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

Collective Thomson scattering for non-equilibrium plasma measurements

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Collective Thomson scattering (CTS) is a powerful tool for observing local quantities in high energy density plasmas. Since CTS is a parametric resonance among incident electromagnetic, scattered electromagnetic, and plasma waves, the dispersion properties and amplitude of plasma waves, functions of local plasma parameters, are directly observed. While a well-established theory describes the scattered spectrum of CTS in linear, steady, stationary, and equilibrium plasmas, the spectral shape of CTS in non-equilibrium plasmas is not yet fully understood. We have been studying CTS in the two-stream state, where two collisionless plasma flows interact and the distribution functions deviate from Maxwellian, in the context of laboratory astrophysics experiments [1,2]. We conducted particle-in-cell simulations and extracted CTS spectra by solving the wave equation for the scattered wave. By comparing theory with simulation, we found that the conventional theory of CTS spectrum is not directly applicable to the two-stream state because the plasma state changes rapidly, particularly in the presence of fast-growing electron-scale instabilities. However, the simulated spectrum is explained by the quasi-equilibrium distribution functions after the instabilities saturate, indicating that the measurement timescale significantly influences the shape of the scattered spectrum. In addition to theoretical and numerical investigations, we have been working on a proof-of-principle experiment of CTS in non-equilibrium plasmas [1] and the data-driven analysis of CTS spectra in non-equilibrium plasmas using Bayesian inference [3].

References

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