Mode characterization using Lithium beam emission spectroscopy on the EAST tokamak

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Introduction

The Lithium beam emission spectrocopy diagnostic (LiBES) injects accelerated Lithium atoms to the plasma. They are excited or ionized at the SOL-edge region. The excited states decay, which is accompanied by emission of photons at around 670.8 nm wavelength. From the spatial distribution of this light the plasma electron density can be deduced [2]. Additionally, perturbations in the density modulate the level of detected light which allows one to study structures at the outer region of the plasma.

A LiBES diagnostic on the EAST tokamak is optimized to investigate fast processes [1]. Its injector accelerates a few milliAmps of Li atoms by 50 kV voltage and then neutralizes them. The gained energy is enough for the atoms to penetrate 10-20 cm deep in the plasma. The light emission of the beam due to collisions with plasma particles is typically the highest around the pedestal top: ahead of the light profile peak the collisional excitation is lower and beyond it the number of Li atoms decreases due to ionization. The emitted beam light is directly imaged via a high throughput optical system to a camera built up from 32x4 APD detectors in the radial-poloidal plane having around 1 cm spatial resolution along the beam. The data is acquired at 1-2 MHz sampling frequency. A signal-to-noise ratio of 60 is typically achieved.

Several parameters can be extracted from the data recorded by a LiBES, e. g. fluctuation and flow properties of turbulent structures, plasma electron density profile in the SOL-edge region. The determination of the latter one is an inverse numerical problem and thus not only the measurement data is used but also *a priori* information: the density profiles should be smooth and monotonic. The calculation is carried out in a Bayesian framework, which fits smooth light profiles to the noisy data via smooth and monotonic density profiles and the fitted light profiles deviate from the measurement data with the error levels. This contribution aims to demonstrate the capability of the LiBES-based density recontruction via several examples in submillisecond timescale carried out on high SNR signals.

Density reconstruction on different timescales

As a first step the method is validated by comparing the reconstructed profiles with density distributions measured by a reflectometer system. Two profiles, one in L-mode and one in ELM-free H-mode are shown in Fig. 1. The data were recorded with slow chopping, i. e. the beam was chopped off after 4 ms of measurement for 1 ms in order to measure and subtract the background light emission. The inversions were done from light profile averages over the entire 4 ms long periods. The vertical black and red lines show the EFIT separatrices and the vertical magenta line depicts the limiter position. The profiles measured by the two diagnostics are similar both in L-mode and H-mode from the aspect of pedestal height and differ only by approximately 1 cm in pedestal position. The deviation in pedestal gradient may originate from the LiBES oversmoothing due to the finite field-of-view of the observation system, which is currently not included in the code.

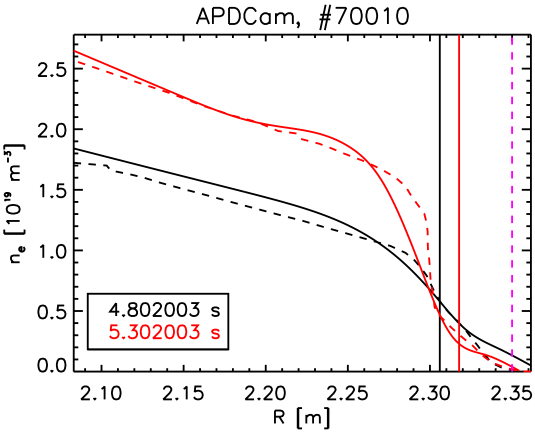

Figure 1: *Comparison if LiBES and reflectometer density profiles, black: L-mode, red: H-mode. Solid: Li-BES, dashed: reflectometer.*

The second example (Fig. 2) shows nine consecutive LiBES profiles each averaged over 100 μs. This measurement was carried out in H-mode when the plasma edge was manipulated with RMP coils. Here the 4 millisecond long beam on period was divided into pieces to get the time resolution. ELM event did occur neither during the depicted time period nor in the neighboring 1 ms long backgound measurement periods. The light profiles revealed approximately 1 channel movement of the peak back and forth while the position of the bottom parts of the profiles were not

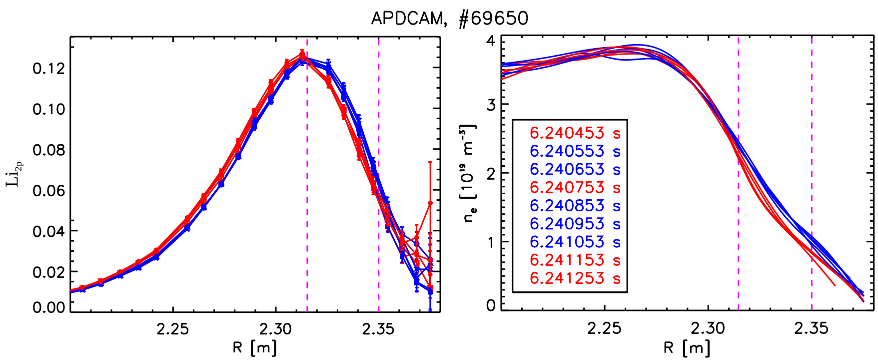

Figure 2: *Demonstration of density profile shape modulation in an interELM H-mode plasma during RMP application. 9 consecutive frames, 100 μs time average each. Slow chopping. Left: measured light profiles, right: reconstructed density profiles.*

moving. The red curves denote the profiles at deeper peak positions and the blue ones show the cases when the peaks were at a higher radius. (This color code was selected arbitrarily.) The corresponding density profiles show that this behaviour is related to changes in the pedestal shape around its bottom-middle part. The vertical dashed magenta lines denoting the EFIT separatrix and limiter positions may not be relevant due to the deformation of plasma column by RMP operation. (The limiter is on the opposite side of the torus.)

