High-Resolving-Power, Streaked X-Ray Spectroscopy on the OMEGA EP Laser System

Laser: 50 J, 0.7 ps  
Target: 500 × 500 × 20 μm Cu

Laser: 905 J, 10 ps  
Target: 250 × 250 × 10 μm Cu

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A platform (HiRes) has been developed on OMEGA EP to study changes in the electronic structure of metals heated to extreme conditions

- Experiments with Cu foils were performed with up to kJ-class, 10-ps laser pulses
- High-resolution Kα emission spectra, which are sensitive to ionization state, show clearly visible, time-dependent changes in energy and shape over the heating phase
- Initial $LSP^1/PrismSPECT^2$ simulations overestimate the heating rate; a more-complete physics model$^3$ that includes additional energy sinks is in development
- Absolute calibration to test the predicted Kα-emission rates is the next step

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Summary

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Motivation

Ultrafast heating at high density produces matter in extreme thermodynamic conditions

- The possible extremes in temperature enable novel material and radiative properties experiments\(^1,2\)
  - e.g., mean opacity of solar interior matter\(^3\)
- New diagnostic techniques are sought for testing
  - temperature-equilibration dynamics\(^1\)
  - plasma-dependent atomic processes\(^4\)
  - plasma opacity\(^5\)
  - equation-of-state models\(^6\)

These studies require dense, high-temperature plasmas that are well characterized.

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\(^3\) J. E. Bailey et al., Nature 517, 56 (2015).
X-Ray Spectroscopy

High-resolution x-ray fluorescence spectroscopy is sensitive to time-dependent changes in ionization state

With increasing ionization, the Kα_{1,2} lines increase their energy.²–⁶

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An energy-coupling and collisional-radiative model provides insight into the $K\alpha$ parameter dependence on heating

- **LSP**\(^1\) calculates
  - energy-transport physics
  - electromagnetic-field generation
  - target heating
- **LSP** is post-processed based on tabulated *PrismSPECT*\(^2\) calculations using
  - the local density and temperature at the time of emission
  - line-of-sight and high-$T_e$ opacity effects

To measure these rapidly evolving radiation signatures, high spectral-temporal resolution is required.

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\(^2\)Prism Computational Sciences Inc., Madison, WI 53711.
A high-resolving-power x-ray spectrometer (HiRes) has been developed to measure ultrafast radiation signatures from hot dense matter.

The HiRes System operates on high-power shots, with $E/\Delta E > 2000$ and 2-ps temporal resolution.
Experimental Results

Time-integrated and time-resolved measurements show clear changes in the Kα emission spectrum with increasing target energy density.

Laser: 50 J, 0.7 ps  
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FWHM: full width at half maximum
Model Comparison

Initial analysis with LSP/PrismSPECT overestimates the temperature and ionization state inside the heated region of the target.

Data interpretation implies accurate modeling\(^1,2\) of
- the hot-electron source and heating
- spatial and temporal nonuniformities
- hydrodynamic evolution of the target
- the radiative properties of the heated sample

A more-detailed physics model is in development
- preplasma formation
- laser coupling
- target normal sheath acceleration
- hydrodynamic evolution

\(^1\) V. Dervieux et al., High Energy Density Phys. 16, 12 (2015).
Summary/Conclusions

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- Experiments with Cu foils were performed with up to kJ-class, 10-ps laser pulses
- High-resolution Kα emission spectra, which are sensitive to ionization state, show clearly visible, time-dependent changes in energy and shape over the heating phase
- Initial LSP\(^1\)/PrismSPECT\(^2\) simulations overestimate the heating rate; a more-complete physics model\(^3\) that includes additional energy sinks is in development
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A model\textsuperscript{1} combining 3-D HYDRA and 2-D LSP shows good agreement with K$\alpha$ flash-time measurements.

The HYDRA/LSP model includes:
- preplasma formation
- intense laser–plasma coupling
- hot-electron transport
- target normal sheath acceleration
- hydrodynamic evolution

Absolute calibration is the next step.