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Radial profiles of plasma turbulent fluctuations in the scrape-off layer of the Tore Supra tokamak

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Abstract

The measurements of ion saturation current fluctuations in the scrape-off layer of the Tore Supra tokamak are presented. As the radial distance from last closed flux surface increases more and more rare, but larger positive bursts become dominant in the signal and its probability density function becomes strongly asymmetric with pronounced positive tail. At the same time burst duration and inter-burst time increase dramatically. We explain this phenomenon by radial propagation and dynamics of the ensemble of different size large scale coherent structures.

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Keywords: Tore supra; SOL plasma; SOL transport; Plasma turbulence

1. Introduction

Understanding the nature of anomalous cross-field transport in the scrape-off layer (SOL) of tokamaks is one of the key issues of magnetic fusion research. For a long time the transport in the SOL of tokamaks has been described as a diffusive process. However, it becomes more and more clear that plasma transport has a highly bursty character [1–5], especially in the far SOL, which cannot be explained by a random diffusion mechanism. Nowadays it is widely accepted that edge plasma transport in tokamaks has mostly convective character – transport background is diffusive and on this background coherent turbulent structures are formed intermittently causing the rapid convective radial transport of plasma towards the wall with the speed which is a fraction of an ion sound speed. Coherent turbulent structures are responsible for large amplitude fluctuations of ion saturation current (I_{sat}) [4]. In the present paper the study of the I_{sat} fluctuations in the SOL of the Tore Supra tokamak is presented.

2. Main consideration

A reciprocating Langmuir probe, inserted from top of the machine, is used to measure I_{sat} in the SOL of the Tore Supra tokamak. The probe makes

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several plunges in plasma per discharge. During each plunge close to the deepest position of the probe fast acquisition of data with sampling frequency 1 MHz is triggered which continues for 16 ms. It is possible to program independently the depth of each plunge with respect to the last closed flux surface (LCFS). This way we make radial scan of the SOL.

The results presented here are mostly based on the measurements done during single lower hybrid (LH) heated discharge of Tore Supra – TS35000, but generally they are universal over variety of discharge conditions including Ohmic discharges. During the discharge TS35000 plasma major radius $R = 2.38$ m, minor radius $a = 0.72$ m, plasma current $I_p = 1$ MA and toroidal magnetic field $B_t = 3.8$ T, edge safety factor $q = 4.8$ and average core plasma density $n = 2.2 \times 10^{19}$ m^{-3}, LH power injected in plasma $P_{LH} = 1.4$ MW and the probe made four plunges into plasma.

Time evolution of I_{sat} at four different radial locations in the SOL is presented in Fig. 1. Near the LCFS ($r - a = 15$ mm) positive and negative fluctuations of I_{sat} are of almost equal amplitude and its probability density function (PDF) is almost perfectly symmetric (see Fig. 2). Deeper in the SOL the mean level of I_{sat} signal decreases and it is dominated with more and more rare, but larger positive bursts. Really, one can clearly see in Fig. 1 the radial increase of inter-burst time together with burst duration and burst amplitude relative to the mean level of I_{sat} signal. At the same time I_{sat} PDF becomes strongly asymmetric in the far SOL (see Fig. 2) with pronounced tail towards positive values. This is reflected in Fig. 3 by radial increase of I_{sat} skewness and also kurtosis, which are third

