SAND2018-13122C

Examination of Metal Strength at High Strain Rates Using Richtmyer-Meshkov Instability Experiments at the Advanced Photon Source

Joseph D. Olles*,
Christopher Tilger **, Nathaniel Sanchez **, and Brian Jensen **

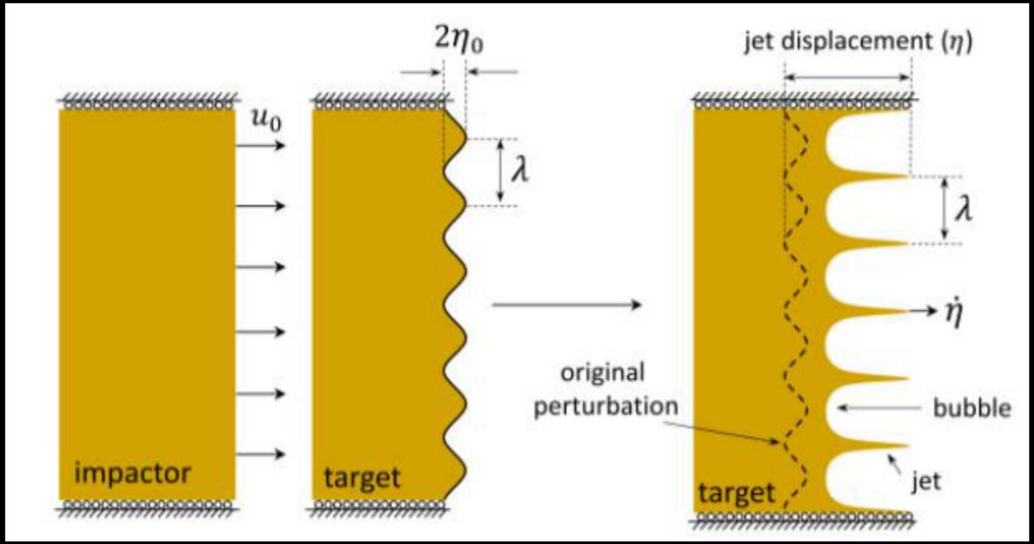
*Sandia National Laboratories, Albuquerque, NM, U.S.A.
**Los Alamos National Laboratories, Albuquerque, NM, U.S.A.

Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

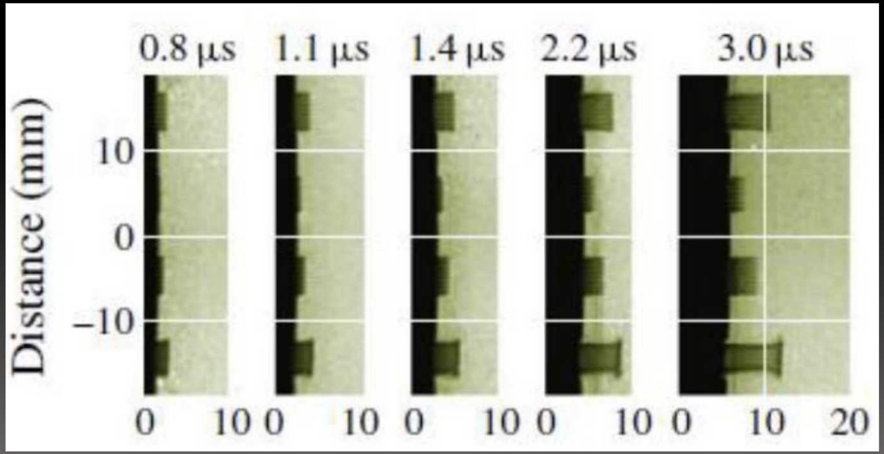
Motivation

- Strength characteristics of metal under extreme conditions (shocked).
- Extreme states of matter produced using shock waves from explosives, lasers, and impact systems (gas or powder guns). ps → μs timescales.
- Utilize and show Argonne's X-ray PCI capabilities: spatial resolution of 2-3 microns with sub-nanosecond exposures.
- Zero pressure environment (~100mTorr chamber)

