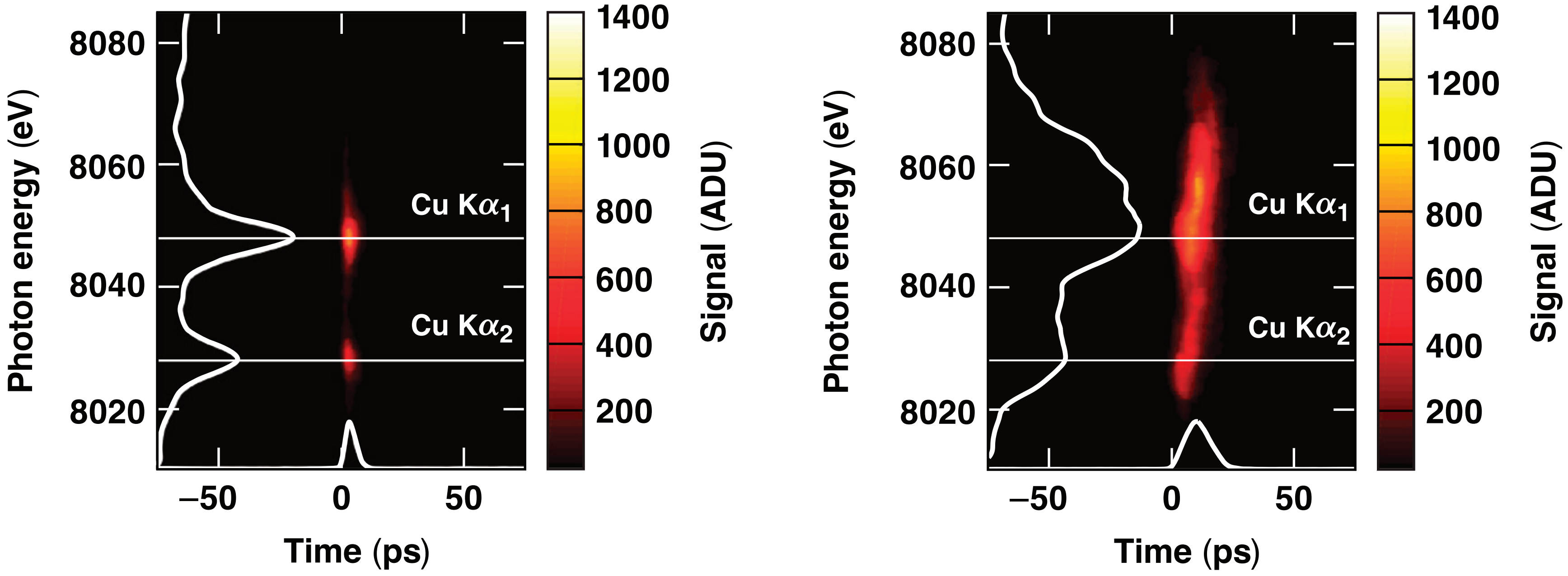
High-Resolving-Power, Streaked X-Ray Spectroscopy on the OMEGA EP Laser System



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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Summary

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

1 D. R. Welch *et al.*, Phys. Plasmas 13, 063105 (2006).
2 Prism Computational Sciences Inc., Madison, WI 53711.
3 M. Schollmeier *et al.*, Phys. Plasmas 22, 043116 (2015).

