Multi-Angled Multi-Pulse Time-Resolved Thomson Scattering on Laboratory Plasma Jets

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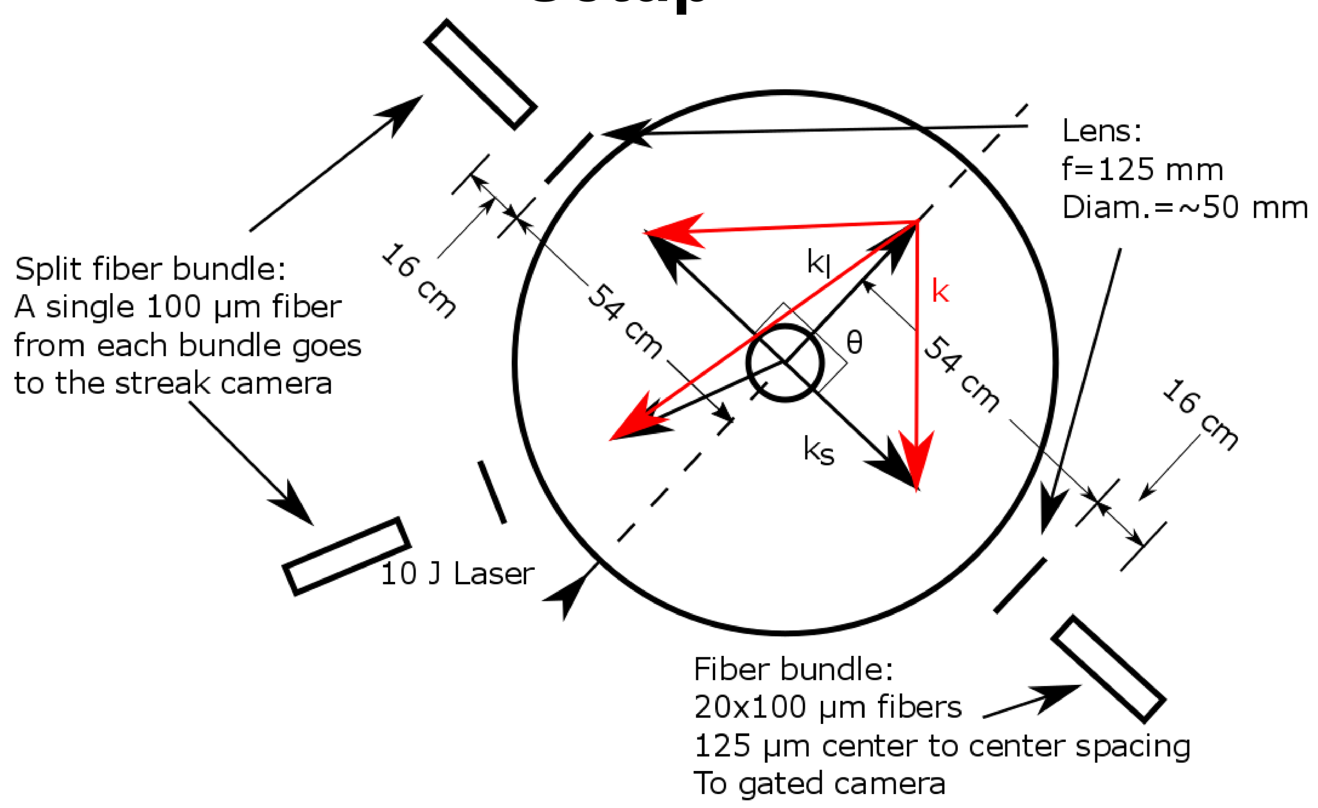
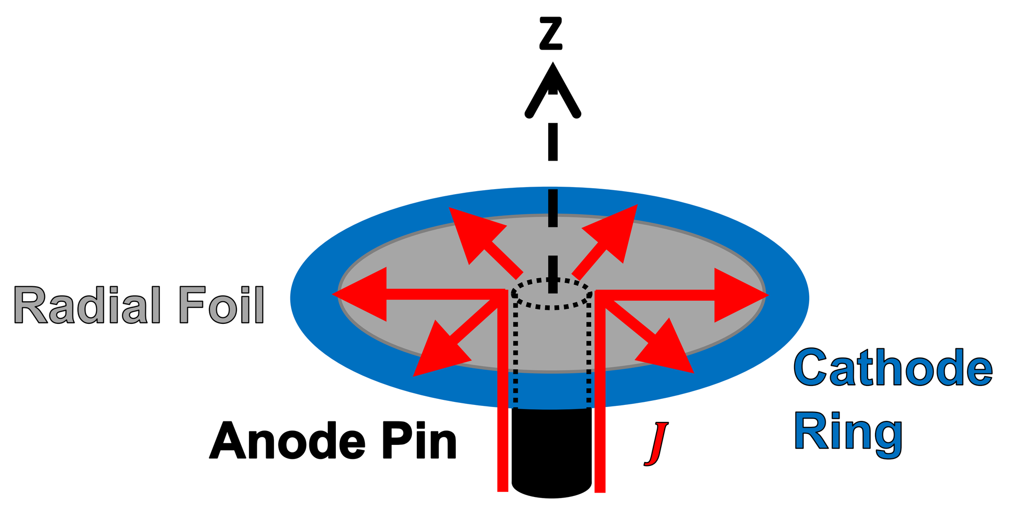
Overview

