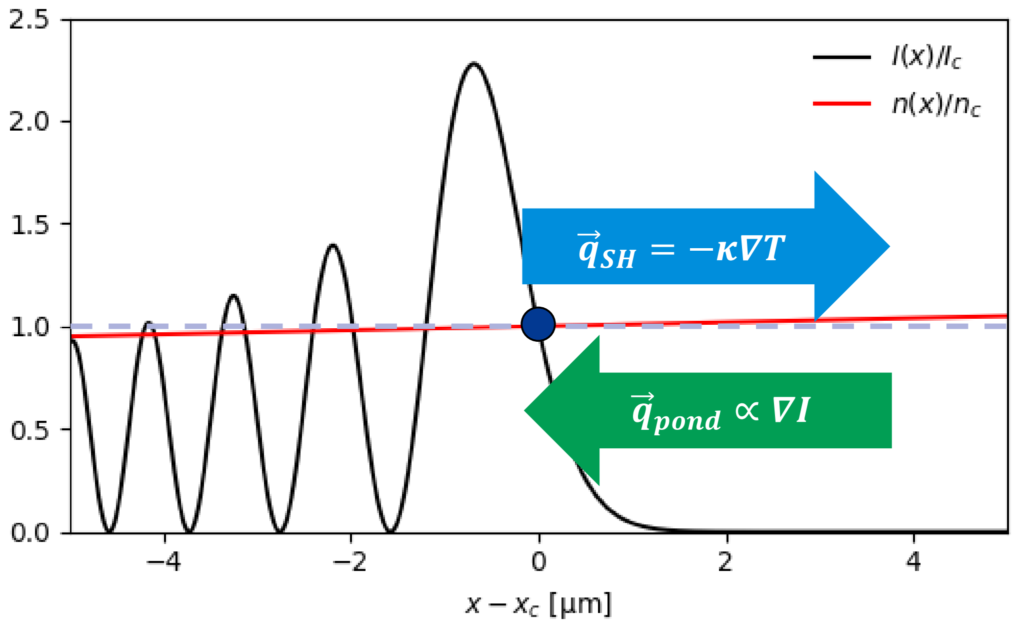
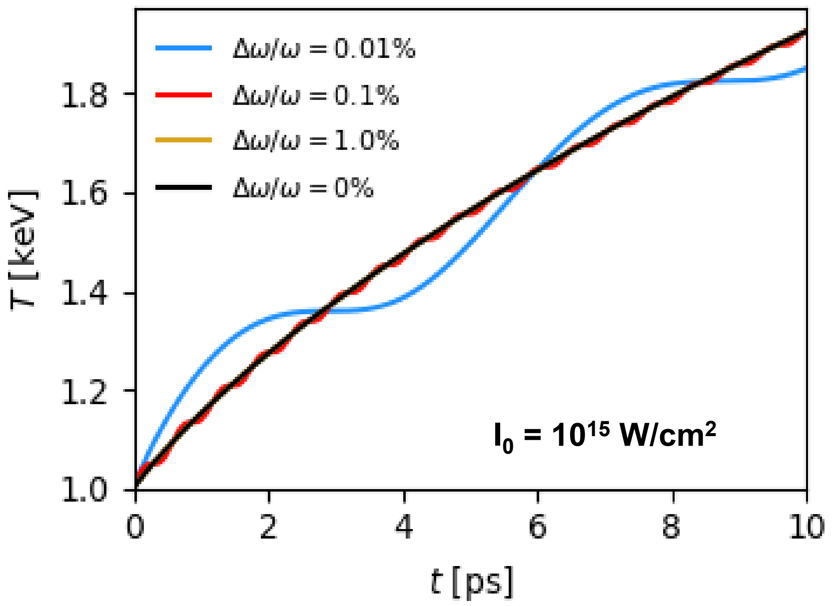
Impact of Bandwidth on the Electron Distribution Functions of Laser-Produced Plasmas





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CHANGING WHAT'S POSSIBLE

U.S. DEPARTMENT OF ENERGY | Office of Science

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Pittsburgh, PA / Virtual
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High intensity and strong intensity gradients impact heat transport

