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Measurements of Electron Density Fluctuations in the Scrape-Off Layer (SOL) and Edge Plasma of the Stellarator Wendelstein 7-AS by means of Lithium Laser Blow-Off

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Introduction

The injection of atomic lithium beams by laser blow-off (LBO) has been used for many years to determine the electron density profiles in SOL and edge plasmas [1]. The spatial resolution of an atomic beam diagnostic in its direction of propagation is determined by the velocity of the atoms and the equilibration time of the involved atomic processes. In the case of Li-LBO the spatial resolution in direction of propagation is about 2 mm. By using slower Li atoms from a thermal source as in [2], one can further improve the spatial resolution, but the penetration depth is drastically decreased. On the other hand, a high energetic Li beam as the one used in [3] has a significantly higher penetration depth but a much poorer spatial resolution (1–2 cm). The LBO beam is therefore the best compromise between spatial resolution and penetration depth for the investigation of the spatial structure of electron density fluctuations which have typical correlation lengths of 5–15 mm in radial and poloidal direction. The short duration ($\leq$ 300 μs) of the individual pulses and the strong time dependence of the Li flux, however, limit their use for the analysis of the temporal development of the fluctuations or their frequency range.

Experimental Set-Up

For the measurements that are discussed in this paper, a repetitive LBO system was installed on the high field side in the equatorial plane of the Wendelstein 7-AS stellarator. The pulses of a XeCl excimer laser with a pulse energy of 300 mJ and a wavelength of 308 nm were focused on a LiF coated quartz target. The laser energy was absorbed by the coating which in term was atomized and accelerated into the plasma. The velocity of the atomic beam was in the order of 10^4 m/s which corresponds to a kinetic energy in the order of a few eV.

The region of interaction between the Li atoms and the plasma could be observed simultaneously by a radial array of 8 photomultipliers that were sampled with 1 MHz and a 2D-camera for profile measurements that took an integrated picture of the blow-off pulse.

Data Evaluation

Figure 1 shows the timetrace of a photomultiplier signal for a LBO pulse. Only the part between the vertical lines was used for further evaluation.

To take the temporal variation of the Li flux into account, a 2$^{\text{nd}}$ order polynomial was fitted to the time trace. This polynomial was used as measure for the actual Li flux. To eleminate the influence of this flux, the time trace was normalized to the polynomial. From the resulting curve, its mean – which was close to 1 – was subtracted so that the processed signal had a mean of 0 and its fluctuations were assumed to be either statistical noise or caused by plasma fluctuations. However, to be sure that the remaining influence of the variations of the Li flux was negligible, we have closely checked the correlation functions (see below). From the resulting time traces spatiotemporal correlation functions were calculated for every blow-off pulse and the correlation functions of the different pulses were averaged. To get good statistics, it was necessary to average the correlation functions from several discharges.

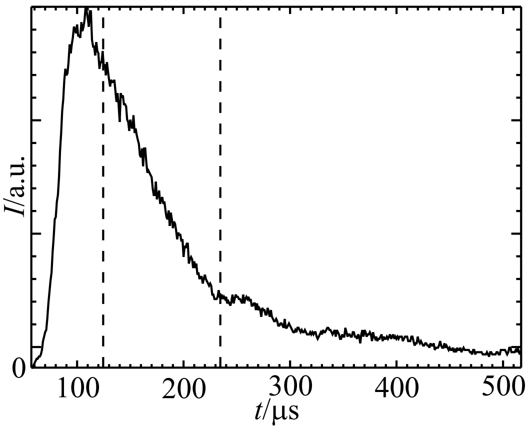

Figure 1: Time trace of a photomultiplier signal for a LBO pulse.

