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Gyrokinetic simulation of tokamak edge physics: present and future

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As often expressed via the idiom "the tail wags the dog," tokamak experiments ubiquitously find that the edge plasma controls the core plasma condition, thus the fusion performance. Even though it has been almost 40 years since the discovery of "the tail wags the dog" phenomenon that has been accepted by ITER as its basic operation principle in achieving the Q=10 goal, its fundamental physics understanding has been a difficult task in the theoretical fusion community due to the nonlinear, nonlocal, nonthermal, multiscale, and multi-physics nature of the problem in complicated edge geometry.

Charged and neutral particles in the edge travel through the confined and unconfined regions on a time-scale not much different from the turbulence decorrelation time-scale and nonlocally mix up the neoclassical and turbulence physics between the equilibrium and non-equilibrium (non-Maxwellian) regions. The collisionality varies from almost collisionless pedestal to highly collisional scrape-off regions to further complicate the nonlocal physics study. Furthermore, ITER is planning to utilize RMP coils to suppress the edge localized modes, that will create the magnetic islands in the confined region and induce the stochastic field-line connection between the pedestal and the divertor plates.

A total-f kinetic simulation is required for a more complete understanding of this complicated edge physics, but it has not been an easy task due mostly to lack of robust high-performance computational algorithms and computing power. Riding the explosive increase in the computing power, US DOE established a collaborative SciDAC activity among fusion physicists, applied mathematicians and computer scientists about 15 years ago to attack this difficult edge physics problem. As a result, the total-f gyrokinetic code XGC has been developed that includes most of the edge physics described above and will include more physics as the exascale computers arrive soon. This talk will summarize the present status of the gyrokinetic edge physics discoveries and validations – including the L-H turbulence bifurcation dynamics [1], as shown in Fig. 1, the divertor heat-load footprint [2], the edge turbulence property [3-5], the edge-specific neoclassical physics [6-10], the neutral particle and atomic-physics effect [11], the RMP effect [12], and others. The future directions in the kinetic edge simulation will also be discussed, that will include the full-6D simulation, the MHD/fluid mode studies, tungsten impurity effects, and the stellarator physics.

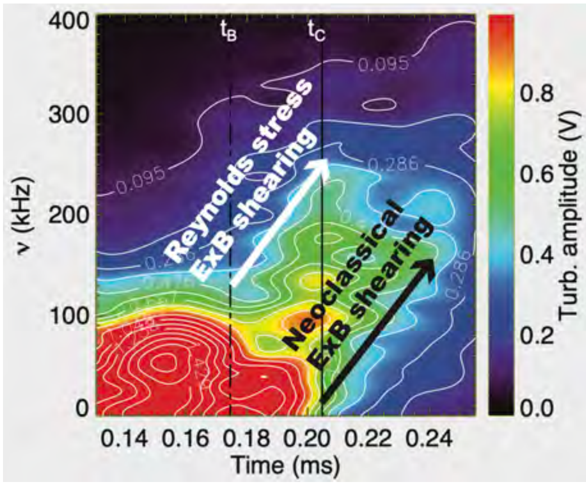

Fig. 1. L-H transition dynamics discovered from XGC [1]. Self-generated sheared ExB flows from turbulence-driven Reynolds-stress mechanism and neoclassical mechanism work together to suppress the turbulence.

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