9th Asia-Pacific Conference on Plasma Physics, 21-26 Sep, 2025 at Fukuoka

Experimental Verification of Cascade of Electron Entropy in Laboratory Plasma Experiments

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To realize nuclear fusion as a commercially available power source, one of the major obstacles that must be overcome is the confinement of high temperature plasma. In magnetized fusion plasma, it has been considered that turbulence is the main cause of the rapid lost (anomalous transport) of particles and energy from the confinement region [1]. Therefore, understanding the nature of turbulence in the context of magnetized plasmas is of fundamental importance to mitigate anomalous transport.

One way to tackle with problems related to turbulence is through the point of view of its irreversible nature involving fluctuations spanning over a wide range of length scales, for which the entropy spectrum in both real- and velocity-space represents the crucial quantity to be evaluated. Between the largest scale where energy is injected into the system and the smallest scale where it is dissipated as heat, both energy and entropy are cascaded through this hierarchy of length scales. Such cascades have been measured for ion-scale turbulence in laboratory plasmas previously [2]. Here we present a new diagnostics method for the electron-scale turbulence case, based on measurements of the electron cyclotron emission (ECE) spectrum.

ECE has been widely-adopted for electron temperature measurements of magnetized fusion plasmas, where under the condition of optically thick plasmas, the emission spectrum will be that of a blackbody, hence directly revealing the temperature profiles. However, for low-density and temperature cases, the emission modes retain the original electron gyromotion information, which results in a spectrum that is a weighted sum of the electron velocity distribution function (EVDF) [3]. The implication is that the intensities of the various harmonics of ECE constrain the form of EVDF, and the information of electron phase space (i.e., EVDF itself) may be inverted using these constraints. For this purpose, we adopt the method of maximum entropy, as the equilibrium state is the state which maximizes the entropy $S_e = -\int f_e \ln f_e \, d^3v$, where $f_e(v)$ is the EVDF. The problem of maximizing the fluctuation part of the entropy $\tilde{S}_e \equiv -\int \delta f_e^2 \, d^3v$ under the constraints given by the ECE harmonics is accomplished via Lagrange multipliers after transforming into the velocity-wavevector space via Hankel transform, where the amplitudes of the fluctuating components δf_e is automatically obtained as the multipliers themselves [4]. Finally, the reconstructed entropy spectrum may be compared with theoretical models to verify the cascade due to turbulence.

For the experimental verification of these ideas, results from the MPX linear mirror device ($n_e \lesssim 10^{18}$ [m^{-3}], $T_e \lesssim 10$ [eV], $B \lesssim 0.1$ [T]) will be presented. ECE spectrum measured with radiometers from the optically-thin plasmas will be used for the reconstruction of EVDF and to verify the cascade of entropy. The reconstruction results will be crosschecked with measurements from Langmuir probes.

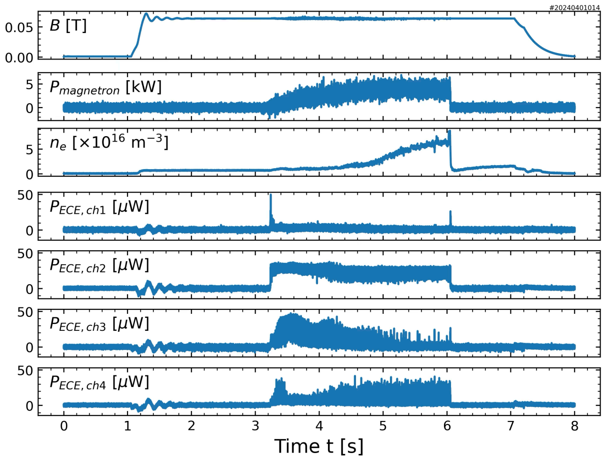

Figure 1. Waveforms of the magnetic field strength, heating power, electron density, and ECE signals measured by the radiometer measured at the MPX linear mirror device that will be used for the reconstruction of the EVDF and to verify the cascade of entropy.

References

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