Measurement and simulation of intermittent characteristics in the boundary plasma of EAST tokamak

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Introduction

The transport of particles and energy in the plasma edge and in the scrape-off layer (SOL) of magnetic-fusion devices is mostly non-diffusive and occurs in the form of the intermittent convection of coherent meso-scale plasma structures in the low-confinement regime (L mode) [1]. Such coherent plasma structures, known as blobs or filaments, can carry particles, momentum and energy into the far-SOL at their outward propagation. It can lead to high level of impurity erosion on main chamber walls.

Intermittent characteristics of turbulent fluctuations have been investigated in the edge and the SOL by fast reciprocating Langmuir probe measurements in L mode plasma on EAST. Plasma structures, blobs and holes are found to originate inside the edge shear layer [2]. Recently, the two dimensional ESEL code [3] based on interchange dynamics is used to simulate the probe measurements on EAST [4].

In our investigation, a reasonable agreement between ESEL simulations and probe measurements on EAST is reached both on the equilibrium profiles and the statistical characteristics of turbulent fluctuations in the SOL. It strongly suggests that the interchange driven turbulence is the prime candidate for the generation of plasma coherent blob structures and intermittent transport in Edge/SOL plasma.

Statistical properties of the density fluctuations on EAST

The statistical properties of the density fluctuations across the separatrix are investigated with the ion saturation current signal. In order to ensure the statistics to be reliable, the Ohmic heating power were kept at the low value (~200kW) during the discharge to prevent plasma arcing on the tips of ion saturation current. The detailed discharge condition can be reviewed in [2]. The probability distribution function (PDF) of density fluctuations is used to investigate the deviation from the Gaussian distribution. The deviation from the Gaussian distribution can be obtained by analyzing the skewness (S) and the kurtosis (K) [5]. The skewness $S = \langle (x - \langle x \rangle)^3 \rangle / \langle (x - \langle x \rangle)^2 \rangle^{\frac{3}{2}}$ describes the asymmetry of the PDF, while the kurtosis $K = <(x-<x>)^4> / <(x-<x>)^2>^2$ describes the tail weight with respect to the central distribution, where *x* is the statistical quantity (ion saturation current here). In particular, for the Gaussian distribution function: S=0, K=3.

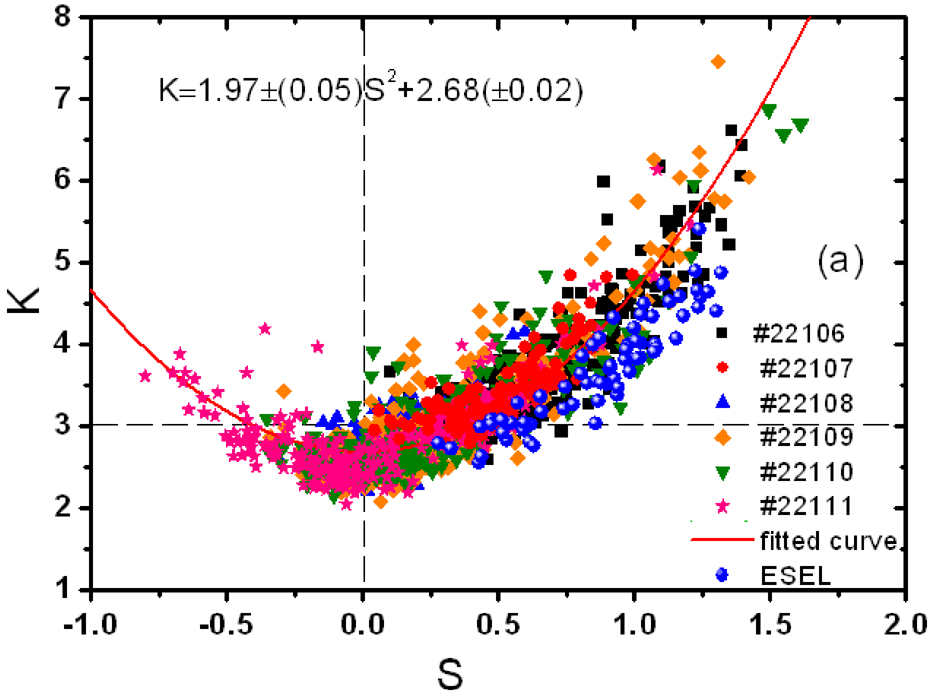

Figure 1*. Parabolic relationship between kurtosis and skewness of ion saturation current fluctuation signals. For the Gaussian distribution function: S=0, K=3.*

The statistical data of plasma turbulence are collected from the boundary plasma (-4cm<Δr<3cm) in several similar discharges (#22106 - #22111). As is shown in Figure 1, the S and K are found to obey a parabolic relationship ($K = 1.97S^2 + 2.68$). The positive S is dominated by density enhancement events (blobs), and negative S is related to density depletion events (holes). An extensive comparison of edge turbulence data taken from multiple machines proves this parabolic curve between S^2 and K universally exists in different configurations [5] as well as in hydrodynamical and astrophysical systems dominated by intermittent fluctuations [6,7]. The coefficient in front of the S^2 might be related to a drift-interchange turbulence physical process, which is investigated on TORPEX [8]. Recently, many statistical models are developed to interpret such parabolic relationship [9-11]. Some of them point out that the parabolic relation between *S* and *K* encountered in the statistical treatment of data from turbulent systems is not likely to provide relevant information about the underlying instability [11,12]. In particular, when the intermittent burst events occur in accordance to Poisson process, a parabolic relation between the skewness and kurtosis moments of the plasma fluctuations can be predicted by a model, in which the plasma density is prescribed by a random sequence of bursts with a fixed wave form[11].

