Topic: TH-D

Effects of Collisionality on the Nonlinear Characteristics of Boundary Turbulence and Blob/hole Transport in Tokamak Plasmas

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Blob/hole dynamics near tokamak separatrix is of striking importance in determining the boundary transport. Based on simulations using an extended 2-region (edge/SOL) fluid model, we found that blob/hole dynamics are sensitively influenced by the plasma collisionality, i.e., ion-electron and ion-neutral collisions. Namely, the holes are enhanced in highly collisional edge whereas the blobs are weakened at the SOL, causing larger particle convection. These blob/hole dynamics are closely correlated with potential dipoles. The trends are experimentally evidenced on the HL-2A tokamak. Moreover, as the neutral-ion collision increases, the blobs at the SOL tend to develop into streamers propagating outwards with reduced amplitude while the holes inwards are suppressed, showing a key role in nonlinear structure regulation and resultant transport suppression. Results suggest that adjusting the plasma collisionality by fueling, e.g., gas puffing, could serve as a method to nonlinearly select turbulent structures, i.e., blobs, holes or streamers, to access the control of boundary transport.

Introduction: Blobs and holes in boundary plasmas violently transport edge plasma to the scrape-off-layer (SOL) across the separatrix or last closed flux surface(LCFS). Generally, the blobs/holes are created by edge turbulence[1], even conceivably are a manifestation of localized avalanche [2]. Recent blob/hole simulations and theories have predicted many common features, which have been also verified experimentally. Hence, blob/hole control is critical in handling boundary transport. Here we study the effects of plasma collisionality on the nonlinear structure selection of boundary turbulence to explore new approach to control.

Nonlinear features of blob/hole dynamics: In tokamak plasma, blobs/holes are created near the separatrix and propagate outwards and inwards, respectively. The blob/hole transport is governed by their birth rate, size, amplitude and radial motion. Hence, a 2-region(edge/SOL) fluid model[3], which contains essential physics ingredients of electron response on both closed and open field lines, is employed in simulations. We perform a simulation scan of ion-electron collision rate ν_{ie} at the edge as shown in Fig.1, in which Fig.1(a) represents the skewness $S=<\hat{n}^3>/<\hat{n}^2>^{3/2}$ with $\hat{n}$ being the density deviation from averaged value characterizing the asymmetry of density PDF and Fig.1(b) corresponding particle flux. In the low-collisionality case shown by the solid curve in Fig.1(a), the blob and hole are found to provide roughly same contribution. Namely, positive (or negative) S signifies blob (or hole) dominated state, while $S\approx 0$ near the separatrix $x=0$ indicates equal creation of blobs/holes. Interestingly, as ν_{ie} increases, the holes are enhanced at highly collisional edge ($x<0$), whereas the blob dynamics are weakened at the SOL ($x>0$). Meanwhile, the holes cause larger particle flux than the blobs for high ν_{ie}, as plotted in Fig.1(b), showing their importance in boundary transport even if they are measured difficultly in experiments. Note that blob/hole velocity can be estimated from the radial shift of positive/negative peaks of $S(x)$. Large ν_{ie} accelerates holes to move inwards and reduces the blob velocity outwards. Moreover, a close correlation between solitary potential dipoles and blobs/holes, more notably for holes, is observed, showing that the dipole field leads the blob/hole to propagate.

To verify such predictions, the blob/hole measurement has been curried out using a Langmuir probe array in Ohmic-heating limiter plasma on the HL-2A tokamak[4]. Discharge parameters are: $I_p = 140 \sim 160$, $B_t = 1.6 \sim 1.9T$, line-averaged density $n_{el} = 1.0 \sim 2.0 \times 10^{19} m^{-3}$. The probe is localized at Δr=-6*mm*, inside the LCFS. Plasma horizontal displacement $D_h = 2mm$ is smaller than the probe exposed length(3*mm*). The blobs/holes are separated from the signals of saturation ion current I_s using conditional average method. Fig. 2 plots a typical waveform of shot #12197 with n_{el} via HCN, skewness S and blob/hole burst rate. As n_{el} increases (corresponding to ν_{ie} increasing), S changes the sign from positive to negative over a critical density. Meanwhile the blob birth rate decreases whereas hole birth rate increases then both finally arrive at a quasi-steady state. The trends qualitatively agree with the predictions, exhibiting a structure selection of blobs/holes. In addition, the correlation between potential dipoles and blobs/holes has also been verified.

Blob/streamer transition and blob/hole control: Neutral gas can not only stabilize resistive drift wave due to ion-neutral collision rate ν_{in} but also affect structure formation in turbulence[5]. To simulate such dynamics, the 2-region fluid model is extended to newly incorporate ν_{in} effect. A simulation is designed to increase ν_{in} after turbulence saturation, as shown in Fig.3 from *t*=1800. Comparison 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. Most distinctly, the blobs elongate to form streamers during the propagation, as shown in Fig.3, revealing a structure transition. The resultant particle flux stays at lower level due to the amplitude reduction although the streamer may generally enhance transport.

These observations show that blob/hole 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. Hence we suggest a probable approach to control blob/hole transport by adjusting plasma collisionality, e.g. using gas puffing and/or supersonic molecule beam injection(SMBI).

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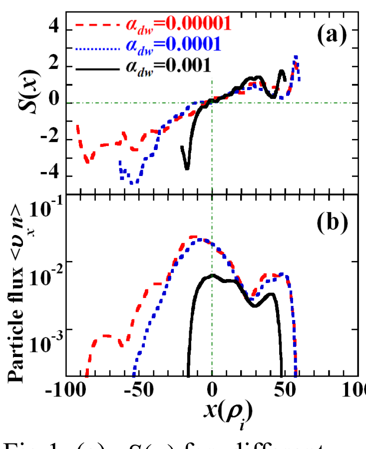

Fig.1 (a) $S(x)$ for different ν_{ie} . (b) Turbulent particle flux in the simulations corresponding to (a). Here $\alpha_{dw} \propto 1/\nu_{ie}$.

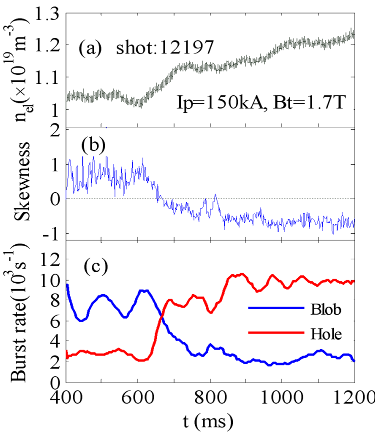

Fig.2 A typical discharge waveform in the HL-2A. (a) line- averaged density n_{el} , (b) skewness, (c) burst rate of blobs and holes.

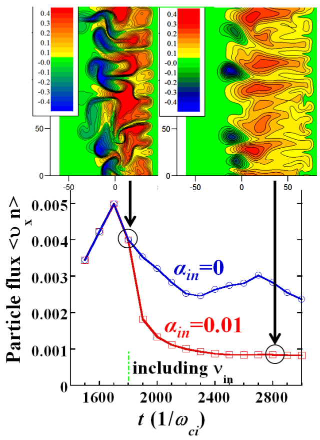

Fig.3 Time evolution of averaged particle flux in simulations with and without ν_{in} effect. Contour plots show the density fluctuation structure. Here $\alpha_{in} \propto \nu_{in}$.