Study of island localized modes with alkali Beam Emission Spectroscopy diagnostic in Wendelstein 7-X

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Introduction: During the OP1.2b operating campaign quasi periodic edge plasma fluctuations with few hundred Hz frequency were observed in some plasma configurations. The underlying instability was found to be originated at the 5/5 magnetic island positions and thus was termed "Island Localized Mode" (ILM) [1][2]. These instabilities appear in plasma configurations, where the 5/5 magnetic islands are in the plasma core and change their behavior as the magnetic island position is varied [3]. These ILM instabilities have been studied with multiple diagnostics: Alkali Beam Emission Spectroscopy (ABES), Mirnov coil, Soft X-ray and Partial Rogowski coil diagnostics.

Island Localised Mode: The origin of ILM fluctuations were found to be localized near to the last closed flux surface around 5/5 magnetic island. ILMs appear as less than 100 μs peaks in H-alpha signal and cause discrete losses of stored energy. During one ILM event typically 1-4 % of the diamagnetic stored energy is lost [1]. Inter-ILM periods show some irregularity in length ($\sim$ 10 - 50 ms) and the width and size of ILM peaks are also not homogeneous during a plasma shot. ILM events can be identified clearly in various diagnostics' signals. Figure 1 shows ILM periods (left) and one ILM event (right) in various diagnostics' signals.

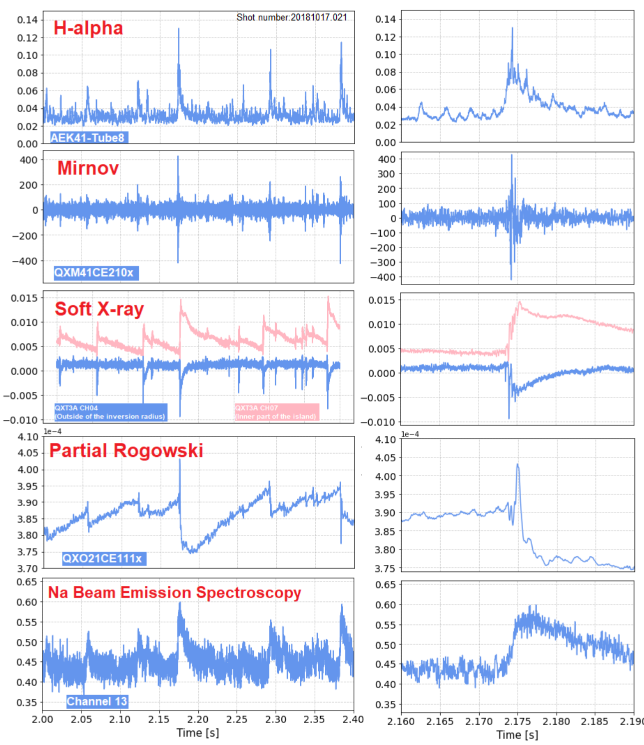


Figure 1: *ILM events in various diagnostics' signals (left) and one ILM event in each signal (right)*

Alkali Beam Emission Spectroscopy diagnostic (ABES): In Wendelstein 7-X the ABES diagnostic is located at $\Phi = 72°$ and injecting a 60 keV neutral Sodium beam at vertical midplane. The observation system is measuring the edge plasma from poloidal direction with 40 channels each collecting light with spatial resolution of 40 mm toroidally and 5 mm radially. The achievable temporal resolution of the ABES diagnostic is 50 μs. The injected Sodium atoms are excited and ionised through collisions with various plasma components, and the magnetic field diverts the ions from the beam path. This gives a limitation for the penetration depth of the beam. By detecting the light profile along the beam, the edge density profiles can be reconstructed up to 100 kHz, which allows the study of fast density fluctuations.

Edge density change caused by ILM: The temporal evolution of reconstructed edge density profiles was studied in multiple shots where ILM activity were observed. Figure 2 shows the position of the magnetic island present in this configuration compared to the position of the 40 channels of ABES (numbering from 1 to 40). A light profile and a corresponding density profile can also be seen on Figure 2. Towards to inner channels of ABES, the error of the density reconstruction is increasing, thus limiting the reliability of these channels.