Collaborators

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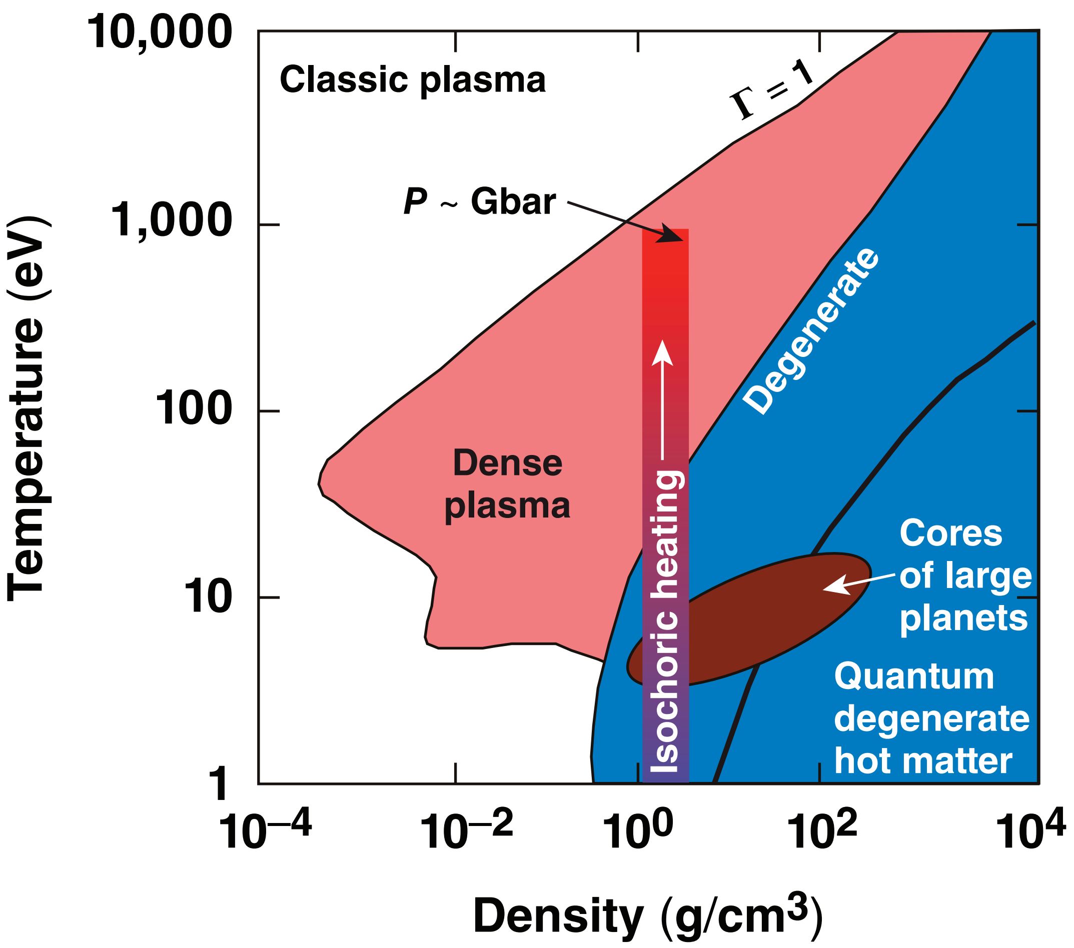
Motivation

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.



1 A Report on the SAUUL Workshop, Washington, DC (17–19 June 2002).
2 K. Nazir *et al*., Appl. Phys. Lett. 69, 3686 (1996).
3 J. E. Bailey *et al*., Nature 517, 56 (2015).
4 D. J. Hoarty *et al*., Phys. Rev. Lett. 110, 265003 (2013).
5 R. A. London and J. I. Castor, High Energy Density Phys. 9, 725 (2013).
6 M. E. Foord, D. B. Reisman, and P. T. Springer, Rev. Sci. Instrum. 75, 2586 (2004).

