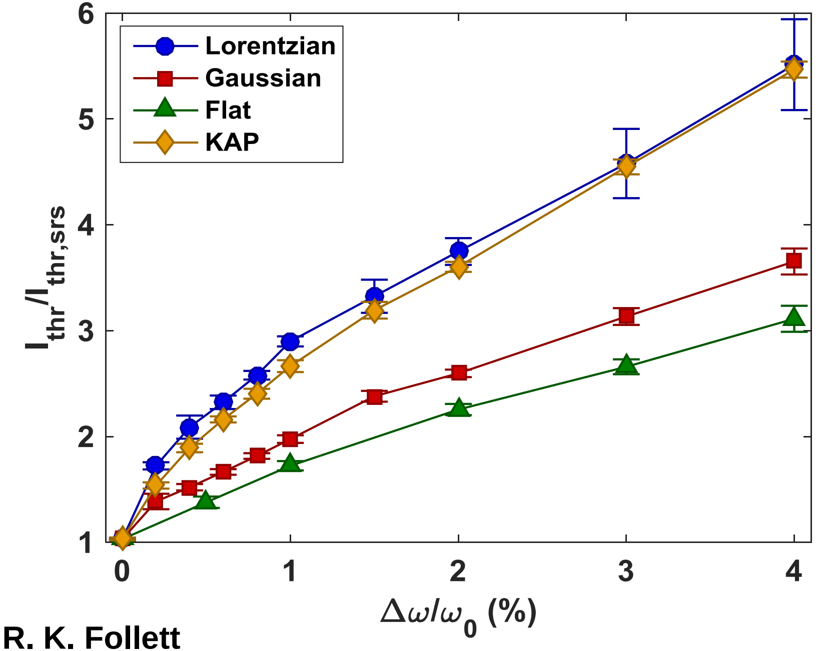
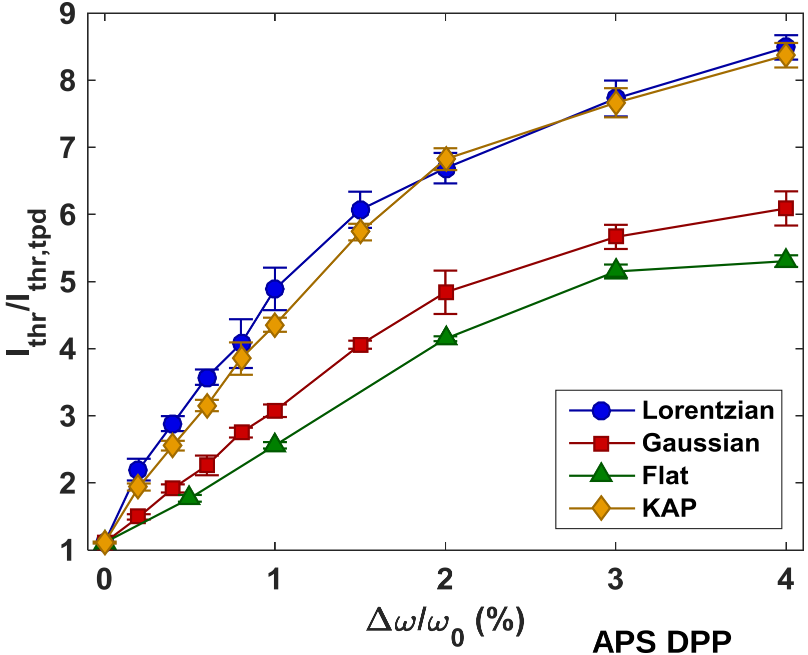
Broadband mitigation of laser-plasma instabilities

Stimulated Raman scattering (SRS) absolute threshold



Two-plasmon decay (TPD) absolute threshold



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Summary

Temporal incoherence of the drive lasers can be used to suppress laser-plasma instabilities (LPIs)

- Laser-plasma instabilities limit the laser intensity that can be used in inertial confinement fusion (ICF) implosions

- The key factor in determining the effectiveness of a bandwidth scheme at suppressing instabilities is the coherence time

A future broadband laser based on optical parametric amplifiers is currently being developed at LLE

