First comparison between numerical predictions and experimental observations with Collective Thomson Scattering in FTU

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Introduction

Collective Thomson Scattering (CTS) emission has been studied to investigate the ion dynamics in the plasmas, exploiting the interaction between an injected high power microwave beam and the plasma collective fluctuations that scatter radiation with frequency spectra mainly characterised by ion features. Presently a CTS system is foreseen for ITER, with the main aim of characterizing Fusion born alpha particles [1]. CTS measurements of several bulk ion parameters as temperature, drift velocity and composition have been demonstrated in TEXTOR and in ASDEX [2-4].

The CTS system in FTU can operate in different "non-resonant" regimes, with the Electron Cyclotron resonances outside the plasma, as foreseen for the CTS system in ITER, allowing investigating bulk ions (thermal) features with low disturbance from ECE emission. Up to now, just few non-resonant discharges could be carried out in FTU as part of the experimental programme aimed at studying the effects of Parametric Decay Instabilities (PDIs) on ECH [5]. The scattering set up is described in section 1 and calibrated thermal spectra are compared (in section 2) for the first time with the power spectral densities (PSD) simulated with the Thermal Collective Scattering (TCS) code [6].

1. Experimental setup

Experiments were performed at central toroidal magnetic field B=3.6 T and plasma current I_{pl}=350 kA, with the plasma between the first and the second EC harmonic resonances, both outside the plasma. The recently renewed CTS diagnostic setup of FTU exploited for the experiments is described in detail in [7]. The gyrotron probe beam (140 GHz, 400 kW, launched in O-mode from the low field side) crosses the receiving beam at the equatorial plane in correspondence of the q=2 surface, which corresponds to nearly middle radius, as shown in fig. 1 for shot #40282. Normally the launcher injects the probe with a fixed toroidal angle $\beta\sim5$ degrees in order to avoid direct back-reflection by the vessel wall. The receiving mirror, instead, sweeps toroidally during the discharge, covering an angular range of a few degrees around the angle expected for beams overlapping. The CTS measurement, localized in the scattering (crossing) volume, resolves plasma fluctuations with wave vector $\mathbf{k}_\delta=\mathbf{k}_s-\mathbf{k}_i$, where $\mathbf{k}_s$ and $\mathbf{k}_i$ are the wave vectors of the scattered and the incident beams, defining the so called scattering angle θ_s. The configuration above implies scattering near perpendicular to the magnetic field, i.e. with the magnetic angle ϕ_m (defined as angle between $\mathbf{k}_\delta$ and the magnetic field) close to 90 degrees, giving rise to spectral signatures of ion cyclotron motion and of weakly damped ion Bernstein waves [8]. This strongly enhances the dependence of CTS spectra on ion features and plasma composition. In order to resolve such ion cyclotron structures, which can be separated by 20-40 MHz, a fast digitizer with proper high frequency resolution capability has been recently implemented in the acquisition system [7].

The experimental discharges are characterized by different central line electron densities, ($0.5\text{-}1.2*10^{20}$ m^{-3}), and electron temperatures between 0.5 and 1.5 keV. In some discharges Neon was injected to induce MHD, since the experiments were mainly focused on studying the possible emissions due to PDIs from magnetic islands. The effect of Neon on the plasma composition has to be taken into account, together with the other impurities, while performing thermal CTS data interpretations.

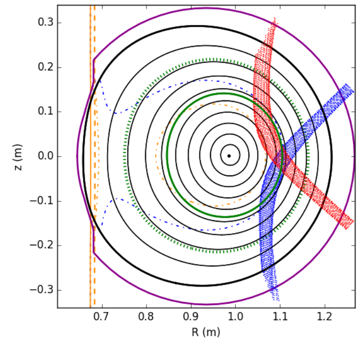

Figure 1: Poloidal view of O-polarized beams launched (red) and received (blue) in the FTU shot #40282 at time 0.505 s. The q=2 (3) rational surface is the green solid (dotted) line, the Upper Hybrid layer and X-mode right cut-off are the dash-dotted lines (yellow and blue respectively)

