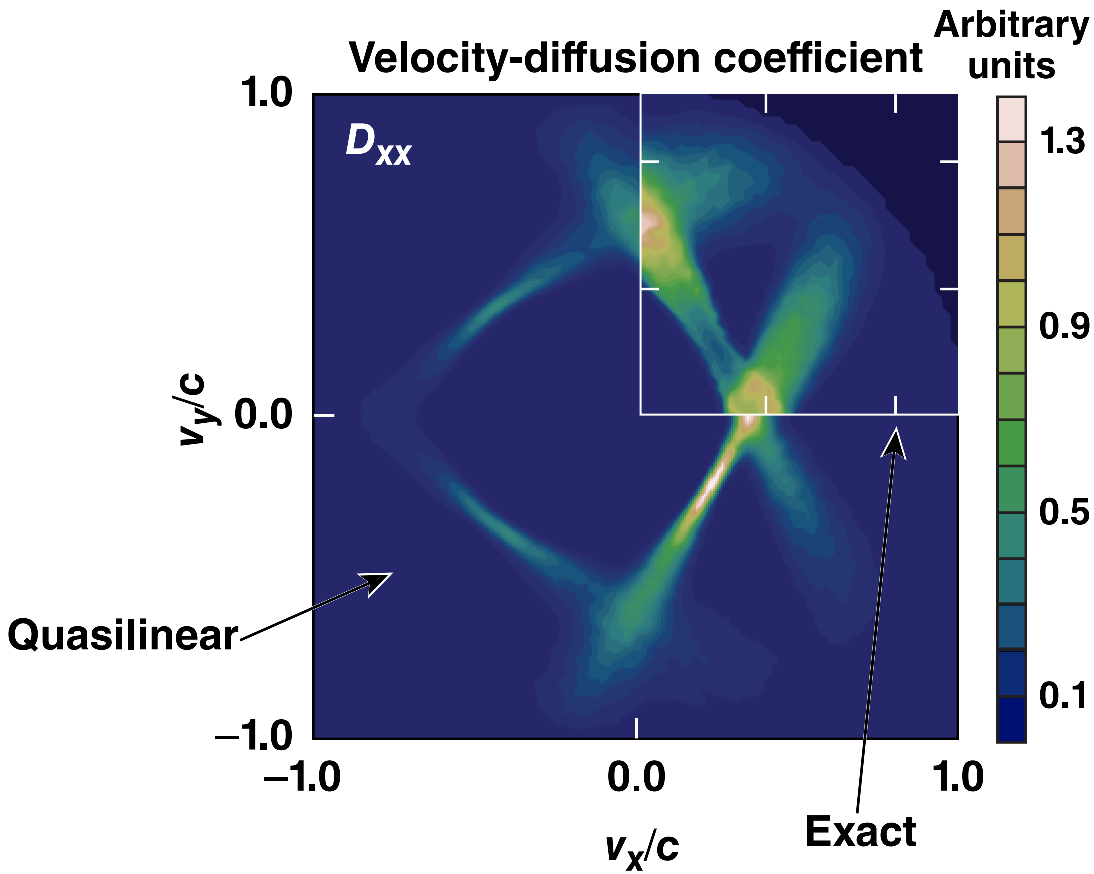
A Quasilinear Model for the Two-Plasmon-Decay Instability in Inhomogeneous Plasmas



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Summary

A quasilinear Zakharov model for two-plasmon decay has been developed for inhomogeneous plasmas

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- Predictions for hot-electron generation in direct-drive ICF targets can be obtained
  - hot-electron spectrum (energy and angle)
  - preheat
- The model is to be validated
  - computation of test-particle trajectories
  - comparisons against reduced particle in cell (RPIC)*

*H. X. Vu *et al*., Phys. Plasmas 17, 072701 (2010).
*H. X. Vu *et al*., "Langmuir Turbulence and Suprathermal Electron Production from the Two-Plasmon Decay Instability Driven by Crossed Laser Beams in an Inhomogeneous Plasma," this conference.

