The Effects of Beam Intensity Structure on Two-Plasmon Decay in Direct-Drive Laser Fusion Targets

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Summary

Smoothed-beam hot spots may enhance two-plasmon growth but not impact hot-electron production

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- SBS and SRS have maximum growth rates for backscatter, but in two-plasmon decay, the fastest-growing plasma waves have perpendicular components comparable to their parallel components.
- Small-radius hot spots in smoothed beams are aligned along the pump and would be expected to be less effective in driving TPD.
- TPD is near threshold for direct-drive conditions, but the threshold is exceeded in hot spots.
- The two-plasmon decay waves tend to propagate out of hot spots laterally, but absolute growth can still occur.
- Shorter amplification range may reduce hot-electron production by nonlinearly saturated waves.

Outline

- Calculation of intensity distribution in spherically symmetric coronas
- Calculation of transverse absolute instability thresholds for two-plasmon decay (TPD)
- Comparison with hot-spot radii and intensities
- Summary and conclusions

The intensity pattern in a spherically symmetric plasma corona may be calculated using spherical harmonics

- Neglecting polarization, the field amplitude satisfies the scalar wave equation:

$$\nabla^2 E + \frac{\omega^2}{c^2}\,\varepsilon(r)E = 0$$

- Absorption can be included by using a complex dielectric function:

$$\varepsilon(r) = 1 - \frac{\omega_{pe}^2(r)}{\omega\left[\omega + i\upsilon_{ei}(r)\right]}$$

- $E(r, \theta, \phi)$ is expanded in spherical harmonics:

$$E(r,\theta,\phi) = \sum_{\ell,m} a_{\ell,m}\,\frac{1}{r}\,g_{\ell}(r)Y_{\ell,m}(\theta,\phi)$$

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The solution to the radial wave equation can be represented by an asymptotic approximation

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- The radial wave functions satisfy

$$\frac{d^2 g}{ds^2} + \left[\varepsilon(s) - \frac{\ell(\ell+1)}{s^2}\right] g = 0,\ s = \frac{\omega_0}{c} r$$

- The approximate solution can be written:

$$g_\ell(s) = 2\sqrt{\pi}\left(\frac{3}{2}S_0\right)^{1/6}\left[Q(s)\right]^{-1/4} \mathrm{Ai}\left[\left(\frac{3}{2}S_0\right)^{2/3}\right], Q(s) = \varepsilon(s) - \frac{\ell(\ell+1)}{s^2}, \text{and}$$

$$S_0 = \int_{s_t}^{s} Q^{1/2}(s)\,ds$$

- This solution is valid for all radii (both over- and underdense plasma) and, for scale lengths longer than a few microns, is virtually identical to the exact numerical solution.

Growth rates and instability thresholds for TPD are obtained from the dispersion relation

- The dispersion relation for TPD can be written $D(\omega, k) = 0$, where

$$D(\omega,k) \equiv \left(\omega^2 - \omega_{e,k}^2\right)\left[(\omega - \omega_0)^2 - \omega_{e,k-k}^2\right] - \left\{\frac{k \cdot v_{osc}\omega_{pe}\left[(k - k_0)^2 - k^2\right]}{2k\left|k - k_0\right|}\right\}^2 .$$

- If $k_{\perp max}$ is the perpendicular wave number giving the maximum growth rate, the propagation velocity of the fastest-growing amplitude is

$$V = \left.\frac{\partial \omega_r}{\partial k_\perp}\right|_{k_{\perp max}} = \left.\frac{\partial D(k,\omega)/\partial k_\perp}{\partial D(k,\omega)/\partial \omega}\right|_{k_{\perp max}}$$

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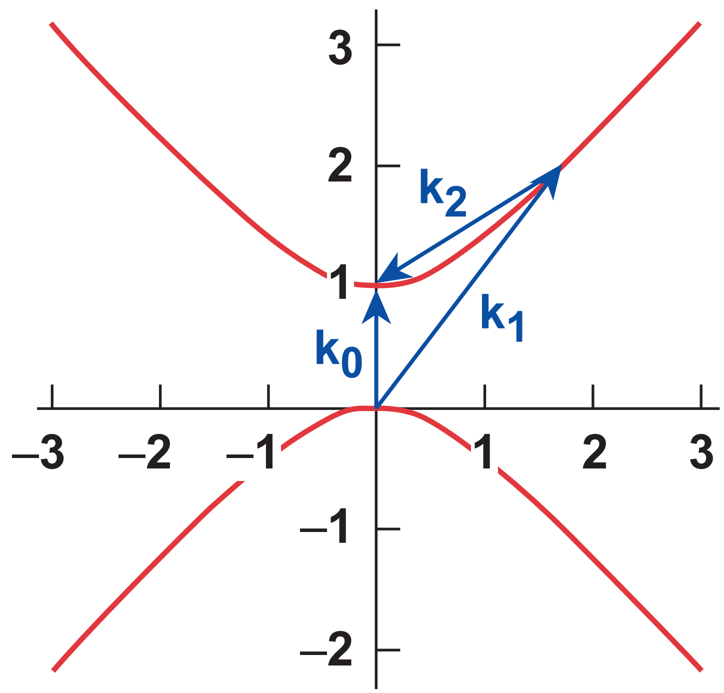
Fastest growth rates occur for comparable perpendicular and parallel wave vectors



- Growth rates are limited by inhomogeneity for small wave vectors and by Landau damping for large wave vectors.
- For NIF, lowest threshold ~10^{14} W/cm^2; marginal, but exceeded in hot spots.

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The threshold for transverse absolute instability can be obtained from the homogeneous dispersion relation

- Assuming the density is uniform perpendicular to the pump, the condition for absolute instability is found by imposing boundary conditions of zero incoming waves at y = 0, L.

- The result is

$$\frac{(k-k_0)^2 - k^2}{k|k-k_0|} \frac{\nu_0}{\sqrt{\nu_{\perp 1}\nu_{\perp 2}}} kL > \pi$$

- This can be approximated by $I_{14}^{1/2} > 0.68 \frac{T_{keV}}{L_{\perp\mu}}$

- Easily satisfied in hot spots.

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