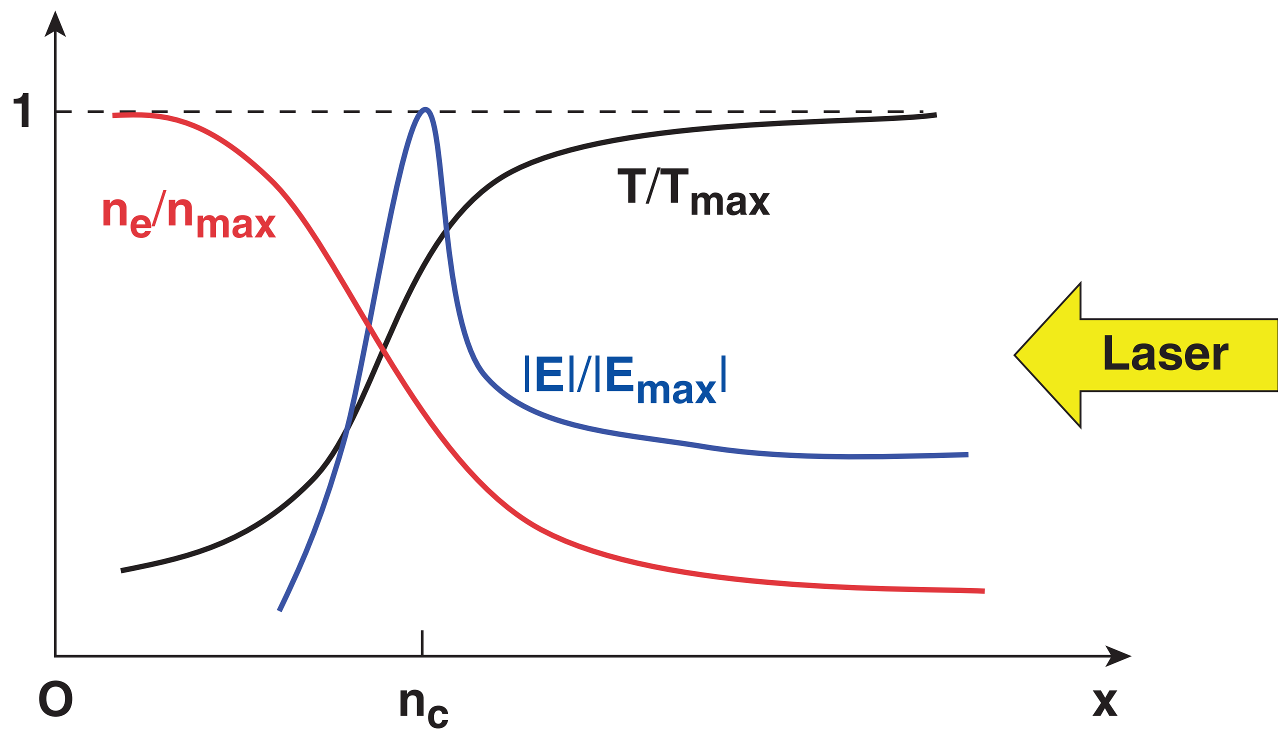
Effect of Ponderomotive Terms on Heat Flux in Laser-Produced Plasmas



