Statistical analysis of the oscillations preceding ELM instabilities

S. Zoletnik[1], L. Zsuga[1,2], TEXTOR Team[3]

[1] *Wigner Research Centre for Physics, Budapest, Hungary*

[2] *Budapest University of Technology and Economics, Budapest, Hungary*

[3] *Institute of Energy and Climate Research, Forschungszentrum Jülich, Germany*

Introduction

Former Lithium Beam Emission Spectroscopy (Li-BES) measurements in limiter H-mode plasmas on TEXTOR[1] showed the appearance of growing oscillations before ELM instabilities[2]. These precursor structures were noticeable only in the middle of the pedestal region a few 10 μs-s before ELMs with about 40kHz frequency. With the purpose of getting more information on the connection of ELM triggering and precursor structures a statistical analysis of Li-BES measurements on TEXTOR are presented in this paper. The ELM frequency in these TEXTOR discharges is around 1 kHz and they are likely type III.

Measurement technique

The measurements were made with the 35 keV Lithium beam diagnostic[3]. At the edge of the plasma the beam light emission is nearly proportional to the local electron density, thus these measurements can give information about density changes in the pedestal region. The light signals were measured by 16 Avalanche Photodiode (APD) detectors with 1 MHz analog bandwidth and 2.5 MHz sampling rate. The APDs measure the light signal with 1 cm radial resolution. The signal to noise ratio was in the 10-20 range. Although the APD system uses a 2 nm narrow band optical filter the background light can be substantial, especially during ELMs. To separate the background from the beam emission the fast chopping technique[3] was used which modulates the beam with 250 kHz. Averaging the signal in the beam-on and beam-off times one gets both the background, and beam+background signals with 4 μs time resolution. After interpolation the background can be subtracted thus a clean Li-beam signal is obtained with 4 μs time resolution. Channels from 9 to 14 examined the pedestal area and the Scrape off layer as shown in *Fig.1a*. The effect of ELMs on the measurement signals deeper in the plasma was negligible.

Detecting ELMs in the signals

The background light emission increases during ELMs because of the increased plasma-wall interaction. This change allows us to locate the starting time of ELMs. An ELM reference signal was created by summing up the background signals from all channels. An approximate ELM onset time was chosen by hand in this reference signal. Well separated ELMs were selected, ELMs too close to each other were neglected. A trigger level was set at about 10% of an average ELM pulse height and a program selected the time around each approximate ELM onset time where the reference signal increases above the trigger level. These times were used as the accurate onset time of the ELMs as shown in *Fig.1b*.

Time interval of precursors

The analysis was done on three shots. Several hundred ELM onset times were chosen in each with the algorithm described above. The background corrected Li-BES signals were examined in the [-100, 0] μs interval relative to the ELM onset time. Overplotting them showed tendencies as seen in *Fig.1c*. In the last 50μs before the ELM onset the amplitude of the oscillations in Li-beam signals 9-11 increases remarkably, thus the [-50,0] μs interval is called "precursor time window". In the [-100, -50] μs interval the oscillations seem to have constant amplitude, therefore this time interval was used as a reference time window in order to estimate the noise level. The source of this noise is the signal amplifier, photon statistics and plasma activity unrelated to ELMs.

