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Experimental and numerical characterisation of fluctuations in the SOL of ASDEX Upgrade during L-mode and ELMy H-mode

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Abstract

Experimental investigations of fluctuations in the scrape-off layer (SOL) and corresponding numerical turbulence simulations were performed for both ASDEX Upgrade L-mode and ELMy H-mode plasmas (ELM = edge localized mode). A fast reciprocating probe on the midplane manipulator was used with a probe head containing five Langmuir probes. The electron temperature in the SOL during L-mode plasmas and during an ELMy H-mode was analysed and discussed. In particular we compare the characteristics of turbulent fluctuations during ELM events and in between ELMs with those of L-mode data. Experimental data are compared by statistical analysis with 2D fluid simulations.

1. Introduction

Transport across the SOL during ELM events is a crucial aspect for the operation of large tokamaks. An experimental characterisation of ELM bursts can give important information on generation and propagation mechanisms of these modes. The relatively cool outer SOL allows for access by Langmuir probes and their capability to measure both, density and electrostatic potential-related quantities as well as combinations thereof like the fluctuation-induced particle flux or Reynolds stress. Here we report on probe measurements of fluctuations in the L-mode phase and H-mode phase of ASDEX Upgrade: fluctuation statistics are obtained for the time during a type-I ELM event and in the phase in between ELMs. The experimental results are compared with 2D fluid simulations of turbulent SOL transport.

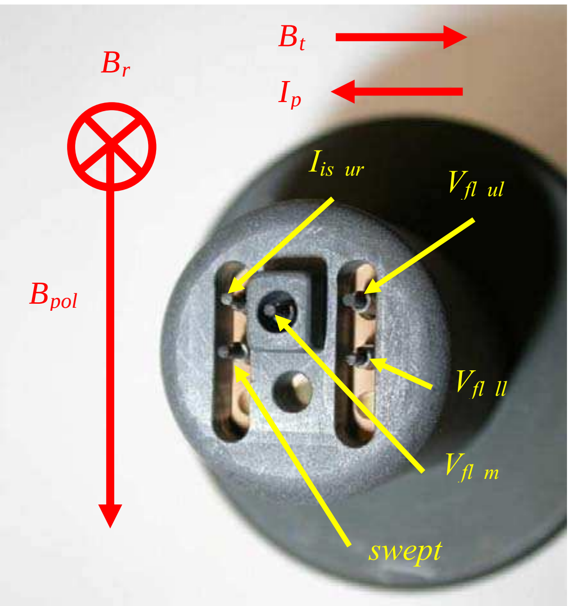


Fig. 1: Five-pin probe head used for fluctuation measurements. Three pins measure the floating potential, one probe the ion saturation current, one is swept to record the current-voltage characteristic.

Recently we have performed various experiments on the relation between Reynolds stress and the fluctuation-induced particle flux in ISTTOK [1,2,3]. The structure of ELMs in the SOL was recently investigated in [4].

2. Experimental set-up and results

The fast reciprocating probe shaft on the ASDEX Upgrade midplane manipulator was used to insert a probe head with five carbon fibre composite pins (each with 1 mm diameter and 2 mm length) (see Fig. 1). Three pins (*ul* – upper left, *ll* – lower left and *m* – middle) measure the floating potential V_{fl}. The poloidal spacing between probes *ul* and *ll* is $d_p = 4$ mm. Probe *m* is radially protruding by $d_r = 4$ mm from the plane of the other probes. Assuming the electron temperature to be equal on all three probe positions, which in the far SOL is acceptable, the radial and poloidal electric field components $E_{r,\vartheta}$ are obtained from the differences of the floating potentials between two poloidally or radially separated pins, respectively. One probe (*ur* – upper right) is biased to –70 V to measure the ion saturation current I_{is}. The fifth probe is swept to record the current-voltage (*IV*-)characteristic from which the electron temperature T_e is derived. With m_i being the ion mass and the effective probe area for ion collection being A_p, the ion density is derived from the ion saturation current by the formula:

$$n_i \cong \frac{I_{is}}{eA_p}\sqrt{\frac{m_i}{k_B T_e}} \tag{1}$$

With these data we can calculate the radial fluctuation-induced particle flux

$$\Gamma = \langle \tilde{n}_i \tilde{v}_r \rangle = \frac{\langle \tilde{n}_i \tilde{E}_\vartheta \rangle}{B} = \frac{\langle \tilde{n}_i (\tilde{V}_{fl\_ul} - \tilde{V}_{fl\_ll}) \rangle}{d_p B} \tag{2}$$

simultaneously with other fluctuating components like the electrostatic Reynolds stress. Data evaluation of this effect is still in progress and will be published later.

