Modeling tokamak boundary plasma turbulence and understanding its role in setting divertor heat flux widths*

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The BOUT++ code has been used to simulate edge plasma electromagnetic (EM) turbulence and transport, including quasi-coherent modes (QCMs), and to study the role of EM turbulence in setting the scrape-off layer (SOL) heat flux width (lambda_q) and its scaling with machine parameters. An important goal of this research is to develop a first-principles model that can reproduce the observed inverse current I_p scaling of lambda_q seen in the international tokamak database and that can project the SOL heat flux width for future machines. More than a dozen tokamak discharges from C-Mod, DIII-D, EAST, ITER and CFETR have been simulated with encouraging success. The plasma profiles inside the separatrix of these discharges used in simulations are taken from fits of a modified tanh function to real experimental data, mapped onto a radial coordinate of normalized poloidal flux for C-Mod, DIII-D, and EAST. The plasma profiles inside the separatrix of ITER and CFETR are taken from feasible burning plasma operation scenarios using CORSICA [1] and ONETWO codes.

For the C-Mod enhanced D_α (EDA) H-mode discharges, BOUT++ six-field two-fluid nonlinear simulations show a reasonable agreement of upstream turbulence characteristics and divertor target heat flux behaviour [2,3]: (a) The simulated quasi-coherent modes (QCMs) show consistent characteristics of the frequency vs poloidal wave number spectra of the EM fluctuations when compared with experimental measurements – frequencies are around 60-120 kHz and k_θ is around 2.0 cm^{-1} which are comparable to the Phase Contrast Imaging measurements; (b) The location of the QCMs is generally consistent with experiment; (c) the simulations yield similar lambda_q to experimental measurements within a factor of 2. The BOUT++ simulations have also been performed for inter-ELM periods of DIII-D and EAST discharges, similar quasi-coherent modes have been found in these discharges. The parallel electron heat fluxes onto the target from the BOUT++ simulations of C-Mod, DIII-D, and EAST follow the experimental heat flux width scaling of the inverse dependence on the poloidal magnetic field with an outlier [4,5]. Further turbulence statistics analysis shows that the blobs are generated near the pedestal pressure peak gradient region inside the separatrix and contribute to the transport of the particle and heat in the SOL region.

To generalize the Goldston heuristic drift-based (HD) model[6], BOUT++ transport model has been developed for transport simulations with the electric and magnetic drifts and with the sheath potential in the SOL. Transport coefficients are calculated from the experimental profiles inside separatrix, then extending to the SOL. Steady state solution of heat flux show: (1) a similar scaling to the Goldston's HD model; (2) The amplitude of the simulated heat fluxes is within a factor of 2 compared to the experiment data; (3) The ExB drift reduces the heat flux width by 30%. The results of the SOL heat flux width for ITER and CFETR will be presented from both BOUT++ turbulence and transport simulations.

[1] S.H. Kim, T.A. Casper, D.J. Campbell, et al., "Simulating Burning Plasma Operation in ITER," paper ITER_D_R9T8J9 v1.1, EPS, Lisbon, 2015; [2] B. Chen, et al, 2017 Nucl. Fusion, 57, 116025; [3] B. Chen, et al, 2017, submitted to Phys. Plasmas; [4] T.Y. Xia, et al, 2017, Nucl. Fusion, 57, 116016; [5] T.F. Tang, et al, 2017, submitted to Phys. Plasmas. [6] Goldston R.J. 2012 Nucl. Fusion 52 013009

Performed under the auspices of the USDOE by Lawrence Livermore National Laboratory under Contract No. DE-AC52-07NA27344.