Electromagnetic total-f simulation of diverted edge plasma in the gyrokinetic particle-in-cell code XGC

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A total-f electromagnetic gyrokinetic algorithm has been implemented in the particle-in-cell code XGC, which, for the first time, can simulate electromagnetic turbulence in tokamak boundary plasma in realistic divertor geometry together with neutral particle recycling and neoclassical physics [1]. Generalization of XGC's total-f method to the electromagnetic regime is based on the reduced delta-f mixed-variable/pullback algorithm [2, 3] previously implemented in XGC and verified by M. D. J. Cole et al. [4]. The new electromagnetic XGC now combines the traditional strengths of its total-f algorithm such as realistic tokamak geometry from the magnetic axis to the material wall, combined neoclassical and turbulence physics, neutral particle recycling, a nonlinear Fokker-Planck collision operator, and efficient GPU-accelerated parallelization, with the numerical stability of the mixed-variable/pullback formulation that mitigates the "cancellation problem." An overview of the numerical algorithms of electromagnetic total-f XGC will be presented including time evolution of the background distribution function, time and space discretization, and field aligned Fourier filter.

A pair of comparison simulations in a DIII-D-like H-mode boundary plasma using the electrostatic and electromagnetic total-f method are performed (Fig. 1). The electromagnetic turbulence grows about 10 time faster than electrostatic turbulence. Electron particle and heat transport in nonlinear electromagnetic turbulence show significant enhancement over purely electrostatic turbulence as shown in Figs. 1 (a) and (b). Figure 1 (c) shows that intrinsic homoclinic tangles exist in tokamak edge due to microturbulence. The homoclinic tangle widens the divertor heat-load width in 15MA ITER plasma over the electrostatic case, while its effect on the divertor heat-load width is insignificant in the present tokamaks. However, an integrated understanding of scrape-off layer physics, pedestal physics and the neutral particle physics can be affected significantly by the electromagnetic edge turbulence and homoclinic tangle mixing. These results show that electromagnetic simulation is necessary for a higher fidelity understanding of tokamak boundary physics.

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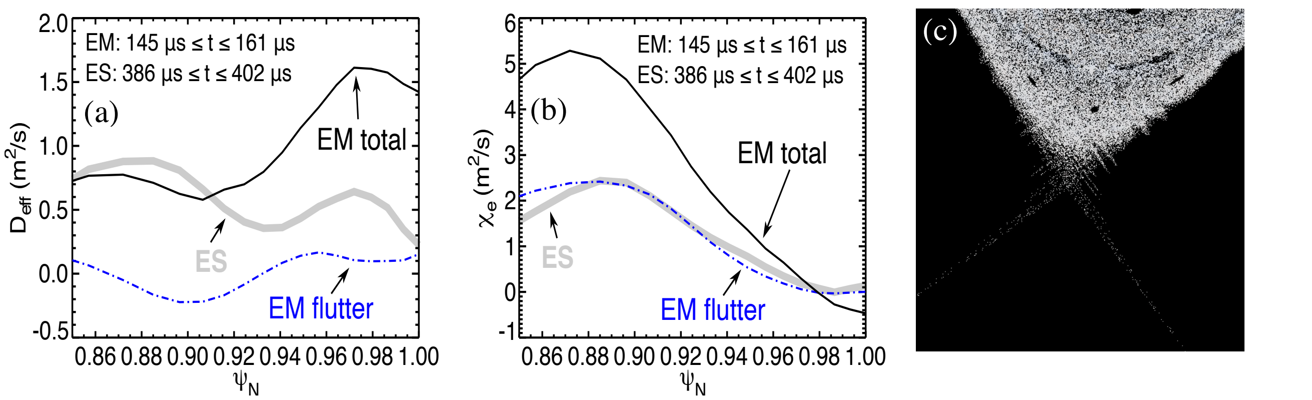

Fig. 1: (a) Effective particle diffusivity, (b) Effective electron heat conductivity, (c) Poincare puncture plot from turbulent magnetic perturbation.