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Observation of Stochastic Process of Turbulence Transition in Linear Plasmas
非平衡極限−直線プラズマにおける乱流遷移の確率過程の観測

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A stochastic transition in equilibrium and fluctuating quantities are observed in linear cylindrical laboratory plasmas in Kyushu University. In the stochastic transition, mainly two states are observed, and characterized by level of floating potential, low-level state and high-level state. The transition in the floating potential takes place almost simultaneously in the whole area of azimuthal and radial locations inside plasma column. A conditional technique based on azimuthally averaged floating potential reveals change in radial profiles of equilibrium, fluctuation mode amplitude, and probability density functions of particle and momentum fluxes between the two states.

1. Introduction

In order to understand physics of far non-equilibrium plasma media in nature and laboratory, study on plasma turbulence is essential because turbulence fluctuations play a dominant role in transport and confinement of the media. Plasma turbulence is composed of multi-scale fluctuations and structures, and is characterized by nonlinear, non-equilibrium, and non-stationary features. Recent experimental research using bispectral analysis has succeeded in unveiling an aspect of complicated nonlinear relationship among multi-scale turbulence. However, plasma turbulence is naturally non-stationary, and stochasticity of transition, bifurcation, and excitation and annihilation of fluctuation modes/quasi-modes are important in structural formation in far non-equilibrium media. In particular, stochastic and abrupt events such as H-mode transition in fusion plasma experiments dominates improvement of plasma confinement. In linear devices in Kyushu University, stochastic transition phenomena are observed in the floating potential and ion saturation current. In this paper, we present preliminary results of conditional analyses on experimental data where the transition is observed.

2. Experimental Apparatus

The experiments have been conducted in the cylindrical linear plasma devices, Large Mirror Device-Upgrade (LMD-U) [1] and Plasma Assembly for Turbulence Nonlinear Analysis (PANTA) [2]. The LMD-U has cylindrical vacuum vessel with the axial length of 3.74 m, and two azimuthal probe arrays are located near the axial center of the vessel. Results in LMD-U are mainly presented because azimuthally averaged turbulence particle and momentum fluxes were measured in LMD-U with the probe arrays. Experimental conditions are axial magnetic field of 0.09 T, filling Ar gas pressure of about 2 mTorr, and radio frequency power of about 3 kW for Helicon plasma production. Under the condition, both analysis of modulational instabilities [3] and large deviation statistics of turbulence fluxes [4] are analyzed in detail.

3. Phenomenology of Abrupt Transition

The transition is mainly characterized by abrupt changes in azimuthally averaged floating potential $<\Phi_f>$ and in power spectrum of Φ_f fluctuation.

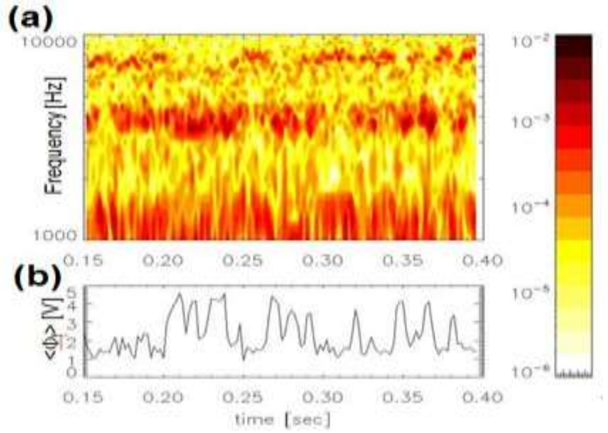

Fig.1. (a) Time evolution of power spectrum of floating potential Φ_f, and (b) that of azimuthally averaged Φ_f.

Figure 1 shows time evolution of Φ_f power spectrum (f > 1 kHz) and $<\Phi_f>$ (<500 Hz), respectively. Temporal scale of the transition is about ms order, and occurs randomly. Therefore, we consider the transition is a stochastic process. The fluctuation power in the frequency range of ~ 8 kHz is roughly synchronized with the transition. Inside the plasma column, the abrupt jump in Φ_f occurs simultaneously in a few 100 μs accuracy. Similar observation in the ion saturation current has been found in PANTA [5]. In the stochastic transition, the state of $<\Phi_f>$ can be roughly categorized as low state and high state. By using conditional technique based on $<\Phi_f>$, radial profile and probability density functions (PDF) of turbulence fluxes are evaluated in the two states and averaged state. The $<\Phi_f>$ is measured at r~4 cm.

4. Results of Conditional Technique

Figure 2 shows radial profiles of Φ_f and plasma density. The density is evaluated by assuming the electron temperature is 3 eV. Cylindrical plasma radius is about 5 cm. In the high state, the floating potential is higher than that in the low state at least r < 15 cm. Plasma density in the high state is also higher are than that in the low state inside r~7 cm. This indicates that the transition take places in wide radial area including outside the plasma column. Figure 3 shows difference of probability density functions of local turbulence Reynolds stress measured at two radial locations. Change in the tail parts of the PDFs was observed. Turbulence momentum transport may link change in radial electric field during the transition, therefore, For further investigation, measurement of radial fluxes of particle and momentum are required.

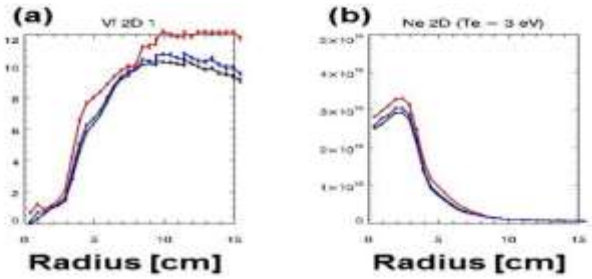

Fig.2. Results of conditional technique. Radial profiles of (a) Φ_f, and (b) plasma density. Red, blue, and black plots indicate high state, averaged state, and low state.

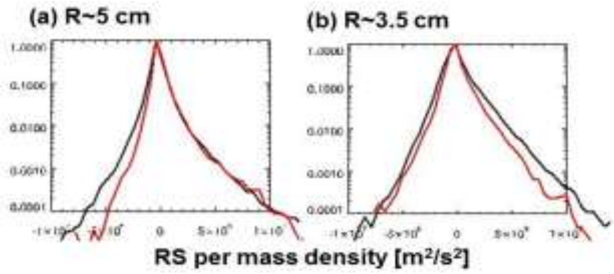

Fig.3. Results of conditional technique. Probability density functions of local Reynolds stress measured at (a) r = 5 cm and (b) r = 3.5 cm. Red and black plots indicate PDF in high state and low state, respectively.

5. Summary and Future Work

By using the conditional technique, the two states in the stochastic transition are preliminarily analyzed. In the future, to confirm original location of the forward and backward transition, a number of Langmuir probes at many radial, azimuthal, and axial locations are under preparation inside and outside the plasma column in PANTA. Correlation between the transition and large deviation statistics of azimuthally averaged turbulence particle and momentum fluxes at arbitrary radial locations will be investigated in PANTA.

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