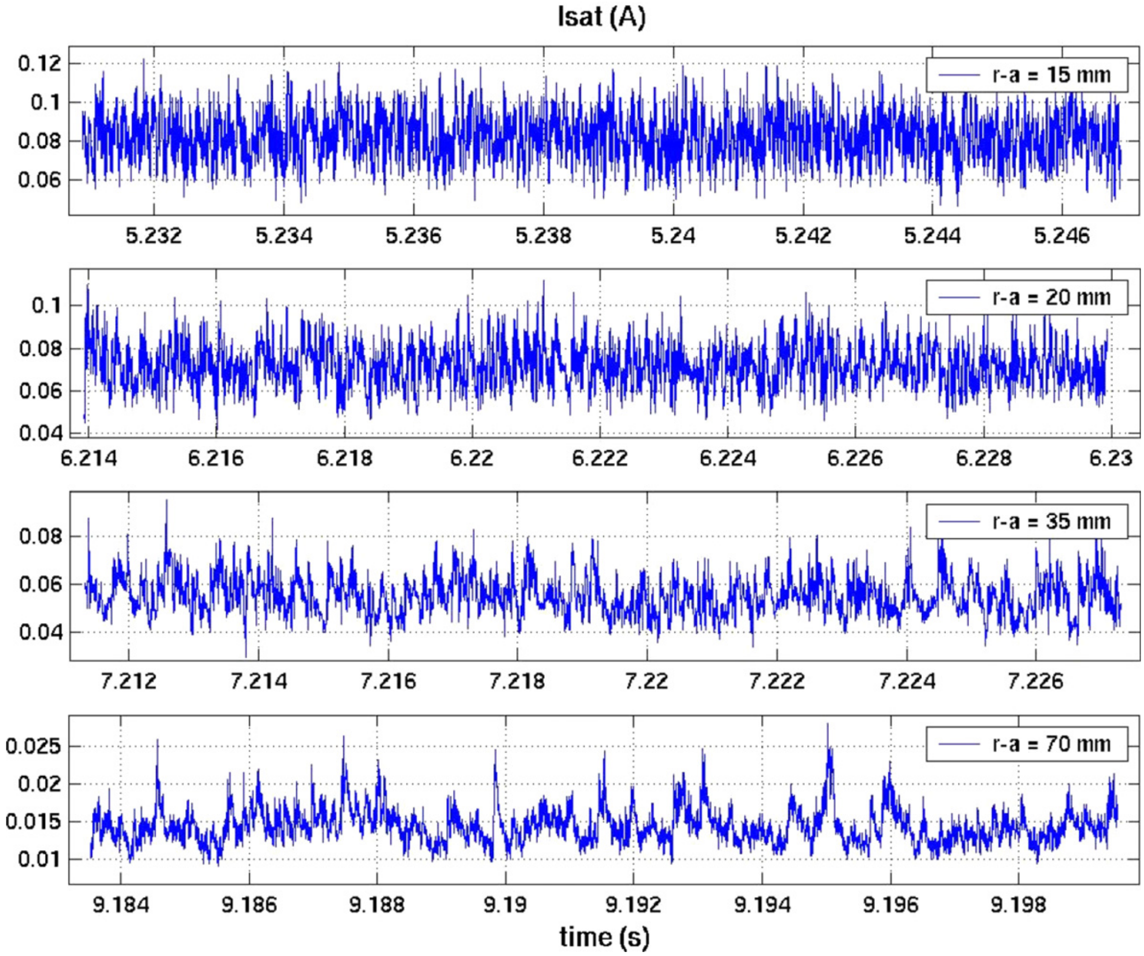

Fig. 1. Time evolution of ion saturation current at four different radial locations.

