Effect of Ponderomotive Terms on Heat Flux in Laser-Produced Plasmas

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Ponderomotive terms modify the heat flux in laser-induced plasmas

- The IMPACT code\textsuperscript{1} is used to study the effects of ponderomotive terms.
- Ponderomotive terms are important near the critical surface.
- Simulation results agree with the simplified heat-conduction model.\textsuperscript{2}


\textsuperscript{2}V. N. Goncharov, BO1.00001.
The electron density, electron temperature, and laser–electric field have sharp profiles near the critical surface.
Local theory* predicts the temperature and laser-field dependence of heat flux

\[ q = nTV_T \lambda_e \left( \beta_T \nabla \ln T + \beta_E \frac{\nabla V_E^2}{V_T^2} \right) \]

\[ \beta_T = -\frac{128}{3\pi} \frac{Z + 0.24}{Z + 4.20} \]

\[ \beta_E = 17.31 Z \frac{Z^2 + 14.04 Z + 2.41}{Z^2 + 14.34 Z + 29.5} \]

Z—average ion number

The IMPACT code is used to study the ponderomotive effect*

\[ f(v, r, t) = f_0(v, r, t) + f_1(v, r, t) \cdot \hat{v} \left( \hat{v} = \frac{v}{|v|} \right) \]

Electron–electron collision

\[ \frac{\partial f_0}{\partial t} + \frac{v}{3} \nabla \cdot f_1 - \frac{1}{3mv^2} \frac{\partial}{\partial v} (v^2 E \cdot f_1) = J_{ee} + J_{IB} \]

Inverse Bremsstrahlung

\[ \frac{\partial f_1}{\partial t} + v \nabla f_0 - \frac{eE}{\partial v} \frac{\partial f_0}{\partial v} - \frac{e}{m} B \times f_1 = -\nu_{ei} f_1 \]

Heat flux \[ q = \frac{4\pi}{3} \int_0^\infty \frac{1}{2}mv^2 f_1(v, r, t) v^3 \, dv \]

Electric current \[ j = -\frac{4\pi e}{3} \int_0^\infty f_1(v, r, t) v^3 \, dv \]

$f_0$ obtained by IMPACT codes is consistent with the analytical solutions

$\sim \exp(-v^{3.4})$

Self-similar $\sim \exp(-v^5)$

FP with $J_{ee}$ (Maxwellian)

FP with $J_{ee}$ and inverse bremsstrahlung term

FP with inverse bremsstrahlung term
Ponderomotive terms appear in the heat flux because of the electromagnetic field dependence in $f_0$.

\[ f_0 \approx f_M \exp \left( \frac{v^2}{2v_T^2} \Phi_{12} \right) \]

\[ q \sim \nabla f_0 \sim \nabla |E|^2 \]

\[ \alpha = \frac{Zv_E^2}{v_T^2}, \quad v_E = \frac{eE}{m\omega_L} \]

\[ f_M \exp \left( \frac{7\alpha}{225\sqrt{2\pi}} \frac{v^5}{v_T^5} \right) \]

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Ponderomotive terms modify the heat-flux profiles near the critical surface.

\[ \nabla n_e \neq 0, \nabla T_e = \nabla |E| = 0 \quad \text{Theoretical result} \]

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The simplified heat flux model* is consistent with the results of the Fokker–Planck simulation.

- **FP simulation**
  \[ q = \frac{4\pi}{3} \int_0^\infty \frac{1}{2} m v^2 f_1(v, r, t) v^3 dv \]

- **Simplified heat-flux model**
  \[ q = -\frac{m}{2} \int_0^1 y \int_0^\infty v^5 dv \int_{-\infty}^\infty dx \frac{3}{2} \sqrt{1 - \xi} \frac{eE_0}{T} f_0 - \frac{x}{\lambda} \]

  \[ + \frac{m}{2} \int_0^1 y \int_0^\infty v^5 dv \left( \int_x^\infty dx' \frac{3}{2} \sqrt{1 - \xi} \frac{f_0}{\lambda} - \int_{-\infty}^x dx' \frac{3}{2} \sqrt{1 - \xi} \frac{f_0}{\lambda} \right) \]

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Summary/Conclusions

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