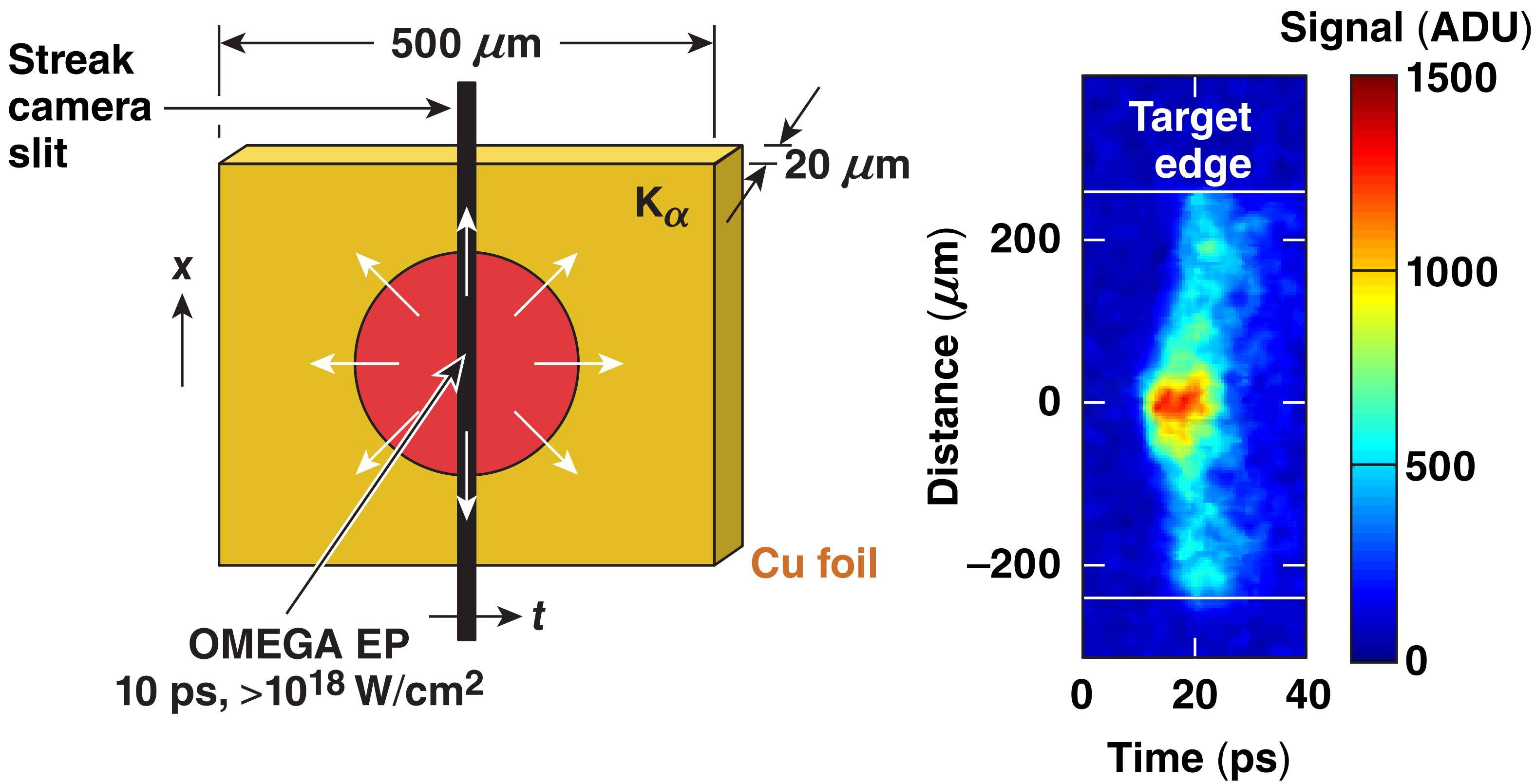
Streaked X-Ray Imaging of Ultrafast Ionization Waves Inside a Metal



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Summary

Hot-electron–driven ionization waves were observed inside a high-intensity laser-irradiated metal target

- A new, monochromatic, streaked x-ray crystal imager has been developed for the OMEGA EP laser to study collisional ionization wave dynamics
- Spatial, spectral, and temporal resolution are obtained by coupling a spherically bent crystal imager with a 2-ps-resolution x-ray streak camera
- The flow of hot-electron–induced K_{α} emission has been tracked through a metal target

