Localization and characterization of MHD instabilities driven by fast particles on the Tore Supra tokamak

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Introduction

In ITER and DEMO, the fusion process and the additional heating systems will produce a large amount of energetic particles. These fast particles can destabilize several MHD instabilities that can affect the energy and particle confinements. The present work reports experimental observations performed in Tore Supra about electron fishbone-like modes and Beta-induced Alfvén eigenmodes.

The perturbations induced by these modes were detected in Tore Supra by the 2 channel reflectometry (sampling rate 1 MHz) and by the 32 channel ECE superheterodyne radiometer (recently upgraded to raise the sampling rate to 1 MHz). The evolutions of the frequencies and localizations of these instabilities were determined and they were found to be well correlated with cyclical core relaxations phenomena.

Electron fishbone-like modes

In LHCD plasmas, electron fishbone-like modes with frequency below 15 kHz were analyzed with the ECE radiometer. Previous works in Tore Supra reported the occurrence of periodic frequency jumps associated with changes of the mode structures and suprathermal electron redistributions [1, 2]. One example of these frequency jumps can be observed in Figure 1, which presents the cross-spectrograms between adjacent central ECE channels in a shot with 1.2 MW of LHCD power (the main plasma parameters for the TS#41117 are: toroidal magnetic field 3.9 T, plasma current 0.6 MA and central density $2.3 \times 10^{19} m^{-3}$).

As can be directly observed in Fig. 1, all the modes are localized inside $\rho \sim 0.25$, and their radial localization are not the same. For instance, the mode around 11 kHz is more intense than the 3.5 kHz one for $|\rho|>0.17$, but it is much weaker in central channels, where the 3.5 kHz is the strongest mode.

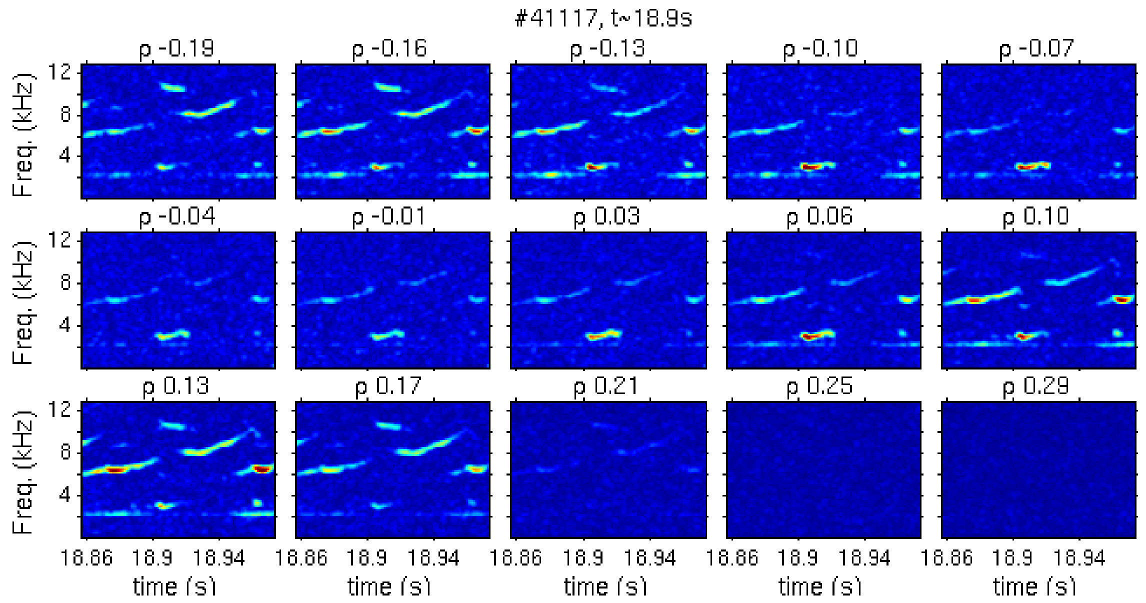

Figure 1 – Cross-spectrograms between adjacent ECE channels on the core region. The same color scale was used for all spectrograms.

Figure 2 shows the evolution on the radial localization of these modes, determined using the procedure described in ref. [3]. A continuous evolution of the mode localizations even during the frequency jumps can be seen in Fig. 2. This continuity agrees with the expectation that the mode localizations are determined by the safety factor profile. These results can be used to study the evolution of the current profile in the presence of these modes.

