Turbulence intermittency and burst properties in the boundary of TEXTOR tokamak

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1. Introduction

Turbulence intermittency at the plasma boundary has long been observed [1-4]. It has been generally found that the intermittent structures are convective in nature and propagate radially carrying a significant fraction of the particle flux [3, 4]. The phenomena have been involved in (i) enhanced erosion of the wall and reduction of the divertor efficiency [2]; (ii) the departure of transport scaling from gyroBohm to Bohm [5]. In recent years, models based on the coherent vorticity [6] and the interchange instability [7, 8] were proposed to account for some of the properties. The bursty transport may also arise due to avalanches in the SOC (self-organized criticality) dynamics [8]. In experiments, although common features have been observed, discrepancies also exist from machine to machine: e. g. (i) in the ADITYA tokamak, the small scale coherent structures are found to play a crucial role in inducing bursty transport [9], while on some other machines the origin of intermittency appears to be different [3]; (ii) in the PISCES linear device, the intermittent transport is linked to certain instabilities and occurs periodically [3]. In this paper, we present the experimental results on the intermittency behavior in TEXTOR by using various analyses to give a comprehensive picture of the intermittent transport.

2. Experimental setup

The experiments were performed in the TEXTOR tokamak under the following ohmic discharge conditions: R=175cm, $a \cong 48$cm, B_T=2.33T, I_p=200kA, V_l =1V and $\langle n_e \rangle = 1.0\times10^{19}$m^{-3}. The measurements were mainly made in the plasma edge and the scrape-off layer (SOL) by a Langmuir probe array (7.5×7.5mm) consisting of 4 carbon tips with each having 4mm long and 3.5mm in diameter. Two of them were biased as a double probe to record the ion saturation current, I_s. We simply assume that the fluctuations on I_s are primarily caused by the density fluctuations. The other two pins were poloidally spaced to measure the poloidal electric field $E_\theta = (V_{f1}-V_{f2})/d$, where V_{f1} and V_{f2} are the floating potentials detected by the two pins and d is the distance between them. The turbulence-driven particle flux, Γ, is thus estimated by $\Gamma = \langle \tilde{n}\tilde{v}_r \rangle = \langle \tilde{n}\tilde{E}_\theta \rangle /B$. The fluctuation data were digitized at a rate of 500 kHz.

3. Results and discussion

The turbulence intermittency can be identified in the raw signals of I_s by a number of bursts in the "sea of turbulence". The amplitudes of bursts are much higher than the standard deviation of fluctuations (σ). For qualifying intermittency, one can calculate the PDF of the fluctuation data (x) and compare it to a Gaussian by computing its skewness ($S=\langle \tilde{x}^3 \rangle / \langle \tilde{x}^2 \rangle^{3/2}$) and kurtosis($K=\langle \tilde{x}^4 \rangle / \langle \tilde{x}^2 \rangle^2 - 3$). For a Gaussian signal, S=K=0,

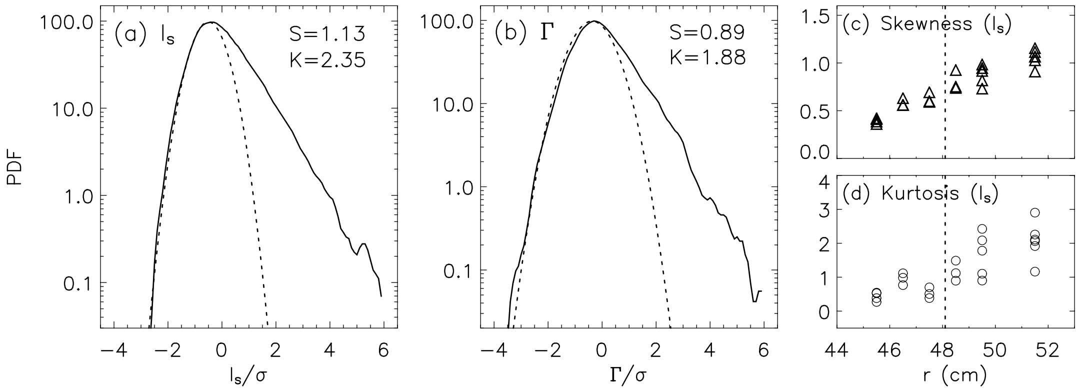

Fig. 1. Semi-log plot of PDFs for (a) the normalized density fluctuations (~I_s/σ) and (b) the turbulent particle flux (Γ/σ) measured in the SOL (r=51.5 cm). Shown in (c) and (d) are the radial profiles of skewness and kurtosis of I_s, respectively. Vertical dashed lines in (c) and (d) indicate limiter position.

