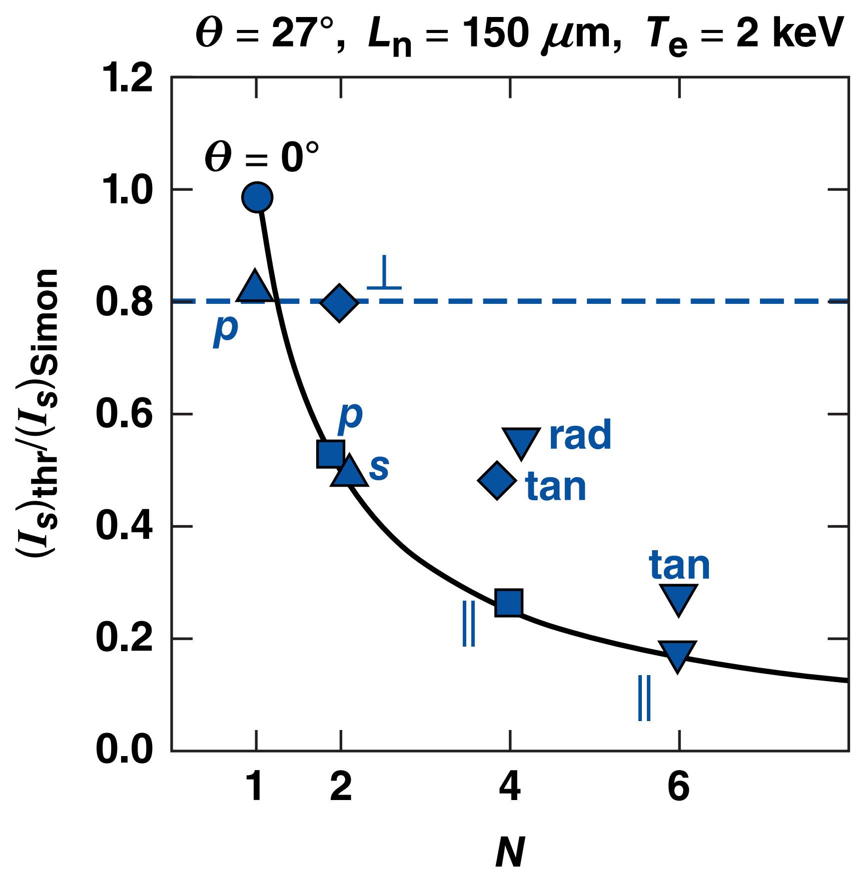
Linear Growth and Nonlinear Saturation of Two-Plasmon Decay Driven by Multiple Laser Beams



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43rd Annual Anomalous Absorption Conference
Stevenson, WA
7–12 July 2013

Two-plasmon decay (TPD) driven by multiple beams in inhomogeneous plasma is investigated using *ZAK3D**

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- Convective growth of shared plasma waves having $k \sim k_0$ have been predicted theoretically†
- Our simulations recover this result, but indicate that small-*k* modes can share plasma waves and therefore give a lower absolute threshold for multiple beams
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*J. Zhang *et al.*, Bull. Am. Phys. Soc. 57, 299 (2012).
**C. Stoeckl *et al.*, Phys. Rev. Lett. 90, 235002 (2003);
D. T. Michel *et al.*, Phys. Rev. Lett. 109, 155007 (2012).
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Collaborators

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The *ZAK3D* model is a time-enveloped fluid moment model that describes the coupling between Langmuir and ion-acoustic fluctuations

Zakharov equation†

$$\nabla\cdot\left[2i\omega_{p0}\left(\partial_t+\overbrace{\nu_e}^{\text{Collisional plus Landau damping}}\circ\right)+3v_e^2\nabla^2-\omega_{p0}^2\left(\delta n+\overbrace{\delta N}^{\text{Density gradient}}\right)/n_0\right]E$$

$$=\underbrace{(e/4m_e)\nabla\cdot\left[\nabla\sum_{m=1}^{N}\left(E_{0,m}\cdot E^*\right)-\sum_{m=1}^{N}E_{0,m}\nabla\cdot E^*\right]e^{-i\Delta\omega t}}_{\text{Laser source}}+\underbrace{S_E}_{\text{Noise source}}$$

$$\left[\partial_t^2+2\underbrace{\nu_i}_{\text{Landau damping for ion}}\circ\partial_t-c_s^2\nabla^2\right]\delta n=\underbrace{\frac{1}{16\pi m_i}\left(\nabla^2|E|^2+\frac{1}{4}\nabla^2\sum_{m=1}^{N}|E_{0,m}|^2\right)}_{\text{Ponderomotive force}},$$

where the laser field $E_L=\sum_{m}^{N}E_{0,m}\exp(-i\omega_0 t)+\text{c.c.}$

$\Delta\omega=\omega_0-2\omega_{pe}$

†D. F. DuBois, D. A. Russell, and H. A. Rose, Phys. Rev. Lett. 74, 3983 (1995); D. A. Russel and D. F. DuBois, Phys. Rev. Lett. 86, 428 (2001).