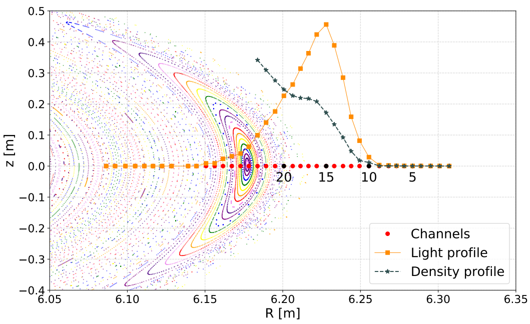
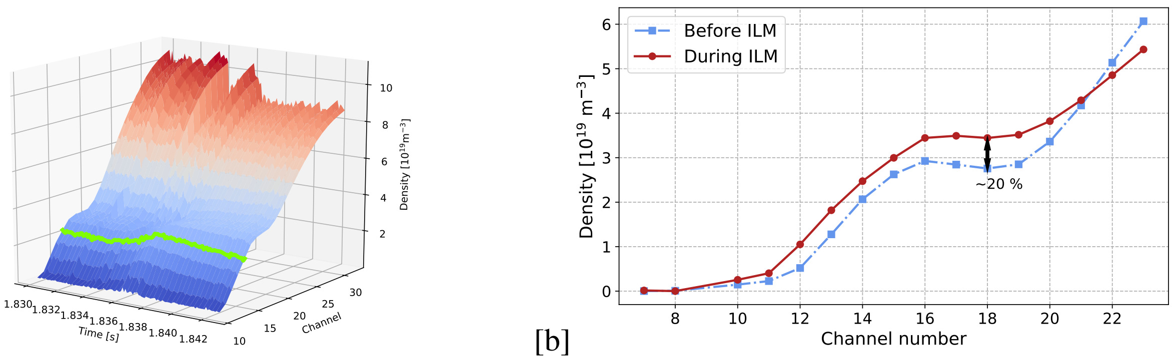


Figure 2: *Channels of ABES diagnostic and the position of the 5/5 magnetic island*



[a] [b]

Figure 3: ***[a]** Time evolution of density profile during an ILM (1.836 s). Green line: Channel 15 and **[b]** density profile before ILM [1.807 s :1.817 s] and during ILM [1.837 s: 1.847 s]*

Figure 3 [a] shows the time evolution of density profiles during an ILM and [b] shows density profiles before and during one ILM event. These density reconstructions show that during an ILM peak there is a $\sim$ 20 % increase of density in the edge, Scrape-Off Layer plasma (ABES channels 10-18), while density decreases on inner channels.

Multidiagnostic analysis: Figure 4 shows a low frequency fluctuation with $\sim$ 2 kHz on inner channel of ABES (Channel 25) preceding ILM instability. This behavior can not be seen on outer channel (Channel 13). For the analysis of this low frequency fluctuation 2 dimensional cross-correlations of signals from Mirnov coil, Soft X-ray detector and Partial Rogowski coil with the 40 channels of ABES (measured light) have been studied. As Figure 5 shows during ILM instabilities relatively high correlation can be seen on inner channels (25-30) with all presented diagnostics, showing that the same fluctuation is present in these signals as well. On the outer channels of ABES (e.g.Channel 14) only weaker or no correlation is present.

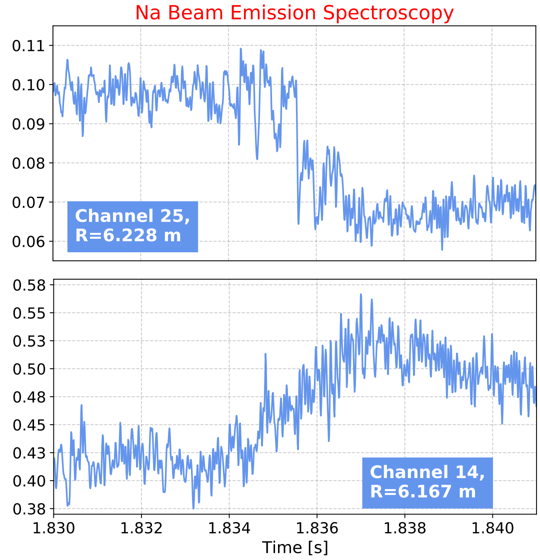
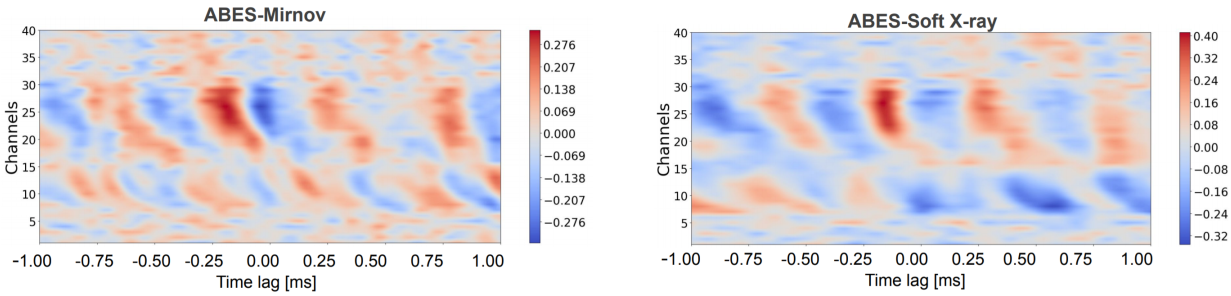


