Plasma flow in the scrape-off layer of ASDEX Upgrade

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Introduction

While the scrape-off layer (SOL) physics in divertor tokamaks is rather well understood, the in/out asymmetries in the SOL, the divertor plasma parameter and the plasma flow are still under investigation. For example profile and transport analysis at the magnetic low field side show a fast radial transport to the outer wall [1]. In contradiction to these observations a comparison of hydrogen and carbon fluxes on the low and high field side showed that recycling at the magnetic high field side dominates [2, 3]. The missing link between these observations might be a global SOL plasma flow, which can be driven by drift effects, poloidal pressure asymmetries or plasma rotation. Significant plasma flows have been observed in several tokamaks usually in L-mode (e.g. [4]); measurements during the ITER relevant H-mode are rare [5]. An interpretation of the flow measurements in the midplane requires additional

Figure 1: Experimental set up and plasma configurations.

input from divertor diagnostics like Langmuir probe measurements in the divertor region.

In this paper we report on a set of flow measurements at ASDEX Upgrade during ohmic and H-mode discharges in lower single null configuration.

Experimental Set up

The main focus of this paper are flow measurements in the outer midplane at ASDEX Upgrade by means of a fast reciprocating probe system. The reciprocating probe is located above the midplane at $z = 0.31$ m. Performing a stroke delivers a profile measurements over a distance of 100 mm within 100 ms. The probe was operated with two different probe heads for flow mea-
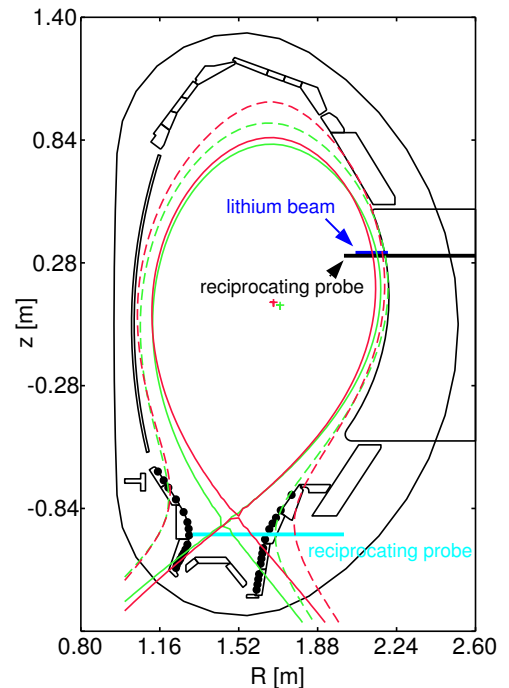
surements. One head was equipped with pin probes. An obstacle is separating 6 pins with 3 of them at each side of the obstacle allowing for up-/downstream measurements. We used a probe configuration with an ion saturation current (I_{sat}) and a swept single probe measurement at each side of the obstacle. A second probe head was equipped with in-plane probes. The probes of this head are tilted by $14°$ with respect to the toroidal direction. In the top view the probe planes form a triangle. They have two advantages over pin probes. The probes can withstand a higher heat flux and the probe area is known more precisely. This probe head was operated with a single probe at each side. All single probes were swept with a frequency of $1.3\,\text{kHz}$ and about $\pm 100\,\text{V}$ to $\pm 150\,\text{V}$. The I_{sat} measurements were performed at about $-60\,\text{V}$.

A second reciprocating probe which allows for flow measurements in the divertor is located in the vicinity of the lower x-point. Further details can be found in [6]. For independent density profile measurements in the SOL a lithium beam diagnostic is available at the same poloidal position as the fast reciprocating probe in the outer SOL. The density in the inner and outer divertor is measured by flush-mounted divertor probes.

Figure 1 shows the poloidal cross section of ASDEX Upgrade and the positions of the discussed diagnostics as well as the plasma shapes used for this investigation. The divertor probes in the lower divertor are marked as black dots. The following definition for the direction of the flow will be used throughout the paper. A positive sign refers to a flow from the lower outer divertor to the lower inner one. This will also be called upstream.

