

Plasma polarization of the separatrix on the CASTOR tokamak

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Introduction: The impact of the sheared electric field on the global particle confinement and on the structure of edge fluctuations was investigated on the small tokamak CASTOR ($R=0.4$ m, $a=0.085$ m). The biasing electrode is immersed into the plasma from the top of the torus and its radial position can be changed on a shot to shot basis. Here, confinement properties are contrasted for the two positions of the electrode with respect to the separatrix (Last Closed Flux Surface), as shown schematically in Fig. 1.

"Standard" configuration of biasing experiments: Electrode is located deep in the edge plasma, i.e. in the region with closed magnetic field lines. Consequently, the sheared radial electric field is amplified between the electrode and the separatrix. This arrangement was demonstrated to be efficient to study properties of polarized plasmas, however, it can be hardly accepted in practice in large-scale or reactor-size experiments, since the electrode would not survive high thermal loads.

Biasing of separatrix: Alternatively, the biased electrode is inserted only into the scrape-off layer (SOL). In this case, the thermal load should be certainly significantly smaller than in the previous case and such scheme can be employed as non-intrusive one.

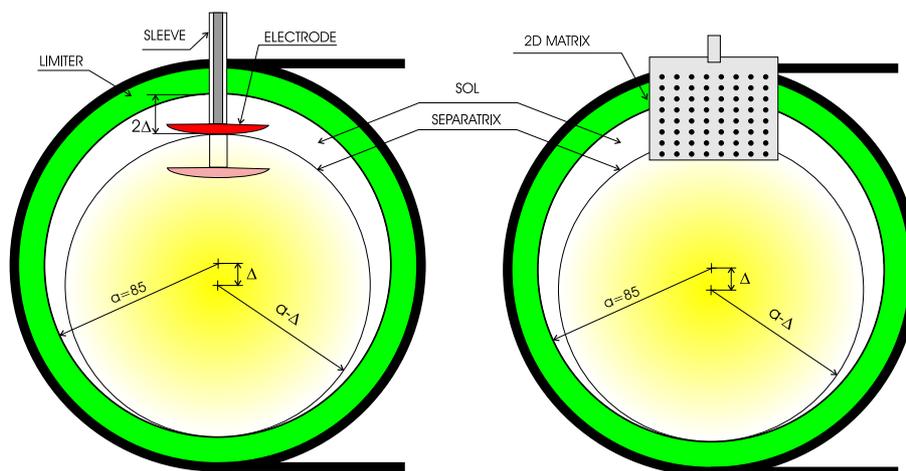


Fig. 1: Poloidal cross section of the CASTOR tokamak. *Left* - Positioning of the biasing electrode at a "standard" and at "separatrix biasing" arrangements. *Right* - Location of the 2D matrix of Langmuir probes.

Note that the second one can be materialized only if the scrape-off layer is broader than the radial extent of the biasing electrode. It is arranged on CASTOR by a downward

shift of the plasma column. The minor radius of the plasma is reduced with respect to the limiter radius and, as a consequence, an "additional" scrape-off layer appears at the top of the torus. It is clearly seen that at separatrix biasing the mushroom electrode is hidden in SOL and its top is just touching the separatrix.

Global Particle Confinement: The confinement properties at both the biasing schemes are compared for similar discharge conditions in Fig. 2. The electrode is positively biased by the pulsed voltage, $U_b = +200$ V, $\tau_b = 3$ ms.

