Fast measurements of ion temperature fluctuations in COMPASS and Asdex Upgrade scrape-off layer

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Introduction

Turbulence in the Scrape-Off Layer (SOL) is a dominant mechanism for particle and energy losses from the confined plasma. Despite considerable long-term theoretical and experimental effort, the understanding of the turbulent processes is still incomplete. One of the missing ingredients are the measurements of the evolution of ion temperature, which is not routinely acquired at temporal resolutions sufficient to resolve the turbulent structures. Codes modelling the turbulent SOL transport such as ESEL[1] usually neglect the ion temperature and its fluctuations. Such cold ion approximations are in contradiction with measured profiles of T_i in SOL, which typically exceed those of T_e [2]. Recent modelling [3][4] with finite T_i showed that ion temperature influences drift wave growth rate and filament propagation speed.

In this paper we present the first fast measurements of T_i fluctuations in the COMPASS and Asdex Upgrade (AUG) tokamak SOL, obtained by a new diagnostics, the E×B analyzer [5][6]. The analyzer consists of an entrance slit, which is negatively biased and as such repels electrons but allows ions to pass inside a cavity, where two planar electrodes biased at potentials V_{top} and V_{bottom} create an electric field $E = (V_{top} - V_{bottom})/d$ (d is the distance between the electrodes). This field combines with the local tokamak magnetic field, B_{loc}, and results in an E×B drift, which is deflecting ions from line-of-sight trajectory of length L towards an array of 12 collectors on the back plate of the cavity. The ion displacement is inversely proportional to their parallel velocity, $v_{||}$.

$$\Delta_x = \frac{E}{B_{loc}} L \frac{1}{v_{||}}. \tag{1}$$

During the experiment, the collector currents are measured and transformed to velocities using equation (1). The ion temperature is then reconstructed by a fit to the tail of the velocity distribution function. When tail of the distribution was dispersed on only 2 collectors, the ion temperature was calculated directly by using formula

$$T_i = \frac{m_i E L}{2eB_{loc}} \left(\frac{1}{\Delta_x^2(a)} - \frac{1}{\Delta_x^2(b)} \right) / log \left(\frac{I_{col}(b)}{I_{col}(a)} \right), \tag{2}$$

The measurement does not involve any sweeping and therefore the temporal resolution is only limited by the frequency of the data acquisition system or frequency of induced noise.

Experiment on COMPASS

E×B analyzer measurements were performed during the flat-top of a single lower-null L-mode discharges with B_T = 1.15 T and I_{plasma} = 160 kA. The analyzer was mounted on the reciprocating manipulator at the outer midplane and used both in reciprocating and fixed position modes during a series of discharges with varying plasma density. Due to the presence of high-frequency noise the time resolution of the T_i reconstruction was limited to 50 μs. An example of the distribution of acquired ion temperatures at low density discharge #7114 (central line averaged density $n_e = 3 \times 10^{19}$ m^{-3}) is shown in Fig. 2A, the entrance slit was located 17 mm outside the separatrix position (calculated by EFIT). Only samples with relative errors of the fit lower than 50% were considered for the analysis. The distribution shows non-Gaussian intermittent nature of the fluctuations. Despite the low mean temperature at 24 eV, 8% of fluctuations show temperatures larger than twice this value. In a similar discharge #7027, the Ball-pen probe head measured electron temperature 28 eV at the separatrix and 10 eV at the same radial position as the E×B analyzer. Although there is some trend of increasing T_i with increasing J_{sat} measured by the entrance slit (see Fig. 2B), the correlation coefficient is only 0.24. The relatively low temporal resolution of the T_i reconstruction could introduce mixing between the background plasma and intermittent blobs, which would deteriorate the correlation between T_i and J_{sat}.

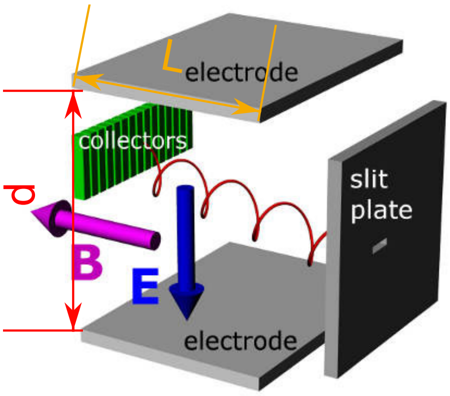

Figure 1: Schematic view of the E×B analyzer.

