Report on FY2009 DOE OFES Theory Milestone:

Continue to increase resolution in simulations of plasma phenomena—optimizing confinement and predicting the behavior of burning plasmas require improved simulations of edge and core plasma phenomena, as the characteristics of the edge can strongly affect core confinement. In FY 2009, gyrokinetic edge electrostatic turbulence simulations will be carried out across the divertor separatrix with enhanced resolution down to the ion gyroradius scale.

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on behalf of
SciDAC Proto-FSP Center for Plasma Edge Simulation (CPES)

Quarterly Milestones

Q1: Simulate collisionless electrostatic ion temperature gradient turbulence in DIII-D edge geometry in XGC1 gyrokinetic code using 8,000 processor on Jaguar at ORNL and Franklin at NERSC, with the radial and poloidal resolution being twice the ion gyro-radius

Q2 Add Coulomb collisions to the edge ITG turbulence simulation using 12,800 processors on Jaguar at ORNL and Franklin at NERSC.

Q3 Enhance the radial resolution down to the ion gyro-radius scale across the separatrix using 16,192 processors on Jaguar at ORNL and Franklin at NERSC

Q4 Complete the enhanced resolution simulation of the electrostatic gyrokinetic edge turbulence across the divertor separatrix down to the ion gyro-radius scale in both radial and poloidal directions, using XGC1 on 20,032 Jaguar processors at ORNL

Introduction

Plasma transport in the edge region is a research area critical to the success of the toroidal magnetic fusion program. Together with the neutral transport, heat flux, and edge localized mode instabilities, edge transport determines the edge pedestal shape and height, which then strongly influences the fusion yield in the core plasma by determining the edge boundary condition. The desired edge pedestal height in ITER can only be obtained when the plasma operation is in high confinement mode (H-mode). It is generally believed that the full-powered ITER will be able to operate in H-mode. However, a cost effective design and operation of ITER demand a predictive capability for transition from the low confinement mode (L-mode) to H-mode, which should be based upon the turbulence study in L-mode plasma prior to the transition.

The L-to-H transition occurs in a thin layer just inside the magnetic separatrix, in which there is usually a density pedestal in L-mode. The density pedestal in L-mode is normally lower in height and wider in radial width than the density pedestal in H-mode. On the other hand, the radial edge temperature gradient in L-mode stays gradual until after the H-mode transition occurs. This leads to low η_i (= $d_r \log T_i / d_r \log N$ =density gradient scale length/ion temperature gradient scale length) in the L-mode density slope except at the pedestal top, making it difficult for the pure ion temperature gradient (ITG) driven mode to be linearly unstable in the transition-layer according to a local theory. However, ITG modes might be nonlocal in the edge of a realistic separatrix geometry. A realistic nonlocal simulation is needed to answer the ITG question in the L-mode edge, in which η_i varies widely across the L-mode edge density pedestal.

Existence of the ITG turbulence in L-mode edge is an important topic for L-H transition physics since the ITG modes are large scale and robust. The existence of the ITG turbulence could also significantly influence the characteristics of other possible turbulence activities in the L-mode edge. Study of ITG turbulence around the transition-layer has been difficult for several reasons. The first reason is the existence of magnetic separatrix geometry including X-point, which makes the guiding center equation of motion in a flux coordinate system to suffer from a mathematical singularity (the magnetic rotational transform vanishes at the separatrix) in an ordinary gyrokinetic code which has been developed for efficient study of core turbulence physics.

The second reason is the non-separability of the radial scale length between the equilibrium gradients $L_\perp$ and the ITG mode correlation length Δ_{turb}. The scale length of the equilibrium radial gradient is similar to the radial extent of the ITG modes, allowing for strong nonlinear interaction between the turbulence and the mean equilibrium. All the physics dynamics, including the meso-scale turbulence dynamics, profile dynamics, and the neoclassical dynamics, are compressed into the same scale length. This invalidates the mixing length argument, which originated from a system with large equilibrium scale length $\Delta_{turb} << L_\perp$. This also could mean break-down of the local diffusion ansatz. The usual delta-f simulations, which have been developed for economical core plasma turbulence simulation, assume non-interacting fixed background equilibrium and study the dynamics of the perturbed part only. Considering the elevated importance of the neoclassical physics in the plasma edge, a proper interaction of the turbulence dynamics consistently with the neoclassical dynamics may be an essential condition for the edge transport study.

Another reason for the difficulty is the co-existence of the open field line and the closed field line regions. A conventional delta-f method is not suitable for handling the open field line region since the assumption of a fixed background distribution function f_0 is invalid due to loss of particles to the wall.