Collaborators

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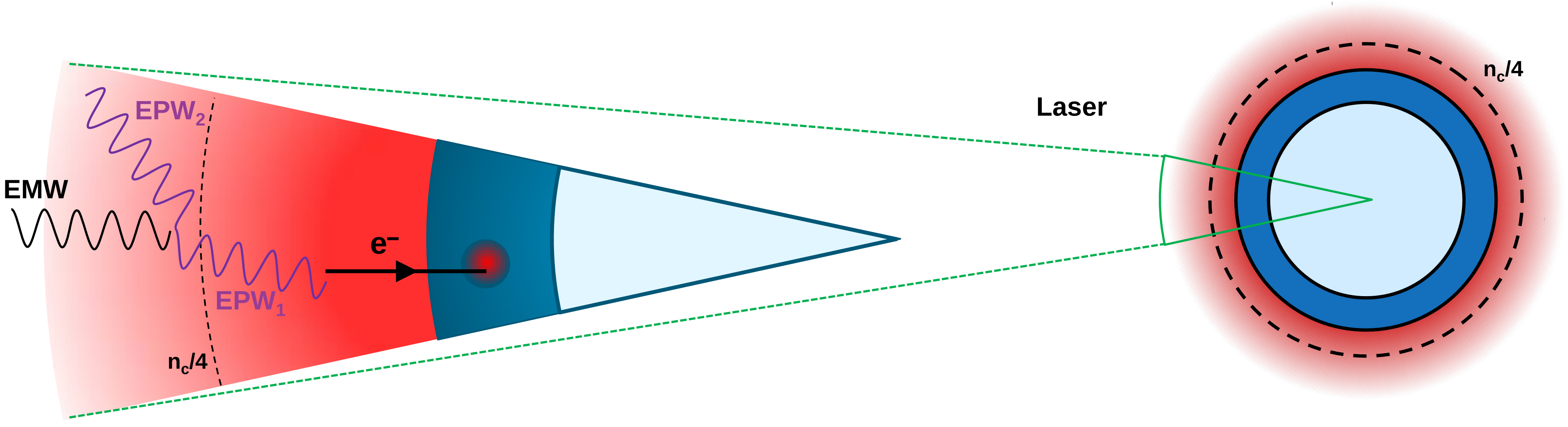
In direct-drive ICF implosions, TPD and SRS can lead to hot-electron preheat

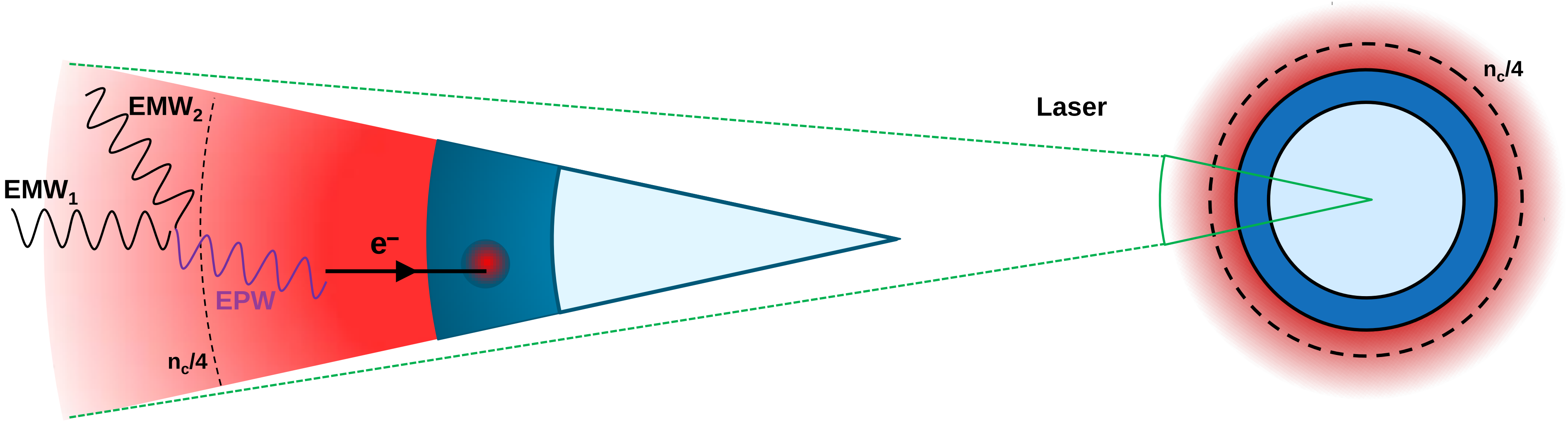
TPD



EMW: electromagnetic wave
EPW: electron plasma wave

In direct-drive ICF implosions, TPD and SRS can lead to hot-electron preheat

SRS



EMW: electromagnetic wave
EPW: electron plasma wave

LLE code development for laser plasma interaction physics is centered around a common environment

LPSE

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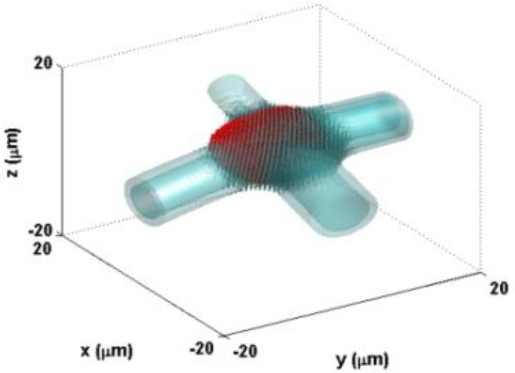
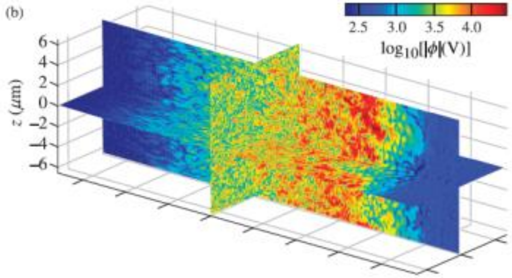
LPSE (Laser plasma simulation environment)