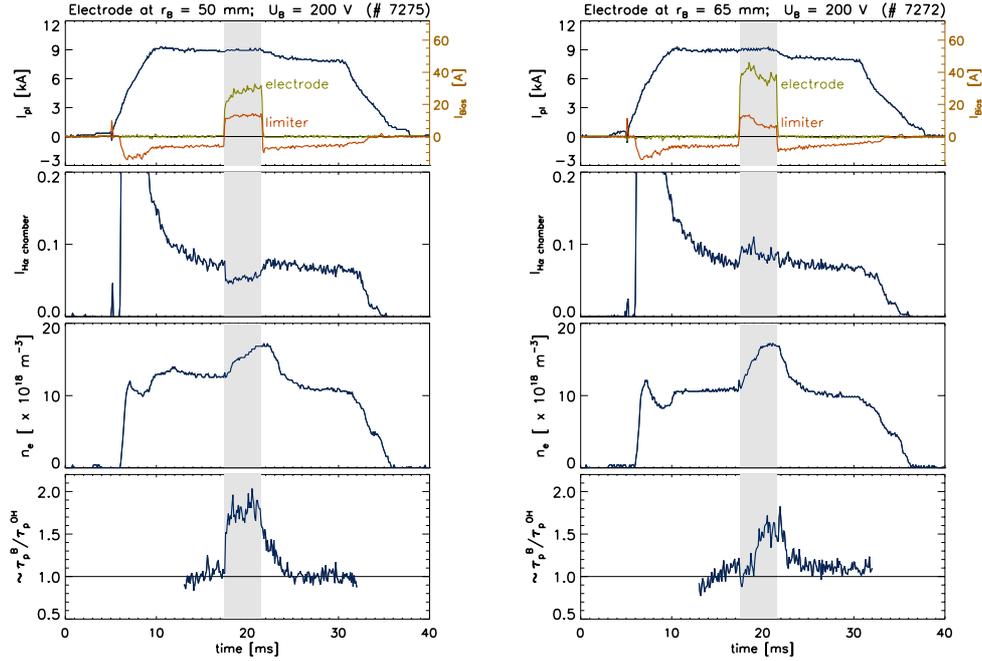


Fig. 2: Evolution of polarized discharges at "standard" and "separatrix biasing" arrangement at nearly identical discharge conditions ($I_p \sim 9$ kA, $B_T = 1$ T and $\bar{n}_e = 1 \div 1.2 \cdot 10^{19} m^{-3}$). Panels from top to bottom: Electrode current and the return current to the poloidal limiter together with the evolution of plasma current; the line averaged density over the central vertical chord (in $10^{18} m^{-3}$); the intensity of H_α spectral line (in [a.u.]); and the relative improvement of the global particle confinement time, calculated using the expression $\tau_p^B / \tau_p^0 \geq (n_e^b I_{H_\alpha}^0) / (n_e^0 I_{H_\alpha}^B)$ (the superscripts B and 0 denote the values in biasing and ohmical heating phases).

As seen in Fig. 2, the current of about 35-40 A is drawn by the electrode during the biasing period. The line average density increases noticeably with biasing in both cases. However, the evolution of the H_α spectral line intensity I_{H_α} exhibits different shapes. For the standard configuration, the intensity drops immediately with biasing, which evidently implies a reduction of recycling and results in improvement of the global particle confinement. On the other hand, at the separatrix biasing, the H_α emission slightly increases during the initial phase of the biasing period. Nevertheless, the global particle confinement time τ_p increases substantially (by 80% at standard biasing and by $\sim 50\%$ at the separatrix biasing), as seen in the bottom panel of Fig. 2.

Radial Electric Field. All these observations are interpreted as formation of a transport barrier. Its radial position is deduced from the radial electric field profile $E_r(r)$, measured by the rake probe with floating tips. The radial profiles of $E_r(r)$ for both the cases discussed are shown in Fig. 3. The transport barrier is expected to be localized at the region of highest shear.

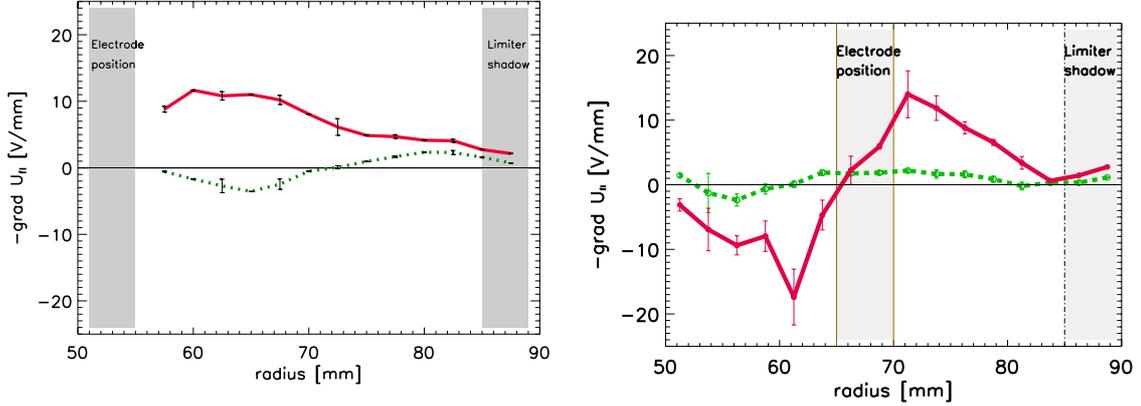


Fig. 3: Radial electric field profile at "standard" (left) and "separatrix biasing" (right) arrangements.

It is evident from the figure that the radial electric field is sheared in both the cases. However, at separatrix biasing, the $E \times B$ shear rate $\omega_{E \times B} \approx dE_r/dr/B_t$ is larger than for the "standard" scheme although the particle confinement improvement is higher in the latter case. The value of $\omega_{E \times B} \sim 10^6 \text{ s}^{-1}$ evidently prevails the typical growth rate of unstable modes ($\gamma \sim 10^5 \text{ s}^{-1}$). Fluctuation measurements have shown a strong impact on the poloidal correlation of turbulent eddies [1] in this case.

2D Structure of Edge Turbulence. To study the electrostatic fluctuation in poloidal and radial directions simultaneously, the 2D matrix of Langmuir probes has been constructed. It consists of 8×8 carbon tips, fixed in a BN — ceramic plate and spaced poloidally by 6 mm and radially by 4.5 mm. The individual tips can operate either in the floating potential or ion saturation current mode. Signals are digitized with a sampling rate 1 Msample.