Figure 2: Density profiles in ohmic discharge at $0.35 n^{GW}$.

Ohmic discharges

The plasma parameters in the SOL have been measured during identical ohmic discharges using both probe heads on the midplane manipulator (for the plasma shape see the red shape in figure 1). The discharges are lower single null discharges with a current of $I_P = 0.8\,\text{MA}$, a toroidal field of $B_t = -2\,\text{T}$ and line averaged densities of $\bar{n}_e = 2.5 \times 10^{19}\,\text{m}^{-3}$ and $\bar{n}_e = 3.6 \times 10^{19}\,\text{m}^{-3}$. This corresponds to a fraction of 0.25 and 0.35 of the Greenwald density n^{GW}. The $\vec{B} \times \nabla \vec{B}$ drift is directed towards the lower x-point.
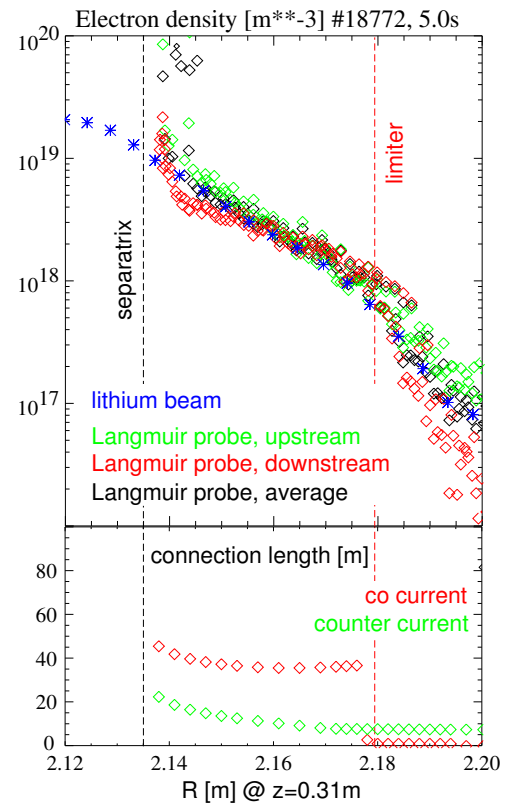
After recalibrating some of the pin areas by cross calibrating and comparison with the in-plane probes the results of the two probe heads agreed well. The top of figure 2 shows a comparison of the density profiles deduced from the single probe measurements at the pin head with the lithium beam data during the $0.35n^{GW}$ period. The vertical black line represents the separatrix position. The vertical red line represents the innermost position where the downstream density was influenced by a limiter. The connection length of the intersected field lines is given in the bottom part of 2. The averaged density profile from the upstream and the downstream pin agrees very well with the lithium beam data up to a separatrix distance of about 5 mm. Up- and downstream density show different fall-off lengths in the SOL and in the limiter shadow. Both sides seem to be affected by the limiter, although the field lines connected to the upstream measurement hit the divertor baffle but no limiters.

Figure 3: Flow profile in ohmic discharge for two densities.

In the figure 3 the flow profiles in the ohmic discharge are shown for both densities. The Mach number is determined from the I_{sat} measurements at the pin probes using Hutchinson's formula $M = 0.43 \times \ln(j_{sat}^{up}/j_{sat}^{down})$ [7]. Here j_{sat} is the ion saturation current density. The vertical black and red lines again show the innermost position affected by the limiters. Just within this position the flow is about zero as expected. Towards the separatrix the Mach number is increasing. Up to $1 - 1.5$ cm outside the separatrix, where we find $M \approx 0.2$, the Mach number is the same for both densities. Close to the separatrix there is a peak. For both line averaged densities the maximum reaches $M \approx 0.5$. At the higher density the peak is narrower and the maximum about 5 mm closer to the separatrix which is within the uncertainty of the separatrix position. Then M decreases again towards the separatrix.

