Density profiles and fluctuations in front of the ICRF antenna on the ASDEX Upgrade using X-mode reflectometry

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Introduction

A new multichannel reflectometer diagnostic (RIC) was recently installed in an ICRF antenna of ASDEX Upgrade (AUG), aiming mainly for ICRF coupling and operation studies [1]. This system also opens up research opportunities in the area of scrape-off layer (SOL) physics by exploring the high temporal and spatial resolution of the diagnostic and by taking advantage of the three channels installed at different poloidal locations (see figure 1c). This reflectometry diagnostic was designed to measure density profiles up to 2×10^{19} m $^{-3}$ in X-mode in the typical 1.5 T–2.7 T magnetic fields of AUG. The full frequency range is swept in 15 μs, generating an electron density profile every 25 μs simultaneously in 3 different poloidal positions. Besides its high sensitivity to density fluctuations, reflectometry also provides localized measurements. Therefore, taking into account its high temporal resolution, the RIC diagnostic can potentially be used to observe SOL density fluctuations. In this contribution, the capabilities of the RIC diagnostic are demonstrated in selected examples.

Experimental set-up

The SOL density profiles and fluctuations are measured in density ramp up discharges where the near SOL profiles flatten accompanied by increased filamentary transport. The profile flattening is associated with the enhancement of radial transport when the Greenwald fraction, f_{GW}, overcomes 0.5, where $f_{GW} = \overline{n}_{e,core}/n_{GW}$ and the Greenwald density, $n_{GW} = I_p/\pi a^2$ (where I_p and a are the plasma current and minor radius) [2, 3]. Two ohmically heated L-mode discharges #34283 (I_p = 600 kA) and #34290 (I_p = 800 kA) are performed to scan the Greenwald density. A magnetic field of B_t = - 2.0 T is chosen to maximize the RIC probing density range. The ion saturation current in the SOL is measured with the Langmuir probes mounted on the mid-plane manipulator (MEM), with the reciprocations shown in figure 1. Additional to the RIC, the electron density profiles are provided by the lithium beam diagnostic (LiB) every 100 μs [5]. Density ramps with maximum line-averaged core density $\overline{n}_e$ (measured by interferometry) in #34283 ($\overline{n}_e = 4.6 \times 10^{19}$ m^{-3}) and in #34290 ($\overline{n}_e = 6.0 \times 10^{19}$ m^{-3}) are achieved by D gas puffing. The gas is injected from the lower divertor area, preventing interference with the measurements of the diagnostics.