- Next-generation broadband laser drivers will open up high-intensity direct-drive ICF design space
- Ponderomotive effects and bandwidth effects are being studied using Vlasov-Fokker-Planck simulations
- Preliminary calculations show broadband IB absorption is in good agreement with monochromatic theory
- An extended set of Fokker-Planck equations are being implemented to enable comprehensive accounting for ponderomotive effects on transport near the critical density

Collaborators

Andrei Maximov, Valeri Goncharov
University of Rochester Laboratory for Laser Energetics

Mark Sherlock
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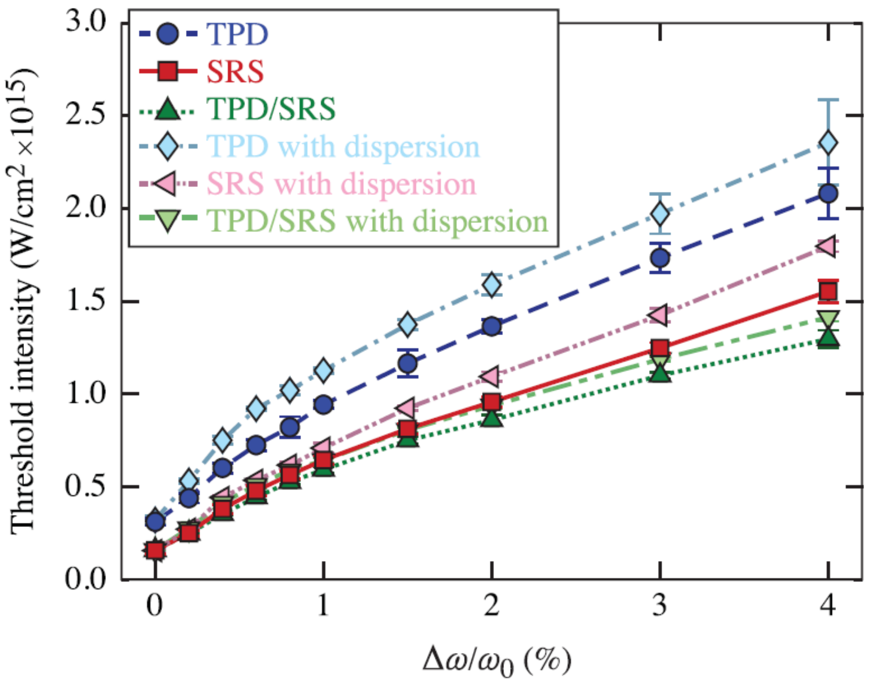
Ultra-broadband ICF drivers motivate revisiting classic LPI problems