- Solves 3-D time-enveloped vector wave equations (no paraxial approximation)
- Two-plasmon decay (TPD)[1-2]
- Cross-beam energy transfer (CBET)[3-7]
- Stimulated Raman scattering (SRS)
- Resonance absorption[8]
- Quasilinear Landau damping and hot-electron production[9-10]
- Arbitrary beam injection with speckle, polarization smoothing, and bandwidth[11]

CBET



TPD

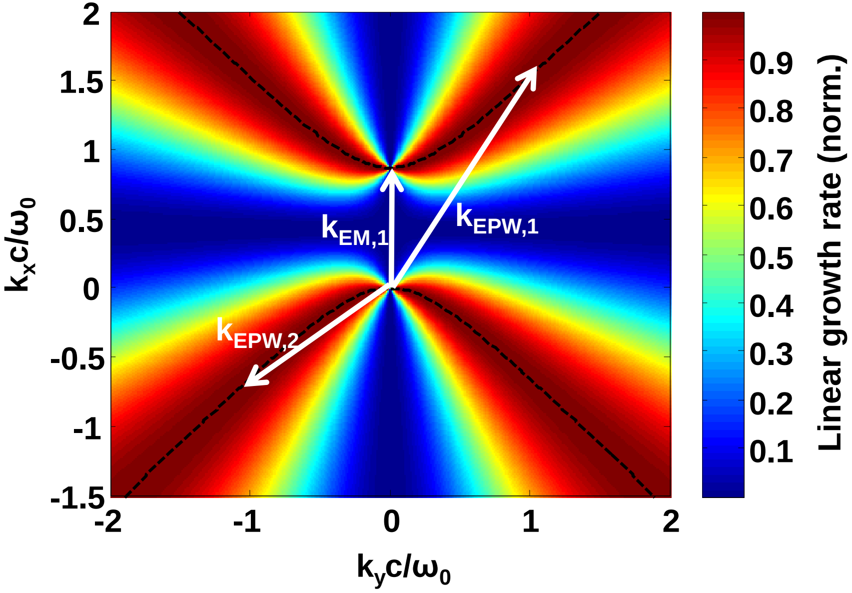


LPSE is a Community code (LLE, NRL, University of Alberta, CELIA, and RAL)

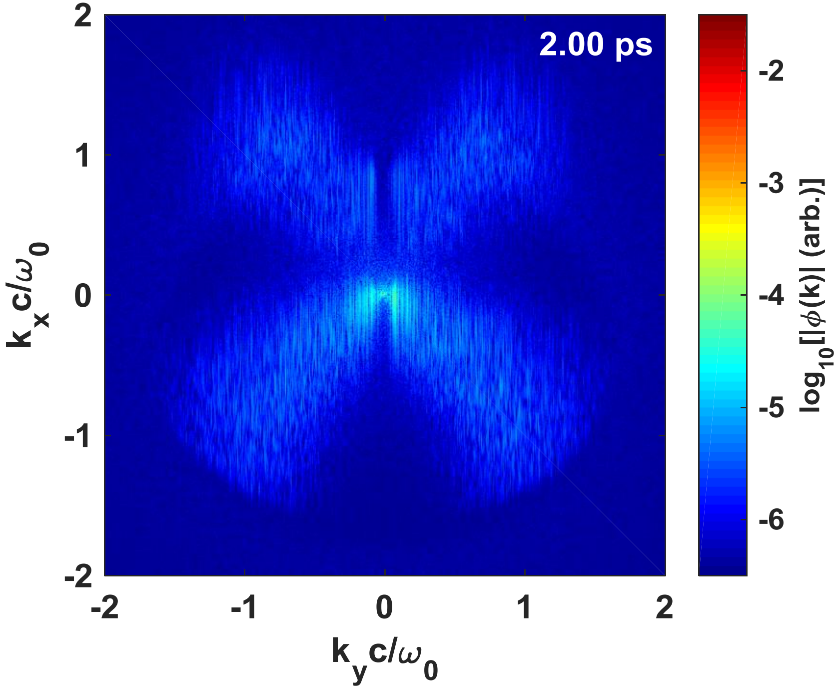
[1] R. K. Follett *et al.*, Phys. Rev. E 91, 031104 (2015)
[2] R. K. Follett *et al.*, Phys. Plasmas 24, 102134 (2017)
[3] J. F. Myatt *et at.*, Phys. Plasmas 24, 056308 (2017)
[4] R. K. Follett *et al.*, Phys. Plasmas 24, 103128 (2017)
[5] J. W. Bates *et al.*, Phys. Rev. E 97, 061202 (2018)
[6] R. K. Follett *et al.*, Phys. Rev. E 98, 043202 (2018)
[7] A. Colaitis *et al.*, Phys. Plasmas 26, 032301 (2019)
[8] J. P. Palastro et al., Phys. Plasmas 25, 123104 (2018)
[9] R. K. Follett *et al.*, Phys. Rev. Lett. 116, 155002 (2016)
[10] R. K. Follett *et al.*, Phys. Rev. Lett. 120, 135005 (2018)
[11] R. K. Follett *et al.*, Phys. Plasmas 26, 062111 (2019)