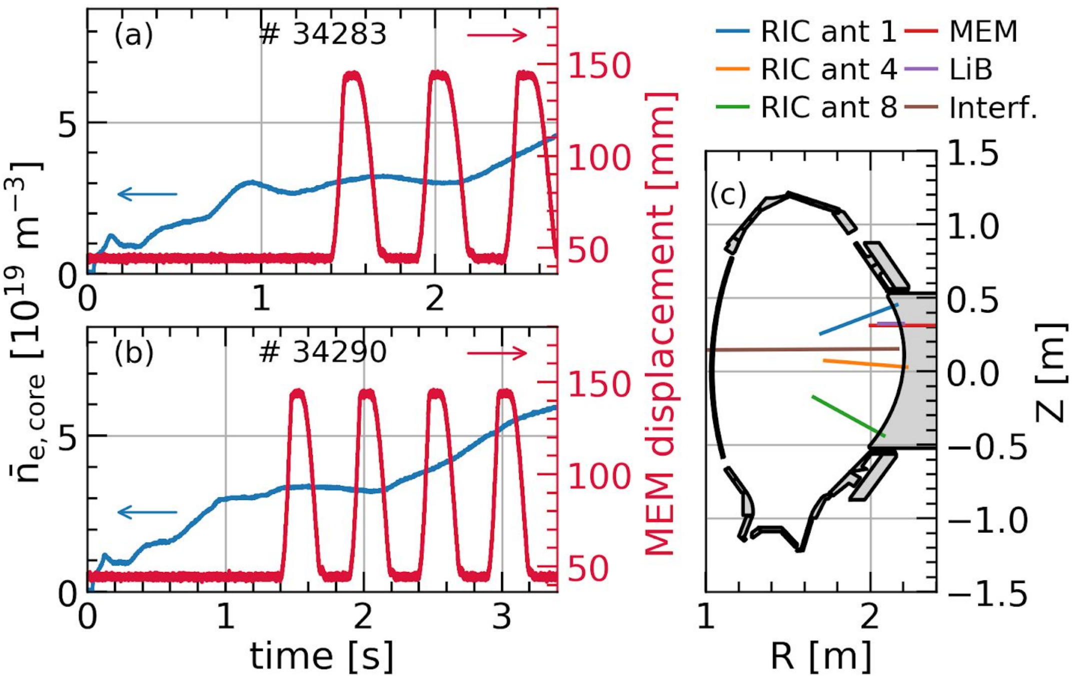

Figure 1. Left, Temporal evolution of line averaged core electron density (blue) and MEM displacement (red) for discharges (a) #34283 ($I_p = 600$ kA) and (b) #34290 ($I_p = 800$ kA) . Right (c), poloidal cross-section of AUG together with line of sights of: RIC antenna 1/4/8 (blue/orange/green), MEM (red), LiB (purple), core interferometry (brown).

Results

The electron density profiles measured by the different diagnostics and averaged over 10 ms are compared in figure 2 for discharge #34290. Two time periods with $\overline{n}_{e,core} \simeq 3.3 \cdot 10^{19}$ m^{-3} (left) and $5.0 \cdot 10^{19}$ m^{-3} (right) are presented. A constant electron temperature across the SOL of $T_e = 10$ eV is assumed. Calculated at the beginning of the probe plunge, LiB and RIC antenna 1 profile of the mean density are shown in solid lines. The

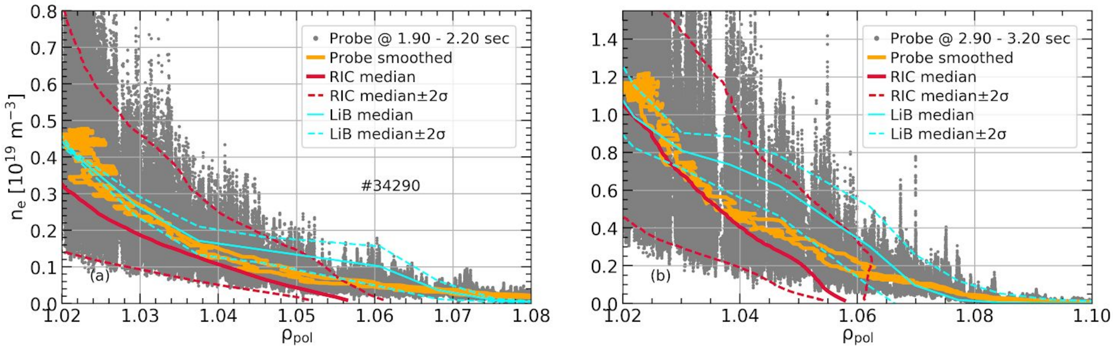

Figure 2. Electron density profiles calculated and averaged over 1 ms for discharge #34290 at two time periods, corresponding to $\overline{n}_{e,core} \simeq 3.3 \cdot 10^{19}$ m^{-3} (a) and $4.0 \cdot 10^{19}$ m^{-3} (b). The actual (gray dots) and smoothed over 5000 points (orange curve) MEM profiles are calculated over plunge periods: 1.9 - 2.2 sec (a) and 2.9 - 3.2 sec (b). LiB and RIC antenna 1 median density profiles, calculated at the beginning of the probe plunge, are presented as cyan and red solid lines correspondingly. The dashed curves indicate the median $\pm$ 2σ profiles.

dashed lines correspond to 2 times the standard deviation (σ) of the density fluctuations above and below the average profiles. As illustrated in figure 2, both the averaged SOL density and the amplitude of the fluctuations increase with core density as expected. A good agreement is observed between the profiles from the RIC, probes and LiB for both selected periods. RIC median $\pm$ 2σ profiles fit reasonably well the upper and lower boundaries of MEM density profiles and may represent the impact of fluctuation activity in plasma profiles. Differences in the amplitude of the fluctuations between the used diagnostics are most probably related with their different temporal resolutions, with larger fluctuations amplitudes naturally obtained for probes (2 MHz) and modest values obtained with LiB (10 kHz). A similar tendency is displayed in discharge # 34283.

