Feasibility study of non-Maxwellian distribution Measurement using an oblique view in ITER electron cyclotron emission diagnostics

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A longstanding and systematic disagreement between electron temperatures measured by electron cyclotron emission (ECE) diagnostics and Thomson scattering (TS) has been attributed to the presence of non-Maxwellian features in the bulk electron momentum distribution. Initially observed in JET and TFTR tokamaks, this discrepancy showed higher ECE temperatures (T_{ECE}) compared to TS temperatures (T_{TS}) for central electron temperatures, $T_e(0)$ exceeding 7 keV. However, recent deuterium-tritium (DT) experiments at JET have revealed cases where T_{ECE} can either exceed or fall below T_{TS} [1]. These inconsistencies are expected to become more pronounced during ITER operations, where $T_e(0)$ is projected to reach ~25 keV.

Previous ray-tracing ECE modeling [2] suggested that moderately oblique viewing angles, such as 10 and 20 degrees, could effectively detect non-thermal electron energies in the range of 20–70 keV, supporting the inclusion of at least one oblique antenna for ITER's ECE diagnostics. As ITER's ECE diagnostic system approaches its final design phase, port engineering limitations have constrained the oblique angle to 9.25°. This study investigates the feasibility of detecting non-thermal electrons with an oblique view at 9.25°. Additionally, it predicts the effects of non-Maxwellian electron momentum distributions on electron temperature measurements and the corrections needed to align ECE readings with those of the TS diagnostic. This analysis is crucial, as future reactor-grade tokamaks are likely to face challenges with current diagnostic systems. ECE diagnostics, being minimally intrusive, are expected to survive the environment to provide parameters for plasma control.

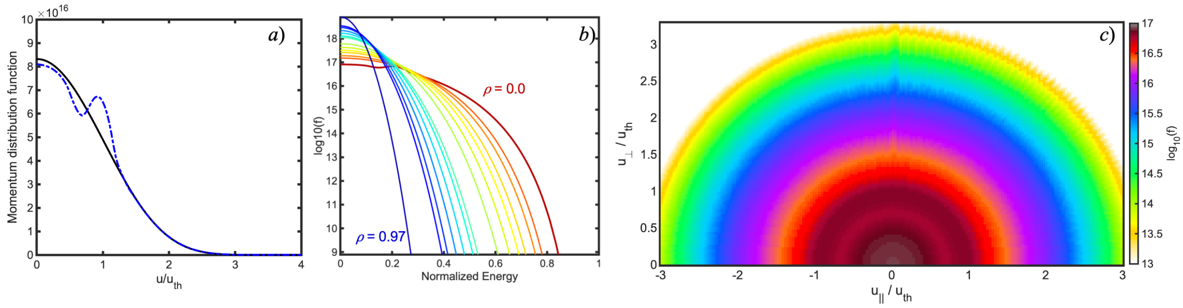

Figure 1. a) Distorted electron momentum distribution function compared with Maxwellian distribution function. b) Profile of distribution function. Only the distribution function in the core is distorted. c) Structure of the core distribution function in parallel and perpendicular momenta space.

The ECE assessment presented in this work was modeled using GENRAY [3], a 3D ray-tracing code designed to calculate emission, absorption, and radiation transport for both thermal and nonthermal electron distributions. The modeling focused on H-mode ITER scenarios with an on-axis temperature of 25 keV at full-field (5.3 Tesla) and half-field. Two types of electron distributions were considered: *a*) an isotropic relativistic Maxwellian distribution and *b*) a non-Maxwellian distribution. The non-Maxwellian distribution was generated by distorting the electron momentum distribution (u) from the Maxwellian distribution in the range of $u < 1.5u_{th}$, where u_{th} is the average electron thermal momentum, to include a two-temperature distribution; an example of the distributions is shown in Figure 1.*a*. To ensure comprehensive analysis, simulations were performed for both X- and O-mode polarizations and repeated at two observation angles: 0 degrees (radial view) and 9.25 degrees (oblique view). Figure 2 shows the emission fluxes measured with an ECE antenna at the edge of the ITER H-mode for both Maxwellian and non-Maxwellian electron momentum distributions. While the X-mode radial view is sensitive to non-Maxwellian distortions, the oblique view is sensitive to electron energies up to 35 keV. For O-mode, the radial view captures temperature distortions caused by non-thermal electrons, whereas the oblique view at the first harmonic is sensitive to energies up to 45 keV. Furthermore, both polarizations at higher harmonics can be utilized to infer temperature. Practically, a Fourier Transform Spectrometer (FTS) can be employed to cover this spectral range for temperature measurements at higher harmonics.