Laser bandwidth can be used to suppress the growth of the absolute TPD mode

Single-beam Two-plasmon-decay growth rate

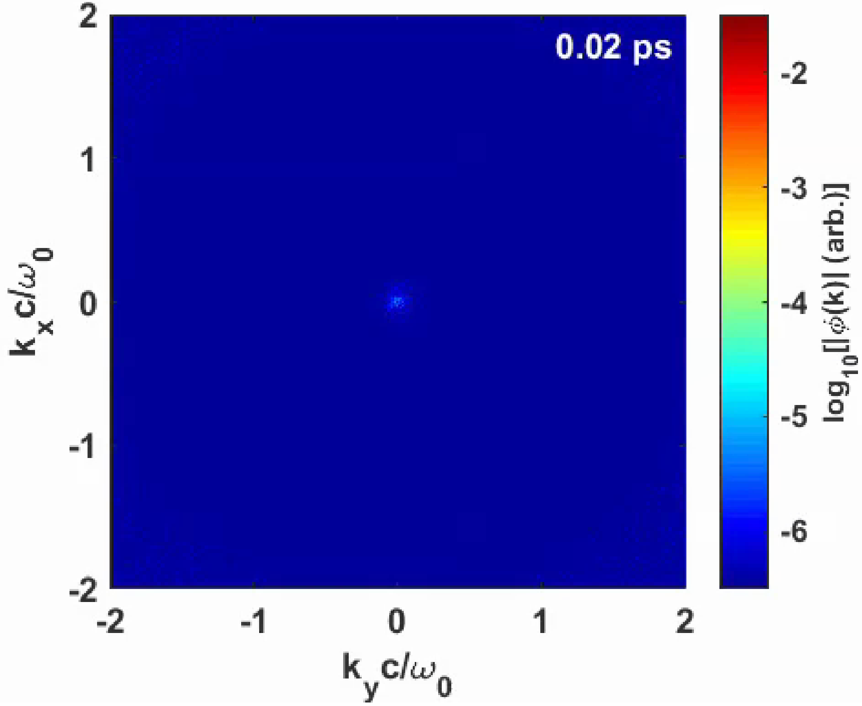


Electron plasma wave k-spectrum for a plane-wave drive beam ($I=3\times10^{14}$ W/cm^2, L_n=162.5 μm, T_e=2 keV)