Ionization-wave speed: (0.11±0.02)c

Collaborators

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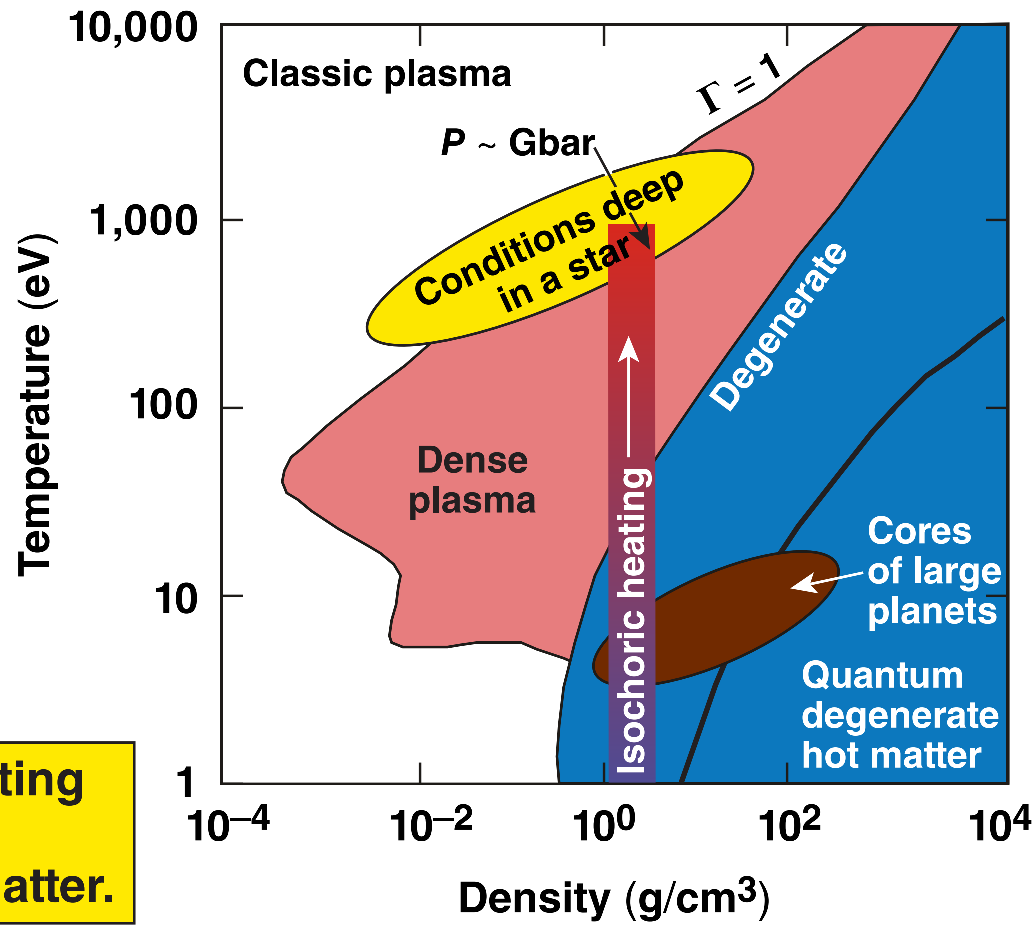
Isochoric heating provides a unique route to warm dense matter (WDM) and HED plasma conditions