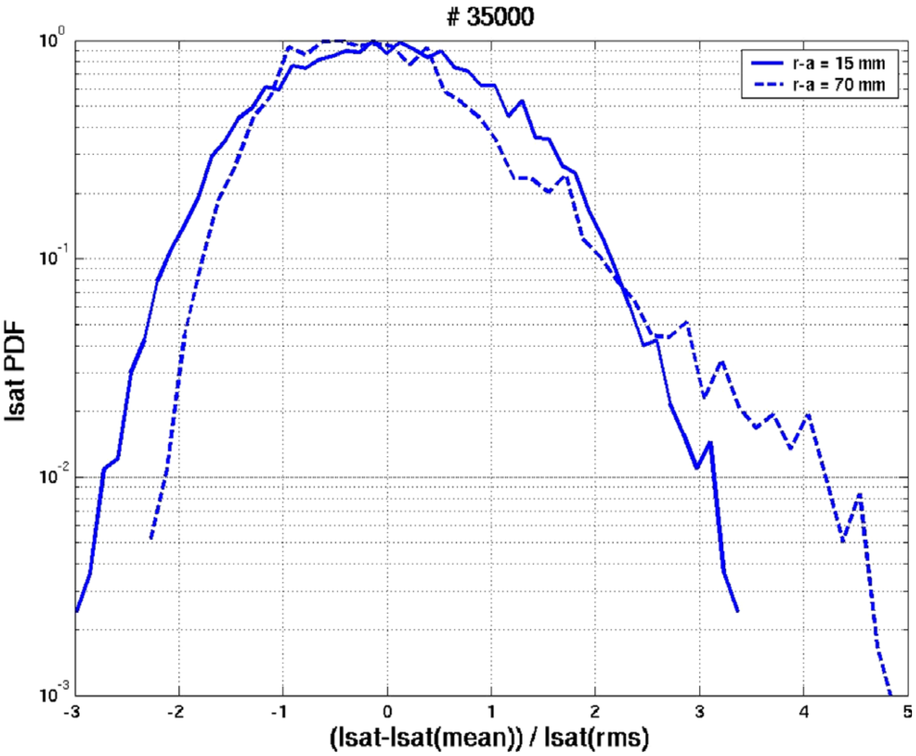

Fig. 2. Ion saturation current PDF near the LCFS and in the far SOL.

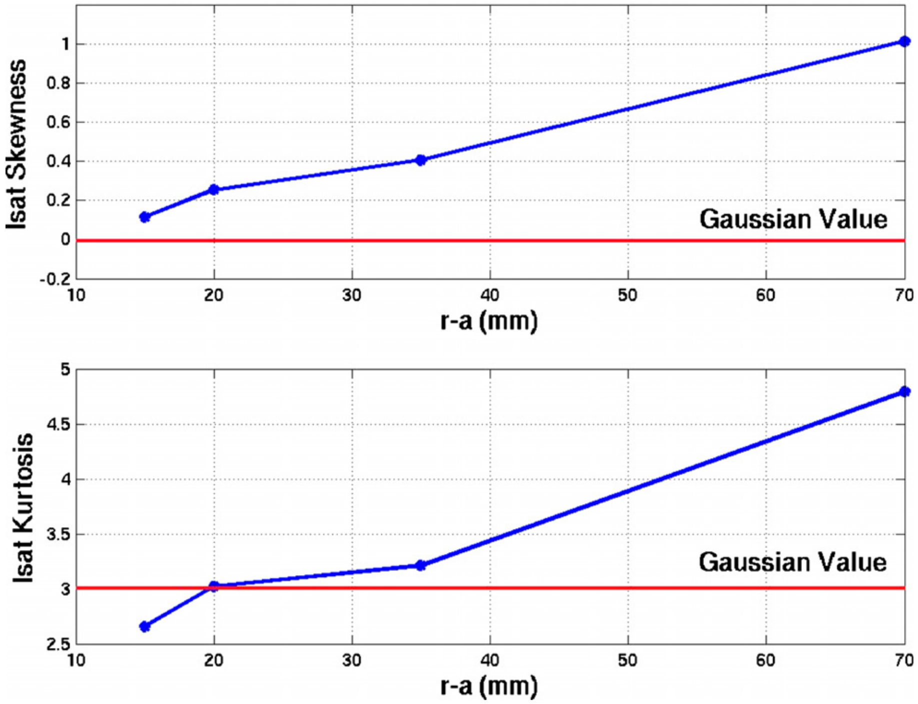

Fig. 3. Radial dependence of ion saturation current skewness and kurtosis.

and fourth order moments of PDF and characterize its asymmetry and level of flatness respectively. In the far SOL, 70 mm outside the LCFS, I_{sat} skewness equals to 1, while the skewness for symmetric Gaussian PDF is 0, and kurtosis reaches 4.8, while the value of kurtosis for Gaussian PDF is 3. Autocorrelation time of I_{sat} also increases radially from about 25 μs near the LCFS up to around 90 μs in the far SOL (see Fig. 4) reflecting the increase of burst duration in the I_{sat} signal.

