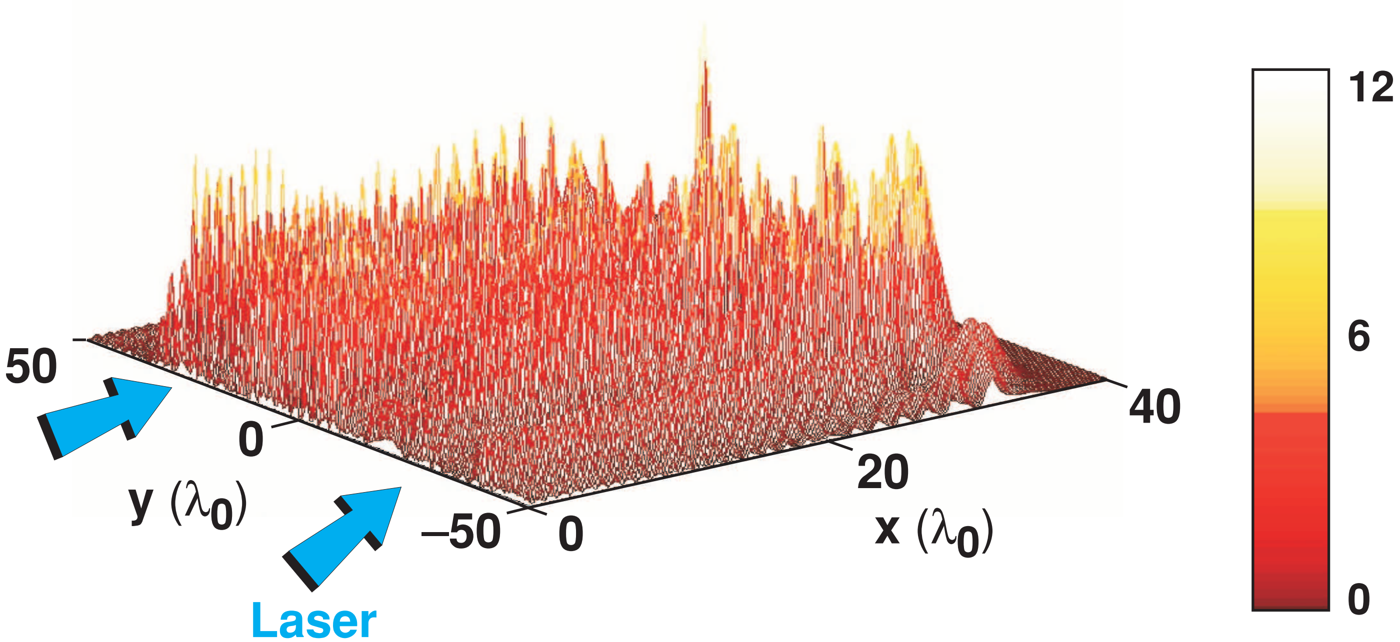
Nonlinear Propagation of Crossing Laser Beams in Direct-Drive Target Plasmas



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Summary

Nonlinear interaction between crossing laser beams influences the propagation of laser light through the coronal plasmas of direct-drive targets

- The strongest interaction between crossing laser beams through ion-acoustic perturbations occurs close to the critical-density surface, where thresholds for SBS and filamentation are likely to be exceeded.

- Crossed-beam interaction increases the spatial and temporal incoherence of laser irradiation in the near-critical density region.

Outline

1. **Motivation:**
   - **The crossed-beam interaction can influence laser propagation and absorption near critical density.**
2. **Non-paraxial modeling of light propagation near critical density**
3. **Oblique incidence of a laser beam on a critical-density surface**
4. **Incoherent crossing laser beams**

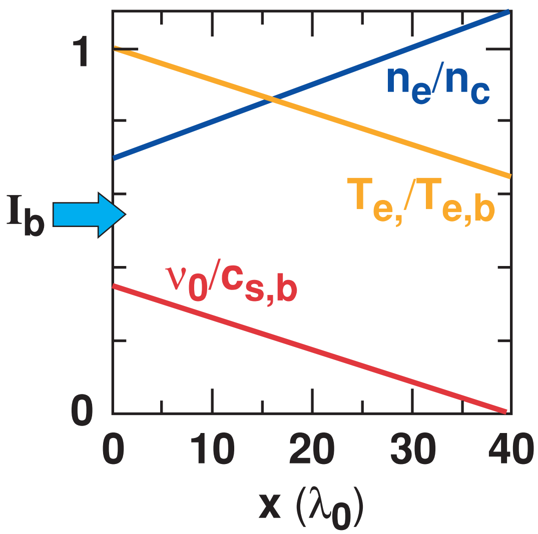
Modeling of SBS and self-focusing near critical-density surface requires a non-paraxial description of light propagation