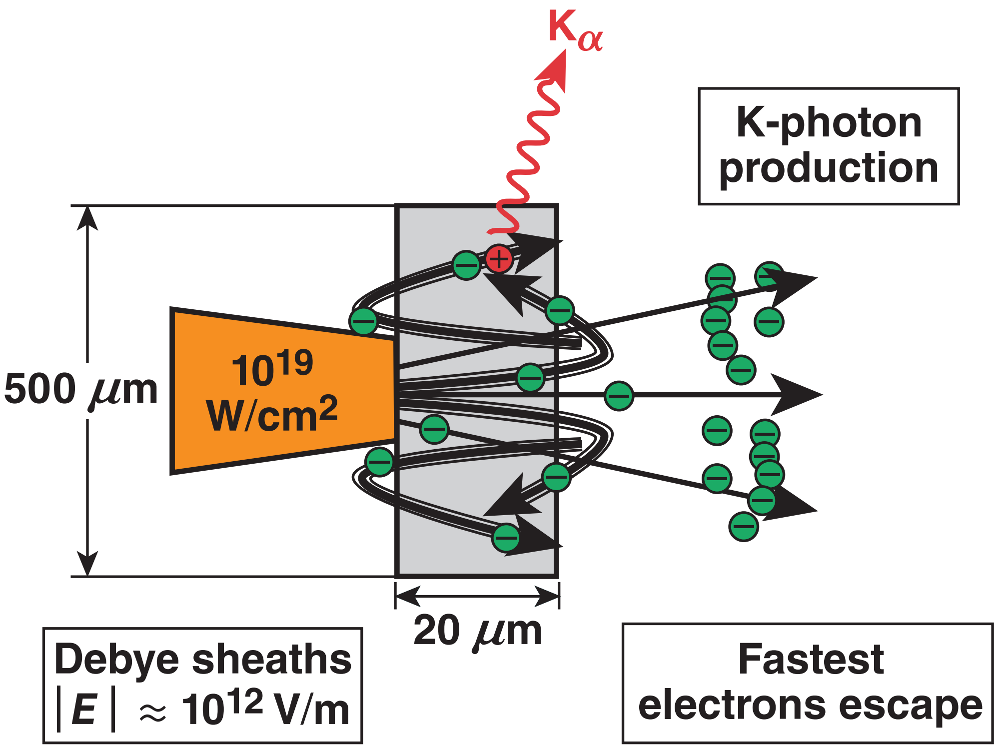
- WDM systems start as a solid and end as plasma
- Found in stellar interiors, cores of large planets, and ICF implosions
- Significant uncertainties exist in WDM equation of state
- Measurements are required for model development

WDM creation relies on generating intense flows of energy inside solid- and laser-compressed matter.



Report of the SAUUL Workshop, Washington, DC (17–19 June 2002).
R. W. Lee *et al*., Lawrence Livermore National Laboratory, Livermore, CA, Report UCRL-TR-203844 (2004).

Hot-electron refluxing in mass-limited targets accesses high-temperature matter at solid density



- Refluxing is caused by Debye-sheath field effects*
- Majority of hot electrons are stopped in the target
- Efficient K_α radiators

*S. P. Hatchett *et al.*, Phys. Plasmas 7, 2076 (2000);
R. A. Snavely *et al.*, Phys. Rev. Lett. 85, 2945 (2000);
W. Theobald *et al.*, Phys. Plasmas 13, 043102 (2006);
J. Myatt *et al.*, Phys. Plasmas 14, 055301 (2007);
P. M. Nilson *et al.*, Phys. Rev, E 79, 016406 (2009).

