Localization of MHD and fast particles modes in ASDEX Upgrade using reflectometry

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1. Introduction

The physics of energetic particle driven modes is of particular interest for fast ion dynamics and transport in burning plasma devices such as ITER. Specifically Alfvén eigenmode instabilities, such as toroidicity induced Alfvén eigenmodes (TAEs), have been studied in DIII-D, TFTR, JET and JT-60U for example using a range of fluctuation diagnostics; including magnetic coils, Beam Emission Spectroscopy, interferometry and Far-Infrared scattering. In ASDEX Upgrade a heterodyne fast frequency hopping reflectometry system has been developed to allow probing of different density (n_e) cutoff layers from the low field side during the same discharge. In this paper, we present results on radial structure of edge localized MHD modes and core TAEs modes using this diagnostic.

2. Technique

In ASDEX Upgrade, the standard reflectometry diagnostic consists of two systems: a multi-channel LFS/HFS broadband FM-CW profile reflectometer capable of operation in either fixed or swept frequency mode, and a dual O-mode channel (Q-band: 33-49.2GHz and V-band: 49-72GHz) fast frequency hopping reflectometer [1] dedicated to n_e fluctuation measurements. Both systems can provide fluctuation measurements, but the fast frequency hopping system uses heterodyne with I-Q detection allowing separation of the phase and amplitude signals. The phase is a measure of the movement of the n_e cutoff layer while the amplitude gives information on scattering effects. The system currently has sample rate up to 1MHz which permits discrimination of MHD modes and turbulent fluctuations up to 500kHz. To obtain the radial structure of coherent modes two analysis techniques were used: (1) each cutoff signal is correlated with the nearest toroidally located Mirnov coil signal to give the coherence of the mode vs radial position; (2) the δn_e fluctuation level at each cutoff position is estimated using the

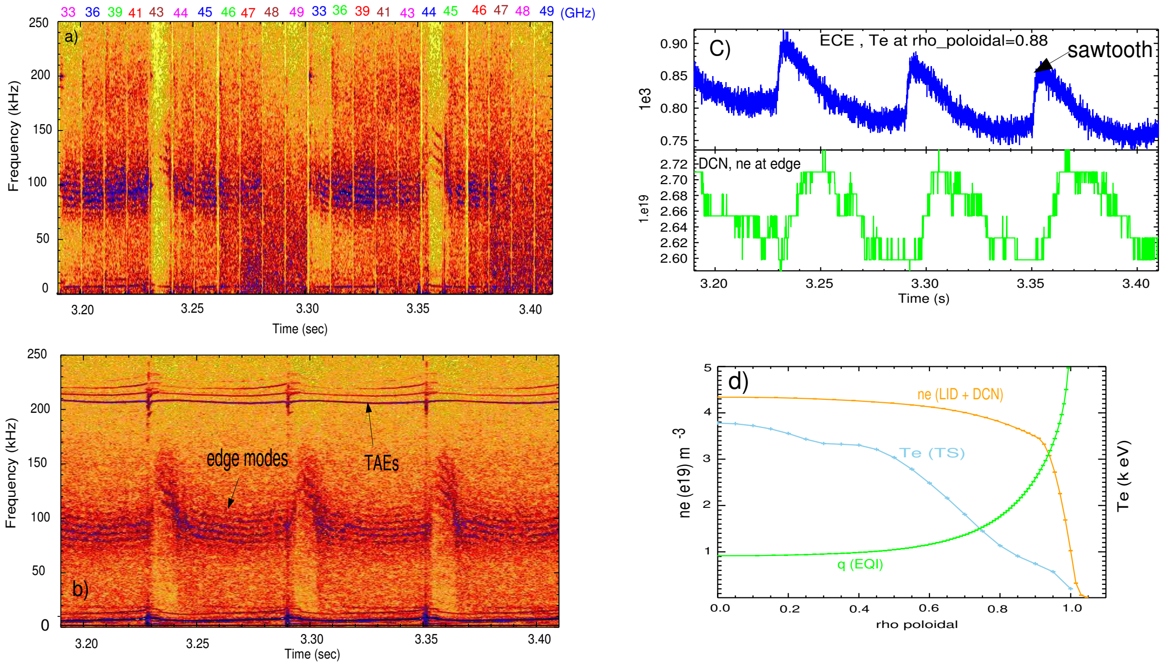

Figure 1: Spectrogram from (a) Q-band homodyne signal during frequency steps; (b) Mirnov coil; (c) time traces of edge T_e and n_e and (d) n_e, T_e and q radial profiles for shot #21011.