We explain the above described radial dynamics of plasma turbulent fluctuations by the following paradigm. First of all, the I_{sat} bursts are associated with coherent turbulent structures [4]. Investigation of inner nature and origin of these structures is beyond the scope of the present work. The most important is that regardless inner nature and origin plasma density inside coherent structures is higher than ambient SOL density, they are formed in the SOL near the LCFS and propagate radially outwards [6–10]. The structures are localized in poloidal–radial plane and elongated in parallel direction – along the magnetic field line [6–10]. During radial propagation when coherent turbulent structures (hereafter transport structures) pass the probe, positive bursts of I_{sat} are observed. Transport structures have distribution in size – larger structures are scarcer [9]. This is an important factor which plays crucial role in establishing radial profiles of both – time average plasma density as well as statistical characteristics and temporal dynamics of density turbulent fluctuations, and which is disregarded in most cases. Only the large structures (containing larger number of particles) survive and reach the far SOL during radial propagation, smaller structures disappear earlier because of parallel losses and spreading in poloidal–radial plane. Therefore, when we discuss the region of the SOL located at larger radial distance from LCFS the number of transport structures reaching the region should decrease. At the same time, since larger structures are scarcer, the time interval between their detection (inter-burst time) should increase in the far SOL. This, together with radial decrease of ambient SOL density, will result in I_{sat} signal which is dominated with more and more rare, but larger positive bursts in the far SOL and has a PDF strongly skewed towards positive values. As for the radial increase of I_{sat}

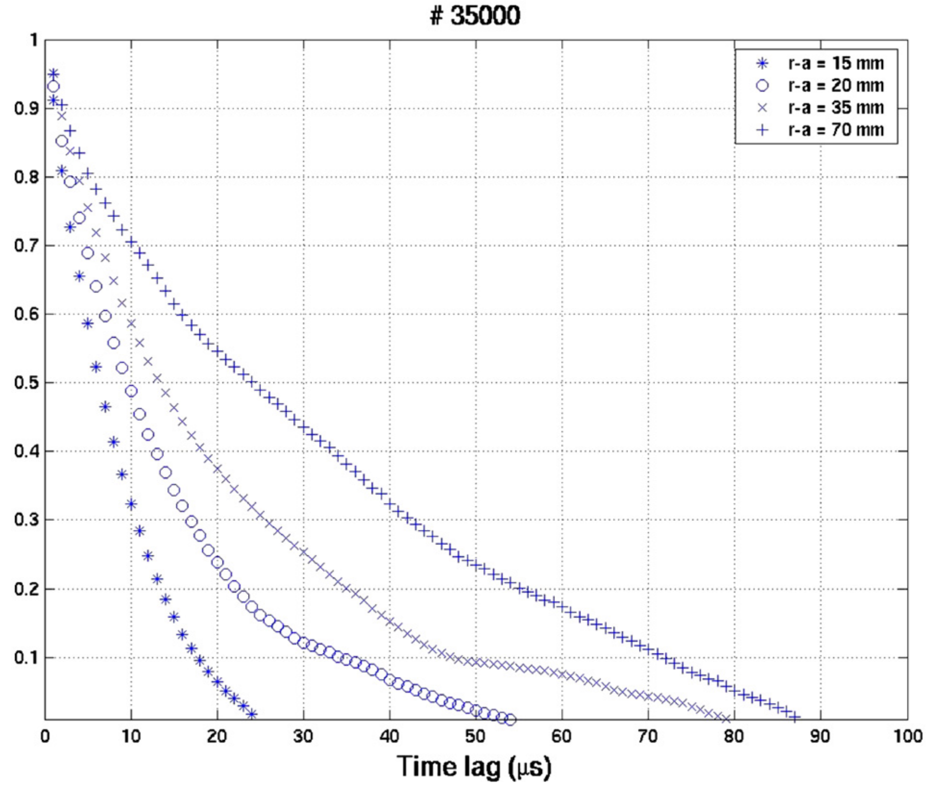

Fig. 4. Autocorrelation function of ion saturation current at four different radial locations.