Collaborators

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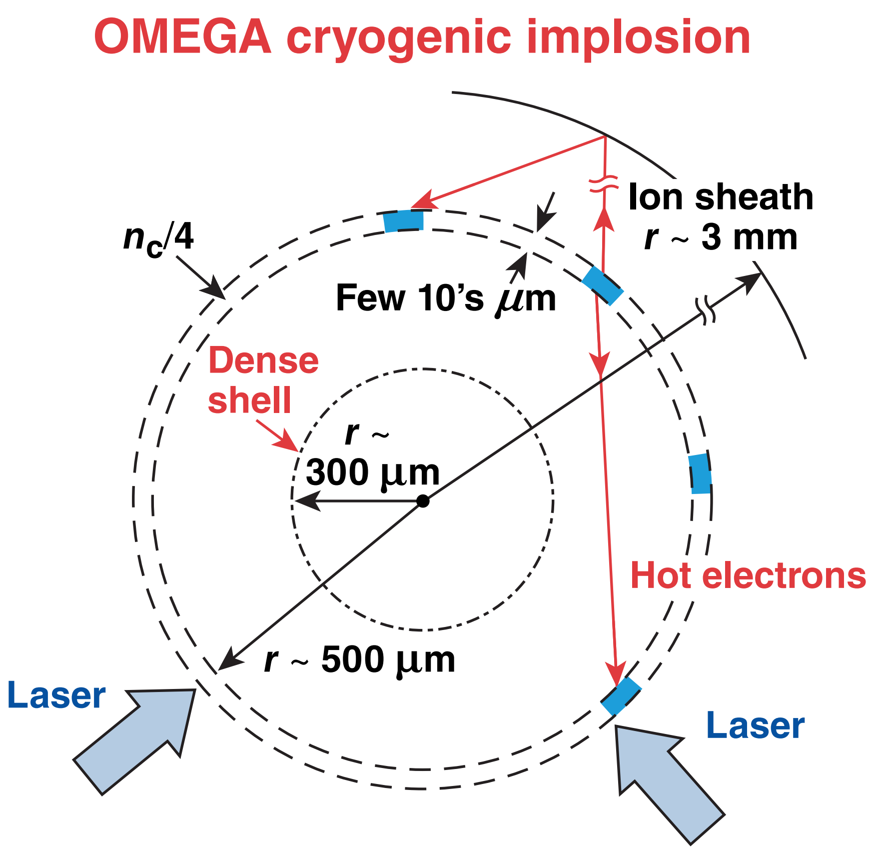
The quasilinear model is applied in a small spatial region in the neighborhood of the quarter-critical surface



- Finite interaction region
- Hydrodynamic profiles characterized by a steady flow velocity and a density gradient
- L_n = (100 to 400 μm)
- Boundary conditions not simple; has been addressed*

*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 Phys. Plasmas (2011).

TC9126

A prediction for the steady-state electrostatic field is obtained from the extended Zakharov model of the two-plasmon-decay instability

UR LLE

- "Extended" Zakharov equations used in ZAK*

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

$$D_{IAW} \delta n = \nabla^2 |E|^2 / (16 \pi m_i) + S_{\delta n}$$

TPD source term

Dispersion relations for LW and IAW

$$D_{LW} = \left[2i\omega_{p0} \left(\partial_t + \vec{v}_0 . \vec{\nabla} \right) + \nu_e * + 3\nu_e^2 \nabla^2 \right]$$

$$D_{IAW} = \left[\left(\partial_t + \vec{v}_0 . \vec{\nabla} \right)^2 + 2\nu_i * \partial_t - c_s^2 \nabla^2 \right]$$

