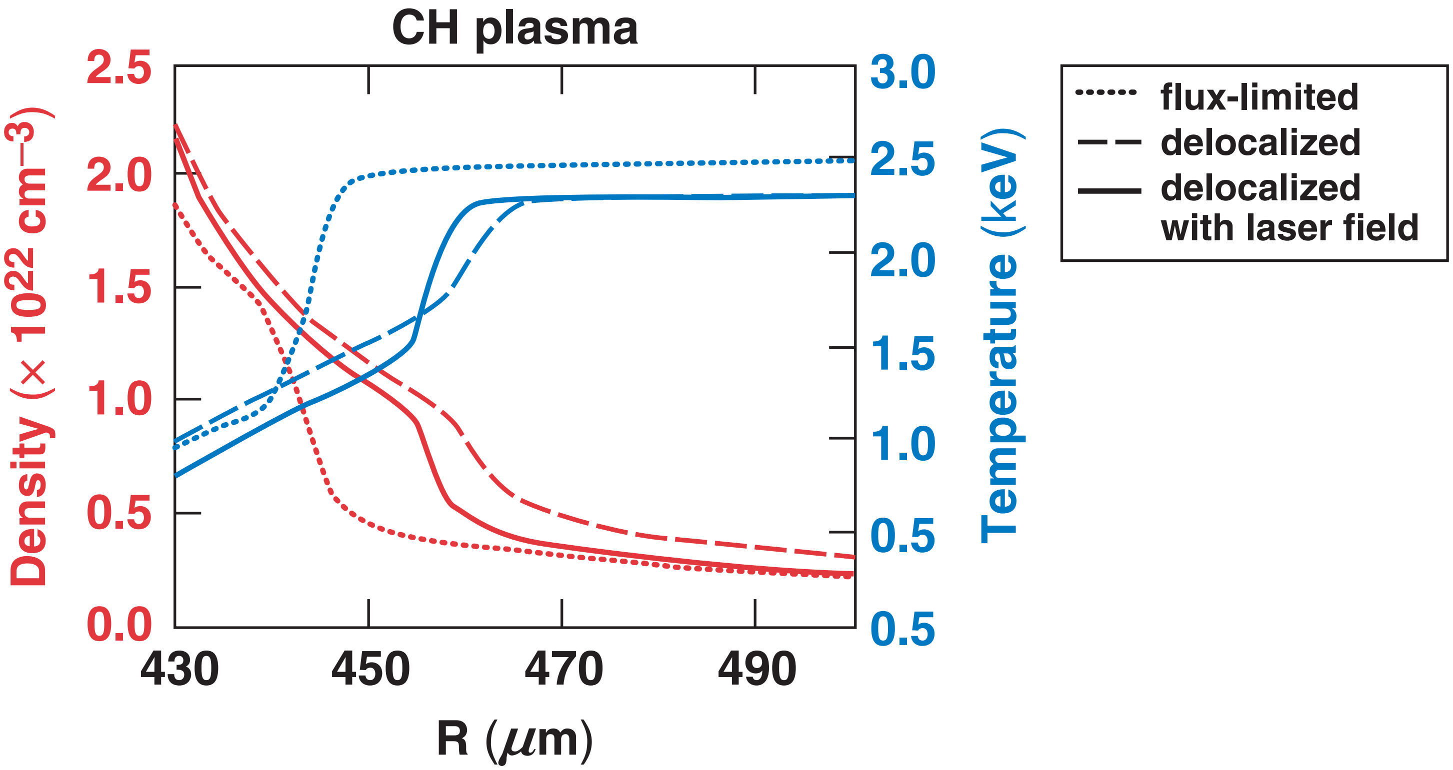
Electron Distribution and Transport in a Laser Field in Direct-Drive ICF Plasmas