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Summary

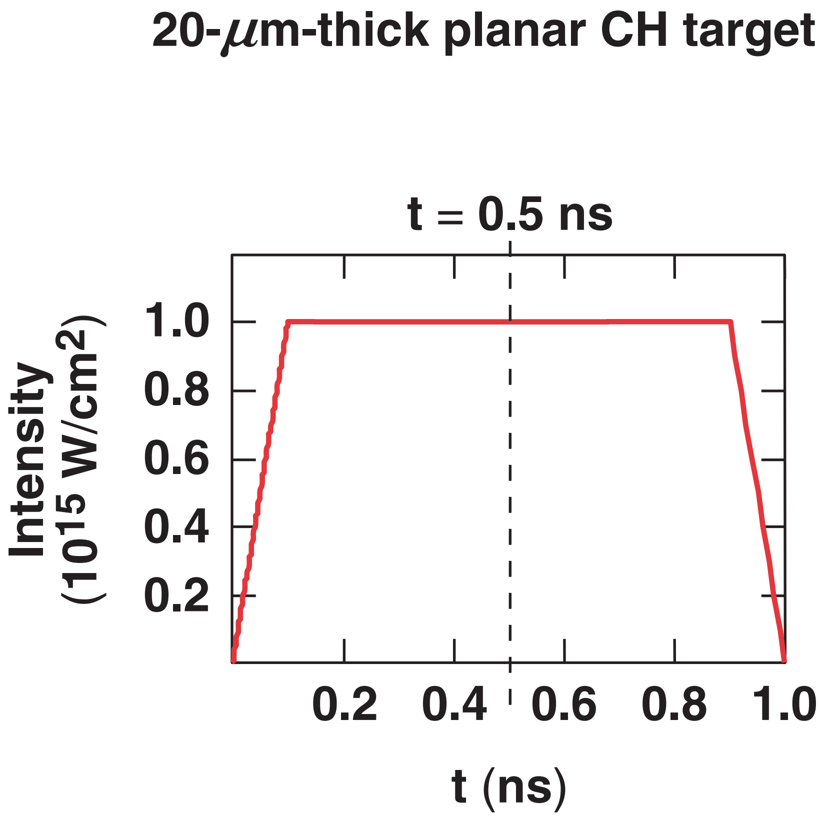
Ponderomotive terms modify the heat flux in laser-induced plasmas

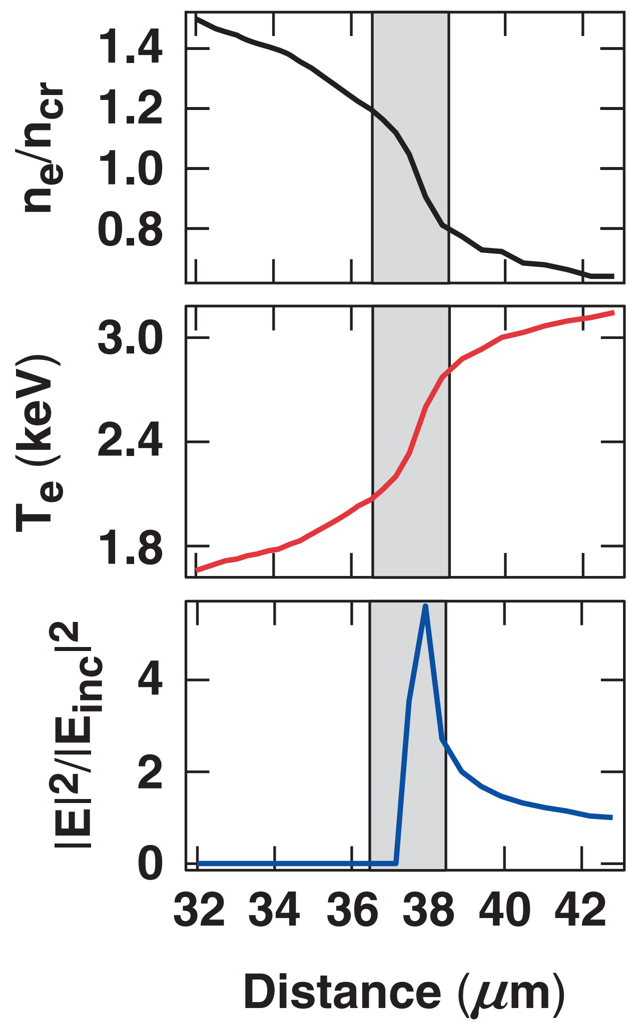
- The IMPACT code[1] is used to study the effects of ponderomotive terms.
- Ponderomotive terms are important near the critical surface.
- Simulation results agree with the simplified heat-conduction model.[2]

[1] R. J. Kingham and A. R. Bell, J. Comput. Phys. 194, p. 1 (2004).
[2] V. N. Goncharov, BO1.00001.