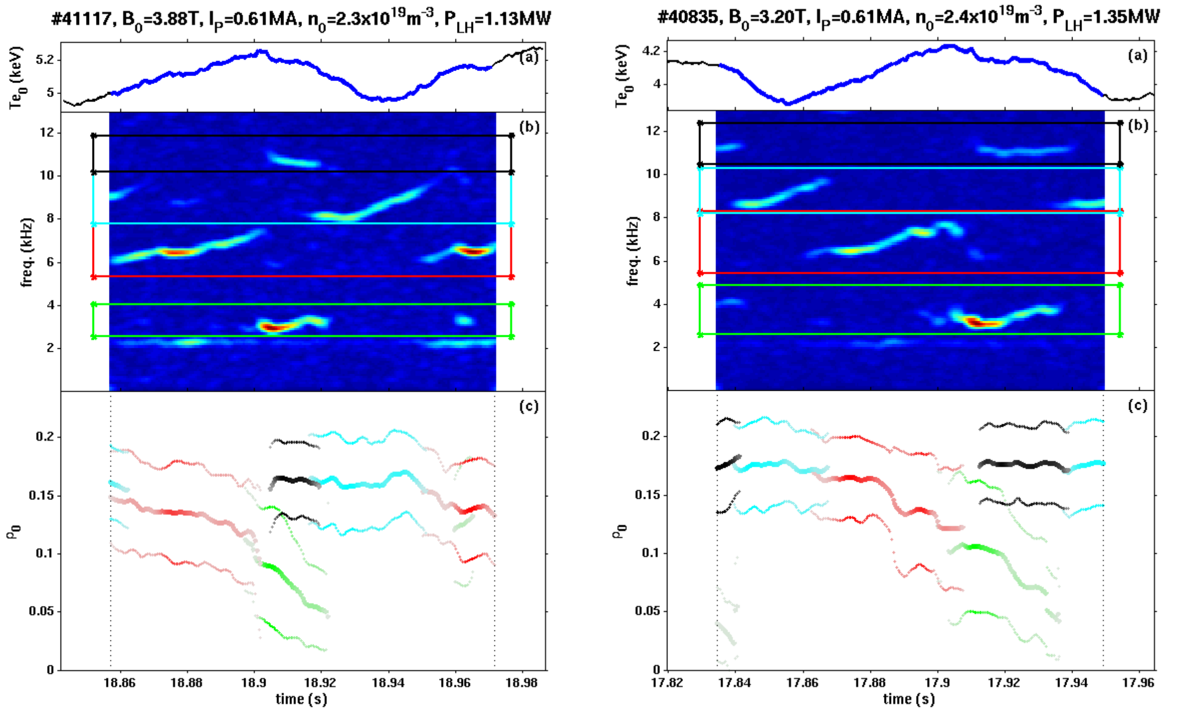

Figure 2 – Central temperature evolution (a), combined spectrograms of several ECE channels (b) and evolution of the mode localizations (c) indicating the mode positions (large marks) and their FWHM (small marks).

Beta-induced Alfvén eigenmodes

Modes in the acoustic range, identified as Beta-induced Alfvén Eigenmodes [4], are observed in some ICRH plasmas. Fig. 3 presents the cross-spectrogram between the densities fluctuations at two radial positions in shots with P_{ICRH}=3.4MW and 4.6MW, respectively. As it can be seem in the amplitude of the cross-spectrograms [Fig. 3(b)], there are several modes present at the same time and the frequencies of these modes vary according the phase of the sawtooth oscillation: the frequencies decrease during the first part of the sawtooth cycle and increase in the final part, but the range of the frequency variation depends on the plasma conditions. Moreover, the phase shifts in the cross-spectrograms [Fig. 3(c)] show that modes with neighbor frequencies have different phase shifts, while the same phase shift is noticed with the second neighbor. It suggests that adjacent modes have opposite poloidal parities. These results have similarities with the observations of BAEs at ASDEX-Up [5], where non-monotonic evolution of the BAE frequency during the sawtooth period was reported.