TC10648

The Zakharov model makes some approximations

Approximations

$$\left|\partial_t^2 E\right| \ll \left|\omega_p \partial_t E\right|;$$

$$\frac{\left|E\right|^2}{4\pi n_0 T_e} \lesssim 1, \frac{\delta n_0}{n_{e0}} \lesssim 1, \text{and } k\lambda_{De} \lesssim 1$$

Limitation

(1) lack of kinetic effects

(2) dissipation is included only approximately

(3) time envelope removes higher-order harmonics

The temporal growth rate agrees very well with Simon* predictions for a single-plane electromagnetic (EM) wave

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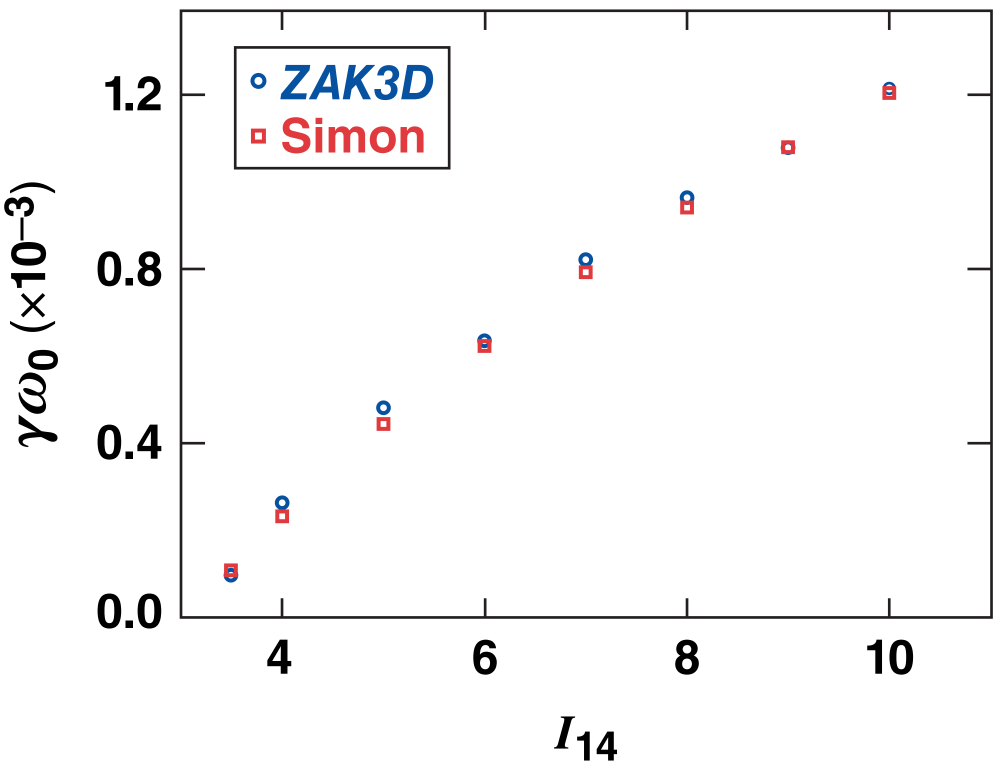
Absolute growth rate of most-unstable mode for different laser intensities



L_n = 150 μm
T_e = 2 keV

Normal laser incidence.

Most unstable modes have $k_\perp \sim 0.1\ k_0$

Extrapolating the growth rate to zero gives the threshold of absolute instability.

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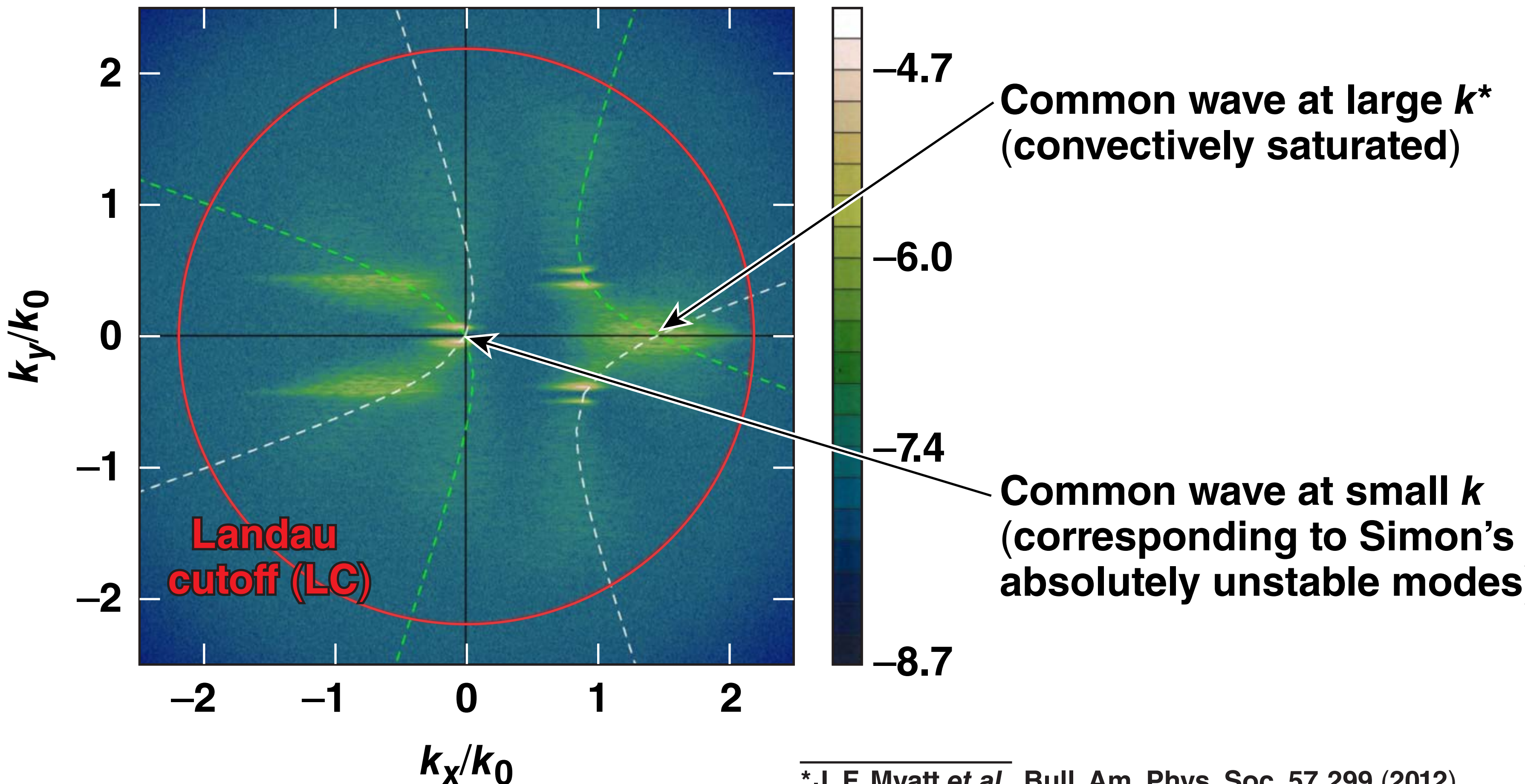
*Simon *et al*., Phys. Fluids 26, 3107 (1983).