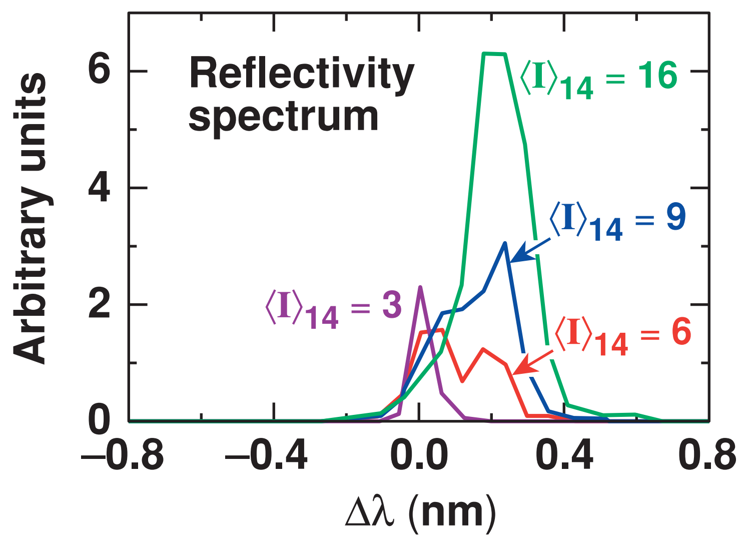
- Simulations are performed with a 2-D non-paraxial code in the region 40 × 200 laser wavelengths.
- Due to absorption and field swelling the average intensity on the boundary $I_b = 0.46\,\langle I \rangle$, $\langle I \rangle$ is the average intensity in vacuum.

DPP beam f/6

$T_{e,b} = 2$ keV

$\langle I \rangle = (3 \div 16)$ 10^{14} W/cm^2





Profiles of density, flow, and temperature modeling OMEGA plasma near critical density (similar to simulations by *SAGE*).