whereas for others the deviation from 0 indicates a higher degree of non-Gaussianity. Plotted in Fig. 1(a) is the PDF of the normalized density fluctuations (I_s/σ) measured in the SOL. The dotted line shows the best fit by a Gaussian. The PDF skews positively, while the negative fluctuations are close to a Gaussian distribution. The corresponding PDF of particle flux Γ is drawn in Fig. 1(b), which shows similar features to the I_s. These non-Gaussian PDFs imply a departure of transport properties from pure diffusion to convection. In Figs. 1(c) and (d), the radial dependences of S and K of I_s are plotted. Both of them are enhanced with increasing r, suggesting increased intermittency from the edge to the SOL. In order to investigate the intermittency structures independently of the background turbulence, the conditional averaging tool [1, 3, 4] is used. In our analysis, the intermittent bursts are selected by their amplitudes by setting a threshold of several times the standard deviation of I_s. Conditional averaging is achieved by recording 60 data points=120μs around the maximum of each burst, then accumulating and averaging. For auto-conditional average (ACV), the maxima selection and averaging are performed on the same signal, while for cross-conditional average (CCV), the selection is made on one signal and the averaging is done on another. The ACV of density burst detected in the SOL for $I_{th}/\sigma=3.0$ is plotted in Fig. 2(a). It shows two features: (i) the density bursts consist of merely positive ones, consistent with the PDFs and skewness shown in Fig. 1; (ii) the decay time of the burst is much longer than the rising time. This time-asymmetry points to relaxation phenomena. These properties are different from those of coherent eddies [6], which usually have a symmetric shape and both positive/negative fluctuations. Using CCV, the intermittent radial volecity V_r for different levels of I_s can be determined. The conditional average of V_r in the SOL for events $I_{th}/\sigma \geq 2.5$ is drawn in Fig. 2(b). The bursts show a radially outward motion with an average speed ≈ 450 m/s. The V_r shape is also asymmetric, consistent with the density intermittency. The contribution from the intermittent bursts to the total particle flux can be evaluated by calculating their ratio, $\langle\Gamma_{int}\rangle/\langle\Gamma_{tot}\rangle = \langle I_s E_\theta\rangle_{intermittent}/\langle I_s E_\theta\rangle_{total}$, where ⟨⟩ denotes an ensemble average. It is found that in the SOL, the bursts with $I_{th}/\sigma \geq 2.5$ carry a fraction of ~ 40% of the total flux. After the bursts selected, the statistics of the waiting time (ΔT) between successive bursts can be obtained. Shown in Fig. 3 are the PDFs(ΔT) of I_s measured at r=48.5cm for two thresholds (I_s/σ=2.5 and 3). It looks that the PDFs have a wide distribution with a maximal ΔT≈150μs. For large ΔT events, the PDF fits well an exponential law for I_s/σ=2.5, whereas for I_s/σ=3.0 an extended power-law appears in the tail of PDF. Such a deformation of PDF from small to large burst events seems to be consistent with the SOC hypotheses [8, 10]. To investigate the long-range correlation and self–similar characters of intermittent fluctuations, the auto-power spectrum S(f) and the Hurst exponent via R/S analysis[11] are calculated for the density fluctuation data. The results for I_s measured in the SOL are plotted in Fig. 4. The S(f) displays three distinct decay regions with scaling indices of 0, −1 and −1.8, respectively, consistent with the sandpile modeling[12]. The f^{-1} scaling indicates avalanche interactions. The power-law dependence of the spectrum reflects the self-similarity. In the R/S plot, Hurst parameter is fit as H=0.71(>0.5), indicating a long-correlation (or self-similar) process. The results are similar to those of potential fluctuations [13], supporting the idea that the SOC dynamics may play a crucial role in the intermittent transport [8].

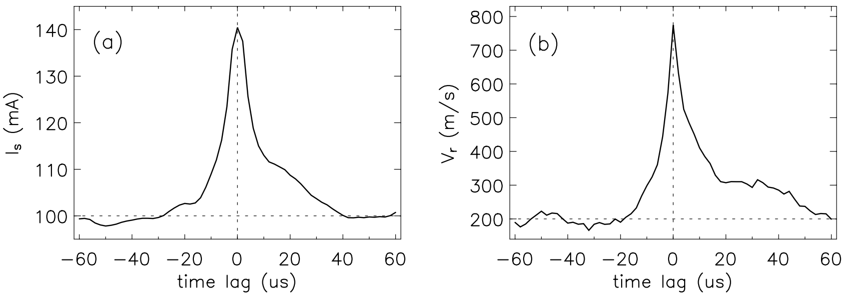

Fig. 2. (a) The auto-conditional average of I_s and (b) the cross-conditional average of V_r measured in the SOL (r=51.5 cm).