Experimental Results

Figure 2 shows the autocorrelation functions from two radial channels, one inside and one outside the LCFS. The minima of the auto correlation function in figure 2 (a) and its rise for $|\tau| > 20\ \mu$s are an artefact of the evaluation procedure. The difference in shape of

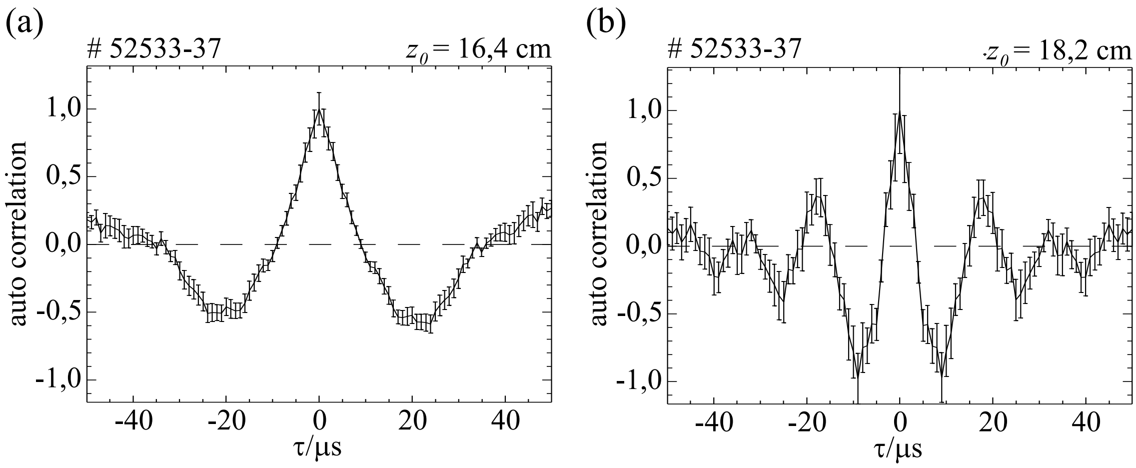

Figure 2: Auto correlation functions for two radial channels: (a) in the SOL, (b) in the confinement region.

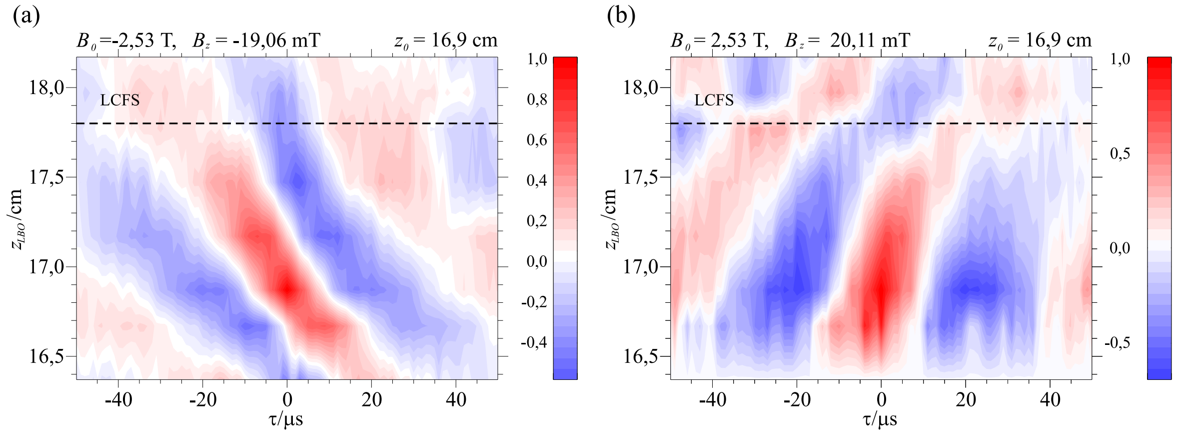

Figure 3: Spatiotemporal correlation functions of Li-LBO signals for different directions of the magnetic field as function of the beam coordinate z_{LBO} (atoms propagate in direction of the positive z_{LBO}-axis towards the plasma center). The position of the last closed flux surface LCFS was calculated by means of the TRANS-code.

the functions in figure 2 (a) and (b), however, is real and seen in many discharges. The auto correlation functions of Mirnov coil signals show a wavelike structure with a period comparable to the one shown in figure 2 (b). A similar observation has already been done in measurements with a high energetic Li beam [3]. The period reported there, however, is significantly higher. The reason for this can be that those measurements were carried out before the installation of the divertor. Since then, the signals of the high energetic Li beam don't show those wavelike structures anymore. This can be due to the generally decreased fluctuation level.

