Target heating in the relativistic transparency regime

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Motivation

Experimental Aims

• Ion acceleration from thin foils
• Explore intersection between relativistic transparency and opaque acceleration mechanisms
• Use optical diagnostics to understand the plasma dynamics

Simulation Aims

• Confirm experimental conclusions
• Track electron heating as a function of density
Experimental Set-Up

- Energy: ~6J on Target
- Pulse Length: 45fs
- Intensity: $3 \times 10^{20}$ Wcm$^{-2}$
- $a_0$: 13

- Amorphous Carbon Targets
- Target thickness range: 2 - 100nm
- Contrast of $10^{14}$
Experimental Results: Transmission Screen

Linear Polarisation

Circular Polarisation

Blank Shot 2nm 5nm 10nm 15nm 25nm 50nm 100nm
Experimental Results: Transmission Screen

- Pinhole effect occurs
- Targets $\leq 15\text{nm}$ go transparent
- Radiation emitted from the rear surface
- Targets $\geq 25\text{nm}$ remain overdense
Experimental Results: Transmitted Energy

- Up to 50% transmission for ≤ 15 nm - direct laser light

- Percent level transmission for ≥25nm - secondary emitted radiation
Simulation Parameters

- EPOCH 2D3V code developed by Warwick
- Completed target thickness scan 2nm-100nm
- Linear and Circular polarisation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulation Resolution</td>
<td>0.6 nm</td>
</tr>
<tr>
<td>Box size ($\hat{x}, \hat{y}$)</td>
<td>3 $\mu$m x 10 $\mu$m</td>
</tr>
<tr>
<td>Peak $a_0$</td>
<td>17</td>
</tr>
<tr>
<td>Initial electron density ($n_e/n_{crit}$)</td>
<td>685</td>
</tr>
<tr>
<td>Time of peak intensity</td>
<td>44 fs</td>
</tr>
</tbody>
</table>
Electron Density

Linear Polarisation:

- **5nm**: density drops from $685n_{\text{crit}}$ to $\sim20n_{\text{crit}}$ by 27fs, underdense by 32fs
- **10nm**: density drops from $685n_{\text{crit}}$ to $\sim8n_{\text{crit}}$ by 51fs
- **50nm**: remains overdense and accelerates electron bunches of density $\sim1n_{\text{crit}}$, density drops to $\sim30n_{\text{crit}}$ at 96fs
Electron Density

5nm

Circular Polarisation:

- 5nm: at 27fs the density remains at $120n_{\text{crit}}$ compared to $\sim 10n_{\text{crit}}$ for linear polarisation. Underdense by 51fs.

- 10nm: by 51fs the front surface has moved 500nm so target no longer normal to incident radiation.

- 50nm: remains overdense. Critical surface has moved by 300nm at 96fs.
Electron Density

- Average electron density in focal spot
- ——— Linear Polarisation
- - - - Circular Polarisation
- 2 - 10nm go transparent
- Targets $\geq$ 25nm remain overdense
Transmitted Electric Field

- Sampled laser electric field at rear of simulation box
- See step-like delay in transparency until 15nm
- Oscillating electric field also for thicker targets
Transmitted Electric Field

- Sampled laser electric field at rear of simulation box
- See step-like delay in transparency until 15nm
- Oscillating electric field also for thicker targets
- Coherent transition radiation
Electron Spectrum

- Electron energies on laser axis
- Sudden increase in hot electrons in the forward direction
- At late times electrons transfer energy to ions or leave the box
Electron Spectrum

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Electron Spectrum

- Maximum electron energies seen for the 10nm target irradiated by a linearly polarised pulse
- Circular polarisation has lower electron temperatures (∼75% of linear)
- Symmetric distribution for targets ≥ 25nm

- **Is this an indication of transparency?**
Electron Spectrum

- Maximum electron energies seen for the 10nm target irradiated by a linearly polarised pulse

- Circular polarisation has lower electron temperatures (\(\sim 75\%\) of linear)

- Symmetric distribution for targets \(\geq 25\)nm

- **Is this an indication of transparency?** Yes
Electron Temperature

- Fit an exponential to the electron spectrum
- Peak temperature reached for 10nm target with linear polarisation
- Approximately same temperature plasma for thinner targets and linear/circular polarisation
- Similar heating rates of almost all linear polarised pulses
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Electron Temperature

- Fit an exponential to the electron spectrum
- Peak temperature reached for 10nm target with linear polarisation
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- Similar heating rates of almost all linear polarised pulses
Strong target heating causes targets < 25nm to go transparent

Electron bunches of density $\sim 1n_{\text{crit}}$ accelerated off 50nm target

Temporal delay in transparency by $\sim 15$fs per thickness increment

Electron temperatures up to 1.7MeV measured in simulations

Big difference in plasma temperatures for different polarisations - up to 50% for $\geq 15$nm targets
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