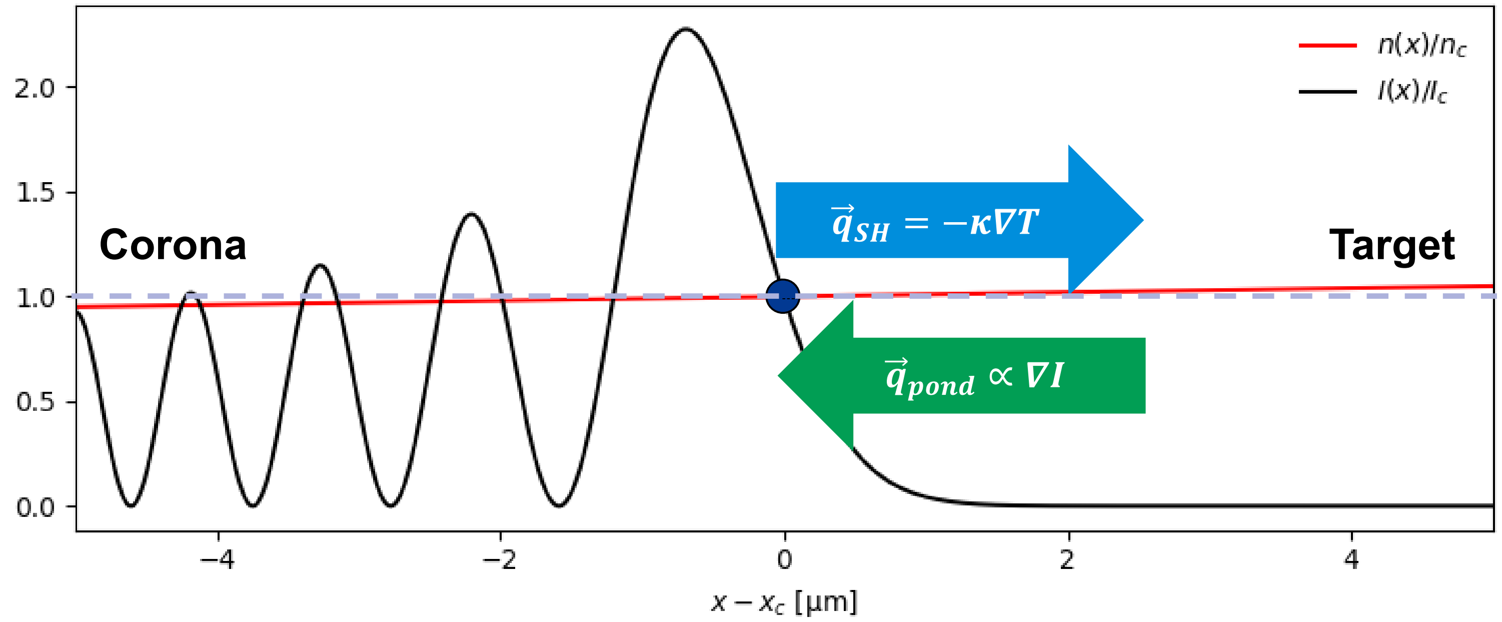
- **Forthcoming FLUX laser system will achieve Δω/ω > 1%**
- **Ultrawide bandwidth will mitigate laser-plasma instabilities***
- **New long-pulse (~100s ns) and high-intensity (~PW/cm²) direct-drive ICF design space**
- **Higher drive pressure → larger fuel mass → higher gain**
- **Ponderomotive effects on heat transport need to be better understood both in the monochromatic case, and also with bandwidth**



* R. K. Follet et al., *Phys. Plasmas* 28, 032103 (2021).

The ponderomotive force is as important as temperature gradients for heat transport near the critical density

Airy intensity profile $\lambda = 0.351\mu m, L_n = 100\mu m$



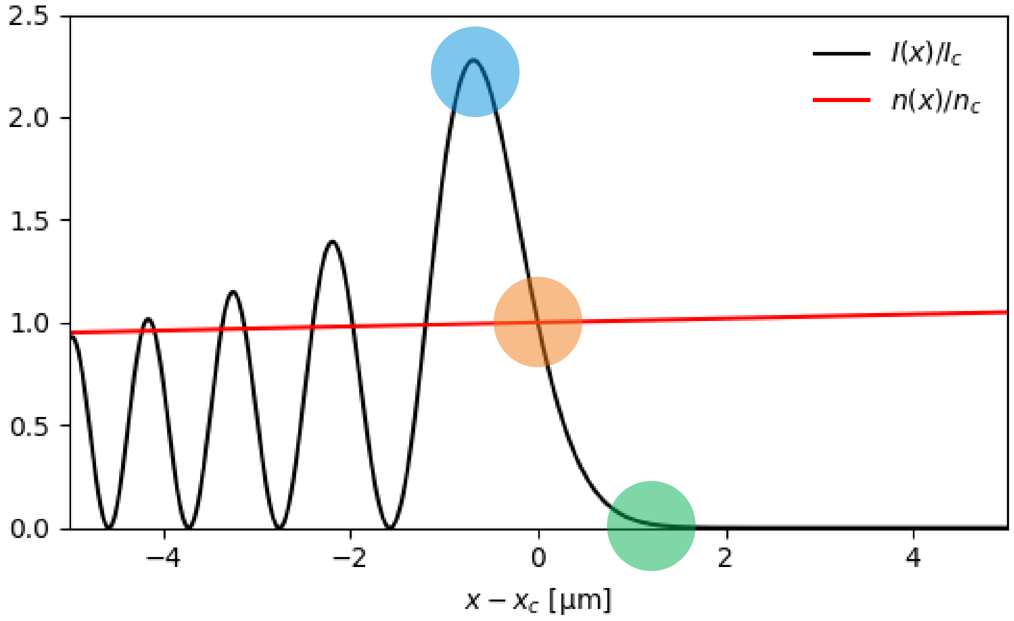
$$L_I \approx 5\left(\lambda/L_n\right)^{\frac{2}{3}} L_n \approx 10\ \mu m$$

