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ELM filaments on ASDEX Upgrade: ECEI observations and modelling

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**See:http://www.euro-fusionscipub.org/mst1.*

Introduction: The Electron Cyclotron Emission Imaging (ECEI) diagnostic on ASDEX Upgrade has two separate arrays looking at two toroidally separated locations inside the plasma under slightly different toroidal angles [1]. Its poloidal extension enables covering the regions above, across and below the midplane. The two arrays can be focused independently and the measuring region can be shifted from the plasma centre to the plasma edge, changing the frequency of the local oscillators. When focused at the plasma edge, the ECEI observation window spans across the separatrix and it covers the Scrape-Off Layer (SOL) region. The low optical thickness (τ) in this region makes the interpretation of the ECE radiation more difficult, therefore analysis has to be done with special care. For this purpose the Electron Cyclotron Forward Model (ECFM), a single ray tracing model that accounts for both radiation transport and refraction has been employed [2][3]. This model includes the Doppler and relativistic broadening mechanisms, but it does not include the broadening due to the frequency bandwidth of the ECEI system. Therefore, every channel is represented by the value of its central frequency. Using this model it has been shown recently that the toroidal and poloidal launching angles have a large effect on the measurement positions of the ECEI on the ASDEX Upgrade tokamak when measuring at the plasma edge [3].

Figure 1a shows the observation window of ECEI when focused at the plasma edge. To first approximation emission is expected to originate from the cold resonance positions (X), determined by the local field strength. Electron temperature and density profiles in the ELM free interval for the shot #33616 at t = 6.8649s, used for the modelling, are shown in figure 1b. The radial ECEI observation window is enclosed with the black dashed lines. It covers most of the steep edge gradients and the pedestal top region. In figure 1c we present the optical thickness. $\tau > 3$ is the region inside the separatrix, representing black body radiation. If the optical thickness was the only criteria for valid ECE interpretation, from figure 1c we would conclude that the diagnostic delivers profiles from the core to the separatrix. However, when taking into account radiation transport along the lines of sight (LOSs) as well as the Doppler effect originating from

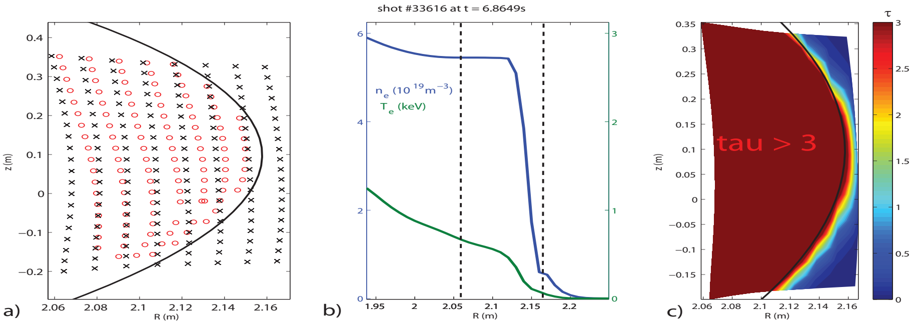

Figure 1: a) ECE Imaging observation window for shot # 33616 at t = 6.8649s. Black crosses are cold resonance positions whilst the red dots are the positions from where the radiation comes from, with radiation transport taken into account. b) the electron temperature and density profiles used in the model. Radial coverage of ECEI is labelled by the dashed lines. c) 2D optical thickness τ

the angle between the LOSs and the magnetic field lines, the signal that should be measured in the near SOL and the separatrix region actually originates from the pedestal top region as shown in figure 1a. Therefore the entire observation window shrinks to the region marked by the red circles. The lower limit on τ for plotted channels is 2.3 as suggested in [3]. Figure 2 shows the

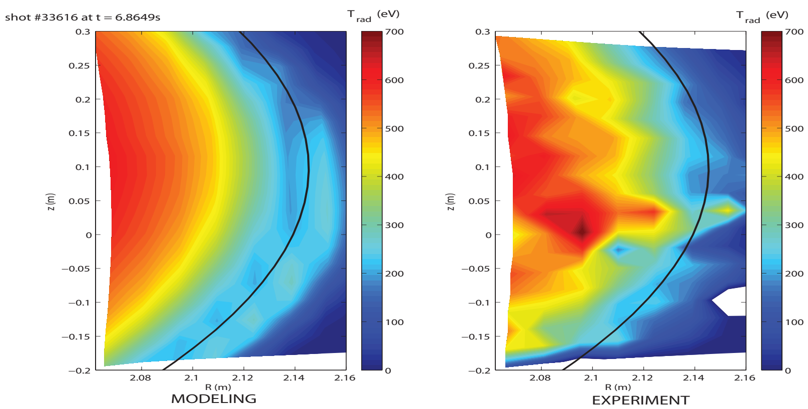

Figure 2: Radiation temperature (T_{rad}) a) Modelled radiation temperature without the presence of the instabilities. b) Measured radiation in the ELM free interval. Measurement positions correspond to the cold resonances. Black lines represent the separatrix position.

comparison between the modelled radiation temperature and the experimental measurements for all the LOSs of one of the arrays of the ECEI system and for the same shot and the time point as in figure 1. The obtained measurements are in a good agreement with the modelling, although with a single ray tracing it is impossible to capture the nature of the measurement entirely. Inside the separatrix is the region of large optical thickness (see fig 1c) therefore the measured temperature T_{rad} can be interpreted as the electron temperature T_e. However, as seen from figure 1a the radiation detected in the SOL originates from the region inside the separatrix.