Two-plane EM waves with *p*-polarization show shared plasma waves in both the large- and small-*k* regions

Energy spectrum of Langmuir wave (LW) during linear growth phase (early time, arbitrary units).



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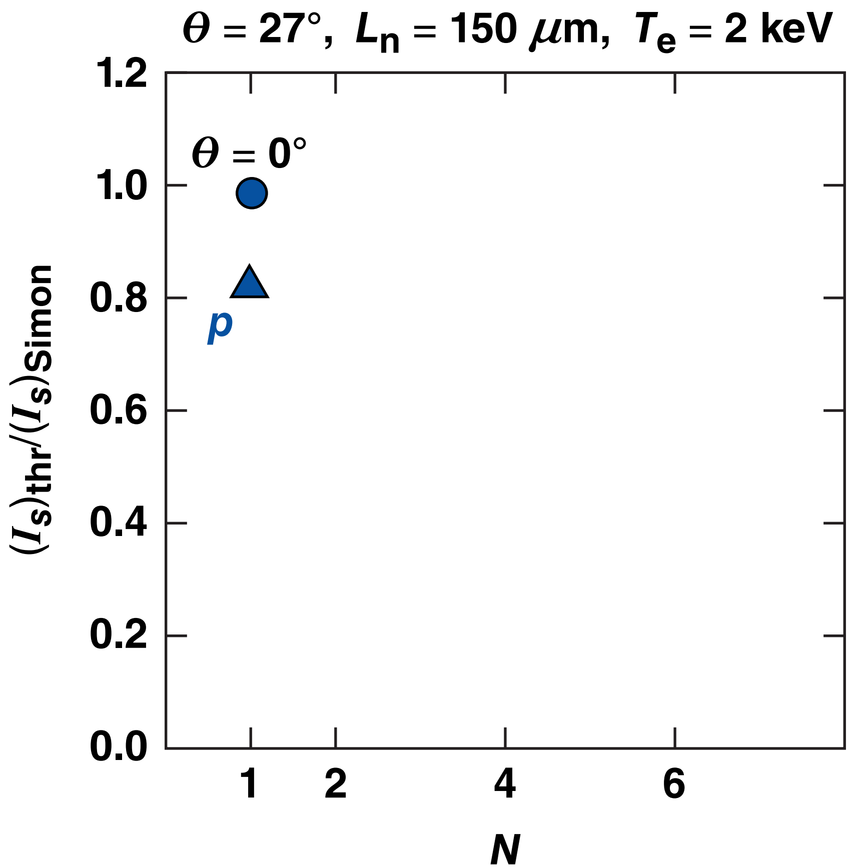
The absolute thresholds for different numbers of beams and beam configurations have been computed



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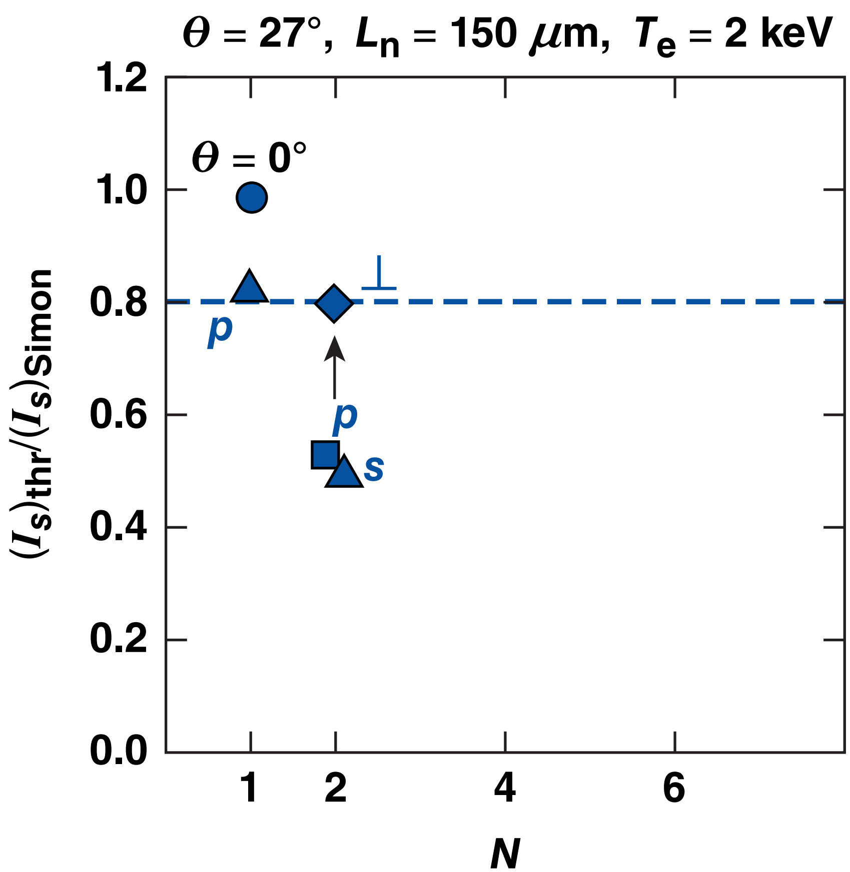
The absolute thresholds for different numbers of beams and beam configurations have been computed