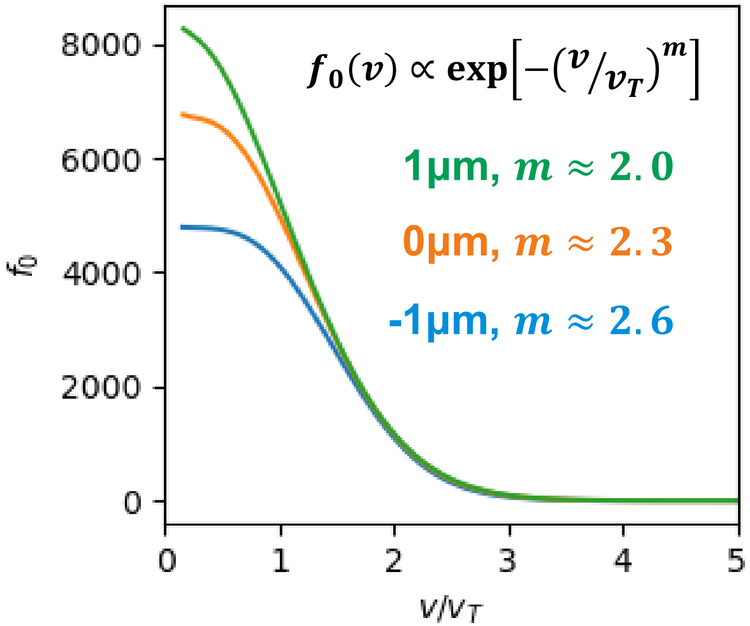
$$L_{pond} = \frac{k_B T}{F_{pond}} \approx 5\frac{T_{keV}}{\lambda_{\mu m}^2 I_{15}} L_I \approx 100 - 1000\ \mu m$$

L_{pond} is of the same order as L_n, L_T

* W. L. Kruer, *The Physics of Laser – Plasma Interactions* (CRC Press, 2003).
** V. N. Goncharov and G. Li, *Phys. Plasmas* 11, 5680 (2004).

Sharp intensity gradients lead to non-uniform flattening of the distribution function via the inverse bremsstrahlung absorption





$$\nabla f_0 \propto \nabla n, \nabla T, \underline{\nabla I}$$

Heat transport is based on non-uniformly non-Maxwellian thermal populations

* A. B. Langdon, *Phys. Rev. Lett.* 44, 570 (1980).
** E. Fourkal et al., *Phys. Plasmas* 8, 550 (2001).

The addition of broadband will affect the feedback cycle between the hydro scale and the electron kinetic scale