4. Conclusion

Turbulence intermittency and burst properties at the boundary of TEXTOR have been investigated. The PDFs of density and particle flux fluctuations are both skewed positively with a Gaussian distribution for the negative fluctuations. The intermittency

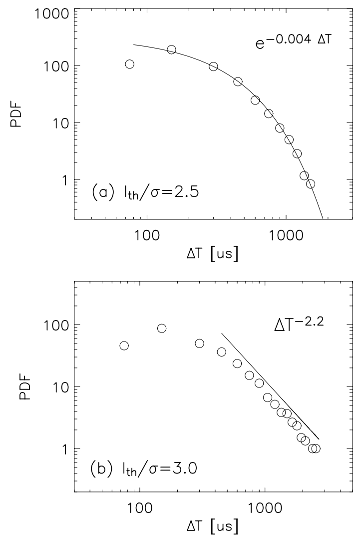

Fig. 3. The PDFs of waiting-time between successive bursts in I_s detected at r=48.5 cm for (a) I_{th}/σ=2.5 and (b) I_{th}/σ=3.0.

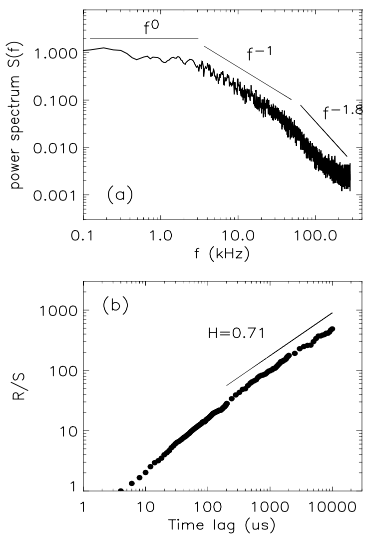

Fig. 4. (a) Power spectrum S(f) and (b) R/S analysis of density fluctuations measured at r=51.5 cm.

becomes stronger from the plasma edge to the SOL. The averaged shape of bursts is time-asymmetric and composed of only positive ones. In the SOL, the bursts travel radially outwards at a speed of ~ 450 m/s, carrying ~40% of the total particle flux. The PDF of the waiting-time exhibits a Poisson-distribution for small-size events and a power-law for larger-size ones. The S(f) and Hurst parameter reveal self-similarity of the intermittent fluctuations. The results indicate that the intermittency in TEXTOR is not dominated by coherent vortices and probably related to avalanche-like transport.

Reference:

[1] S. J. Zweben, Phys. Fluids **28**, 974 (1985); A. V. Filppas, *et al.*, Phys. Plasmas **2**, 839 (1995).

[2] H. Maier *et al*., J. Nucl Mater **266–269**, 1003(1999), B. LaBombard, Nucl. Fusion**40**, 2041 (2000).

[3] G. Y. Antar, *et al*., Phys. Plasmas **10**, 419 (2003), G. Y. Antar, ibid, **10**, 3629 (2003).

[4] J. A. Boedo *et al*., Phys. Plasmas **10**, 1670 (2003).

[5] F. W. Perkins, *et al.*, Phys. Fluids B **5**, 477 (1993).

[6] M. N. Rosenbluth, *et al*., Phys. Fluids **30**, 2636 (1987).

[7] N. Bian, *et al.,* Phys. Plasmas **10**, 671(2003); O. E. Garcia, *et al.,* Phys. Rev. Lett. **92**,165003 (2004).

[8] B. A. Carreras, *et al.,* Phys. Plasmas **3**, 2903(1996); Y. Sarazin *et al.,* Phys. Plasmas **5**, 4214 (1998).

[9] R. Jha, *et al*., Phys. Plasmas **10**, 699 (2003); R. Jha, *et al*., Phys. Rev. Lett. **69**, 1375 (1992).

[10] R. Sánchez, *et al.*,Phys. Rev. Lett. **90**, 185005 (2003); R. Sánchez, *et al.,* ibid, **88**, 068302 (2002).

[11] H. Hurst, Trans. Am. Soc. Civ. Eng **116**, 770(1951); B. Mandelbrot, Water Resour Res **4**, 909(1968).

[12] T. Hwa and M. Kadar, Phys. Rev. A **45**, 7002 (1992).

[13] Y. H. Xu, S. Jachmich, R. R. Weynants *et al*., Phys. Plasmas **11**, 5413 (2004).