H-mode discharges

For the H-mode measurements a low power H-mode discharge with 2.5 MW NBI heating was chosen to keep the heat flux onto the probe moderate. The discharge stayed in H-mode all the time but with short ELM free periods. The plasma parameters were $I_P = 1$ MA, $B_t = -2.5$ T and $\bar{n}_e = 4.7 \times 10^{19}$ m^{-3} which is $\approx 0.37n^{GW}$. The plasma shape is shown in green in figure 1. The flow was determined from the ion saturation branches of the in-plate single probes ($U_{sweep} < -100$ V). In figure 4 the flow in the SOL of the H-mode plasma is compared to the flow in the ohmic discharge at a similar $\bar{n}_e/n^{GW}$. The red and black lines indicate the innermost position
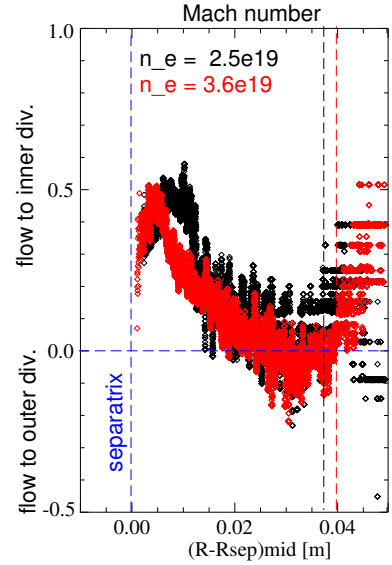
affected by the limiters. The H-mode flow profile is also about zero just in front of the limiter. Towards the separatrix the flow rises like the flow in the ohmic discharges. But while the ohmic discharge shows a rather flat profile directly in front of the limiter the H-mode profile increases immediately. Therefore the H-mode shows a larger upstream flow up to a distance to the separatrix of about $\Delta \approx$ 1.5 cm. This difference is somewhat larger than the assumed uncertainty in M of ~ 0.1. At a distance of $\Delta \approx 1.5$ cm to the separatrix the H-mode flow profile flattens at $M = 0.3$ and shows the same flow at $\Delta = 1$ cm as the ohmic case. It is not certain if there is a peak close to the separatrix as in the ohmic case.
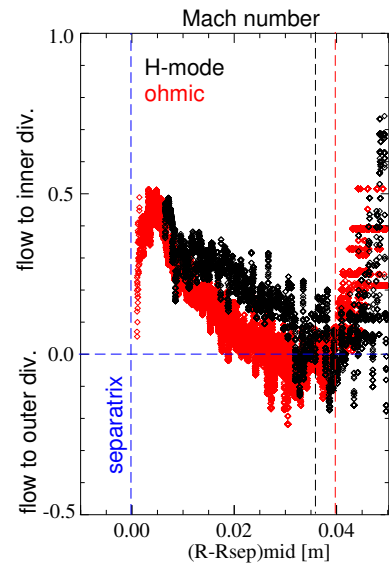
Figure 4: Comparison of flow profiles in H-mode and ohmic discharges.

Discussion and Summary

The flow profiles observed at ASDEX Upgrade in the outer SOL are in shape and value comparable with the flow profiles measured at JET [5]. At Alcator C-mod narrower flow profiles with lower peak levels have been observed at higher densities [4]. The flow observed at ASDEX Upgrade can account for a significant transport from the outer midplane towards the inner divertor. Nevertheless the reciprocating probe in the divertor always detects a flow towards the inner divertor at the inside and towards the outer divertor at the torus outside (except for ELMs) [6].

The origin of the plasma flow is still unclear. The pressure in the SOL does not (always) seem to be the key player. In the studied ohmic discharge at $\bar{n}_e = 0.35 n^{GW}$ the pressure in the divertor and at the reciprocating probe position at $z = 0.31$ m is approximately the same.

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