Figure 4: *One ILM event in signal of channel 14 and channel 25 of ABES diagnostic*



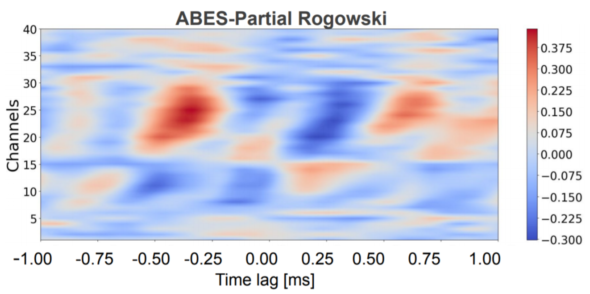


Figure 5: *two-dimensional cross-correlation of signals from Mirnov coil, Soft X-ray detector and Partial Rogowski coil with the 40 channels of ABES (measured light)*

Analysis of high frequency fluctuations: In the analysis of the ABES signals during ILM, high frequency fluctuation behavior has been compared in time intervals before ILM peak and during ILM peak. Figure 6. shows the 10 ms long intervals selected for the analysis. Figure 7. [a], [b] show cross-correlation of measured light intensity of ABES channels with reference channel ABES-13. A radially few cm wide structure can be seen in these correlation maps, which is propagating radially outward. The 2D correlation analysis confirms that neither the radial velocity, nor the frequency range of the turbulence show any significant change during an ILM event.

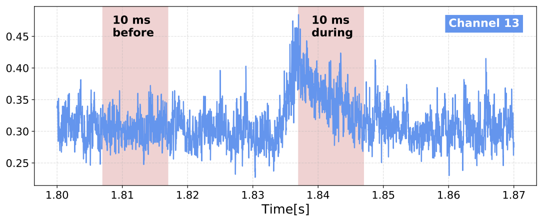


Figure 6: *10 ms long intervals before and during an ILM selected for the analysis*

Figure 7 [c] shows the relative fluctuation amplitude profiles and the density profiles of these two intervals. No significant changes in the relative fluctuation amplitude have been observed despite of the significant density changes.

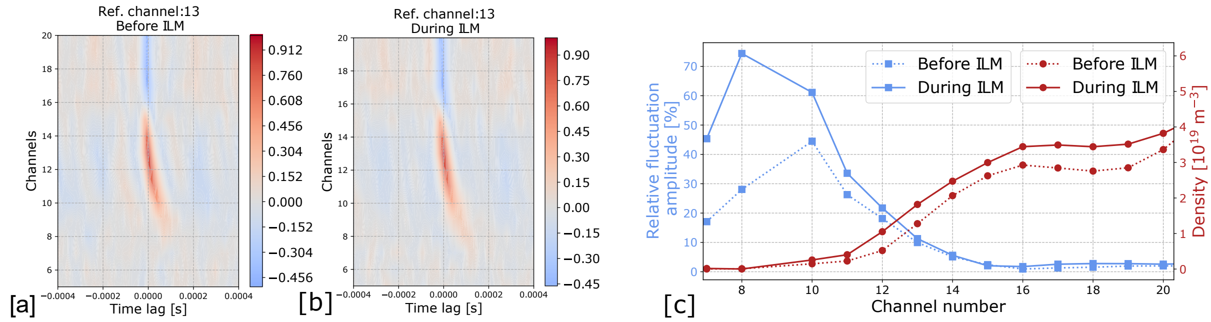


Figure 7: *Cross-correlation of ABES channels* ***[a]*** *before and* ***[b]*** *during ILM.* ***[c]*** *Relative fluctuation amplitude profiles and the density profiles before and during ILM*

Discussion: High temporal resolution density reconstruction from ABES diagnostic shows, that during ILM peaks ~ 20 % increase can be observed in channels localised to the edge and Scrape-Off Layer plasma region (channels 10-18), while density decreases in the inner channels. Preceding ILM instability a low frequency fluctuation with ~ 2 kHz can clearly be identified on inner channels of ABES (shown on Figure 4). Similarly cross-correlation calculated from signals of Mirnov coil, Soft X-ray detector and Partial Rogowski coil with the 40 channels of ABES (measured light) show similar behaviour with clear correlation on inner channels (25-30) and only weaker correlation on the outer channels of ABES. During analysis of high frequency fluctuations with ABES, no significant changes in the relative fluctuation amplitude have been observed despite of the density changes. The 2D correlation calculated from the ABES signal analysis confirms that neither the radial velocity of the turbulent structures propagating outwards, nor the frequency range of the turbulence show any significant change during an ILM event.

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