1D Geometric optics model [2]: $\delta\phi = 4\pi\,\delta r/\lambda = (4\pi/\lambda)\,(\delta n/n)\,\nabla n^{-1}$, where λ is the vacuum wavelength of the probing wave and δr the radial displacement. This model is strictly only valid for long fluctuation wavelength and small amplitude fluctuations. In both analysis methods the n_e profile is needed to give the radial cutoff position. Here, a fitted profile is obtained using Thomson Scattering (TS), Lithium Beam (LID) and reflectometry data. In particular for calculating n_e fluctuation level, the local n_e gradient must be known.

3. Edge modes

In ICRH heated discharges, edge MHD modes are observed together with TAEs but have not yet been identified. The frequency of the edge MHD modes appears to scale directly with the local temperature (T_e) and n_e. Fig. 1 shows spectrograms of the Q-band reflectometry and Mirnov signals together with time traces of edge T_e and n_e with n_e, T_e and safety factor q radial profiles of shot #21011. The effect of sawteeth are clearly seen in the edge n_e and T_e. The decrease in the integrated power spectrum of the reflectometry signal just after sawtooth can be due to either a change on the local density gradient ∇n_e or a reduction in the fluctuation level. After the increase of edge T_e, the frequency between two consecutive toroidal modes increases by around 4kHz suggesting a modification in the plasma rotation. From magnetic measurements it is deduced that the edge modes rotate in the electron diamagnetic drift direction with toroidal mode numbers $n = 2, 3, 4$ and 5 where n increases with frequency.

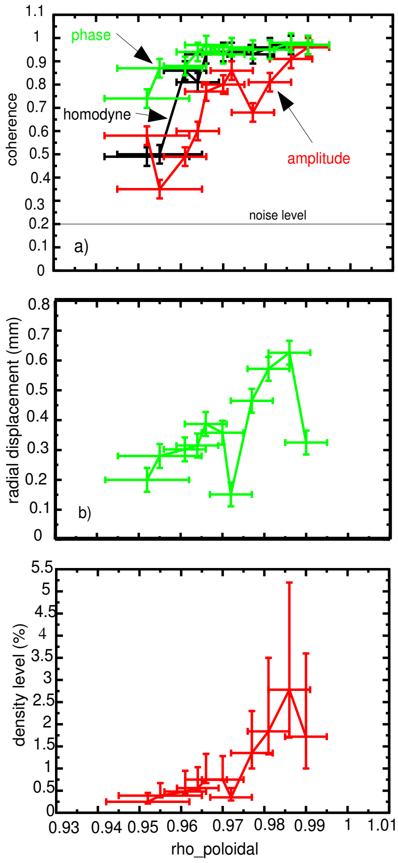

Figure 2: Radial profiles of (a) magnetic-reflectometry coherence (b) δr and (c) δn_e of edge mode.

In this discharge the reflectometer frequency pattern was a stair case of 11 steps of 10ms. Fig. 2 shows the radial structure of the edge modes using the coherence and δn_e analysis. For the coherence technique, various reflectometer signals (phase, amplitude and homodyne) were investigated, but the homodyne signal (which includes both amplitude and phase information) seems to be more reliable, as noted in some papers on correlation reflectometry [3]. The statistical noise level of the coherence analysis is approximately 0.21, defined by the number of spectral averages and window length, in this case 6ms and $N = 22$. For the δn_e analysis method, it is necessary to filter the phase signal with a bandpass filter (65-135kHz) in order to isolate the mode from the turbulence background. The RMS phase is then deduced to give radial profile of δn_e as well as the radial cutoff layer displacement δr. The error bars in fig. 3(c) arise mainly from the experimental ∇n_e. Nevertheless, the two techniques give consistent results and indicate that the modes are stronger at the edge especially around $\rho_{pol} = 0.985$.