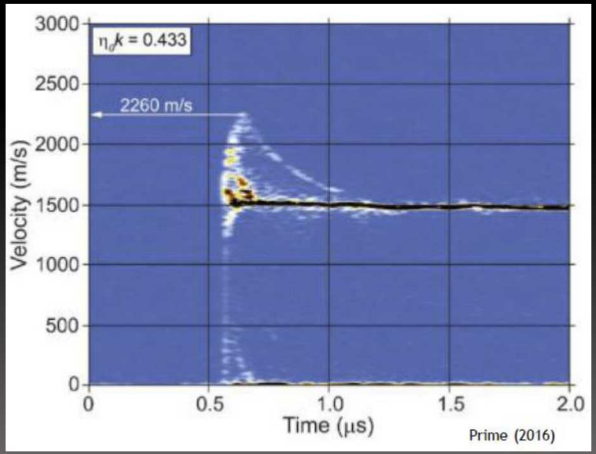
Previous Work



Radiography

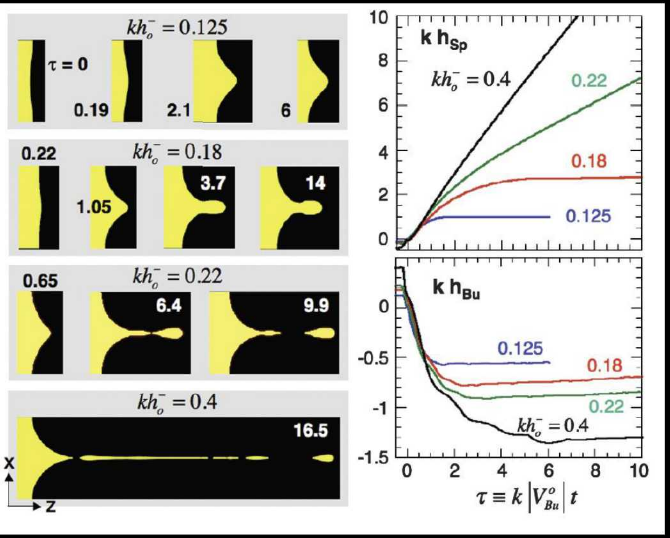


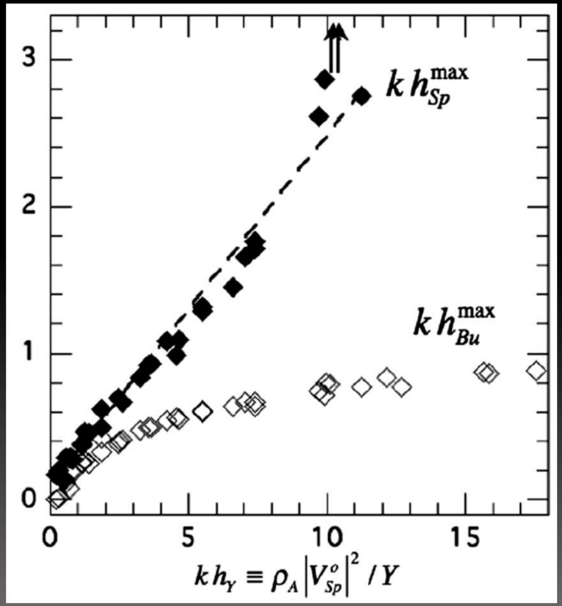
Velocimetry

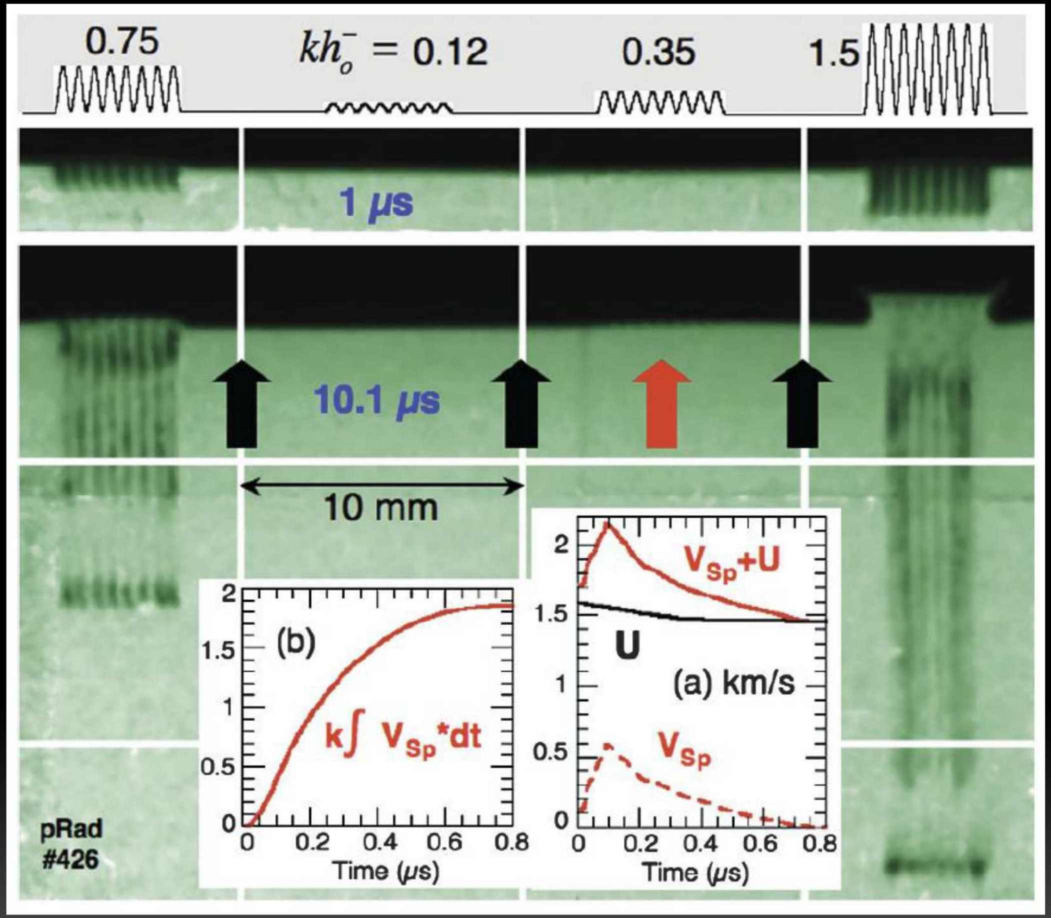


- By studying how the shock wave propagates through a material, traditional measurements have provided insight into various phenomena including elastic-plastic deformation, shock-induced phase transitions, equation-of-state (EOS), and material strength.
- Richtmyer-Meshkov instabilities (RMI) are formed when a shock wave interacts with a perturbation at an interface, and have shown a sensitivity to strength in the post-shock state
- Material strength during high strain-rate, dynamic deformation, in both compression and tension, remains a significant scientific challenge because of the difficulty in generating well-defined loading conditions.

Previous Work



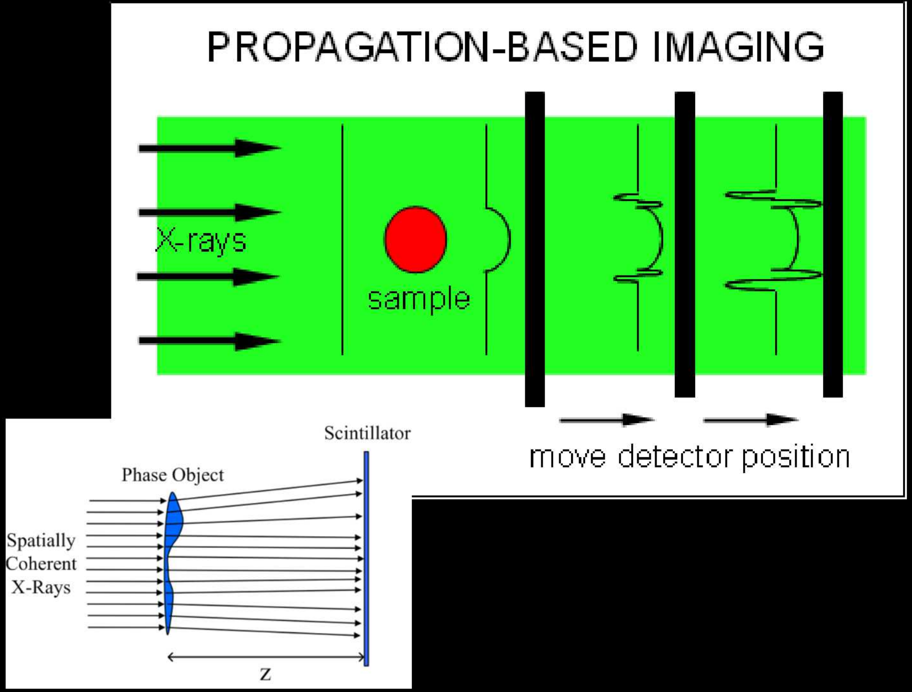




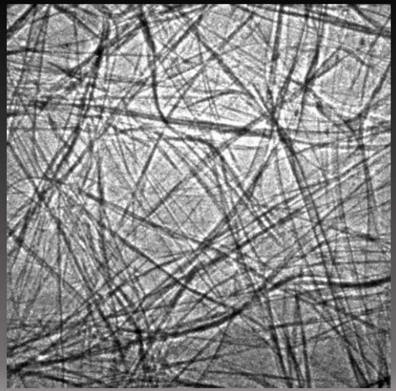
- Copper has been studied as well as Aluminum for strength at high strain
- Added spatial and temporal resolution allow validation and expansion of these works.