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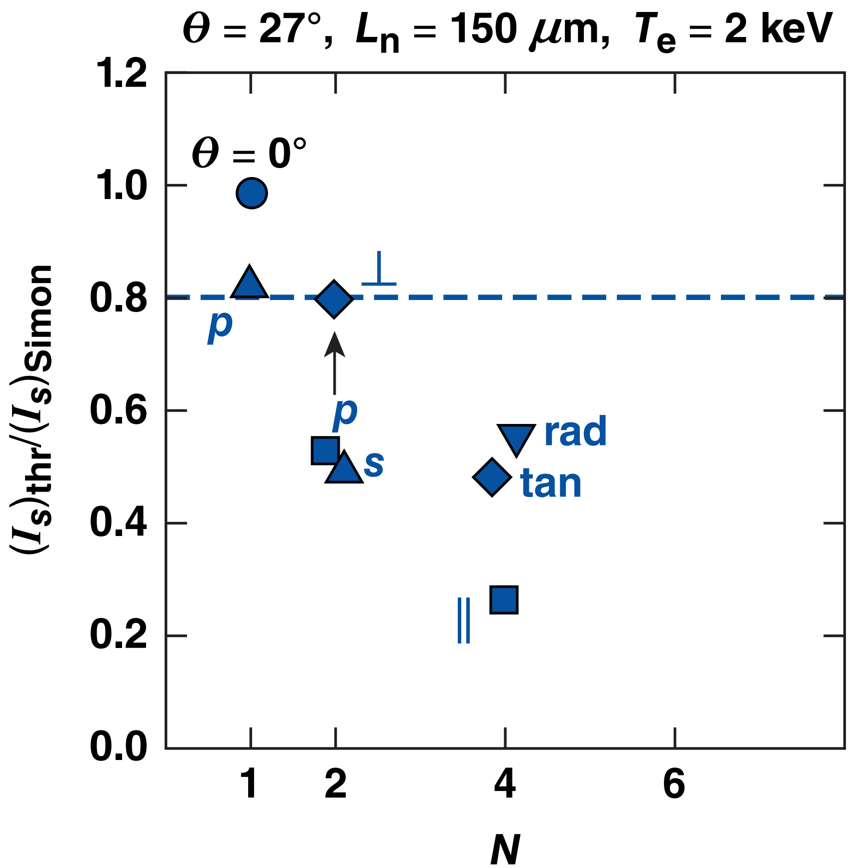
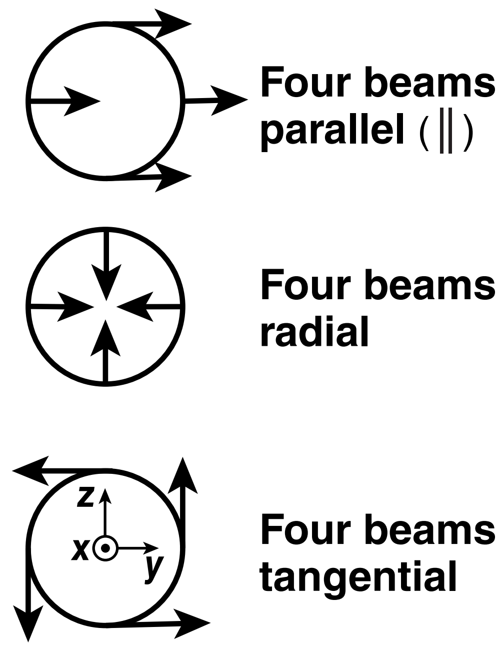
The absolute thresholds for different numbers of beams and beam configurations have been computed