Fig. 2a shows a typical example of the *IV*-characteristics taken with the swept probe in between two ELMs. This characteristic was fitted with an appropriate function from which T_e was determined as 5,4 eV [5]. Fig. 2b yields information on the fluctuation level of the

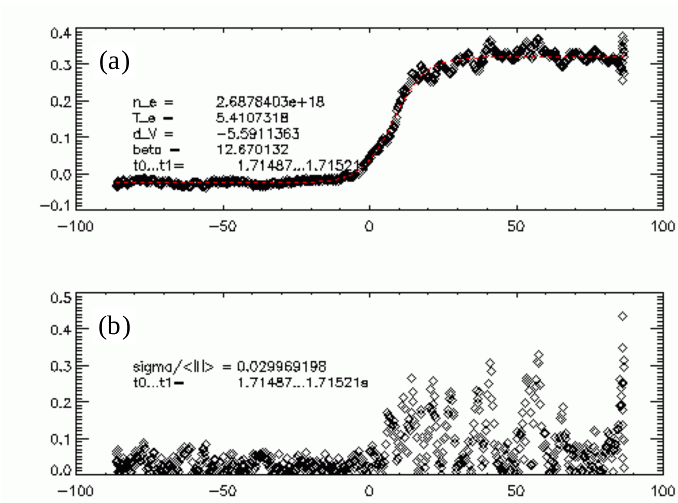


Fig. 2: (a) Typical current-voltage characteristic of the swept probe between ELMs, fitted over the entire range (red curve); (b) Fluctuation level of the probe current.

probe current. An evaluation of all available 97 *IV*-characteristics during one shot in between ELMs yielded 5,6±1,7 eV as mean value with a rather wide spread. This low value of T_e is somewhat surprising, but the probe was 5 cm outside the last closed flux surface. Due to the low scanning rate, we did not obtain *IV*-characteristics during an ELM.

The parameters of this shot were: toroidal magnetic field 2,5 T, plasma current 1 MA, averaged line density 9×10^{19} m^{-3}, 2,5 MW neutral beam injection in the beginning, later being increased to 5 MW.

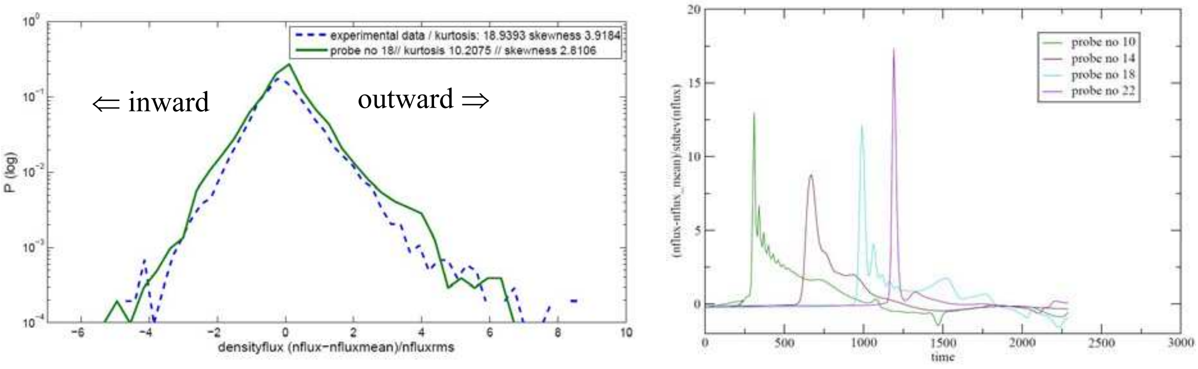
The probability density functions (PDF) of the radial fluctuations-induced particle flux was compared for three cases: in the L-mode, in the H-mode between ELMs and in the H-mode during a type-I ELM. The PDF during an ELM was found to be very asymmetric, which is an evidence for strong radial transport. Consequently also the fluctuations-induced particle flux is more than an order of magnitude larger in this case than between ELMs.

