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Plasma drift velocity measurements near the ASDEX Upgrade lower x-point

M. Tsalas [1], N. Tsois [1], V. Bobkov [2], A. Herrmann[2], H. W. Muller [2], J. Neuhauser [2], V. Rohde [2] and the ASDEX Upgrade Team [2]

[1] *NCSR "Demokritos", Inst. of Nucl. Technology – Rad. Prot., Attica, Greece*

[2] *Max – Planck – Institut für Plasmaphysik, EURATOM Association, Garching, Germany*

1. Introduction

Studying the plasma flow in the scrape-off layer (SOL) and divertor is crucial, not only to determine the particle and power flow towards the divertor plates, but also to understand impurity transport and migration between the main chamber and divertor (see e.g. [1] and references therein). Recent measurements from Alcator C-mod have also indicated that near-sonic SOL flows can couple across the separatrix into the main plasma and influence the H/L-mode transition [2]. Such measurements from the high field side (HFS) and low field side (LFS) mid-plane must however be complemented by (and be consistent with) measurements in the divertor. There, the picture is further complicated by the outer SOL / private flux / inner SOL interaction, by the coupling with the recycling neutrals and, in H-mode discharges, by transients (e.g. flow reversals during ELM's etc.).

In ASDEX Upgrade, a reciprocating probe recently refurbished for the Div IIb divertor and capable of accessing both the HFS and LFS divertor legs as well as the private flux region was equipped with a Mach head and used in a variety of discharges to measure plasma flows. Here we report and discuss some of our results, focusing on lower single null ohmic and low power H-mode discharges.

2. Experimental setup

ASDEX Upgrade has currently two fast reciprocating probe systems, measuring in the LFS mid-plane and in the x-point vicinity. The fast probe system whose results are primarily discussed here is operated in the divertor region (typically just under the x-point), as shown in figure 1. The probe head consists of three graphite tips, two of which in Mach configuration. The mach probe orientation permits measurement of the toroidal flow velocity and direction. The corresponding poloidal flow direction can be deduced from the local magnetic field line geometry. The tip potential can be either swept (typically with a frequency ~ 700 Hz, non-symmetric to avoid the electron

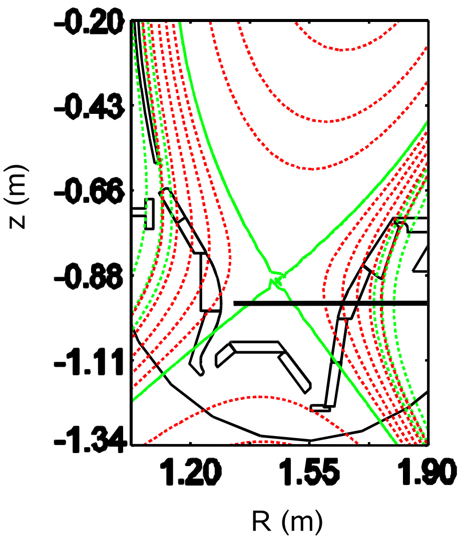

Figure 1: The x-point reciprocating probe position in ASDEX Upgrade.

saturation branch and the large power fluxes associated with it) or biased at a constant potential of ~ -100 V. The data acquisition system frequency of ~ 100 kHz permits the detection of events occurring in timescales of the order of 10^{-4} seconds. A full probe sweep lasts about 300 ms, during which the probe can travel approximately 32 cm inside the plasma (power load permitting), traversing both the LFS and HFS legs as well as the private flux region at a height of ~ 10 cm above the divertor roof baffle. More details on the probe specifications can be found in [3], [4].

3. Flow measurements in ohmic discharges.

Flow velocities were measured in three lower single null ohmic discharges of increasing central density (and therefore edge collisionality): $\langle n_e \rangle \sim 2.5 \cdot 10^{19}$ m^{-3}, $\langle n_e \rangle \sim 3.5 \cdot 10^{19}$ m^{-3} and $\langle n_e \rangle \sim 5 \cdot 10^{19}$ m^{-3} (approximately 0.265, 0.36 and 0.51 of n_{GW} respectively). Other discharge characteristics where: I_p ~ 800 kA, B_T ~ -2 T (ion **B**x∇**B** drift towards the x-point), and q_{95} ~ 4, at low triangularity. Flow velocities for all three cases as a function of the major radius R are shown in figure 2. The positions where the probe crosses the separatrix are also indicated, as determined by the observed features of the actual I^+_{sat} measurements (see e.g. [4]). In the LFS (HFS) SOL and private flux, positive (negative) Mach numbers indicate flow towards the divertor target plates. The following observations can be made: a) very large flow velocities are observed in the HFS SOL for the two higher density cases, typically exceeding M = 1. Although it is currently not possible to measure flow velocities at the HFS mid-plane of ASDEX Upgrade, the very large values of the flow indicate that the divertor sink action accelerates the HFS SOL plasma to even higher velocities from what is already generated there by a combination of asymmetric ballooning transport and toroidal rotation [2]. b) Different behaviour is observed at the HFS SOL for each density case. At lowest and medium density the maximum flow velocity is reached approximately on the separatrix (figure 2a and 2b) although for lowest density the flow does not exceed M = 1. In the highest density level measured (figure 2c), a drop in the flow velocity is observed around the separatrix, to about M ~ 0.5. Taking into account the