Argonne - DCS

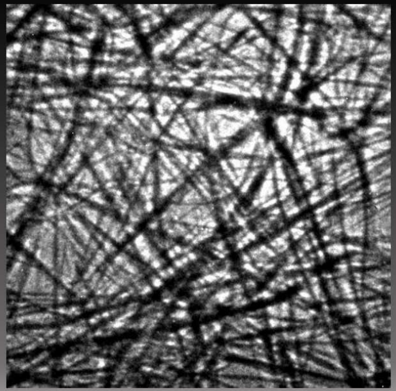
- Propagation based PCI is a phase diffraction effect
- Sensitive to differences in refractive index proportional to density
- Requires spatially coherent beam
- Enhanced contrast brings out features such as edges/voids
- Resolution vs. contrast trade-off



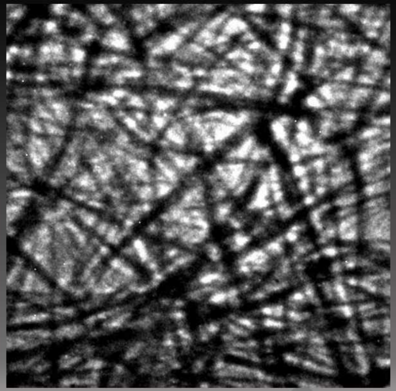
Phase Contrast Images of Polymer Foam



Z = 50 mm

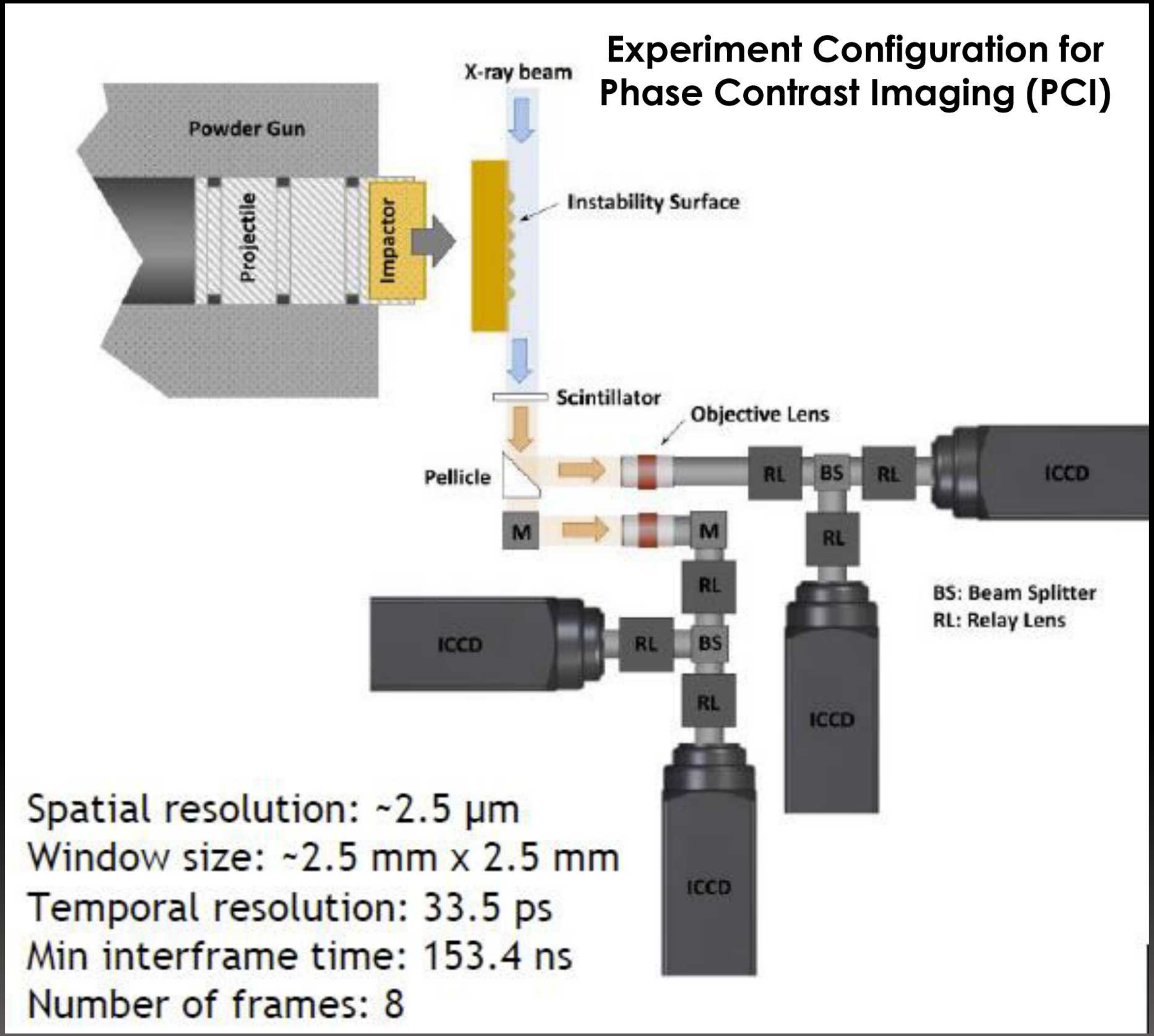


Z = 400 mm



Z = 800 mm

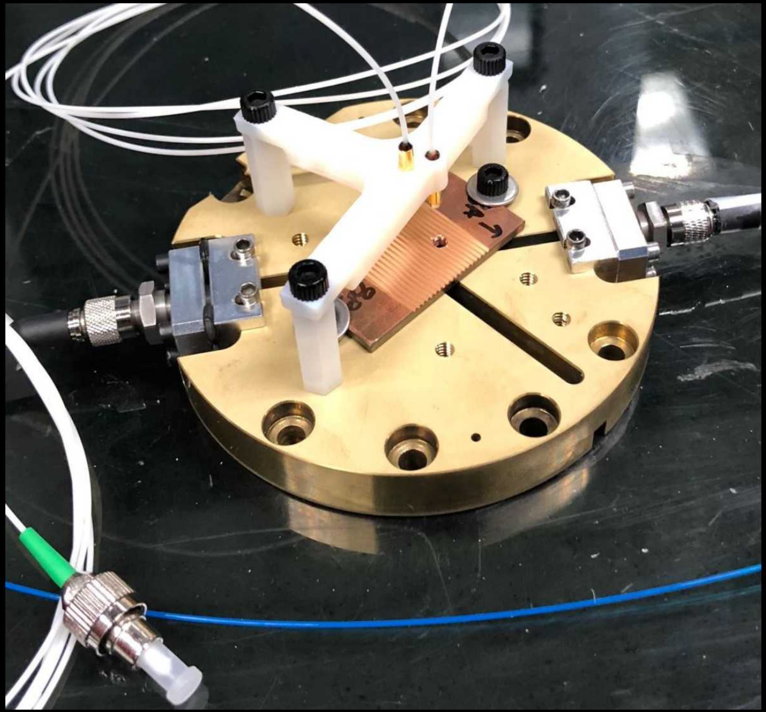
Argonne - DCS

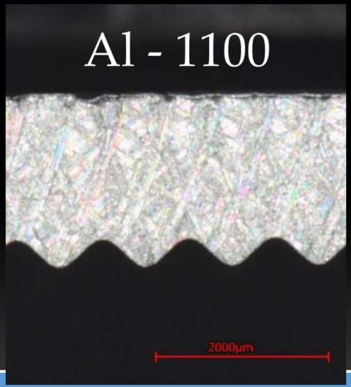


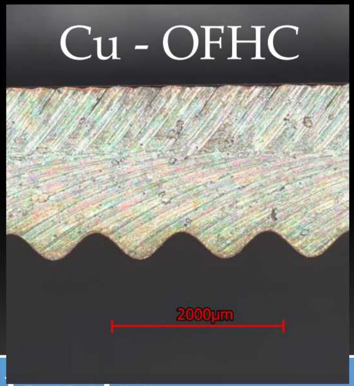
- 1st harmonic undulator white beam, tuned to ~18 keV
- Beam operated in standard mode with one 80-ps pulse (33.5 ps FWHM) every 153 ns
- Slow shutter synchronized with the projectile launch – opened for 60 ms
- Targets designed for quick setup/turn-around (every 1-2 hours)

