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New Gyrokinetic Understanding of ITER's Wide Divertor Heat-Flux Width*

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Gyrokinetic XGC predictions for the divertor heat-flux width λ_q in the wide range of the poloidal magnetic field on low-recycling NSTX, DIII-D, NSTX and JET plasmas match the Eich-14 scaling formula ($\lambda_q^{(14)} \propto B_{pol}^{-1.19}$, where B_{pol} is the poloidal magnetic field at outboard-midplane separatrix) [1]. Prediction for λ_q on a low-current ITER plasma – in which B_{pol} is similar to those in the present tokamak plasmas – also proves Eich-14 scaling, indicating that the large physical size of ITER does not alter the Eich-14 formula. However, when the simulation input is changed to the full-current 15MA ITER plasma, XGC reveals over six-times wider heat-flux width than the Eich-14 predicted width, which could significantly relax the divertor material, design and operational scenario requirements [1].

After the publication of [1], the highest current experiments on C-Mod then produced plasmas that have ITER-similar ion gyroradius and B_{pol} values, while showing that λ_q still obeys the Eich scaling formula. Follow-on XGC simulations of this plasma also showed λ_q values satisfying the Eich-formula. Thus, in the B_{pol} space alone, XGC produced double valued answers between the highest current C-Mod and full-current ITER plasmas. If the gyrokinetic results are correct, then there should be hidden parameters and hidden physics.

We report here that recent search for the hidden parameters using some machine learning techniques reveals that the well-known neoclassical dimensionless parameter a/ρ_i is the hidden parameter, and a simple modification to the Eich formula is discovered. The new formula not only recovers Eich-14 formula for the present tokamak plasmas and the low current ITER plasma, but also removes the double valuedness in the XGC results. The distance between the highest current C-Mod plasmas and the full-current ITER becomes very far in the new parameter space. ITER 13.5MA plasma and NSTX-U 2MA plasma further refines the new λ_q formula and the hidden physics. The physics mechanism responsible for the deviation of λ_q from the Eich-14 scaling turns out to be the radial heat-spread by trapped-electron turbulence at large a/ρ_i or at small electron collisionality. Suggestions for corresponding experimental explorations on today's tokamaks will be discussed. Suggestions for the edge plasma operation conditions will also be made to take advantage of the new physics discovery.

[1] C.S. Chang et al., "Gyrokinetic projection of the divertor heat-flux width from present tokamaks to ITER," Nucl. Fusion 57 (2017) 116023

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