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Studies on LH-generated Fast Electron Tail Using the Oblique ECE Diagnostic at JET

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Abstract. The new Oblique ECE diagnostics of JET allows simultaneous measurement along three lines of sight at different toroidal angles. JET pulses, in which modulated LHCD power was applied, were analyzed by means of the SPECE emission code, which takes into account the fast electron tail generated by LH. The code results were compared to the ECE spectra from the oblique ECE diagnostic. The match between the computed and the experimental data from the three lines of sight provides an estimate of the density of superthermal electrons and of their maximum energy from which the fraction of the plasma current driven by LHCD is derived.

Keywords: Electron Cyclotron Emission, Superthermal Electrons, Lower Hybrid.
PACS: 5255Fa

INTRODUCTION

Electron Cyclotron Emission collected through antennae oriented in radial direction in the tokamak geometry is usually a reliable tool for electron temperature measurements. However a wider exploitation of the physics information brought by the EC waves is possible if the radiation is observed at multiple angles and over a wide spectral extension. In fact the resonance condition at a given frequency ω for a given propagation angle is matched by emitting electrons of energy specified through Eq 1:

$$\omega - k_{\parallel} v_{\parallel} = n \Omega / \gamma \quad (1)$$

where $\Omega = eB(R)/m_e$ is the cyclotron frequency corresponding to the local magnetic field $B(R)$, v_{\parallel} and k_{\parallel} are respectively the components of the electron velocity and of the wave vector parallel to $B(R)$, $\gamma = (1 - v^2/c^2)^{-1/2}$ is the relativistic factor, n the harmonics number and m_e the electron mass. Multiple angle observations then are a way to probe the electron velocity distribution function at multiple electron energies. This paper deals with the interpretation of the well known spectral feature arising in the region below the ECE 2nd harmonics peak when

¹ See the Appendix of F. Romanelli et al., Fusion Energy Conference 2008 (Proc. 22nd Int. FEC Geneva, 2008) IAEA, (2008)

a substantial amount of RF power at Lower Hybrid frequency is injected in the plasma.

OBLIQUE ECE SYSTEM AND ANALYSIS TOOLS AT JET

The Oblique ECE (ObECE) system at JET comprises five active channels. Three antennas oriented respectively at 0° , 10° and 22° with respect to the radial direction feed a multi-channel spectrometer which allows the simultaneous acquisition of nearly eXtraordinary (0° , 10° , 22°) and nearly Ordinary (10° and 22° only) spectra in the range of 80-350 GHz, corresponding to 1st-4th ECE harmonics, at 7ms per radial profile of temporal and 7-20 GHz of spectral resolution [1].

Data analysis is performed with the emission code SPECE that computes EC waves emission and propagation in the relativistic formulation for general tokamak equilibria, assuming Maxwellian or multi-Maxwellian electron velocity distribution functions [2]. This last feature allows the spectra computation when a fast electron tail is driven by Lower Hybrid waves. Magnetic equilibrium reconstruction from EFIT, electron temperature and electron density profiles from LIDAR, HRTS, ECM and KG1 are taken as input for spectra computation [3].

EXPERIMENTAL RESULTS

Measurements and analysis of the ECE spectra have been performed for a group of plasma pulses in which a significant LH power was injected using a time modulated waveform in order to identify the region of the power deposition [4]. The launched spectrum was set to $N_{//}=1.8$ in all cases here presented. Other plasma parameters are listed in Table 1. Besides the LH power, the main factor affecting the measured ECE spectrum is the plasma density.

TABLE 1 . JET plasma pulses with relevant LH power injection in which the analysis of the Oblique ECE measurements has been performed

Pulse	t(sec)	B(T)	I _p (MA)	n _e (10 ¹⁹ m ⁻³)	T _e (KeV)	P _{LH} (MW)	P _{NBI} (MW)
73417	65.4	2.7	1.75	6.2	5	2.9	6
73422	65.2	2.7	1.75	6.3	4.8	2.9	4.3
73646	64.15	2.3	2	4.3	3.4	1.9	-
73471	64.03	2.7	1.75	11.5	5.2	3.1	13.8
75401	55.95	3.4	2.5	5.2	3	2.5	-

In Figure 1 the ECE spectra for pulses at different plasma density are shown. Error bars in data take into account errors propagation due to statistical variance over ~100ms time average and uncertainty in ObECE calibration [5]. The most evident feature in pulses at low density is the development of an intense emission peak in the frequency range between the first and the second harmonics. The nature of this emission peak, present at all the angles of sight and for both the polarization modes, is well known [6] and can be ascribed to the relativistic 2nd harmonics downshift of the emission due to fast electrons accelerated by LH waves. Information about the characteristics of the superthermal tail can be derived from the analysis of emission peak using the set of simultaneous measurements supplied by the ObECE diagnostics.

DATA ANALYSIS AND DISCUSSION

The experimental data in Figure 1 are compared with simulated spectra, computed assuming a Maxwellian electron velocity distribution function (73471, highest density case) or, in the cases in which the superthermal feature appears in the spectrum, assuming the presence in the plasma of a fast electron tail (73417 and 73422).

