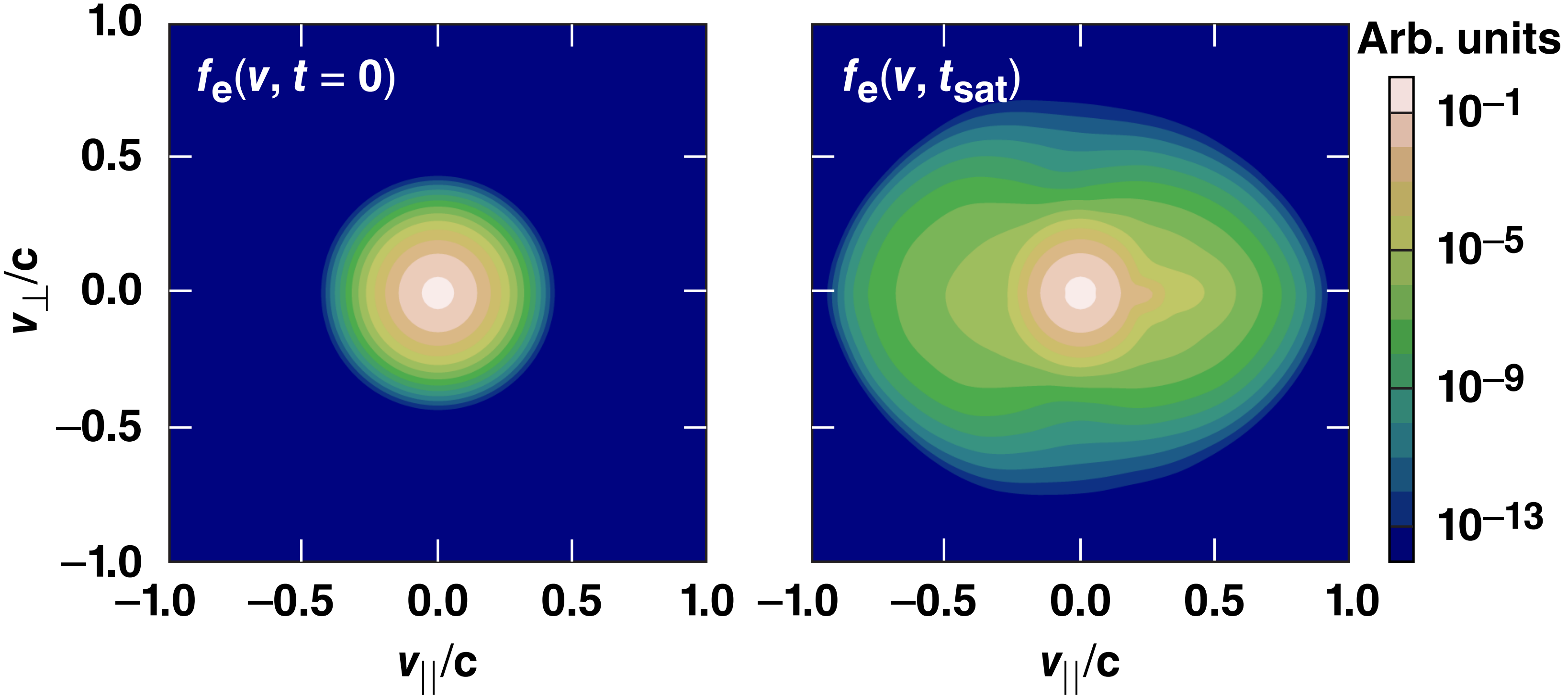
A Self-Consistent Quasilinear Model for the Two-Plasmon-Decay Instability in Inhomogeneous Plasmas

Electron distribution function



J. F. Myatt
University of Rochester
Laboratory for Laser Energetics

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Summary

A self-consistent quasilinear Zakharov model for two-plasmon decay (TPD) has been developed for inhomogeneous plasmas

- Predictions for hot-electron generation in direct-drive ICF targets can be obtained more efficiently than in PIC*
  - hot-electron spectrum (energy and angle)
  - preheat
  - example case shows $T_{\text{hot}} \sim 40$ keV, $E_{\text{hot}}/E_{\text{laser}} \gtrsim 1\%$ for $\eta = 2.6$
- The model will be used to explore effect of crossed beams, beam speckles and possible mitigation strategies

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*H. X. Vu *et al.*, Phys. Plasmas 17, 072701 (2010); H. X. Vu *et al.*, in preparation.