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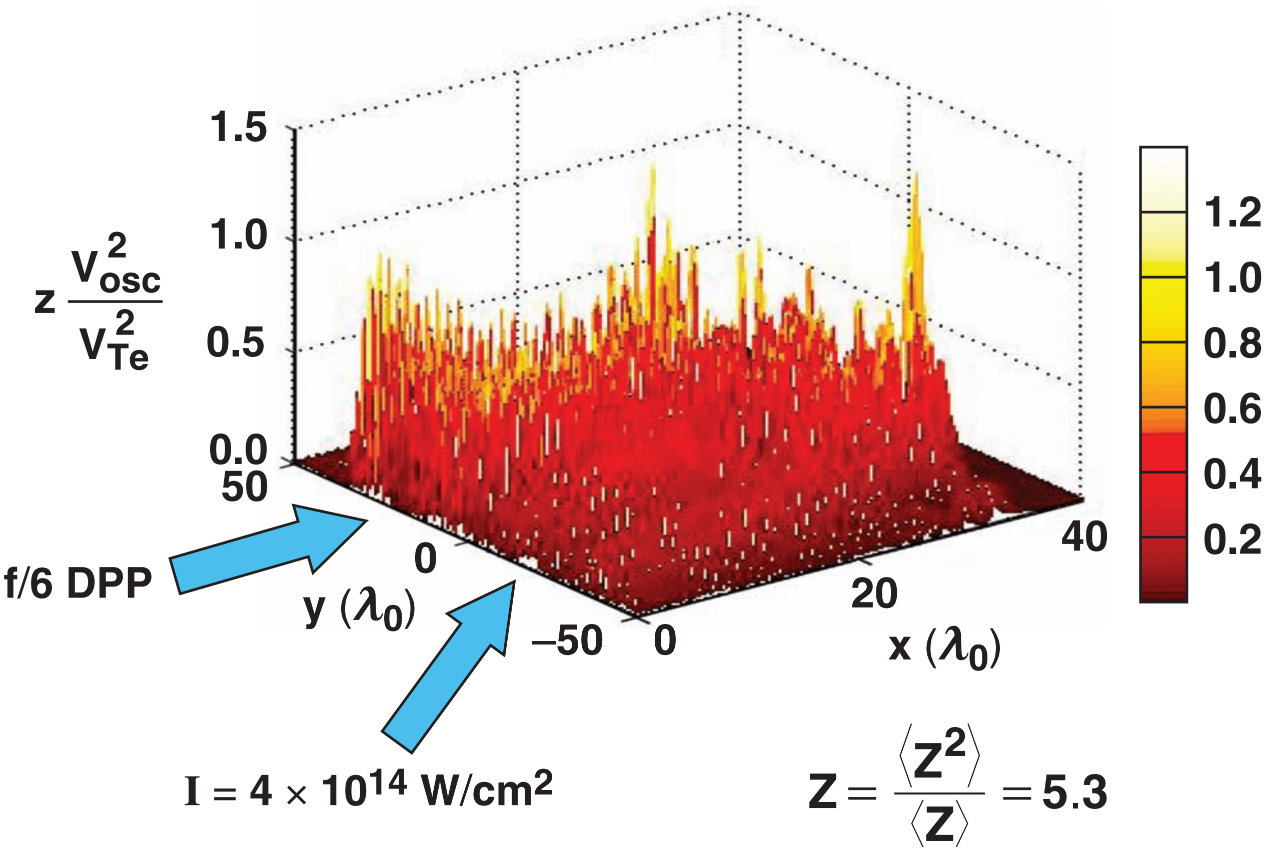
Summary

The modification of electron heat flux on hydrodynamic scales by a moderate laser field influences the target evolution

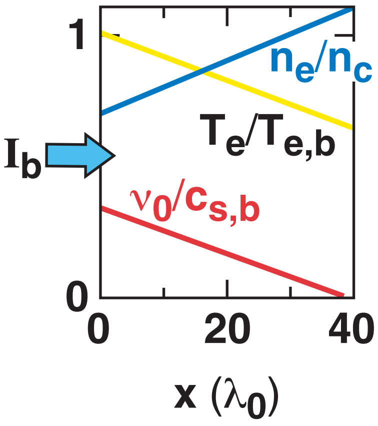
- For moderate laser intensities, the heating strongly affects low-velocity electrons, which allows an analytical solution for the electron distribution function.
- In a laser field, the electron heat flux on hydrodynamic scales is reduced.
- In hydrodynamic modeling with delocalized transport, the modification of the electron heat flux decreases the absorption of laser energy.