Experimental Setup

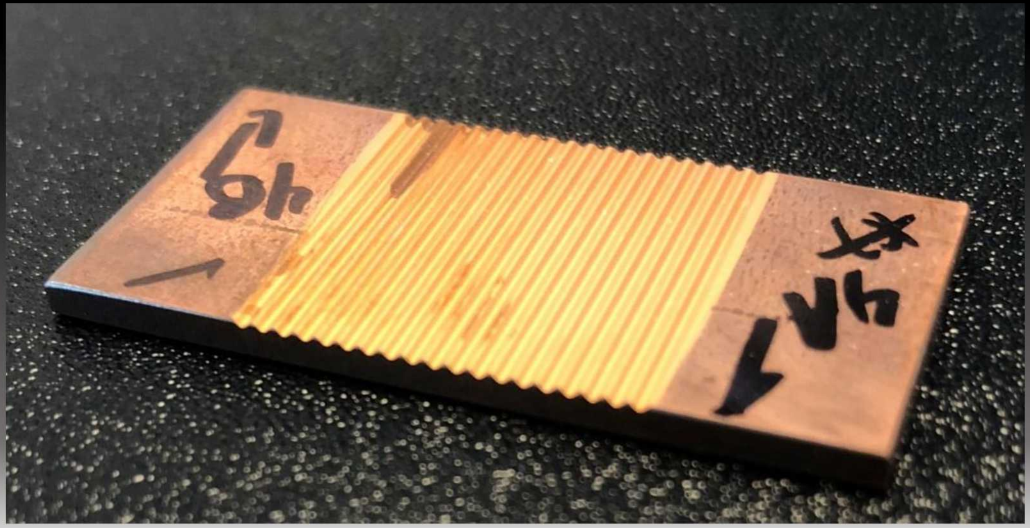
- Copper impactor ~4mm thick ½” diameter (~5g)
- Chamber pressure ~120 mTorr
- Projectile velocities ~1.0 km/s or 2.2 km/s
  - 2 shots for each material at each impact velocity (repeatability)
- Non-dimensional Wave Number $\eta_0 k = \frac{2\pi}{\lambda}\eta_0 = 1$ → growth and breakup
- Atwood number $\frac{\rho_1 - \rho_2}{\rho_1 + \rho_2} = -1$





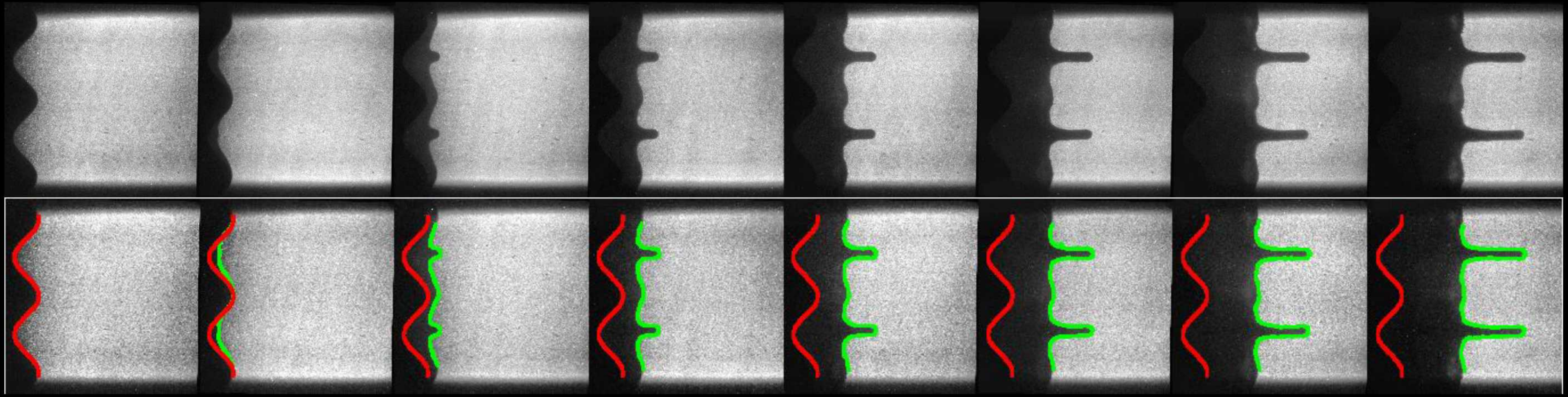


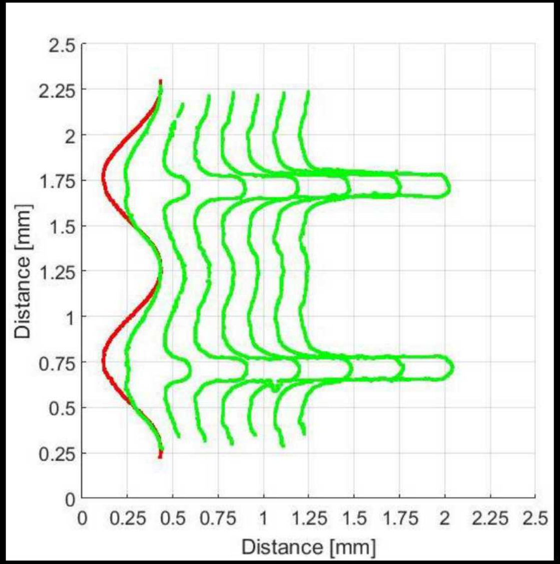
Dektak Profilometer			
	Designed	Measured	Std. Dev.
Mean λ	1.000 mm	1.0098 mm	0.027 mm
Mean $2\eta_0$	$1/(2\pi)$ mm	0.303 mm	0.0097 mm