Collaborators

J. Zhang, A. V. Maximov, and R. W. Short

University of Rochester
Laboratory for Laser Energetics

D. F. DuBois

Los Alamos National Laboratory
and Lodestar Research Corporation

D. A. Russell

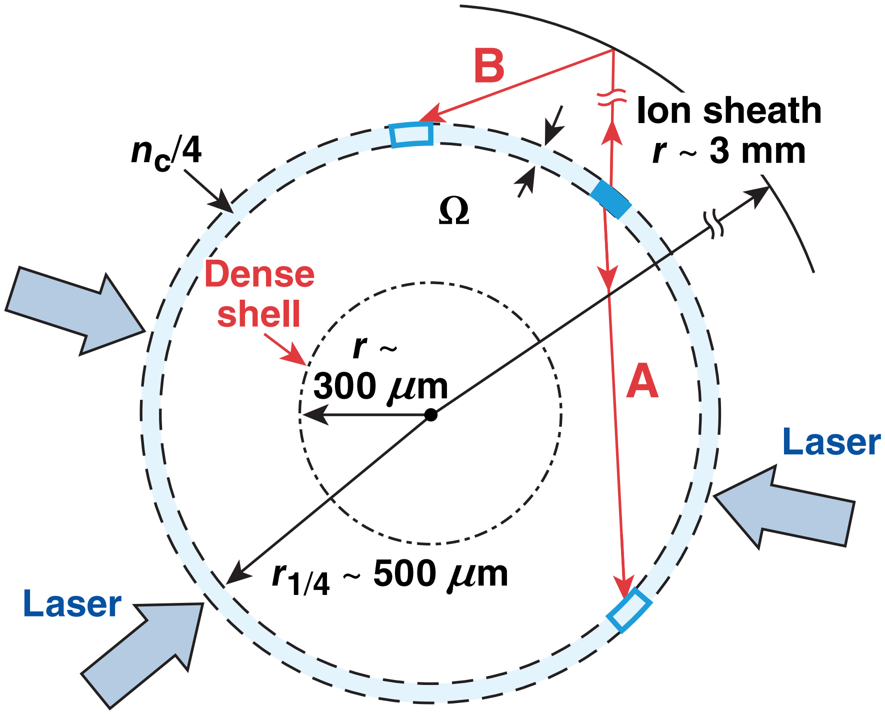
Lodestar Research Corporation

H. X. Vu

University of California at San Diego

The two-plasmon-decay instability occurs in a small spatial region in the neighborhood of the quarter-critical surface

- Hydrodynamic profiles characterized by a steady-flow velocity and a density gradient
- L_n = 100 to 400 μm
- $T_e \sim 2$ keV, $V_0 \gtrsim C_s$
- I (W/cm^2) = 5×10^{14} to 1×10^{15}
- $\eta = \dfrac{I_{14} L_{\mu m}}{230\, T_{e,\, keV}} \sim 1\text{–}3$ [†]
- Boundary conditions not simple; has been addressed*



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*J. F. Myatt *et al*., "The Dynamics of Hot-Electron Heating in Direct-Drive Implosion Experiments Due to the Two-Plasmon Decay Instability," submitted to Physics of Plasmas (2011).

[†] A. Simon *et al*., Phys. Fluids 26, 3107 (1983).