Under crossed-beam irradiation, the laser intensity profiles are strongly inhomogeneous



I = 4 × 10^{14} W/cm^2

$$Z = \frac{\langle Z^2 \rangle}{\langle Z \rangle} = 5.3$$

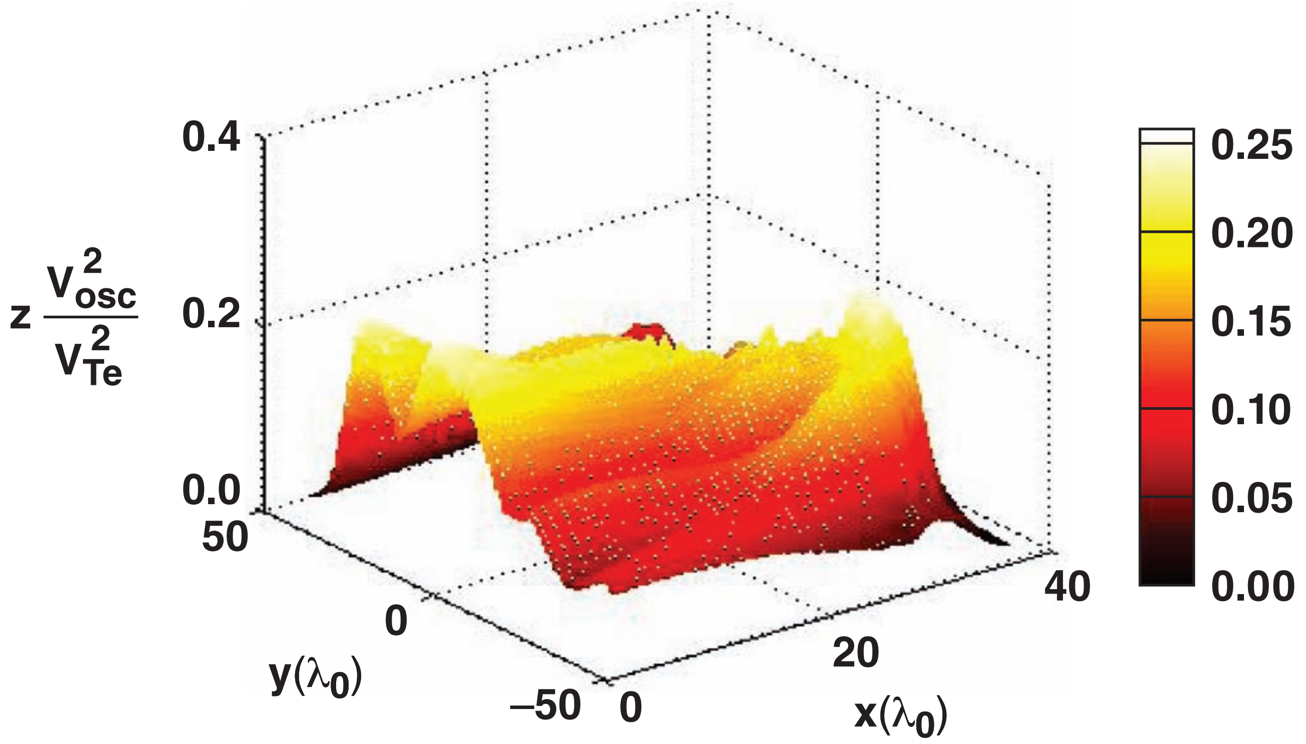


$T_{e,b}$ = 2 keV

Small-scale perturbations are weakly collisional.

For large-scale modeling, the laser intensity is averaged over spatial scales much larger than the laser wavelength

Large-scale modeling resolves hydrodynamic scales for density and temperature.