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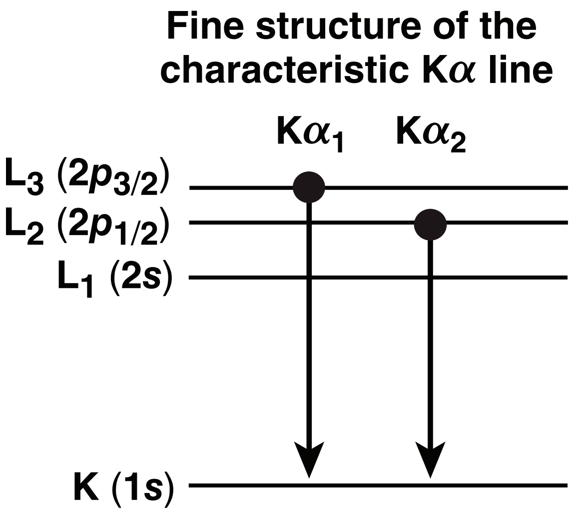
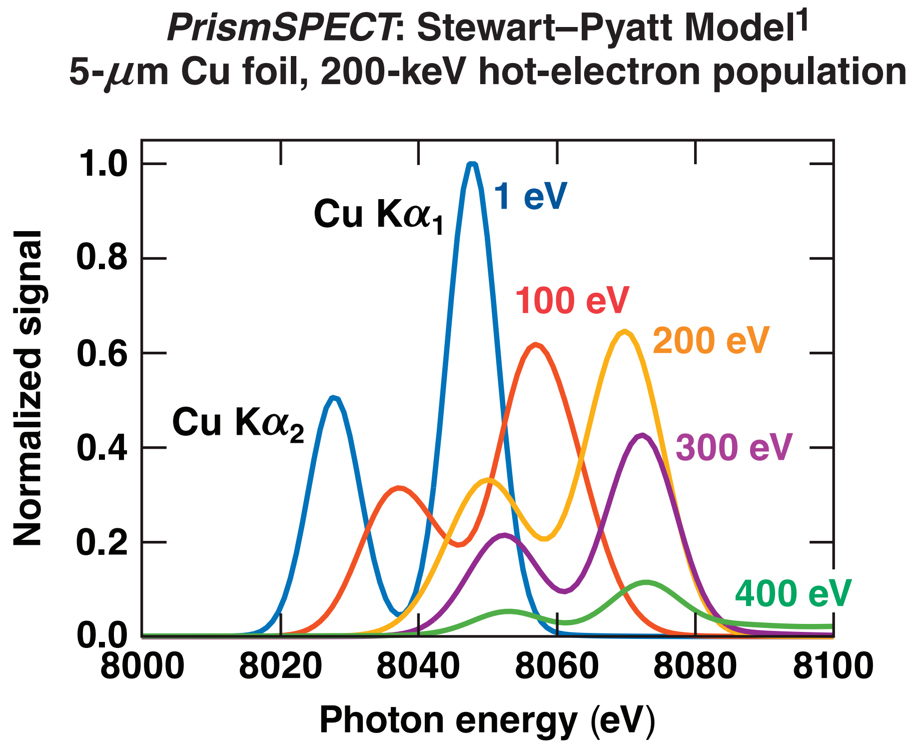
High-resolution x-ray fluorescence spectroscopy is sensitive to time-dependent changes in ionization state





With increasing ionization, the $K\alpha_{1,2}$ lines increase their energy.[2–6]

[1] J. C. Stewart and K. D. Pyatt, Jr., Astrophys. J. 144, 1203 (1966).
