A local-field approach to understanding multibeam laser-plasma instabilities

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The local-field approach is a procedure for developing simple models of laser-plasma instabilities in complex laser configurations

- Simple models for laser-plasma instabilities are often limited to plane-wave thresholds, but speckled laser beams introduce local field structure.

- Global instability behavior can be understood by convolving the local instability behavior with the statistical properties of the laser field.

- A semi-analytic model for the absolute two-plasmon-decay (TPD) instability was developed that accurately predicts the instability threshold for a speckled beam.

This approach can be applied to other instabilities or expanded to include effects like polarization smoothing or speckle motion.
Collaborators

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Motivation

The prevailing picture of multibeam laser-plasma interactions does not account for the local structure of a speckled laser field.

Idealized picture of multibeam interactions with a shared daughter wave along the axis of symmetry*

Electric field for a 23° cone of beams with phase plates

The local fields and statistical properties of a 23° cone of beams are similar to a single f/1 beam

As an example, consider the absolute TPD instability in a speckled beam
The local-field approach uses the instability behavior in a single speckle to construct a semi-analytic theory of the global behavior

\[ I_{\text{thr}} = \text{(function of speckle statistics)} \times \text{(function of single-speckle instability properties)} \]

\[ = \frac{1}{\langle I_M / I_0 \rangle} \times I_{\text{thr,speckle}}(L_n, T_e, \lambda_0, w_s, l_s) \]

\[ \langle I_M / I_0 \rangle \text{ can be determined analytically using the probability distribution of speckle intensities*} \]

\[ \langle I_M / I_0 \rangle = -\sum_{a=1}^{N} \left( \frac{N}{a} \right) a^{-1-a} \left( \frac{-2 - \pi}{4 + \pi} \right)^a e^{\frac{a(4+\pi)}{2+\pi}} \Gamma \left[ 1 + a, \frac{a(4+\pi)}{2+\pi} \right] \]

\[ N = \frac{P_L}{\langle P_s \rangle} \approx \frac{w_g}{f_0 \lambda_0} \frac{4+\pi}{3+\pi} \sqrt{\log 2} \frac{\sqrt{\pi}}{\pi} \]

Single-speckle simulations can be used to find $I_{\text{thr,speckle}}(L_n, T_e, \lambda_0, w_s, l_s)$

Single-speckle absolute TPD threshold

$(L_n=200 \mu m, T_e=4 \text{ keV}, \lambda_0=0.351 \mu m)$

![Graph showing single-speckle absolute TPD threshold](image-url)
Single-speckle simulations can be used to find $I_{\text{thr, speckle}}(L_n, T_e, \lambda_0, w_s, l_s)$

An analytic approximation can be obtained by assuming the transverse spectrum of absolutely unstable modes be broad enough for absolute growth to occur within a speckle:

$$\Delta k_\perp = \frac{2\pi}{\text{speckle width}} = \frac{2\pi}{f_\# \lambda_0}$$

$$\frac{\Delta k_\perp}{k_0} = \frac{1}{f_\#}$$
Single-speckle simulations can be used to find $I_{\text{thr, speckle}}(L_n, T_e, \lambda_0, w_s, I_s)$

Single-speckle absolute TPD threshold
($L_n=200 \, \mu m$, $T_e=4$ keV, $\lambda_0=0.351 \, \mu m$)

![Graph showing $I_{\text{thr, speckle}}/I_{\text{thr, TPD}}$ vs. Speckle width (µm)]
The analytic approximations show good agreement with speckled-field thresholds calculated using LPSE.

2-D absolute TPD threshold
($L_n=200 \, \mu m, \, T_e=4 \, keV$)

3-D absolute TPD threshold
($L_n=400 \, \mu m, \, T_e=4 \, keV$)
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- Global instability behavior can be understood by convolving the local instability behavior with the statistical properties of the laser field.
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