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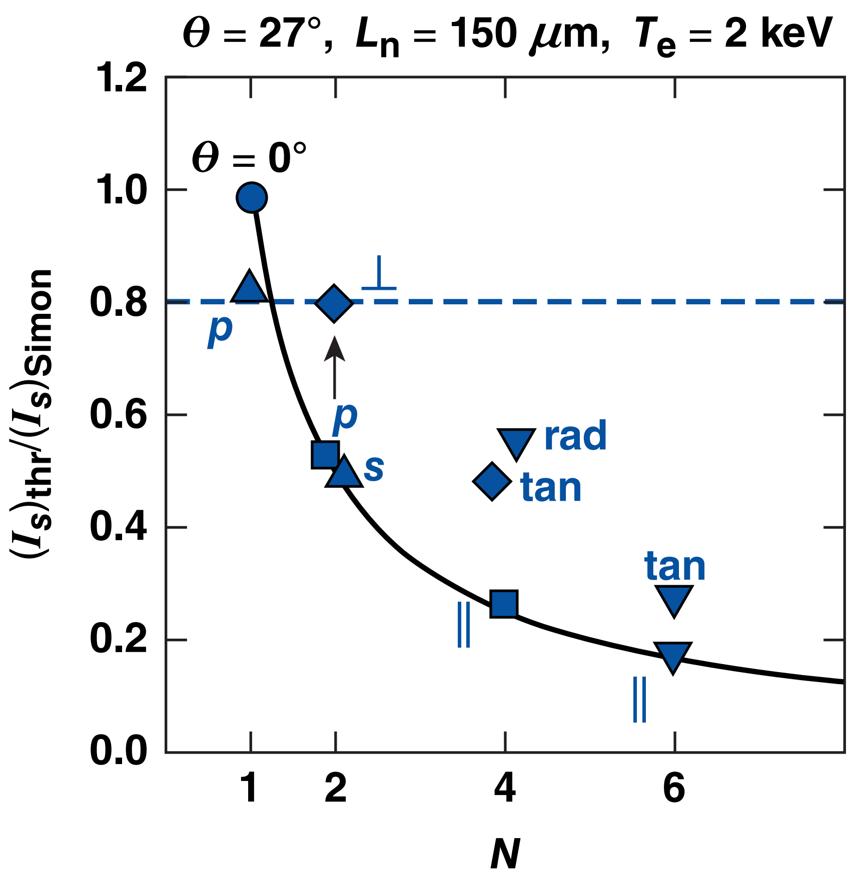
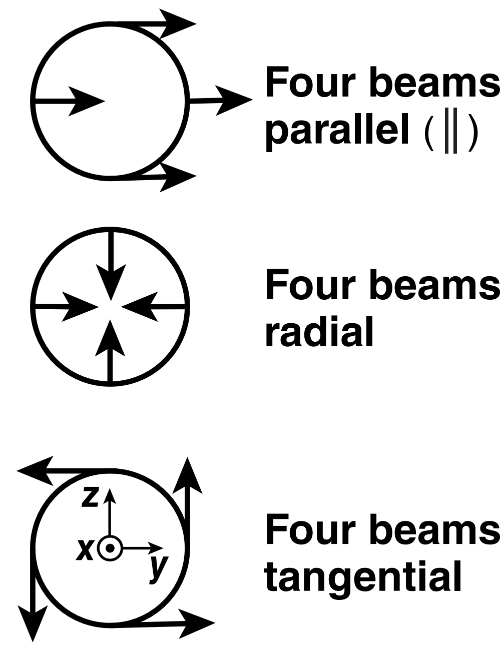
The absolute thresholds for different numbers of beams and beam configurations have been computed





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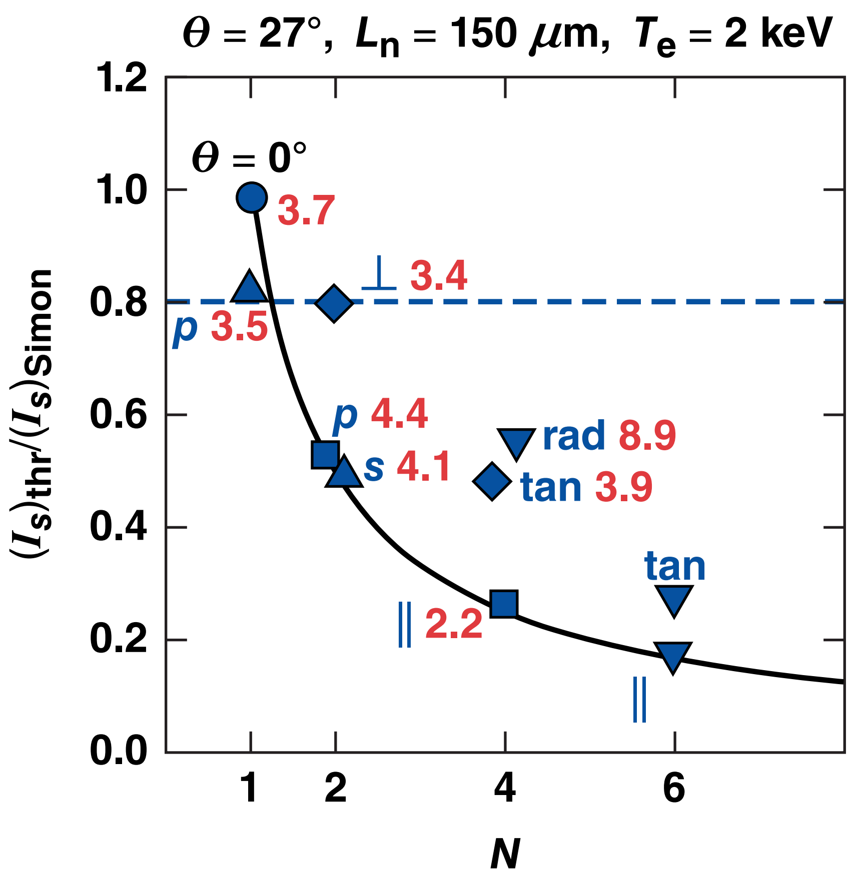
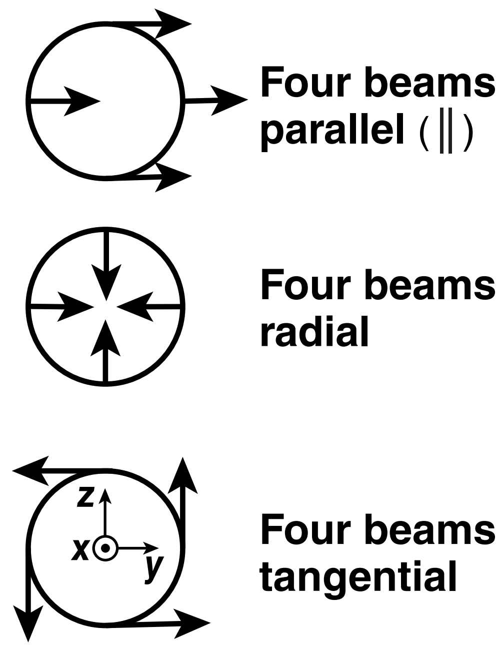
The absolute thresholds for different numbers of beams and beam configurations have been computed





