Fast-Electron Energy Deposition
In Solid-Density Plasmas

High-Speed X-Ray Streak Camera Data

Signal (arbitrary units)

Time (ps)

Bulk $T_e > 200$ eV
18 ps

5-J, 1-ps; $10^{19}$ W/cm$^2$
Copper-foil targets

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Summary

Two intense x-ray flashes are resolved from isochorically heated foils in the high-energy-density limit.

- The first x-ray flash is caused by fast-electron-induced bremsstrahlung and K-photon emission.
- Thermal radiation from the rapidly heated target bulk causes the second x-ray flash.
- The lag time between the two x-ray flashes is sensitive to the fast-electron temperature.

Dual x-ray flashes provide a stringent test for energy-coupling models.
Collaborators


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Fast-electron refluxing in small-mass targets allows access to high-energy-density phenomena

- Refluxing is caused by Debye-sheath field effects\textsuperscript{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\textsuperscript{3,4}

$E \approx 10^{12} \text{ V/m}$

20 to 500 $\mu$m

\begin{itemize}
  \item $10^{19}$ W/cm$^2$
  \item 2 to 20 $\mu$m
\end{itemize}

\textsuperscript{1}S. P. Hatchett \textit{et al.}, Phys. Plasmas 7, 2076 (2000).
The LLE ultrafast x-ray streak camera time-resolves the x-ray emission

MTW Laser: 5 J, 1 ps; $10^{19}$ W/cm$^2$

- Streak camera specifications:
  - 10 lp/mm spatial resolution
  - 2-ps temporal resolution
  - KBr photocathode
  - filtered sensitivity $> 1$ keV

HOPG spectrometer

Single-hit spectrometer

500 x 500 x 20 $\mu$m$^3$

100 x 100 x 2 $\mu$m$^3$

Time

Single flash

50 ps

Double flash
A “double-flash” of radiation >1 keV is observed as the target volume is reduced.

- Bremsstrahlung and K-photon emission dominate in the cold limit.
- As target volume reduces, the plasma energy density increases.
The fast-electron lifetime is governed by collisions with thermal electrons and adiabatic ion-front expansion.

- 1-D energy relaxation model*
  - electron-electron collisions
  - adiabatic expansion cooling
- Initially cold, 20-μm-thick copper foil
- Fast-electron-energy loss causes heating to tens of electron volts

High bulk-electron temperatures in small mass targets are confirmed by K-photon spectroscopy

- Inelastic electron-electron collisions heat the target
- Collisional ionization with the thermal background occurs
- L- and M-shell depletion at high bulk-electron temperatures causes spectral line shifts* and $K_B/K_\alpha$ suppression**

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Two x-ray flashes are resolved from targets that are heated to the highest bulk-electron temperatures

- The first x-ray flash is induced by fast electrons losing energy in initially cold target material.
- The second x-ray flash is a finite-time isochoric heating effect not observable in the cold material limit.
- Thermal emission $> 1$ keV is consistent with the inferred bulk-electron temperatures.

Summary/Conclusions

Two intense x-ray flashes are resolved from isochorically heated foils in the high-energy-density limit

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