[2] K. Słabkowska *et al.*, High Energy Density Phys. 15, 8 (2015).
[3] K. Słabkowska *et al.*, High Energy Density Phys. 14, 30 (2015).
[4] G. Gregori *et al.*, Contrib. Plasma Physics 45, 284 (2005).
[5] P. M. Nilson *et al.*, Phys. Plasmas 18, 042702 (2011).
[6] J. F. Seely *et al.*, High Energy Density Phys. 9, 354 (2013).

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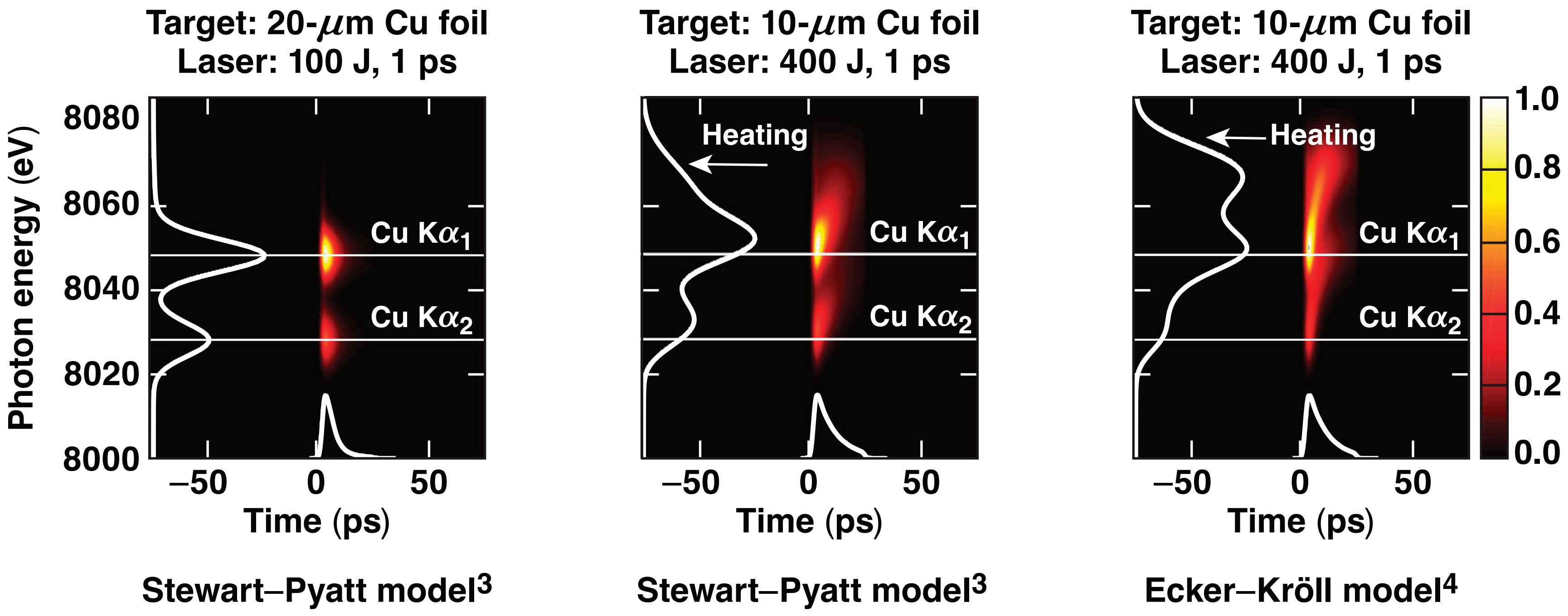
Integrated Model