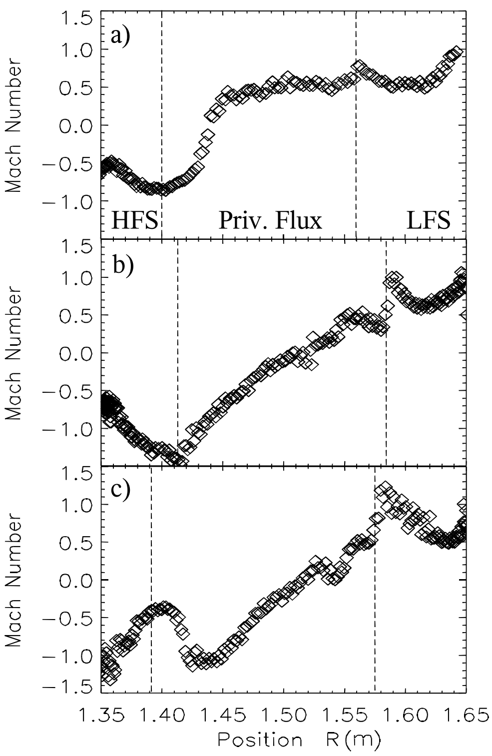

Figure 2: Flow profiles for the three density cases. From top to bottom: (a) $\langle n_e \rangle \sim 2.5 \cdot 10^{19}$ m^{-3}, (b) $\langle n_e \rangle \sim 3.5 \cdot 10^{19}$ m^{-3} and (c) $\langle n \rangle \sim 5 \cdot 10^{19}$ m^{-3}.

increased neutral density in the inner divertor (at these densities the inner leg is typically detached) this slowdown is most probably due to neutral friction caused by the enhanced recycling. c) In the private flux region the flow reversal occurs near the poloidal field minimum for the two higher density cases, with the flow directed towards the outer target plate in the LFS and towards the inner target plate in the HFS. The flow velocities at the HFS private flux reach supersonic values. In contrast, at lowest density the flow is predominantly oriented towards the outer target. The flow reversal occurs very near the inner separatrix and the flow velocity remains subsonic at approximately M ~ 0.5. Thus, in this case, the plasma flows mostly away from the target plates on the HFS private flux. This flow is probably driven by the in/out divertor asymmetry and not by the target plate sink action and is consistent with the pressure asymmetry observed in [4]. d) In all three cases, the plasma velocity approaches M ~ 1 near the LFS target plates and separatrix, with a decrease in between. This is not dissimilar to what is observed at the mid-plane for similar densities, where however the flow orientation is in the opposite direction, towards the inner divertor [5]. Finally, in the vicinity of the LFS separatrix, a sharp decrease in the flow velocity is observed in a narrow region ~ 2 cm thick.

4. Measurements from H-mode discharges

To minimize the power load onto the probe tips, a low-power lower single null H-mode discharge was employed, with 2.5 MW of NBI, low triangularity, $<n_e> \sim 6.7 \cdot 10^{19}$ m^{-3} central density, type I ELMs, ion **B**x∇**B** drift towards the x-point and with a slightly elevated x-point position to avoid close contact during the probe trajectory. As for the ohmic discharges, the voltage sweep was asymmetric to avoid the electron branch of the characteristics.

An example of the inter-ELM flow profile across a full probe trajectory is shown in figure 3. During ELM phases, transient flow reversals were observed in the HFS and LFS SOL as well as in the private flux region. These have been documented in [6] and will be discussed in detail elsewhere. In figure 3 they have been cut out. One observes in the profile that the Mach probe detects very large flow velocities, especially near the LFS target plates and around the HFS separatrix. The flow profile around the LFS separatrix is not that clear since, even with a probe sweep reaching -100 V, the ion current on the probe tips did not saturate in its vicinity. Compared to the ohmic discharges, the profile is observed to be more symmetric. In the LFS private flux, velocities are lower (M ~

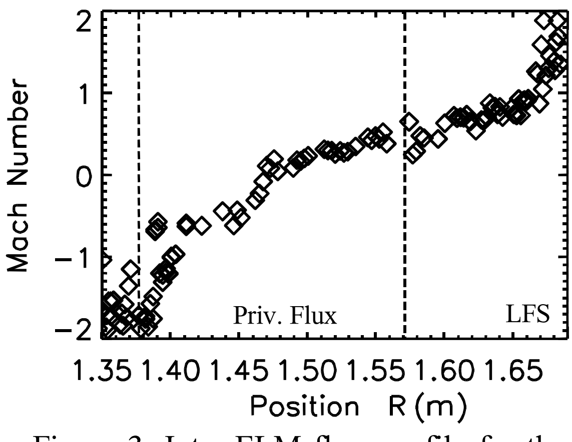

Figure 3: Inter-ELM flow profile for the H-mode discharge discussed in the text.

0.3) and the flow reverses very near the poloidal field minimum. In the HFS private flux, velocities are somewhat larger than in the LFS, but again exceed M = 1 only in a narrow region around the separatrix.

5. Discussion

Large variations have been shown to exist between divertor flow profiles in ohmic discharges of different densities, most visibly in the private flux and HFS SOL, where dominant flow regulating mechanisms are thought to be the divertor target sink action (which tends to accelerate the plasma to even higher velocities than at the mid-plane, typically exceeding M = 1), neutral friction (which tends to decelerate the plasma) and, in the private flux region, the in/out divertor pressure asymmetry, which can generate flows away from the target plates. Such flows could in principle aid impurities escape the target plate vicinity.

Concerning impurity deposition, one observes a correlation between the carbon deposition patterns observed in the ASDEX Upgrade divertor [7], [8] and regions where the enhanced flow velocity observed is combined with low temperatures (reducing sputtering). Although it is not possible to determine with the reciprocating probe if similar flow patterns persist at higher heating powers, it seems significant that there is a correlation and would suggest that fast (super-sonic) plasma velocities tend to bring impurities towards the divertor targets at an accelerated rate, enhancing impurity accumulation in these regions.

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