QUEST プラズマ SOL 揺動の高次モーメントを用いた“偶然力”の評価
Evaluation of “Stochastic force” using higher order moments in the SOL fluctuations in QUEST

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Statistical features of SOL fluctuations including blobs are investigated using the fast camera imaging technique in ohmic + ECR plasma in QUEST. Two SOL regions, narrow inboard and wide outboard sols are studied.

The SA5 fast camera was used for these experiments. Each frame is made up of 526×240 pixels, and framing rate is 50000 frames s^{-1}. Comparison with images using an H_α filter indicates that the observed visible image is mainly attributed to the H_α emission ($\propto n_0 n_e$).It is assumed that the neutrals n_0 are distributed uniform in the chamber and images are due to the local evolution of plasma or propagating plasmoid whose electrons n_e can excite neutral atoms immediately.

Ohmic plasma is evolved from the inboard side near the ECR slab plasma when the inductive field (< 5V/m) is induced. As Ip is ramped-up and the LCFS grows, the slab plasma is bent outwards significantly, as shown in Fig.1 (a). Fluctuations appear inboard side, extend vertically and slightly bend along the LCFS. The intensity of the fluctuations grows as I_p grows and saturates for a few msec. The vertical extended zone is due to the field lines winding round the center stack CS. The

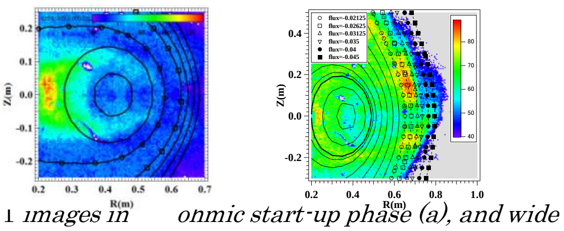

Fig.1 images in ohmic start-up phase (a), and wide SOL in ohmic plasma(b).

L_c just outside the LCFS becomes short because the field lines near it intersect the center stack, on the other hand outside it the L_c is kept long. Thus, two inboard and outer fluctuations are separated by short L_c zone each other.

The fluctuation level δI/I is ~ a few % for inboard fluctuation. Data are taken for 2 ms at I_p~ 10 kA and the mean μ(R, Z) and standard deviation profiles σ(R, Z) are shown in Fig.2 a-c. It is observed that μ is relatively high and σ is low inside the LCFS. Although the highest μ is localized near the CS on the mid-plane, the boundary of the ratio μ/σ, denoted by black solid curve, follows the LCFS. This indicates that the statistical nature is different with respect to the LCFS. Two dimensional contours of S and k_e are shown in Fig.2 (c,d), where S and K are skewness and kurtosis. S ranges from -1 to 1 except the upper-left region and it is small positive within LCFS. k_e also ranges within ± 2 and almost zero on the mid plane. These suggest that the probability density function *p(x)* is close to the Gaussian distribution.

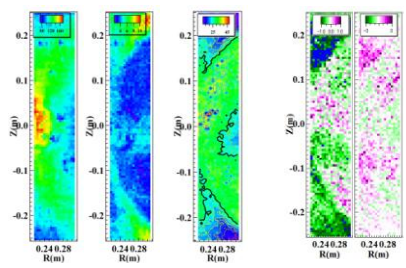

Fig.2 Contours of μ (a), σ (b) and μ/σ (c) of inboard fluctuations. Contours of S (d)and k_e(e) of inboard fluctuations.

At I_p ~ 50 kA the outboard fluctuation in the outer SOL shows again strong helical perturbations, compared with the quiet inboard fluctuation. The pitch of those seems to be the same as those of magnetic field lines in the outer SOL. Since 70 kW ECWs are injected and interact to the SOL plasma at the top and bottom region outside the LCFS along the vertical line at $R=R_{res}$, the plasma source due to ECWs is considered to dominate this SOL region. The edge profiles for one cycle of the blob generation and ejection are shown in Fig. 3(a). The change in the gradient is similar to those in a slab geometry. The temporal profiles oscillate around the mean profile μ(R) denoted by a dotted curve. The temporal evolution of I(R, Z, t) is shown in Fig. 3 (b). The intermittent plasma intensity evolution is observed and the blob propagates clearly from the top to bottom and also radially. This direction of the trajectory is the ion drift direction. The frequency of the blob is ~ 2 kHz.