As the line-averaged density is increased, a flattening of the SOL plasma density profile is observed to occur above a Greenwald fraction of about $f_{GW} = 0.45 - 0.5$ (see figure 3 left), in good agreement with previous results, suggesting an enhancement of the SOL radial transport [3].

The evolution of the density fluctuations levels from RIC and MEM profiles, estimated at normalized poloidal radius $\rho_{pol} = 1.04$, were also compared, revealing a reasonable agreement. However, fluctuation levels measured with RIC increase faster with line-averaged density than those obtained with the MEM, reaching values in the order of 40 to 90% in #34283 and of 40 to 70% in #34290 (see figure 3 right), above typical Langmuir probe measurements of 40 - 50% in both discharges.

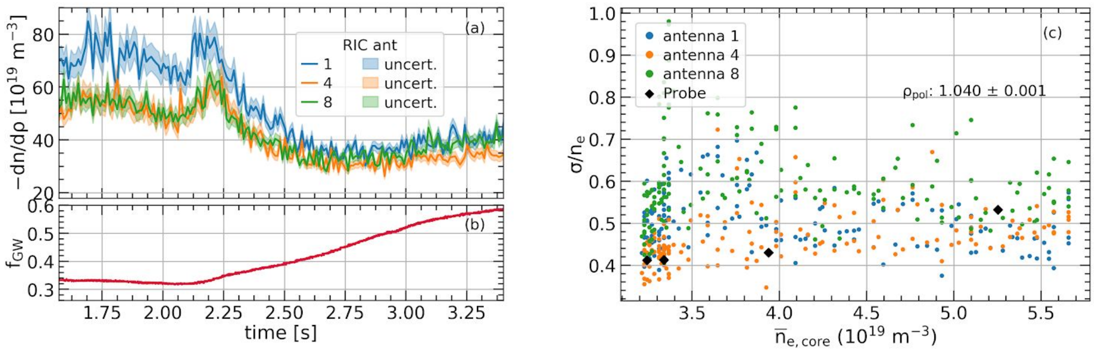

Figure 3. Left, on the top evolution of profile gradients (and statistical uncertainty) in discharge #34290, calculated between densities $0.75-1.25\cdot10^{19}$ m^{-3}, corresponding to the near SOL region; on the bottom, evolution of Greenwald fraction. Right, the fluctuation level estimated at $\rho_{pol}=1.04$ from RIC and MEM profiles in dependence on line averaged core electron density.

Conclusions

Plasma density profiles are measured by a new multichannel reflectometer system (RIC) with a temporal resolution of 25 μs in L-mode density ramp up discharges with plasma currents of 600 kA and 800 kA. Measurements show a good agreement with profiles obtained by the lithium beam diagnostic and the Langmuir reciprocating probe. A flattening of the RIC profiles is also observed, when the Greenwald fraction goes above $0.45-0.5$ level, as expected from previous results [3]. Density fluctuation levels in the range of 40 - 90% (600 kA) and 40 - 70% (800 kA) obtained with RIC were slightly larger than those measured by the Langmuir reciprocating probe. The dependence of the density profiles and fluctuation characteristics measured by the RIC on parameters such as plasma current, density, and magnetic configuration will be explored for L and H-mode conditions.

Acknowledgments

This work has been carried out within the framework of the EUROfusion Consortium and as part of the training in the framework of the Advanced Program in Plasma Science and Engineering (APPLAuSE, sponsored by FCT under grant No. PD/00505/2012). It has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053 IST activities also received financial support from “Fundação para Ciência e Tecnologia” through project UID/FIS/50010/2013 and grant PD/BD/114475/2016. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

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