An Extended Vlasov-Fokker-Planck approach to laser absorption and ponderomotive transport effects

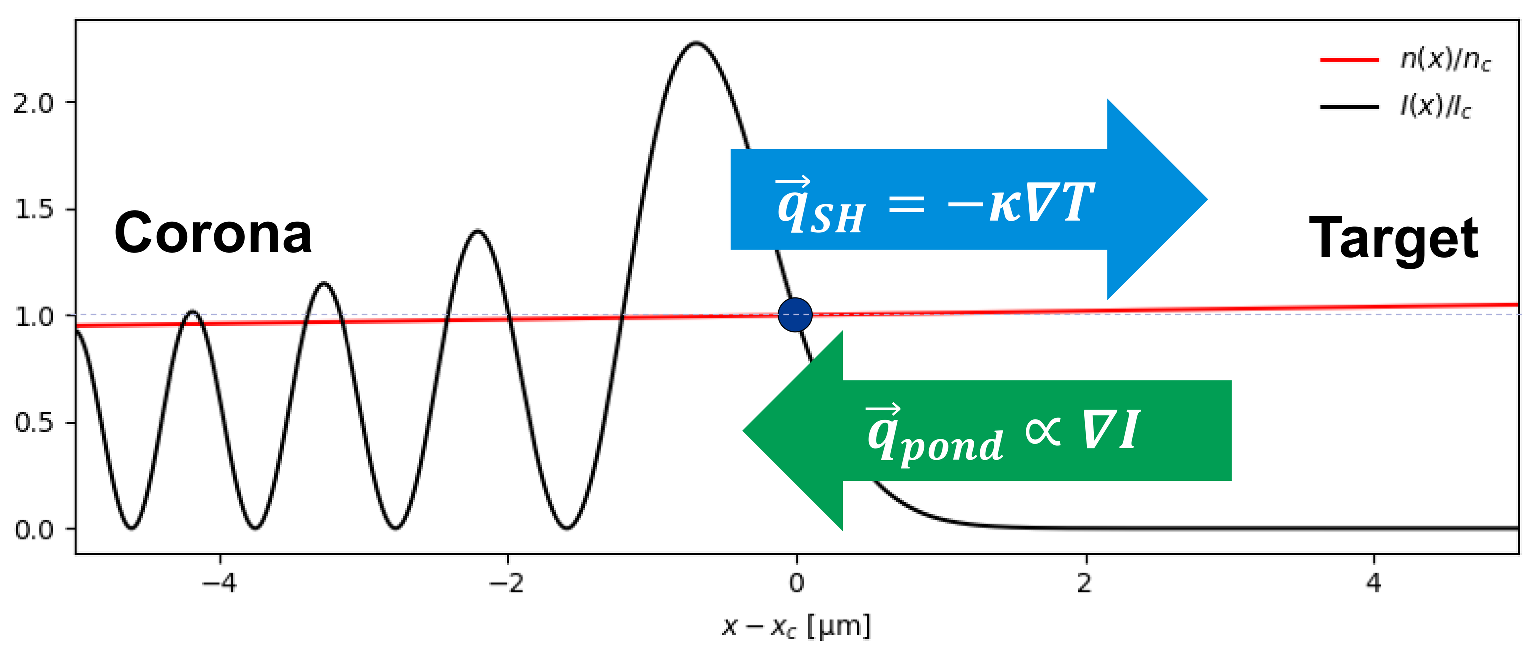
N. R. Shaffer, V. N. Goncharov, A. V. Maximov, and M. Sherlock†