- Objective: Study the properties of plasma jets produced from radial foils [1] using Thomson scattering.
- This work focuses on using time-resolved Thomson scattering to measure the changing electron temperature as the probe laser heats the plasma of the jet.
- The goal of the latest experiments: to collect scattering from two different locations at two different times.

Setup





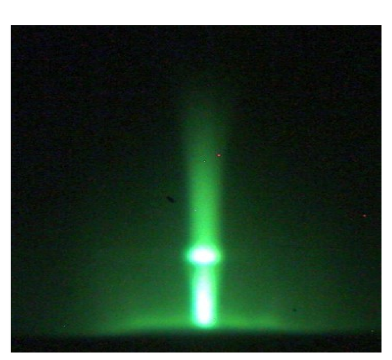
Foil: 15 µm thick aluminum (Al), 15 µm thick titanium (Ti), or 12.5 µm thick copper (Cu) disk

***J*:** Current from Cornell's COBRA pulsed power machine (1 MA, 100 ns rise time, shown in reverse polarity)

Diagnostic Setup

- Spectrometer: 750 mm Czerny-Turner
- Grating: 2400 ℓ/mm
- Instrumental FWHM: 0.42 Å
- Streak camera sweep speed: 20 ns full streak
- Temporal resolution: 250 ps with a 125 µm input slit
- Laser: two 2.5 J pulses, FWHM of 2.2 ns @ 526.5 nm
- Pulse delay: 12 ns

Laser interacting with Jet



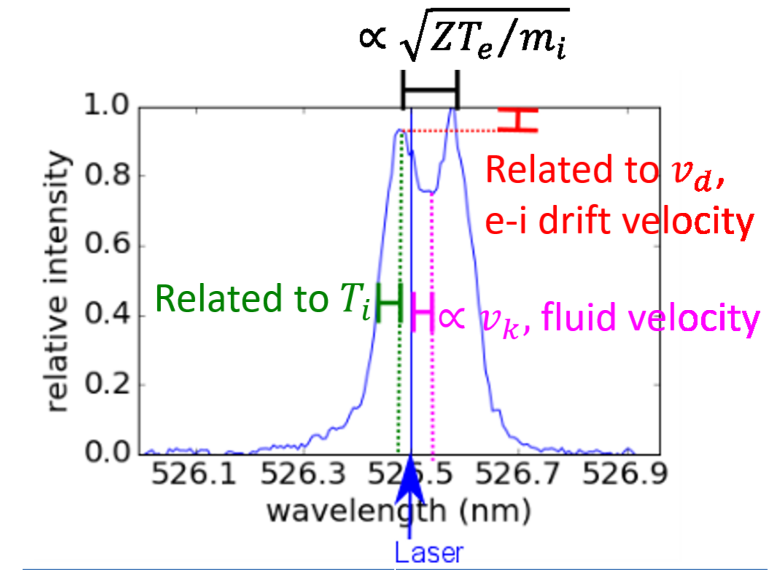
- Using a 10 J or 2.5 J laser pulse creates a bubble in the jet in the XUV images.
- Using streaked Thomson scattering we time resolve the changing electron temperature.

Theory

- Collective Thomson scattering occurs when $\alpha = \frac{1}{k\lambda_{de}} \geq 1$.
- $\mathbf{k} = \mathbf{k}_s - \mathbf{k}_l$ with $\mathbf{k}_s$ and $\mathbf{k}_l$ being the scattered and laser wavevector.
- Using a laser wavelength, $\lambda_l = 526.5$ nm, angle of scattering $\theta = 90^o$, and the plasma $T_e = 50$ eV and $n_e = 5\times10^{18}$ cm^{-3}, gives $\alpha \approx 2.5$.
- n_e is estimated from interferometry images at the time of the laser pulse.
- When $ZT_e \geq 3T_i$ the ion acoustic features appear as two resolvable peaks in the scattered spectrum (see example profile) with separation

$$\Delta\lambda \cong \frac{4\lambda_l}{c}\sin\left(\frac{\theta}{2}\right)\sqrt{\frac{T_e}{m_i}\left[\frac{Z}{1+k^2\lambda_{De}^2}+\frac{3T_i}{T_e}\right]}$$

