Fast particle triggered modes: experimental investigation of Electron Fishbones on TORE SUPRA

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Magneto-hydro-dynamic MHD modes driven by both fast electrons and ions have been already identified as a possible reason for energy losses in tokamak plasmas. Since alpha particles, generated by fusion reactions in the MeV energy range, will represent the main heating source in future reactors the understanding of these instabilities seems to be crucial. While numerous observations of fast ion driven phenomena have been accomplished, investigation of modes related to supra-thermal electrons remains actually a much less explored issue. These modes could have an important impact on the current driven by the lower hybrid (LH) and/or electron cyclotron techniques which could be crucial for achieving steady state in future reactors. In Tore Supra, a circular tokamak with major radius $R = 2.45$m and minor radius a=72cm, where electron cyclotron resonance heating (ECRH) and lower hybrid (LH) techniques are used to produced fast electrons, several diagnostics permit the methodical study of related instabilities.

During last experimental campaign, in LHCD discharges, different coherent modes are observed in low frequency range, $4-15$ kHz, and represent the subject of this work. Cross and Fast electron cyclotron emission (ECE) acquisitions and a reflectometer, installed 120 far in toroidal direction, have been used in order to acquire informations on, respectively, electron temperature fluctuation, δT_e, and density fluctuation, δn. Cross-ECE diagnostic, as well as the reflectometer, has the possibility to record signals up to 1s with 1MHz of sampling rate viewing the plasma equatorial plane from the low field side. Fast-ECE uses the 32 standard ECE chan-

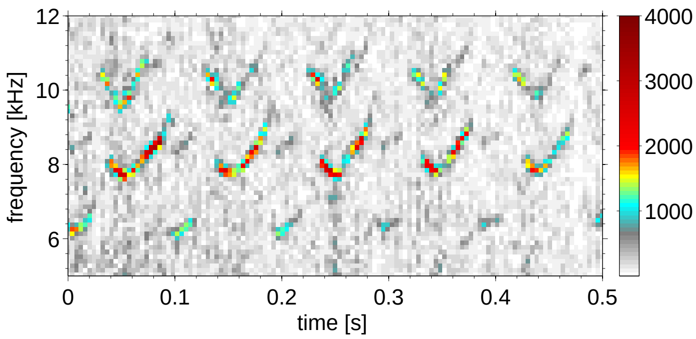

Figure 1: Shot 41121. Spectrogram of the signal obtained by reflectometry technique at $\rho \approx 0.2$

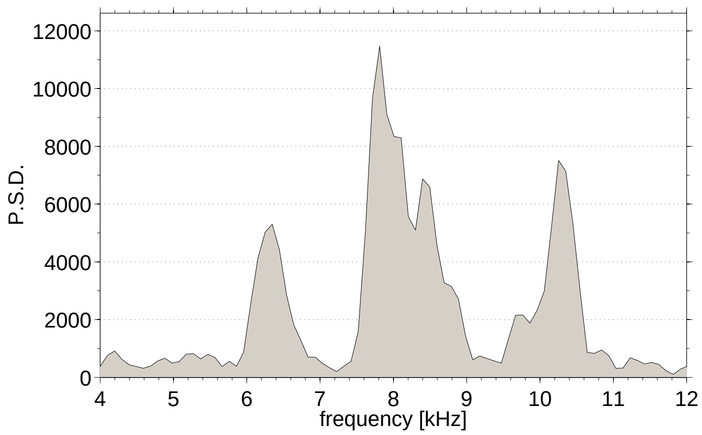

Figure 2: Shot 41117. Power spectral density obtained cross-correlating electron temperature fluctuation signal, δT_e, and density fluctuation, δn measured at $\rho \approx 0.2$ in two different toroidal position.

nels, which means a space resolution of 2.5cm, with sampling rate equal to 83kHz recording up to 120ms.