TC7186

The electron density, electron temperature, and laser–electric field have sharp profiles near the critical surface





TC7187

Local theory* predicts the temperature and laser-field dependence of heat flux

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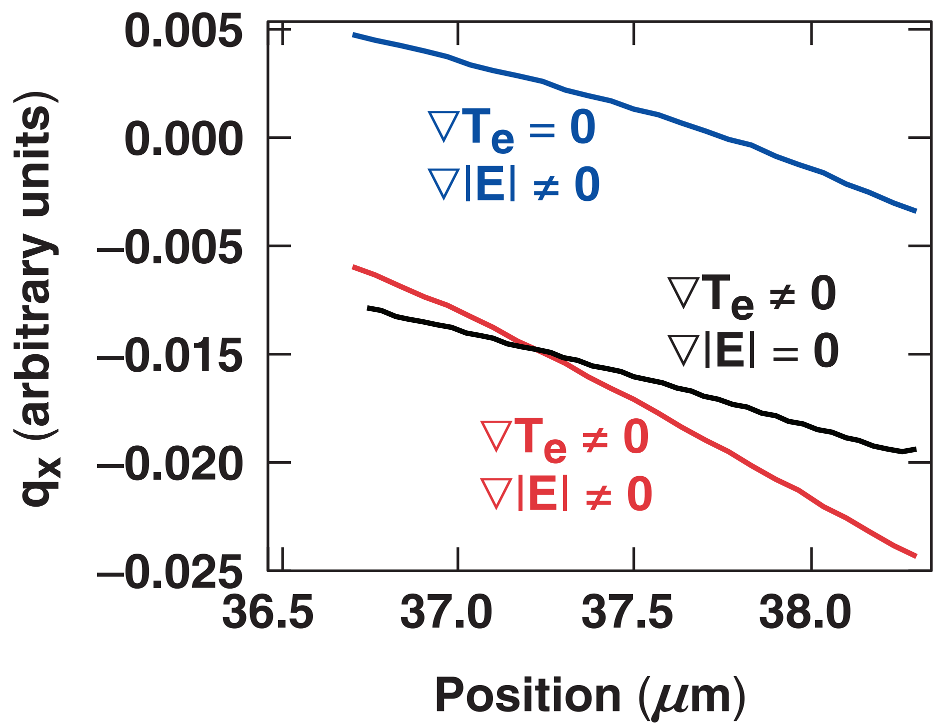
$$q = nTv_T\lambda_e\left(\beta_T\nabla \ln T + \beta_E\frac{\nabla v_E^2}{v_T^2}\right)$$

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

$$\beta_E = 17.31\,Z\;\frac{Z^2+14.04\,Z+2.41}{Z^2+14.34\,Z+29.5}$$

Z—average ion number



TC7188

*V. N. Goncharov and G. Li, Phys. Plasmas 11, p. 5680 (2004).

The IMPACT code is used to study the ponderomotive effect*

$$f(\mathbf{v},\mathbf{r},t) = f_0(\mathbf{v},\mathbf{r},t) + \mathbf{f}_1(\mathbf{v},\mathbf{r},t)\cdot\hat{\mathbf{v}}\left(\hat{\mathbf{v}} = \frac{\mathbf{v}}{|\mathbf{v}|}\right)$$

Electron–electron collision

$$\frac{\partial f_0}{\partial t} + \frac{v}{3}\nabla\cdot\mathbf{f}_1 - \frac{1}{3mv^2}\frac{\partial}{\partial v}\left(v^2\mathbf{E}\cdot\mathbf{f}_1\right) = J_{ee} + J_{IB}$$

Inverse Bremsstrahlung

$$\frac{\partial \mathbf{f}_1}{\partial t} + v\nabla f_0 - \frac{e\mathbf{E}}{\partial v}\frac{\partial f_0}{\partial v} - \frac{e}{m}\mathbf{B}\times\mathbf{f}_1 = -\nu_{ei}\mathbf{f}_1$$