University of Rochester, Laboratory for Laser Energetics

†Lawrence Livermore National Laboratory

Background & Motivation

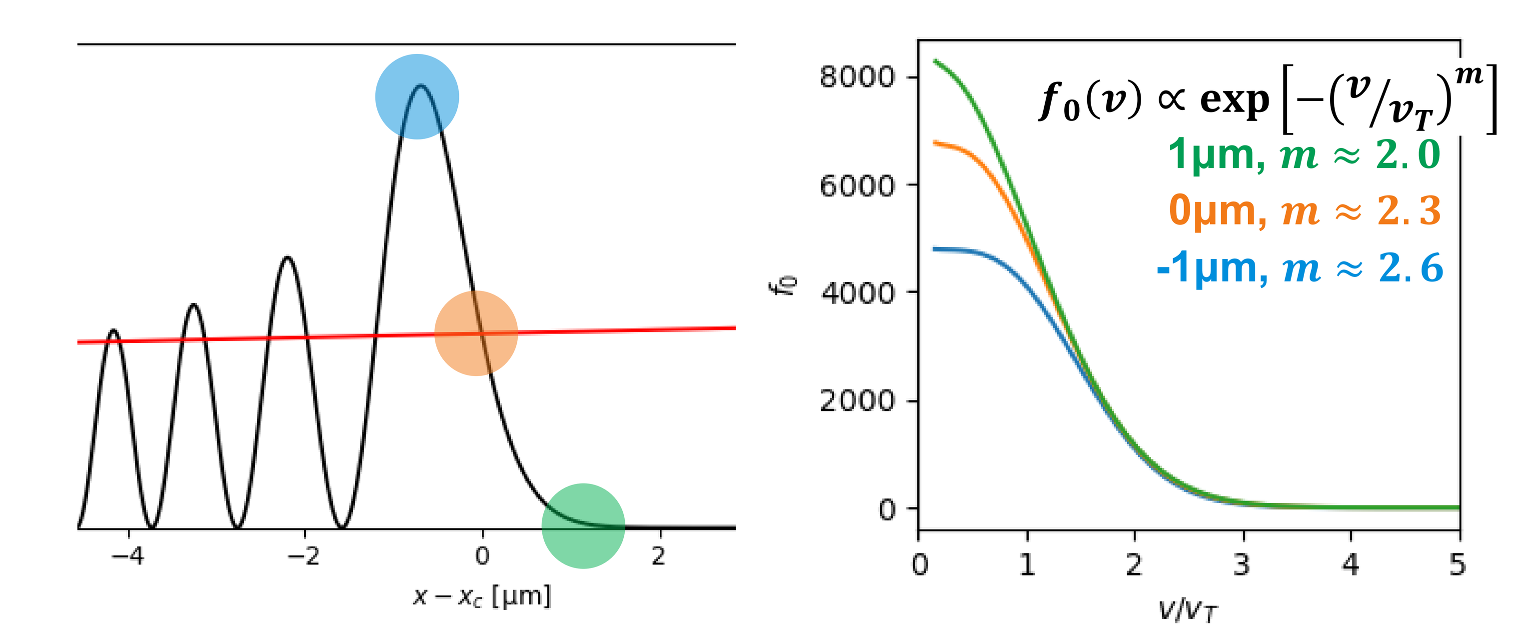
Absorption at the critical density produces a sharp intensity gradient. This gradient influences heat conduction via the ponderomotive force and non-uniform inverse bremsstrahlung & Langdon effect[1-3].



$$\lambda_L = 0.351\mu\text{m} \quad L_n = 100\mu\text{m}$$

$$L_I \approx 5\left(\lambda/L_n\right)^{\frac{2}{3}} L_n \approx 10\ \mu\text{m}$$

$$L_{pond} = \frac{k_B T}{F_{pond}} \approx 100 - 1000\ \mu\text{m}$$



Technical Challenge with VFP Modeling

A naïve approach to simulating heat conduction at the critical density is impractical due to the huge scale separation between the laser field and collisional transport.