An energy-coupling and collisional-radiative model provides insight into the Kα 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

Cu foil: $E/\Delta E$ = 1000, 2-ps temporal resolution



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

[1] D. R. Welch *et al.*, Phys. Plasmas 13, 063105 (2006).
[2] Prism Computational Sciences Inc., Madison, WI 53711.
[3] J. C. Stewart and K. D. Pyatt, Jr., Astrophys. J. 144, 1203 (1966).
[4] G. Ecker and W. Kröll, Phys. Fluids 6, 62 (1963).

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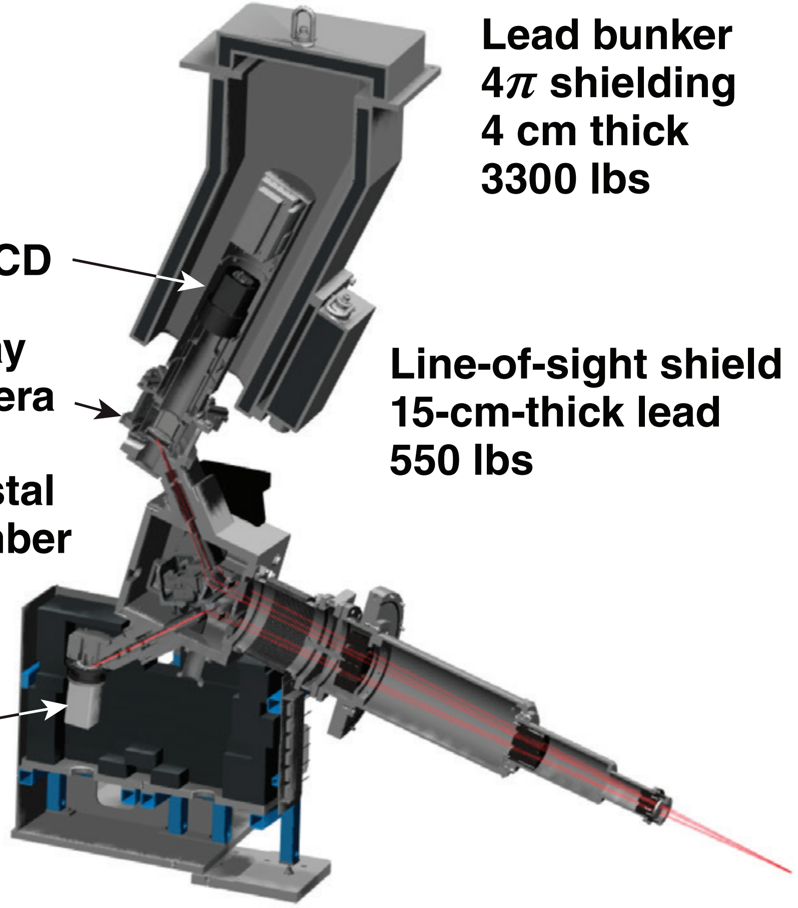
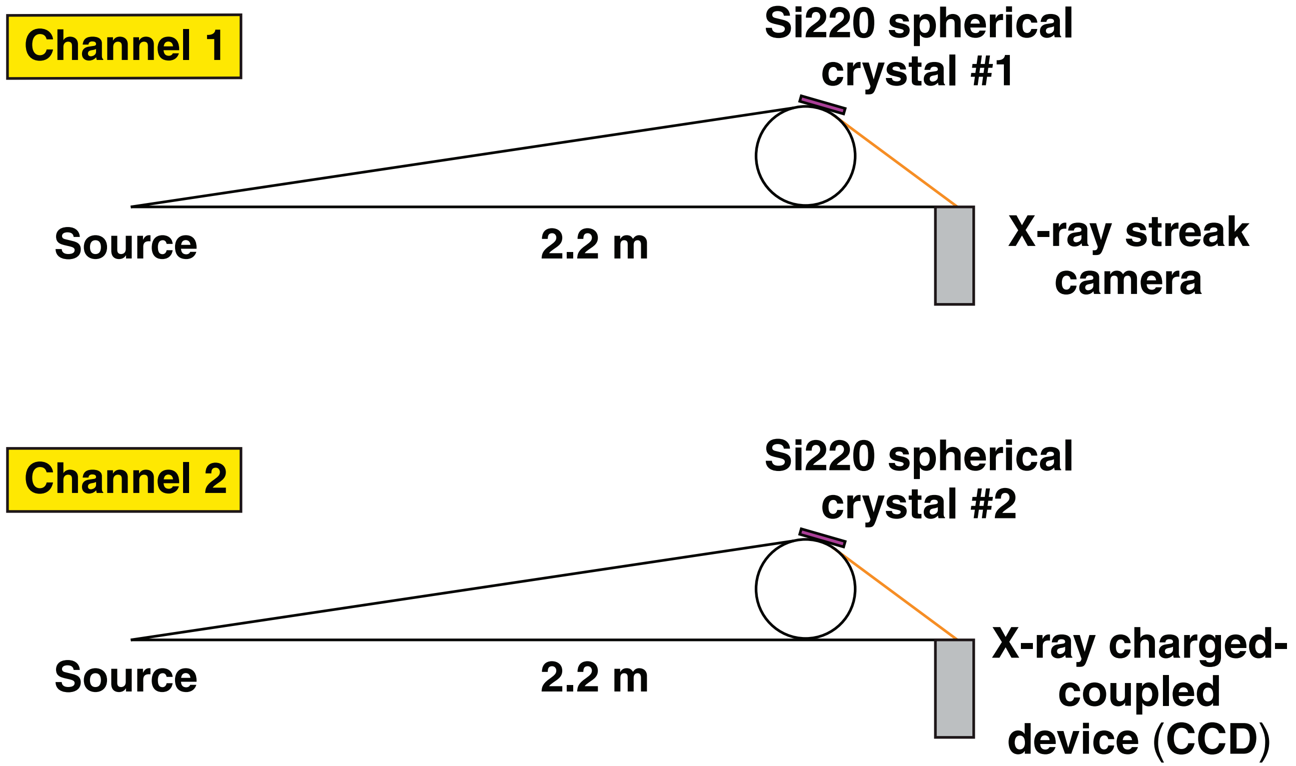
A high-resolving-power x-ray spectrometer (HiRes) has been developed to measure ultrafast radiation signatures from hot dense matter





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

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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
Target: 500 × 500 × 20 μm Cu