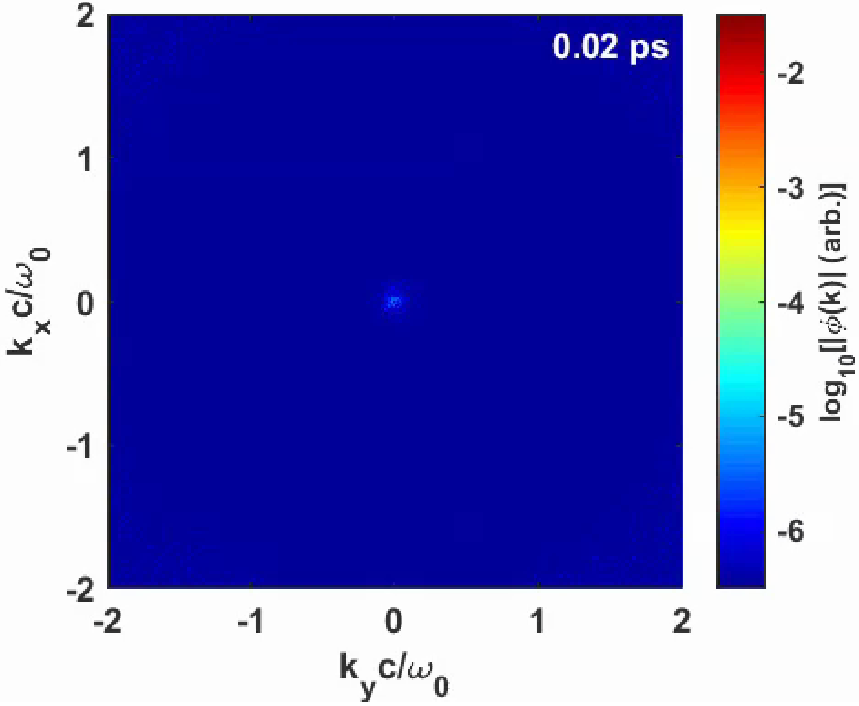


Laser bandwidth can be used to suppress the growth of the absolute TPD mode

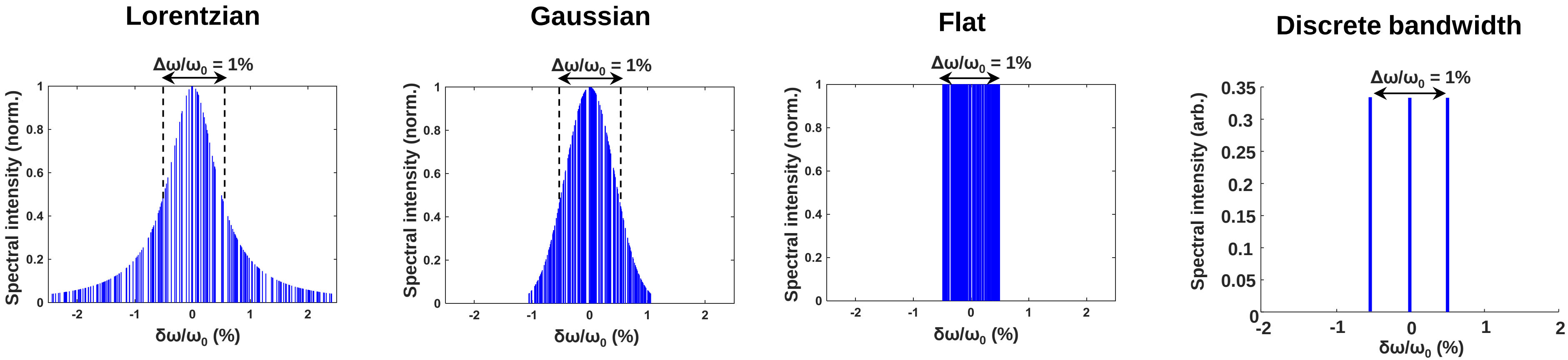
EPW spectrum for a plane-wave drive beam
($I=3\times10^{14}$ W/cm^2, L_n=162.5 μm, T_e=2 keV)



