Measurements of edge turbulence in ASDEX Upgrade L- and H-mode discharges

B. Nold*[1], H. W. Müller[2], M. Ramisch[1], U. Stroth[1,2]
and the ASDEX Upgrade Team[2]
[1] *Institut für Plasmaforschung, Universität Stuttgart, Stuttgart, Germany*
[2] *Max-Planck-Institut für Plasmaphysik, EURATOM Association, Garching, Germany*

Introduction

Losses of energy and particles in the edge of magnetically confined plasmas are driven by turbulent processes and may lead to a substantial power load on the first wall in a future fusion reactor. Therefore detailed understanding and control of the turbulent processes is crucial for operation with a high duty cycle.

Intermittent bursts of plasma from the closed flux surfaces have been observed in various plasma devices. They are elongated in the direction of the magnetic field lines and propagate perpendicular to them. These *blob* filaments should not be mixed up with the much denser but less frequent edge localized mode (ELM) filaments that can arise from magneto hydrodynamic instabilities in the high (H-mode) confinement regime. Blobs may cause about half of the turbulent losses in the low (L-mode) confinement regime [1], but are also observed in between ELMs or ELM-free H-mode plasmas. In Ohmic L-mode discharges, blobs were found to be generated closely inside the last closed flux surfaces (LCFS) and to experience little change while passing a shear layer close to the LCFS of ASDEX Upgrade [2]. In H-modes the edge transport barrier observed is related to enhanced $E \times B$ shear flows, but their effects on mesoscale turbulent structures are not yet fully understood. This contribution compares the profiles and fluctuations from Langmuir probe measurements in ASDEX Upgrade L and H-mode discharges.

Experimental setup

Experiments were carried out in the tokamak ASDEX Upgrade (AUG) with major radius $R_0 = 1.65\,\mathrm{m}$ and minor radius $a = 0.5\,\mathrm{m}$ [3]. The reciprocating Langmuir probes penetrate the plasma for about 100 ms horizontally 0.31 m above the outer midplane. The probe array consists of 9 free standing cylindrical carbon pins separated poloidally by 2.75 mm and 4 additional pins retracted radially by 4 mm. One probe was biased to record Langmuir probe characteristics, while the others measured alternating potential or ion-saturation current, as shown in Fig. 1. The probe array is aligned perpendicular to the magnetic field lines in the SOL. The effective probe surfaces are not sensitive to small variations of this angle, because the cylindrical probes do not enter the shadow of their neighboring pins.

The toroidal magnetic field was clockwise 2.5 T and the plasma current 800 kA counter clockwise (looking from the top). Experiments were conducted in deuterium plasmas with lower single null configuration. Additional electron cyclotron heating was applied with 0.6 MW and 2.3 MW for L-mode (#26530, $t = 3.5\,\mathrm{s}$) and H-mode (#26524, $t = 4.6\,\mathrm{s}$), respectively. The plasma was in a stable phase during the probe motion with an edge density of $4.0 \times 10^{19}\,\mathrm{m}^{-3}$ ($5.5 \times 10^{19}\,\mathrm{m}^{-3}$) and an energy content of 1.3 kJ (3.1 kJ) for the L-mode (H-mode).

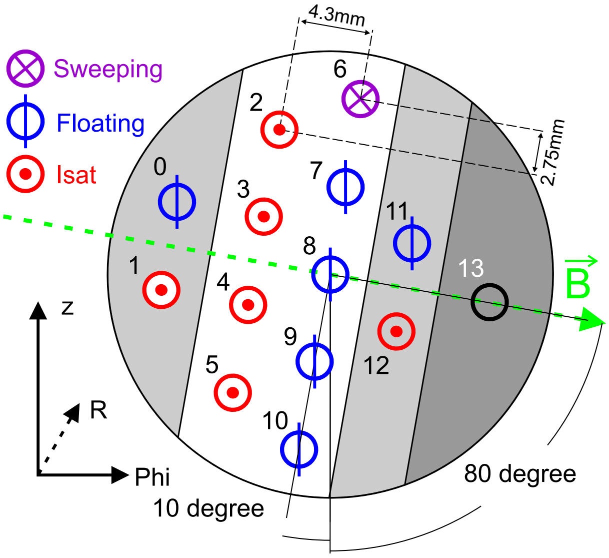

Figure 1: View from the plasma to the multi pin probe. The shaded areas are retracted by 4 mm and 8 mm (pin 13).

