control

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Simultaneously controlling large ELMs and divertor heat loads in H-mode plasma is crucial for achieving steady-state operation of a tokamak fusion reactor. Recently, both experiments and simulations have shown that H-mode plasma regimes with small/grassy ELMs can help to reduce the ELM size and broaden the SOL width λ_q, while maintaining high plasma confinement compared to type-I ELMs. However, the physics underlying the small ELM regime is still unclear. Investigating how turbulence spreading affects the SOL width is essential for divertor heat load control.

BOUT++ turbulence simulations were conducted to investigate the effects of turbulence spreading on λ_q broadening in small ELM regimes. This study is motivated by 4 EAST discharges with 2 different poloidal magnetic field B_p in small ELMs, where the pedestal is near marginal stability and relaxes into a linearly stable state after the initial ELM crash. BOUT++ nonlinear simulations have shown that turbulence energy intensity flux Γ_ε is a crucial factor in the broadening of the SOL width λ_q. λ_q is broadened as fluctuation energy intensity flux Γ_ε at last close flux surface (LCFS) increases due to increasing pedestal ExB flow shear and local SOL turbulence, as shown in Fig.1. The transition from ELM-free to small ELM regime leads to a significant broadening of the SOL width (λ_q) due to the strong radial transport of turbulence energy. Same trend has also been found by EAST experimental database.

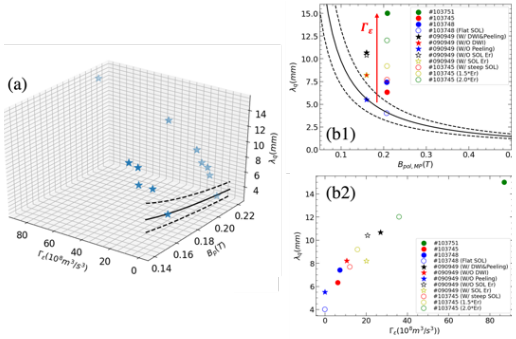

Fig. 1. (a) 3D plot of heat flux width $\lambda_q$vs poloidal magnetic field B_p and fluctuation energy intensity flux Γ_ε; 2D plot of heat flux width λ_q vs poloidal magnetic field B_p (b1) and fluctuation energy intensity flux Γ_ε (b2).

The spreading of turbulence from the pedestal to the SOL is highly dependent on the pedestal plasma parameters, as shown by Fig. 2. Here the black curves are ∇P_0 scan with low collisionality $\upsilon_{ped}^* = 0.108$ (solid curve) and high collisionality $\upsilon_{ped}^* = 1$ (dashed curve); the red curves are υ_{ped}^* scan with small $\nabla P_0 \sim 200\ kPa/m$ (solid curve) and large $\nabla P_0 \sim 200\ kPa/m$ (dashed curve). As the pedestal pressure gradient ∇P_0 increases and the pedestal collisionality υ_{ped}^* decreases, the fluctuation energy intensity flux Γ_ε increases. Turbulence spreading from pedestal to SOL depends on the radial mode structure. The low-n peeling mode induces more fluctuation energy flux Γ_ε for low collisionality as compared to the high-n ballooning mode for high collisionality, due to the wide radial mode structure for peeling mode but narrow for ballooning mode. However, strong peeling turbulence will cause a large ELM crash and large heat load on the divertor. Week peeling turbulence will be a best solution, such as small ELM regime.

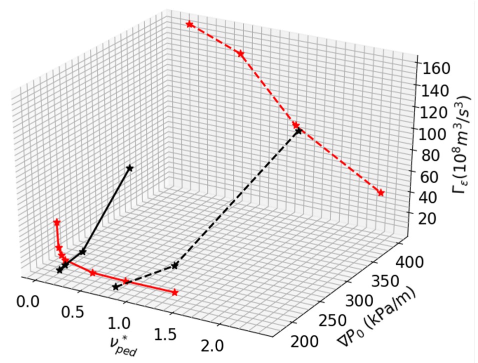

Fig. 2. 3D plot of fluctuation energy intensity flux Γ_ε vs pressure peak gradient ∇P_0 and υ_{ped}^*.

Operating in H-mode with small ELMs has tremendous potential to address two of the most critical problems for Tokamak fusion reactors: significantly reducing the ELM size and substantially broadening the SOL width.

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