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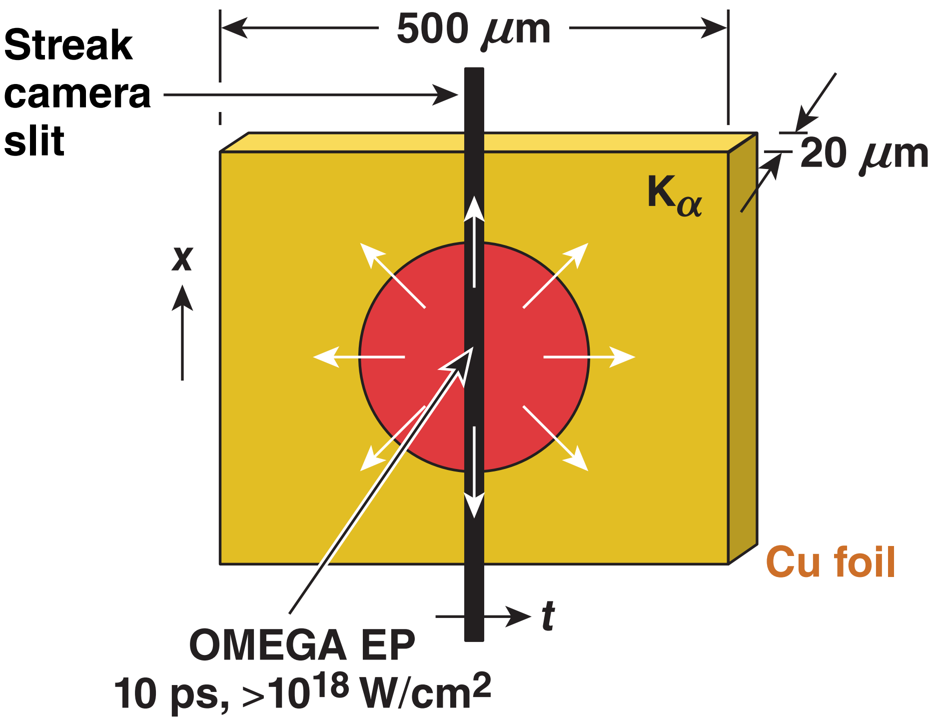
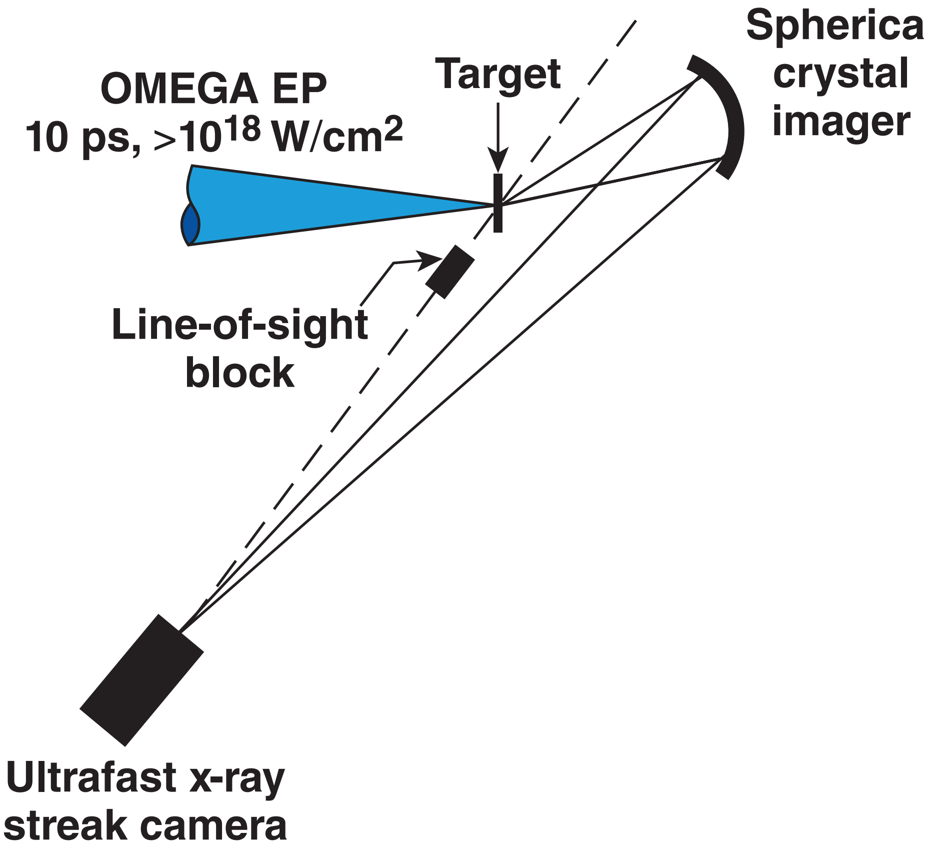
Spatial, spectral, and temporal resolution are obtained by coupling a spherical crystal imager with an ultrafast x-ray streak camera