For a plasma heated by 1.1MW of LH with 3.8 T of main confinement magnetic field B, plasma current $I_p = 0.6$ MA, line-integrated density, n_l, fixed at $2.3 \cdot 10^{19}\ m^{-2}$ so that the loop voltage was $V_{loop} = 0.18$ V, three modes are observed around 6.5, 8.5 and 11 kHz as shown in Fig. **??** with the spectrogram obtained by the reflectometer aiming $\rho \approx 0.2$. The power spectral density, pictured in Fig. **??**, obtained cross correlating one of the two available channels of the cross-ECE diagnostic with the reflectometer acquisition confirms that found frequencies are related to global instabilities and are not due to spurious effect of supra-thermal electron. Both diagnostics aimed the same $\rho \approx 0.2$. These modes are strongly suspected to be bounce electron fishbones [**?**] first observed in D-IIID [**?**] and recently pointed out in other machine [**?**, **?**]. The related frequency mode is given by $\omega_d = qnE/rRB$, where n is the toroidal mode number, E is the involved energy of the fast particle population, r is the minor radius, R the above mentioned major tokamak radius and B the magnetic field. From experimental MHD analysis, the mode at 8.5kHz has its maximal amplitude at $\rho \approx 0.2$ where q-surface has been indirectly measured and results to be approximatively 1. Found frequency agrees with an electron fishbone like mode having $n = 1$ and $E \approx 80$keV which is consistent with fast electron produced by LH heating. More detailed analysis have been done elsewhere [**?**] in order to support the above conjectures and trying to explain the other two found modes at lower and higher frequencies.

In a similar shot with $B = 3.1$T, increasing methodically LH power up to 1.8MW, another

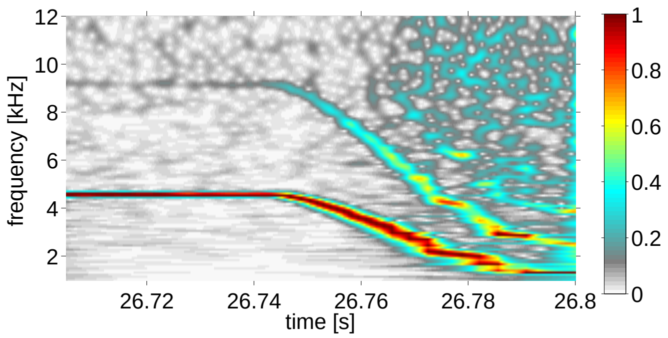

Figure 3: Shot 40816. Spectrogram of the signal obtained by the Fast-ECE diagnostic at $\rho \approx 0.2$

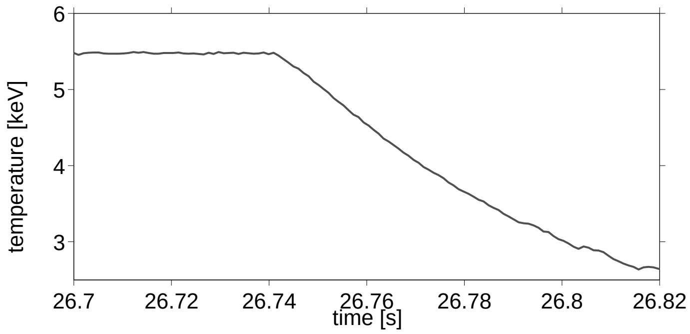

Figure 4: Shot 40816. Electron temperature time trace at $\rho \approx 0$

instability takes place displaying a lower frequency at 4 kHz, as shown in Fig. **??**. This mode is still localized at $\rho \approx 0.2$ where fast electrons population are mainly produced. Several hypothesis could be done in order to clarify the nature of this instability; it is factually checked that recorded frequency is consistent with the estimate of the diamagnetic electron fishbone like mode frequency [**?**] which is given by $\omega_i^* \propto T_i/B$ where T_i is the ion temperature and B the main magnetic field. It is observed that when LH dropped to 0 MW and no fast electrons are produced the mode still persists, as aspected by theory, and its frequency is found to be linearly related to the electron temperature ($T_e \propto T_i$) as one can check from Fig. **??** compared to Fig. **??** where electron temperature time trace is displayed for the channel corresponding to $\rho \approx 0$. Further investigation are needed to support this very basic analysis and avoid any other interpretation.

In summary we have briefly shown how in Tore Supra different kind of instabilities related to the presence of a fast electron population can be found. By using methodically LH heating power mainly two cases can be highlighted: modes identified as bounce precession electron fishbone, for which fast particles are necessary to survive, and for enough LH power, modes to lower frequency which can be identified as diamagnetic fishbone for which fast particles are necessary to be destabilized but not to evolve. Other experiment have been already planned to check if these modes are responsible of particle displacements and energy losses. This work, supported by the European Communities under the contract of Association between EURATOM and CEA, was carried out within the framework of the European Fusion Development Agreement. The views and the opinion expressed herein do not necessarily reflect those of the European Commission.

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