In the third example the measurements were done in fast chopping mode. In this case the beam was moved out of the observation volume for two μs after each 2 μs of measurement. This way background subtraction, Li emission calculation and density profile determination became possible even on such fast timescales. The method is necessitated by the EAST environment where the background is highly influenced by the interaction between the ELMs and the Lithium-handled wall. The top graph of Fig. 3 shows the reconstructions in a 400 μs long time interval recorded in an ELMy H-mode shot. Here the outer magenta line denotes the recontructed density at the limiter and the inner one the density at the EFIT separatrix. Shift in the real separatix position by a few centimeters is probable in this case. However, the curve, located in a fixed spatial position and in the middle of the pedestal at the beginning of the time period, can highlight the changes in the pedestal properties. Namely, the appearance of 3 periods of an oscillation 70 μs before the ELM onset. This modulation is detailed in the bottom graphs of the same figure. Here the red lines denote the phases where the density had maxima and the blue lines show the opposite phases at minimum density. The light profiles can be seen in the left graph and the reconstructed densities on

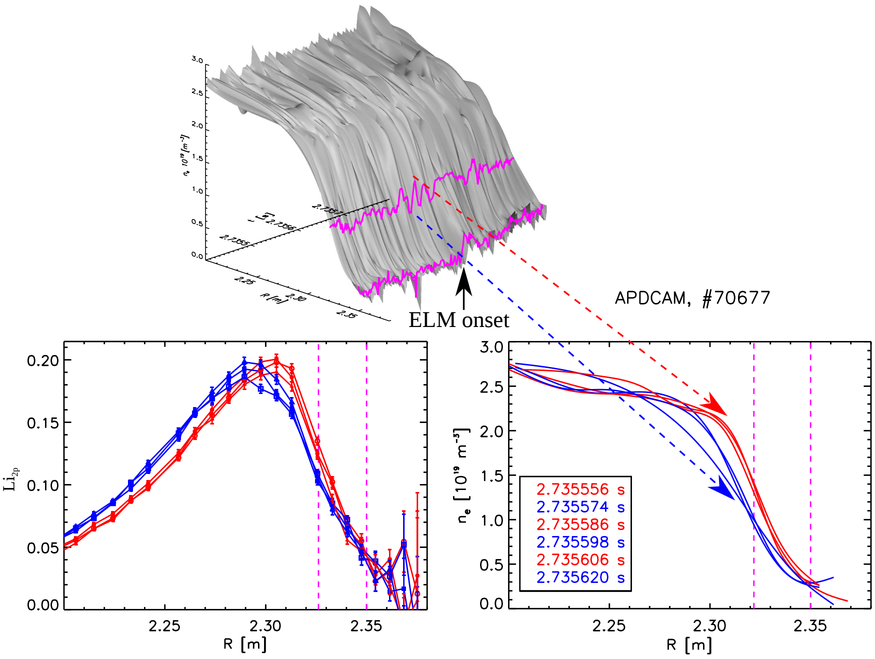

Figure 3: *Demonstration of density profile position modulation preceding the ELM onset. Top: profiles in a 400 μs long time period, bottom: oscillations highlighted. Fast (250 kHz) chopping. Bottom left: measured light profiles, bottom right: reconstructed density profiles.*

the right. The plots suggest that the position of the entire light and thus density profile oscillated in this case. The ELM onset can be observed as a sharp increase of the density in the SOL about one time period after the last period of the oscillation.

Low-amplitude pedestal density modulations in the 20-50 kHz frequency range are typical in the interELM periods of EAST [3]. An attempt is made to localize these oscillations: density profiles were reconstructed in an 50 ms long timerange and the APSDs of the density and the light signals were calculated. The spatial distribution of the fluctuation amplitudes in the 25-35 kHz range is depicted in Fig. 4. Here the calculation results are not reliable at high radius due to the effect of ELMs (the measurements were carried out in slow chopping mode) and inside because of the decreasing sensitivity to fluctuations behind the light profile peak [4]. The oscillation peak in the middle of the pedestal in both density and light, the second peak at the pedestal top only in density (this corresponds to the light profile peak where the fluctuations do not have light response) and the minimum in fluctuations at $R = 2.26m$ suggest that the fluctuations are localized to the pedestal middle-top and have a complex spatial structure. Numerical tests will be carried out in the near future to justify thes conjecture.

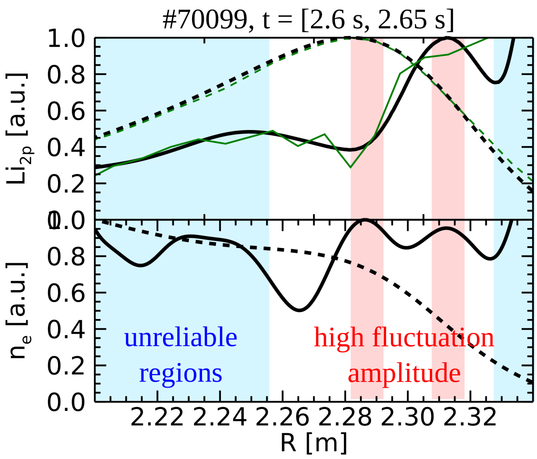

Figure 4: *Pedestal fluctuations in the 25-35 kHz freqeuncy range. Solid: fluctuations, dashed: profiles. Top: light, bottom: density. Black: reconstructed, green: measured.*

Summary

The contribution demonstrates that SOL-edge electron density profile measurement on a 10 μs timescale is possible and reveals details of ELMs and other key phenomena.

Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement number 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

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