The absolute threshold is lower than the convective threshold in most cases; the regime of linear convective growth is very restricted.

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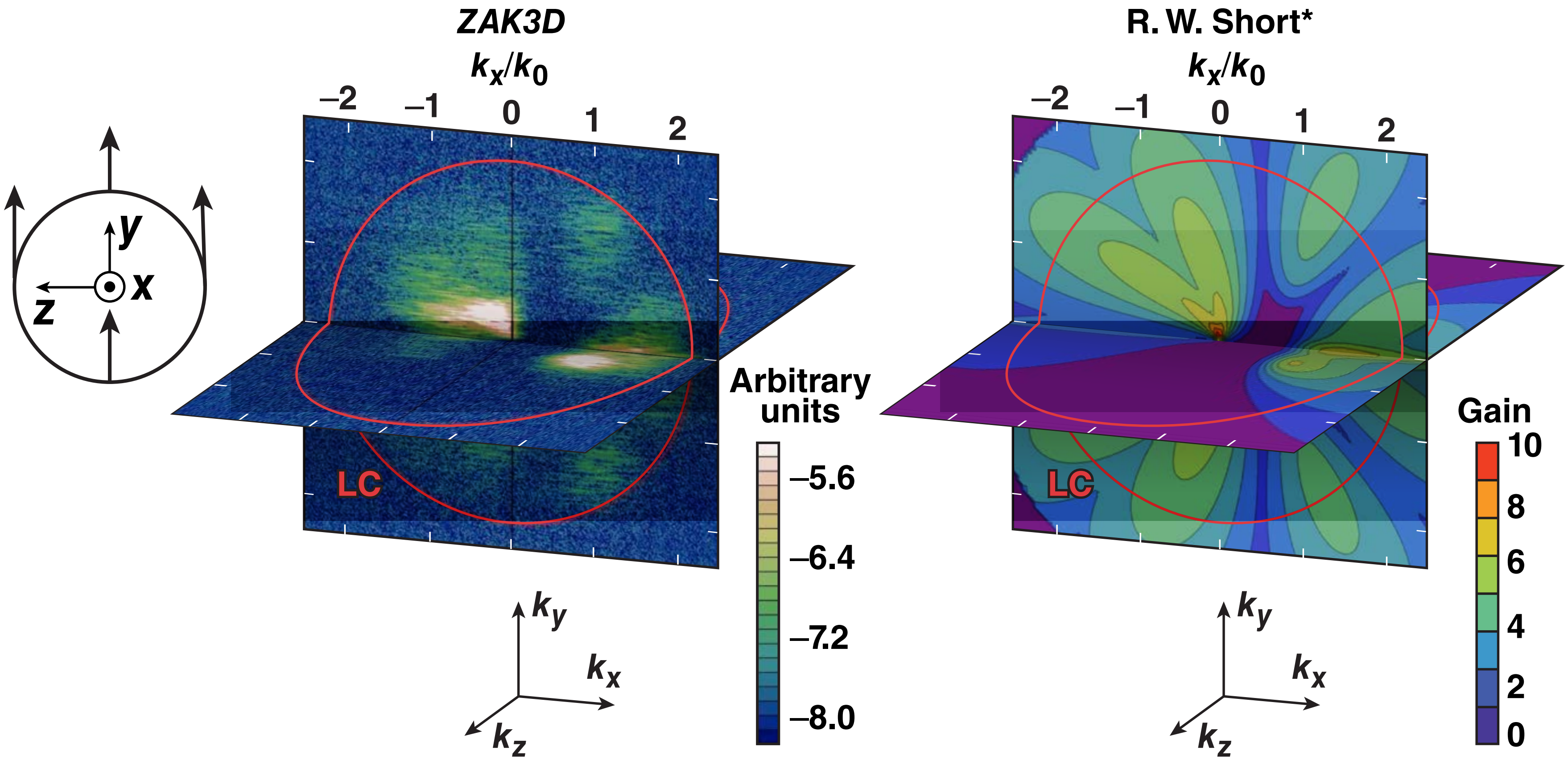
Comparison between *ZAK3D* and convective gain for four beams with parallel polarization shows consistency for large *k*



