Effects of strong density fluctuations at the plasma edge on ECEI measurements at ASDEX Upgrade

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Introduction: The Electron Cyclotron Emission Imaging (ECEI) diagnostic, with multiple lines of sight (LOS), where each LOS behaves like a conventional 1D radiometer, measures the electron temperature and its fluctuations on μs time scales and is specially suitable for 2D or quasi-3D visualisation of MHD phenomena. Its excellent poloidal resolution enables measurements of the poloidal velocity of MHD events.

In the case of optically thick plasmas, where optical thickness is proportional to the product of electron density and the temperature, the intensity of the electron cyclotron radiation equals the level of the black body emission. However, when measuring at the plasma edge, where the density and temperatures are relatively low, the electron cyclotron emission no longer equals the black body radiation and the density contribution cannot be neglected. The ECEI diagnostic has an oblique observation angle [1] enhancing the Doppler shift of the resonant positions and the deflection of the beams with the largest incident toroidal and poloidal angles. The measurements of the ECEI are focused on hot H-mode plasmas where the hot electrons of the Maxwellian tail obey relativistic mass increase, and so the resonances are shifted towards the higher magnetic field. Taking into account all these effects the radiation transport equation is solved in order to obtain the radiation temperatures and correct resonance positions called the warm resonances [2, 3, 4]. For the discharge studied in this work, the forward model has shown that the presence of the density fluctuations can influence the radiation temperatures. Therefore the knowledge on both, density and temperature, is very important for the interpretation of the ECEI signal.

Experimental observations: Comparison between conventional ECE, ECEI, Lithium Beam Emission Spectroscopy (Li-BES) and magnetic pick-up coil measurements at the edge is shown in figure 1 a), 1 b), 1 c), 1 d), respectively, in the form of spectrograms. ECEI, ECE and Li-BES spectrograms
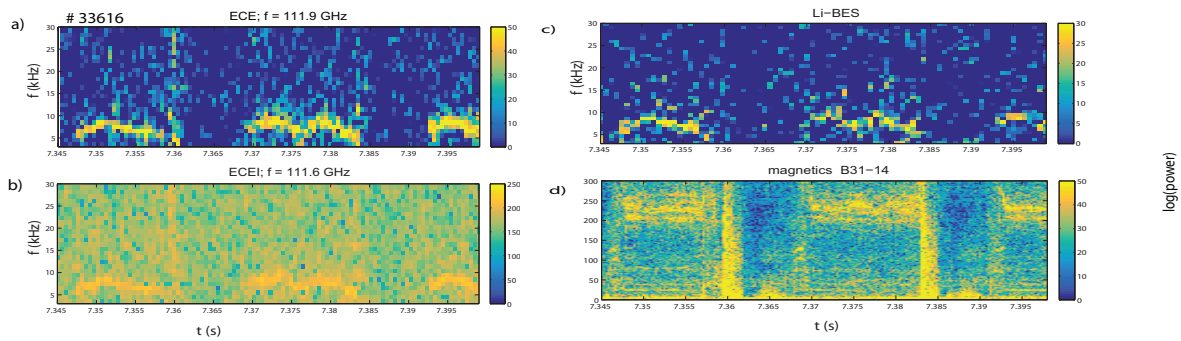
Figure 1: Power spectral density showing a narrow band mode; a) in the ECE channel, b) ECEI, c) Li beam channel, d) magnetic pick-up coil at the low field side midplane.

show activity in the $\sim$ 8kHz range indicating the perturbation is present in both, electron density and electron temperature. The ECE, ECEI, and LI-BES measure single mode in the 8 kHz range, whilst the magnetics measures multiple modes in the high frequency range. The amplitude of the density fluctuations measured by the Li-BES is estimated to be between 20 and 40 %. Important to note is that the low frequency mode is also observed in the magnetic signal, but of very low amplitude. The toroidal mode numbers n of the high frequency modes, determined from the magnetics are -8, -9, -10 whilst the toroidal mode number of the low frequency mode was not resolvable due to the low signal amplitude.

A closer look at the inter-ELM mode of a single ELM is taken in figure 2. The measurement positions of the edge ECEI channels are shown in figure 2 a). All channels distributed along the flux surface, marked as red crosses, measure the modulation in the relative temperature level. The temporal evolution of the temperature fluctuations measured by the single ECEI channel at the vertical position z = 0.1 m, corresponding to the magnetic mid-plane, is shown in figure 2 b). A spectrogram of the mid-plane measurement, presented in figure 2 c), shows the strong mode in the $\sim$ 8 kHz range. The observed mode slightly changes in frequency during its lifetime. The duration of the mode is $\sim$ 10 ms and the measured absolute fluctuation level during the lifetime of the mode is about 10 %.

