Simulation Study of Nonlinear Saturation of Cross-Beam Energy Transfer in TOP9 Experiments at the Omega Laser Facility

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Summary

Pump depletion limits the gain of cross-beam energy transfer in plasmas relevant to direct-drive inertial confinement fusion

- Particle-in-cell simulations were performed to model experiments on the dedicated cross-beam energy transfer (CBET) platform, TOP9, at the Omega Laser Facility
- The simulations exhibit nonlinear processes such as ion-acoustic harmonic generation, Raman forward scattering, and ion trapping, but not at levels sufficient to saturate CBET
- Pump depletion plays the dominant role in limiting the CBET gain

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Background and Motivation

Cross-beam energy transfer scatters laser light into unwanted directions, inhibiting inertial confinement fusion implosions

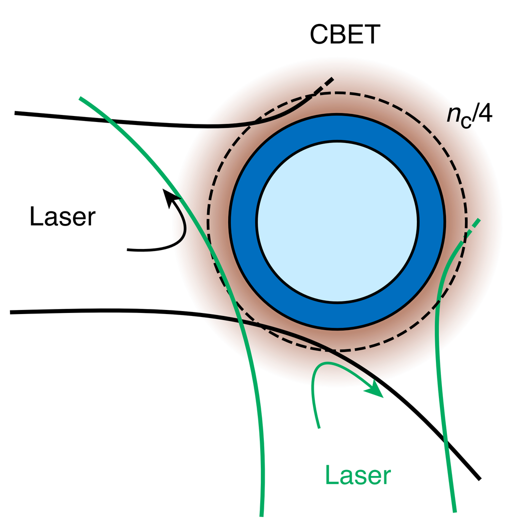
- Cross-beam energy transfer refers to the exchange of energy between two electromagnetic (EM) waves mediated by their mutually driven ion-acoustic wave (IAW) [1]
- The energy transfer is maximized when the phase matching conditions are satisfied

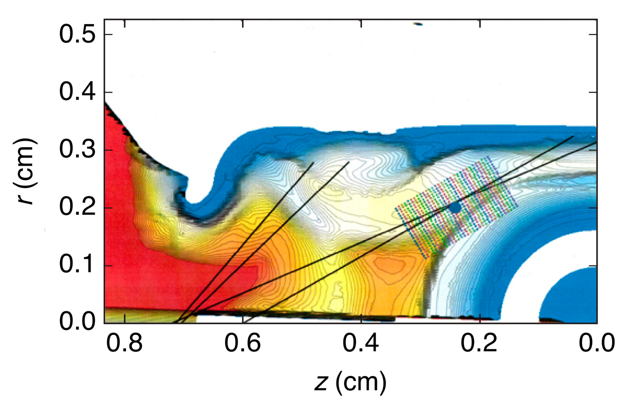
$$\vec{k}_{EM1} = \vec{k}_{EM2} + \vec{k}_{IAW} \qquad \omega_{EM1} = \omega_{EM2} + \omega_{IAW}$$

- In the presence of a plasma flow, V, the interaction can occur between frequency degenerate EM waves

$$\omega_{EM1} = \omega_{EM2} + \omega_{IAW} - \vec{k}_{IAW} \cdot \vec{V}$$

- CBET disrupts both direct- and indirect-drive inertial confinement fusion (ICF)





Integrated ICF simulations rely on ad hoc clamps to reproduce experiments, but lack insight into the mechanisms behind CBET saturation.

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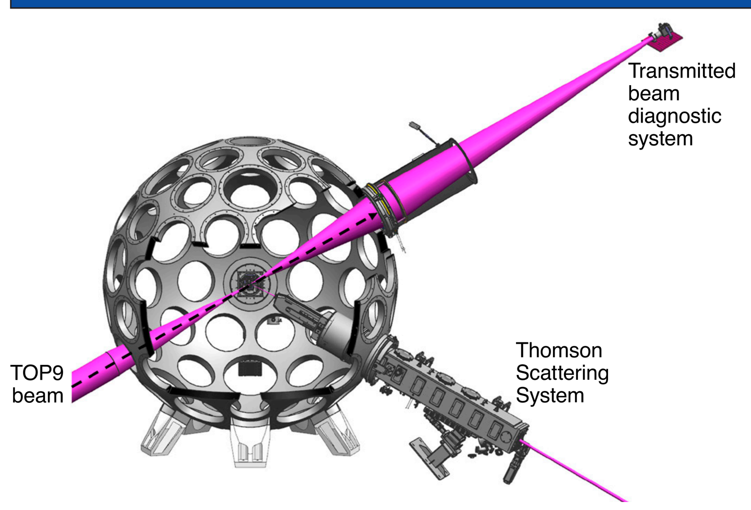
The TOP9 platform has been developed at LLE for focused studies of CBET in ignition-relevant parameters



