§28. Comparison of Boundary Plasma Turbulence Simulations with Experiments on the Heliotron J

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The boundary plasma, which is a transitional region covering core-edge and scrape-off-layer (SOL), influences the global confinement in magnetic fusion devices such as tokamaks through the pedestal formation and L-H transition. Edge fluctuation in a supersonic molecular-beam injection (SMBI) fueled plasma has been investigated in Heliotron J using an electrostatic probe array. To understand the effect of molecules/atoms on the large-scale structure dynamics through the ion-neutral collision in SMBI fueled plasmas, in this project, edge fluctuation dynamics and associated transport in weak magnetic shear plasmas including Heliotron J are investigated in SMBI/GP (gas puffing) plasmas based on theoretical analyses and simulations.

To simulate the response of blob/hole as well as large-scale structures to the SMBI fueling, we extend the 2-field 2-region Hesegawa-Wakatani(HW) turbulence model including the ion-neutral collision effects. This may be a minimal model although it is not complete for SMBI physics in boundary plasmas, which involve complex atomic and molecular processes. The focus here is on the ion-neutral collisionality dependence of blob/hole structure transition dynamics. The model equations governing the electrostatic potential Φ and total electron density n are

$$\partial_t \nabla_\perp^2 \Phi + [\Phi, \nabla_\perp^2 \Phi] = \bar{\alpha}_{dw}(\Phi - N)/n + \bar{\alpha}_{sh}\Phi - \kappa \partial_y N - \nu_{in} \nabla_\perp^2 \Phi + \mu \nabla_\perp^4 \Phi \quad , \qquad (1)$$

$$\partial_t n + [\Phi, n] = \bar{\alpha}_{dw}(\Phi - N) - \bar{\alpha}_{sh} n + D\nabla_\perp^2 n + S \quad . \qquad (2)$$

Here $N = \ln n$, $\bar{\alpha}_{dw} = \alpha_{dw0}\alpha_{dw}(x)$, $\bar{\alpha}_{sh} = \alpha_{sh0}\alpha_{sh}(x)$ model the electron response in the core-edge and the SOL regions, respectively. ν_{in} is the ion-neutral collision, which corresponds to the so-called Peterson current effect. Here,

$$\alpha_{dw}(x) = \{1 - \tanh[(x - x_{dw})/\Delta x_{dw}]\}/2 \quad , \qquad (3)$$

$$\alpha_{sh}(x) = \{1 + \tanh[(x - x_{sh})/\Delta x_{sh}]\}/2 \quad , \qquad (4)$$

are taken.

Nonlinear simulations are performed to investigate the effect of neutral gas on the edge turbulence and the zonal flow as well as the dynamics of large-scale structures. It is observed that the ion-neutral collision, ν_{in}, can suppress the turbulence, further reduce the ZF level much more efficiently, as shown in Fig.1. The particle flux is also reduced greatly. Most importantly, the generation and propagation of the holes inside the separatrix/LCFS are restrained and the blobs in the SOL are intensified. Remarkably, the blobs tend to elongate radially, then become streamers. Comparison of simulations with and without ν_{in} effects shows that besides particle flux is reduced due to the ν_{in} stabilization, the holes are shrunk back to the separatrix/LCFS. Most distinctly, the blobs elongate to form streamers during the propagation. The resultant particle flux still stays at lower level due to the amplitude reduction although the streamer may generally enhance transport. These observations show that blob/hole dynamics can be controlled if turbulent structures are selected by changing ν_{ie} and/or ν_{in} due to the correlation between the blob/hole and potential dipole. Such a tendency is also quantified through the 2D spatial correlation function in the quasi-steady state. Hence a probable approach to control blob/hole transport is suggested by adjusting plasma collisionality, e.g. using gas puffing and/or SMBI.

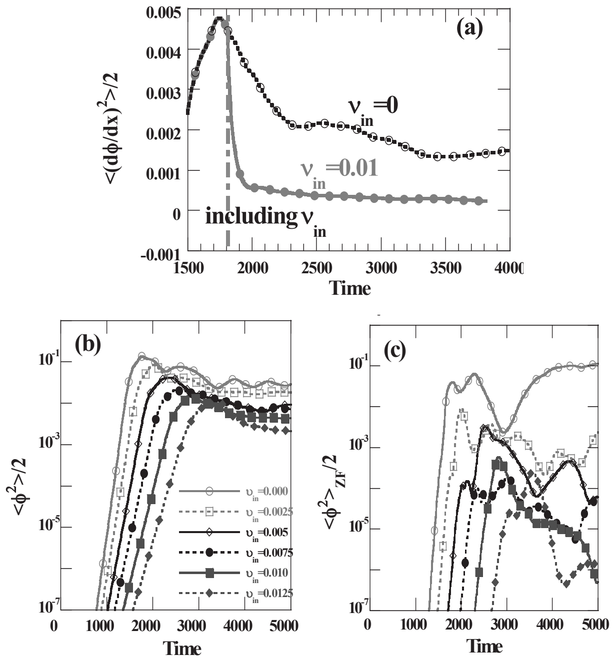

Fig.1 (a) Time evolution of averaged particle flux in simulations with and without ν_{in} effect. Effects of ion-neutral collision on the edge turbulence(b) and zonal flows(c).

The magnetic shear is weak in Heliotron J plasmas. To understand probable dynamics of the blob/hole structures in weak shear plasmas, simulations are performed for different $\hat{s}$, showing that in the shearless case, big blobs are broken up into smaller pieces by a secondary process, perhaps an interchange instability. Note that this secondary instability creates new holes inside primary blobs and then gives rise to a radial cascade of blobs, which may decelerate the blob movement so that the convective particle flux occurs just around the separarix/LCFS. However, the magnetic shear could stabilize the secondary interchange mode. The simulation with finite magnetic shear shows that the blobs tend to be robust solitary structures without secondary instability. The blobs propagate fast in the SOL and cause convective particle transport in the region far from the separatrix/LCFS. These observations show that the magnetic shear may also govern the structure transition in the boundary plasmas. These results may suggest the observation of a blob structure cascading in Heliotron J plasmas.