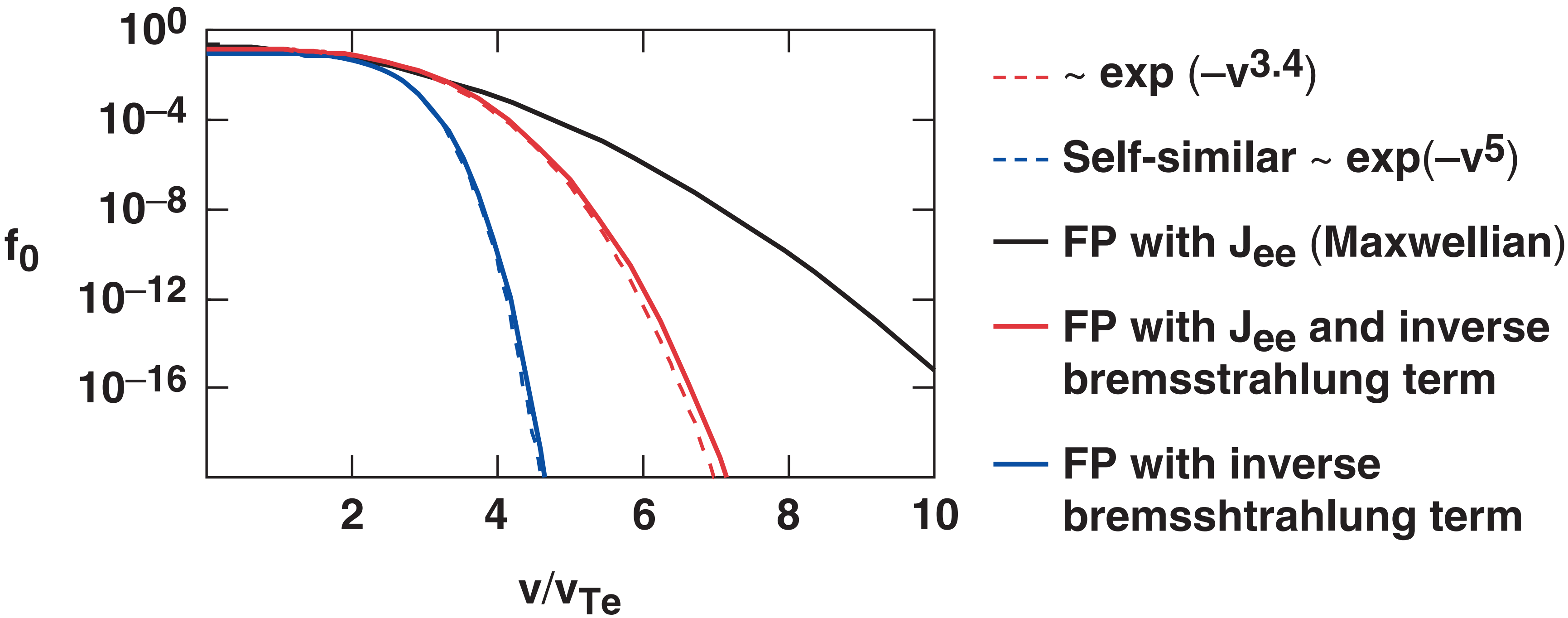
Heat flux $\quad \mathbf{q} = \frac{4\pi}{3}\int_0^\infty \frac{1}{2}mv^2\mathbf{f}_1(v,r,t)v^3dv$

Electric current $\quad \mathbf{j} = -\frac{4\pi e}{3}\int_0^\infty \mathbf{f}_1(v,r,t)v^3dv$

TC7189

*R. J. Kingham and A. R. Bell, J. Comput. Phys. 194, p. 1 (2004).

f_0 obtained by IMPACT codes is consistent with the analytical solutions



TC7190

Ponderomotive terms appear in the heat flux because of the electromagnetic field dependence in f_0

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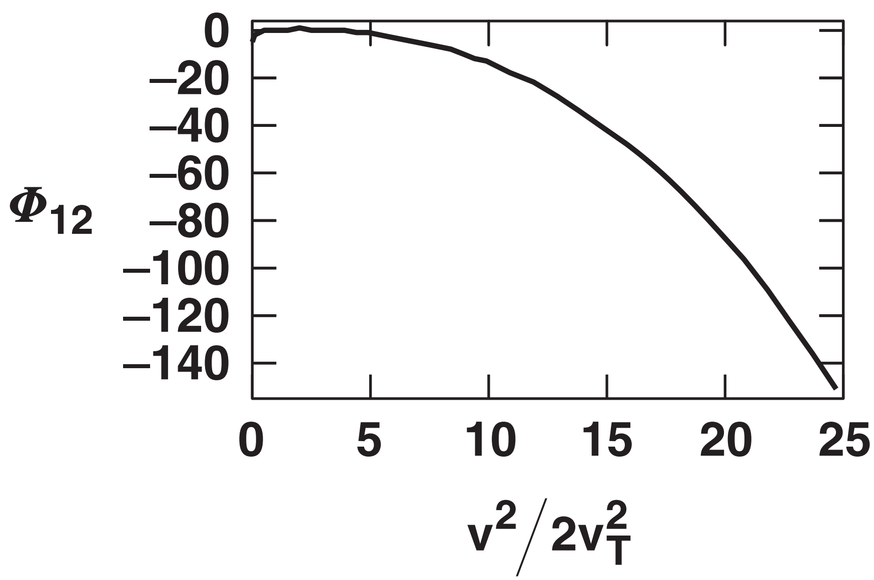

