Fast-Electron Generation with Multi-kJ Pulses on OMEGA EP

\[ E_L = 1 \text{ J}, \quad \tau_L = 1 \text{ ps} \]

\[ \eta_{L\rightarrow e} = \sim 20\% \]

Increasing energy density

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Fusion Science Center for Extreme States of Matter and Fast-Ignition Physics and Laboratory for Laser Energetics

51st Annual Meeting of the American Physical Society
Division of Plasma Physics
Atlanta, GA
2–6 November 2009
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\[ 10 \text{ J} \leq E_L \leq 2100 \text{ J}, \tau_L = 10^{-12} \text{ ps} \]

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OMEGA EP experiments show fast-electron coupling independent of laser energy and pulse duration

- High-energy-conversion efficiency into fast electrons is critical for various HEDP applications, e.g., dense-matter probing and fast ignition
- K-photon-emission suppression measurements within copper foil targets indicate $\eta_{L\rightarrow e} \approx 20\%$ over a wide range of target volumes
- Time-resolved x-ray emission measurements suggest energy coupling occurs over the whole duration of the incident drive
Collaborators


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Fast-electron recirculation in mass-limited targets allows access to high-energy-density phenomena

- Refluxing is caused by Debye-sheath field effects\(^1,2\)
- Majority of fast electrons are stopped in the target
- Provides a simple geometry for testing laser-coupling, electron-generation, and target-heating models\(^3,4\)

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Target bulk-heating affects $L \rightarrow K$ and $M \rightarrow K$ electron transitions*

- Inelastic electron–electron collisions heat the target
- Collisional ionization with thermal background plasma occurs
- $T_e > 100$ eV causes significant M-shell depletion
- Target heating is inferred from $K_\beta/K_\alpha$

$K_\alpha$ ($\gtrsim 8.05$ keV)  
$K_\beta$ ($\gtrsim 8.91$ keV)

Copper energy levels

OMEGA EP experiments were performed with up to 2.1-kJ, 10- to 12-ps laser pulses

- Laser intensities $I \sim 5 \times 10^{18} \text{ W/cm}^2$
- Copper foil targets
- Target volumes: $500 \times 500 \times 50 \mu\text{m}^3$ to $75 \times 75 \times 5 \mu\text{m}^3$
The effect of bulk-target heating on the K-shell-emission spectrum is observed with OMEGA EP.

Cu target: 500 × 500 × 20 μm³
Laser: 950 J, 10 ps

Cu target: 75 × 75 × 5 μm³
Laser: 1042 J, 10 ps
Electron-energy coupling efficiency is independent of laser energy and pulse duration*

- $\eta_{L\rightarrow e}$ inferred from K-photon suppression measurements represents a minimum electron-energy conversion efficiency
- Energy-conversion efficiency offset due to high-energy proton acceleration is assumed to be small
- $\eta_{L\rightarrow p} \sim 1\%$ with 1-kJ, 10-ps pulses**

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$E_L = 1 \text{ J}, \tau_L = 1 \text{ ps}$
$10 \text{ J} \leq E_L \leq 2100 \text{ J}, \tau_L = 10\sim12 \text{ ps}$

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**Private communication with L. Gao.
Time-resolved x-ray emission measurements suggest energy coupling occurs over the whole duration of the incident drive.

- Streak camera is sensitive to bremsstrahlung, inner-shell radiation, and thermal ionic-line emission.
- OMEGA EP: $E_L = 974 \text{ J}, \tau_L = 11 \text{ ps}$
  $100 \times 100 \times 10^{-\mu \text{m}^3} \text{ Cu}$

X-ray emission rise time correlates to the laser-pulse duration.
Summary/Conclusions

OMEGA EP experiments show fast-electron coupling independent of laser energy and pulse duration

• High-energy-conversion efficiency into fast electrons is critical for various HEDP applications, e.g., dense-matter probing and fast ignition

• K-photon-emission suppression measurements within copper foil targets indicate $\eta_{L \rightarrow e} \approx 20\%$ over a wide range of target volumes

• Time-resolved x-ray emission measurements suggest energy coupling occurs over the whole duration of the incident drive
1-D LILAC calculations confirm target decompression is minimal over a 10-ps drive time

- **500 × 500 × 20-μm³ Cu target**
- **200 J of electron energy with \( T_h = 1 \) MeV**
- **10-ps energy-deposition phase (FWHM)**

**Thermal decompression dominates.**
1-D *LILAC* calculations confirm target decompression is minimal over a 10-ps drive time.

- $100 \times 100 \times 10^{-3} \text{ Cu target}$
- 200 J of electron energy with $T_h = 1 \text{ MeV}$
- 10-ps energy-deposition phase (FWHM)

Radiation cooling quenches the HED state in mass-limited targets prior to decompression.