Energetic-Electron Generation in Two-Plasmon-Decay Instabilities in Inertial Confinement Fusion

 electron (\(>50\) keV) phase space

\[ t = 9.8 \text{ ps} \]

\[ x (c/\omega_0) \]

\[ P_x (m_e c) \]

Quarter-critical surface

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Summary

Particle-in-cell (PIC) simulations up to 10 ps for OMEGA parameters show saturation of two-plasmon decay (TPD) and hot-electron generation

- In PIC simulations, significant laser absorption and hot-electron generation occur in the nonlinear stage
- Generation of hot electrons is correlated with new TPD modes in the lower-density region during the nonlinear stage
- Hot electrons are accelerated from the low-density region to the high-density region through a staged process
- The simulation with a single narrow beam shows reduction of hot-electron generation
Collaborators

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PIC simulations of 10 ps with *OSIRIS* have been conducted for a range of OMEGA parameters

- Plane wave and Gaussian beams are used
- The simulation box is transversely periodic
- The open boundaries are used for fields and the thermal-reflecting boundaries are used for particles in the longitudinal direction
- Boundary diagnostics record the energy distribution of the particles going out of the thermal-reflecting boundaries

*R. A. Fonseca et al., Lect. Notes Comp. Sci. 2331, 342 (2002).*
The net particle-energy flux reaches a quasi-steady state after \( \sim 5 \) ps

- In the quasi-steady state
  - absorbed laser energy is balanced by the energy flux exiting the box
  - the particle and field energies in the simulation box are essentially constant

\[
I = 6 \times 10^{14} \text{ W/cm}^2 \\
L = 150 \mu\text{m} \\
T_e = 3 \text{ keV}
\]
Most hot electrons are produced in the nonlinear stage.

Electron >50-keV distribution in $P_x$–$P_y$ space

Quasi-steady state
Saturation
Linear

$L = 150 \ \mu m$
$T_e = 3 \ \text{keV}$
$I = 6 \times 10^{14} \ \text{W/cm}^2$
The net energy flux exiting the high-density boundary includes significant contribution from the hot electrons.

Normalized instant net $e^-$ energy flux at $t = 9.9$ ps

- 0 to 5 keV: $-1.5\%$
- 5 to 10 keV: $-0.4\%$
- 10 to 25 keV: $3.1\%$
- 25 to 50 keV: $4.5\%$
- 50 to 100 keV: $5.5\%$
- 100 to 150 keV: $4.3\%$
- 150 to 200 keV: $2.0\%$
- 200 to 250 keV: $0.6\%$
- 250 to 300 keV: $0.2\%$
- 300 to 350 keV: $0.11\%$
- 350 to 400 keV: $0.2\%$
- Over 400 keV: $0.2\%$
The hot electrons are generated through staged acceleration initiated by new TPD modes with low phase velocity in the nonlinear stage.
Important differences exist between the simulations and experiments

- Collision could suppress TPD at the marginal unstable laser intensities
- Speckles
  - in experiments, polarization smoothing changes laser polarization even within a single speckle, which needs 3-D modeling
  - simulation with a narrow beam has shown a reduced hot-electron generation

![Diagram showing E₂ field at t = 7.9 ps](image-url)
Simulation with a narrow beam showed a reduced hot-electron generation.

<table>
<thead>
<tr>
<th>Plane wave</th>
<th>$I_{14max}$</th>
<th>$T$ (keV)/$T_i$ (keV)</th>
<th>$L$</th>
<th>$\eta^*$</th>
<th>Total absorption</th>
<th>Hot (&gt;50-keV) electrons</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>3/1.5</td>
<td>150</td>
<td></td>
<td>0.6</td>
<td>~0</td>
<td>~0</td>
</tr>
<tr>
<td>6</td>
<td>3/1.5</td>
<td>150</td>
<td></td>
<td>1.2</td>
<td>42%</td>
<td>17%</td>
</tr>
<tr>
<td>8</td>
<td>3/1.5</td>
<td>150</td>
<td></td>
<td>1.4</td>
<td>39%</td>
<td>15%</td>
</tr>
<tr>
<td>8 (d = 4 μm)</td>
<td>3/1.5</td>
<td>150</td>
<td></td>
<td>1.4</td>
<td>22%</td>
<td>5%</td>
</tr>
</tbody>
</table>

TPD threshold

$$\eta = \frac{(I_{14} \lambda_{\mu m} L_{\mu m} / T_{\text{keV}})}{82}$$

*A. Simon et al., Phys. Fluids 26, 3107 (1983).*
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Ion-density fluctuations are driven by plasma waves propagating to lower-density regions.

- The region of ion-density fluctuations is spreading at the group velocity of plasma waves with the largest $k$.
- Ion fluctuations at the low-density region can induce new TPD modes locally.