$$\frac{\partial f}{\partial t} + \vec{v}\cdot\frac{\partial f}{\partial \vec{r}} - e\left[\vec{E}_0 + \vec{E}_L\cos(\omega_L t)\right]\cdot\frac{\partial f}{\partial \vec{p}} = C_{ei}[f] + C_{ee}[f,f]$$

$$\omega_L \gg \tau_e^{-1} \qquad \lambda_L \ll \lambda_{mfp}$$

Extended VFP Equations for LPI

Assume the electric field cleanly separates into quasistatic (ambipolar - dc) and quasiharmonic (laser - ac) components. If the intensity is not too high (neglect harmonic generation), then the distribution function can also be decomposed.

$$\vec{E}(\vec{r},t) = \vec{E}_0(\vec{r},t) \quad + \quad \Re\left[\vec{E}_L(\vec{r},t)e^{-i\omega_L t}\right]$$

$$f(\vec{r},\vec{p},t) \to f(\vec{r},\vec{p},t) + \Re\left[\vec{f}_L(\vec{r},\vec{p},t)e^{-i\omega_L t}\right]$$

The dc and ac distributions obey coupled kinetic equations. Conduction-relevant LPI processes emerge from the coupling terms. These terms have been implemented in the K2 VFP code using implicit time-stepping methods[4].

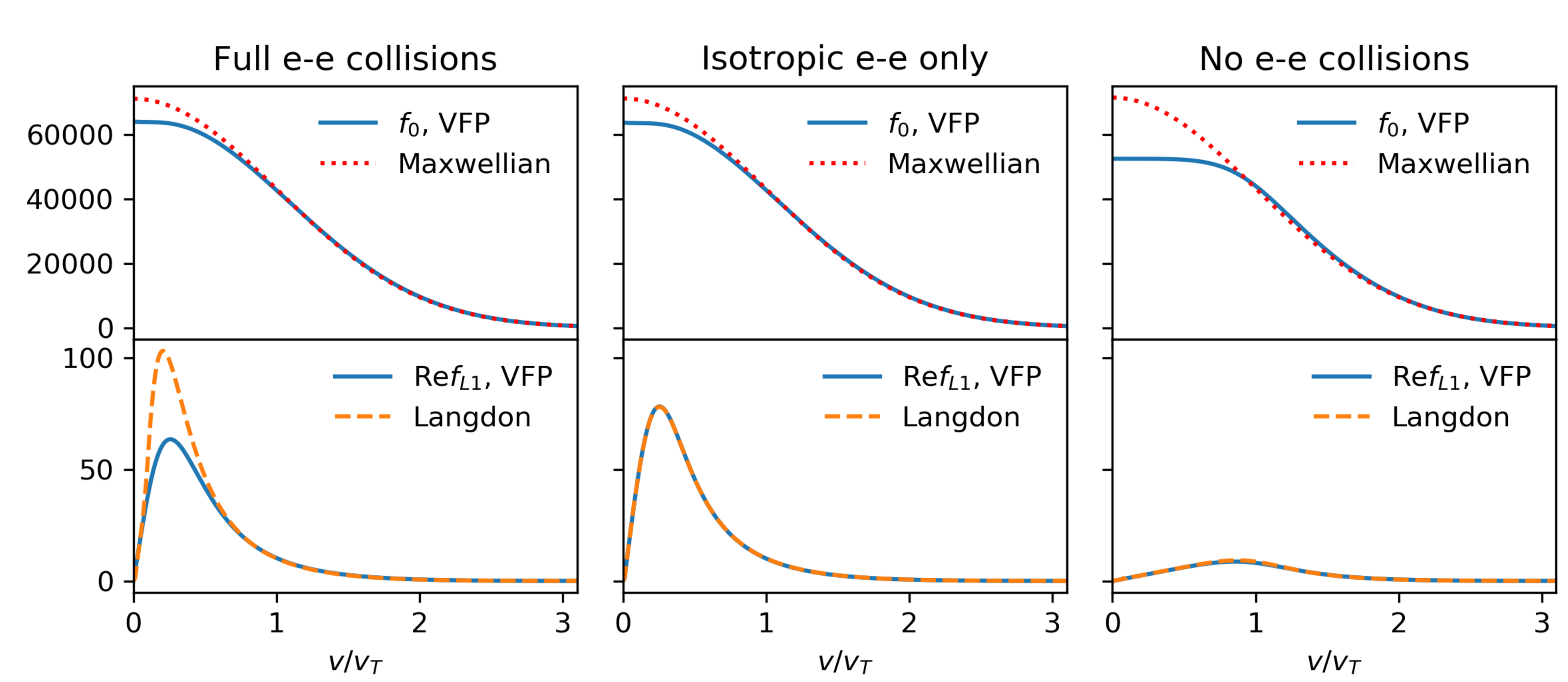
$$L_0[f] - \frac{e}{2}\Re\left\{\vec{E}_L\cdot\frac{\partial f_L^*}{\partial \vec{p}}\right\} = C_{ei}[f] + C_{ee}[f,f] + \frac{1}{2}\Re\{C_{ee}[f_L, f_L^*]\}$$