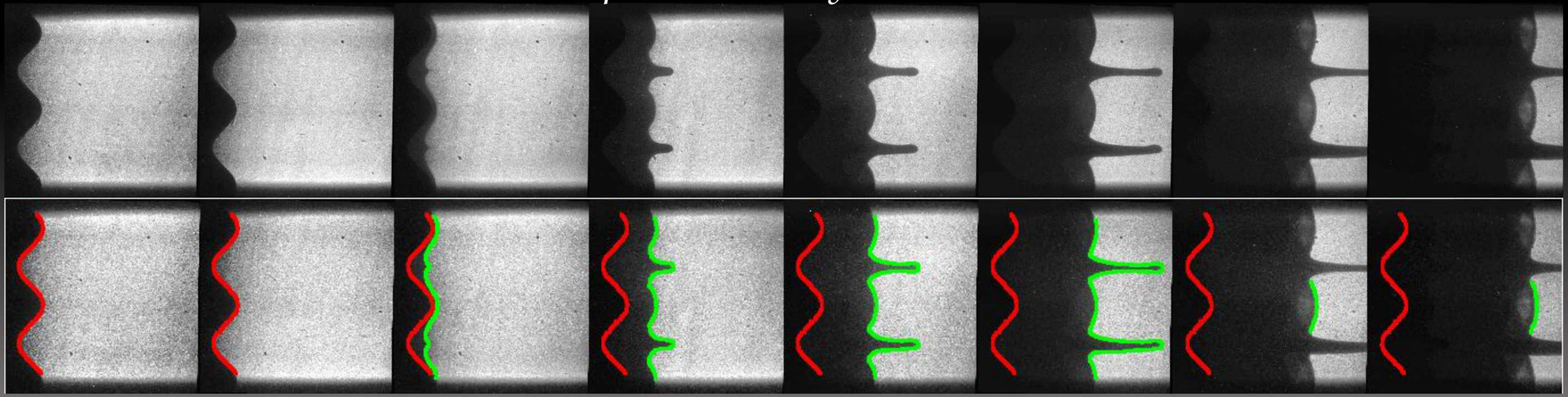
Experimental Results - Cu

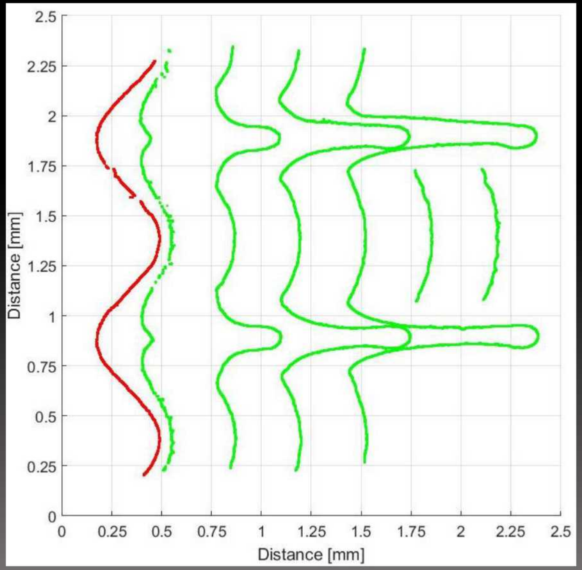
Cu impactor velocity – 1.0 km/s



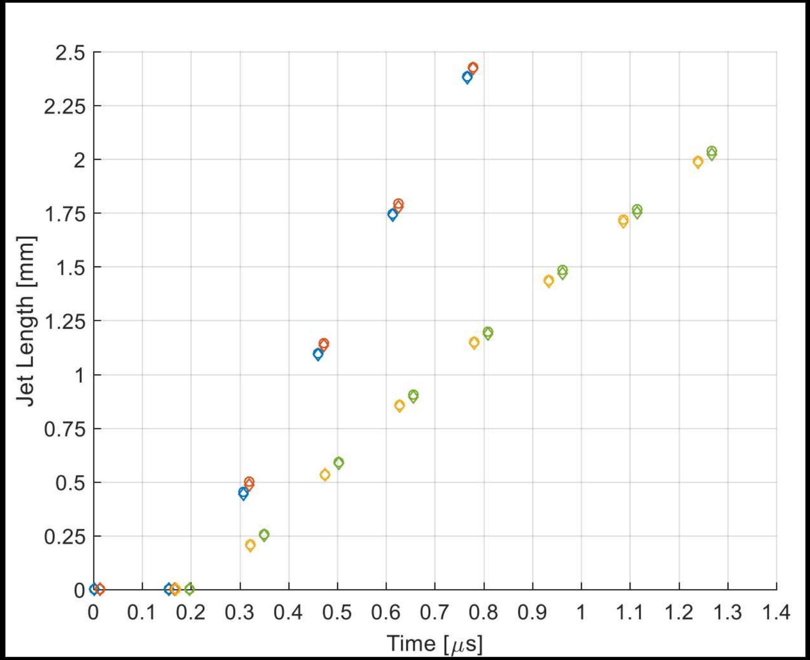


Cu impactor velocity – 2.2 km/s



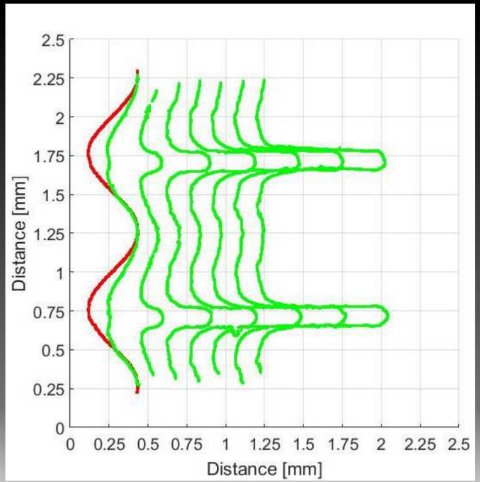