Linear theory:
$\Delta\lambda = 0.26$ nm

Self-focusing parameter:
$p_{sf} = 0.25\,\langle I \rangle_{14}$

Backward SBS gain:
$G_{sbs} = 1.20\,\langle I \rangle_{14}$

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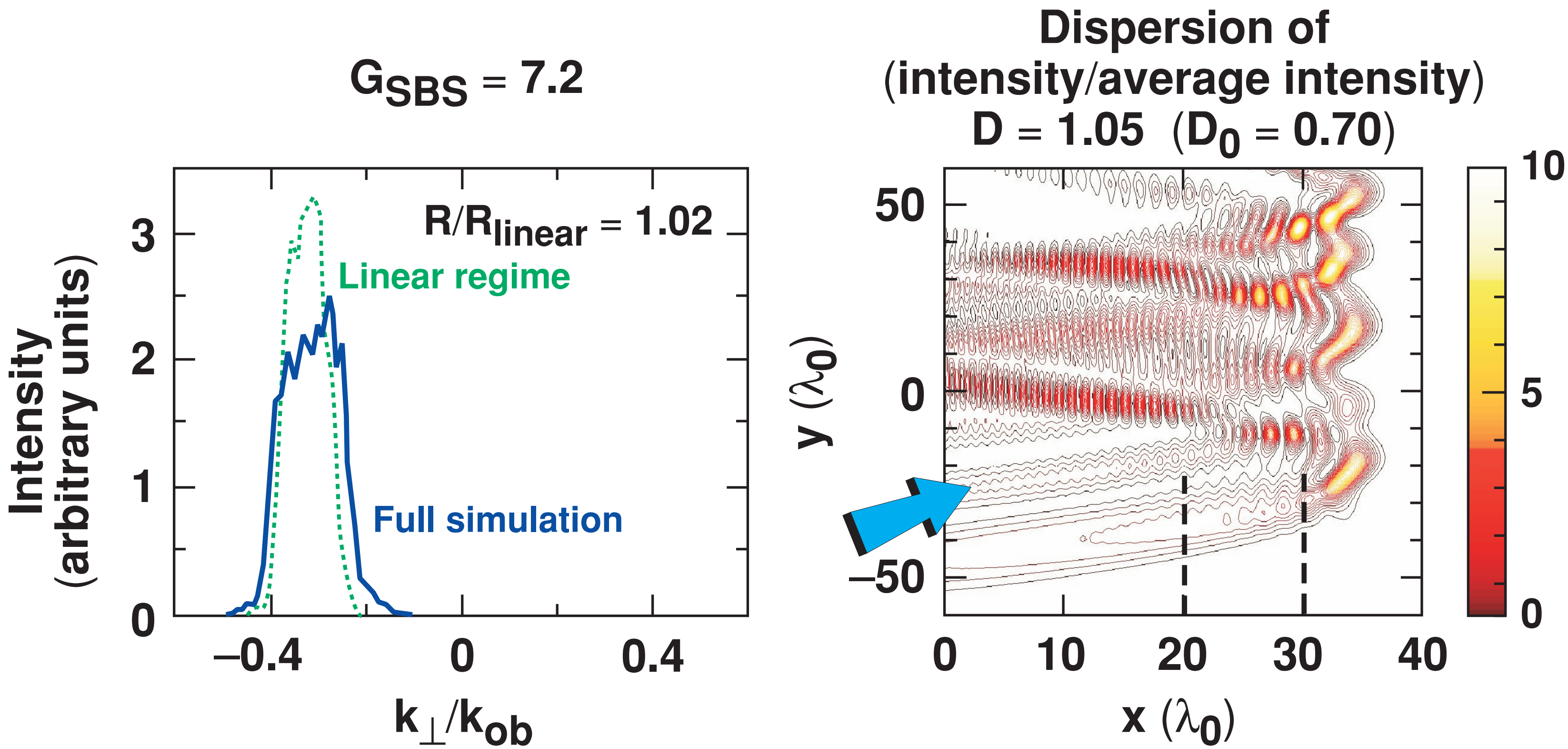
The non-paraxial model allows study of nonlinear light propagation for oblique incidence on the critical-density surface

- DPP beam with average intensity $\langle I \rangle_{14} = 6$ and angle of incidence 20°



- No spreading of backscattered light in angle or frequency is observed because the reflection from the critical-density surface does not seed backward SBS, and backward SBS, growing from noise, is weak.

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The spectrum of backscattered light is determined by backward SBS and reflection from the critical-density surface