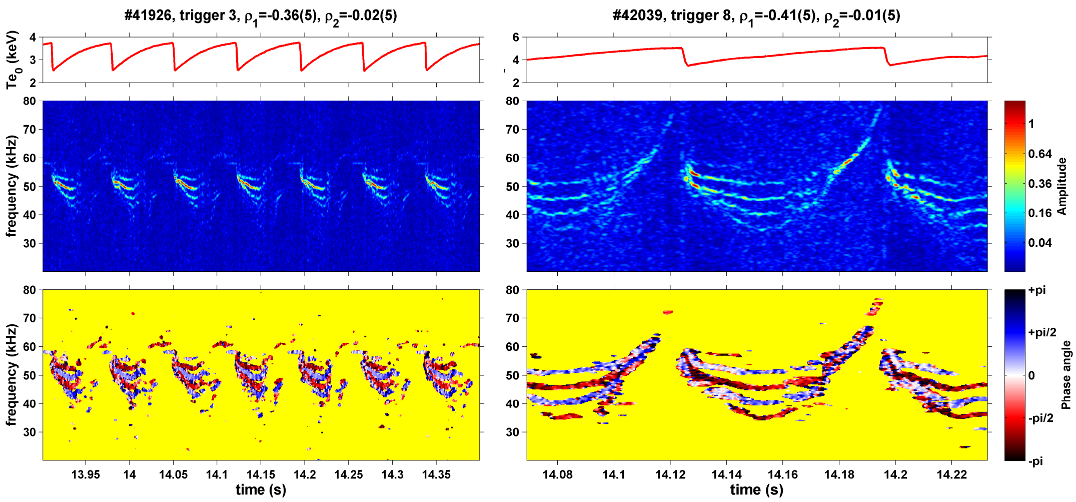

Figure 3 – Central electron temperature (upper) and amplitude (middle) and phase (bottom) of the cross-spectrogram between density fluctuations measured by reflectometry.

Using the ECE data the radial position of the modes during the sawtooth crash was determined. However, as the sensibility of the ECE is lower than reflectometry, it was necessary to combine the measurements for several sawteeth which was possible since that the evolution is reproducible with respect to the sawtooth phase. To do it, it was performed a coherent addition of the spectrograms according to the phase of the sawtooth cycle ($t* = \frac{t-t_{crash}}{\Delta t}$, where Δt is the duration of the considered sawtooth). Figure 4 presents the results obtained using this method for another shot. The strongest mode in Fig. 4 slowly drifts toward to the center during the sawtooth cycle. The positions of the other modes, observed only at the beginning of the cycle, are almost the same as the strongest one.

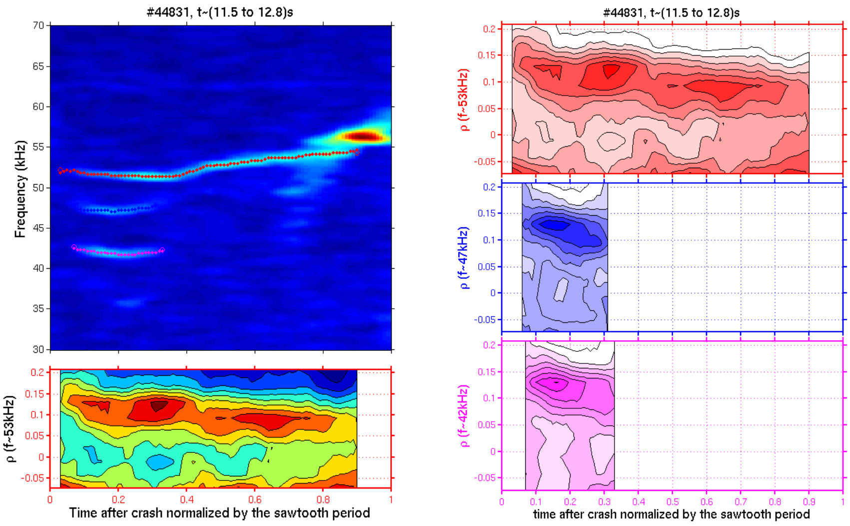

Figure 4 –Spectrogram of electron temperature fluctuations combined according to the phase of the sawtooth cycle (upper left) and evolution of the radial positions of the modes (bottom left and right).

Conclusion

The analysis of the electron fishbone-like modes shows that the radial positions of these modes present a continuous evolution even during the frequency jumps. For the Beta-induced Alfvén eigenmodes it was found that several modes are present at the same time, and these modes slowly drift inside during the sawtooth cycle. For both instabilities, the evolutions in the frequencies and the radial positions follow the phase of the cyclical central temperature oscillations.

These experimental observations offer valuable informations about these MHD modes allowing comparisons with theoretical and numerical predictions. Moreover, they also point out the relationship between these MHD instabilities and the core relaxation phenomena in tokamak plasmas, like sawteeth and the so-called Oscillation regime. The evolutions of the mode localizations can be useful to evaluate the safety profile evolution.

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