Wave envelopes

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

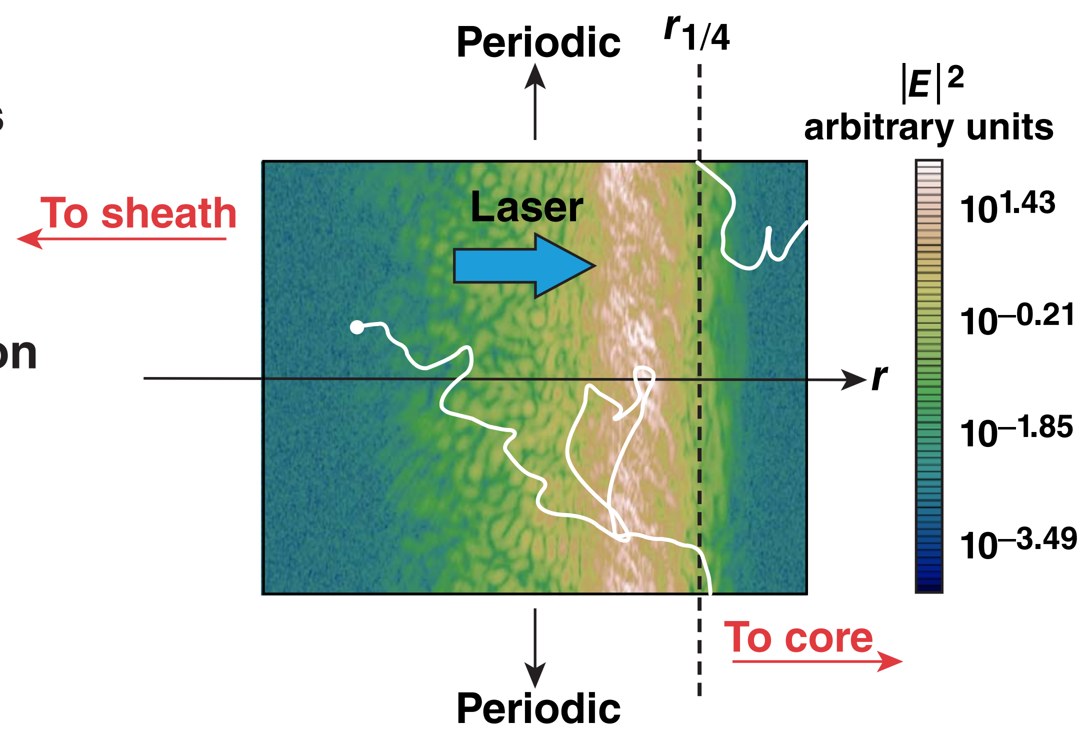
$$\tilde{E}_0 = e_y \sum_i |E_0|_i \exp \left[i\, \vec{k}_{0i} \cdot \vec{x} - i \left(\omega_0 - 2\omega_{p0} \right) t \right]$$

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

TC8454a

Electron heating is first computed by exactly integrating test-particle trajectories in the saturated ZAK fields

- Non-self-consistent dynamics
- ZAK fields at saturation