EPW spectrum for a plane-wave drive beam
with 0.5% Lorentzian bandwidth

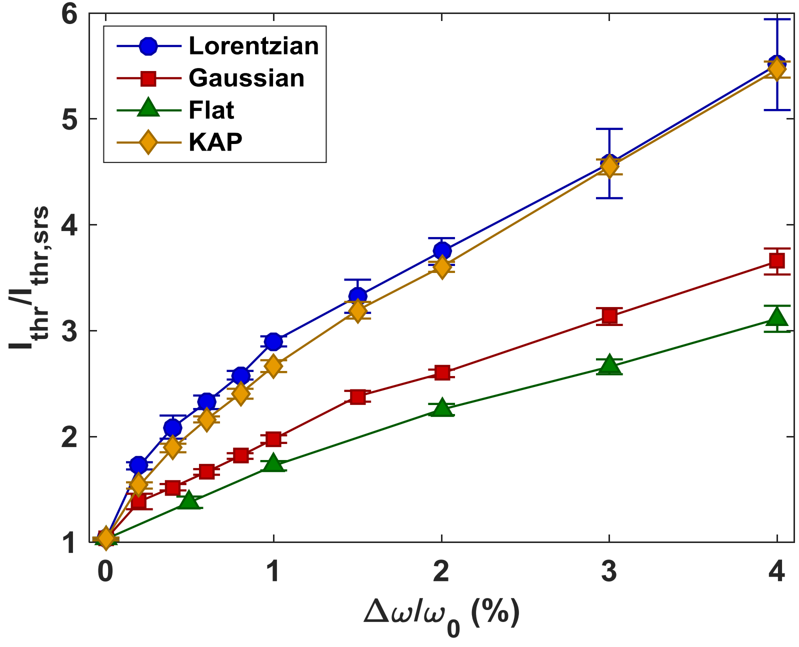


There are many different bandwidth formats that can be used to suppress LPI

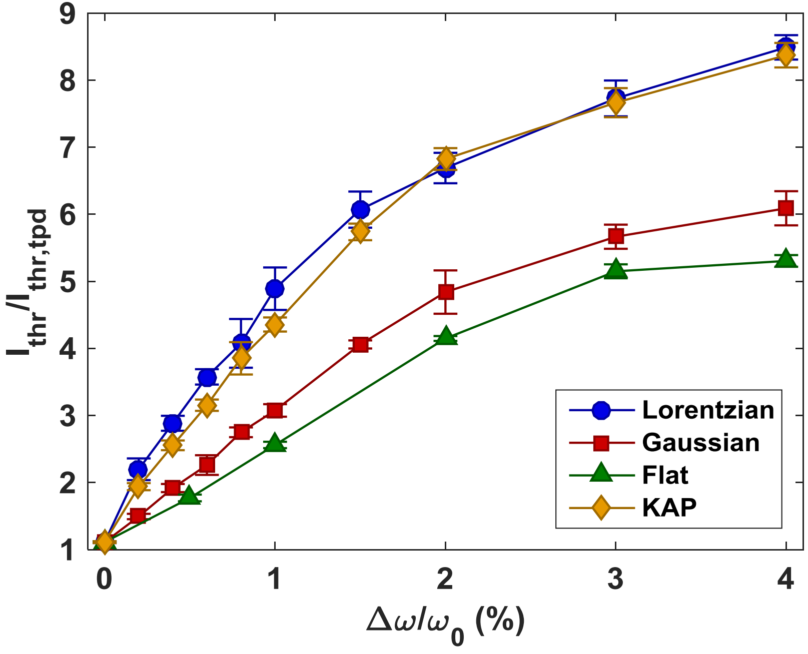


Different bandwidth formats provide varying degrees of instability mitigation

1-D SRS absolute threshold
(L_n=208 μm, T_e= 2 keV)



TPD absolute threshold
(L_n=208 μm, T_e= 2 keV)



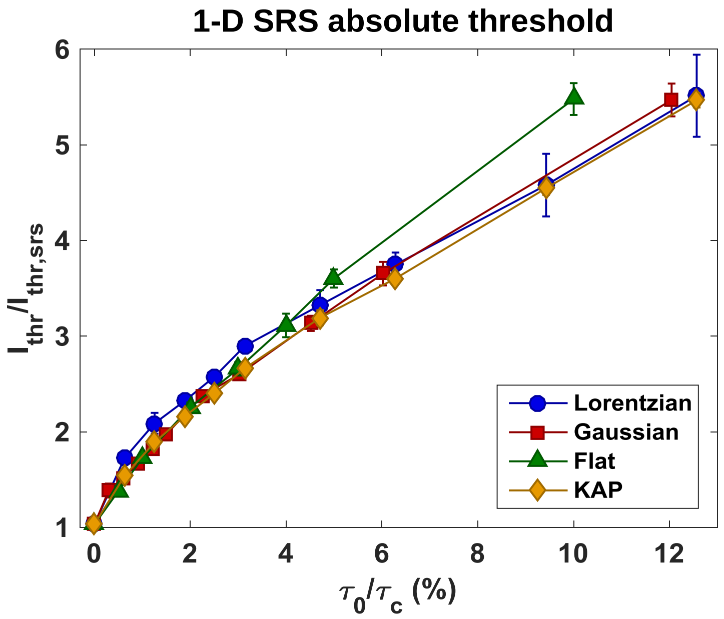
The various types of bandwidth give similar thresholds when plotted in terms of the laser coherence time

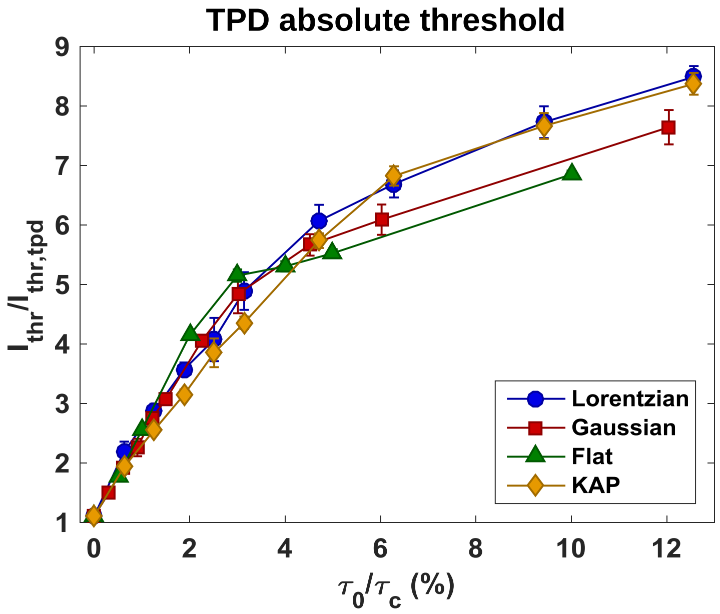
Degree of coherence:

$$g(\tau) \equiv \frac{\langle E_0^*(t) E_0(t+\tau) \rangle}{\langle | E_0(t) |^2 \rangle}$$

Coherence time:

$$\tau_c \equiv \int_{-\infty}^{\infty} |g(\tau)|^2 \, d\tau$$





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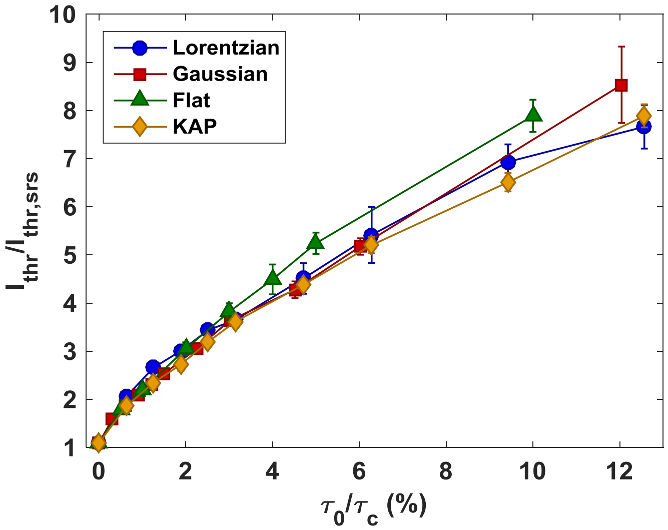
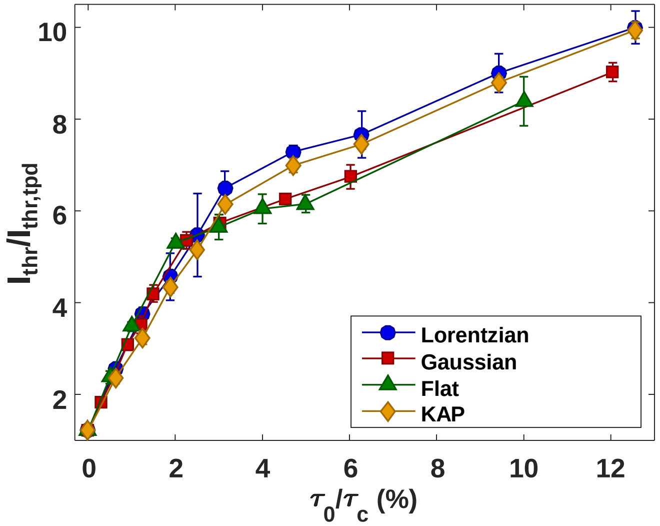
1-D SRS absolute threshold (L_n=416 μm)



TPD absolute threshold (L_n=416 μm)



A large number of LPSE simulations were run to generate scaling laws for absolute SRS and TPD with a broadband pump

SRS thresholds

Monochromatic*:

$$\left(\frac{v_{os}}{c}\right)^2_{\mathrm{thr,srs}} = 0.072\left(\frac{\lambda_0}{L_n}\right)^{4/3}$$

Broadband†:

$$\left(\frac{v_{os}}{c}\right)^2_{\Delta\omega,\mathrm{srs}} \approx 0.067\frac{\lambda_0}{L_n}\left(\frac{\tau_0}{\tau_c}\right)^{1/3}$$

TPD thresholds

Monochromatic:**

$$\left(\frac{v_{os}}{c}\right)^2_{\mathrm{thr,tpd}} = 3\frac{\lambda_0}{L_n}\left(\frac{v_{te}}{c}\right)^2$$

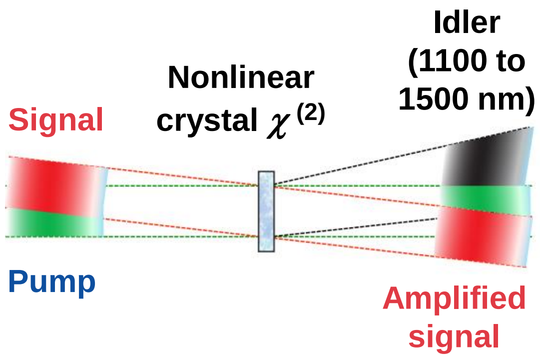
Broadband:

$$\left(\frac{v_{os}}{c}\right)^2_{\Delta\omega,\mathrm{tpd}} \approx 2.1\left(\frac{\lambda_0}{L_n}\right)^{2/3}\left(\frac{v_{te}}{c}\right)^{3/2}\left(\frac{\tau_0}{\tau_c}\right)^{1/2}$$

*B. B. Afeyan and E. A. Williams, Phys. Fluids **28**, 3397 (1985).
A. Simon, et al., Phys. Fluids **26, 3107 (1983).
†R. K. Follett, et al., Phys. Plasmas **26**, 062111 (2019).

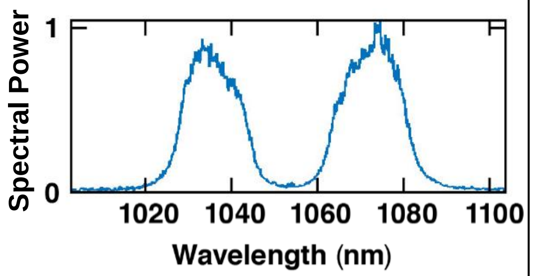
High-bandwidth technologies developed to support short-pulse lasers are being used at LLE to build a next-generation driver for ICF

Optical Parametric Amplifiers
(developed for short-pulse lasers)



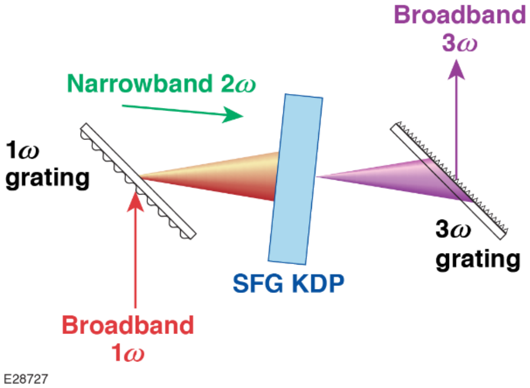
Novel co-linear OPA proposed for efficient amplification