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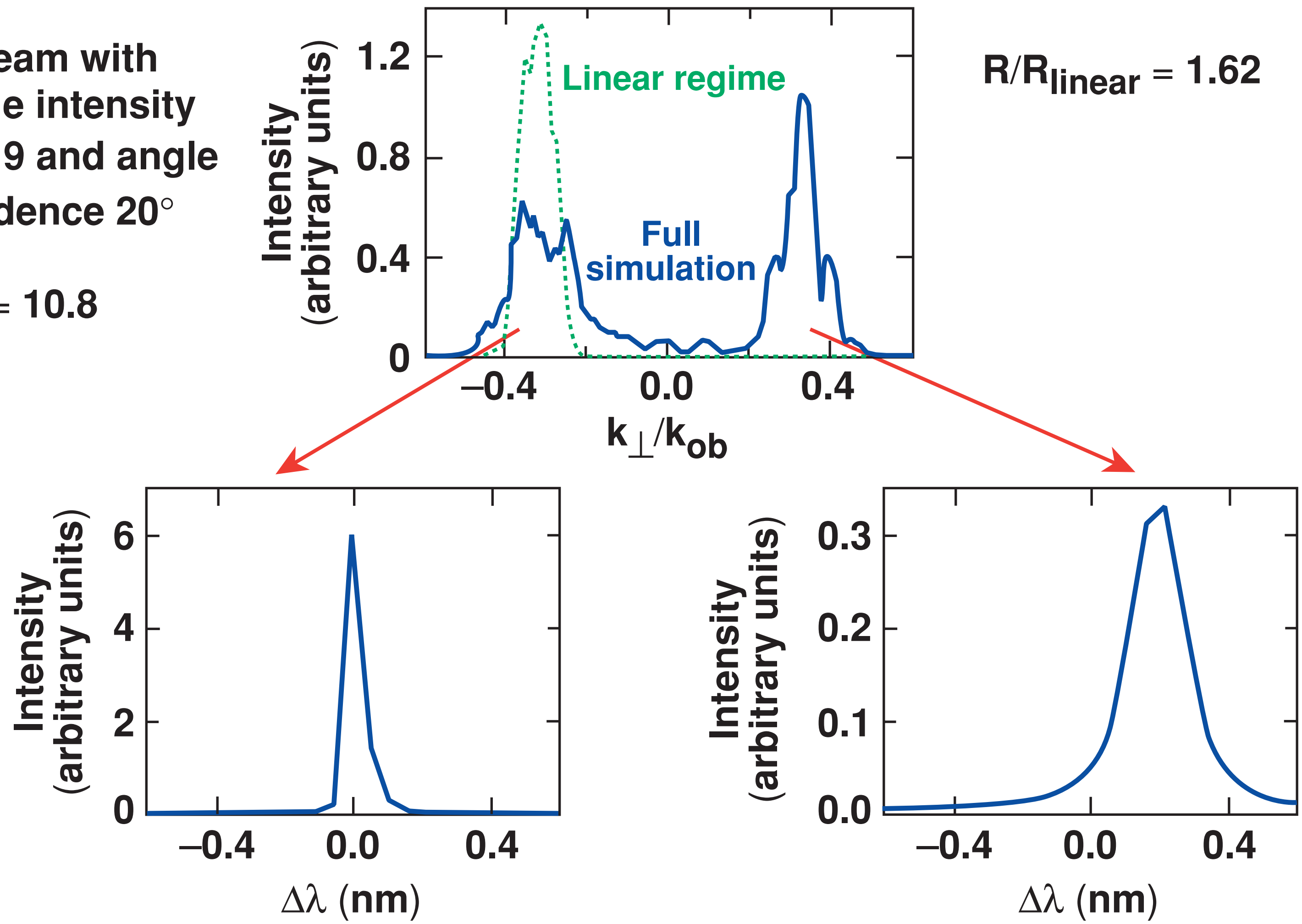
DPP beam with average intensity $\langle I \rangle_{14} = 9$ and angle of incidence 20°

$G_{SBS} = 10.8$

$R/R_{linear} = 1.62$



Frequency spectra at a given angle

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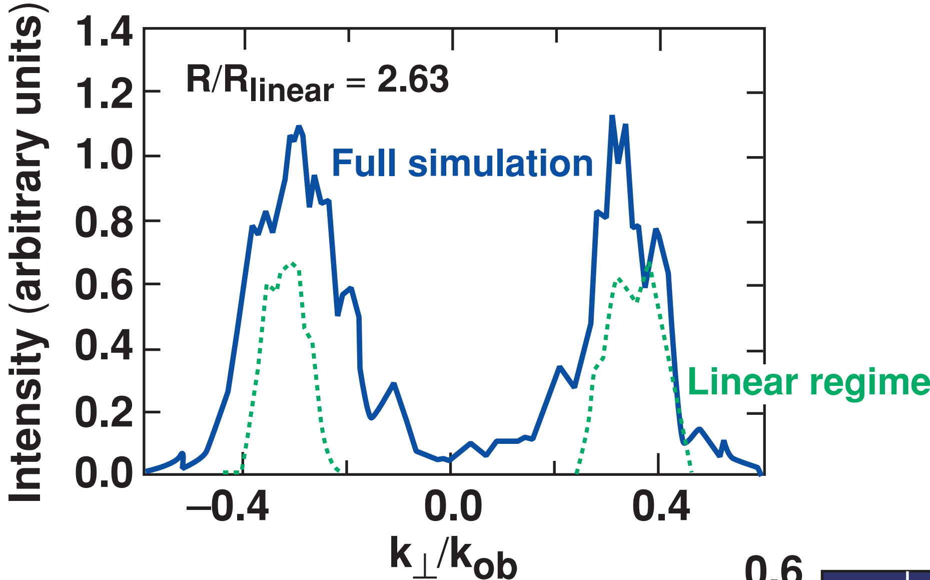
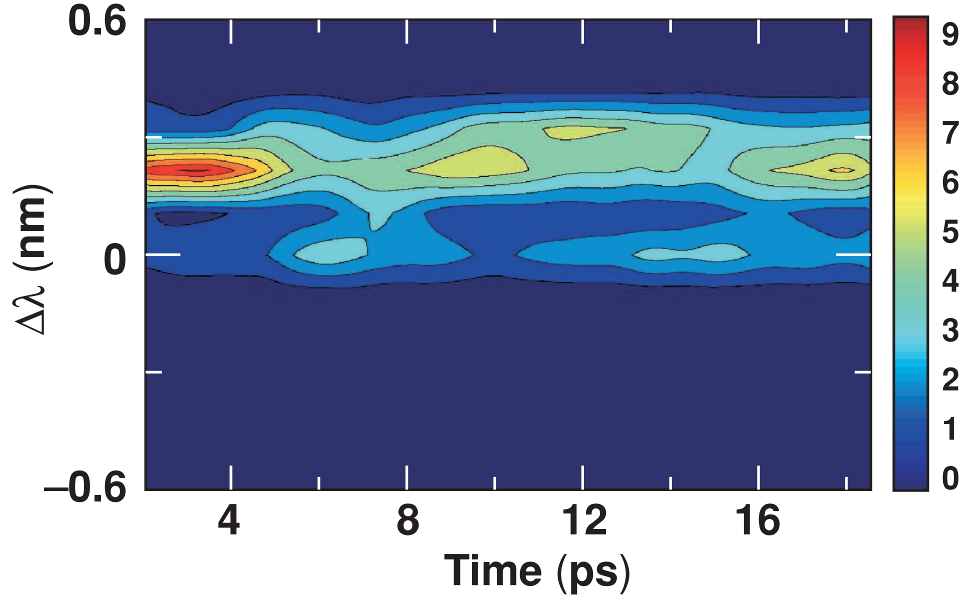
The angular and frequency width of backscattered light increases under crossed-beam irradiation