Background profiles

The ion-saturation current profiles from the scrape-off layer (SOL) in L and H-mode are shown in the top of Fig. 2. The standard deviations of the current fluctuations are shown as vertical error bars in the semi-logarithmic plot. Neglecting the temperature dependence of the saturation currents, they corresponds to the plasma density. The scrape-off layer density in H-mode was found to be about half of the L-mode density, although the edge density was higher in H-mode. The density decay length is almost unchanged. The density fluctuation level close to the separatrix drops from about 30% (80 mA) in L-mode to 20% (30 mA) in H-mode.

The floating potential profiles are compared in the middle of Fig. 2. In L-mode, a steep decrease of the floating potential is observed within the last 2 cm before the separatrix. In H-mode the floating potential is almost flat with an increase to positive potentials close to the separatrix. This indicates a significantly positive plasma potential in the H-mode SOL, as the temperature is increasing towards the separatrix.

Poloidal motion

The perpendicular motion of turbulent structures was addressed by cross-correlation of poloidally separated probes. In the outer SOL, turbulent structures propagate with a velocity 0.6 km/s downward in the ion-diamagnetic drift direction (Fig. 2, bottom) for both, L and H-mode. An abrupt flow reversal into the electron-diamagnetic drift direction is observed in the L-mode discharge about 1.5 cm outside the separatrix, which is consistent to earlier findings [2]. In the H-mode case no flow reversal is observed, but a further velocity increase approaching the separatrix. In L-mode, the perpendicular velocity of the turbulent structures increases up to 2 km/s in vicinity of the separatrix.

Plasma potential and flow

In L-mode, a self emitting probe measured directly the plasma potential during the outward motion of the manipulator. The electron temperature deduced from plasma and floating potential measurements agrees with Thomson scattering and Langmuir probe characteristics, as previously reported by [4]. The radial electric field E_r was deduced and allowed for an estimation of the $E_r \times B$ background flow, as indicated by the rectangles in Fig. 2. In the outer SOL, good agreement is found with the perpendicular velocity from the cross-correlation technique. This indicates that the perpendicular propagation velocity of blobs is dominated by an $E_r \times B$ background flow in this region. Close to the separatrix, the $E_r \times B$ drift seems to change with a radial wave length of about 5 mm. This was not observed by cross-correlation analysis. The discrepancy between both profiles might be related to the average blob size and/or the radial resolution of the probes (2 mm). Inside the shear leyer, the blob size seems to be about 1 cm in radial and perpendicular (i.e. almost poloidal) direction. Such large structures might not follow the fast modulation of the radial electric field.

