

SOL Fluctuations and Cross-Field Transport in Limited and Diverted Magnetic Configurations in DIII-D

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Plasma interaction with the main chamber wall should be minimized in order to prevent damage to the first wall elements and core plasma contamination with impurities. In a divertor tokamak, plasma particles cross the last closed flux surface (LCFS) into the scrape-off layer (SOL) and flow along the open field lines into the divertor volume. However, if the SOL width is comparable to the distance between LCFS and the wall, significant plasma interaction with the wall elements may also occur. In this paper we examine the effect of the connection length to material surfaces in the outboard SOL on the SOL width, fluctuations, and cross-field transport in low confinement (L-mode) discharges. We find that SOL fluctuation levels and cross-field fluxes tend to increase and SOL density and temperature profiles widen with increasing connection length.

The DIII-D tokamak [1] is equipped with two poloidal divertors – upper and lower – and can be operated in lower single-null (LSN), upper single-null (USN), and double-null (DN) diverted magnetic configurations. It can also be operated with the plasma limited by the centerpost tiles, in so-called inner wall limited (IWL) configuration. In all magnetic configurations the width of the outboard SOL is generally set by the balance of the parallel (along magnetic field lines) and perpendicular (across the field lines) transport. Cross-field transport in L-mode is driven by wide-band electrostatic turbulence as well as by convection of coherent filamentary structures, so-called blobs [2-5], featuring densities and temperatures above those of the background SOL plasma. Blobs are born in the vicinity of LCFS at the outboard side of the torus, presumably as a result of interchange instability, and move towards the wall due to ExB drifts [2]. Blobs have been directly observed by beam emission spectroscopy in DIII-D [4] and by gas puff imaging diagnostics in NSTX and Alcator C-Mod tokamaks [5]. Recently blobs have been observed in DIII-D by a fast imaging camera [6].

Local plasma density, electron temperature, and floating potential are measured in the outboard SOL of DIII-D by a fast reciprocating probe array [7]. The diagnostic is capable of measuring the density and potential fluctuations with a bandwidth of 1 MHz and temperature fluctuations with a bandwidth of up to 200 kHz [8]. Fluctuation-induced cross-field fluxes of particles and heat are derived from the measurements [3]. Density and temperature fluctuations and fluxes in the SOL of L-mode discharges are strongly intermittent in time and space. Probability distribution functions of the fluctuations are skewed towards positive (larger-than-average) events and have more large events than could be expected for Gaussian statistics. Intermittent bursts in the density and temperature signals are attributed to blobs passing by the probe tips. The effect of the intermittent convective transport by blobs is to increase

the decay length of the time-averaged density and temperature in the far SOL significantly above the decay lengths at the separatrix. In LSN discharges cross-field transport increases with the discharge density and elevates the far SOL density, thus increasing plasma-wall interaction [9]. Far SOL densities and fluctuation levels in LSN configuration also increase with increasing connection length to material surfaces caused by a plasma current decrease at a constant magnetic field [9]. Since longer connection lengths slow down the parallel transport, it seems reasonable to expect the SOL widths to be larger in magnetic configurations where the connection lengths are large.

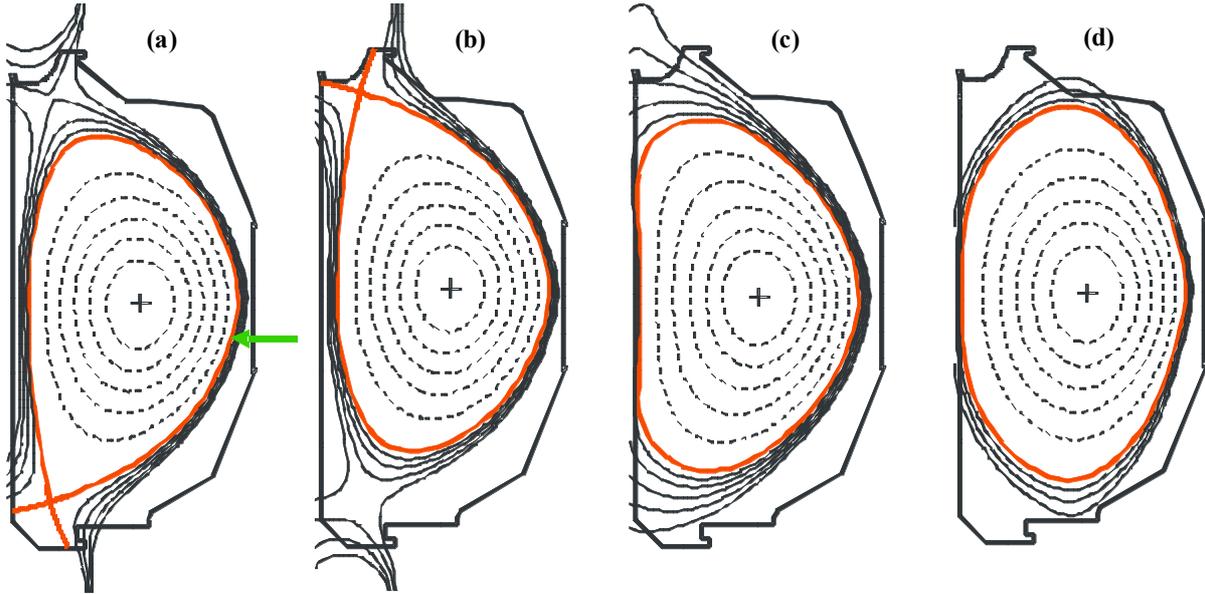


Figure 1: Magnetic configurations studied: LSN (a), USN (b), D-shaped IWL (c), Oval IWL (d). Poloidal location of the probe is shown by an arrow in (a).