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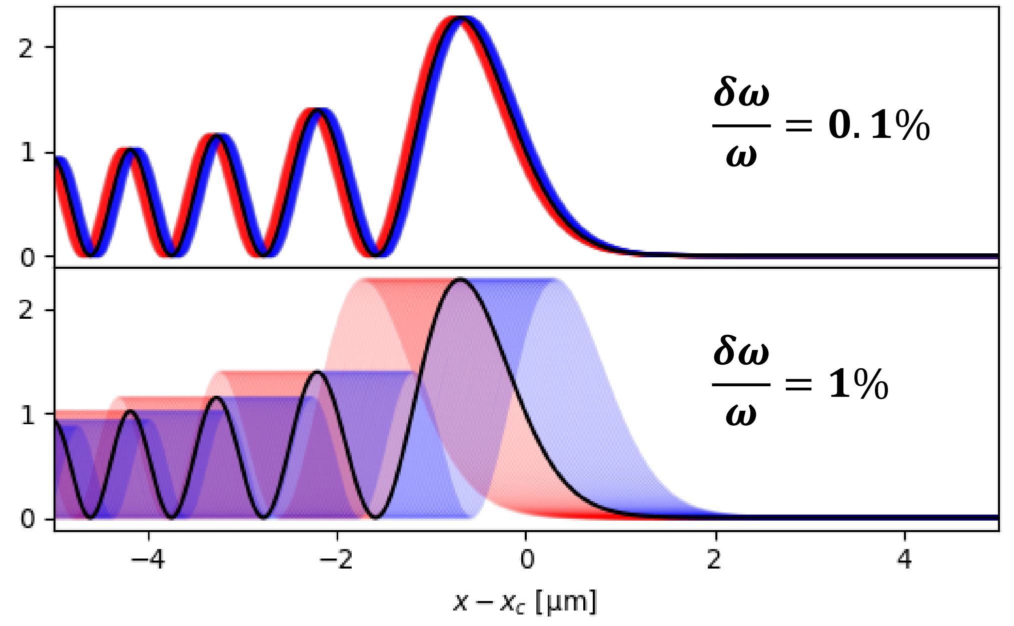
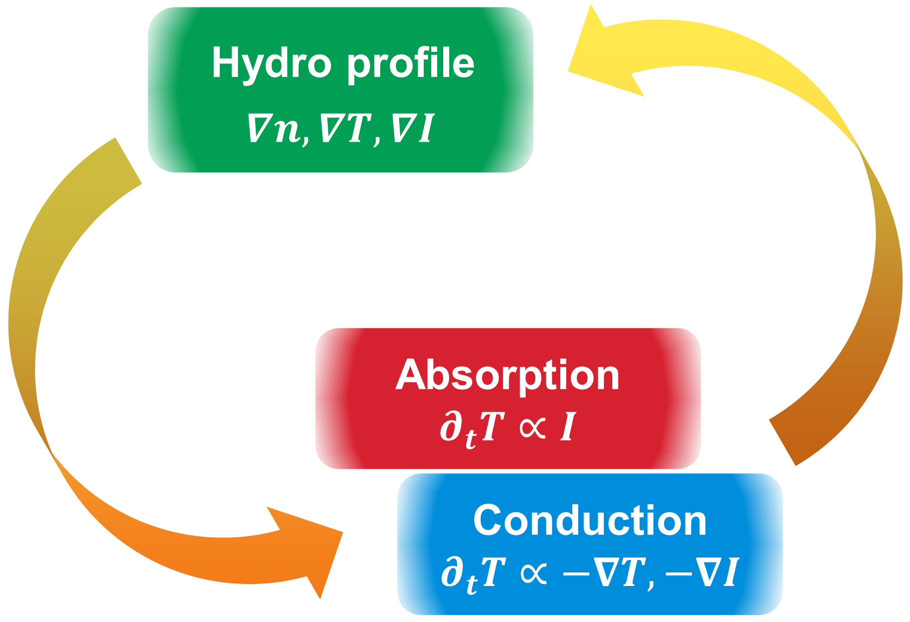
Detuning shifts the critical point & softens ∇I