Two DPP beams with average intensity $\langle I \rangle_{14}$ = 4.5 in each beam and angle of incidence $\pm$ 20°

Gain for one beam G_{SBS} = 5.8

Reflection from critical surface of one beam seeds backward SBS from another beam.



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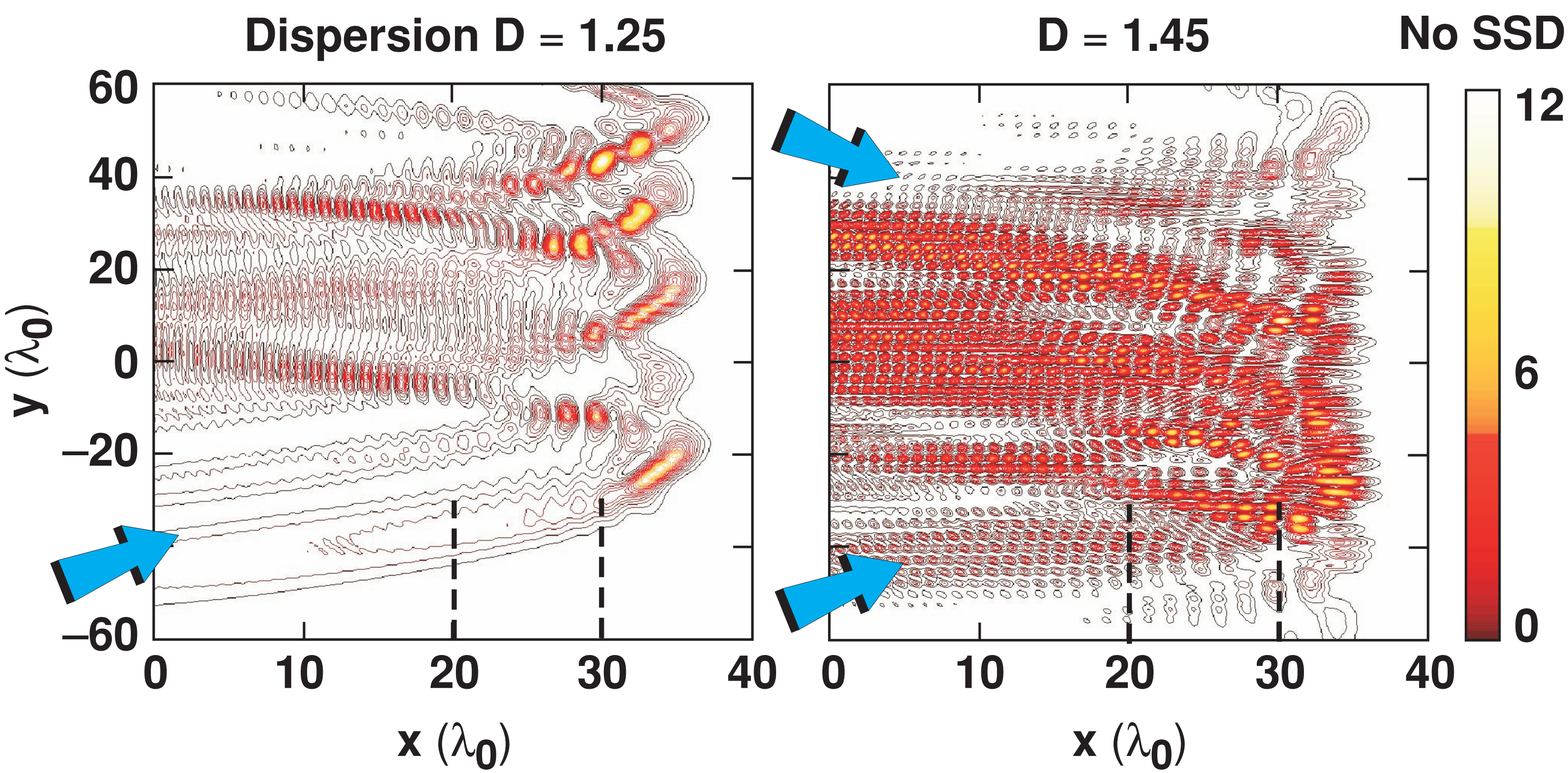
Under crossed-beam irradiation the inhomogeneity scale of laser intensity is much smaller than under single-beam irradiation