After averaging over the electron mean-free path $\lambda_m = \sqrt{\lambda_{ei}\lambda_{ee}} \sim \lambda_{ei}\sqrt{Z}$.

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The symmetric part of the electron distribution function is modified by heating

- For moderate laser intensities $Z\frac{V_{osc}^2}{V_{Te}^2} \ll 1$ in the collisional limit

$$\frac{\partial f_0}{\partial t} - J_{ee}(f_0, f_0) = \frac{v_{osc}^2}{3}\frac{1}{v^2}\frac{\partial}{\partial v}\left[v^2 \nu(v)\frac{\partial f_0}{\partial v}\right]$$

where $\nu(v) = \nu_{ei}\left(v_{Te}^3/v^3\right)$.

For small velocities $V \ll V_{Te}$, the term $\sim v_{osc}^2 \cdot J_{ee}$ can be neglected.

- The heating time $t_{hc} \sim \frac{v^2}{v_{osc}^2}\frac{1}{\nu(v)} \sim v^5$ is much smaller for cold electrons compared to the heating time for the bulk of electron distribution

$$t_h \sim \frac{v_{Te}^2}{v_{osc}^2}\frac{1}{\nu_{ei}}.$$

Heating strongly affects the low-velocity part of the distribution function

- The solution for $V \ll V_{Te}$

$$f_{0,S}(v) = f_0(0)\exp\left(-\frac{1}{v_{Te}^2}\int_0^v \frac{u^4 du}{u^3 + v_L^3}\right) \qquad v_L = v_{Te}\left(\sqrt{\frac{\pi}{8}}\,\frac{Zv_{osc}^2}{v_{Te}^2}\right)^{1/3}$$

describes the transition from $\ln f_0 \sim -v^5$ to $\ln f_0 \sim -v^2$; different from the super-Gaussian distributions*

$$f_0(v) \sim \exp\left[-\left(\frac{v}{v_m}\right)^m\right] \qquad m = 2 \div 5.$$

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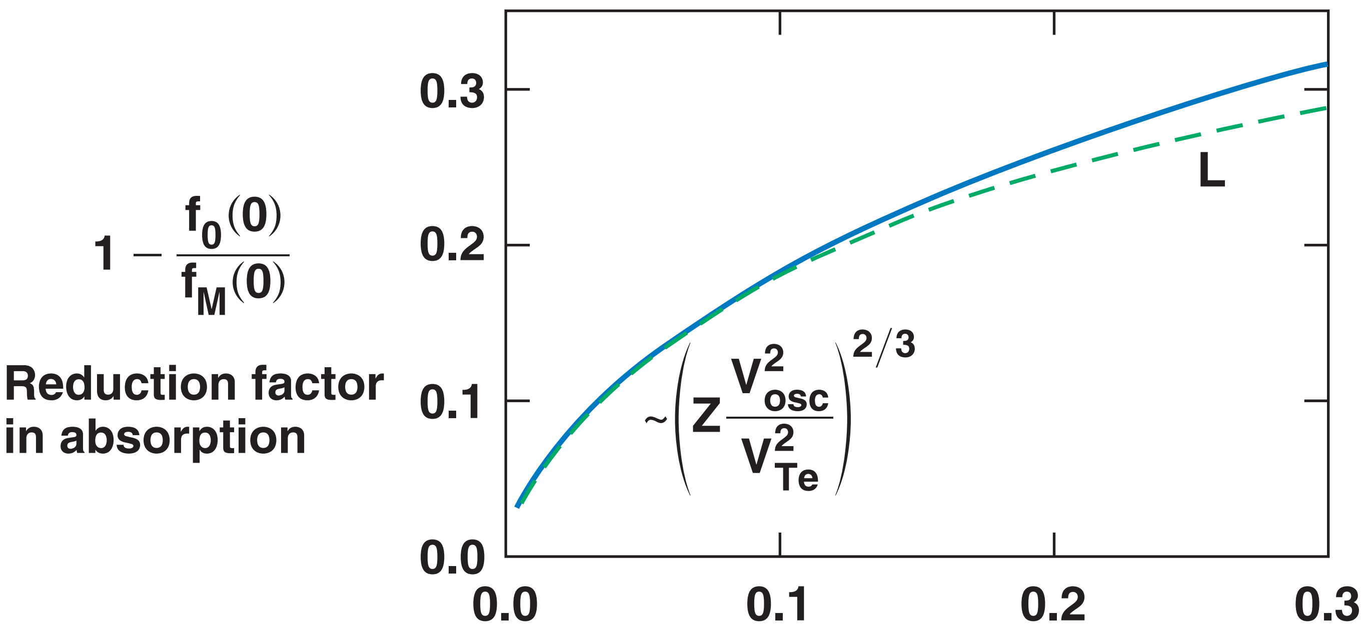
*J. P. Matte *et al.*, Plasma Phys. Contr. Fusion 30, 1665 (1988).