- Knowledge of the saturated spectrum allows for calculation of the distribution function
- A large ensemble of electron test-particle trajectories are run randomizing over the initial position



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An exponential tail is observed once the TPD threshold is exceeded and the temperature scales with the "η" parameter

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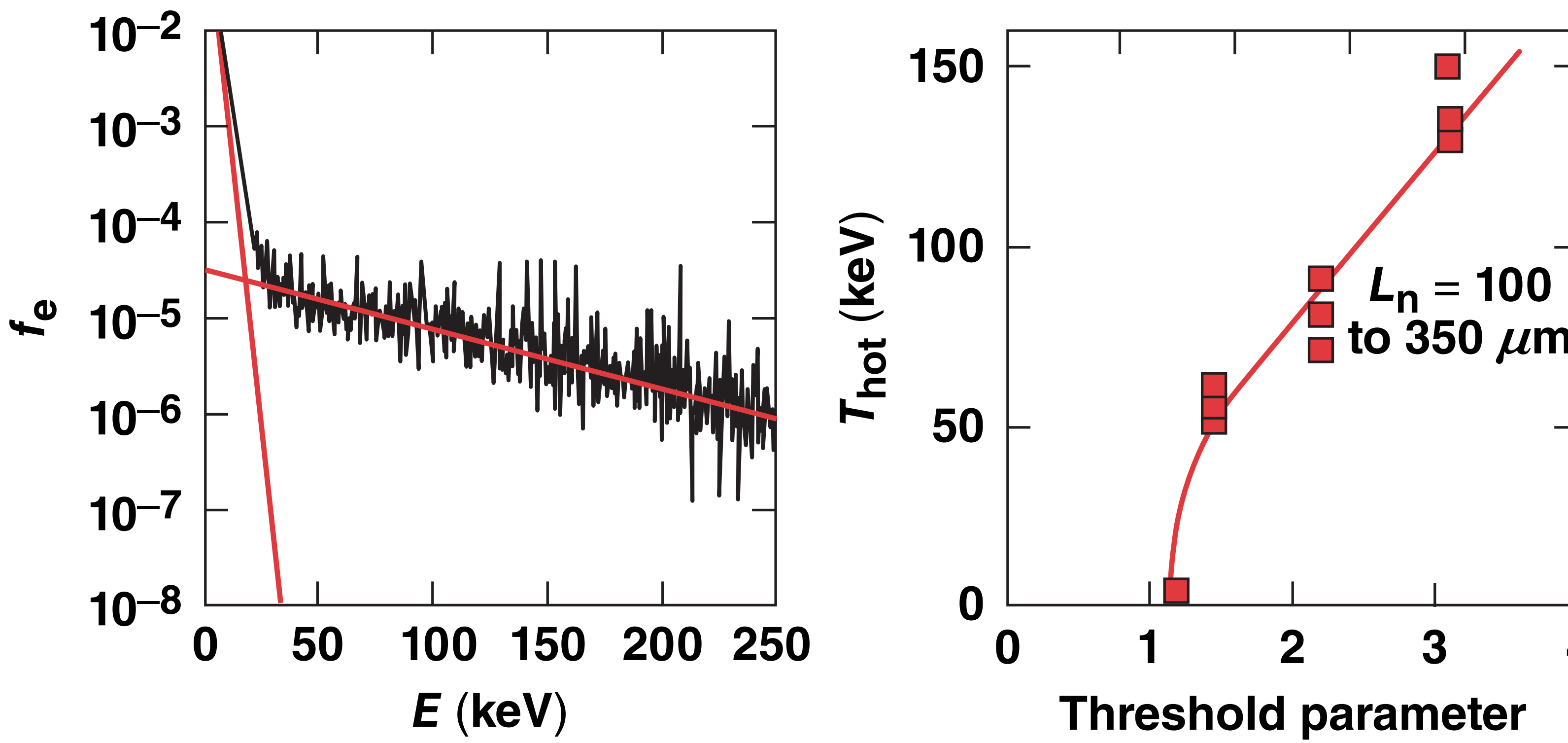
- The threshold parameter* is given by $\eta = I_L/I_{thr} = I_{14}L_{\mu m}/(230\ T_{keV})$



