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

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Edge turbulent transport dominates the performance of magnetic fusion devices through the pedestal formation and L-H transition. The boundary plasma influences the global confinement. Strong boundary turbulence has been observed extensively in almost all tokamaks, usually with a filamentary coherent structure extended along the magnetic field lines, termed density or pressure blob and/or hole. These objects can violently transport plasma across the separatrix in divertor plasmas or the LCFS in limiter plasmas to the SOL region and enhance the interaction between the plasma and the first-wall. Understanding the blob/hole transport is considered to be essential for the H-mode operation. The generation of blobs/ holes has been mainly investigated through both numerical simulations and experiments since such solitary structures are hardly derivable analytically, unlike the poloidally symmetric zonal flows (ZFs). The formation of such structures is not only determined by complex nonlinear interaction among boundary turbulence but also depends on plasma discharge conditions including fueling and heating, which could govern the plasma collisionality. Hence, it is interesting to investigate the collisionality dependence of nonlinear characteristics of the blob/ hole dynamics with a numerical and experimental comparison.

Simulation model: In this research project, we employed a 2-field 2-region Hesegawa- Wakatani turbulence model to simulate boundary turbulence dynamics in tokamak and helical plasmas. The focus is on the collisionality dependence of blob/hole structure transition dynamics. The model equations governing the electrostatic potential Φ and total electron density n are

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

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

Here $N = \ln n$, $\overline{\alpha}_{dw} = \alpha_{dw0}\alpha_{dw}(x)$, $\overline{\alpha}_{sh} = \alpha_{sh0}\alpha_{sh}(x)$ model the electron response in the core-edge and the SOL regions, respectively. Here, $\alpha_{dw}(x) = \{1 - \tanh[(x - x_{dw})/\Delta x_{dw}]\}/2$ and $\alpha_{sh}(x) = \{1 + \tanh[(x - x_{sh})/\Delta x_{sh}]\}/2$ are taken.

To address blob/hole generation mechanism, nonlinear simulations are performed to scan the role of electron non-adiabatic response along the field lines in the core-edge and SOL regions. That is, we simulate the generation of the blobs/holes for different α_{dw} and α_{sh} through adjusting the plasma collisionality ν_{ei} (as $\alpha_{dw} \propto \nu_{ei}^{-1}$, here $\nu_{ei} \propto nT_e^{-3/2}$) and/or parallel connection length $L_{//}$ roughly through $L_{//} \sim qR$ in tokamak plasmas. Simulation scan for different α_{dw0} and α_{sh0} remarkably shows that as α_{sh0} decreases and/or α_{dw0} increases, which may be determined by the current (or q) profile and/or the electron-ion collision frequency ν_{ei}, the blob generation is dramatically enhanced. Big blobs are formed in the SOL region and rapidly propagate outwards. Otherwise, the holes tend to dominate the edge turbulence with decreasing α_{dw0}.

To validate the numerical predictions above, the blob/hole experiments have been carried out using a reciprocating Langmuir five-probe array in ohmically heated limiter deuterium plasmas on the HL-2A tokamak (major radius R= 1.65 m and minor radius a= 0.4 m). A critical electron-ion collisionality for the blob/hole structure transition is observed based on various statistical analyses of the saturated ion current in the blob/hole measurements on the HL-2A tokamak. Fig.1 shows the evolution of burst rates of blob and hole in the case with decreasing the ion-electron collisionality. Systematic statistical analyses show perfectly same experimental and numerical characteristics of blobs/holes as the electron-ion collisionality varies.

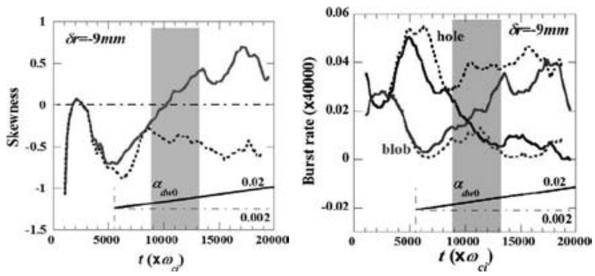

Fig.1 Time evolution of the skewness factor (left) and the burst rates of blobs and holes (right) in the simulations.

Motivated by the comparison between simulation and experimental observation on the HL-2A tokamak, the statistical analyses of the experimental data on the Heliotron J are analyzed using the same approaches as for the tokamak data. It is shown that the blobs dominate the Heliotron J edge turbulence in the NBI heated plasma as shown in Fig.2, while the hole is rather weak in whole edge plasma, exhibiting a different characteristic from the tokamak counterpart.

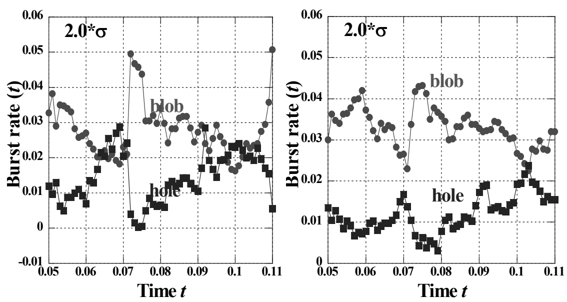

Fig.2 Time evolution of burst rates of blob/hole in the NBI heated Helitron J plasma with SMBI at t=0.072 s for different loaction of the Langumir probe at -4mm inside the LCFS(left), on the LCFS (right).