The laser absorption fraction is calculated from the electron distribution at low velocities



$$Z \frac{v_{osc}^2}{v_{Te}^2} = 0.046 \cdot Z \cdot \frac{I(10^{15}\,\mathrm{W/cm^2})}{T_e(\mathrm{keV})}$$

L A. B. Langdon, PRL 44, 575 (1980).

The modification of the electron distribution function in the laser field at large velocities is calculated using the Chapman–Enskog method

- The laser field also modifies the electron distribution in the range of velocities contributing to the heat flux* $V > V_{Te}$.

  $$f_{0,\ell}(V) = f_M(V)\left(1 + \Phi_E(V) \cdot \frac{ZV_{osc}^2}{V_{Te}^2}\right)$$

  where $\Phi_E(V)$ does not directly change the density and temperature

- The solution for low velocities is close to Maxwellian

  $f_{0,s}(V) \sim f_M(V)$, when V approaches V_{Te};

  allowing solutions to match at low and large velocities.

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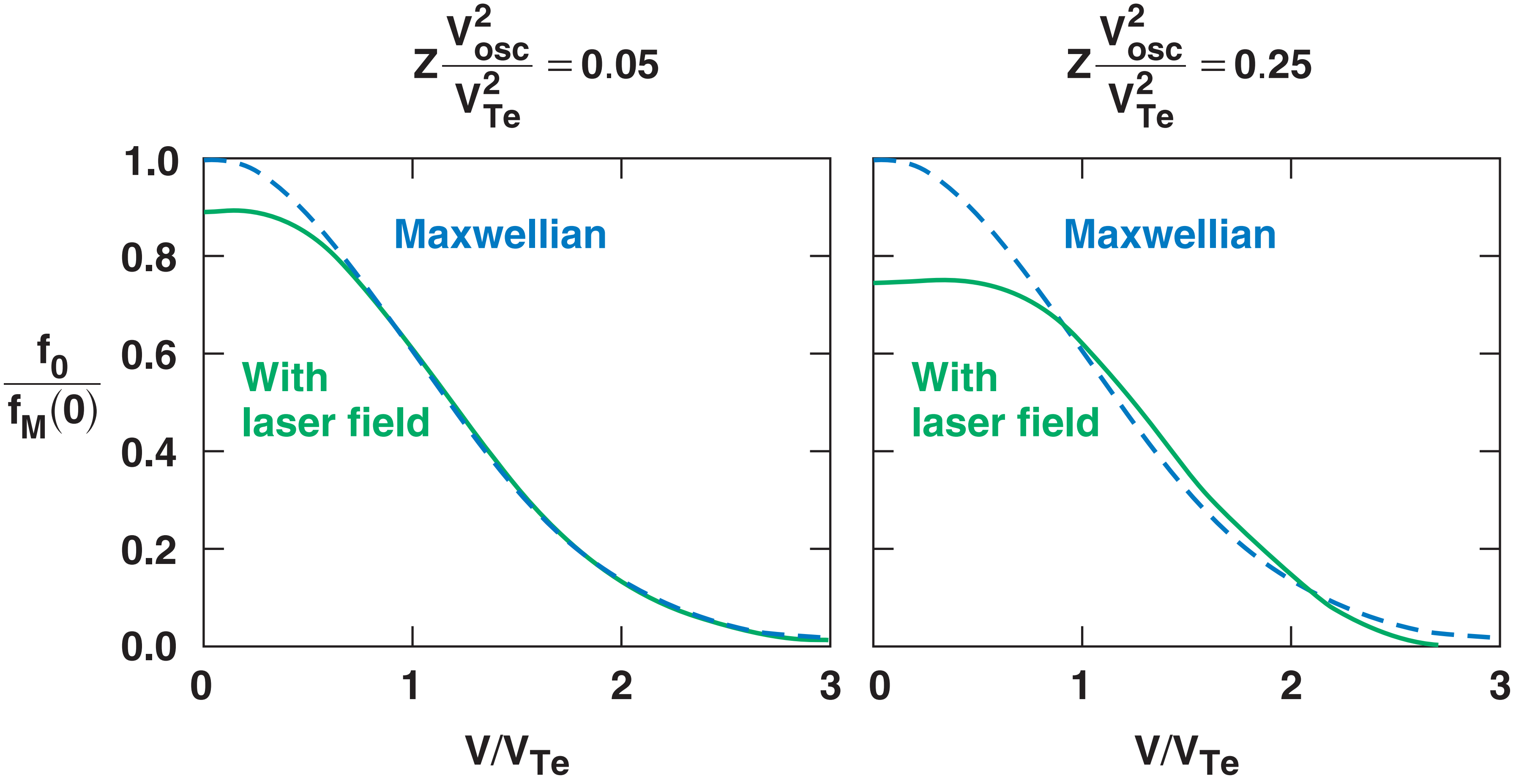
* A.V. Maximov *et al.,* Sov J. Plasma Phys. 16, 331 (1990); V. N. Goncharov, Phys. Plasmas 11, 5680 (2004).