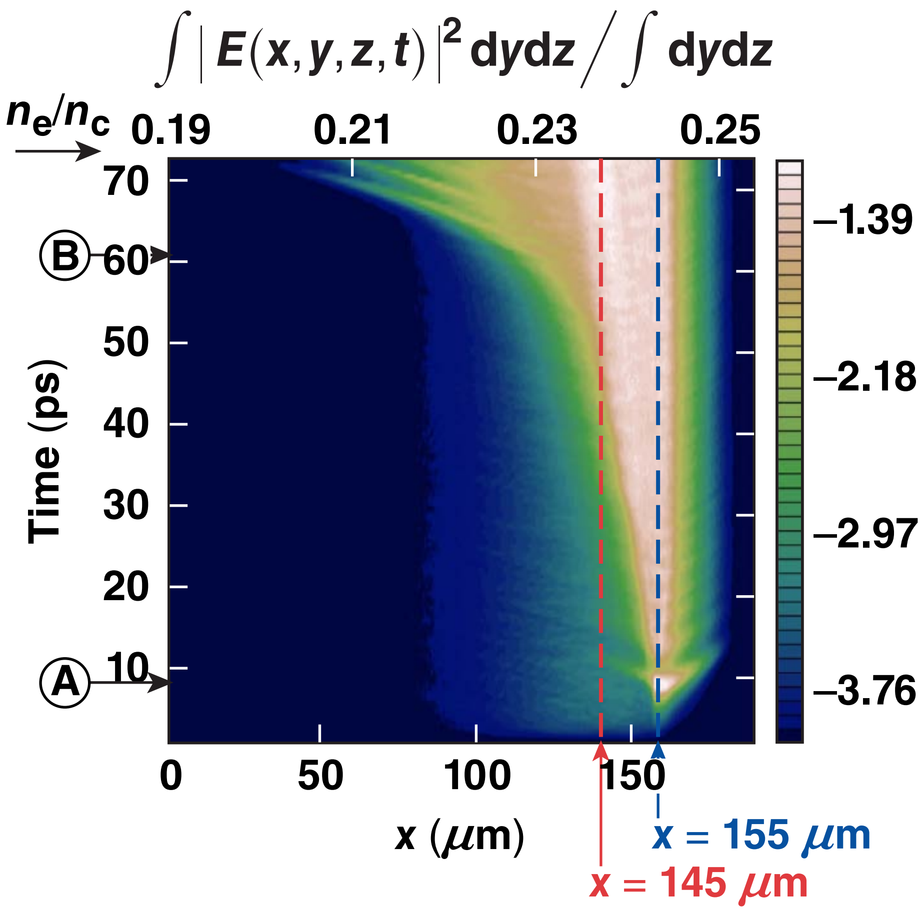
The presence of absolute instability requires a treatment of nonlinear saturation.

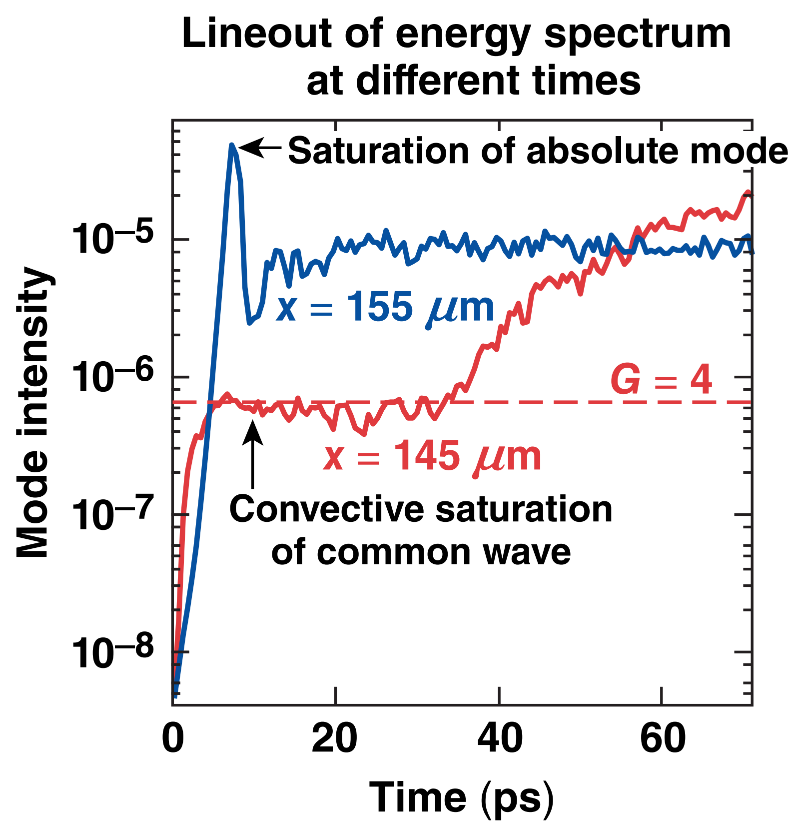
TC10653

*R. W. Short, this conference

In the nonlinear stage, a state of nonlinear Langmuir wave turbulence propagates to lower densities

- TPD driven by two beams with in-plane polarization (*p*-polarized) is simulated in the nonlinear stage $I_{14} = 1.2$, $L_n = 330\ \mu m$, and $\theta = 27°$