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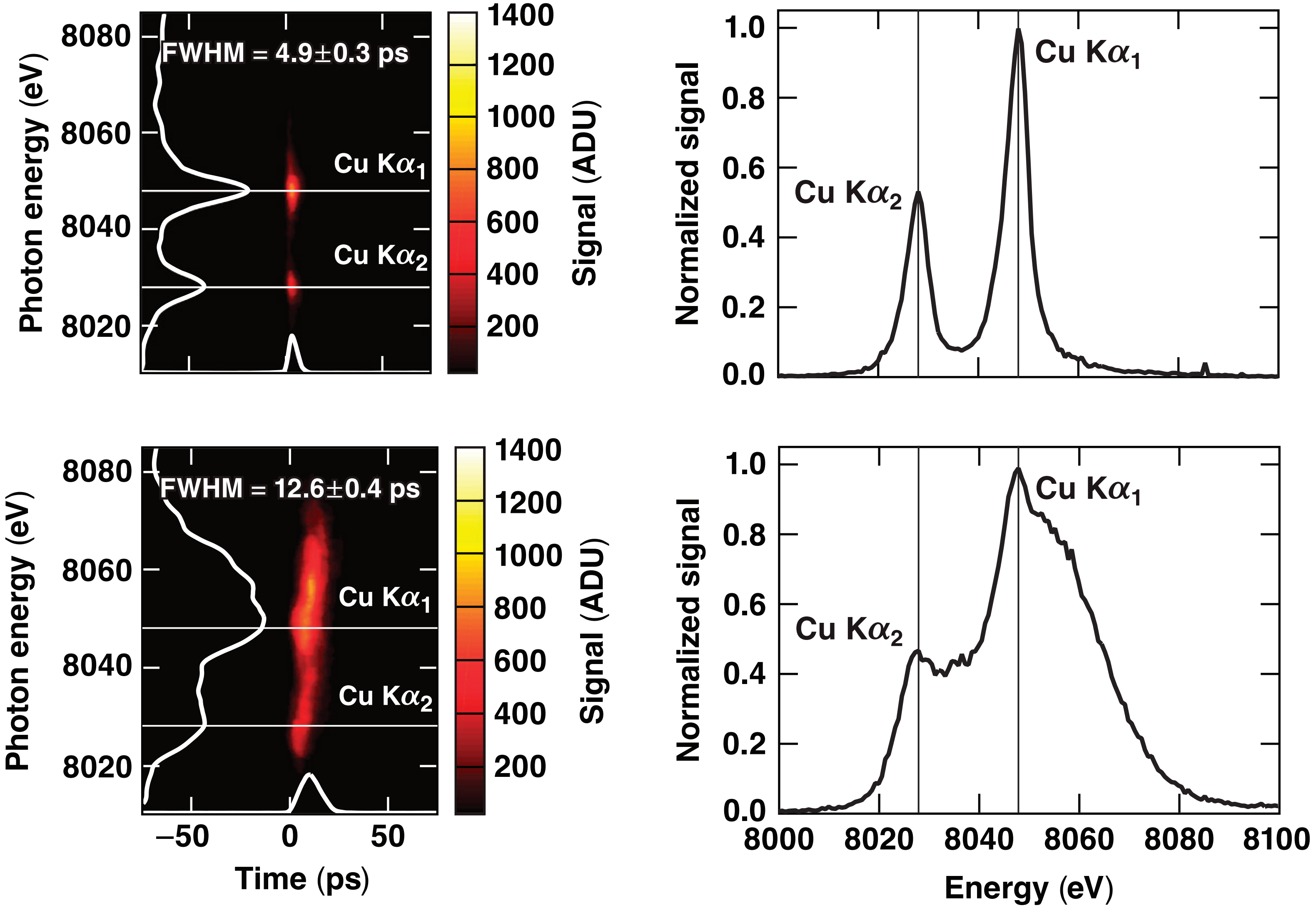

*FWHM: full width at half maximum

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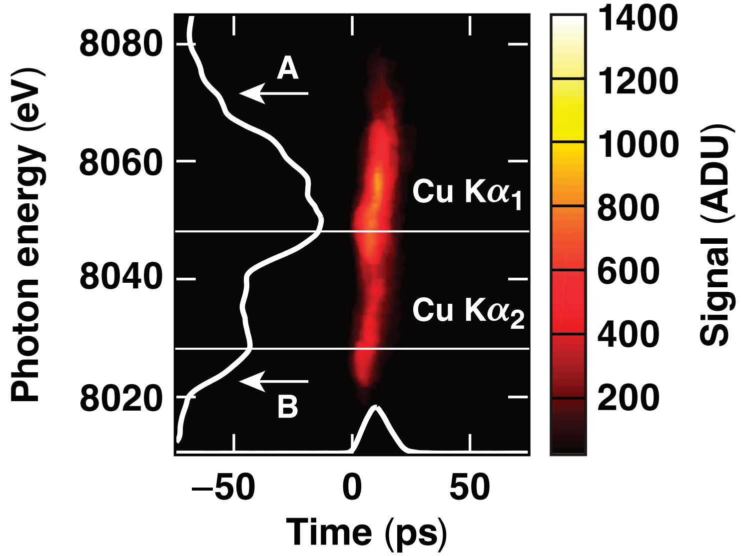
Initial analysis with LSP/*PrismSPECT* overestimates the temperature and ionization state inside the heated region of the target