Figure 3 shows the spatiotemporal correlation functions of Li-LBO signals as a function of the beam coordinate z_{LBO}. The red regions represent the structures that are strongly correlated with the reference channel z_0 which was chosen to be outside the LCFS in both plots. Obviously the structures have a different orientation on both cases which translates in a reversal of the observed radial velocity v_r. From this, one can conclude that these structures are caused by plasma fluctuations and not artefacts that are transported by the Li beam. Additionally, the radial velocity one can derive from these strucures is in the order of 400 m/s which is significantly lower than the velocity of the injected atoms. Experiments with Langmuir probes show that the radial velocity v_r of potential fluctuations which is estimated by means of a purely radial diagnostic is determined by the projection of the poloidal movement of structures that are inclined in the radial-poloidal plane [4]. There, the authors discuss two mechanisms that can lead to such an inclination. They suggest that these strucures should be inclined either as result of the sheared poloidal E×B-drift or the local magnetic shear. According to the first mechanism, the observed radial velocity v_r is not expected to change if the magnetic field is reversed but according to the latter it is. As v_r in figure 3 (b) is clearly reversed compared to figure 3 (a), the second mechanism seems to be decisive for the orientation of thoses structures.

The absolute value of v_r for both directions of the magnetic field is different. Assuming that the absolute values of all velocities do not depend on the direction of the magnetic field one can seperate two contributions to v_r. One that alters its direction when reversing the magnetic fields and one that does not. In this case, one sees that the dominant component changes its direction together with the magnetic field and — according to the mechanism summarized above — is, therefore, caused by the projection of a poloidal movement. This is in agreement with the observations reported in [4].
In the SOL, v_r is observed to have a density dependence as shown on figure 4.
As the observed radial velocity is influenced by the poloidal movement of structures that are inclined in the radial-poloidal plane, its variation with $\int n\, dl$ can have several reasons: the inclination of the structures, the poloidal E×B-drift velocity or the minor contribution of v_r that does not reverse its direction could change.
From the data we have, we cannot decide which of these possibilities cause the rise of v_r with decreasing density.

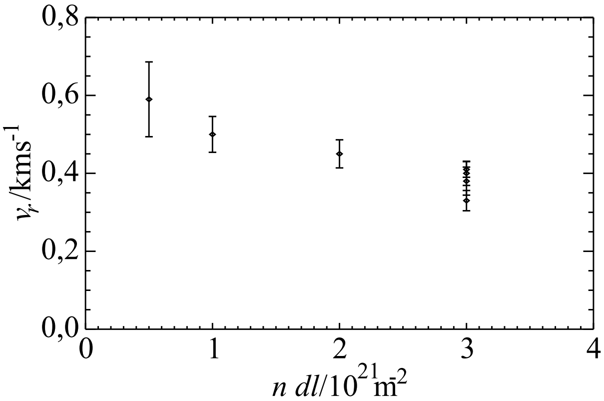

Figure 4: Dependence of the measured radial velocity on the line integrated density $\int n\, dl$.

Summary

A repetive LBO system has been used for measurements of the fluctuations of the electron density. Compared to other atomic beams, this diagnostic combines good radial resolution with high penetration depth which makes it well suited for the investigation of spatial structures. The short length of the pulses on the other hand limits its use for measurements of temporal developments. By comparison of our results with those from other diagnostics, we could draw conclusions on the structure of the fluctuating cells.

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