3. Comparison with numerical simulations

The measured data were compared with 2D fluid edge/SOL electrostatic simulations of interchange turbulence using the code ESEL [6,7] for experimental ASDEX Upgrade edge parameters [8]. The simulation domain was situated around the probe location at the outer midplane with a spatial extent of $200\times100\ \rho_i = 4{,}6\times2{,}3$ cm (radial×poloidal). The experimental data (ion saturation current, floating potential and flux) and simulation data (density, plasma potential and flux derived at same distances as for the probe) time series were compared by statistical methods. For the L-mode data, good agreement was found between the respective probability distribution functions for the density n and density flux $n\cdot v_r$, shown in Fig. 3a.

Conditional averaging of wave forms [9], which removes the noise from repetitive signals and leads to more useful statistics for large-scale events above a specified trigger, was applied to analyse the relative importance of different scales. In L-mode conditional wave forms revealed good agreement between experiment and simulations. It was found that at the probe position in the far outer SOL, small events below the standard deviation dominate the signal in both cases. Less agreement was found between the frequency spectra. In the simulations, linear mode remnants appearing due to the interchange drive model were still apparent in the spectra, whereas the experimental ones clearly reflect fully developed cascaded turbulence. So, the dissipative ranges show discrepancies, probably due to the simplified parallel damping model in the code. In future, more sophisticated models (including drift-Alfvén) for edge turbulence will have to be used.

The H-mode ELM probe signals were compared with artificially imposed large-scale blob structure in the simulations as a simplified model for ELMs [8]. This model clearly does not capture the probably electromagnetic (peeling ballooning [10]) generation mechanism of ELMs but should lead to the same phenomenology in propagation. Propagation times and arrival signals of the structures had similar features as in the experiment: in the simulations, steep initial rises followed by trailing wave like forms due to the nonlinear break-up of structures were observed (see Fig. 3b). More detailed studies are in progress.



(a) (b)

Fig. 3: a) Density flux PDFs for experimental probe (dotted blue) and simulation at a corresponding location (solid green). b) Nonlinear break-up of large-scale blobs as a simplified model for ELMs in the simulation for different locations relative to the separatrix.

References

[1] C. Ionita, P. Balan, R. Schrittwieser, H.F.C. Figueiredo, C. Silva, C.A.F. Varandas, R.M.O. Galvão, *Rev. Sci. Instrum.* 75 (2004), 4331.

[2] P. Balan, H.F.C. Figueiredo, R.M.O. Galvão, C. Ionita, V. Naulin, J.J. Rasmussen, R. Schrittwieser, C.G. Silva, C. Varandas, *Europhys. Conf. Abstr.* 28G (2004), p. 5.119.

[3] P. Balan, C. Ionita, R. Schrittwieser, C. Silva, H.F.C. Figueiredo, C.A.F. Varandas, J.J. Rasmussen and V. Naulin, *Europhys. Conf. Abstr.* 30I (2006), P-1.141.

[4] A. Herrmann, A. Kirk, A. Schmid, B. Koch, M. Laux, M. Maraschek, H.W. Müller, J. Neuhauser, V. Rohde, M. Tsalas, E. Wolfrum, ASDEX Upgrade, *J. Nucl. Mat.* 363-365 (2007), 528.

[5] M. Weinlich and A. Carlson, *Phys. Plasmas* 4 (1997), 2151.

[6] O.E. Garcia, V. Naulin, A.H. Nielsen, J.J. Rasmussen, *Phys. Plasmas* 12 (2005), 062309.

[7] O.E. Garcia, J. Horacek, R.A. Pitts, A.H. Nielsen, W. Fundamenski, J.P. Graves, V. Naulin, J. Juul Rasmussen, *Plasma Phys. Control. Fusion* 48 (2006), L1.

[8] S. Konzett, Diploma thesis (unpublished), University of Innsbruck (2007).

[9] T. Huld, A.H. Nielsen, H. Pécseli, J. Juul Rasmussen, *Phys. Fluids* B 3 (1991), 1609.

[10] H.R. Wilson, J.W. Connor, A.R. Field, S.J. Fielding, R.L. Miller, L.L. Lao, J.R. Ferron, A.D Turnbull *Phys. Plasmas* 6 (1999), 1925.