Alfvén Cascade mode studies in ASDEX Upgrade using reflectometry

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1. Introduction

Alfvén eigenmode instabilities, such as Alfvén cascades (ACs) have attracted much attention recently due to their potential to expel α particles with resulting damage to the first wall components of a reactor, as well as reducing the efficiency of plasma self-heating [1]. On ASDEX Upgrade an O-mode multi-channel broadband Frequency Modulation-Continuous Wave (FM-CW) reflectometer (which can be operated in either fixed or swept frequency mode) covering the density range $0.3 - 6.64 \times 10^{19}$ m^{-3} [2] is used to compare density fluctuations on the tokamak High-Field-Side (HFS) and Low-Field-Side (LFS). In this paper, a direct HFS/LFS comparison is shown and the experimental radial eigenfunction for $n = 2$ AC quasi-mode is presented.

2. Technique

ACs were discovered in JT60U and are associated with the temporal evolution of $q_{min}(t)$ with a frequency ramp described by $df_{AC}(t)/dt \simeq (mv_a)/(2\pi R)(dq_{min}(t)^{-1})/dt$ [3] where f_{AC} is the AC frequency, v_a the Alfvén velocity and R the major radius. On the JET tokamak, the reflectometer diagnostic was used as an interferometer for monitoring the discrete spectrum of ACs and hence the evolution of the safety factor [4]. In ASDEX Upgrade, ACs are present in reflectometer signals even with the absence of a cutoff layer. However, it is not possible to receive any detectable signal reflected from the inner wall heat shield due to the geometry of the reflectometer (REF) antennas. Here it is believed that the signal arises from a modulation of the Bragg backscattering response by an Alfvén mode structure located at the center of the plasma [5].

The radial structure of AC modes has been obtained by correlating reflectometry with Electron Cyclotron Emission Imaging (ECEI)[6] and magnetic signals. In these studies, the ECEI channels at the midplane are used and so only the 1D structure of ACs is considered.

3. HFS/LFS comparison

In ASDEX Upgrade, first experiments of NBI-driven ACs by introducing tangential NBI during the current ramp phase in low density plasmas were successful. In this analysis, the discharge #25525 with 2.5 MW early NBI heating and $B_T = -2.5$ T was used. Figure 1 shows the time-frequency spectrogram of both HFS and LFS Q band signals with probing frequency at 48 GHz corresponding to $n_e = 2.86 \times 10^{19}$ m^{-3}. During the current ramp phase, the average electron density ($\bar{n}_e$) is changing and so this explains the different phases in figure 1 (backscatter and reflectometer mode). In backscatter mode (t= [0.23−0.38 s]), ACs (as well as the AC-TAE transition) are clearly seen as they are not affected by turbulence and the position of the density cutoff layer while in reflectometer mode (t = [0.41−0.71 s]) clear HFS/LFS asymmetries are observed. The Ka band signal on the HFS (not shown here) at around $\rho_{pol} \simeq 0.8$ and $\delta t \simeq$ [0.23−0.32 s] exhibits ACs modes while on the LFS no modes are observed. Figure 2 shows the Q band reflectometer power spectra from HFS and LFS for three different time windows (δt_1 = [0.427-0.432 s], δt_2 = [0.530−0.535 s] and δt_3 = [0.620−0.625 s]) in reflectometer mode. On the HFS, the ACs peak amplitudes are similar for the three time windows. On the LFS, ACs are present during δt_1 ($\rho_{pol} \simeq 0.23 \pm 0.05$), then the power spectrum rises uniformly accross the whole frequency band (δt_2 and $\rho_{pol} \simeq 0.3 \pm 0.05$) due to a slight change in ∇n_e and the ACs disappear. At δt_3, the ACs are again clearly visible while the overall power spectrum is similar to those of δt_2, however, the density cutoff layer is slightly further inside ($\rho_{pol} \simeq 0.17 \pm 0.05$). It seems that either the turbulence amplitude or a small change on the density cutoff layer position may have an effect on the appearance