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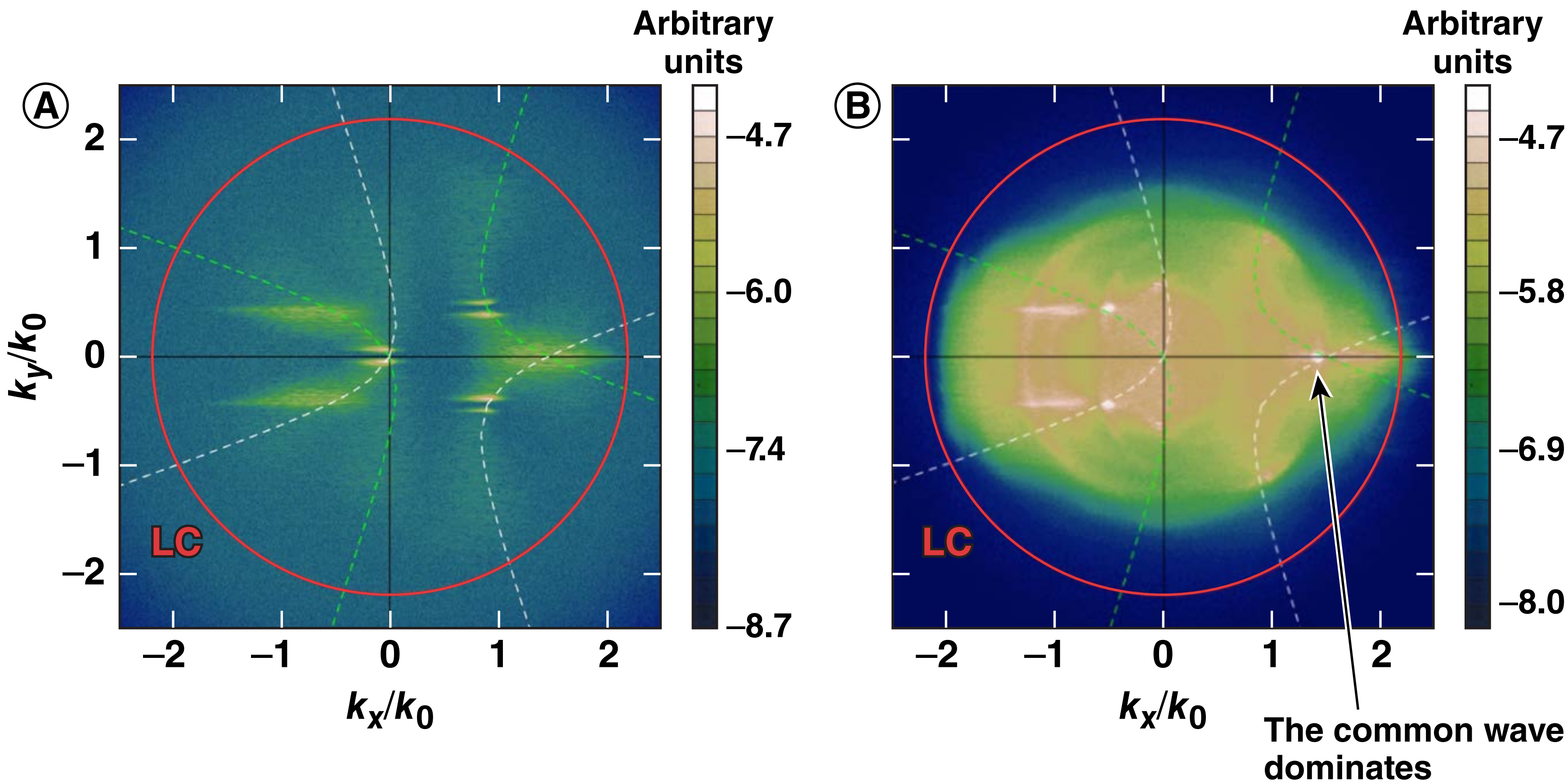
Density perturbations generated by the strong Langmuir turbulence restore growth to the convectively saturated modes; these dominate at late times

- Two beams, *p*-polarized, $I_{14} = 1.2$, $L_n = 330\ \mu m$, and $\theta = 27°$



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Summary/Conclusions

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The Langmuir wave equation is formally equivalent to the fluid equations used by Liu† and Simon‡

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Fourier transforming the Langmuir wave (LW) equation in time and space, after simple derivation it leads to these N + 1 equations

$$\begin{cases} \left[2\omega_{pe0}(\omega-\Delta\omega/2)-3k^2V_{te}^2\right]u+\dfrac{i\omega_{pe0}^2}{L}\left(\dfrac{\partial u}{\partial k_x}-\dfrac{k_x}{k^2}u\right) \\ \quad =\displaystyle\sum_{m=1}^{N}\dfrac{\omega_{pe0}}{4}\left(\dfrac{k^2}{k_{d,m}^2}-1\right)\left(\vec{k}\cdot V_{0,m}\right)u_{d,m}^{*} \\ \left[2\omega_{pe0}(\omega_d+\Delta\omega/2)+3k_{d,m}^2V_{te}^2\right]u_{d,m}^{*}-\dfrac{i\omega_{pe0}^2}{L}\left(\dfrac{\partial u_{d,m}^{*}}{\partial k_x}-\dfrac{k_{xd,m}}{k_{d,m}^2}u_{d,m}^{*}\right) \\ \quad =\dfrac{\omega_{pe0}}{4}\left(\dfrac{k_{d,m}^2}{k^2}-1\right)\left(\vec{k}\cdot V_{0,m}^{*}\right)u \end{cases}$$

where $\omega_{d,m}=\omega-\omega_{0,m}$ $k_{d,m}=k-k_{0,m}$, $u_{d,m}=u-u_{0,m}$
V_0 is the electron oscillation velocity in laser field

†C. S. Liu and M. N. Rosenbluth, Phys. Fluids 19, 967 (1976).
‡A. Simon *et al*., Phys. of Fluids 26, 3107 (1983).

TC10659