Three-Dimensional Modeling of the Two-Plasmon–Decay Instability and Stimulated Raman Scattering Near the Quarter-Critical Density in Plasmas

$E_x$ field, linear stage, 3-D simulation

Convective TPD

SRS

Density ($n_c$)

<table>
<thead>
<tr>
<th>Arbitrary units</th>
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</thead>
<tbody>
<tr>
<td>4</td>
</tr>
<tr>
<td>3</td>
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<tr>
<td>2</td>
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<tr>
<td>1</td>
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</tbody>
</table>

H. Wen
University of Rochester
Laboratory for Laser Energetics

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In 3-D particle-in-cell (PIC) simulations, the coexistence of two-plasmon decay (TPD) and stimulated Raman scattering (SRS) is observed near the quarter-critical density

Summary

- The results of three PIC simulations (3-D, 2-D in-plane, and 2-D out-of-plane) have been compared
- TPD and SRS spectral features in 3-D simulations are in agreement with respective 2-D simulation results
- Field energy levels in PIC simulations indicate that SRS is important in the saturation stage
Collaborators

A. V. Maximov, R. Yan, C. Ren, and J. F. Myatt

University of Rochester
Laboratory for Laser Energetics

W. B. Mori

University of California, Los Angeles
PIC simulations have been performed for parameters relevant to direct-drive inertial confinement fusion experiments

- Physical parameters
  - scale length $L_n = 100 \, \mu m$
  - intensity $I = 2.7 \times 10^{15} \, W/cm^2$
  - CH plasma, temperature $T_e = 2 \, keV$, $T_i = 1 \, keV$
  - laser propagates along the x axis
  - linear density profile from 0.21 to 0.26 $n_c$

- Numerical parameters
  - simulation box size: $400 \times 150 \times 32 \, c/\omega_0$
    ($21 \times 8 \times 1.7 \, \mu m$) for 3-D simulation,
    $400 \times 300 \, c/\omega_0$ ($21 \times 16 \, \mu m$) for the two 2-D simulations
Both TPD and SRS features are observed in the field spectra in the linear stage of the 3-D PIC simulation

- TPD is localized in \(x-y\) plane
- SRS side scattering is observed at \(k_z \neq 0\)
- SRS scattered light has a small wave vector compared to \(k_0\)

\[ E_x \text{ field, linear stage, 3-D simulation, } k_z = 0 \]

\[ E_x \text{ field, linear stage, 3-D simulation, } k_z = 0.2 k_0 \]
TPD and SRS features are identified in the frequency spectra of plasma daughter waves in the linear stage of 2-D and 3-D simulations.

- **Solid black lines:** $\omega_1 + \omega_2 = \omega_0$, $\vec{k}_1 + \vec{k}_2 = \vec{k}_0$

For TPD:

$$k_y^2 = k_x(k_x - k_0)$$

For SRS:

90° side scattering

- **2-D in-plane**
- **2-D out-of-plane**
- **3-D $k_z = 0$**
- **3-D $k_z = 0.2 k_0$**
TPD and SRS develop independently in the linear instability stage

- Spectra are Fourier-transformed in two transverse directions and averaged over $k_z$
- The growth rates of TPD and SRS are comparable
SRS is important in the instability saturation stage

- The field energy in the simulated region reaches a quasi-steady state at \( \sim 1 \) ps
- SRS accounts for more than 50% of the total field energy associated with the instability
The temperature and flux of fast electrons in 3-D and 2-D PIC simulations are close

- The distribution is fitted with the expression $A \exp(-KE/T)$, where $KE$ is the kinetic energy and $T$ is the temperature of hot electrons.

### Electron energy distribution

<table>
<thead>
<tr>
<th>Kinetic energy (keV)</th>
<th>3-D</th>
<th>2-D in-plane</th>
<th>2-D out-of-plane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (keV)</td>
<td>28.1</td>
<td>22.9</td>
<td>29.2</td>
</tr>
<tr>
<td>Energy flux (carried by electrons above 50 keV)</td>
<td>21.1%</td>
<td>19.9%</td>
<td>21.3%</td>
</tr>
</tbody>
</table>
Summary/Conclusions

In 3-D particle-in-cell (PIC) simulations, the coexistence of two-plasmon decay (TPD) and stimulated Raman scattering (SRS) is observed near the quarter-critical density.

- The results of three PIC simulations (3-D, 2-D in-plane, and 2-D out-of-plane) have been compared.
- TPD and SRS spectral features in 3-D simulations are in agreement with respective 2-D simulation results.
- Field energy levels in PIC simulations indicate that SRS is important in the saturation stage.