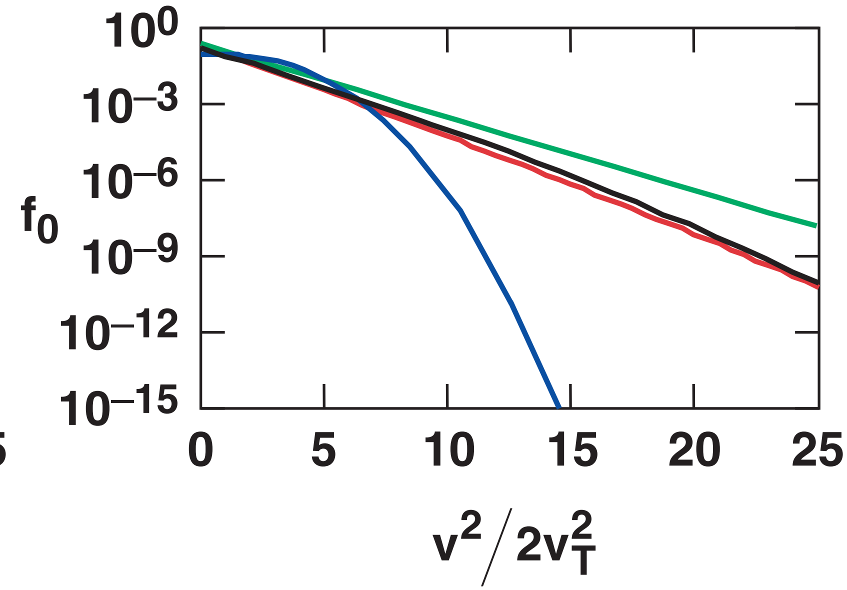

$$f_0 \sim f_M \exp\left(\frac{v_E^2}{v_T^2}\Phi_{12}\right)^* \xrightarrow{v/v_T >> 1} f_M \exp\left(-\frac{7\alpha}{225\sqrt{2\pi}}\frac{v^5}{v_T^5}\right)$$

$$q \sim \nabla f_0 \sim \nabla |E|^2$$

$$\left(\alpha = \frac{Zv_E^2}{v_T^2} \qquad v_E = \frac{eE}{m\omega_L}\right)$$

- f_M (green)
- Self-similar (blue)
- $f_M \exp\left(\frac{v_E^2}{v_T^2}\Phi_{12}\right)$ (red)
- f_0 by IMPACT code (black)