In the present work, we use a special full-function (full-f) gyrokinetic code XGC1 [1] to study ITG turbulence across the magnetic separatrix in a realistic divertor geometry. Neoclassical and turbulent plasma dynamics are simulated together self-consistently, with their radial scale lengths being similar to each other in an L-mode type of edge plasma in DIII-D geometry.

[1] C.S. Chang and S. Ku, Phys. Plasmas 15, 062510 (2008).

First Qtr Report

Q1 Milestone: Simulate collisionless electrostatic ion temperature gradient turbulence in DIII-D edge geometry in XGC1 gyrokinetic code using 8,000 processor on Jaguar at ORNL and Franklin at NERSC, with the radial and poloidal resolution being twice the ion gyro-radius.

> **Executive summary of the Q1 achievement:** Collisionless ion temperature gradient (ITG) turbulence simulation has been achieved in the XGC1 gyrokinetic code in a realistic DIII-D edge geometry using 8,000 processors on Jaguar at ORNL and Franklin at NERSC, with the radial and poloidal resolution (4 mm) being twice the ion gyro-radius (2 mm). It has been found for the first time that a robust ITG turbulence activity exists in the L-mode edge-density gradient.

To start the investigation, the simulation has been performed in a coarse grid system with the poloidal and radial grid size twice the ion gyro-radius in a realistic DIII-D geometry.

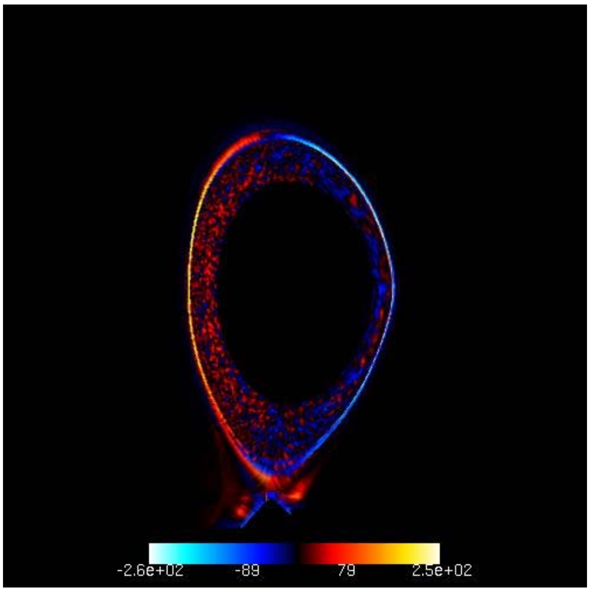

Figure 1. ITG turbulence in edge with coarse poloidal and radial grid size (2x ion gyroradius)

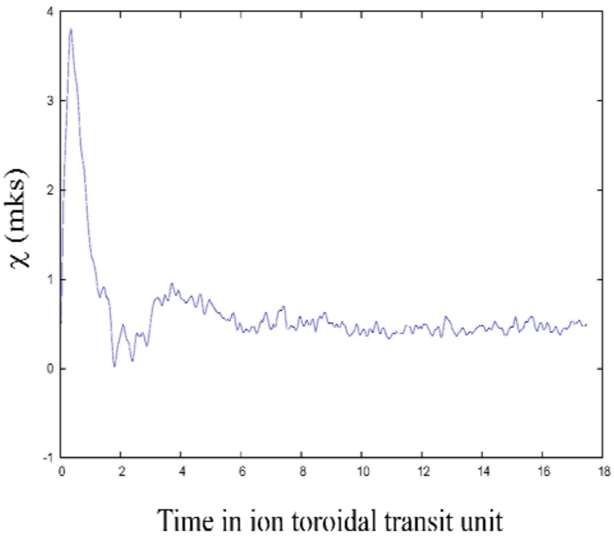

Figure 2. Behavior of "effective" ion thermal conductivity in coarse grid in toroidal transit time

Figure 1 shows the electrostatic potential fluctuation by ITG turbulence in coarse grid (2x ion gyroradius). Careful inspection of the ITG potential fluctuation reveals that the turbulence exists in the entire density pedestal, from the top to the bottom, even though ITG is expected to be locally unstable only at the density pedestal top. This is a strong sign of nonlocal ITG turbulence in the edge. In this coarse grid simulation, growth of the radial streamers appears to be weak (this may be a grid effect). In a nonlocal turbulence across strong equilibrium gradient, the concept of local ion thermal conductivity is not justified. Never-the-less, we define an "effective" ion thermal conductivity by dividing the heat flux by the local temperature gradient. Figure 2 is the "effective" ion thermal conductivity behavior in time. The effective ion thermal conductivity saturates at ~0.5 m^2/s, which is the right ballpark number with experimentally inferred values. The physics phenomena observed here can change as we increase the grid resolution. Such studies will be performed and reported in the future quarters.