Poloidally resolved measurements of the temperature fluctuations along the flux surface are shown in figure 2 d) in a form of vertically distributed time traces. This kind of visualisation helps to follow the propagation direction of the mode. It can be seen that the mode propagates from the bottom to the top, corresponding to the electron diamagnetic direction. Such poloidally resolved measurements enable the determination of the poloidal velocity of the observed mode. In order to determine the velocity of the mode in the vertical plane we use the cross-correlation between the reference channel and all the other poloidally distributed channels along the flux surface as shown in figure 3. The reference channel is taken to be at the position of z = - 0.1 m. The velocity measured this way, shows no variations along the flux surface, and follows the straight line as indicated by
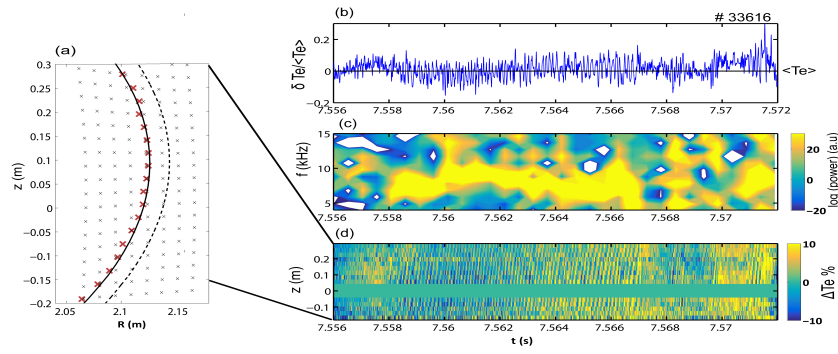
Figure 2: Localization and the temporal evolution of the T_e fluctuations seen in the ECEI observation window. a) Warm resonant channels (red crosses) of the array 2 distributed along the flux surface at the $\rho_{pol} \sim 0.985$. (b) Fluctuation level of a single channel 10 cm above the midplane. c) Time resolved spectrogram of the channel as in (b) showing the presence of the strong mode in the 7 - 8 kHz range. d) Temporal evolution of the fluctuation level in percentage measured by the channels whose positions are shown in (a) as red crosses. This allows to track the propagation of the fluctuations in the poloidal direction, from the bottom to the top channels, along the flux surface.

the black arrow. The measured velocity of the mode is ~ 3 km/s. High cross correlation between three vertical positions is present, indicating the structure with three maxima fitting in the ECEI observation window. The poloidal wavelength of this mode, therefore is $\lambda_{pol} \sim 15$ cm. The back-
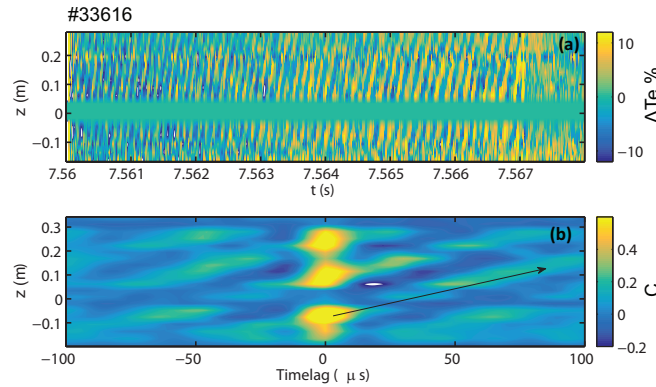

Figure 3: Cross-correlation of the reference channel taken at the vertical position z = -0.1 m with all other poloidal channels during the mode activity. The black arrow approximates the direction of the mode propagation in space and time.

ground $v_{E \times B}$ velocity is calculated as $v_{E \times B}(r) = \frac{\vec{E}(r) \times \vec{B}(r)}{B(r)^2}$, where the radial electric field E_r profile is evaluated using the neoclassical assumption for the poloidal impurity rotation [5]. As shown in figure 4, the radial extent of the plasma contributing to a different edge diagnostics used in this work is colour coded. Gray corresponds to the radial resolution of the ECEI and red to the Li-BES and ECE, respectively. It can be seen that the ECEI averages the signal over much wider range of plasma radius. However, an excellent radial resolution of the Li-BES enabled localization of the mode to a precision of up to 5 mm. As a result, the evaluated $v_{E \times B}$ at the position of the mode is about 25 km/s. This is, however, not in agreement with the velocity obtained from the ECEI diagnostic, which is measured to be 3 km/s.
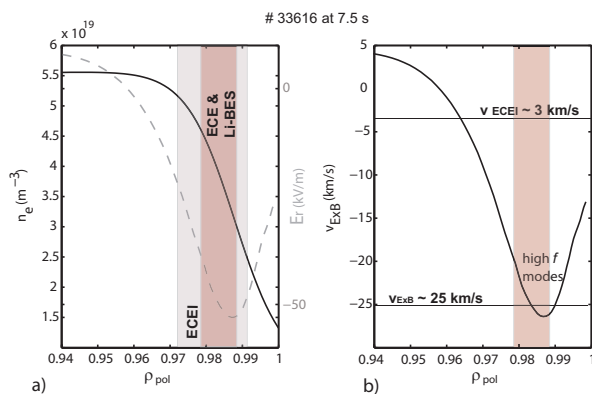
Figure 4: Shot # 33616 at t= 7.5 s. a) Density profile of the steep gradient edge region shown as a black solid line; radial electric field E_r is presented as a dashed gray line. Radial resolution of the edge diagnostics used in this work is color coded: red corresponding to the Li-BES and 1D ECE channel; grey corresponding to the ECEI channel. b) $E \times B$ velocity calculated using the E_r. The red shaded area shows corresponds to the measured low f and high f modes.

Conclusion: The discrepancy of the poloidal velocities between the magnetics and the ECEI measurement open up for multiple hypotheses regarding the observed modes. The first one is that the low frequency mode is the beat wave from the high frequency magnetic fluctuations amplified by non linear coupling of those at the bad curvature region. In this case the measured 3 km/s could correspond to the group velocity of the beat wave. Another hypothesis is that the low frequency mode is an individual mode, with a large phase velocity $v_{ph} = 22$ km/s in the ion diamagnetic direction.

As could be shown in this work the ECEI diagnostic is an excellent tool to determine poloidally velocities of structures in the plasma. In the pedestal region the fluctuation intensities, however, can be dominated by density fluctuations and information about the Te fluctuation amplitude must be carefully assessed. In order to distinguish between the two options more data analysis needs to be carried out with the focus on different plasma parameters that influences the change in the frequency of the high frequency modes.

Acknowledgements

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