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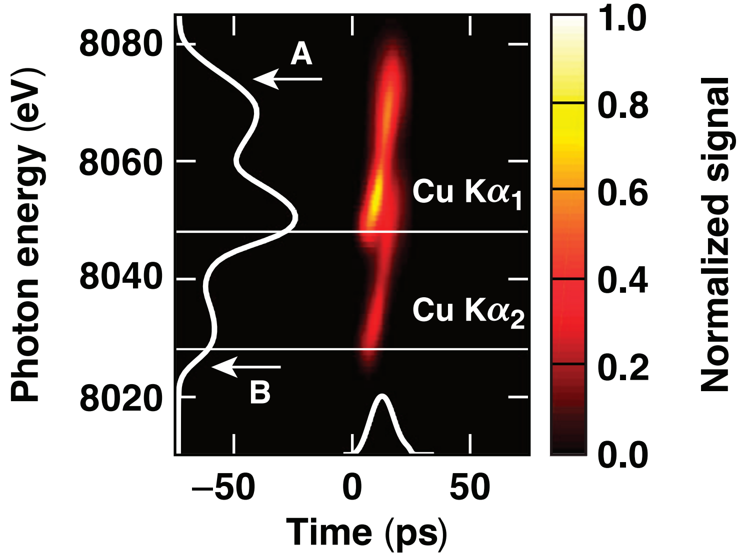
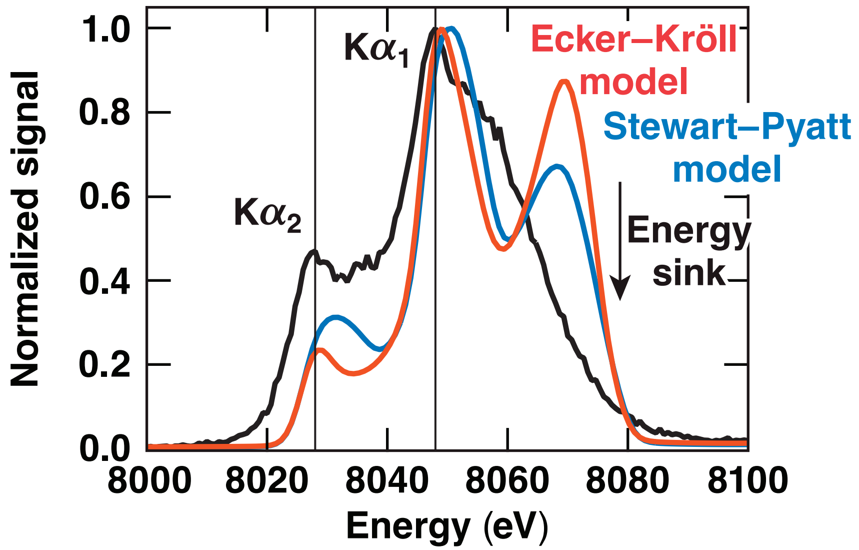


***LSP/PrismSPECT* Stewart–Pyatt Model**



Time-integrated data

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).
[2] S. B. Hansen *et al.*, High Energy Density Phys. 24, 39 (2017).

