Modeling Two-Plasmon-Decay Instability in Direct-Drive Inertial Confinement Fusion

\[ T_h = 36 \text{ keV} \]
The saturation of two-plasmon-decay instability is caused by the broad spectrum of low-frequency density perturbations

- In the linear stage of two-plasmon-decay instability (TPD), the convective and absolute growth produces a broad angular spectrum of primary Langmuir waves.

- In the saturation stage of TPD, a broad spectrum of low-frequency density perturbations is generated, including the perturbations at the onset of the Langmuir decay instability.

- The temperature of the fast electrons, produced in TPD, is defined by the spectrum of Langmuir waves, including the Landau cutoff.
Outline

• The threshold of TPD for OMEGA parameters
• The linear stage of TPD growth: absolute and convective
• The properties of the fast electrons, generated in TPD
• The saturation of TPD
In OMEGA experiments, the hard x-ray production depends on ion composition.

![Graph showing the relationship between laser intensity and hard x-ray signal](TC8036d)
The TPD instability threshold is influenced by the interplay of plasma inhomogeneity, wave damping, and resonance detuning caused by beam incoherence.

- Plasma-wave damping

\[
\left( \frac{\gamma_e}{\omega p_0} \right)_{\text{coll}} = 0.5 \times 10^{-3} \frac{(Z/5.3)}{(T_e/2 \text{ keV})^{3/2}}
\]

- Detuning due to inhomogeneity

\[
\frac{1}{2 k_0 L} = 2.1 \times 10^{-4} \frac{(L/150 \mu m)}{(L/150 \mu m)}
\]

- Homogeneous 3-wave growth rate

\[
\gamma^0 = \frac{k_0 |V_{osc}|}{\omega p_0} = 0.26 \times 10^{-2} \sqrt{I_{14}}
\]

- Detuning due to beam incoherence

\[
\frac{\Delta \omega}{\omega p_0} = 3 k k_0 \lambda_{De}^2 |\sin \theta_c| \Delta \theta
\]

\[
\frac{\Delta \omega}{\omega p_0} = 4 \times 10^{-2} \left( \frac{T_e}{2 \text{ keV}} \right) \Delta \theta \sin \theta_c
\]
The calculated TPD threshold is in reasonable agreement with the hard x-ray onset intensity.
The fastest-growing wave vectors change with the position in the homogeneous plasmas.

The longitudinal and transverse wave vectors lie on the TPD maximum-growth hyperbola.

\[ E_x \left( m_e c \omega_0 / e \right) \]
\[ \Phi \left( m_e c^2 \right) \]

\[ K_\perp (\omega_0/c) \]
\[ t = 3535/\omega_0 \]
\[ t = 3465/\omega_0 \]

\[ n_0 (n_c) \]

PIC OSIRIS simulation

Fluid simulation

\[ I = 10^{15} \text{ W/cm}^2, \ T_e = 2 \text{ keV}, \ L_N = 150 \mu \text{m} \]

In the linear stage of TPD, absolute and convective growth generates a broad spectrum of Langmuir waves.

$\gamma(\omega_0)$

$K_{\perp}(\omega_0/c)$

$I = 10^{15} \text{ W/cm}^2$, $T_e = 2 \text{ keV}$, $L_N = 150 \text{ } \mu\text{m}$

*A. Simon et al., Phys. Fluids 26, 3107 (1983).*
The distribution of fast electrons, generated in the TPD, depends on the spectrum of the Langmuir waves.

\[ f(\varepsilon) \sim \sqrt{\varepsilon} \cdot \exp \left( -\frac{\varepsilon}{T_h} \right) \]

Boundary conditions:
- periodic (transverse)
- thermal (longitudinal)

\[ T_h \sim \frac{m_e}{2} \left( \frac{\omega}{k} \right)^2 \sim 20 \cdot T_e \]

\[ K \lambda_{De} \approx 0.22 \gamma_L \approx \gamma_c \]

Landau cutoff

Also see talk for J. F. MYatt at this conference
The plasma spectral density characterizes the low-frequency density perturbations driven by the ponderomotive force.

Spectral density

$$\frac{S}{\omega} = \text{Im} \left[ \frac{(\delta n_e/n_e)_{\omega,k}}{|E^{2}_{\omega,k}/16\pi nT_e|} \right]$$
The interaction of incoherent laser beams with plasmas produces low-frequency perturbations in electron density.

\[ \left\langle I \right\rangle = 9 \times 10^{14} \text{ W/cm}^2, \quad T_e = 2 \text{ keV}, \quad n_0 \approx \frac{n_c}{4} \]
The threshold of the Langmuir decay instability depends on the characteristics of ion-acoustic waves.

LDI threshold in the random-phase approximation:

\[
\frac{\langle |E_L|^2 \rangle_{LDI}}{4\pi nT_e} \cdot \frac{S}{\omega} = \frac{\Delta \omega}{\omega_p} \cdot 4
\]

\[\Delta \omega = \text{resonance width}\]

Seeding by laser-driven perturbations
Summary/Conclusions

The saturation of two-plasmon-decay instability is caused by the broad spectrum of low-frequency density perturbations

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