Sensitivity of ECEI on ELM filaments: The optical depth τ in a tokamak is approximately proportional to the product $n_e \cdot T_e$, therefore any change in the density and the temperature should induce a change in τ. To account for this, the density and the temperature profiles during an ELM crash, with clearly distinguished filaments expelled, are taken from the JOREK[4] simulation of an ELM crash on ASDEX Upgrade [5]. These profiles, shown in fig 3a and 3b, together with the equilibrium for the discharge #33195 at t = 2.5872s and are used for the forward modelling. Figure 3c shows the 2D electron density of the filaments expelled during an ELM

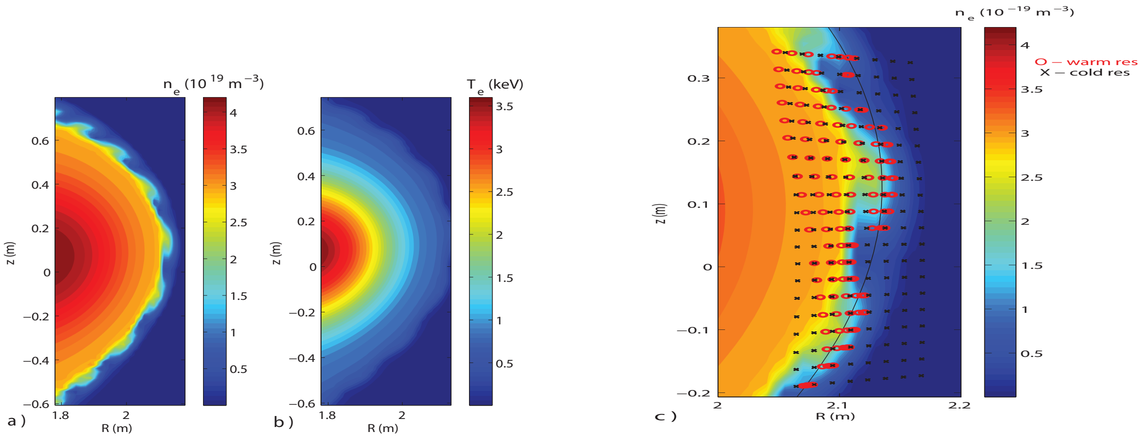

Figure 3: 2D JOREK profiles of a) Electron density; b) electron temperature. These profiles are adjusted to the actual values of the density and the temperature for the shot # 33195 at time t = 2.5872 s and used as an input for ECFM. c) Warm resonance positions as calculated with the ECFM (O); Cold resonance positions along the LOS (X).

crash at the midplane together with the calculated cold and warm resonance positions. As seen from this figure the positions of the outermost measurements match with the positions of the filaments. These outermost warm resonances of the LOSs at the midplane are in the SOL region. This shows that the presence of the filamentary structures influences the measurement position locally and that the ECEI signal originates also from the SOL region during these events.

In figure 4 we show the modelled measurement positions for shot #32583 during the ELM free interval where it is demonstrated that the signal, without the presence of the filaments, originates from the region inside the separatrix. Figure 5 shows the time traces, for the same shot as in figure 4, of the temperature fluctuations measured with the ECEI system. First, the time trace of divertor current is shown in figure 5a, as a signature of an ELM crash. Averaged temperature fluctuations corresponding to a SOL region and the pedestal top are shown in figure 5b and 5c, respectively. Dashed lines represent the ELM filaments seen in the ECEI signals above the midplane. In the channels with the cold resonances in the SOL region we distinguish

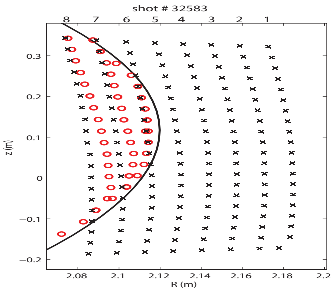

Figure 4: Cold and warm resonance positions for the shot #32583 just before an ELM crash

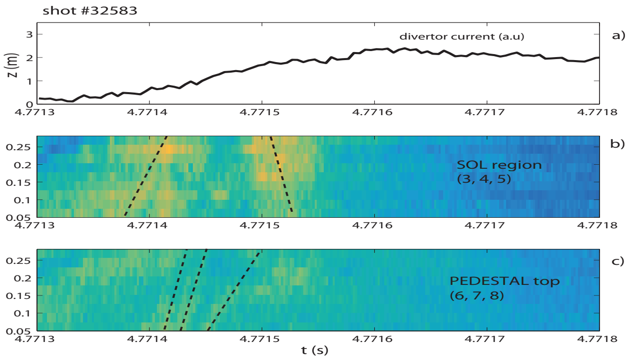

Figure 5: a) Divertor current. Averaged temperature fluctuations for different radial channels shown in: b) the SOL region; c) the pedestal top

two filaments: the first filament moving upwards with the velocity of$\sim$ 5 km s^{-1}. It is correlated with the onset of the ELM crash and the second filament, moving downwards with a velocity of$\sim$ 9 km s^{-1}. Thus, we observe the two different velocities in electron and ion diamagnetic direction, respectively. Under the assumption that the $\vec{E} \times \vec{B}$ velocity determines the propagation direction of the filament, the filament going upwards would be inside the separatrix, and the one appearing 100 μs later, moving downwards, would be the filament in the SOL. This change in the rotation of the filaments has also been observed in the modelling [6]. As shown in figure 5c the filaments seen at the pedestal top move upwards in the direction that is in agreement with the sign of the E_r in that position but with the different velocities [7].

In summary the ECEI diagnostic is sensitive to the filamentary structures in the SOL region, although the same channels can contain the signal from the pedestal top. By using both ECEI systems it is possible to localize filaments at two different toroidal locations simultaneously inside the plasma, therefore the spatio-temporal structure of these events can be examined in more details.

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