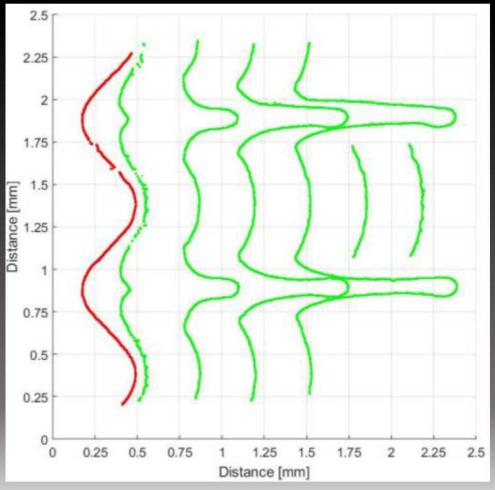
Jet Displacement- Cu

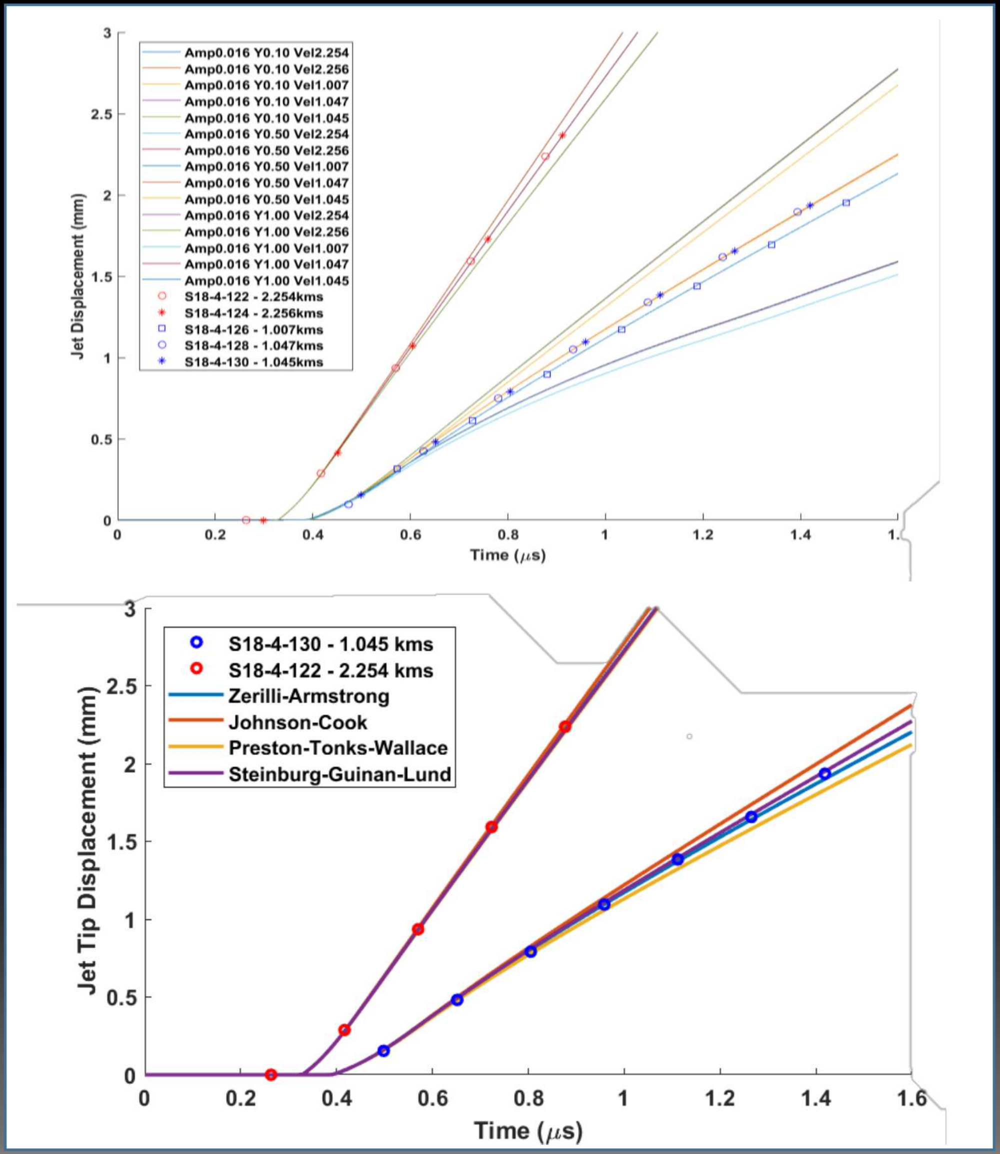


Cu impactor velocity

1.0 km/s *2.2 km/s*





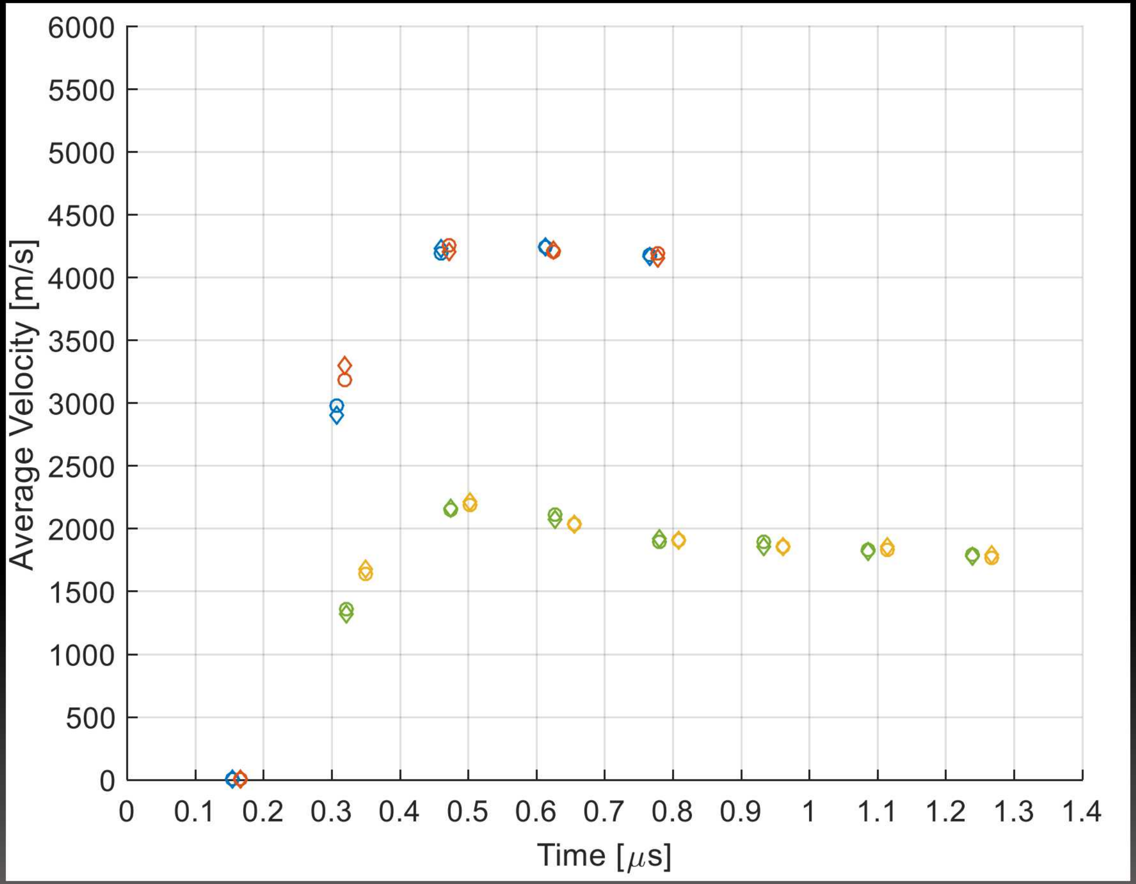


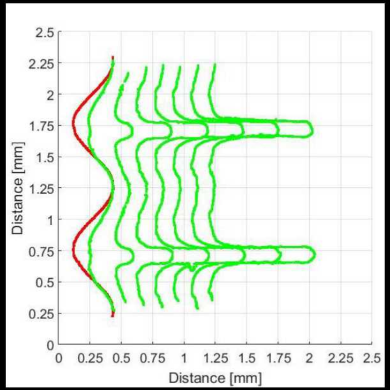
Jet lengths used in hydrocodes for matching strength