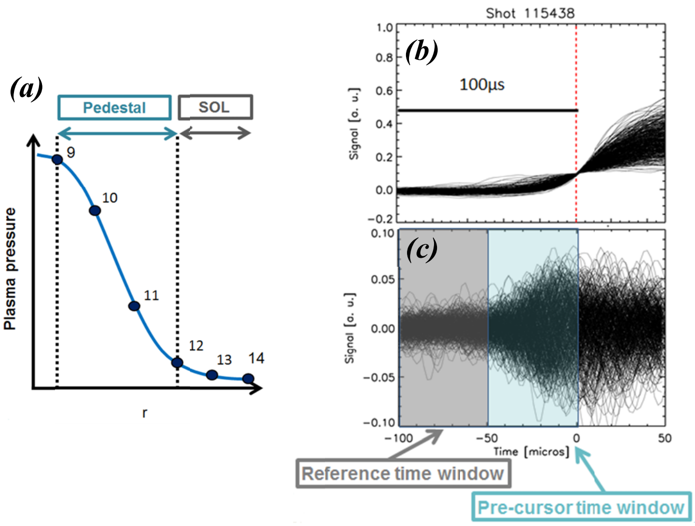

Fig. 1. (a) Cartoon of the location of the analysed measurement channels relative to the pedestal. (b) ELM reference signals overplotted around the determined exact ELM onset times. The reference signal crosses the trigger level at the red dashed line. (c) Background corrected and 10-70 kHz bandpass filtered Li-beam signal in channel 11 overplotted around the exact ELM onset times.

Statistical analysis

As the first step the frequency distribution of the precursor oscillations was studied. As their amplitude changes on a 100 μs timescale the frequency resolution cannot be better than 10 kHz. The background corrected Li-beam signals were digitally filtered with a series of 10 kHz wide bandpass filters covering the 0-100 kHz frequency range. The mean energy of the oscillations in the [t_1,t_2] time interval of the $\tilde{S}_c^f$ filtered signals was calculated as

$$E(c,f,t_1,t_2) = \frac{\sum_{n_{ELM}} \int_{t_1}^{t_2} \left(\tilde{S}_c^f - \langle \tilde{S}_c^f \rangle\right)^2}{n_{ELM}},$$

where t_1, t_2 are the start and end times of the time window in μs, n_{ELM} is the number of processed ELMs, c stands for the channel (c = 9, 10, …, 14) and f stands for the frequency band of the filter (f = 0-10 kHz, 10-20 kHz, …, 90-100 kHz). These mean energies were calculated in both the reference and precursor time windows. $E(c, f, -100, -50)$ was used as the noise level of the precursor energy calculation. As the noise energy is expected to be statistically independent of the precursor oscillations, the precursor mean energy can be calculated as

$$E_p(c, f) = E(c, f, -50, 0) - E(c, f, -100, -50).$$

$E_p(c, f)$ were depicted for all three shots on *Fig. 2a*. The graphs suggest that the precursor energy has a maximum in the pedestal region between 10-40 kHz frequency. In order to study the spatial distribution of precursors in more detail the signals were filtered for the