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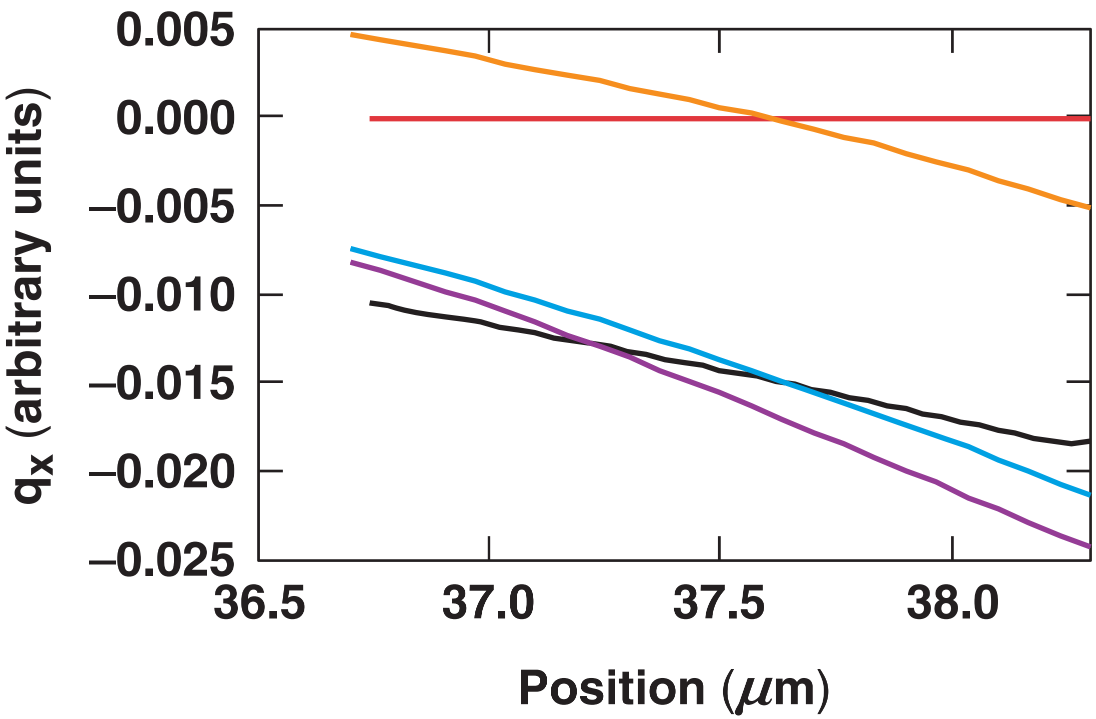
TC7191

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



- $\nabla n_e \neq 0$, $\nabla T_e = \nabla|E| = 0$
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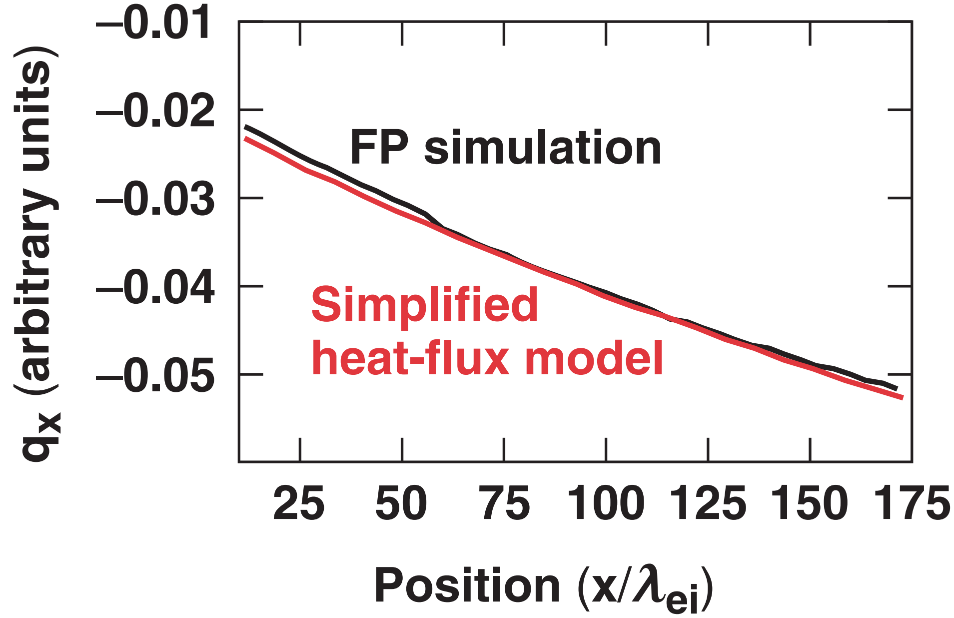
- $\nabla n_e \neq 0$, $\nabla T_e \neq 0$, $\nabla|E| \neq 0$
- Theoretical result

TC7192

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

$$q = -\frac{m}{2}\int_0^1 y dy \int_0^\infty v^5 dv \int_{-\infty}^{\infty} dx' \frac{3}{2}\sqrt{1-\xi}\, \frac{eE_0}{T} f_0 \qquad \xi \sim \frac{x}{\lambda}$$

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

TC7260

*V. N. Goncharov, BO1.00001

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