Investigation of Collisional Electron Plasma Waves and Picosecond Thermodynamics in a Laser-Produced Plasma using Thomson scattering Spectroscopy

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The rapid, picosecond time-scale evolution of electron density and temperature in a laser-produced plasma was measured using collective Thomson scattering [1]. As is the case for many laser-plasma applications, an underdense (~10^{19} cm^{-3}) H_2 plasma was created by a 60-ps, 1053-nm laser pulse with an intensity of ~3×10^{14} W/cm^2. Unprecedented picosecond time resolution, enabled by a pulse-front–tilt compensated spectrometer, revealed a transition in the plasma-wave dynamics from an initially cold, collisional state to a stable, collisionless state. The temperature heated from 3 eV to 16 eV over the first 18 ps. Over this time, the density increased from 8.4×10^{18} cm^{-3} to its plateau at 1.0×10^{19} cm^{-3}. Once the plasma was fully ionized, the temperature rapidly increased to a plateau temperature of ~90 eV. The Thomson-scattering spectra were compared with theoretical calculations of the fluctuation spectrum using either a conventional Bhatnagar–Gross–Krook (BGK) collision operator or a full set of Landau collision terms—the BGK model overestimates the electron temperature by 50% in the most collisional conditions. This overestimation of collisions by the BGK model has implications that extend well beyond Thomson scattering as this is one of the most widely used collisional models in plasma physics. These picosecond electron temperature and density measurements can be applied to laser-plasma devices that require knowledge of the rapidly evolving plasma conditions. For example, laser-plasma amplifiers require frequency matching between an electromagnetic beat wave and the plasma frequency for efficient energy transfer from the pump laser to the seed, but if the plasma frequency is rapidly evolving, as it does in these experiments, the amplifier will be detuned and the efficiency will be poor. With measurements of the plasma evolution, the system could be properly tuned to recover efficient energy transfer.

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Reference

[1] “Picosecond Thermodynamics in Underdense Plasmas Measured with Thomson Scattering,” A. S. Davies, D. Haberberger, J. Katz, S. Bucht, J. P. Palastro, W. Rozmus, and D. H. Froula, Physical Review Letters (2019).