The symmetric part of the electron distribution function in the laser field deviates from the Maxwellian distribution at low and high velocities



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The modification of the symmetric part of the distribution function leads to changes in the electron heat flux

- The electron heat flux after using the condition $\vec{j} = 0$

$$\vec{q} = -\frac{m_e}{\nu_{ei} V_{Te}^3}\left[\begin{array}{l}\alpha_{SH} \cdot n_e V_{Te}^5 \dfrac{\partial V_{Te}^2}{\partial \vec{r}} - \alpha_1 \cdot \dfrac{\partial}{\partial \vec{r}}\left(n_e V_{Te}^5 Z V_{osc}^2\right) \\ \qquad + \alpha_2 \cdot V_{Te}^2 \dfrac{\partial}{\partial \vec{r}}\left(n_e V_{Te}^3 Z V_{osc}^2\right) - \alpha_p \cdot n_e V_{Te}^5 \dfrac{\partial}{\partial \vec{r}}\left(V_{osc}^2\right)\end{array}\right]$$

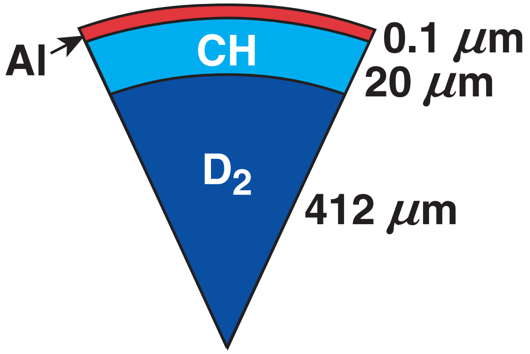
coefficients