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

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†

*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.
‡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 Phys. Plasmas (2011).

The diffusive nature of electron trajectories has also been investigated in the case of prescribed ZAK fields

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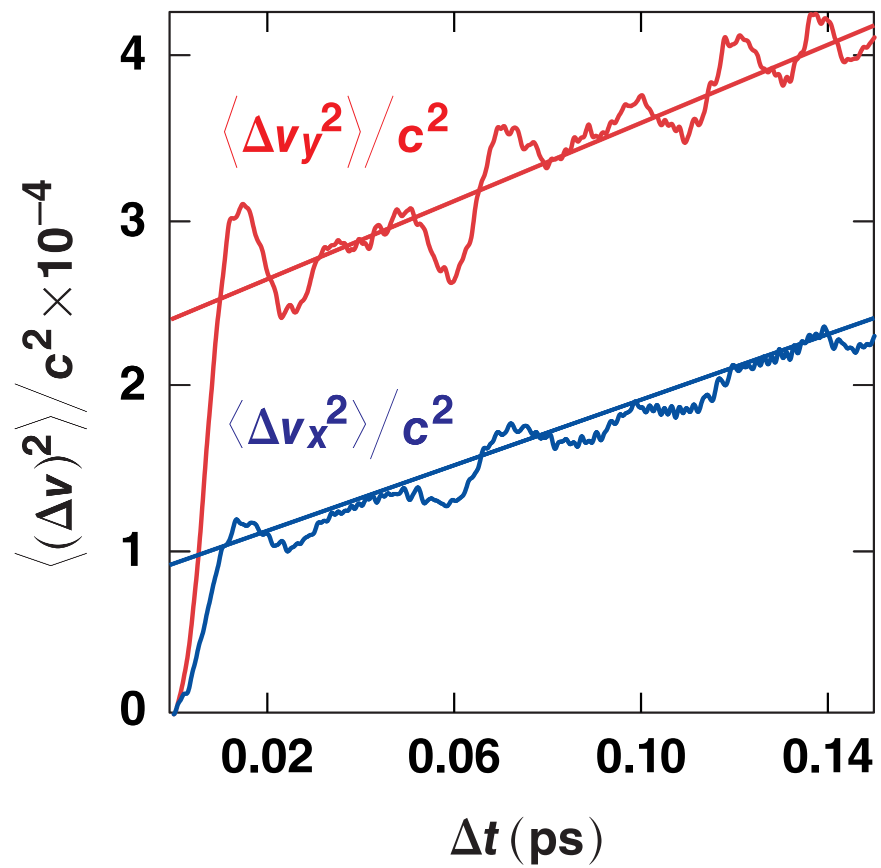
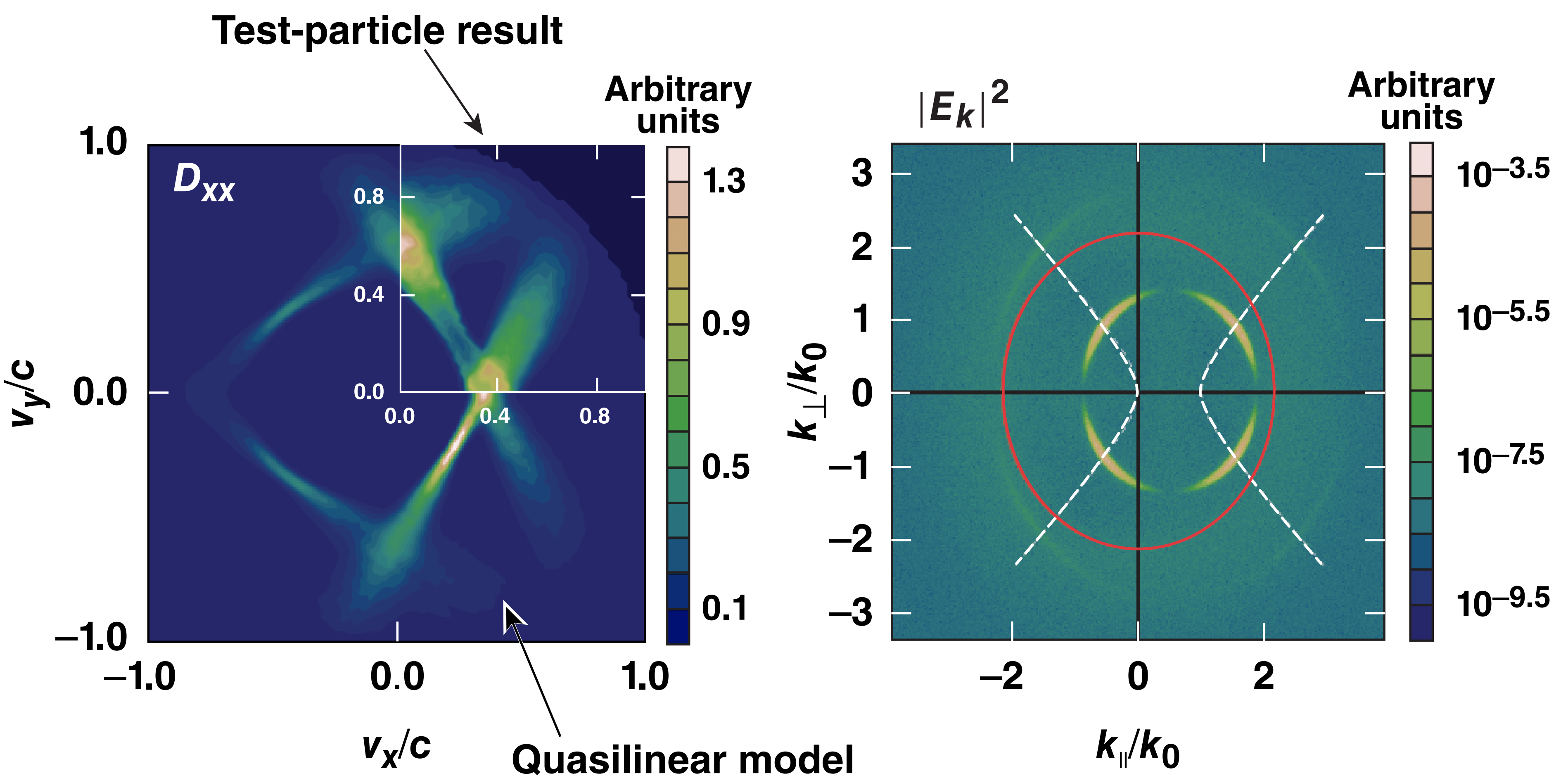
- A test of the validity of the velocity space-diffusion model for plasma heating is to measure the dispersion in velocity of a group of test particles
- The variance of test particle velocities should be linear in time: $\langle \Delta v^2 \rangle \sim t$



*J. J. Thomson *et al.*, Phys. Fluids 17, 973 (1974).
J. I. Katz *et al.*, Phys. Fluids 16, 1519 (1973).