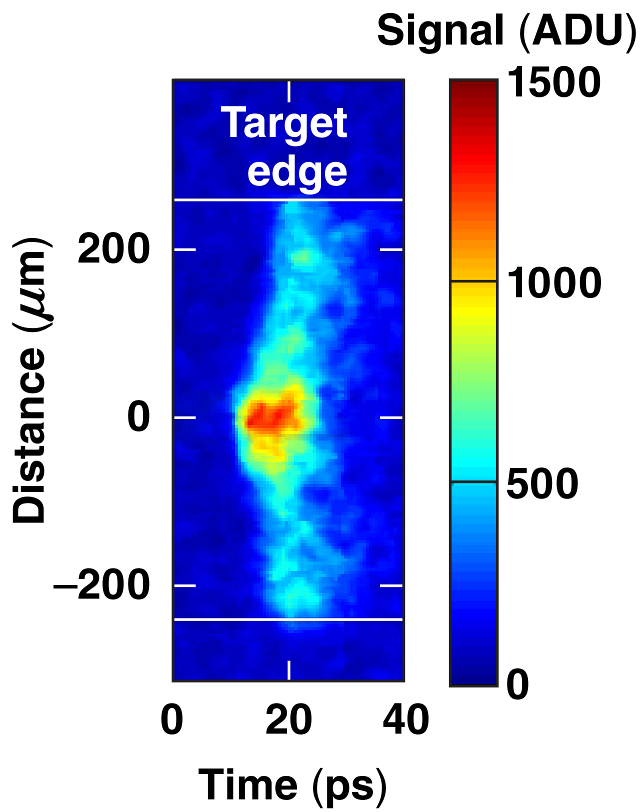


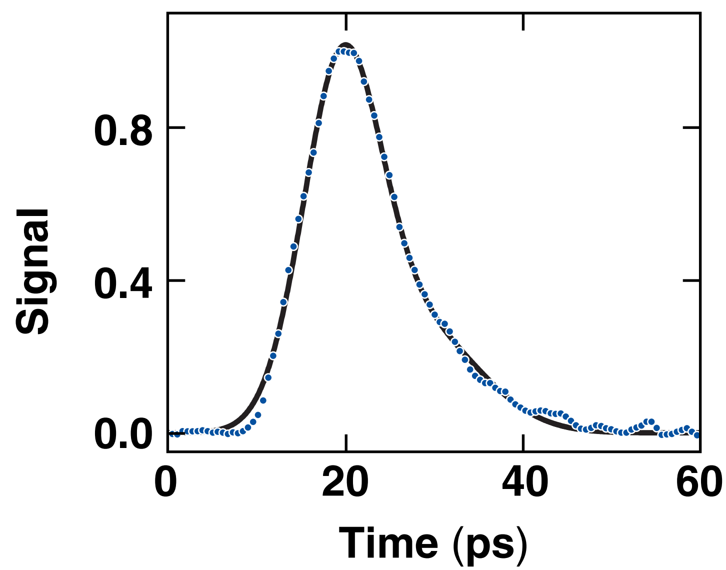


S. A. Pikuz *et al*., Rev. Sci. Instrum. 68, 740 (1997).
J. A. Koch *et al*., Rev. Sci. Instrum. 74, 2130 (2003).
Y. Aglitskiy *et al*., Phys. Rev. Lett. 87, 265001 (2001).
R. B. Stephens *et al*., Phys. Rev. E 69, 066414 (2004).

Streaked K_α imaging shows a collisional ionization wave and ultrafast energy transport into the target