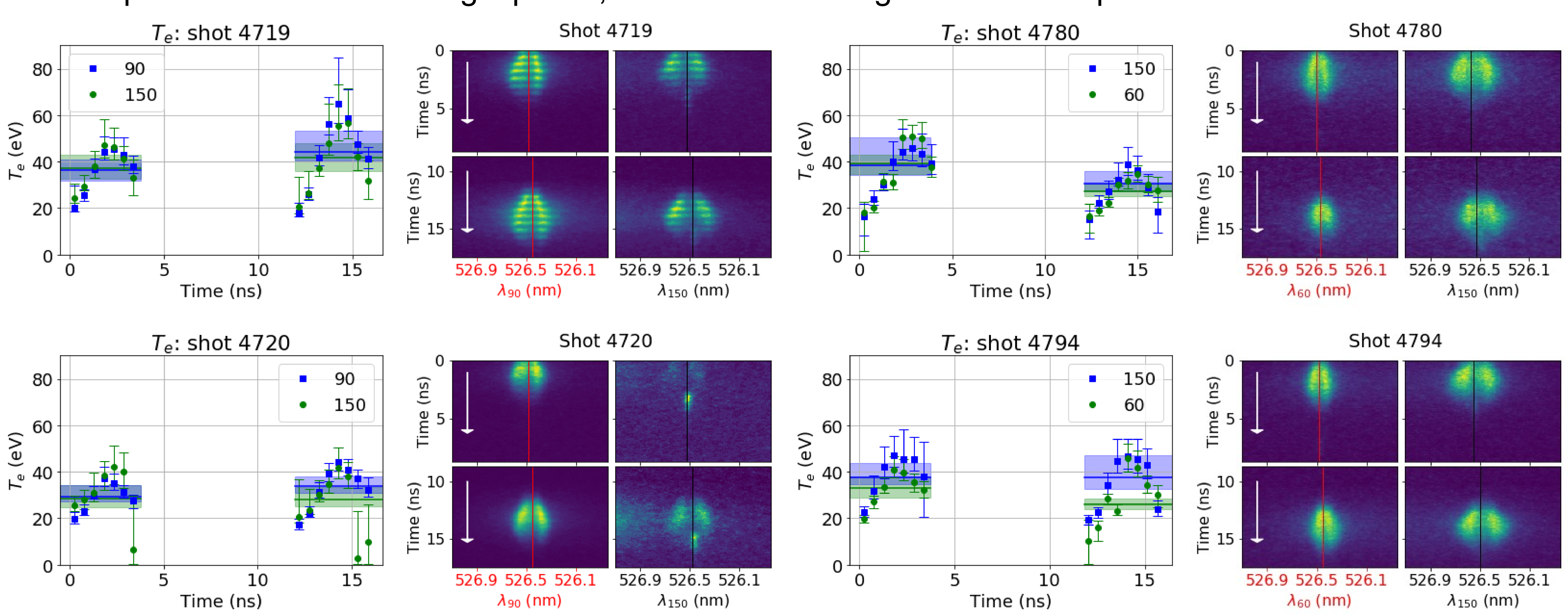
- Plasma parameters are determined from profiles using formulae in [2].
- Error bars are estimated using a Monte Carlo simulation, with variation in parameters shown on the right, and noise added based on the variance between the best fit and the raw data.



Parameter	Standard Deviation
n_e	50 %
Z	10 %
Instrument function	20 %
λ_l	0.2 Å
Linear dispersion	1.5 %

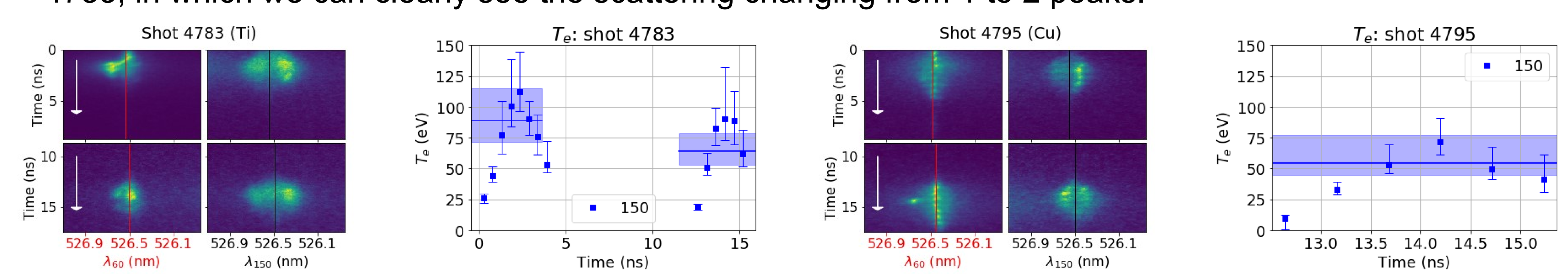
Results from streak-camera spectra – Al

- Increased separation of the ion-acoustic peaks in time shows heating of the plasma jet by the laser.
- T_e for the jet increased from 20 eV to peak temperature of 40-50 eV in about 2 ns (inverse bremsstrahlung).
- T_e then stayed steady for about 0.5 ns prior to cooling off at the end of the laser pulse.
- This cooling is primarily caused by the plasma expanding as the laser heats the plasma.
- Time points are shown as single points, while the time integration of each pulse is shown as a colored band.