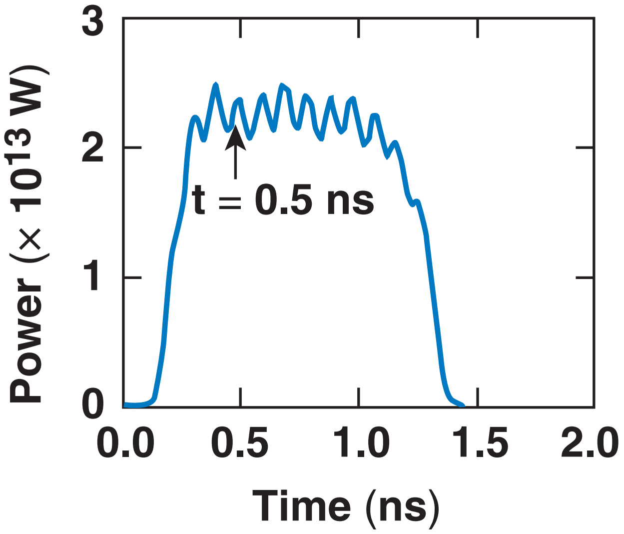
$\alpha_{SH} = 13.6,\ \alpha_1 = 31.2,\ \alpha_2 = 13.9, \alpha_p = 2.3 \qquad Z \gg 1$

$\alpha_{SH} = 3.2,\ \alpha_1 = 15.2,\ \alpha_2 = 11.1,\ \alpha_p = 2.7 \qquad Z = 1$

- New terms in the heat flux depend on $\dfrac{\partial n_e}{\partial \vec{r}}, \dfrac{\partial T_e}{\partial \vec{r}}$, and $\dfrac{\partial V_{osc}^2}{\partial \vec{r}}$

Modification of electron heat flux influences the hydrodynamic evolution of a target in the absorption region

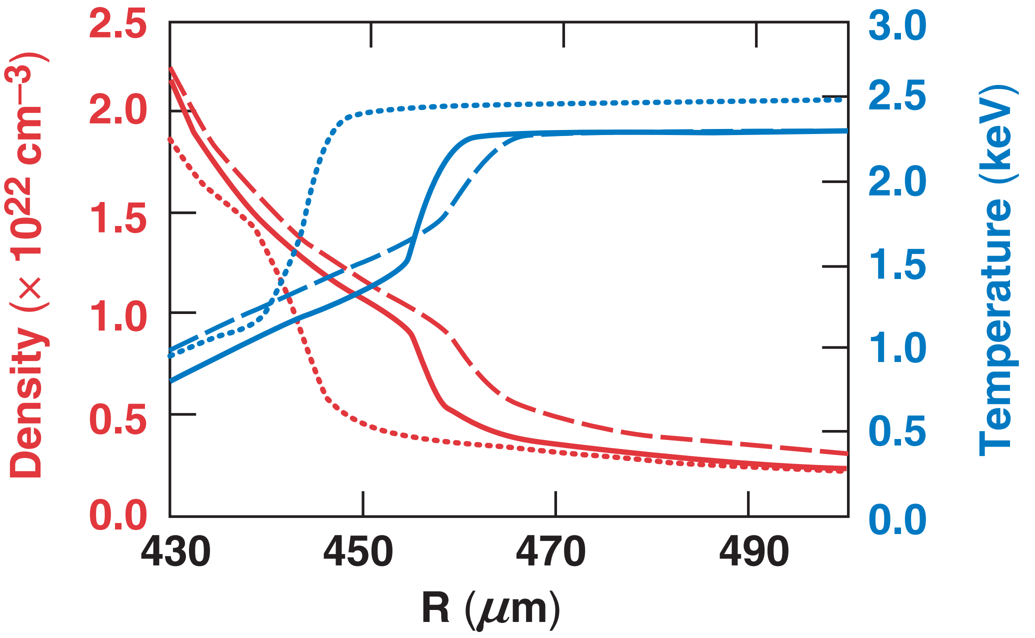




Hydrocode *LILAC*[1] simulations with delocalization model[2]

	Absorption
⋯⋯ flux-limited (f = 0.06)	0.60
– – delocalized	0.73
—— delocalized with laser field	0.64
experiment	0.62±0.02

$\lambda_{m,cr} \sim 1\,\mu m$



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[1] J. A. Delettrez *et al.*, PRA 36, 3926 (1987).