The probe head is covered by the layer of B_4C (plasma sprayed) to reduce its interaction with the edge plasma. It is oriented perpendicularly with respect to the magnetic field lines. Therefore, it acts as an additional rail limiter (see Fig. 1), which can be inserted within the separatrix without any significant macroscopic modification of the discharge. Preliminary experiments have shown, however, a local re-distribution of the plasma potential if the probe is inserted into the plasma. The impact of this effect on the structure of the edge turbulence must be studied in detail in further experiments.

First experimental results are shown in Fig. 4, where snapshots of potential fluctuations in poloidal plane are displayed. The interval between the pictures is $2 \mu\text{s}$. The left column shows the 2D structure of the edge turbulence in the ohmic phase of the discharge, while the right column corresponds to the biasing phase. The electrode is located within the separatrix, i.e. the "standard" biasing scheme is used.

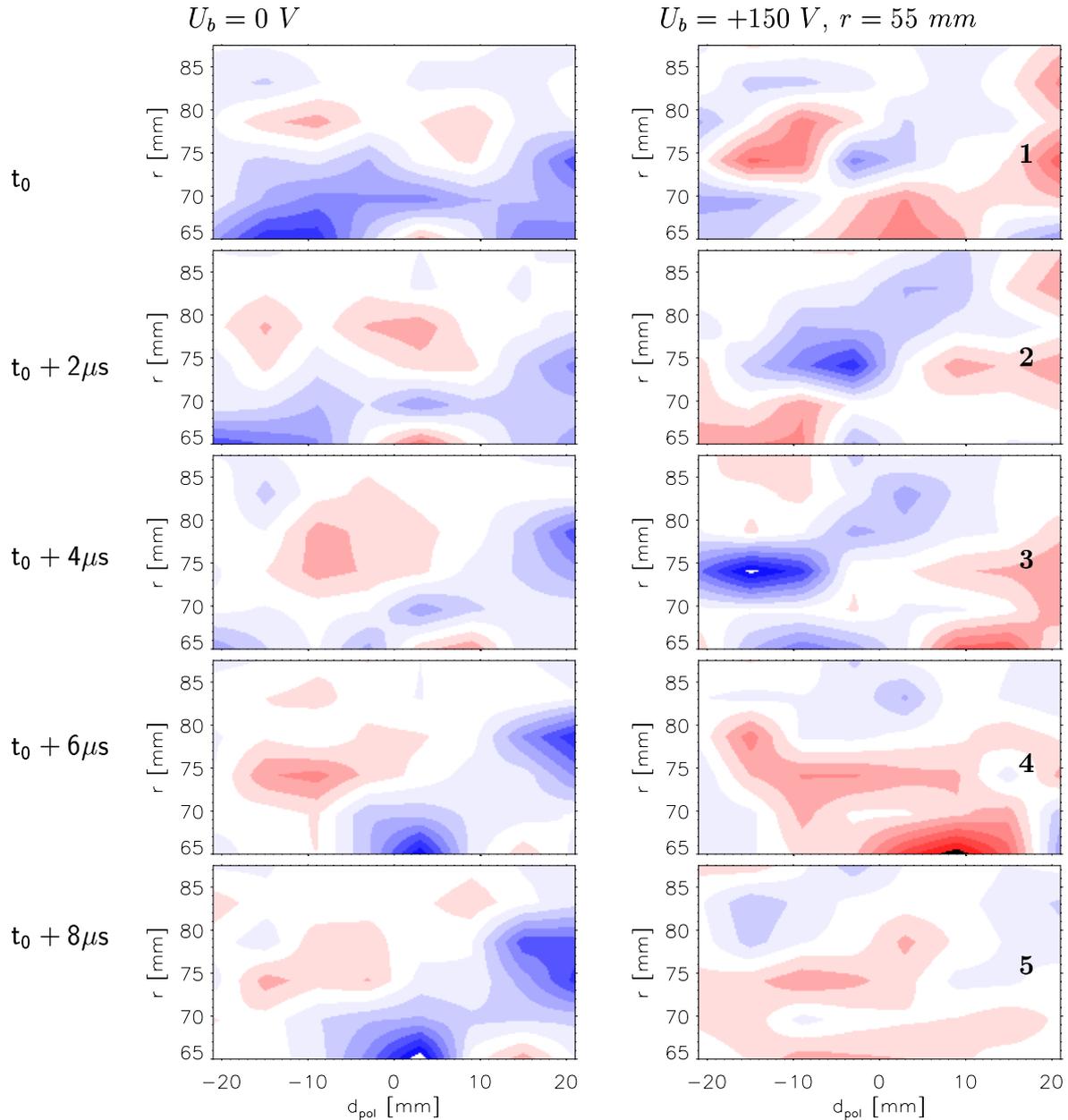


Fig: 4. Snap-shots of potential structures. Red and blue structures correspond to maxima and minima of potential, respectively. Left column — without biasing. Right column — Electrode is biased positively.

One can distinguish the poloidal propagation of the structures, which seems to be faster with biasing. Narrowing the structures in the radial direction at biasing is also apparent (see panels 2 and 3 at the right-hand side). More precise processing of data (2D correlation analysis) is in progress.

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References:

1. J. Stockel et al: In Proc. of 26th EPS Conf on Contr. Fusion and Plasma Physics, p.1589.