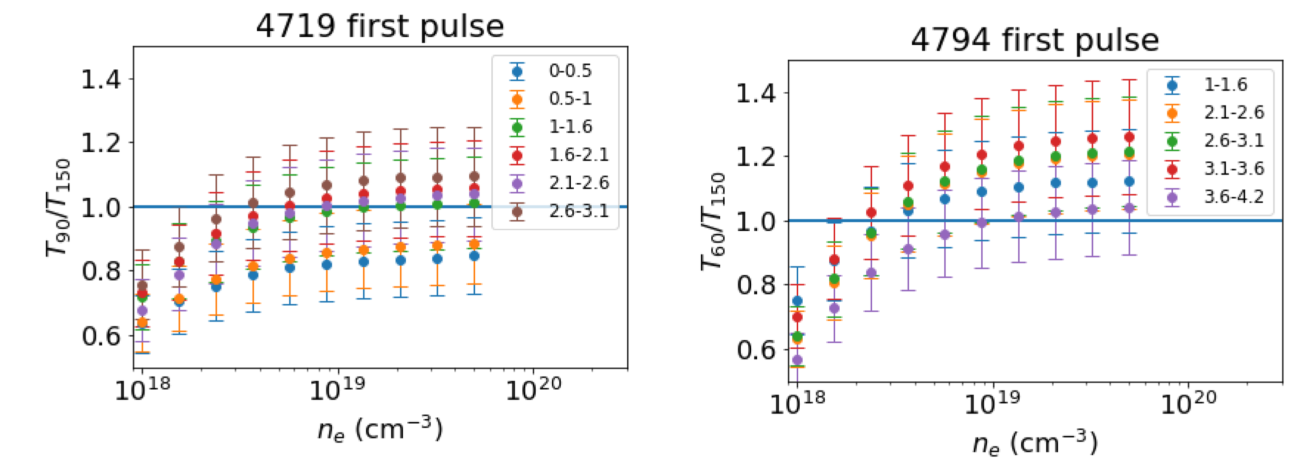
Results – Ti and Cu

- Changing the jet material to either Ti or Cu leads to some interesting results.
- From initial data it appears that Ti has the strongest heating and then Cu followed lastly by Al.
- Ti jet heated to over 100 eV while the Cu jet heated to about 75 eV
- Many of the shots had complex Thomson scattering results like the first pulse at a view angle of 60^0 for shot 4783, in which we can clearly see the scattering changing from 1 to 2 peaks.



Density Measurements

- Tried to measure n_e by comparing the peak separation at 2 different angles [3].
- May show some drop in n_e as the laser heats plasma.
- Not enough change in temperature ratio based on the assumed electron density for accurate measurements.



Next steps

- Use this diagnostic in other experiments where time resolved Thomson scattering would be of interest.
- Gather more data with jets other then Al, to see if we can understand the results.
- Switch from reverse to standard polarity, and compare the experimental results to PERSEUS simulations.
- Shorten the gap time between pulses to scatter from a still heated plasma.

Summary

- We have enabled the use of a streak camera to acquire temporally resolved Thomson scattering spectra at two points in time and from two different locations.
- Measured heating of 40-50 eV within 2 ns on Al jets.
- Jets begin to cool at the end of the laser pulse.
- Ti and Cu jets showed more heating then Al jets and also had some difficult to interrupt spectra.
- Trying to measure the density in this parameter range is challenging with the accuracy of our measurements.

References

[1] T. Byvank, J. Chang, W. M. Potter, C. E. Seyler, and B. R. Kusse, IEEE Trans. Plasma Sci. **44**, 638 (2016).

[2] D. Froula, S. H. Glenzer, N. C. J. Luhmann, and J. Sheffield, *Plasma Scattering of Electromagnetic Radiation: Theory and Measurement Techniques*, second (Elsevier Ltd, Amsterdam, 2011).

[3] D. Froula, P. Davis, L. Divol, J. Ross, N. Meezan, D. Price, S. Glenzer, and C. Rousseaux, Phys. Rev. Lett. **95**, 195005 (2005).

Acknowledgments

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