The test-particle diffusion coefficient is in reasonable agreement with quasilinear predictions



The quasilinear model can be used to evolve the electron-distribution function

- **Electrons are heated by velocity space diffusion caused by the turbulent spectrum of plasma waves (Zakharov equations)**

$$\frac{\partial f}{\partial t} + \frac{\partial}{\partial \vec{v}} \cdot \left(D(\vec{v}) \cdot \frac{\partial f}{\partial \vec{v}} \right) = \sigma (f - f_m)$$

- **The diffusion tensor is evaluated in the quasilinear approximation**

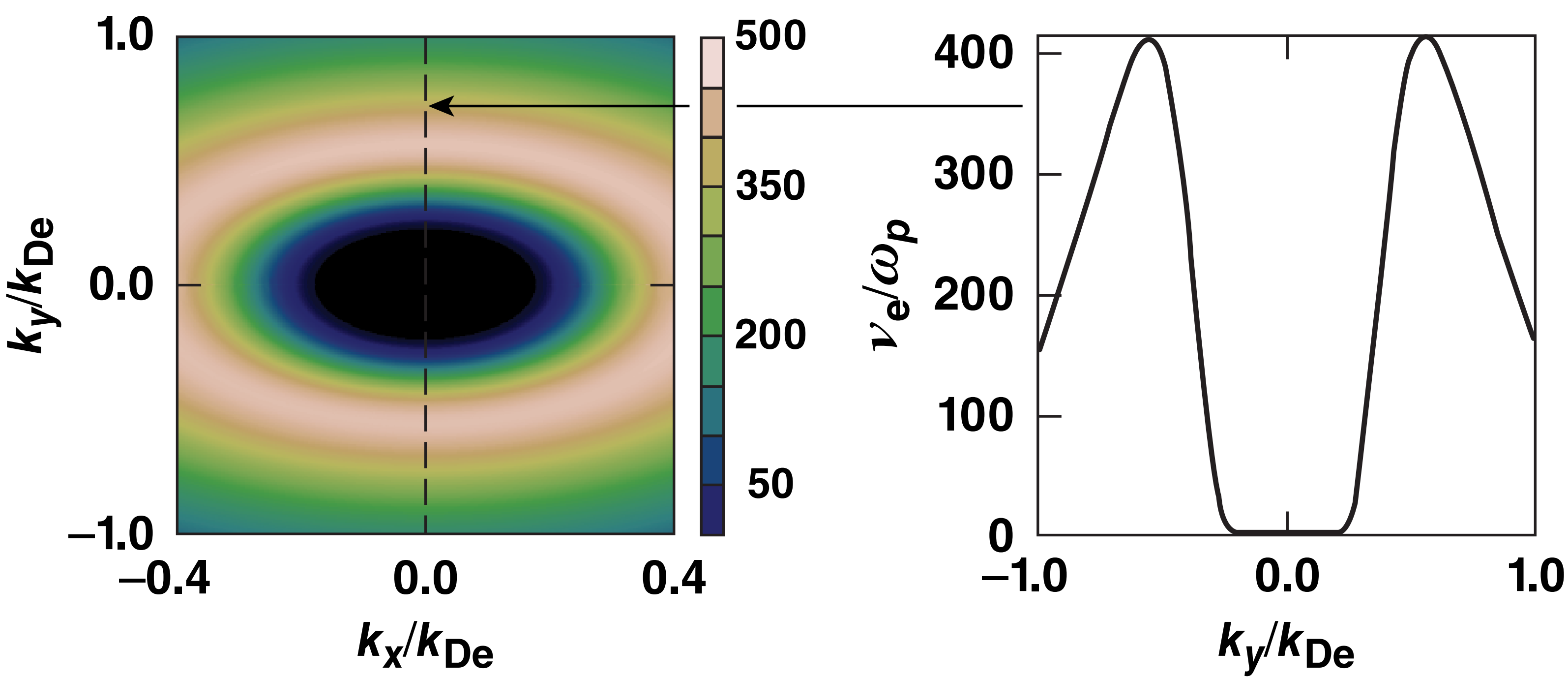
$$D(\vec{v}) = \frac{\pi e^2 \, |\Delta \vec{k}|}{2 m_e^2 \Delta k_x \Delta k_y} \sum_{\omega_p - \vec{k} \cdot \vec{v} = 0} \frac{\vec{k}\,\vec{k}\, |\psi(\vec{k}, t)|^2}{|\vec{v}|}$$