[2] G. P. Schurtz *et al.*, Phys. Plasmas 7, 4238 (2000).

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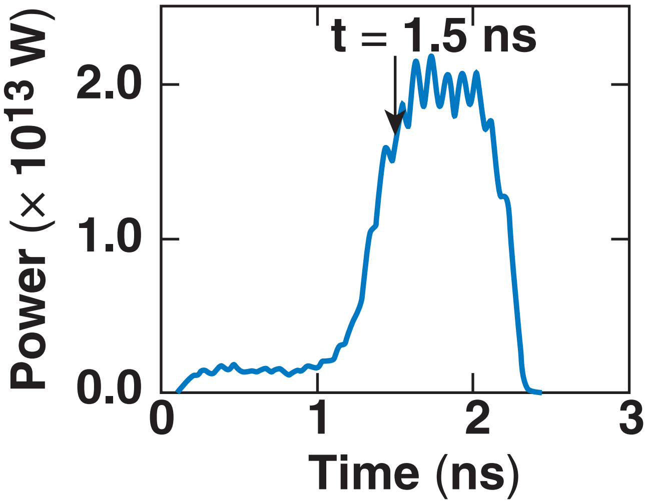
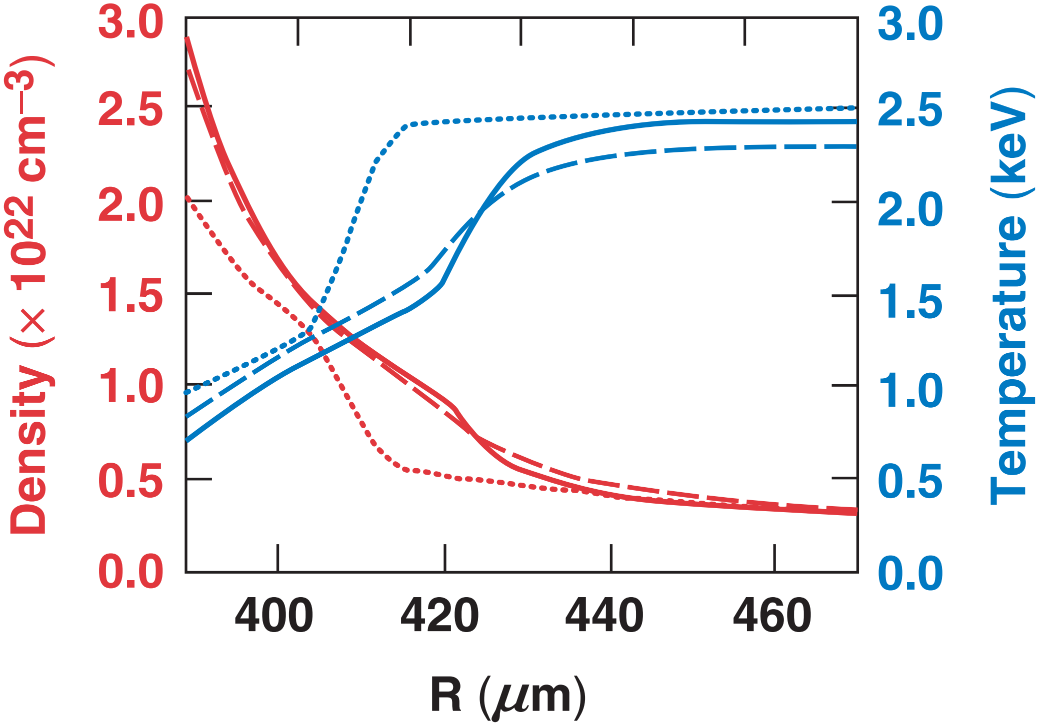
For a shaped pulse, the absorption is reduced because electron temperature and density are changed by the modified heat flux



		Absorption
······	flux-limited (f = 0.06)	0.78
– –	delocalized	0.83
——	delocalized with laser field	0.76
	experiment	0.70±0.03



Summary/Conclusions

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