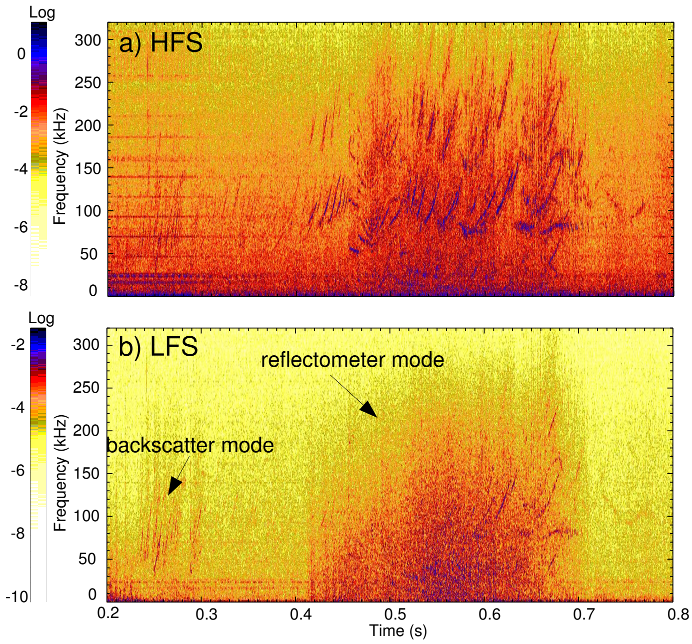

Figure 1: Time-frequency spectrograms of (a) HFS Q band (48 GHz) and (b) LFS Q band signals (48 GHz) for shot #25525.

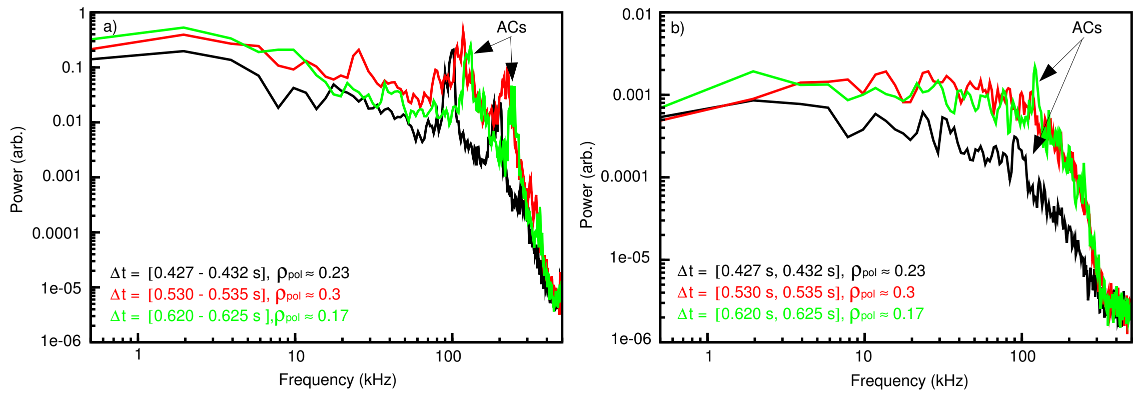

Figure 2: Reflectometer power spectra for 3 time windows (in reflectometer mode) of: (a) HFS Q band and (b) LFS Q band signals for shot #25525.

of ACs on LFS signals. Figure 3 shows the power spectrum of the HFS Q-band signal during a Grand cascade (GC) corresponding probably to $q_{min} = 2$ at $t \simeq 0.48s$. This GC is characterized by downward and upward sweeping modes. This feature has been observed in a few discharges at JET tokamak and the downward sweeping modes have been called "ACs quasi-modes" and are associated with a very flat q profile [7]. The ACs rotate in the ion diamagnetic drift direction and the frequency ramps (df_{AC}/dt) of the upward and downward ACs are similar. At the inflection point of ACs, the difference between the frequencies of two adjacent toroidal mode numbers (δf_{AC}) is constant and around 7.81 kHz. The impurity ion B^{+5} toroidal rotation (v_{tor}) profile by means of charge exchange recombination spectroscopy was measured for this shot and at around $\rho_{pol} \simeq 0.24$ and $t = 0.475$ s, v_{tor} is approximatively 37.9 ± 1.4 km/s. The δf_{AC} cannot be explained solely by toroidal plasma rotation which is $f_{rot} = v_{rot}/(2\pi R) = 3.66$ kHz. One possible explanation for this difference is the existence of kinetic effects [8].