4. Core modes (TAEs)

In the previous discharge TAEs modes were observed in the magnetics but not in the reflectometer signal due to the flat n_e profile in the core. However, in shot #20489 the core ∇n_e is steeper as shown in fig. 3. In fig. 4 the spectrogram of a Q-band homodyne signal shows the radial localization of a sawtooth postcursor mode at the edge, TAEs and sawtooth precursor in the core. Combined Q and V-band reflectometer measurements show the TAEs extend across the radial region $\rho_{pol} = 0.35 - 0.7$. In shot #21007 two main TAEs modes with toroidal modes number

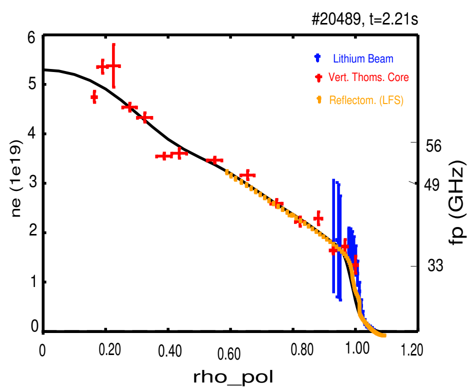

Figure 3: n_e profile for #20489.

$n = 4$ and $n = 5$ are present. The reflectometer frequency pattern (Q and V-band) is 11 steps of 15ms. From spectrograms not presented here, TAEs are clearly seen at edge and core, but as yet no conclusion can be drawn on their relative strength. However, using the coherence technique with homodyne reflectometry signal the radial structure of the $n = 4$ and $n = 5$ modes are shown in fig. 5. The main contribution is localized in the core ($\rho_{pol} < 0.5$) with a secondary peak at the edge. Further analysis of the mode amplitude is in progress.

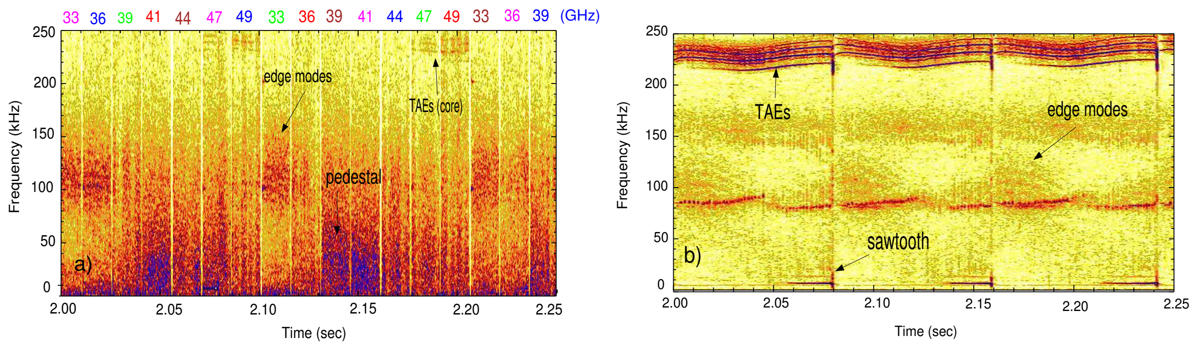

Figure 4: (a) Q-band homodyne and (b) from Mirnov spectrograms for # 20489.

5. Conclusions

The combination of fast frequency hopping heterodyne reflectometry with correlation analysis has been used not just to localize mode activity but to give the radial structure, or eigenfunction of the mode. Both the edge and core modes have complex structure, varying with mode number. Validation of the results with code simulations are planned.

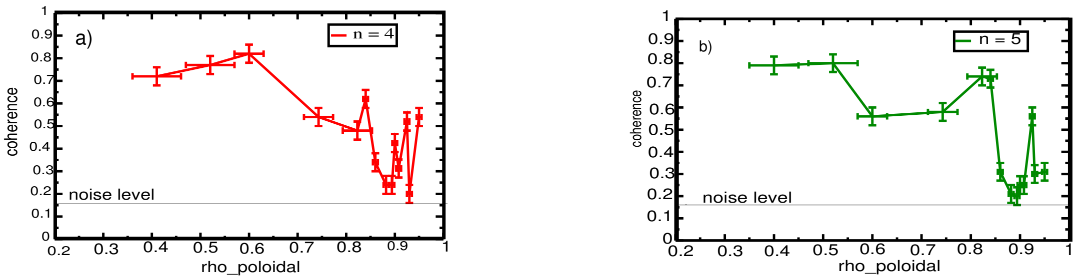

Figure 5: Radial coherence profile for (a) $n = 4$ and (b) $n = 5$ TAE modes.

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