Plasma parameters
$\bar{Z}T_e/T_i = 23.9$
$n_e/n_c = 1.2\%$
Ion species: H and N
Electron distribution: super-Gaussian (m =3)
Laser parameters
λ = 351 nm
Detuning wavelength: $\Delta\lambda$= 1.027 Å
I_{pump} = 9.0 × 10^{14} W/cm^2
I_{seed} varies
F/6.7
Beam width: w = 80 μm

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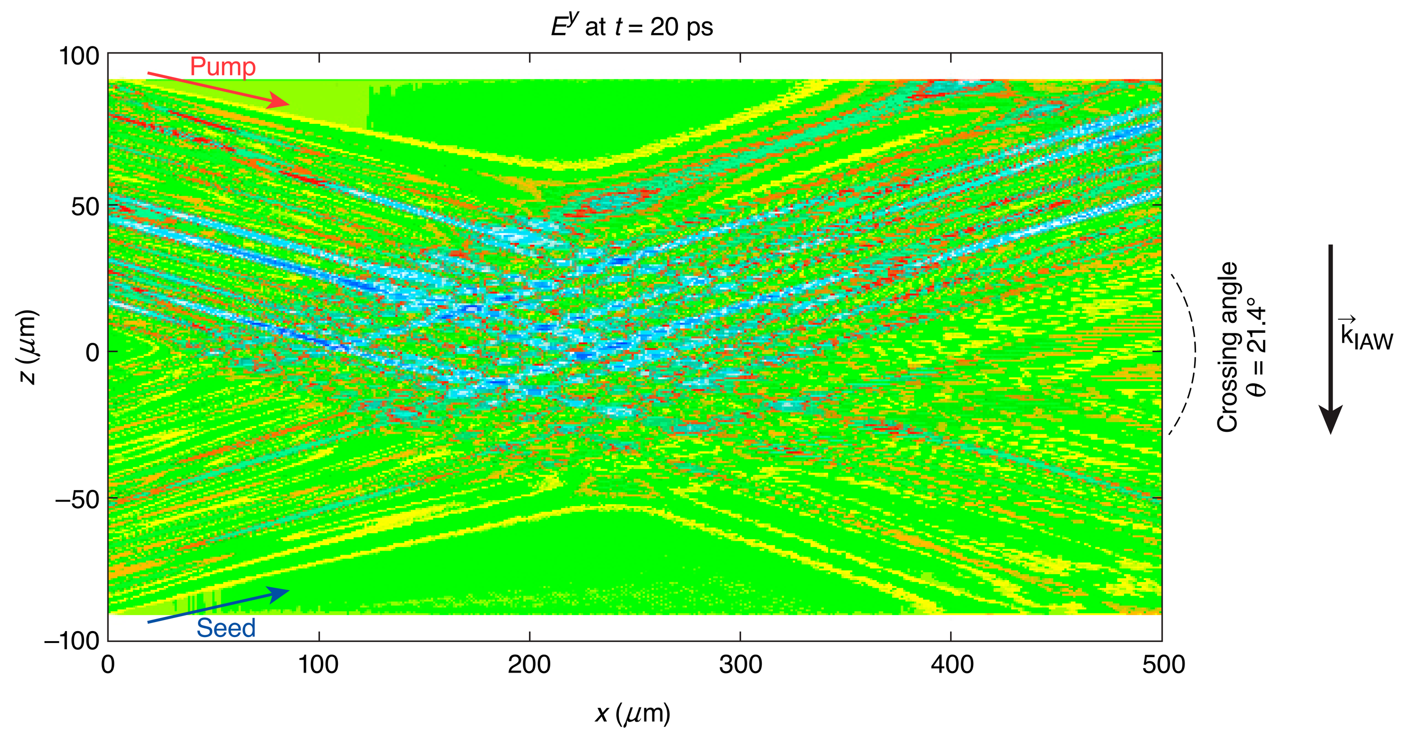
Simulation and Modeling

VPIC simulations were conducted to determine the CBET saturation mechanism for TOP9 experimental parameters