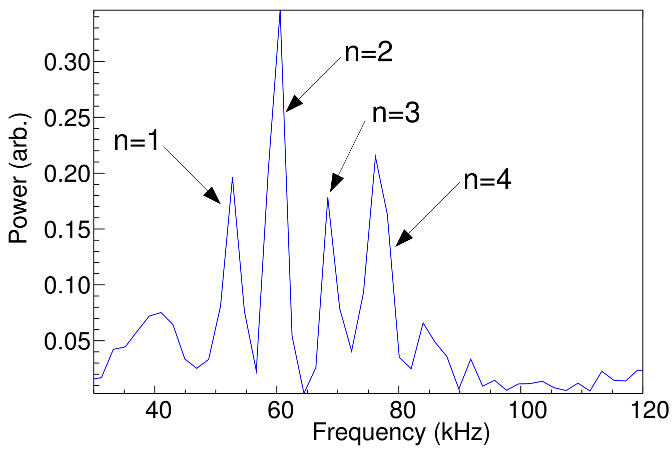

Figure 3: Reflectometer power spectrum of Q band on the HFS during a Grand Cascade ($\delta t = 0.480 - 0.481$ s) for shot #25525.

4. Radial structure

For the same discharge, #25525, a coherence analysis technique is applied to determine the radial structure of $n = 2$ AC quasi-mode. The significance level of the coherence is $\gamma_0 = 0.23$, defined by the number of spectral averages and window lengths, in this case 5 ms and $N_{av} = 18$. Figure 4 shows the radial coherence profile for n= 2 AC quasi-mode for two consecutive time windows ($\delta t = 0.465 - 0.470 s$ and $\delta t = 0.470 - 0.475$ s). Here small time windows are employed for coherence analysis as the AC frequency is changing in time. In the case of ACs, reflectometer measurements give more details than magnetics and so the coherence between two signals from localized measurements (REF and ECEI) have been used. Figure 4 (b) shows good agreement between the coherence profile by using ECEI and a magnetic coil B31-13 measuring dBr/dt signals and the coherence profile obtained with ECEI and REF (HFS Q-band) signals. The radial coherence profiles in figures 4(a) and (b) have a maximum at around $\rho_{pol} \simeq 0.28 \pm 0.05$. However, in figure 4(b) the radial structure of n= 2 quasi-mode is broader than in figure 4(a) and the maximum coherence value is lower.

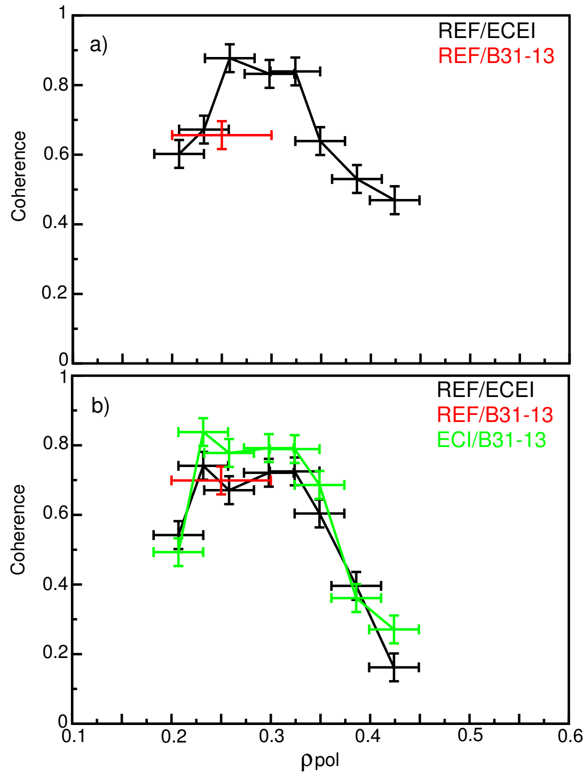

Figure 4: Radial eigenfunction of n= 2 AC quasi-mode at (a) $\delta t = 0.465 - 0.470$ s and (b) $\delta t = 0.470 - 0.475$ s using ECEI/REF, B31-13/REF and ECEI/B31-13 correlation for shot #25525.

5. Conclusions

Two distinct modes of operation have been detected: backscatter and reflectometer modes. In backscatter mode, the signals are not affected by the turbulence and the position of the density cutoff layer, leading to a better frequency and time resolution of ACs, however no localization of ACs can be deduced. In reflectometer mode, HFS/LFS asymmetries have been observed. The radial structure of n=2 AC quasi-mode is presented.

Acknowledgements: This work has been carried out in the frame of the Contract of Association between the European Community and IST and has received financial support from Fundação para a Ciência e a Tecnologia (FCT). The content of publication is the sole responsibility of the authors and it does not necessarily the views of the Commission of the European Union or FCT or their services.

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