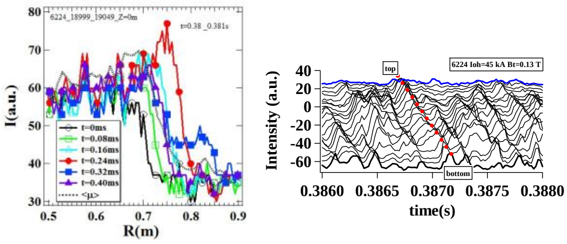

Fig. 3 (a) I(R,t)intensity profile near the edge within one cycle for blob ejection. The dotted curve in (a) indicates the mean profile μ(R). (b) I(Z,t) along the magnetic field lines from the top to bottom regions. The intensity in (b) is plotted with an offset in the vertical coordinate. Do tted line is an eye-guide for a trajectory of a blob.

In the outboard SOL, it is found that S and k are not only a function of the magnetic flux, but also the magnetic field lines, as shown in Fig. 4. The pdf is consistent with the Gaussian one in the relatively flat profile, and becomes gamma one in the steep gradient region far from the LCFS. Based on a simple stochastic differential equation a relation between stochastic force and change in pdf is discussed.

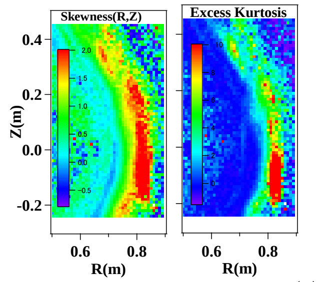

Fig. 4 2D contour of S (a) and k_e(b) of outer SOL fluctuations

It implies that the stochastic force acts even in the region with small positive ∇μ and is reduced in the region with negative large ∇μ. The shape of *p(x)* measured by S and k_e does not show the increment for R<0.7 m, but it increases in the steep ∇μ region and peaks at the end of its region. Therefore it is suggested that the *p(x)* deviates from the Gaussian to gamma continuously from the inner edge to the outer one of steep ∇μ region. The numerical coefficients in this region also support the relation between change in *p(x)* and ∇μ,(not shown)

A simple model to describe the density fluctuation X is considered as a stochastic differential equation and a relation between *PDE* and model will be discussed.

$$\frac{dX}{dt} = X(g(X) - s(X)\Lambda(t)) \quad (1)$$

,where g and s are functions of variable X and Λ(t) is Gaussian white noise. When the second term in the r.h.s. is neglect, the fluctuation grows exponentially. The stochastic term regulates the fluctuations and an equilibrium state is assumed. *PDE* can be derived by Ito calculus,

$$\frac{\partial p}{\partial t} = -\frac{\partial}{\partial X}\left\{\langle M\rangle p - \frac{1}{2}\frac{\partial}{\partial X}(\langle V\rangle p)\right\}, \quad (2)$$

where $\langle M\rangle$ and $\langle V\rangle$ are the mean and variance of eq.(1), respectively. If we assume the stationary pdf, the following *p(x)* is derived.

$$\frac{d(\log(P(X)))}{dX} = -\frac{\langle V\rangle' - 2\langle M\rangle}{\langle V\rangle} \quad (3)$$

,where $\langle M\rangle = Xg(X)$ and $\langle V\rangle = (\varepsilon X s(X))^2$. $\langle V\rangle'$is a derivative with respect to X and ε is a parameter measuring the amplitude of the random noise. For simple case of *s(X)* and *g(X)* eq.(3) belongs to Pearson type. For example, a logistic model with an X-independent noise ($s(X)$=1) and $g(X)=\gamma(1-X/X_e)$ with a constant growth rate γ is considered. The following gamma distribution can be derived, where at $X=X_e$ a stationary amplitude of the fluctuation is possible,

$$p(X) \propto \frac{1}{\varepsilon^2} X^{\alpha-1} exp\{-\beta X\}, \text{if } \alpha > 0 \text{ and } \beta > 0 \quad (4)$$

where $\alpha=2\gamma/\varepsilon^2-1$, and $\beta=2\gamma/(X_s\varepsilon^2)=(\alpha+1)/X_s$. Since $\alpha=4(\mu_2)^3/(\mu_3)^2=4/S^2$ and $\beta=2\mu_2/\mu_3=2/(\sigma S)$, it is concluded that the increment in S is caused by the enhancement of the stochastic force(ε^2). Thus, if the stochastic force is enhanced by ∇μ, the deviation of *p(x)* from the Gaussian to gamma distribution can be interpreted

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