One beam $\langle I \rangle_{14} = 9$

Two crossing beams
$\langle I \rangle_{14} = 4.5$ in each beam

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The assumption of a small correlation angle for the incident light allows the derivation of the dispersion relation for the TPD instability

Consider a plasmon $\Psi_\alpha(\vec{k})$ in a homogeneous plasma model:

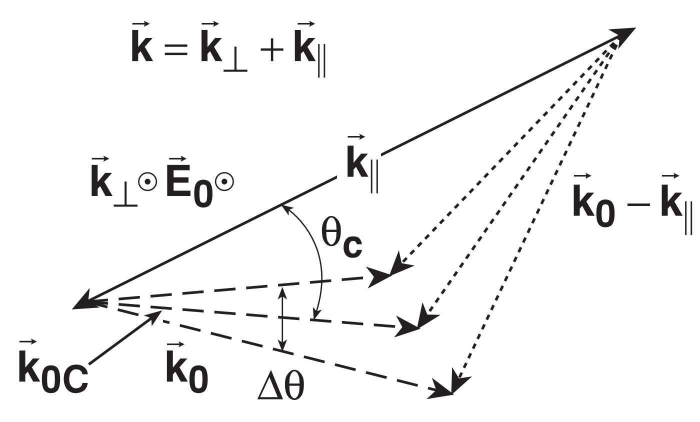
The following correlation properties are assumed: $\left\langle \Psi_\alpha(\vec{k}_1)\Psi_\alpha^*(\vec{k}_2) v_0(\vec{k}_{01}) v_0^*(\vec{k}_{02}) \right\rangle = \left\langle \Psi_\alpha(\vec{k}_1)\Psi_\alpha^*(\vec{k}_2)\right\rangle \left\langle v_0(\vec{k}_{01}) v_0^*(\vec{k}_{02})\right\rangle,$

where $\left\langle v_0(\vec{k}_{01}) v_0^*(\vec{k}_{02})\right\rangle = \dfrac{\left\langle |v_0|^2 \right\rangle \delta(\vec{k}_{01} - \vec{k}_{02})}{k_0 \Delta\theta}$ for light smoothed with DPP.