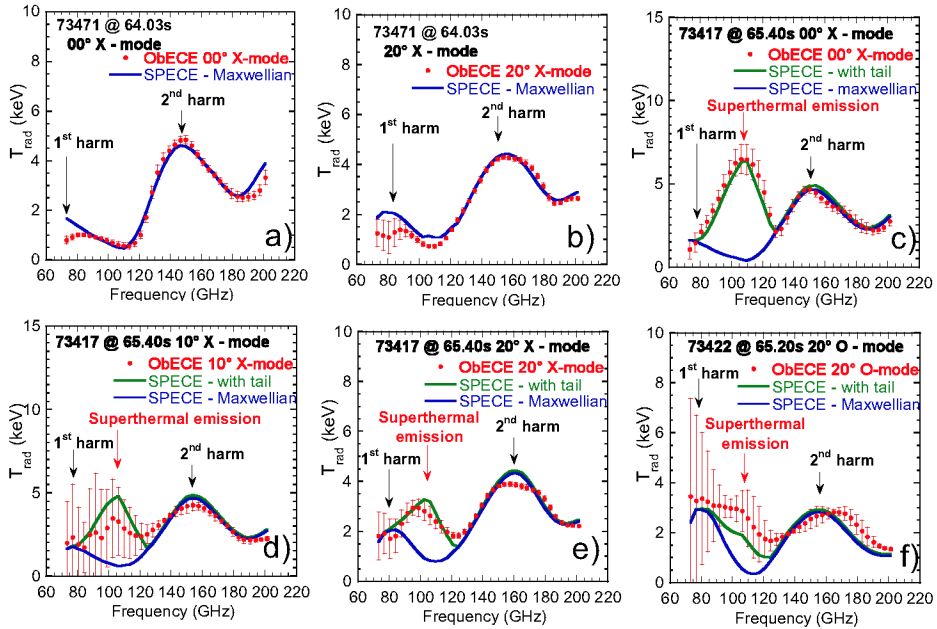


FIGURE 1: Experimental (red dots) and simulated (solid lines) spectra for pulse 73471 (a,b), 73417 (c,d,e) and 73422 (f). Maxwellian EDF simulations are added for comparison in c, d, e, f.

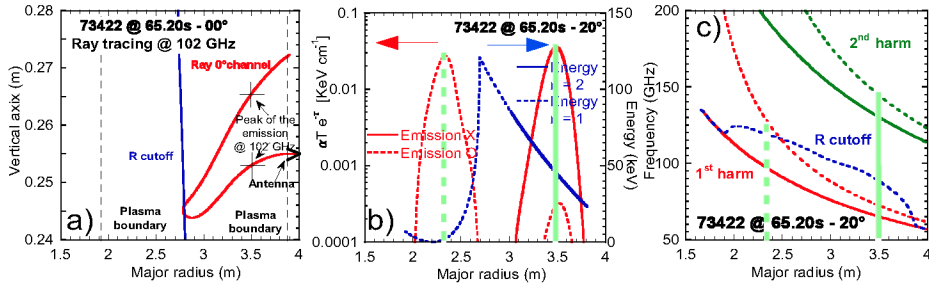
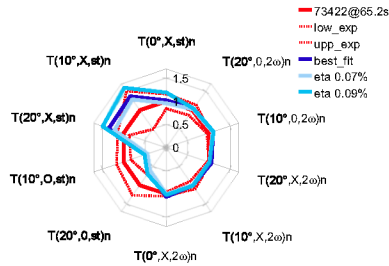


FIGURE 2: Ray path(a), emission lines width, energy and radial location (b, c) for pulse 73422 at 20° line of sight. Plots refer to a frequency of 102GHz, the peak of the superthermal emission.

Agreement between experimental data and simulations is generally less satisfactory for O mode spectra, where the superthermal feature is underestimated by simulations. Similar behavior has been found in pulses at higher magnetic field, where all the spectral features are shifted at higher frequencies. Figure 2 shows the features of the

superthermal emission at the frequency of its peak value. Rays originated in the low field side are deviated outwards by the R cutoff. X mode around $R=3.5\text{m}$ (electron energy $\sim 30\text{-}70\text{ keV}$) and O mode at 2.3m ($\sim 0\text{-}30\text{ keV}$) and 3.5m ($\sim 30\text{-}50\text{ keV}$) contribute at the emission at this frequency. The discrepancies in the peak temperatures (normalized to experimental data) obtained from measurements and from simulations in pulse 73422 are compared in Figure 3. In the case represented the density of superthermal electrons has been varied (cyan lines) in simulations of 12.5% around the best fit value (blue line). Dotted red lines represent experimental error bars. The peak value of superthermal X emission feature results notably sensitive to this parameter. The other parameters used in the simulations and giving information on the characteristics of the electron tail are listed in Table 2.



Figures 3: Comparison between simulated and measured peak temperature (normalized) values for pulse 73422 (see text).

The peak value of superthermal X emission feature results notably sensitive to this parameter. The other parameters used in the simulations and giving information on the characteristics of the electron tail are listed in Table 2.

TABLE 2. Parameters of superthermal tail in SPECE simulations corresponding to best fit of experimental data. From left: pulse number, max normalized momentum p_{\parallel}/mc corresponding to launched N_{\parallel} , temperature and density of the tail, centre and width of the spatial distribution of the tail in poloidal flux coordinates, fraction of plasma current driven by fast electrons.

Pulse	u_{\parallel}	$N_{\parallel}^{\text{launch}}$	T_{tail} (keV)	η (%)	Ψ_0	Ψ_c	$I_{\text{st}}/I_{\text{pl}}$ (%)
73417	-0.45	1.8	38	0.08	0.4	0.2	15
73422	-0.45	1.8	28	0.08	0.4	0.2	12
73646	-0.35	1.8	45	0.1	0.5	0.3	13
73471	-	-	-	-	-	-	-
75401	-0.2	1.8	35	0.9	0.9	0.3	13

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