Wave-Based Cross-Beam Energy Transfer Simulations with Laser Speckle and Polarization Smoothing

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Full-scale LPSE simulations

Plane-wave beams

Laser

Speckled beams

Laser

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A 3-D wave-based model has been developed to understand the physics of cross-beam energy transfer (CBET) in an inhomogeneous plasma

- Detailed CBET calculations are used to study ray-based CBET models that are implemented in hydrodynamics codes
- The comparisons highlight the accuracy of ray-based models
- Discrepancies between the models are found related to beam speckle and polarization smoothing when the speckle length is longer than the interaction region
Collaborators

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Ray- and wave-based CBET models give the same result in simple interaction geometries (plane-wave beams, no caustics)

All of the approximations made in the ray model are satisfied in this configuration.
Speckled beams can transfer more energy than plane-wave beams with the same average intensity.

*LPSE simulation of counter-propagating speckled beams*  
\(I_{\text{pump}} = 2 \times 10^{15} \text{ W/cm}^2, I_{\text{seed}} = 10^{12} \text{ W/cm}^2\)
The CBET gain is sensitive to beam speckle for gains greater than ~1 and relative beam angles of less than ~30°.

\[ \text{Gain} \equiv \log \left( \frac{\text{Seed energy out}}{\text{Seed energy in}} \right) \]

CBET gain versus pump intensity for various relative beam angles.

- --- Plane wave (LPSE)
- - - Speckled beam (LPSE)
- × Plane wave (rays)
A good approximation to the CBET between speckled beams can be obtained by using the linearity of Maxwell’s equations.
The ray-based speckled field calculations show good agreement with the wave-based results.

CBET gain versus pump intensity for various relative beam angles.

- Plane wave (LPSE)
- Speckled beam (LPSE)
- Plane wave (rays)
- Speckled beam (rays)
Speckled beams result in a modest decrease in laser absorption in full-scale two-beam LPSE simulations at ICF-relevant plasma conditions.

- Full-scale LPSE simulations ($I = 2 \times 10^{14} \text{ W/cm}^2$)

![Diagram showing absorption comparison between plane-wave and speckled beams](image)
Polarization smoothing is accounted for in ray-based CBET models by multiplying the gain coefficient by a factor of \((1 + \cos^2\theta)/4\)*

- The factor of \((1 + \cos^2\theta)/4\) comes from assuming that the interacting beams have random relative polarizations with uncorrelated speckle patterns.

\[
\langle |\phi|^2 \rangle_{PS} = \frac{1}{4}(1 + \cos^2\theta)|\phi|^2
\]

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*P. Michel et al., Phys. Plasmas 20, 056308 (2013).*
The factor of \(\frac{1 + \cos^2 \theta}{4}\) used to account for the modification of the CBET gain between beams with polarization smoothing is valid only when the speckle length is shorter than the interaction region.*

CBET gain versus relative beam angle for beams with polarization smoothing averaged over 12 realizations of polarization/phase

\[ I_{\text{pump}} = 5 \times 10^{14} \text{ W/cm}^2, \quad I_{\text{seed}} = 2 \times 10^{13} \text{ W/cm}^2 \]

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