LLE MTW Experiments
(configured with Collinear-OPA)



77% efficiency from pump to broadband ($\Delta\omega/\omega$>3%) pulse

Novel Sum-Frequency Generation (SFG)



Efficient broadband frequency conversion (1ω to 3ω) by SFG with narrowband 2ω

MTW: Multi-Terawatt

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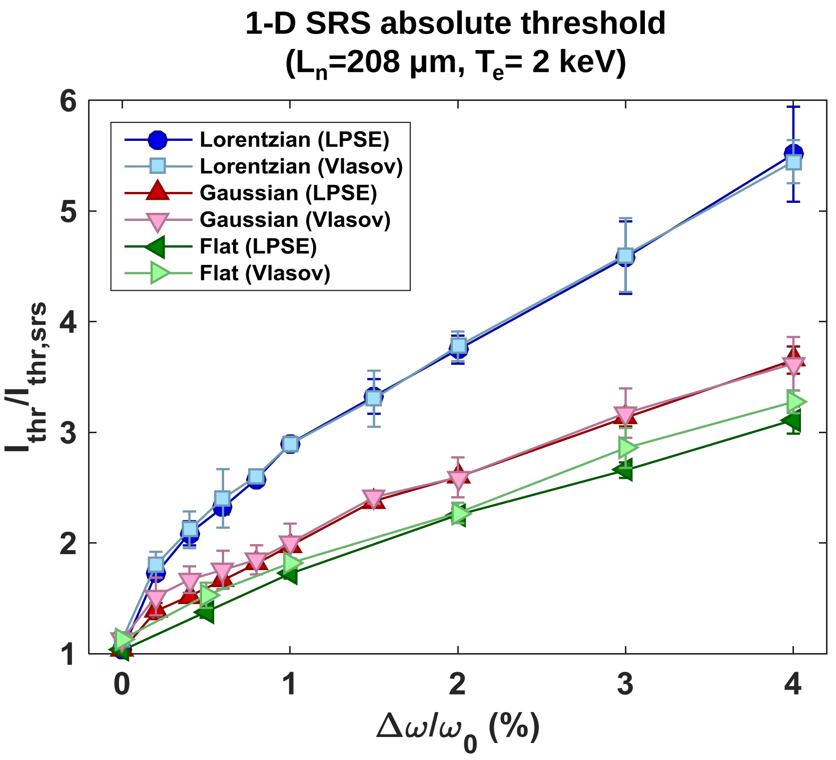

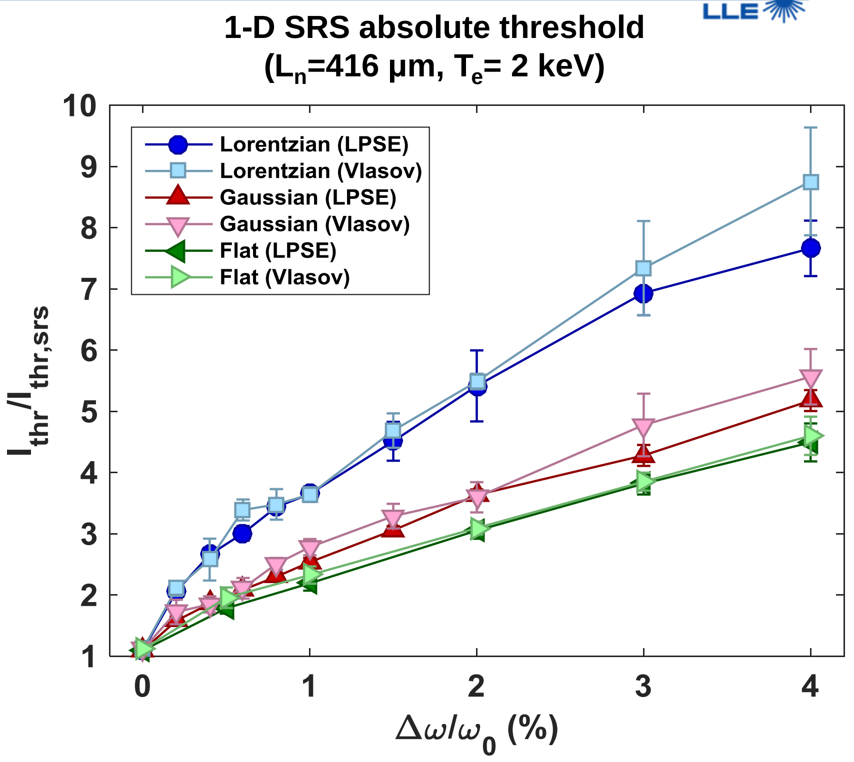

*R. K. Follett *et al*., Phys. Plasmas 26, 062111 (2019)