$$L_0[f_L] - e\vec{E}_L\cdot\frac{\partial f}{\partial \vec{p}} = i\omega_L f_L + C_{ei}[f_L] + C_{ee}[f, f_L] + C_{ee}[f_L, f]$$

- Ponderomotive force & stress
- Collisional laser absorption (IB)
- Modified electron-electron collisions

Application to the Langdon Effect

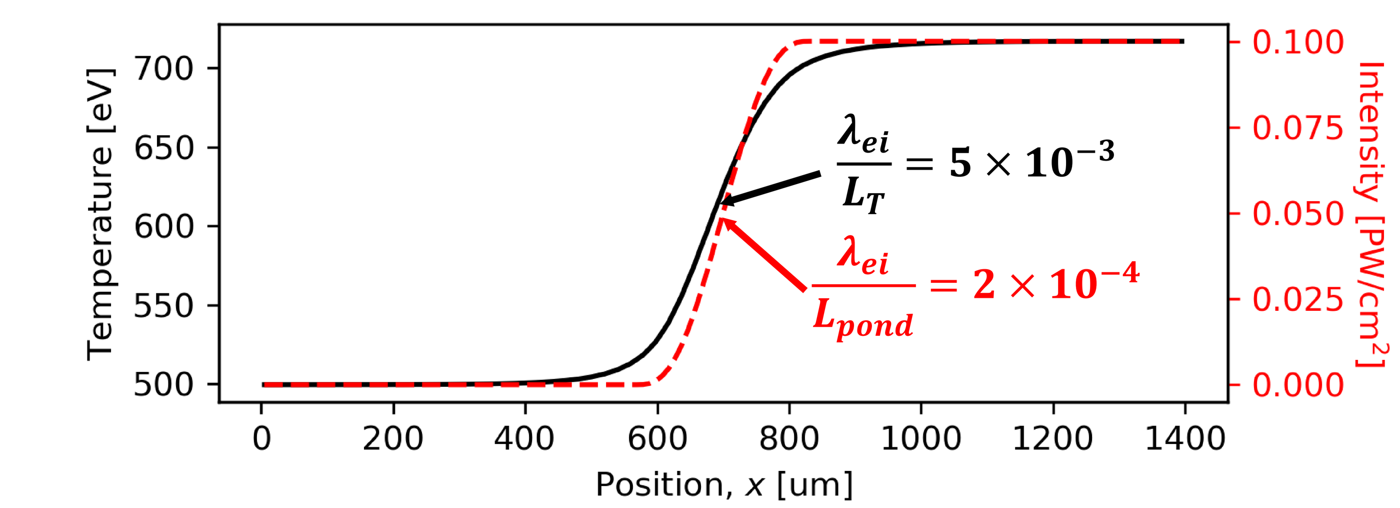
Our method enables detailed studies of absorption with a full account of e-e collisions. Langdon's theory neglects anisotropic e-e collisions and overestimates absorption in low-Z plasmas[5].