The quasilinear Zakharov model evolves the turbulent LW spectrum driven by the TPD instability

- "Extended" Zakharov equations used in *QZAK**

$$\nabla\cdot\left[D_{\mathrm{LW}}-\omega_0^2\left(\delta n+\delta N\right)/n_0\right]E=\left(e/4\,m_c\right)\nabla\cdot\left[\nabla\left(E_0\cdot\bar{E}\right)-E_0\nabla\cdot\bar{E}\right]+S_E$$

$$D_{\mathrm{IAW}}\delta n=\nabla^2\left(|E|^2+\frac{1}{4}|E_0|^2\right)\Big/\left(16\,\pi M_i\right)+S_{\delta n}$$

TPD source term

Dispersion relations for LW and IAW

$$D_{\mathrm{LW}}=\left[2i\omega_{p0}\left(D_t+\nu_e*\right)+3\nu_e^2\nabla^2\right]$$

$$D_{\mathrm{IAW}}=\left(D_t^2+2\nu_i*D_t-c_s^2\nabla^2\right)$$

Wave envelopes

$$\tilde{E}=1/2\;E\left(x,y,t\right)\exp\left[-i\left(\omega_{p0}t\right)\right]+\mathrm{c.c.}$$

$E_0\left(x,y,t\right)$ is prescribed (paraxial, plane wave(s), Airy)

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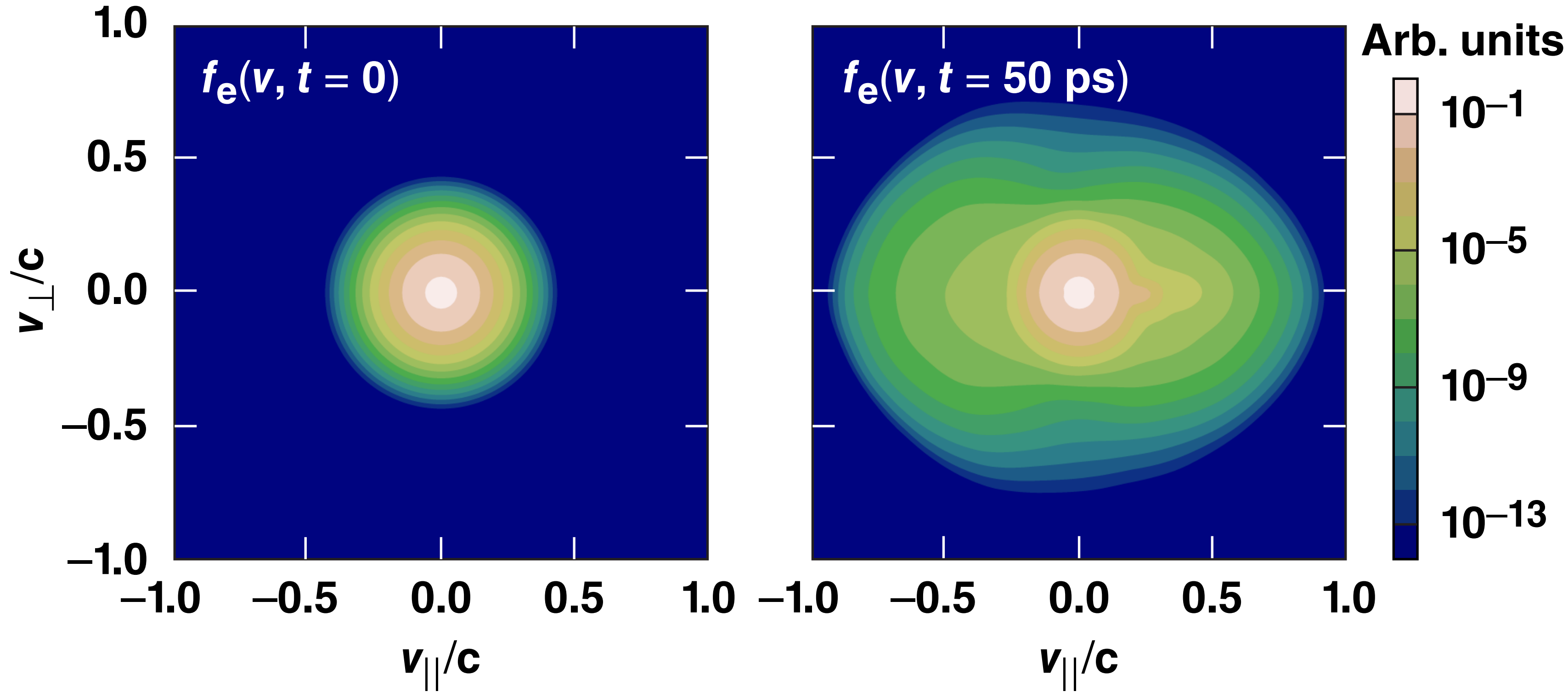
[*] D. F. DuBois *et al*., Phys. Rev. Lett. 74, 3983 (1995);
D. A. Russell and D. F. DuBois, Phys. Rev. Lett. 86, 428 (2001).

