Impact of Non-Maxwellian Electron Velocity Distribution Functions on Inferred Plasma Parameters in Collective Thomson Scattering

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Optical Thomson scattering is a powerful diagnostic that is widely used to measure plasma conditions in laser-produced plasmas.[1] As large multibeam facilities are constructed to achieve inertial confinement fusion around the world,[2–4] accurate measurements of plasma conditions are becoming increasingly important for understanding the importance of missing physics in the large hydrodynamic simulations. Local and time-resolved measurements of Thomson-scattered spectra have provided valuable insight into a range of studies, including laser–plasma instabilities,[2] thermal transport,[5] and more generally inertial confinement fusion.[6,7]

The high density present in laser-produced plasmas results in scattering optical light from collective plasma-wave fluctuations. The scattering from low-frequency fluctuations generates ion-acoustic spectral features, while scattering from high-frequency fluctuations generates electron plasma wave spectral features. Early collective scattering measurements from high-frequency fluctuations used the theory developed two decades earlier by Salpeter[8] to associate the wavelength of spectral peaks with density, through the Bohm–Gross dispersion relation, and the width of spectral peaks to temperature, through Landau damping, but the small scattering cross section for Thomson scattering has resulted in relatively few experiments where electron temperature and density were measured from the electron plasma wave features.[6,9–11] Recent experiments have used the full Thomson-scattered spectrum to extract plasma conditions, but these studies have been limited to assuming Maxwellian distribution functions. However, variation in the shape of the distribution functions can lead to significant changes to the Thomson-scattering spectrum.[12]

Here, we investigate the sensitivity of electron temperature and density inferred from collective Thomson scattering to non-Maxwellian electron distribution functions. Analyzing synthetic electron plasma wave Thomson-scattering spectra, under the false assumption that the electron distribution function is Maxwellian, can lead to gross errors in the inferred electron density and temperature. Figure 1 shows that the inferred temperature and density can differ from the actual values by 50% and 30%, respectively. These errors stem from changes in the shape of the scattered spectra and can be removed by including the correct shape of the electron distribution function in the analysis. Other changes to the shape of the electron distribution function can result in errors in the inferred parameters, as in the case of heat flux.[7] These errors of 50% in temperature and 30% in density are for extreme changes to the electron distribution function, but even for small changes in the shape of the distribution function, the errors in temperature and density are larger than the statistical uncertainty of ~5% that is typical[10,11] and can be a limiting factor in determining plasma conditions.

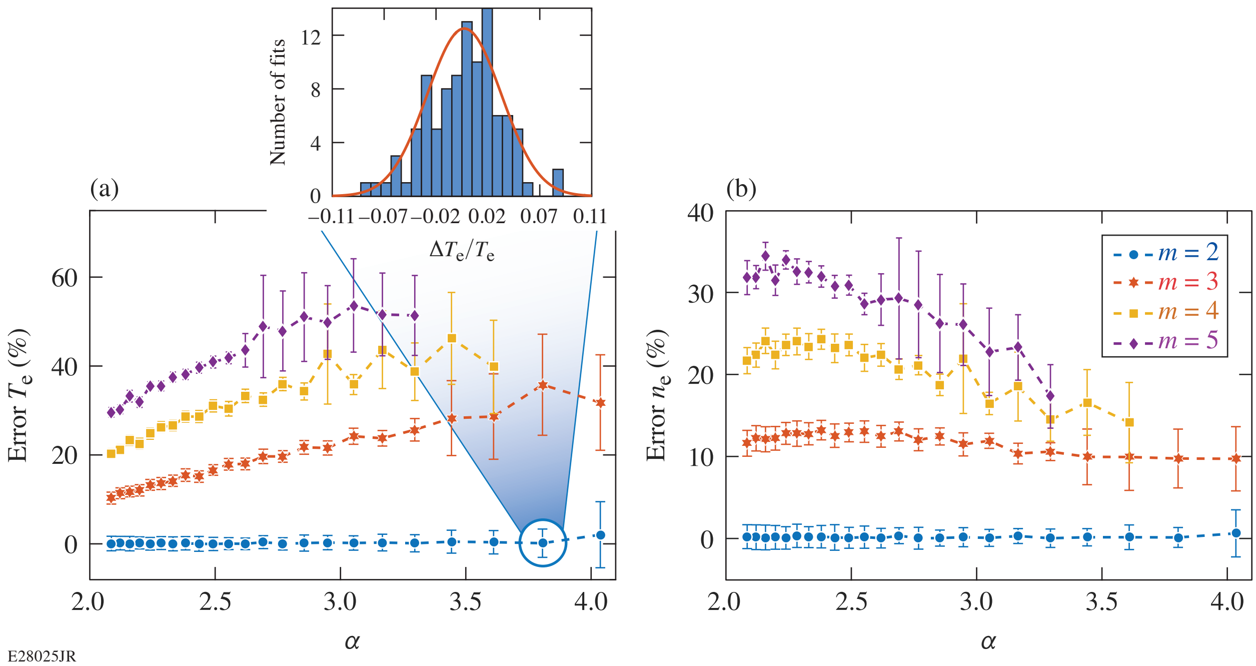

Figure 1
Percent error in (a) temperature and (b) density as a function of the normalized phase velocity $\left(\alpha = v_\phi / v_{th}\right)$ when the fit model assumes a Maxwellian electron distribution function and the true electron distribution function is super-Gaussian. The absolute difference between the inferred and actual parameter dividend by the actual parameter (percent error) is calculated for a range of phase velocities. The values for four different super-Gaussian orders are plotted in different colors with error bars that represent the standard deviation of 100 fits.

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1. D. H. Froula *et al*., *Plasma Scattering of Electromagnetic Radiation: Theory and Measurement Techniques*, 2nd ed. (Academic Press, Amsterdam, 2011).
2. C. A. Haynam *et al*., Appl. Opt. **46**, 3276 (2007).
3. J. L. Miquel, C. Lion, and P. Vivini, J. Phys.: Conf. Ser. **688**, 012067 (2016).
4. W. Zheng *et al*., High Power Laser Sci. Eng. **4**, e21 (2016).
5. R. J. Henchen *et al*., Phys. Rev. Lett. **121**, 125001 (2018).
6. S. H. Glenzer *et al*., Phys. Plasmas **6**, 2117 (1999).
7. D. H. Froula *et al*., Phys. Plasmas **13**, 052704 (2006).
8. E. E. Salpeter, Phys. Rev. **120**, 1528 (1960).
9. J. S. Ross *et al*., Phys. Rev. Lett. **104**, 105001 (2010).
10. J. S. Ross *et al*., Rev. Sci. Instrum. **81**, 10D523 (2010).
11. S. C. Snyder *et al*., Phys. Rev. E **50**, 519 (1994).
12. J. Zheng, C. X. Yu, and Z. J. Zheng, Phys. Plasmas **4**, 2736 (1997).