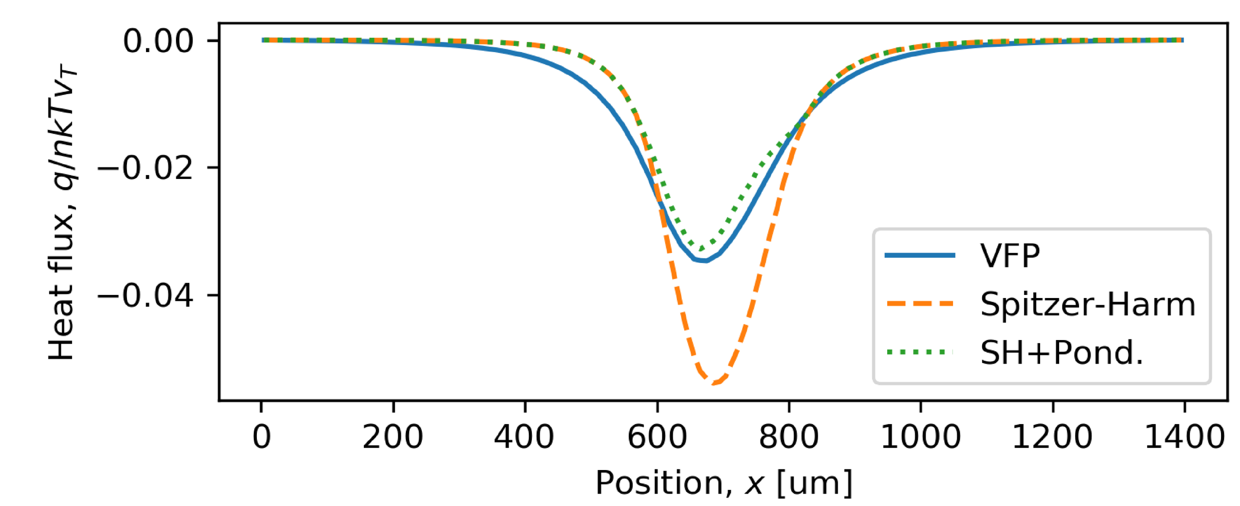


$$Z = 1, T_0 = 1\text{keV}, n_e = 0.3\, n_c, I = 10^{15}\ \text{W/cm}^2,$$
$$\lambda_L = 0.35\mu\text{m}, t = 1\text{ps}, Z(v_E/v_T)^2 = 0.02$$

Application to Thermal Conduction

An intensity gradient induces heat flow in a uniform plasma via non-uniform IB absorption. Even for weak gradients, the ponderomotive force reduces the heat flux compared to Spitzer-Harm, in good agreement with analytic predictions[1,2].





$$Z = 10, T_0 = 500\ \text{eV}, n_e = 0.3n_c, Z\left(v_E/v_T\right)^2 = 0.04, t = 50\text{ps}$$

Continuing Efforts

- Investigation of ponderomotive heat flux suppression in non-local scenarios
- Pairing with realistic hydro profiles to assess the impact of intensity gradients on emerging IFE designs
- Investigation of broadband/multi-color effects
- Mitigation of harsh CFL condition imposed by short-wavelength intensity oscillations in underdense plasma

References

[1] V. N. Goncharov and G. Li, *Phys. Plasmas* 11, 5681 (2004).
[2] A. V. Maksimov, V. P. Silin, and M. V. Chegotov, *Fiz. Plasmy*. 16, 575 (1990).
[3] A. B. Langdon, *Phys. Rev. Lett.* 44, 576 (1980).
[4] M. Sherlock, J. P. Brodrick, and C. P. Ridgers, *Phys. Plasmas* 24, 082706 (2017).
[5] S.-M. Weng, Z.-M. Sheng, and J. Zhang, *Phys. Rev. E* 80, 056406 (2009).