First results from the thermal helium beam diagnostic at ASDEX Upgrade

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Line ratio spectroscopy on thermal helium is a diagnostic method allowing the determination of electron density (n_e) and electron temperature (T_e) simultaneously [1,2,3,4]. The line ratio of two singlet transitions is mainly dependent on density, while the ratio of a singlet and a triplet transition is dominantly dependent on electron temperature. Evaluable signal of He I line radiation can only be collected in plasmas restricted to certain combinations of density and temperature. At the low end of both quantities the signal is too weak due to the low excitation rate and towards higher electron densities and temperatures the neutral helium density is strongly attenuated. Such a diagnostic has recently been implemented at the tokamak ASDEX Upgrade. It is very well suited to investigate the plasma edge, with the measurable radial region from the far scrape-off layer (SOL) to the near SOL and in low density cases even across the separatrix into the confined region.

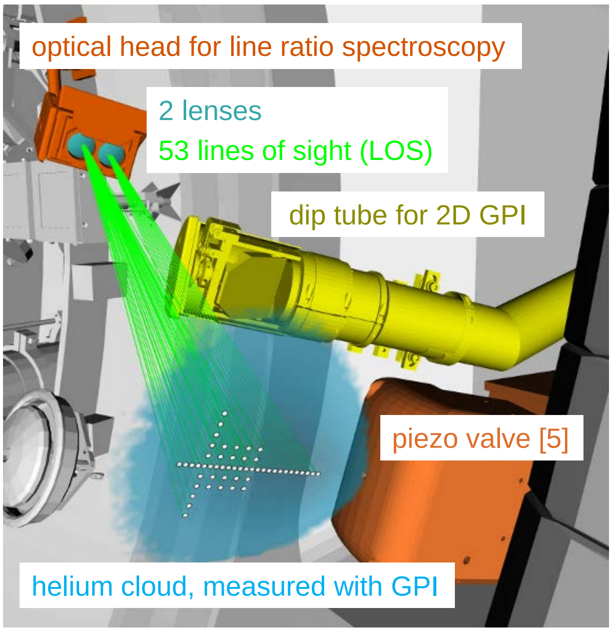

Figure 1: CAD drawing of the piezo valve, the optical head for line ratio spectroscopy and the dip tube for 2D GPI in Sector 13 of ASDEX Upgrade. The lines of sight (green) cross the He gas cloud (blue) at the white dots.

A piezo valve [5], mounted at the vessel wall very close to the plasma is used to inject neutral helium into the plasma. As shown in figure 1, the lines of sight, optimised for radial resolution (~ 4 mm), cover a radial range of 8 cm in the plasma edge region, with additional ones for poloidally resolved measurements. The helium gas cloud can simultaneously be observed with the dip tube for 2D gas puff imaging (GPI) [6] using a camera with a high frame rate. The line resolved emission intensities of four He I lines are measured simultaneously with a newly developed 32 channel polychromator system, based on dichroic mirrors, narrow-band interference filters and linear array photomultiplier tubes [7]. With a data acquisition rate of 900 kHz this diagnostic provides not only a good spatial but also an excellent temporal resolution.

