Suppression of Two-Plasmon Decay by Ion-Density Fluctuations

Electron-density perturbation $n_p (n_c)$

Without ion-density fluctuation

With ion-density fluctuation

Range of ion-density fluctuation

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Correlations between two-plasmon decay (TPD) and ion-density fluctuations were observed in particle-in-cell (PIC) simulations.

- Analytical theory for homogeneous plasmas shows that transverse ion-density fluctuations can raise the TPD threshold by coupling the two otherwise independent pairs of plasmons.

- A fluid code has been developed to show the suppression of TPD caused by ion-density fluctuations in both homogeneous and inhomogeneous plasmas.
Collaborators

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The two-plasmon decay (TPD) is an important concern in direct-drive ICF

- TPD is a laser–plasma instability with a low threshold and high-energy electron generation
- Energetic (hot) electrons generated from laser–plasma interactions can preheat the shell and degrade the implosion
PIC simulations show the correlation between TPD saturation with ion-density fluctuations

**OSIRIS** simulations with $I = 2 \times 10^{15} \text{ W/cm}^2$, $T = 1 \text{ keV}$, $L = 25 \mu\text{m}$

- TPD was observed to be intermittent\(^2,3\)
- TPD saturates as ion fluctuations increase to a certain level
- TPD recurs after ion fluctuations drop

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The ion-density fluctuation is driven by the ponderomotive pressure of the plasma waves

- The ion-density fluctuations calculated from the ion-acoustic equation match the PIC results
- Ion-acoustic wave (IAW) equation

\[
(\partial_{tt} - C_s^2 \nabla^2) \delta n = \nabla^2 |E|^2 / (16 \pi m_i)
\]

Drop \(\nabla^2_{\parallel}\), since \(\nabla^2_{\parallel} \ll \nabla^2_{\perp}\)
Understanding how the ion fluctuations saturate TPD is important for modeling the long-term behavior of TPD.

- Previously, various energy sinks were proposed as saturation mechanisms:
  - Ion fluctuations can scatter the plasma waves to high $k_{\perp}$ regions, where they are Landau damped\(^1\)
  - Langmuir decay instability (LDI) as an energy sink described by the Zakharov model\(^2\)

- The observed decrease of $|Ex|$ indicated TPD suppression.

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Ion-density fluctuation ($\delta n$) can suppress TPD by coupling the two otherwise independent pairs of plasmons\textsuperscript{1}

- Two symmetric pairs of plasmons with $\pm k_\perp$ can be coupled by the transverse ion-density fluctuation with $k_s = 2k_\perp$

- Theory predicts a threshold $\delta n$ above which the growth of four coupled plasmons becomes zero in a homogeneous plasma

A four-plasmon model predicts that a large $\delta n$ can suppress TPD growth in homogeneous plasmas.

- We solved two coupled three-wave equations and found the dispersion relation for homogeneous plasmas.

$I = 1 \times 10^{15} \text{ W/cm}^2$
$T = 2 \text{ keV}$
$k_\perp = 0.5 \omega_0/c$

$k_x = 1.1 \omega_0/c$
A linear fluid code has been developed to study the influence of ion-density fluctuation in inhomogeneous plasmas.

\[
\frac{\partial \psi}{\partial t} = \frac{e\phi}{m} - \frac{3n_e^2 n_p}{n} - \vec{v}_0 \nabla \psi \\
\frac{\partial n_p}{\partial t} + \vec{v}_0 \cdot \nabla n_p = -\nabla (n \nabla \psi) \\
\nabla^2 \phi = 4\pi e n_p
\]

The density fluctuation is included in \( n = n_0(x) + \delta n \) as a prescribed function.

BC’s

\[
\partial_x \psi |_0 = \partial_x \psi |_L = 0 \\
\partial_x \phi |_0 = \partial_x \phi |_L = 0 \\
n_p |_0 = n_p |_L = 0
\]
The theoretical results for homogeneous plasmas are verified by the fluid code

\[ I = 1 \times 10^{15} \text{ W/cm}^2 \]
\[ T = 2 \text{ keV} \]
\[ n_0 = 0.241 \, n_c \]

\[ \text{FFT}(n_p)(n_c) \]
\[ t = 6188/\omega_0 \]

- Those modes with \( k_\perp \sim k_s/2 \) are most effectively impacted
- Only a range of \( k_x \) can be suppressed, consistent with the dispersion relation

\[ n_p \, (n_c) \times 10^{-4} \]

Without \( \delta n \)

\[ \delta n = 0.6\% \, n_0 \]
\[ k_s = 1.0 \, \omega_0/c \]

\[ \delta n = 3\% \, n_0 \]
\[ k_s = 0.9 \, \omega_0/c \]
Preliminary results show static ion-density fluctuations can suppress TPD in inhomogeneous plasmas

- $\delta n$ can suppress TPD by raising the threshold

  Ponderomotive drive

  $\delta n$

  TPD

  Raising TPD threshold

- This can help find ways to reduce TPD

  With ion-density fluctuation

  Without ion-density fluctuation

$I = 1 \times 10^{15} \text{ W/cm}^2$

$T = 2 \text{ keV}$

$L = 150 \mu\text{m}$

$\delta n = 6\% n_0$

$k_s = 0.15 \omega_0/c$

$I = 1 \times 10^{15} \text{ W/cm}^2$

$T = 2 \text{ keV}$

$L = 150 \mu\text{m}$

$\delta n = 6\% n_0$

$k_s = 0.15 \omega_0/c$
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Related talk: W. Seka (GO5.00006).