2. Spectra analysis

In order to properly interpret the experimental CTS spectra, the TCS code [6], developed for the analysis of thermal ions spectral functions, was recently generalized and upgraded [9]. This code is based on a kinetic electrostatic approach [8] where the incident beam scatters off electron density fluctuations. The code is capable either to predict CTS spectra for a given set of input parameters or to infer a number of plasma parameters by best fitting an input spectrum. It allows the interpretation of modulated spectra from a multi-species magnetized plasma, containing information about its composition [10]. The code was improved in order to provide the dimensional PSD and thus to have a first comparison between the expected and the calibrated experimental spectra. The location and dimension of the scattering volume, together with the crossing geometries, were calculated with the beam tracing code GRAY [11], which takes into account beams refraction. The electron temperature was measured by incoherent Thomson scattering, the electron density from interferometric measurements, while the ion temperature could be assessed from neutron diagnostics data. Regarding the plasma composition, the type of impurities and the ionization level were obtained by spectroscopy. Fig. 2 shows the first example of a calibrated measured spectrum and relative TCS prediction for FTU discharge #40282. The distribution of the peaks in the low frequency range of the spectrum is well reproduced by the code. The distance among the peaks is ~25 MHz, in agreement with the ion cyclotron frequency of the main impurities, as foreseen by theory. On the higher frequency range of the thermal spectrum, beyond a frequency shift of ~90 MHz from the probe frequency, instead, the calculated and measured spectra significantly differ.

2.1 Sources of uncertainties in the analysis

Despite measurements of the impurities type and ionization level are obtained by spectroscopy quite straightforwardly, the relative concentrations, required to properly predict CTS spectra, are hardly inferable in FTU. Only an approximate estimate of the range of the concentration level of the impurities can be made, and the accurateness of such interval depends on several parameters, as the effective ion charge Z_{eff} and the brightness of elements. The dependence of PSD on the impurities concentration is a critical point for the analysis of these data. In the analysis for the shot reported in fig. 2 the concentration of the known main impurity (i.e. Oxygen) has been inferred from the comparison of the measured spectrum with the TCS spectrum including contributions from impurities, in line with the measurements of Z_{eff}. TCS calculations performed using a single impurity (and with fixed Z_{eff}) seem to confirm Oxygen as dominant impurity: as shown in the box of fig. 2, the peaks amplitude ratio is better reproduced with Oxygen rather than with Neon. Another critical point is the size and localization of the beams overlapping, since they are highly refracted due to the high plasma density. This limits the accuracy of the interpretation of the measured PSD, which relies in the assumption of homogeneous plasma and constant wave-vectors in the whole scattering volume in our present analysis. The uncertainty on the superimposition of the probe and the receiver beams motivated the on-going study aimed to the calculation of spectra as possible overlapping of PSDs associated with different **k**-

components of the beams. Furthermore, plasma rotation cannot be measured in FTU and this phenomenon is known to affect the CTS spectra in terms of frequency shift [4]. Finally, calibrating spectra acquired in non-resonant plasmas is, in general, much more challenging than in the presence of harmonic resonances, that provide a reference ECE signal with high signal-to-noise ratio for calibration.

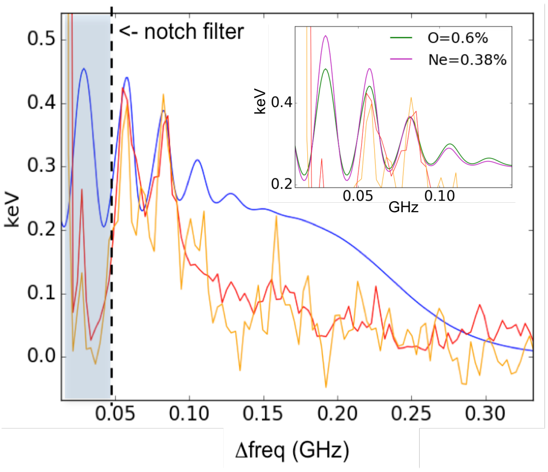

Fig. 2: CTS spectrum of FTU shot #40282 at time 0.505 s averaged on two time intervals (larger=red, smaller=yellow line), and dimensional PSD predicted by TCS (blue line) for central line density $n_{el}=8.7\ 10^{19}\ m^{-3}$, $B=3.6\ T$, $T_{e0}=1.3\ keV$, $T_{i0}=1\ keV$, $\theta_{sc}=109°$, $\phi_m=79°$. *The calibration method is reported in Ref. [9]. A concentration close to 0.5% of Oxygen was inferred by a fitting with TCS, including also small concentrations of Neon and Molybdenum, respectively 0.05%, 0.0005%. At low frequency the signal is strongly damped by a notch filter centered at zero Δfreq (frequency difference from the probe), which protects the receiver from stray radiation. In the top right box, the TCS spectrum with only Oxygen (in green) results in a better fit than with Neon (in magenta).*

3. Conclusions

In this work a first quantitative comparison between an experimental CTS spectrum measured in the FTU plasma and the prediction of the TCS code has been presented. A good agreement on the low frequency spectrum has been shown, while higher discrepancies are found at high frequencies. Investigations are ongoing, in particular to understand the effects on the spectra of the different critical aspects highlighted in the paper. New experiments are planned, aimed at measuring thermal emissions at high toroidal field, in non-resonant conditions similar to the configuration foreseen for the CTS in ITER, presently available only in FTU.

Acknowledgments: this work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

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