Laser: 250 J, 10 ps
Target: 500 × 500 × 20-μm^3 Cu

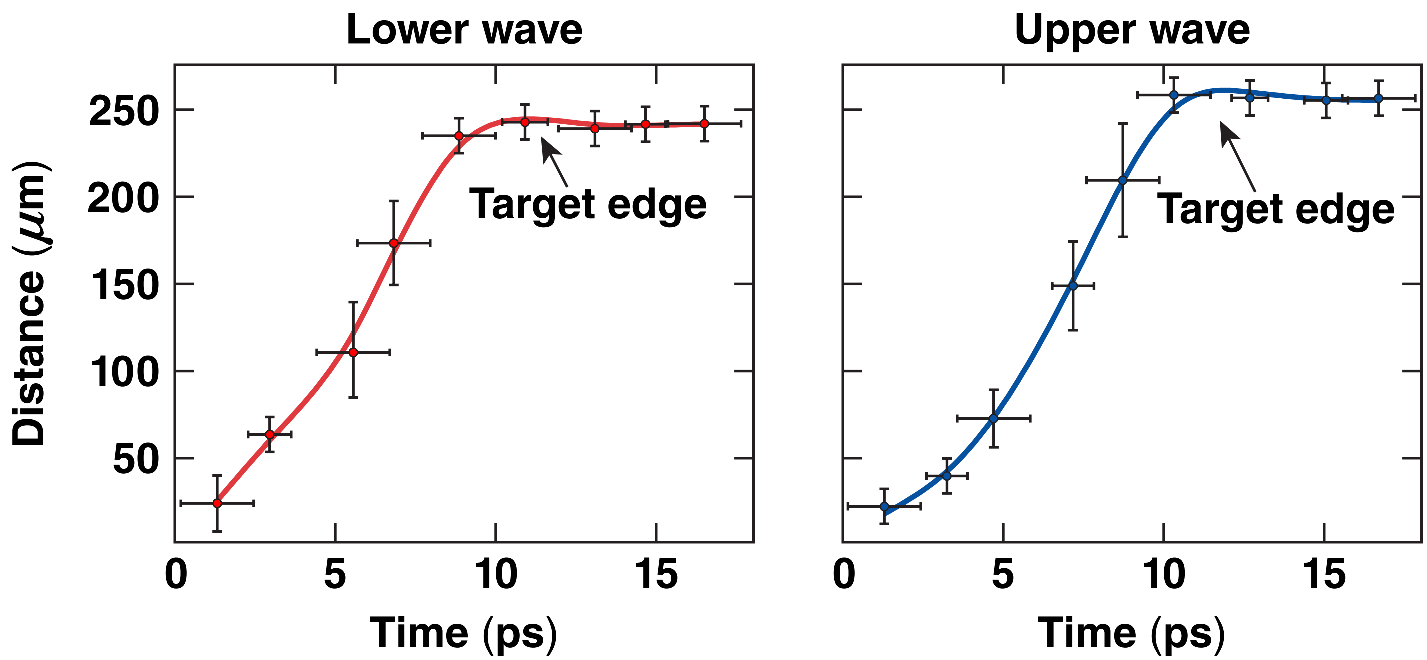




- The FWHM of the impulse-response function is subtracted from the streak-camera trace in quadrature

K_α flash time (FWHM): (12.0±0.1) ps

The ionization wave is observed to move with a speed of 0.11±0.02 c



- Data from several adjacent time steps are grouped together into a single bin to estimate statistical errors
- The error bars report the standard deviation for each bin
- Suggests the ionization-wave speed increases with time

The ionization wave is driven by a time-dependent hot-electron source with an intensity-dependent hot-electron temperature

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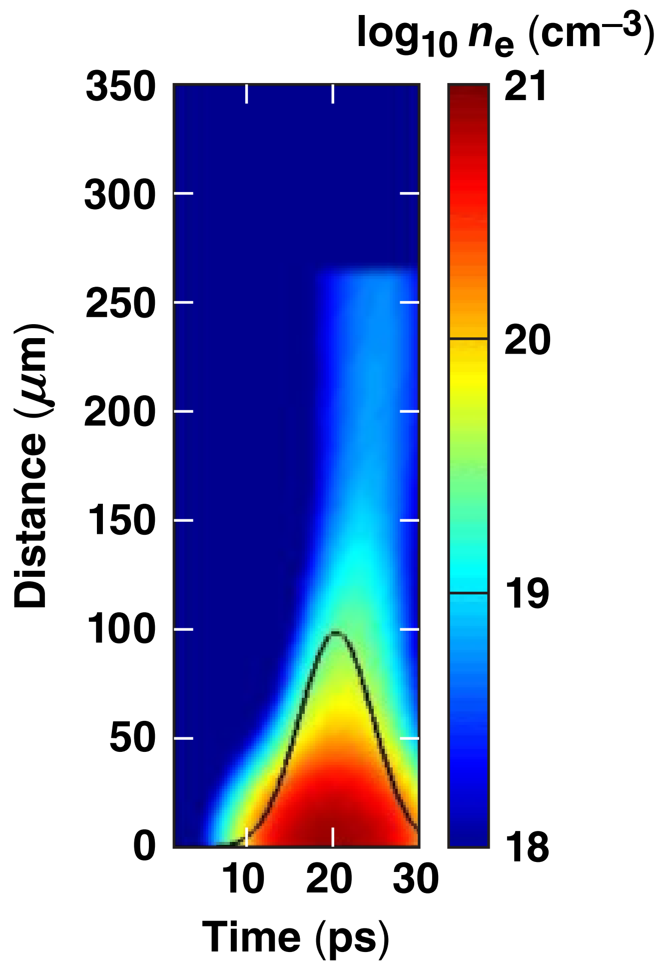
- *LSP** calculates hot-electron flow
  - 250-J, 10-ps pulse
- Hot-electron source is prescribed with varying energy
- Full target volume and interaction time scale are modeled
- LSP calculates electromagnetic fields self-consistently— accounts for refluxing