- **The quasilinear model evolves the electron-distribution function self-consistently**

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

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

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



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Heating in Prescribed Field

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

- "Extended" Zakharov equations used in ZAK*

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

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Wave envelopes

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

$$\tilde{E}_0=e_y\sum_i|E_0|_i\,\exp\left[i\,\vec{k}_{0i}\cdot\vec{x}-i(\omega_0-2\omega_{p0})t\right]$$

*D. F. DuBois *et al.*, Phys. Rev. Lett. 74, 3983 (1995);
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TC8454b

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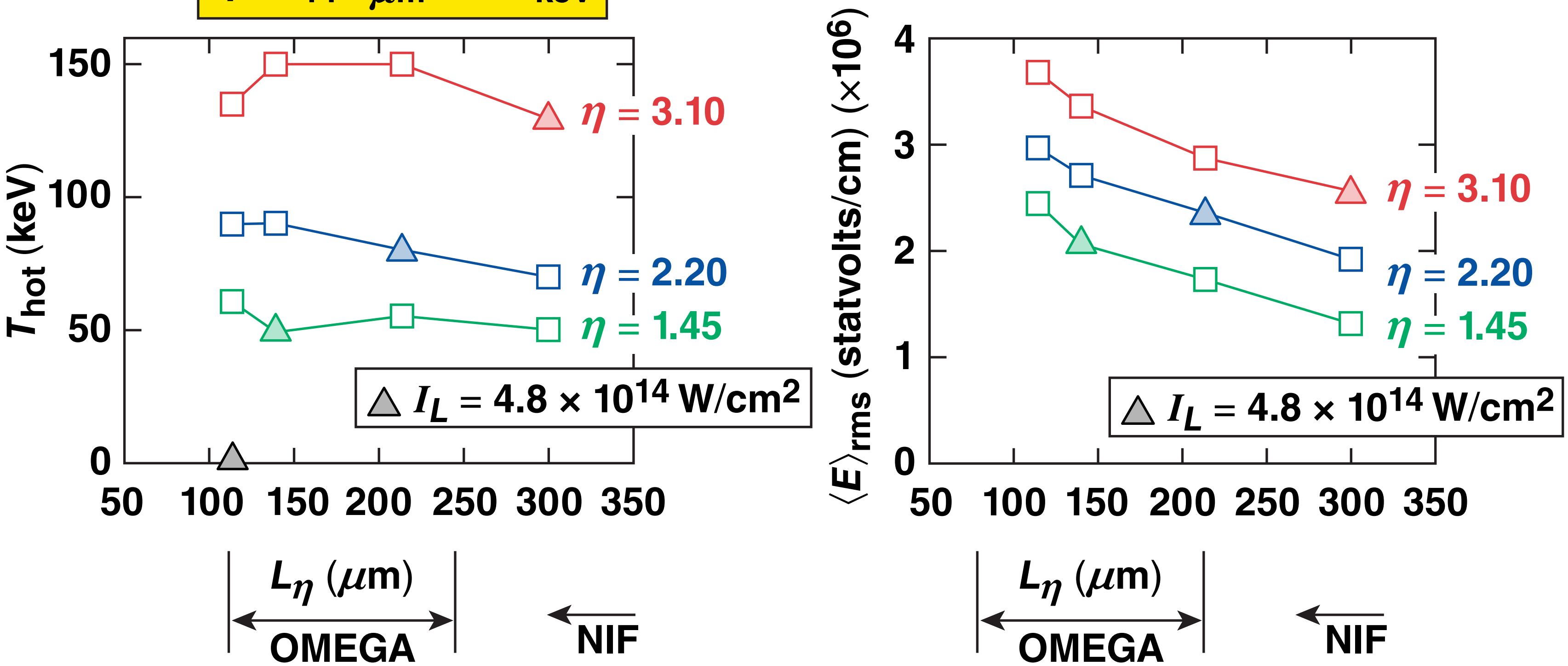
Heating in Prescribed Field

For a fixed value of the threshold parameter η, the hot-electron temperature scaling with electron-density scale length is weak

- For all cases the initial electron temperature T_e = 2 keV
- As L_n is increased, I_L is decreased to keep the product constant

$\eta = I_{14} L_{\mu m}/230\ T_{keV}$



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