Simulation results from ESEL code

In order to describe the formation and evolution of experimentally observed blob structures and to investigate their statistical properties, ESEL (Edge-SOL Electrostatic) use a set of reduced fluid equations appropriate for the boundary region on the outboard mid-plane of a toroidally magnetized plasma [3]. It is benchmarked using plasma parameter measured by Langmuir probe on EAST (#22111) in this work, and some preliminary simulation results of ESEL simulation will be described in this section.

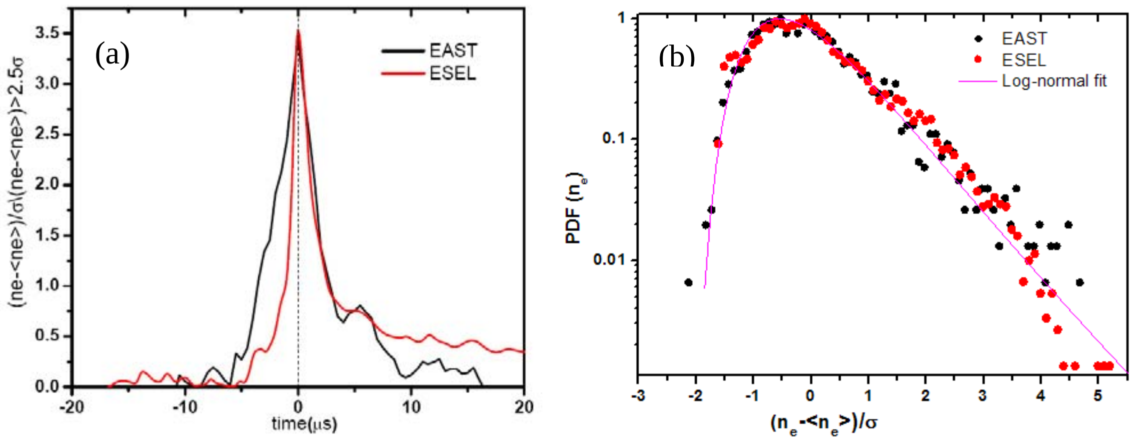

Figure 2 *Comparison of the conditionally averaged waveforms (a) and the PDF of density signal (b) from experiment and simulation data at the radial SOL position* Δr *~2.5 cm*

Conditional average [13] is applied to the density signal of probe measurement on EAST and simulation data, respectively. The conditional average is taken over all density bursts exceeding 2.5 times the standard deviation of density fluctuations in the far SOL. As shown in the Fig. 2 (a), the amplitude of the burst is almost equal for experimental observation and simulation results. A pronounced asymmetric feature is presented on the density burst structure on ESEL results, which is characterized by a steep front and trailing wake as reported on TCV [14]. This kind of asymmetric structure has been widely realized on other machines [15]. However, asymmetry is less pronounced for the coherent plasma structures/blobs in EAST. The rising time of the burst is found to be comparable to the decaying time.

The rescaled PDF of normalized particle density fluctuations in the Fig.2 (b) demonstrates an excellent agreement with experimental measurements. Both of the PDFs exhibit an asymmetric wing with large positive amplitudes events. The ESEL results and probe measurements significantly indicate the dominance of bursts/blobs in the density fluctuations. The pink line in Fig. 2 (b) is a Log-normal fit on the PDF of density fluctuations, which match well with the experimental and simulation results. Such log-normal distribution has also recently been reported to be a typical representation of the PDF of density fluctuations in the SOL of the RFX device and TCV [9,12]. Furthermore, the skewness and kurtosis of the PDF of density fluctuations in the SOL are also investigated in the ESEL simulation. As is shown in Fig.1, the statistical skewness and kurtosis evaluated in ESEL density fluctuations is well consistent with it from probe measurements.

Summary

The statistical characteristics of turbulence fluctuations have been studied with reciprocating Langmuir probe in the boundary plasma of EAST Tokamak. The PDF of density fluctuations are evaluated along different radial position across the edge shear layer (-4cm<Δr<3cm) on EAST. The skewness and kurtosis of PDF acquired in different radial location exhibit a parabolic relation. The interchange turbulence ESEL code has been invoked to perform simulations for the EAST boundary plasma turbulence transport. A fine agreement has been achieved between the model and experiment measurement. The results are suggestive that the blob-like objects, which are universally found in the magnetic fusion device, are related to the interchange instability origin.

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