*D. Welch *et al*., Nucl. Inst. Methods Res. A 464, 134 (2001).
**Prism Computational Sciences, Inc., Madison, WI 53711

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Summary/Conclusions

Hot-electron–driven ionization waves were observed inside a high-intensity laser-irradiated metal target

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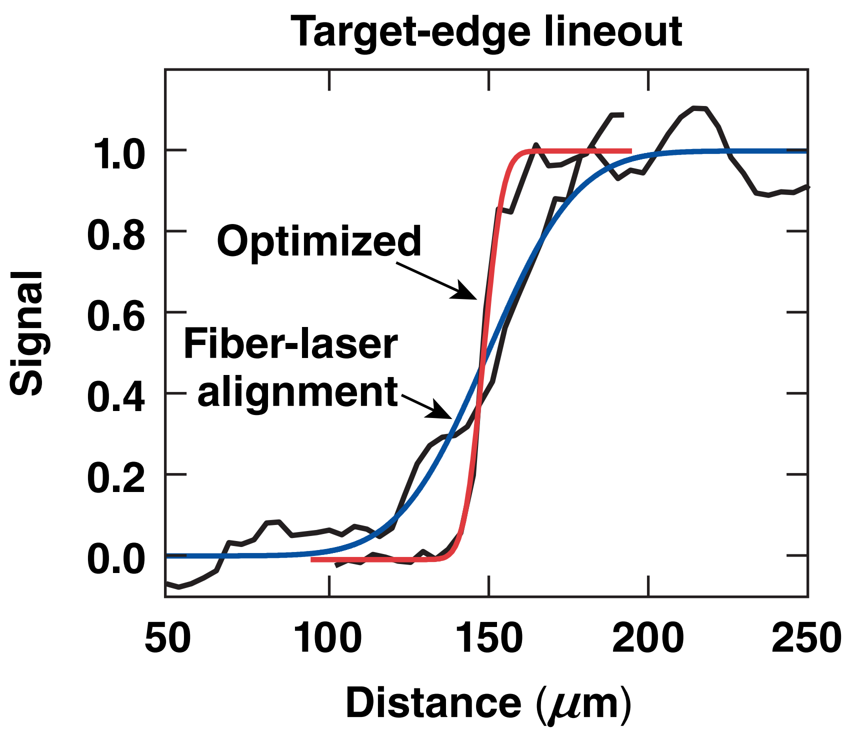
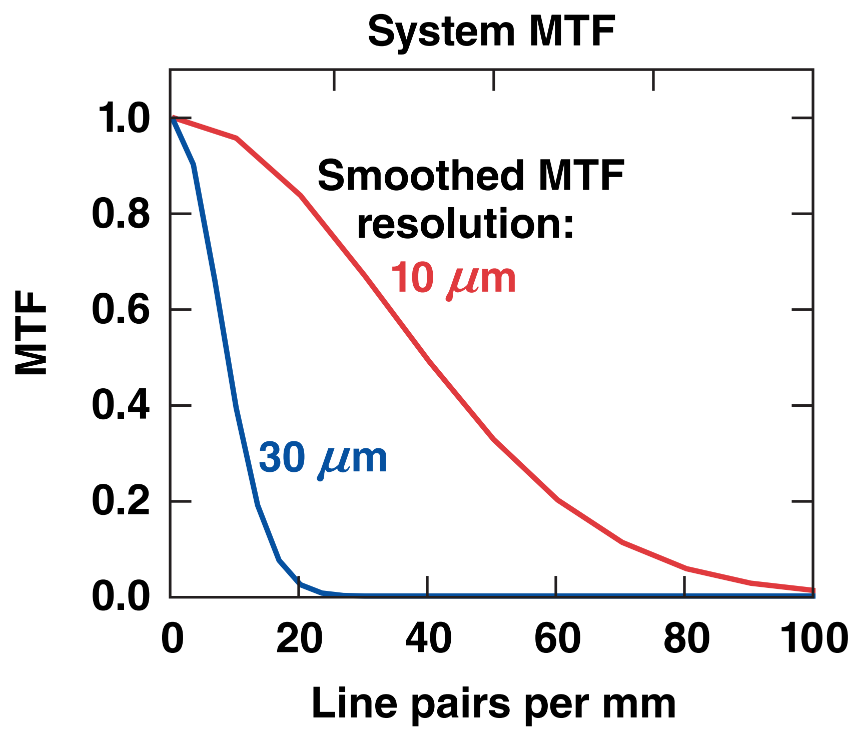
Ionization-wave speed: (0.11±0.02)c

The crystal was initially aligned with a single-mode fiber laser*

- X-ray imaging on low-power shots optimized alignment





Approximately 10-μm resolution was measured based on x-ray imaging optimization.