Standard frequency-matching conditions for TPD instability:

$$\omega^2 = \omega_{p0}^2 + 3k^2 v_{Te}^2,$$

$$(\omega_0 - \omega)^2 = \omega_{p0}^2 + (\vec{k}_{0C} - \vec{k})^2 v_{Te}^2$$



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The growth rate of the TPD instability can be proportional to the average laser intensity

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Equation for the instability increment γ:

$$\frac{2(\gamma+\gamma_e)}{\omega_{p0}} = -\mathrm{Im}\int d\vec{k}_0 \frac{|V_0|^2(\vec{k}_0)F(\vec{k}_0,\vec{k})}{2i(\gamma+\gamma_e)\omega_{p0} - 3v_{Te}^2\left[(\vec{k}_0-\vec{k})^2 - (\vec{k}_{0C}-\vec{k})^2\right]}$$

where $F(\vec{k}_0,\vec{k}) = \frac{\left[k_0^2 - 2\vec{k}_0\vec{k}\right]^2}{4\left[(\vec{k}_0-\vec{k})^2 k^2\right]} k_\perp^2$

γ_e: damping coefficient

$\int d\vec{k}_0 \rightarrow \int d\theta$: to integrate over the reasonant denominator in the integrand

- Small angular width $\Delta\theta$: $A \equiv \frac{(\gamma+\gamma_e)\,\omega_{p0}}{3v_{Te}^2 k_\| k_0 |\sin\theta_c| \Delta\theta} >> 1$

$$\gamma + \gamma_e = \sqrt{\left\langle |v_0|^2 \right\rangle F(\vec{k}_{0C},\vec{k})/4}$$

- Large angular width $\Delta\theta$: $A << 1$

$$\gamma + \gamma_e = \omega_{p0} \frac{\pi \left\langle |v_0|^2 \right\rangle F(\vec{k}_{0C},\vec{k})}{12 v_{Te}^2 k_\| k_0 |\sin\theta_c| \Delta\theta}$$

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The growth rate of the TPD instability can be determined by the overlapped beam intensity of crossing incoherent beams

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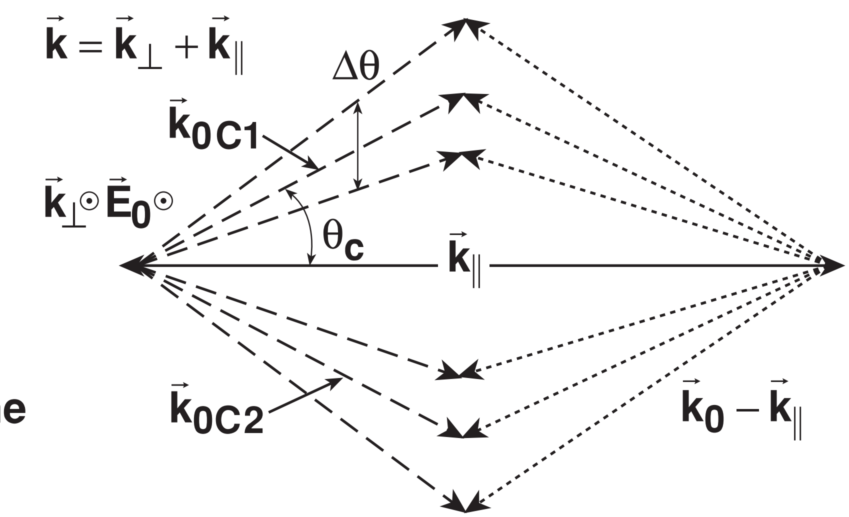
For certain orientations of a plasmon k-vector:

$$\left(\vec{k}\vec{k}_{0C1}\right) \approx \left(\vec{k}\vec{k}_{0C2}\right)$$



TPD resonance conditions for two beams are similar, and growth rate γ depends on the overlapped beam intensity.

For the parameters: $k_0\lambda_{De} = 0.15, k_{\parallel} = 1.5k_0,\ \ \Delta\theta = 0.2, \theta_c \approx 20^0,\ \ \gamma_e/\omega_{p0} = 2 \cdot 10^{-3}$

the threshold intensity $I_{av} = 4 \cdot 10^{14}$ W/cm^2

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- The strongest interaction between crossing laser beams through ion-acoustic perturbations occurs close to the critical-density surface, where thresholds for SBS and filamentation are likely to be exceeded.
- Crossed-beam interaction increases the spatial and temporal incoherence of laser irradiation in the near-critical density region.
- The influence of crossed-beam irradiation on laser imprint is studied.