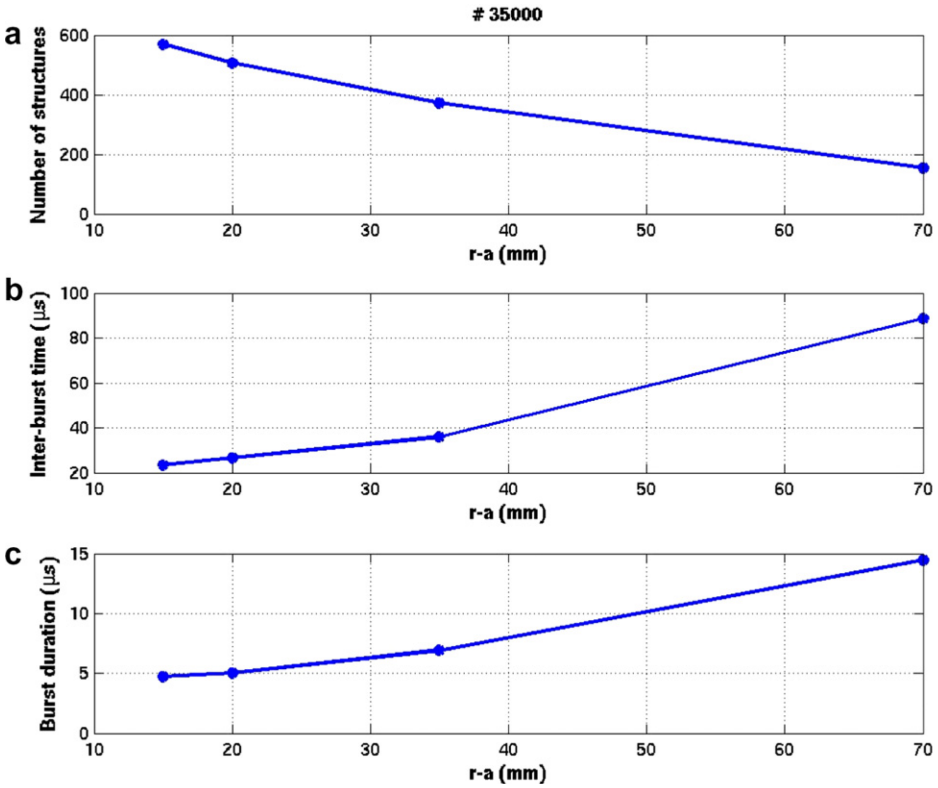

Fig. 5. Number of structures counted at four different radial locations in the SOL (a), radial dependence of average inter-burst time (b) and average burst duration (c).

autocorrelation time, which reflects the increase of burst duration in the signal, there are two processes which can be responsible for this, namely transport structure deceleration and increase of their size in poloidal–radial plane because of spreading during radial propagation.

In order to confirm above presented points we have selected large amplitude bursts in I_{sat} signal and investigated their characteristics at four different radial locations, as well as radial evolution of these characteristics. For this purpose threshold method has been used. First of all, one should remember that, as it has been already mentioned above, bursts in I_{sat} signal are associated with large scale coherent turbulent structures passing the probe during their radial propagation. Then, one has to make sure that at each radial location only the large bursts, for the appearance of which the coherent structures coming from the region located radially closer to the LCFS, remain in discussion after selection procedure. Therefore, we used the threshold of one standard deviation – only the bursts having the amplitude larger than threshold have been kept, the rest of the signal being rejected. As it has been presumed, number of transport structures strongly decreases radially outwards (see Fig. 5(a)) and, as one can see in Fig. 5(b), inter-burst time increases dramatically in the far SOL. The duration of bursts increases radially too (see Fig. 5(c)). The latter should be the combined effect of transport structures deceleration and their spreading in poloidal–radial plane during radial propagation. In order to determine the relative importance of these two processes in radial increase of burst duration one needs to follow in real time radial propagation of transport structures. These investigations are planed in near future on the Tore Supra tokamak by means of radial array of Langmuir probes and also fast camera.

3. Conclusions

In conclusion, we have presented the measurements of I_{sat} fluctuations in the SOL of the Tore Supra tokamak. As the radial distance from LCFS increases I_{sat} becomes more bursty – dominated by rare, but larger positive bursts and characterized by strongly skewed PDF. We have shown that coherent turbulent structures and their radial dynamics are responsible for the observed phenomenon. In particular, the far SOL region is reached by smaller number of coherent turbulent structures in comparison with the region of the SOL located radially closer to the LCFS and this, together with radial decrease of ambient SOL density, results in I_{sat} signal with stronger bursty character and more skewed PDF in the far SOL.

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