We have measured SOL density and temperature profiles and fluctuations in LSN [Fig. 1(a)], USN [Fig. 1(b)], and IWL [Fig. 1(c,d)] L-mode discharges with comparable plasma parameters: toroidal magnetic field, $B_T = 1.9\text{--}2$ T, plasma current, $I_p = 1\text{--}1.2$ MA, neutral beam heating power, $P_{\text{NBI}} = 1\text{--}2.8$ MW, average plasma density, $\bar{n}_e = 2.0\text{--}3.0 \times 10^{19}$ m^{-3} . In all configurations $\mathbf{B} \times \nabla B$ drift was directed down. The connection length from the outer mid-plane to the nearest material surface in near SOL (~ 1 cm outside of LCFS) was between 20–26 m in all configurations. In the mid-SOL region (~ 3 cm outside of LCFS) the connection lengths differed substantially; being the longest (~ 22 m) in the D-shaped IWL configuration, shorter (15–16 m) in LSN and USN configurations, and the shortest (~ 8 m) in the oval IWL configuration. Shown in Fig. 2 are SOL profiles (versus the distance from the separatrix) of n_e (a), T_e (b), their respective root-mean-square (rms) fluctuation amplitudes (c,d), and turbulent cross-field fluxes (e,f) measured in four configurations of Fig. 1. Density and temperature in the D-shaped IWL configuration are well above those in other configurations through most of the SOL, which is consistent with connection length in this configuration being the longest. The oval IWL configuration has the shortest connection length for $R - R_{\text{sep}} > 2$ cm, consequently both density and temperature in this region are lowest among the four configurations considered.