Summary/Conclusions

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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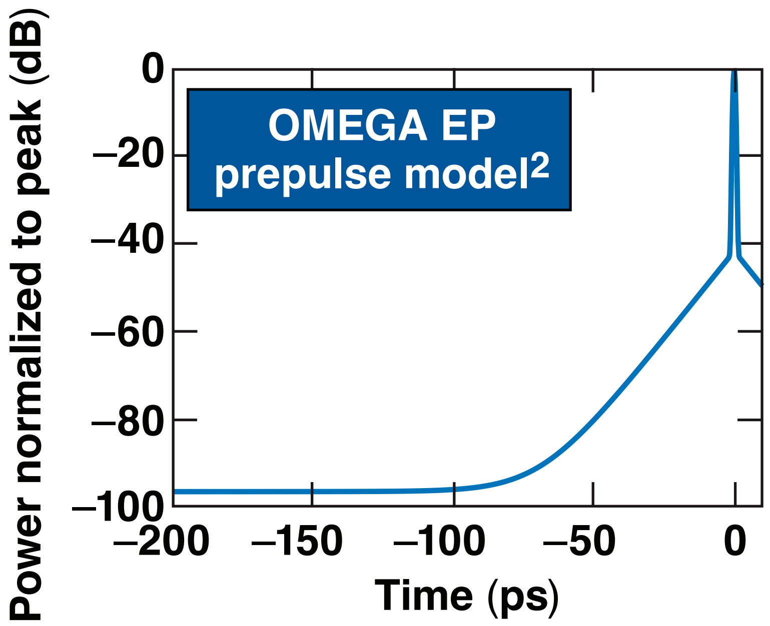
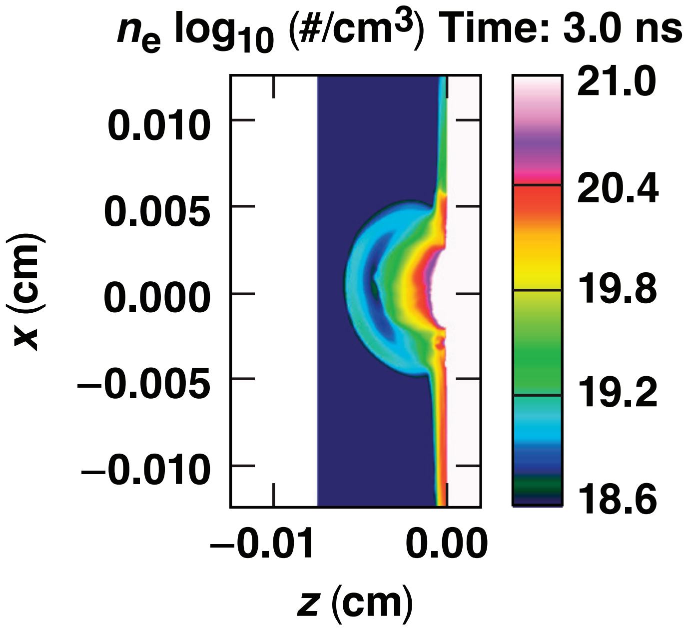
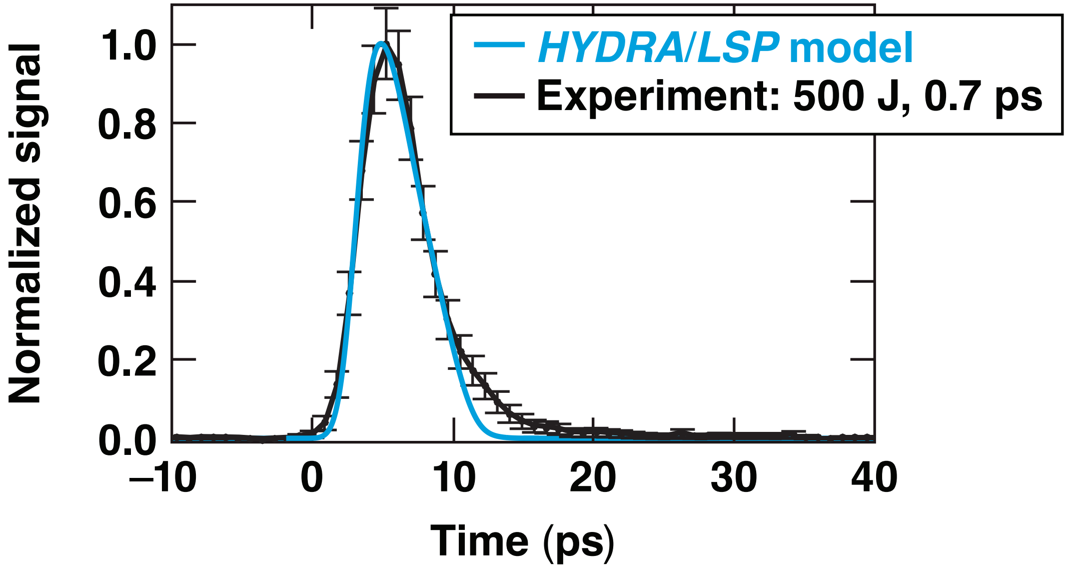
A model[1] combining 3-D *HYDRA* and 2-D *LSP* shows good agreement with $K\alpha$ flash-time measurements







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.

[1] M. Schollmeier *et al.*, Phys. Plasma 22, 043116 (2015).
[2] C. Dorrer, A. Consentino, and D. Irwin, Appl. Phys. B 122, 156 (2016).

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