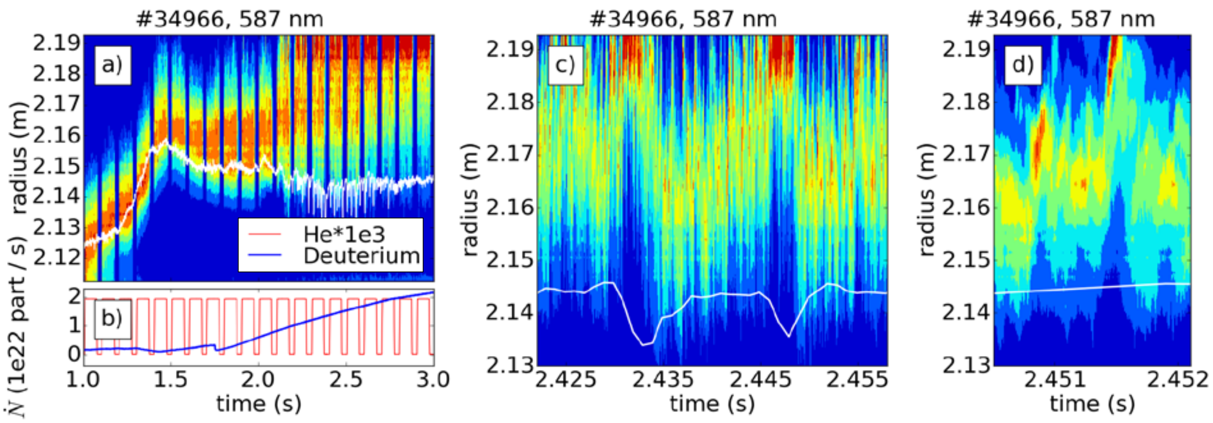

Figure 2: a) Intensity contour of He I at 587 nm versus time (x-axis) and mid-plane radius (y-axis) together with the separatrix position (white line). b) Deuterium fuelling rate (blue) and He gas puff (red). c) 30 ms temporal zoom of a) around 2.44 s. d) 1.5 ms temporal zoom of a) around 2.451 s.

Figure 2a) shows the temporal evolution of the radial intensity profile of the He I transition at 587 nm, compared to the separatrix position which is indicated as a white line. The ASDEX Upgrade discharge #34966 (I_p = 800 kA, B_T = -2 T) is in L-mode until t = 2.03 s, followed by an I-phase and H-mode with a first ELM at t = 2.143 s. At the same time the density is increased via a D_2 gas puff ramp depicted in figure 2b), where also the He gas puff is shown, which is chopped allowing for background subtraction. The maximum in the intensity profile follows closely the position of the separatrix until 2.2 s, and there is enough signal to determine the profiles of n_e and T_e also inside the separatrix. At higher densities, however, the signal maximum shifts further out into the SOL, and finally the He beam is excited already in the far SOL and consequently attenuated, so that the profiles cannot be determined up to the separatrix. Figure 2c) shows a temporal zoom into the same signal at around t = 2.44 s, including two edge localised modes (ELMs). ELMs eject filaments that increase the density in the SOL up to the first wall, where the maximum helium emission can be detected. In between ELMs the plasma is not quiescent in this case, but smaller filaments can be seen to cross the He gas cloud, also indicated by the increased He emission in the far SOL. In figure 2d) an even higher temporal magnification of the signal is shown, demonstrating that the radial velocity of filaments, here visible as inclined structures can be determined.

In the following we will show an example of fast profile measurements during the I-phase of this discharge #34966 and in a second example the results of the analysis of radial propagation velocities of filaments measured in a different discharge with stationary phases necessary for the statistical analysis.

The measured line ratios can be mapped to n_e and T_e values locally, via a collisional radiative model using ADAS data [4, 8] and stationary assumptions. Figure 3 shows n_e and T_e profiles evaluated with the stationary collisional radiative model.

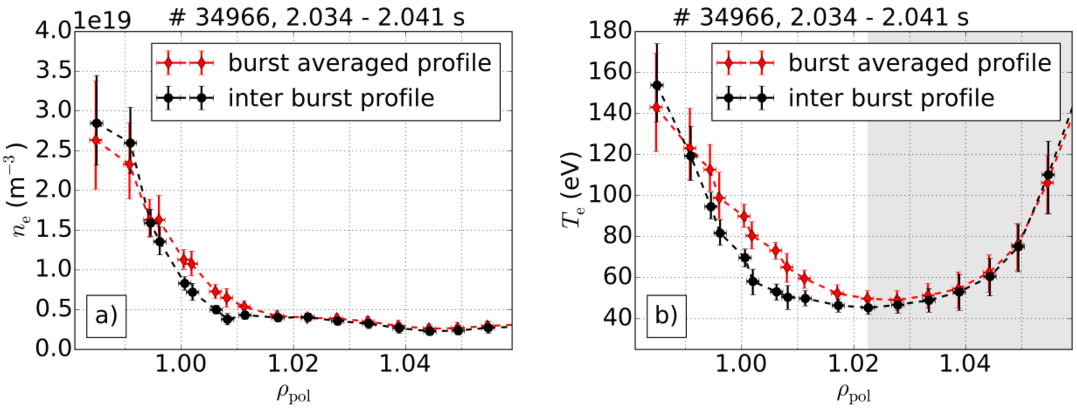

Figure 3: Profiles of a) n_e and b) T_e measured during the I-phase of #34966. The profiles averaged over bursts (red) are compared to profiles in between bursts (black). The grey shaded area in b) marks the radial region where life-time effects of the excited triplet state become important.