Experiment on AUG

The E×B analyzer was mounted on the midplane reciprocating manipulator, with multiple reciprocations during a single lower-null discharge #30560 (B_T = -2.45 T, I_{plasma} = 800 kA) heated by 0.4 MW of ECRH. Two strokes at t=2.1 and t=3.1s during the L-mode phase with

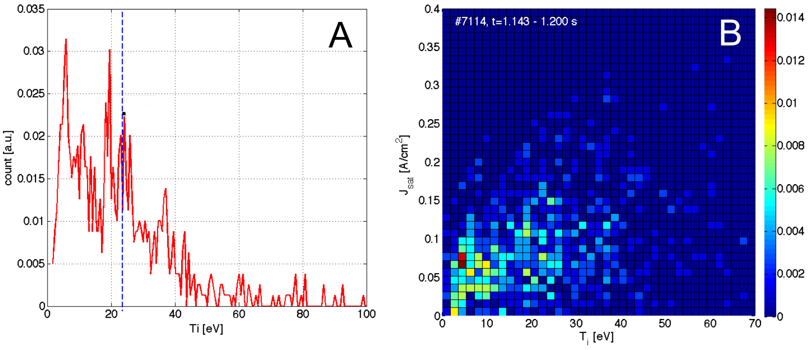

Figure 2: A: Distribution of measured T_i in COMPASS discharge #7114 ($n_e = 3 \times 10^{19}$ m^{-3}). B: T_i correlation with J_{sat}.

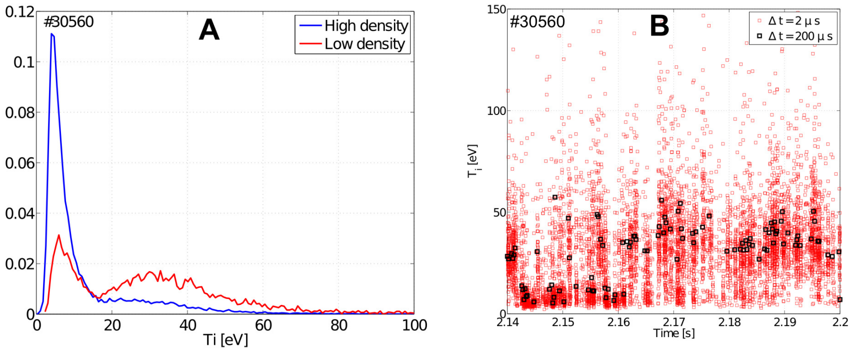

Figure 3: A: Histogram of measured T_i at low ($n_e = 3.9 \times 10^{19}$ m^{-2}) and high ($n_e = 5.0 \times 10^{19}$ m^{-2}) line integrated central density. B: T_i measurements at AUG averaged over 2 μs (red) and 200 μs (black) samples.

density ramp were used to obtain T_i at line integrated central density $n_e = 3.9 \times 10^{19}$ m^{-2} and $n_e = 5.0 \times 10^{12}$ m^{-3} respectively. The data were obtained during the maximum of the reciprocation, when the slit was located 60 mm outside the separatrix (within the limiter shadow). Since the pickup noise on AUG is minimal, the T_i measurements were acquired at 2 MHz and averaged over 2 μs samples. The high temporal resolution is important to obtain T_i fluctuations. Fig. 3B shows that although the mean value of measured T_i is not significantly influenced by the sampling rate, the high temporal resolution reveals samples with high T_i, which may act differently ie. during the plasma-wall interaction.

The distribution of measured T_i samples shown in Fig. 3A shows presence of two distinctive ion populations. The cold ion population has a mean $T_i \sim 5$ eV, while the hot ion population has mean temperature around 30 eV. We can attribute the low temperature population to ions originating from plasma fueling and the hot population to ions transported by turbulence from

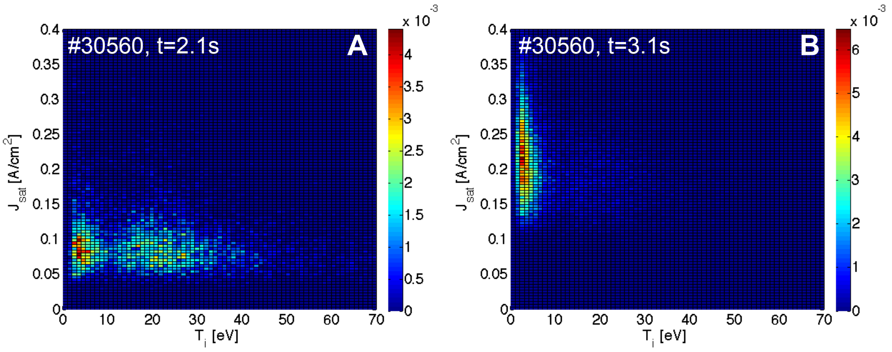

Figure 4: J_{sat} versus T_i during low and high density.

the separatrix. The same feature can be observed in COMPASS in Fig. 2, however due to worse time resolution it is less apparent. The ratio of the two population changes during the density ramp-up, which corresponds to more intensive fueling during the second stroke. The correlation of T_i with J_{sat} (as shown in Fig. 4) is not pronounced for neither of the two populations

Conclusions

We have obtained measurements of ion temperature fluctuations in SOL during L-mode plasmas in tokamaks COMPASS and AUG. The fluctuations are in general non-Gaussian, with high-energy tail, which is not usually taken into consideration for the plasma-wall interaction. The correlation between T_i carried by turbulence filaments and J_{sat} was found to be weak in both tokamaks. Measurements at AUG showed presence of two ion populations with distinctive temperatures, which can be attributed to ions carried by turbulence from the separatrix and ions from fueling. The ratio of the populations changes with density.

Acknowledgements

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