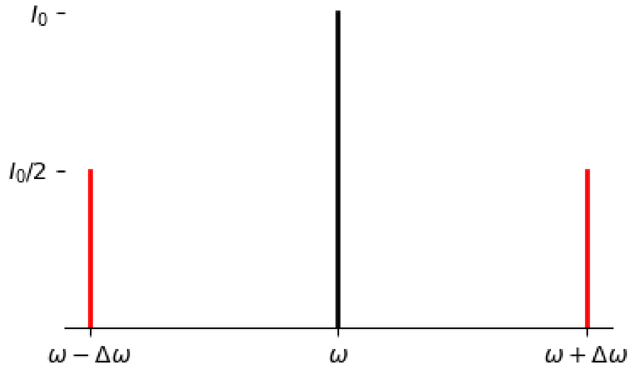


Feedback between hydro & kinetic scales



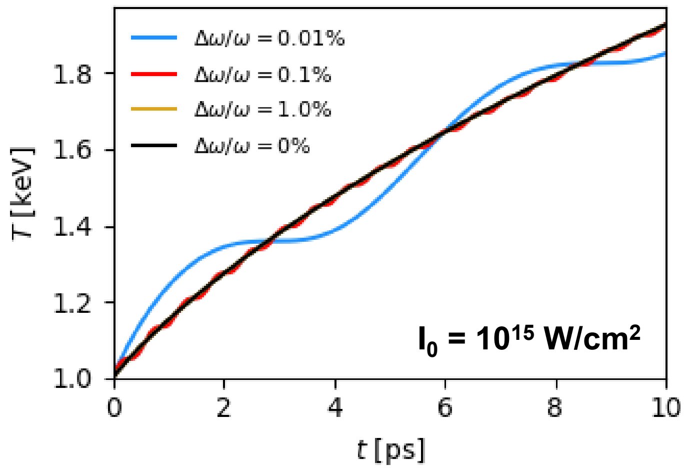
Vlasov-Fokker-Planck simulations of inverse bremsstrahlung absorption show insensitivity to bandwidth

Two-color broadband model



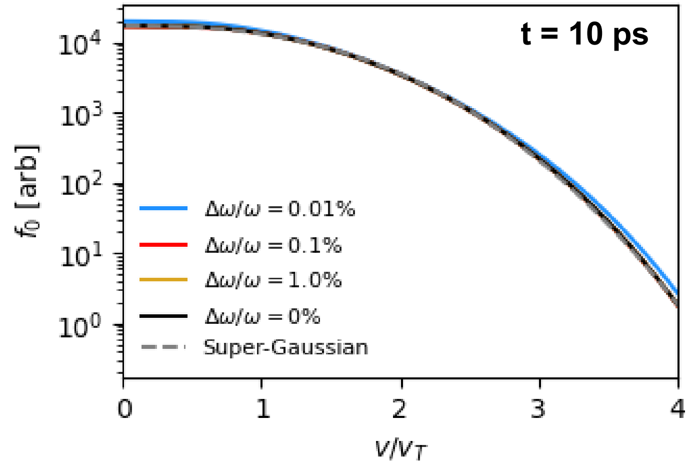
$$E(t) = \sqrt{2}\cos(\Delta\omega\, t)E_{mono}(t)$$

IB heating



$$\frac{dT}{dt} = \underbrace{2\cos^2(\Delta\omega\, t)}_{\approx 1}\left(\frac{dT}{dt}\right)_{mono}$$

Electron distribution function



* M. Sherlock et al., *Phys. Plasmas* 24, 082706 (2017).

Standard Fokker-Planck modeling of laser effects misses many transport-relevant ponderomotive effects

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- Not practical to model the laser field directly because $\omega_L \gg \nu_e$ & $\lambda_L \ll \lambda_{mfp}$

$$\frac{\partial f}{\partial t} + \vec{v} \cdot \frac{\partial f}{\partial \vec{r}} - e\left[\vec{E}_0 + \vec{E}_L \cos(\omega_L t)\right] \cdot \frac{\partial f}{\partial \vec{p}} = C_{ei}[f] + C_{ee}[f, f]$$

- Standard approaches include IB heating and ponderomotive force

$$\frac{\partial f}{\partial t} + \vec{v} \cdot \frac{\partial f}{\partial \vec{r}} + \left(-e\vec{E}_0 + \vec{F}_{pond}\right) \cdot \frac{\partial f}{\partial \vec{p}} = C_{IB}[f] + C_{ei}[f] + C_{ee}[f, f] + others$$

- Careful asymptotic analysis reveals many missing effects of similar order
  - Ponderomotive corrections to electron-electron collisions
  - Ponderomotive stress $\sim \nabla \cdot (\vec{E}_L \vec{E}_L / \omega_L^2)$
- We are extending the K2 code to solve time-enveloped VFP equations for a complete account of laser field effects on heat transport

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

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