Electrons are heated by velocity–space diffusion caused by the turbulent spectrum of plasma waves

- **The diffusion equation** $\frac{\partial \langle f_e \rangle}{\partial t} + \frac{\partial}{\partial \vec{v}} \cdot \left(D(\vec{v}) \cdot \frac{\partial \langle f_e \rangle}{\partial \vec{v}} \right) = \sigma \left(\langle f_e \rangle - f_M \right)$

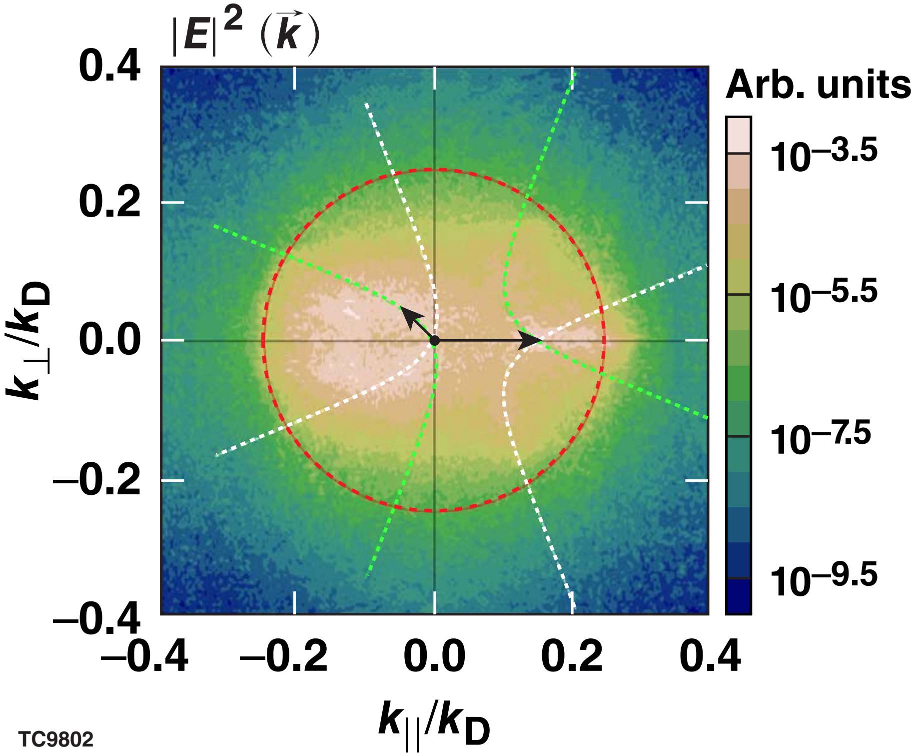


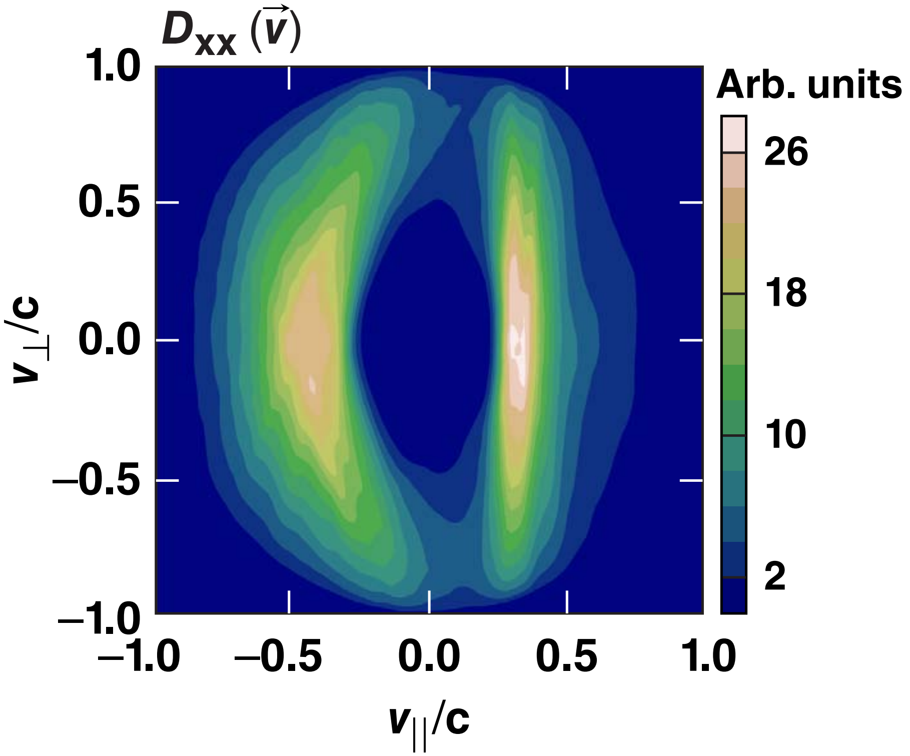
The diffusion tensor $D(\vec{v})$ is evaluated in the quasilinear approximation

$$D(\vec{v}) = \frac{\pi e^2 |\Delta \vec{k}|}{2 m_e^2 \Delta k_\parallel \Delta k_\perp} \sum_{\omega_p - \vec{k}\cdot\vec{v} = 0} \frac{\vec{k}\,\vec{k}\,|\psi(\vec{k},t)|^2}{|\vec{v}|}$$