In the very far SOL this model is not valid, because the life-time of the excited states of the triplet state can be long enough so that the flight time of the excited He atom must be taken into account [9]. While the density profiles are not affected by life time issues and agree very well with the density profiles from the lithium beam [10] and the Thomson scattering diagnostic [11], the temperature profiles are not correct in the far SOL, i.e. beyond ρ_{pol} = 1.023 the case shown in figure 3b), marked as grey shaded area. At higher densities this effect becomes negligible. The two different profiles shown in figure 3 are averaged profiles in the I-phase of discharge #34966. I-phases are characterised by bursts [12] of increased transport across the separatrix, typically with frequencies around 1 - 2 kHz. The comparison of profiles during such bursts (red) and in between bursts (black) shows that bursts flatten both n_e and T_e gradients at a pivot point just inside the separatrix and lead to an increase of n_e and T_e in the near SOL, very similar to ELMs.

The determination of filament velocities can be done with the intensity of the line emission signal alone and is thus independent of the evaluated n_e and T_e profiles. To demonstrate this, the stationary phases of discharge #34867 (I_p = 800 kA, B_t = -2.5 T), one in L-mode lasting around 500 ms and one in H-mode lasting 1.5 s with an ELM frequency around 100 Hz was used to analyse radial velocities of filaments. Filaments were selected when the intensity of a channel in the far SOL exceeded a critical value. Their velocity was then determined via the temporal shift in neighbouring channels determined by correlation analysis. Figure 4 shows the radially averaged velocities in the form of normalised probability distributions. In figure 4a) the filament velocities of L-mode (red) and inter-ELM filaments in the H-mode phase (black) have very similar velocity distributions, peaking around 0.3 km/s, while the filaments ejected during ELMs have much larger velocities peaking around 1.4 km/s (figure 4b), blue), with a significant number being twice as fast. The obtained values are in good agreement to previous investigations for radial inter-ELM filament velocities [13, 14] and ELM filament velocities [15].

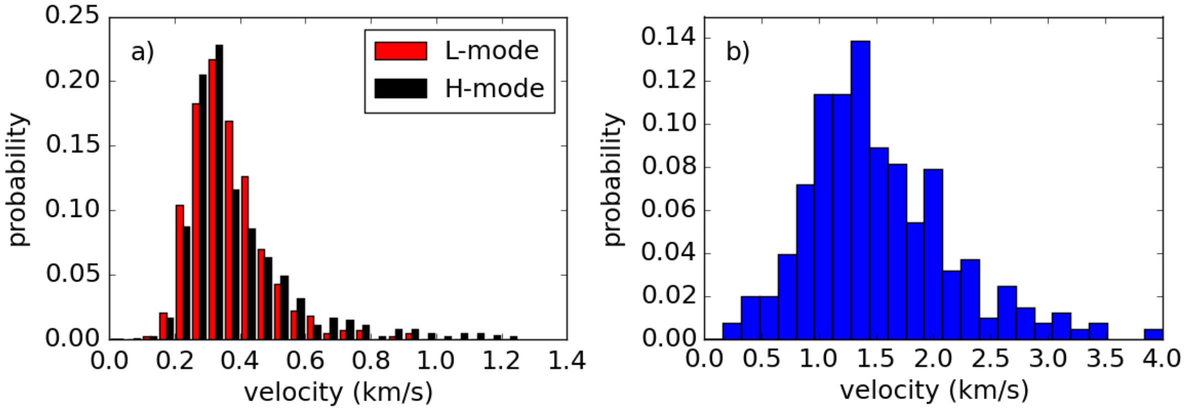

Figure 4: Normalised probability of the radial velocity of a) L-mode (red) and inter-ELM H-mode (black) filaments in discharge #34867 and b) ELM filaments crossing the helium cloud in the SOL.

The newly installed helium beam diagnostic at ASDEX Upgrade can provide fast n_e and T_e profiles from inside the separatrix across the whole scrape-off layer. The region with the best signal depends on the density profile, given a minimum T_e of 5-10 eV, and is usually around 4 cm wide. At low densities the confined region is accessible, while at high densities the signal will be sufficient only in the far SOL. Because of the high spatiotemporal resolution not only changes in profiles can be determined but also the propagation velocity of fast transient events such as bursts and blobs can be measured.

During the next campaign, the sensitivity of the diagnostic to calibration uncertainties will be tested. As the transmission of the in-vessel optics might change during a campaign differently for different wavelengths, this effect will be closely observed. Moreover, a collisional radiative model will be implemented in the framework of Bayesian probability theory so that the diagnostic can be included in the integrated data analysis of profiles [16] on ASDEX Upgrade.

References

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