- Vector particle-in-cell (VPIC), developed and maintained at the Los Alamos National Laboratory (LANL), is a state-of-art particle-in-cell code for modeling kinetic effects in plasmas [2]
- s-polarized, multispeckled pump and seed beams propagate at a relative angle 21.4° [3,4]



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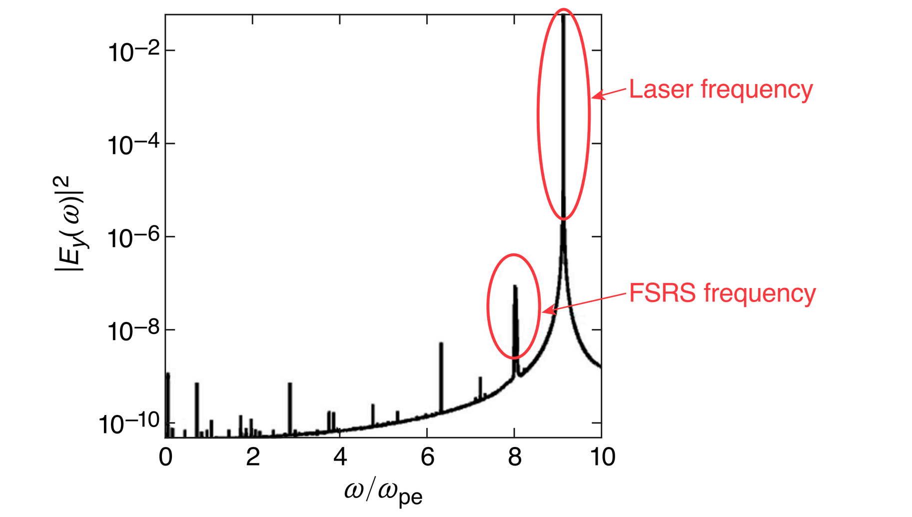
- The spectrum of the electromagnetic waves at the right simulation boundary demonstrates weak excitation of forward-stimulated Raman scattering (FSRS)



- Furthermore, FSRS can be suppressed by a density gradient

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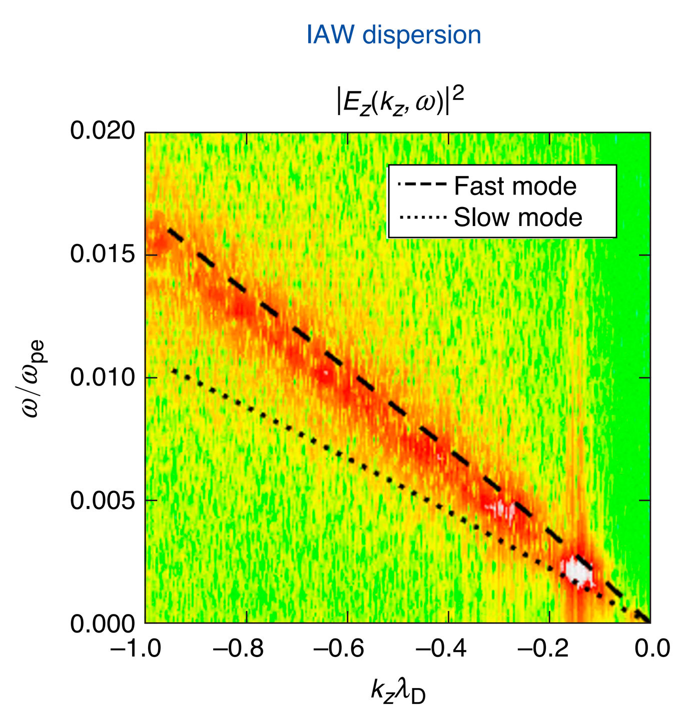
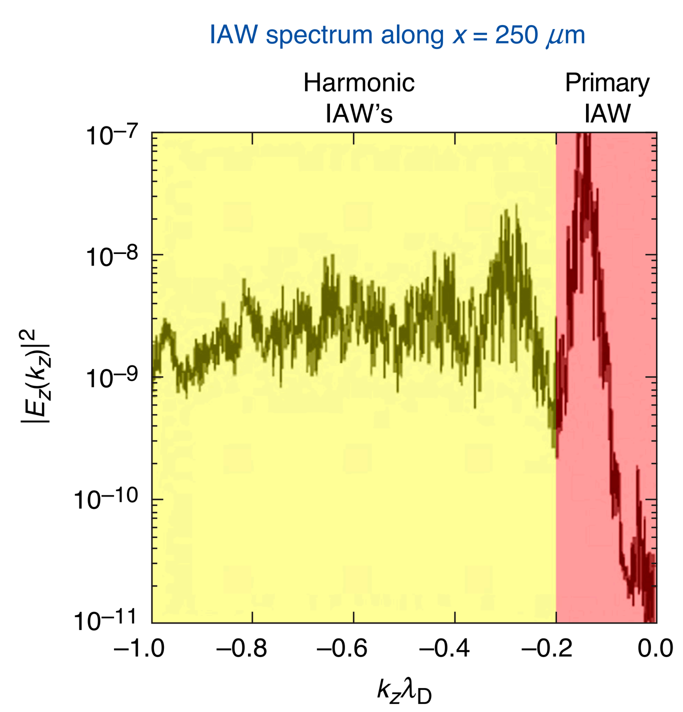
Simulation Results