$$\vec{E} = -\nabla \psi$$

- The validity has been investigated by the use of test particles

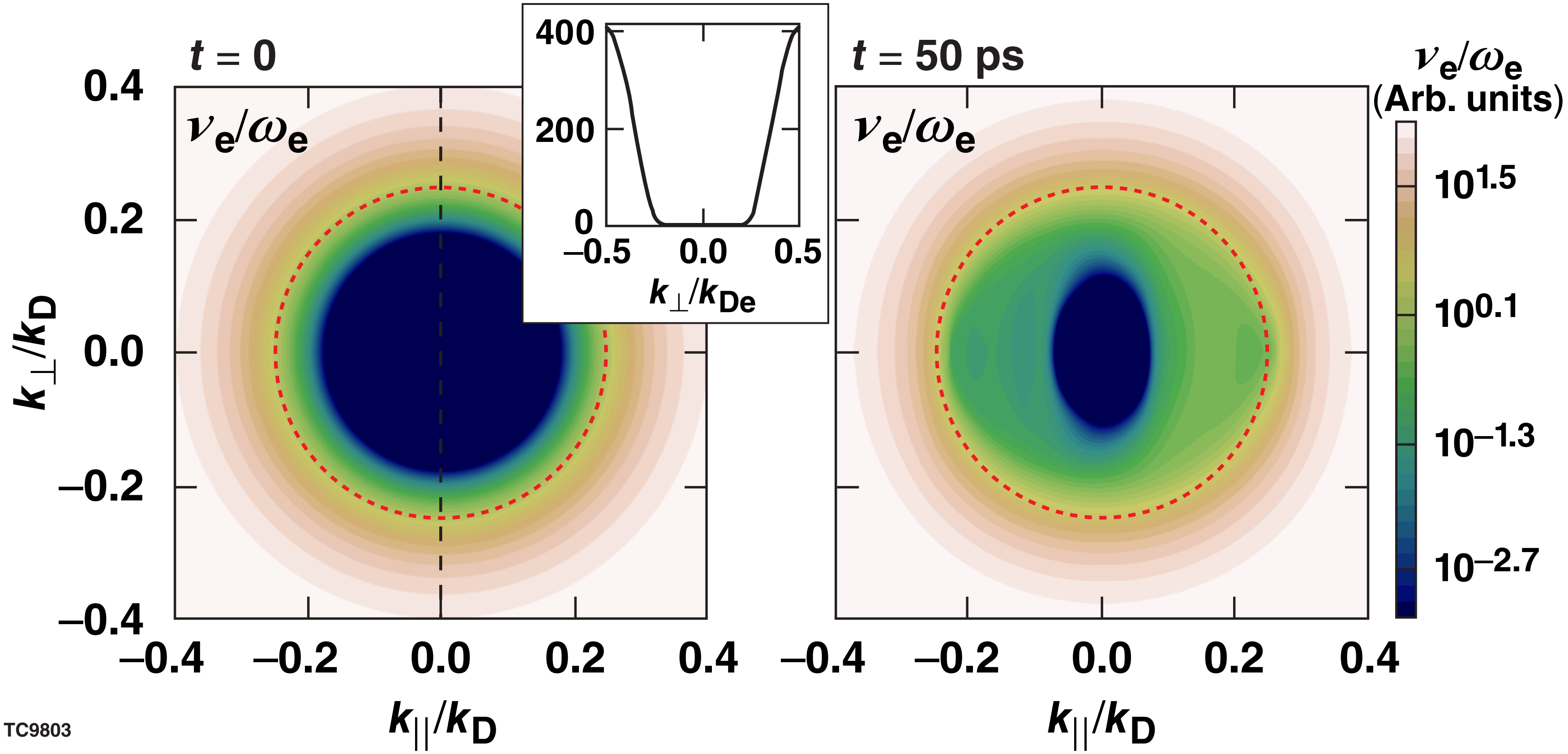




The LW Landau damping rate $\nu_e\,(k)$ is recalculated at each time step based on the evolving distribution function

- The damping is the only mechanism where the particles act back on the waves

$$\nu_e(\vec{k},t) = \frac{\pi}{2}\,\frac{\omega_e^3}{k^2}\int d\vec{v}\,\frac{\vec{k}\cdot\partial\langle f_e(\vec{v},t)\rangle}{\partial\vec{v}}\,\delta(\omega_{pe}-\vec{k}\cdot\vec{v})$$



TC9803

The quasilinear Zakharov model evolves the turbulent spectrum and the electron heating self-consistently

- "Extended" Zakharov equations used in *QZAK**

$$\nabla\cdot\left[D_{\mathrm{LW}}-\omega_0^2(\delta n+\delta N)/n_0\right]E=(e/4\,m_c)\nabla\cdot\left[\nabla\left(E_0\cdot\bar{E}\right)-E_0\nabla\cdot\bar{E}\right]+S_E$$