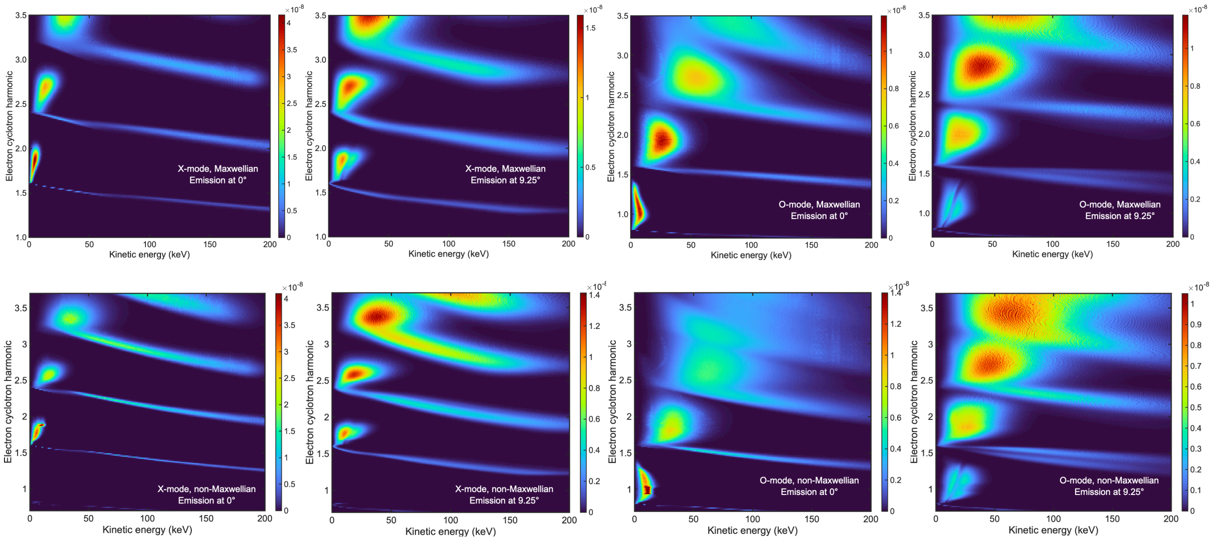

Figure 2. Emission fluxes at the edge of plasma for O-mode and X-mode polarizations at 0° (radial view) and 9.25° (oblique view) of ITER ECE antennae.

Figure 3 illustrates the simulated ECE spectra across multiple cyclotron frequency harmonics. These simulations suggest that O-mode emission at the first harmonic and X-mode emission at the second harmonic may yield unreliable temperature measurements. However, emissions at higher harmonics can provide accurate temperature information using ECE instruments. The results also confirm that the reduced oblique angle is sufficient for detecting non-Maxwellian distributions.

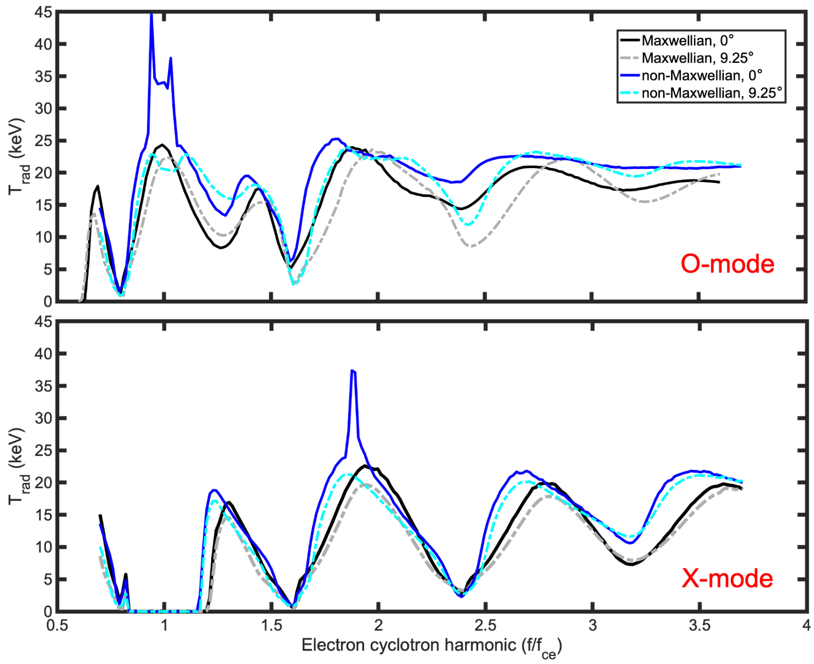

Figure 3. O-mode and X-mode ECE temperature spectra versus emission frequency normalized to the fundamental cyclotron frequency on-axis, for Maxwellian and distorted distributions and for radial and oblique angle at 9.25°.

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