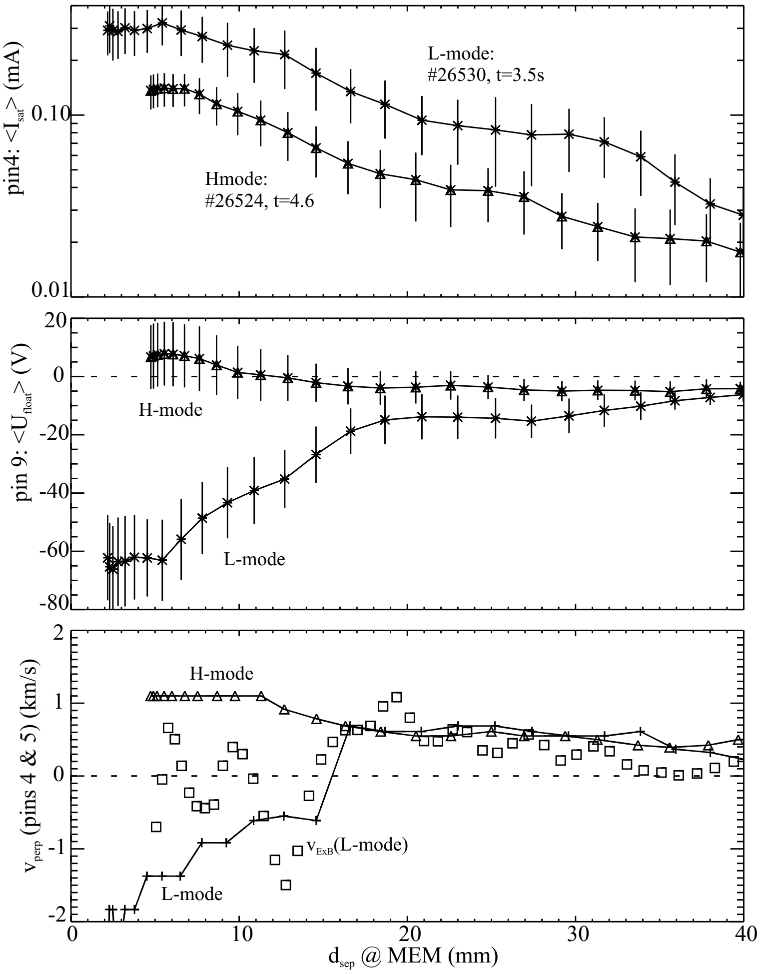

Figure 2: Radial profiles of ion-saturation current (top) and floating potential (middle) in L and H mode. The perpendicular velocity (bottom) is plotted together with $v_{E\times B}$. Positive velocities correspond to the ion-diamagnetic drift direction. The radial position is given as distance to the separatrix in mm in front of the manipulator.

Connection length

The magnetic field lines close to the separatrix pass the x-point and hit the divertor plates. In L-mode, the connection length to the outer divertor is abruptly reduced for field lines starting 1.6 cm outside the separatrix in the manipulator plane. This is the same location, where also the perpendicular $E_r \times B$ shear flow is observed. In H-mode, the magnetic shape fits better to the divertor shape, which leads to a smooth transition from long connection lengths in the divertor to shorter connection lengths in the main chamber above the x-point. The abrupt reduction of the parallel connection length might be related to the drift reversal in L-mode.

Summary and conclusions

Close to the separatrix, the SOL density and fluctuation level were reduced in H-mode despite increased heating power and edge density. However, the statistical properties of turbulence did not change significantly, as reported previously from divertor investigations on ASDEX Upgrade [5]. The low confinement mode shows a strong influence on the floating potential profile as well as the perpendicular blob motion close to the separatrix. Plasma potential measurements indicate that the perpendicular motion of turbulent structures in the SOL is dominated by $E_r \times B$ background flows. This observation would be consistent with interchange instabilities in the SOL. Furthermore, the $E_r \times B$ dominance is crucial for the determination of radial electric fields from Doppler reflectometry, which is based on phase velocity measurements.

References

[1] S. J. Zweben *et al.*, Plasma Physics and Controlled Fusion **49** (2007) S1-S23

[2] B. Nold *et al.*, Plasma Physics and Controlled Fusion **52** (2010) 065005

[3] A. Herrmann and O. Gruber, Fusion Sci. Technol. **44**, 3, 569 (2003)

[4] V. Rohde *et al.*, Journal of Nuclear Materials 241-243 (1997) 712-715

[5] G. Y. Antar *et al.*, Plasma Physics and Controlled Fusion **50** (2008) 095012

*email: nold@ipf.uni-stuttgart.de