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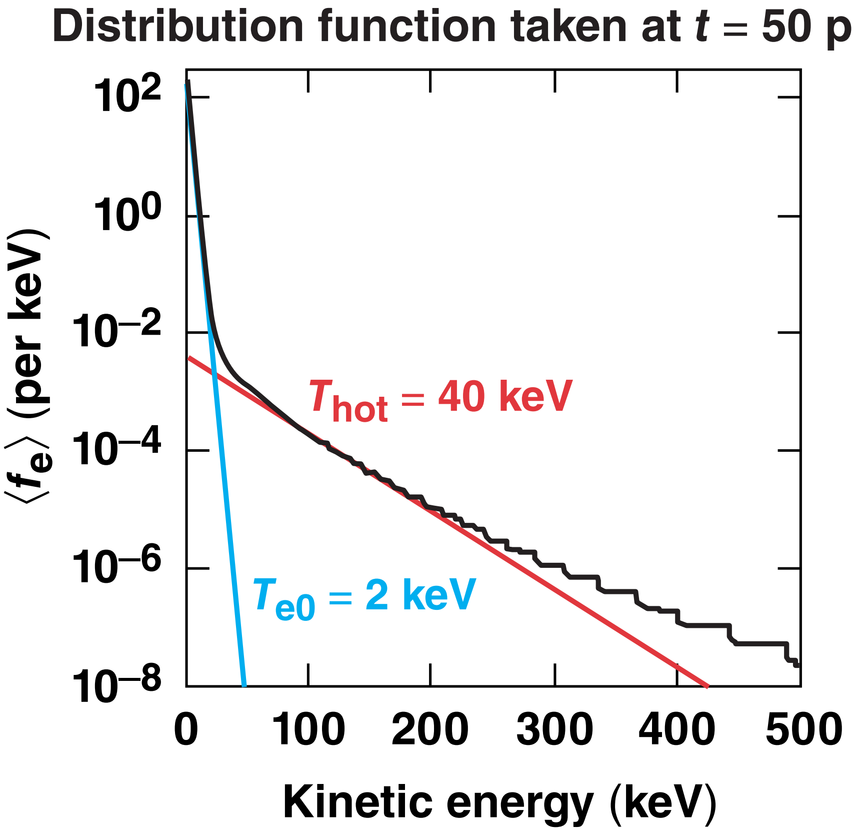
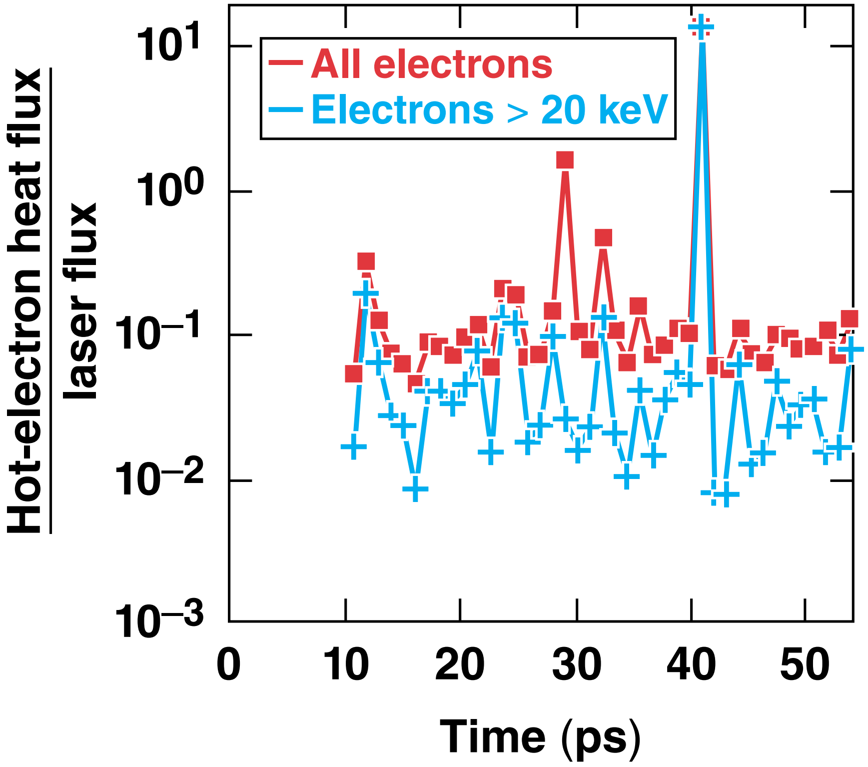
The hot-electron energy flux and hot-electron temperature can be obtained from the electron-distribution function





TC9804

Summary/Conclusions

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Heating in Prescribed Field

Validity of the diffusion approximation is not assured

- $E^2 / (4\pi n_e T_e) \ll 1$
- Gaussian fluctuations*
- Time-scale ordering: $\tau_c \ll \tau_D \,(\ll \tau_{evol})$
- Spatial averaging
- There is a flow velocity and a gradient in plasma density
- The interaction region is finite (one pass, multiple passes‡)
- Computational savings are large when compared with PIC
- Three-dimensional calculations are manageable
  - see Vu on cavitons†

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*D. Pesme, Phys. Scri. T50, 7 (1994).

†H. X. Vu *et al*., "Langmuir Wave Collapse and Associated Suprathermal Electron Production by the Two-Plasmon Decay Instability in Inhomogeneous Plasma," submitted to Phys. Rev. Lett.

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