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BOUT++ simulations on physical mechanisms for divertor heat flux width broadening

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The heat flux distributions on divertor target plates in H-mode plasmas are serious concerns to future fusion devices. The fluid transport code within the BOUT++ framework has been developed with all cross-field drifts to study the physics in setting the divertor heat flux width λ_q. The steady state solutions of divertor heat flux width for both ions and electrons have been investigated for Alcator C-Mod, CFETR and ITER. The BOUT++ simulations with the attached divertor conditions for Alcator C-Mod EDA H-mode discharges well follow the Heuristic-Drift-based (HD) empirical divertor heat flux width scaling, which inversely dependence on the poloidal magnetic field. The simulations identified two distinct regimes via a turbulence diffusivity scan: drift dominant regime and turbulence dominant regime [1]. Goldston's HD model yields a lower limit of the width in the drift dominant regime. The BOUT++ simulations and theoretical estimate further demonstrate from current tokamaks to future large machines like ITER and CFETR, a transition can easily occurs from a drift dominant regime to a turbulence dominant regime due to their large machine sizes, strong magnetic field and high current, all of which lower the required turbulence driven transport for the transition [2, 3].

However, even in the drift dominant regime, HD model is only satisfied for the low-gas-puff H-mode conditions. ASDEX-Upgrade (AUG) data showed that the scrape-off-layer width broadens as the collisionality increases which is outside the scaling law for the detached divertor conditions of H-mode discharges. To identify the physics of these results, the HD model is generalized to take into account finite SOL collisionality, so-called GHD model. The enhancement of parallel energy confinement time compared with zero collisionality limit is found by using the two-point model. The heat flux width enhances since the width from HD model is evaluated as the drift velocity multiplied by the SOL residence time. The GHD model can fit AUG data well [4, 5].

A series of BOUT++ transport simulations are performed to study the physics of the scaling characteristics of the divertor heat flux width vs density/collisionality via a plasma density scan with either fixed pressure profile or fixed temperature profile inside separatrix. The simulations indicated that the divertor heat flux width can be broadened due to the transition of the SOL residence time from the parallel particle flow time to the enhanced parallel conduction time as the collisionality/density increases as posited in the GHD model as shown in Fig. 1. In addition, the heat flux width is found to be proportional to the square root of ion mass for low collisionality while it has a weakly dependence on ion mass for high collisionality. Furthermore, our simulations show that as the density increases, the radial electric field (Er) well shallows, which potentially weakens ErxB flow shear stabilization of turbulence at high density.

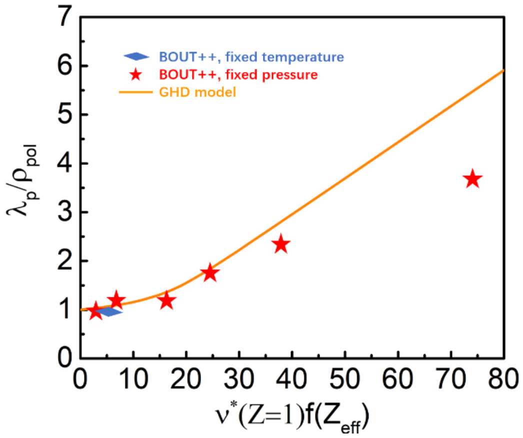

Fig. 1: Pressure gradient scale length in near SOL divided by ion poloidal gyro-radius versus collisionality. The yellow curve is based on the GHD model; the red stars are from BOUT++ transport simulations with fixed pressure profile while the light blue diamond is from BOUT++ transport simulations with fixed temperature profile.

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