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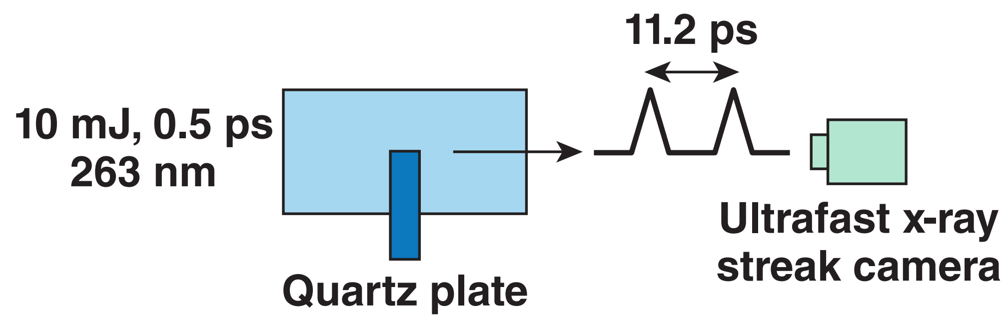
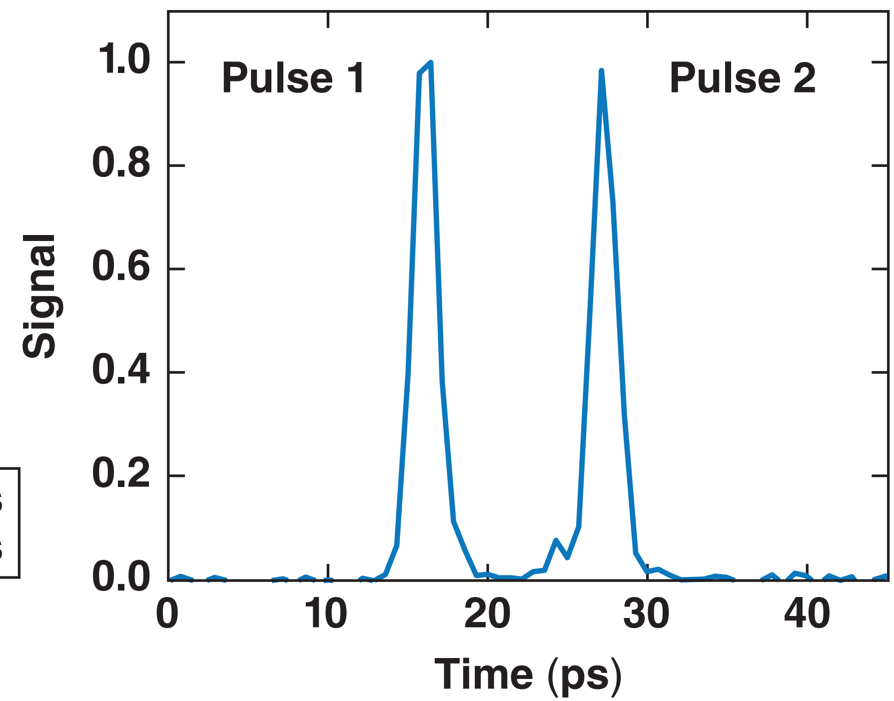
*C. Stoeckl *et al*., Rev. Sci. Instrum. 83, 033107 (2012).

A 2-ps-resolution x-ray streak camera was coupled to the crystal imager

- Temporal dispersion in the streak camera gives a slightly different impulse response for x rays
- Monte Carlo modeling of the electron optics inside the streak tube shows this offset is around 0.2 ps
- The impulse response for x rays is approximately 2 ps





Pulse 1: 1.8±0.1 ps
Pulse 2: 1.9±0.1 ps

P. M. Nilson *et al.*, Phys. Rev. Lett. 108, 085002 (2012).