CBET results in many nonlinear processes, but these are energetically unimportant compared to pump depletion

- The multispecies plasma supports slow and fast ion-acoustic modes [5]
- The fast mode has nearly linear dispersion for a wide range of wave vectors, allowing for ion-acoustic harmonic generation
- The primary IAW contains much more spectral power than the harmonics, indicating that harmonic generation does not play an important role in CBET saturation





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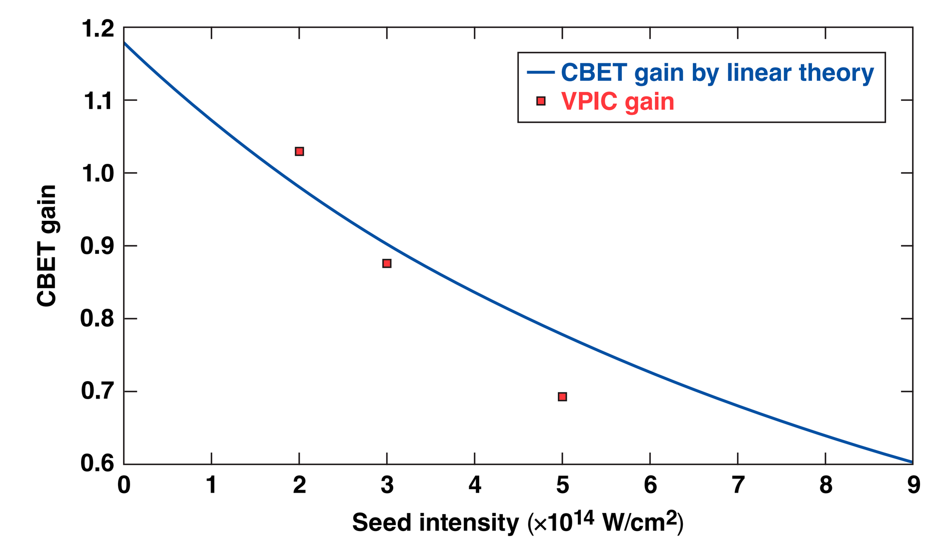
VPIC simulations predict that pump depletion limits the gain of CBET in good quantitative agreement with linear theory



- The CBET gain (G) is defined by the following equation: $G = \ln\left(I_{seed}^{output} / I_{seed}^{input}\right)$
- In the presence of pump depletion, the CBET gain (G) can be estimated by the Tang formula [6,7]

$$\exp(G) = \frac{(1+\beta)\exp[G_{lin}(1+\beta)]}{1+\beta\exp[G_{lin}(1+\beta)]},$$

where G_{lin} is the linear gain without pump depletion and $\beta = \left(I_{seed}^{intput} / I_{seed}^{input}\right)$

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References

[1] J. F. Myatt *et al.*, Phys. Plasmas 21, 055501 (2014).
[2] K. J. Bowers *et al.*, Phys. Plasmas 15, 055703 (2008).
[3] L. Yin *et al.*, Phys. Plasmas 26, 082708 (2019).
[4] L. Yin *et al.*, Phys. Plasmas 20, 012702 (2013).
[5] T. Chapman *et al.*, Phys. Rev. Lett. 110, 195004 (2013).
[6] C. L. Tang, J. Appl. Phys. 37, 2945 (1966).
[7] E. A. Williams *et al.*, Phys. Plasmas 11, 231 (2004).

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