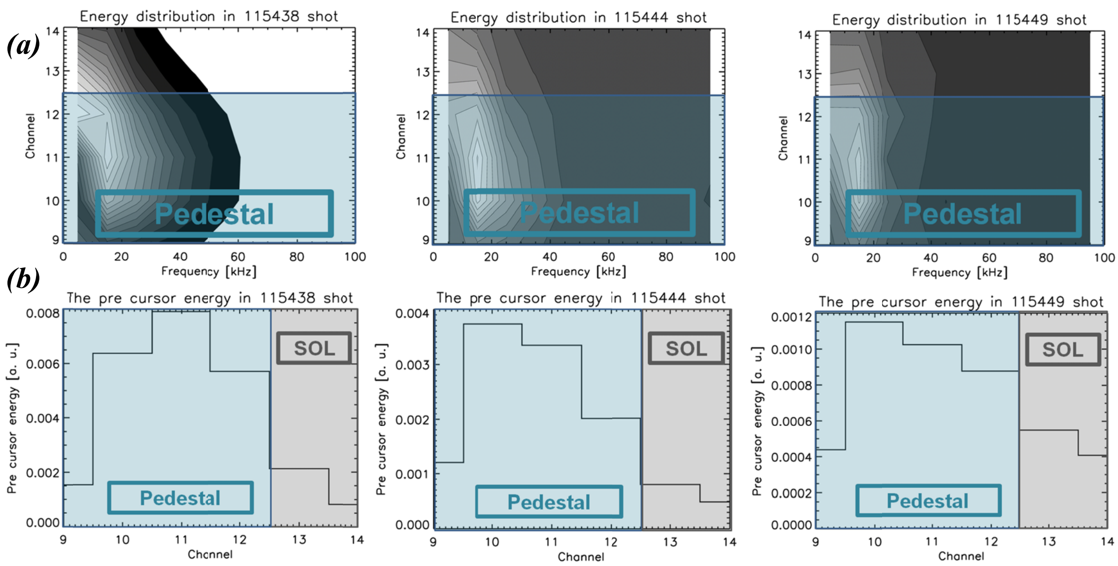

Fig 2. (a) Distributions of the precursor mean energy $E_p(c, f)$ in the three studied shots. (b) Spatial distribution of the precursor mean energy in the 10-40 kHz frequency band.

10-40 kHz band and the spatial distribution of $E_p(c, 10 - 40\ kHz)$ is plotted in *Fig. 2b*. This plot clearly places the precursor structures in the pedestal area of the plasma.

The above investigations only gave information about the precursor activity averaged for all ELMs. The next step was to investigate to what extent the precursor activity changes from ELM to ELM. Therefore the histogram of the precursor energy of each ELM was calculated for each channel and time window for all three shots separately. An example is shown in *Fig. 3*. The energy of the oscillations in the reference time window is limited to small values while in the precursor time window much higher energies are observed. The noise level of the precursor detection was determined from the histogram in the reference time window in a

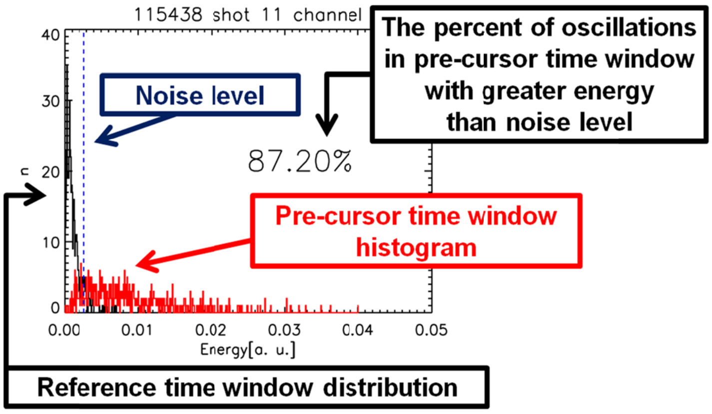

Fig. 3. Histogram of precursor energy in shot 115438, channel 11. The black curve shows the histogram in the reference time window, while the red curve is the histogram in the precursor time window. The percentage of ELMs with precursor energy above the noise level is 87% in this case.

way that 90% of ELMs have oscillations in the reference time window with energy below this value marked by a dashed vertical line. As the final step of the analysis the percentage of ELMs was calculated which have higher precursor energy than the noise level. These percentages are summarized in the table.

	Shot		
Channel	115438	115444	115449
9	50 %	34 %	18 %
10	77 %	45 %	26 %
11	87 %	38 %	23 %
12	79 %	33 %	25 %
13	53 %	37 %	27 %
14	37 %	30 %	24 %

Conclusions

The statistics showed that the ELM precursor activity is concentrated to the middle of the pedestal area with 10-40 kHz frequency. In one shot (115438) nearly 90% of ELMs have clear precursor energy above the noise level. In the two other analysed shots the tendency is less clear. Although in the pedestal area a significant increase is seen in the average energy of oscillations 50 μs before the ELM only for about 30% of ELMs can this precursor activity be detected above the noise level. The global parameters (I_p, B_t, q_a, n_e) are nearly the same for all shots, the difference lies in the ELM activity. In the shot where precursor oscillations are clearly distinguishable ELMs are quasi-periodic ($f \sim 1$ kHz) and they are preceded by a quiet period. In the other shots ELMs happen irregularly. Because of the absence of the quiet period it is more difficult to determine the ELM onset time and the noise level calculated from the reference time interval is also higher.

References

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