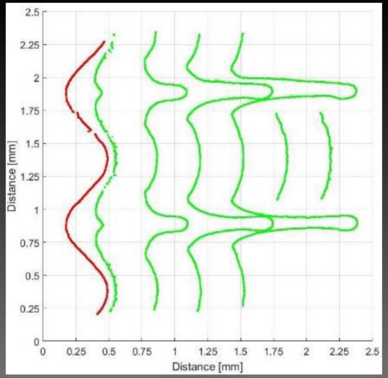
- EPP
- Z-A
- J-C
- PTW
- SGL

Courtesy of:
M. Hudspeth – SNL 2018

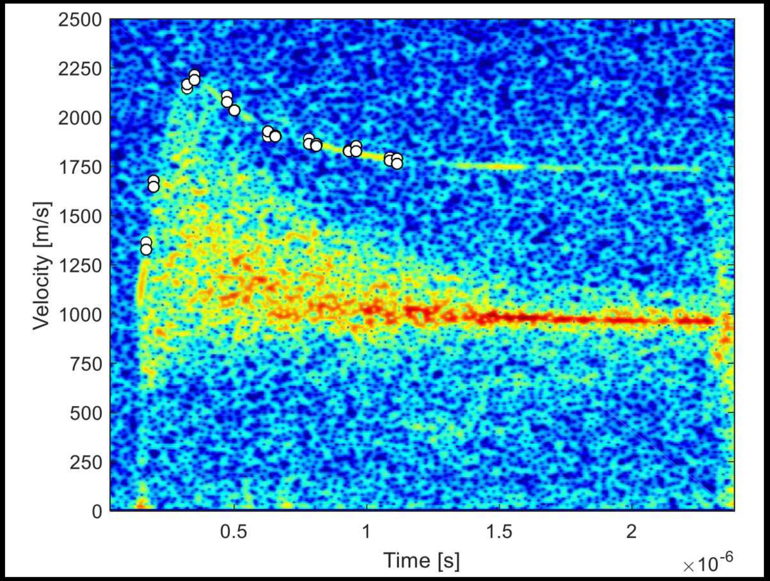
Velocity Measurements - Cu



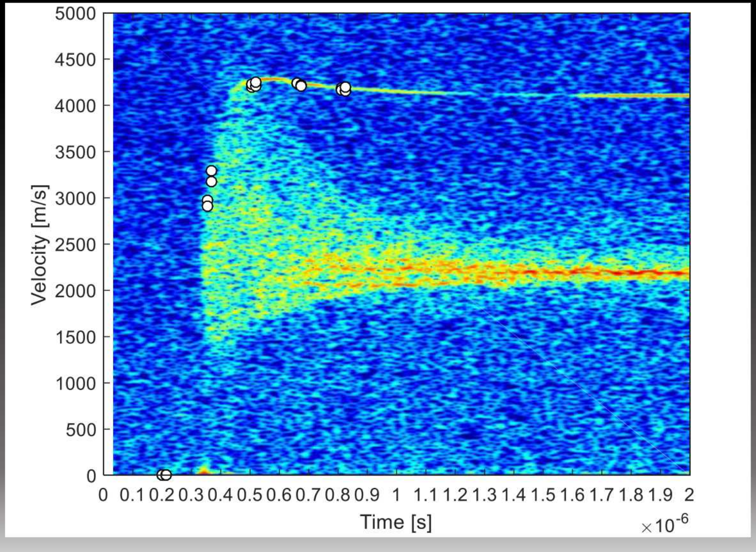




Cu impactor velocity
1.0 km/s

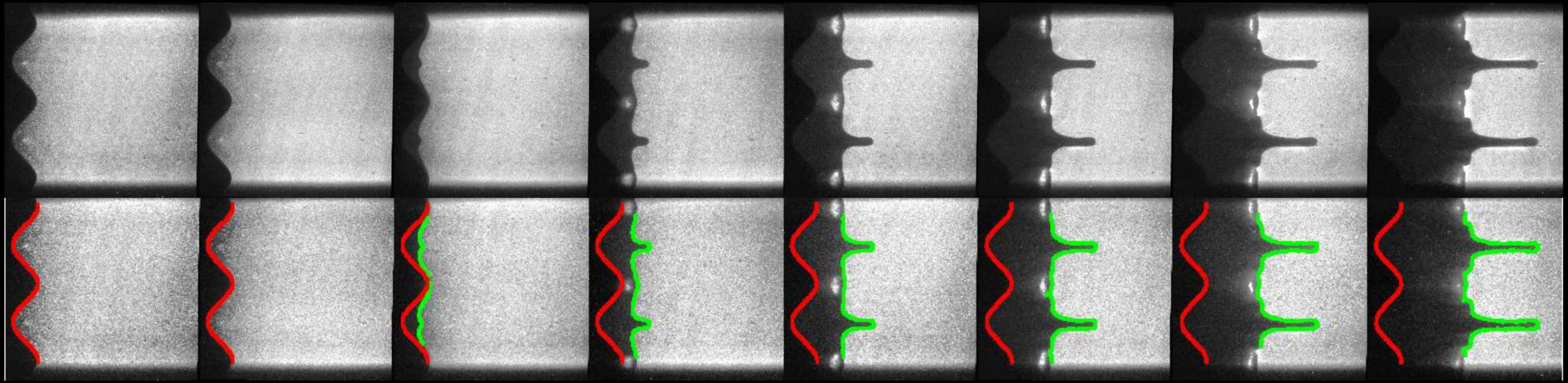


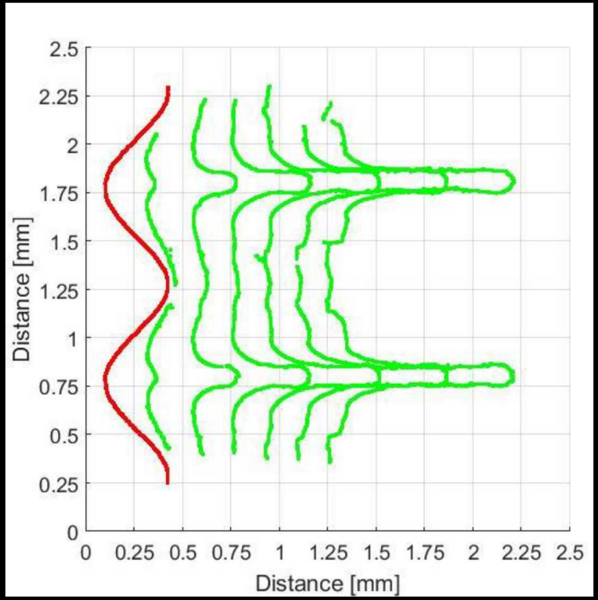
2.2 km/s



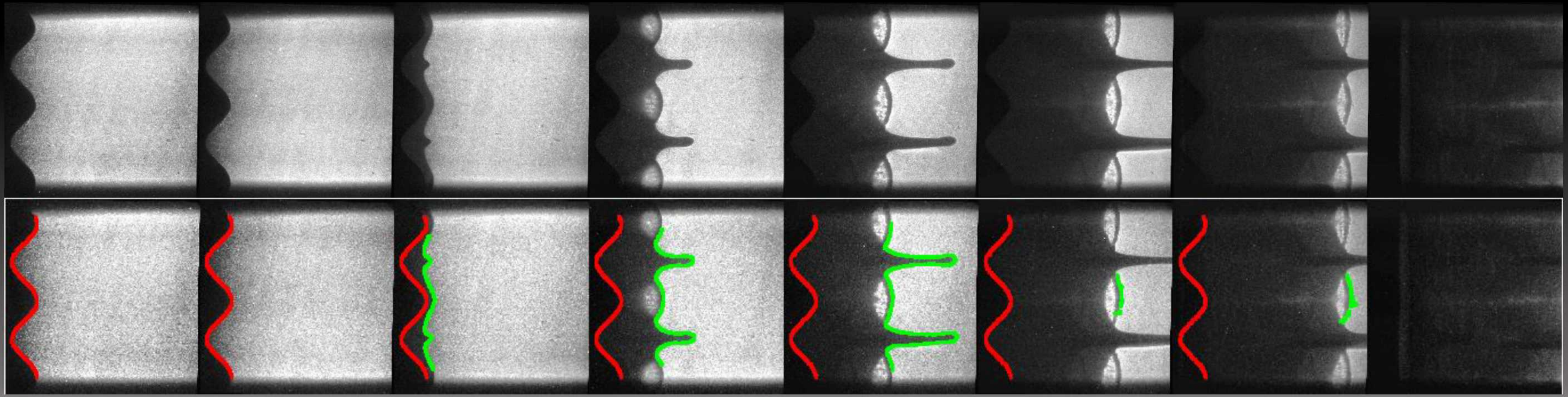
Experimental Results - Al

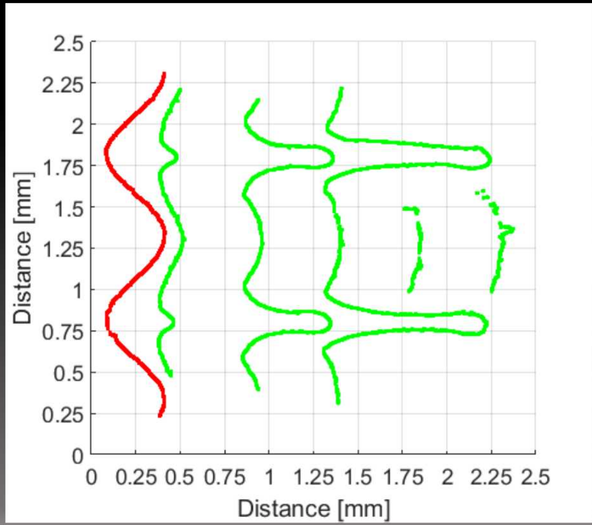
Cu impactor velocity – 1.0 km/s





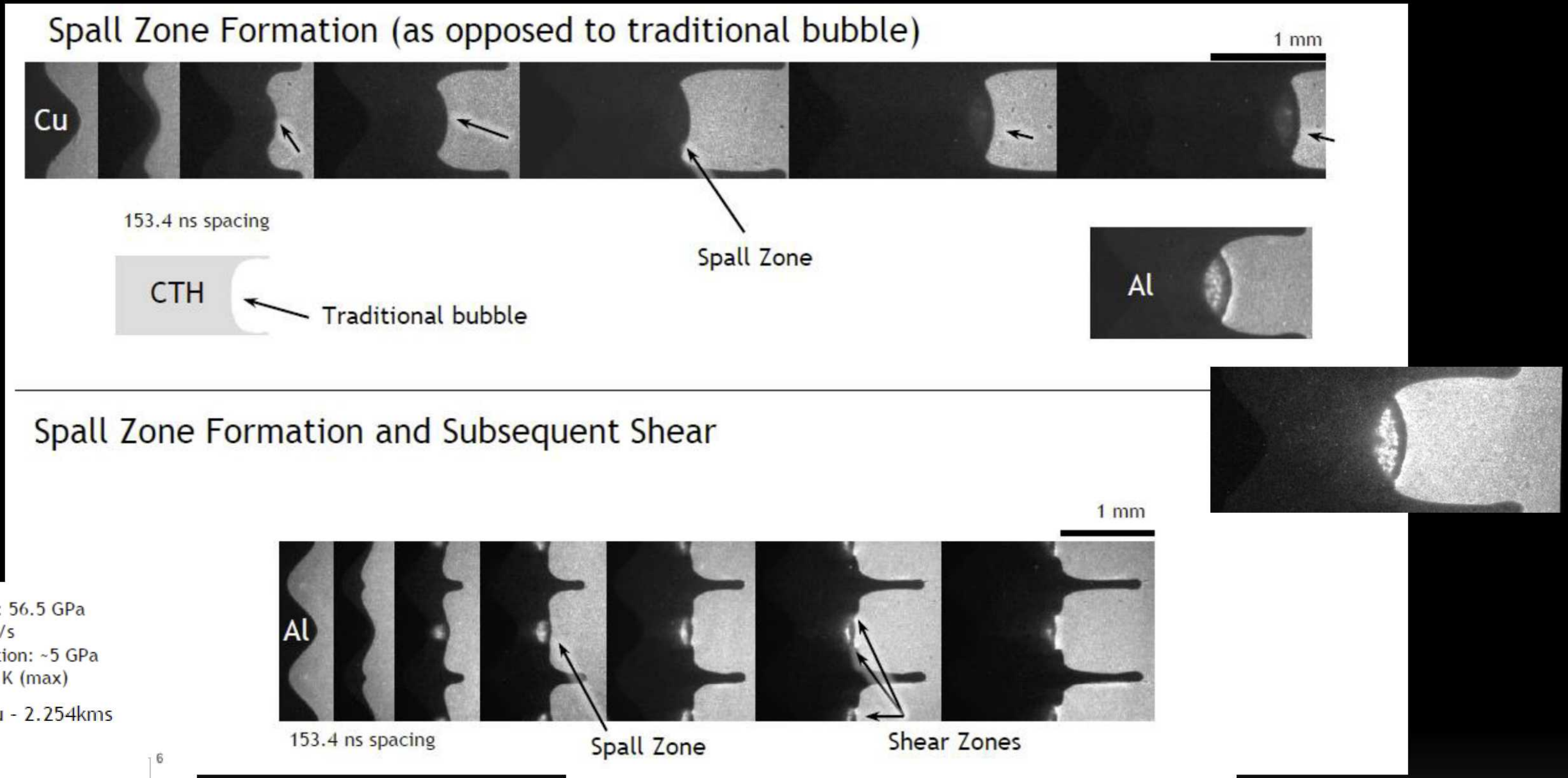
Cu impactor velocity – 2.2 km/s

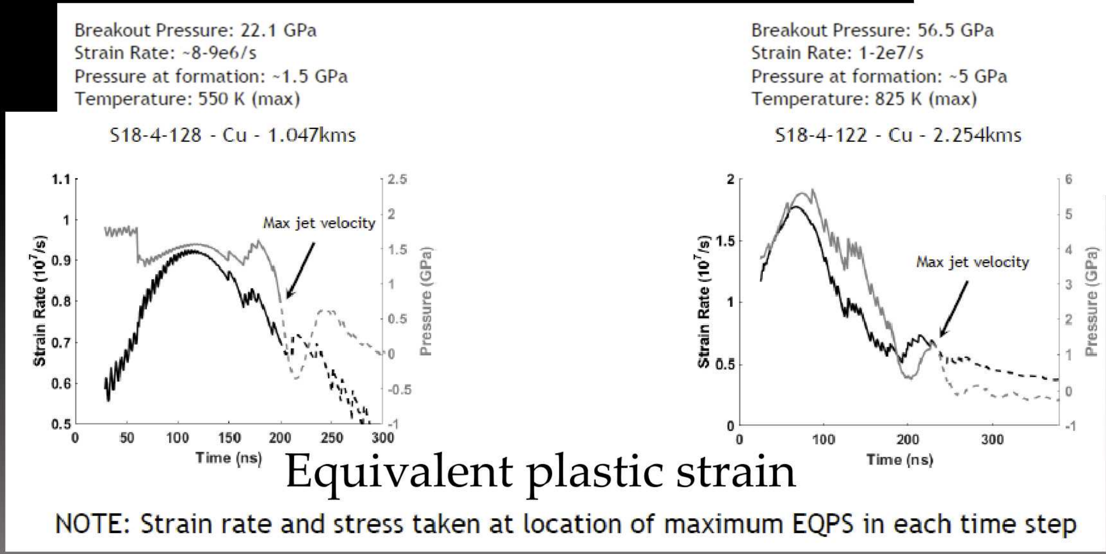


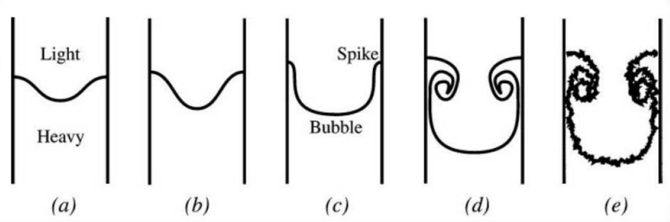


Next Steps

- Computational study the strain rates and how the jets evolve.
- Investigate aluminum similarly to copper.
- Study spall (crazing) and shear zones not seen in metals during RMI with this resolution.







Summary

- Showed ultra-high-speed XPCI at APS to study RMI of shocked copper and aluminum.
  - High spatial resolution ~2.5 μm, temporal resolution 33.5 ps FWHM, interframe 153.4 ns
- Phase congruency algorithms utilized to extract edges of jets and bubbles.
  - Various new features found utilizing image processing: spallation, shear zone, ejecta, etc.
- Jet lengths, mean and interferometric velocities, and repeatability show great agreement.
- Strength models are being tuned to match with jet lengths and velocities. (Cu strain rate ~10^7 and strength 0.5 GPa)