Three-Dimensional Modeling of Laser–Plasma Interactions Near the Quarter-Critical Density in Plasmas

Electron distribution

Number of particles (normalized)

Kinetic energy (keV)

3-D speckle

2-D in-plane

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57th Annual Meeting of the American Physical Society Division of Plasma Physics
Savannah, GA
16–20 November 2015

50 100 150 200 250

10^{-5} 10^{-6} 10^{-7} 10^{-8}
Summary

Fast-electron distributions generated by parametric instabilities near quarter-critical density have been calculated in 3-D and 2-D particle-in-cell (PIC) simulations

- In 3-D PIC simulations, the evolution of two-plasmon decay (TPD), stimulated Raman scattering (SRS), and stimulated Brillouin scattering (SBS) has been characterized.
- The periodic boundary condition is important for modeling the growth of SBS but not as important for modeling the growth of SRS.
- Fast electrons are accelerated mainly by the TPD-generated plasma waves.
- The fast-electron energy distribution and angular distribution depend on the shapes of laser speckles.
Collaborators

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PIC simulations have been performed for direct-drive inertial confinement fusion (ICF)–related parameters

- Physical parameters (plane wave)
  - scale length $L_n = 100 \, \mu m$
  - intensity $I = 9 \times 10^{14} \, W/cm^2$
  - CH plasma, temperature $T_e = 2 \, \text{keV}, T_i = 1 \, \text{keV}$
  - laser propagates along the $x$ axis
  - linear density profile from 0.21 to 0.26 $n_c$
  - $\eta = 1.9^*$

- Numerical parameters
  - simulation box size: $400 \times 150 \times 120 \, c/\omega_0$
    ($21 \times 8.4 \times 6.7 \, \mu m$) for the 3-D simulation

The growth rates of TPD in 2-D and 3-D simulations are in agreement with linear theory

- The growth rates are obtained by integrating the $E_x$ spectrum over $k_x$
- The growth rates of absolute modes with small $k_y$ are in agreement with linear theory

In the early stage of 3-D PIC simulations, the growth of TPD and SRS is consistent with theoretical results.

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The modeling of absolute SBS growth depends on the transverse boundary conditions

- The green line was obtained assuming $E_{\text{total}} = E(\omega_0) + E(\omega_0/2)$
- The angular spread of scattered light is smaller for SBS than for SRS

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\[ B_x(\omega_0, \text{SBS}) \]
\[ t = 2 \text{ ps} \]

\[ B_x(\omega_0/2, \text{SRS}) \]
\[ t = 2 \text{ ps} \]

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*C. S. Liu et al., Phys. Fluids 17, 1211 (1974).*
Fast-electron generation has been studied in 3-D and 2-D PIC simulations for different laser-speckle shapes.

- $R = \text{peak intensity}/\text{average intensity}$
- Parameters (laser speckles)
  - $L_n = 100 \ \mu\text{m}$
  - average $I = 9 \times 10^{14} \text{ W/cm}^2$
  - $T_e = 3 \text{ keV}, T_i = 1.5 \text{ keV}$
  - same transverse size (8 $\mu\text{m}$)

<table>
<thead>
<tr>
<th>Laser-speckle shape</th>
<th>Net fast electrons energy flux/laser flux forward/backward</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-D plane wave</td>
<td>5.2%/4.4%</td>
</tr>
<tr>
<td>2-D speckle $R = 2$</td>
<td>10.2%/4.4%</td>
</tr>
<tr>
<td>2-D speckle $R = 5$</td>
<td>17.1%/4.2%</td>
</tr>
<tr>
<td>2-D speckle $R = 8$</td>
<td>25.6%/6.2%</td>
</tr>
<tr>
<td>3-D speckle $R = 2$</td>
<td>4.9%/4.5%</td>
</tr>
</tbody>
</table>
The acceleration of electrons caused by TPD leads to a characteristic angular distribution

- Normalized angular distribution of hot electrons crossing the right boundary

![Normalized angular distribution](image)
Fast-electron energy distributions have similar temperatures in 3-D and 2-D PIC simulations

- The distributions of fast electrons crossing the right boundary

<table>
<thead>
<tr>
<th></th>
<th>3-D plane wave</th>
<th>3-D speckle $R = 2$</th>
<th>2-D in-plane $R = 2$</th>
<th>2-D in-plane $R = 5$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature***</td>
<td>62 keV</td>
<td>56 keV</td>
<td>62 keV</td>
<td>31 keV</td>
</tr>
</tbody>
</table>

$\eta = 1.9$; $\eta_{av} = 1.3$; ***Fitting between 55 keV and 150 keV
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