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Measurement of High Harmonics ECE in Optically Thin LHD Plasmas For The Reconstruction of Electron Velocity Distribution Function and The Evaluation of Electron Entropy

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In magnetized fusion plasmas, turbulence, characterized by fluctuations across broad ranges of scales, has been regarded as one of the main obstacles in achieving commercial power plants, as the anomalous transport caused by such non-linear phenomena induces a significant loss of particles and energy.[1] One may view upon such a multiscale interaction as the cascade of energy from its input at large scales, to its dissipation as heat at small scales.[2] Due to its irreversible nature, the cascade of entropy through phase space is also of great interest, and has been measured in the ion scale for laboratory plasmas[3] and simulated using gyrokinetic models[4]. However, there seems to be no experiemental measurements in the electron gyroscale so far. Here, we propose a method to evaluate the electron entropy $S_e = -\int f_e \ln f_e \, d^3v$, where $f_e(v)$ is the electron velocity distribution function, via measurements of high harmonics of the electron cyclotron emission (ECE).

In conventional ECE, optically thick plasmas reach thermal equilibrium with the electromagnetic fields, meaning that the emission spectrum is that of a blackbody, which is directly proportional to the local electron temperature. For optically thin plasmas, the coupling between the radiation modes and the electron gyromotion is shown by the emissivity being a weighted sum of f_e[5], suggesting the possibility of exploring different regions of the velocity space. For this purpose, we employ the maximum entropy method for the evaluation of the entropy, where the fluctuation part of the distribution function δf_e shows up as a byproduct during the process.

For the experimental verification of such an idea, we have measured ECE up to the 4th harmonics in low density ($n_e \lesssim 5 \times 10^{18}\ \mathrm{m}^{-3}$) and low temperature ($T_e \lesssim 1.5$ keV) plasmas in the Large Helical Device (LHD) with a low magnetic field setup ($B = 1$ T), where the optically thickness is less than 1 for the 3rd and higher harmonics. NBI and ECR at 56 GHz has been modulated at 50 Hz to perturb the electron velocity distribution function. Measured ECE signal is also crosschecked with different diagnostics, such as the Thomson scattering system for the distribution function reconstruction, and the millimeter wave scattering system for the electron-scale turbulence measurements.

References

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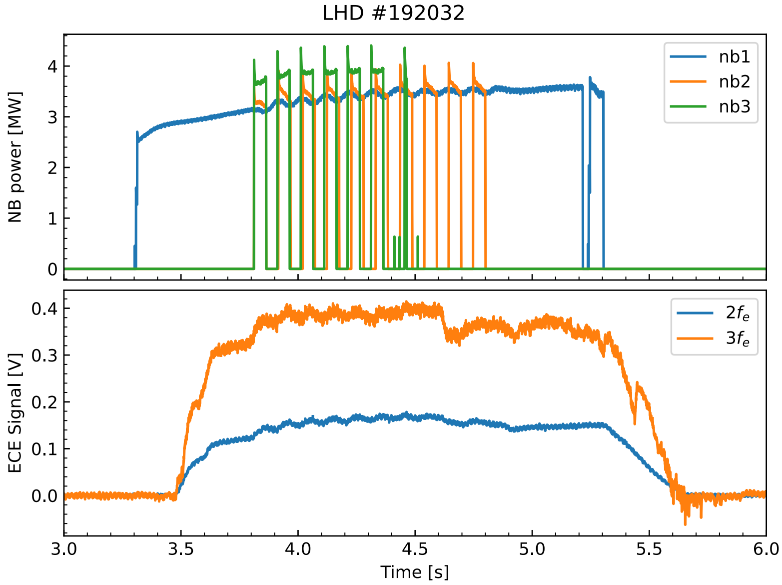

Figure 1. 2nd and 3rd harmonics of ECE signal measured in optically thin LHD plasmas at a normalized radius of $\rho = 0.833$, showing modulation in accordance with the input NBI power.