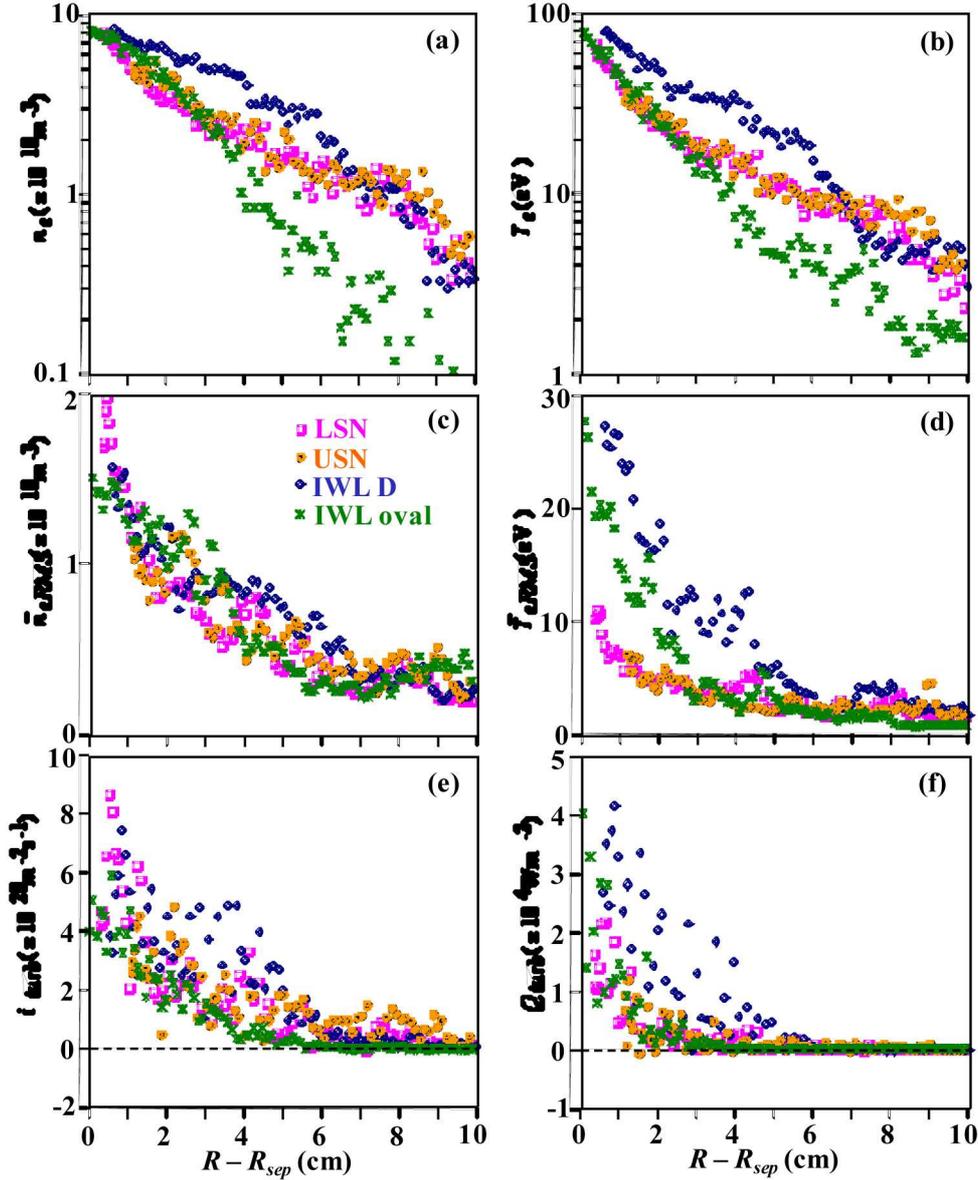


Figure 2: Profiles of SOL density (a), and temperature (b), fluctuations of density (c), and temperature (d), turbulent particle (e) and heat (f) fluxes, measured in four configurations of Fig. 1. Each point is an average over a 0.5 ms interval. Data in (e) have been additionally boxcar averaged over 3 points to reduce scatter. Positive flux is directed outwards. Note semi-log scale in (a) and (b).

Profiles in USN and LSN configurations are rather similar. Density fluctuation levels do not substantially differ between the four configurations and fluctuation-driven particle flux only varies within about a factor of 2 except in the oval IWL configuration, where in the region $R - R_{sep} > 3$ cm it is substantially lower than in the other configurations. Remarkably, the temperature fluctuation levels in the near SOL ($R - R_{sep} < 2$ cm) in both limited configurations are substantially higher than in the diverted ones. For the D-shaped IWL it may be a consequence of additional 0.7 MW of electron cyclotron heating (ECH) power being applied. However, ECH was off during the probe plunge in the oval IWL configuration

and temperature fluctuation levels were still high. Cross-field heat transport is strongest in the D-shaped IWL configuration, which may be partly due to the additional ECH heating power.

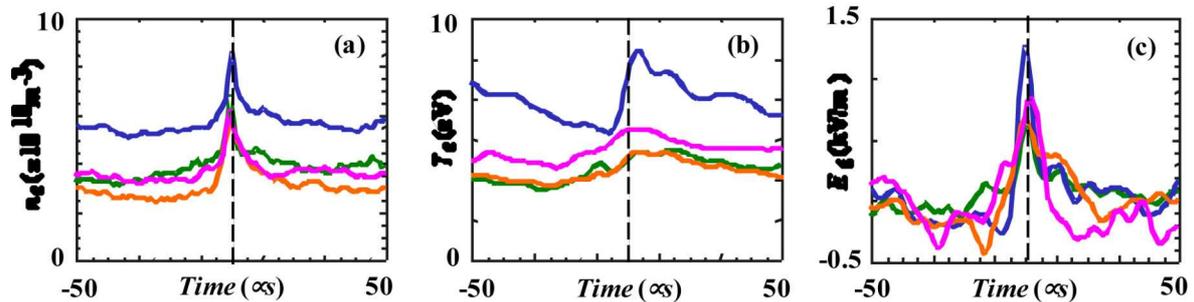


Figure 3: Conditional averaging results for the n_e (a), T_e (b) and E_θ (c) signals measured between 2 and 3 cm outside of the LCFS in configurations of Fig. 1. The color coding is same as in Fig. 2.

The effect of the magnetic configuration and connection length on the intermittent transport is illustrated in Fig. 3. Conditional averaging was performed on signals measured between 2 and 3 cm outside of the LCFS in the four configurations of Fig. 1. The n_e time series was used as a primary (independent) signal and T_e and E_θ (poloidal electric field) time series as secondary signals [3]. Events with amplitude above 2.5 times the rms fluctuation level were selected in n_e signal, binned and averaged. Corresponding intervals of T_e and E_θ signals were also binned and averaged to reveal correlations. In all configurations intermittent density bursts due to passing blobs are correlated with positive E_θ spikes corresponding to outward propagation due to $E \times B$ drift. The radial blob velocity in D-shaped IWL configuration is almost twice as high as in the other configurations. Density and temperature inside the blobs are also considerably higher in this configuration. Therefore, intermittent transport by blobs is strongest in D-shaped IWL configuration.

In summary, measurements performed in IWL, LSN and USN L-mode discharges show longer radial decay lengths of both density and temperature in configurations with longer connection lengths. This seems to be a combined effect of slower parallel transport due to longer connection length and faster cross-field transport, including intermittent transport by blobs. The observed increase of the blob radial velocity with increasing connection length is in agreement with theoretical predictions [10].

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