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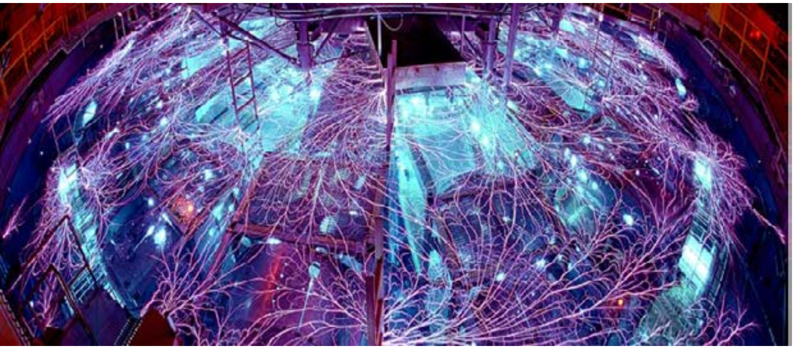

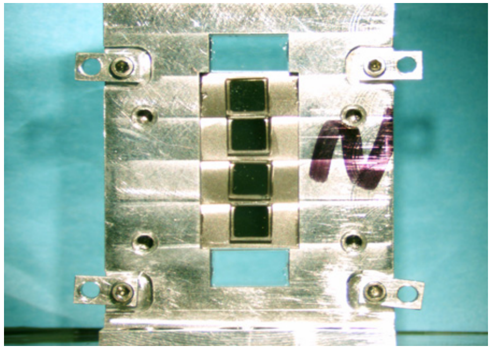

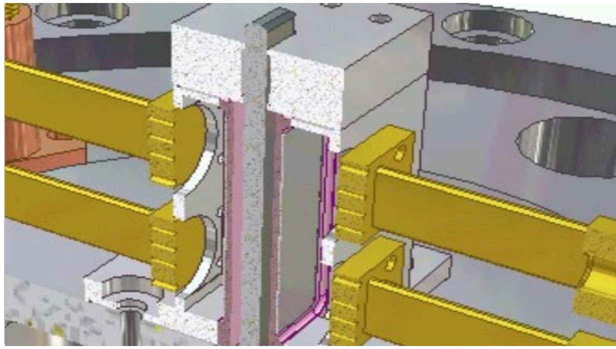

Measurement of Hugoniot sound velocity at extreme pressures on Z

Chad McCoy

Sandia National Laboratories, Albuquerque, NM

8th Fundamental Science with Pulsed Power workshop

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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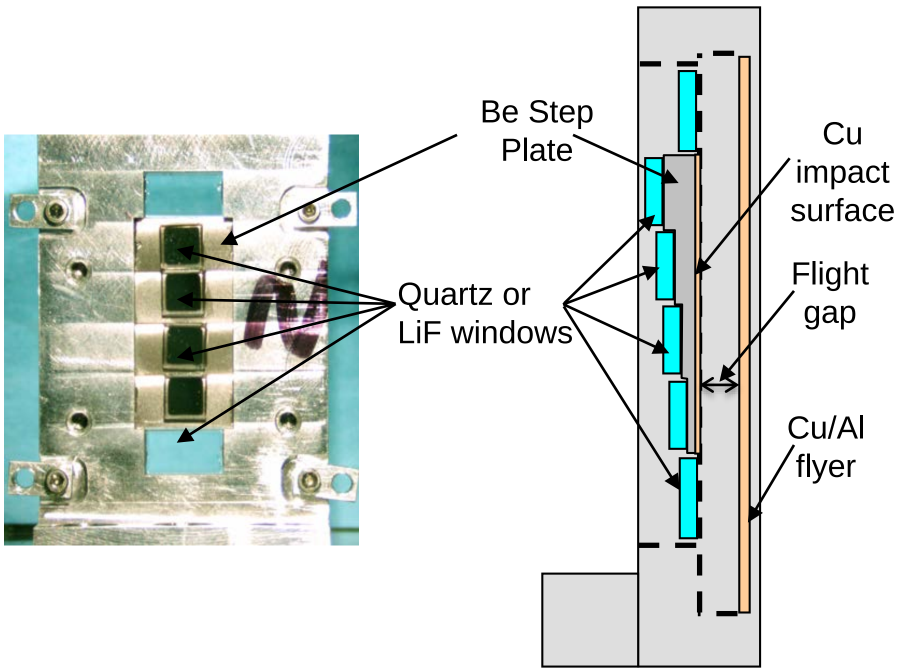
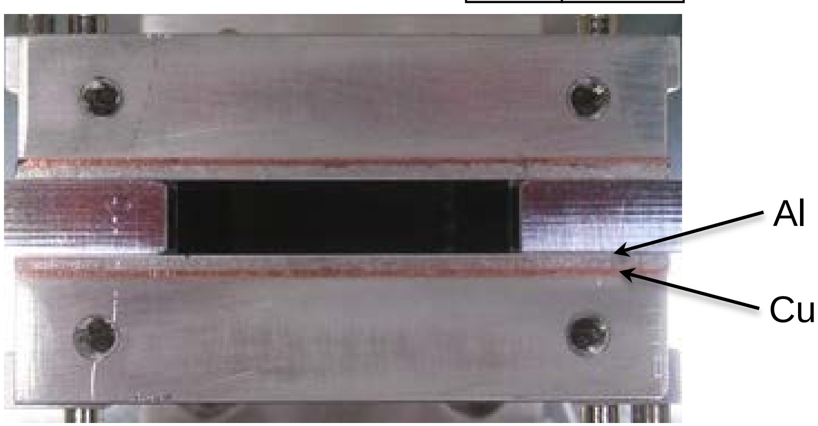
Summary

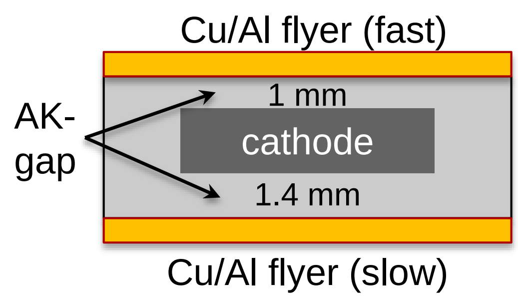
- Measurements of sound velocities at extreme pressures are difficult to perform
  - Require uniform shocks over large areas and precise measurement of sample and/or flyer thicknesses
- Dual-layered Cu/Al flyer plates enable overtaking wave measurements on Z
  - Copper sound velocity was constrained from 300 to 1100 GPa
  - Beryllium was measured from 130-300 GPa identifying shock-melt transition
- Experiments at OMEGA have used reverberating waves to measure sound velocity
  - Similar technique under development for Z

Z overtaking wave experiments impacted stepped targets with multilayered flyer plates





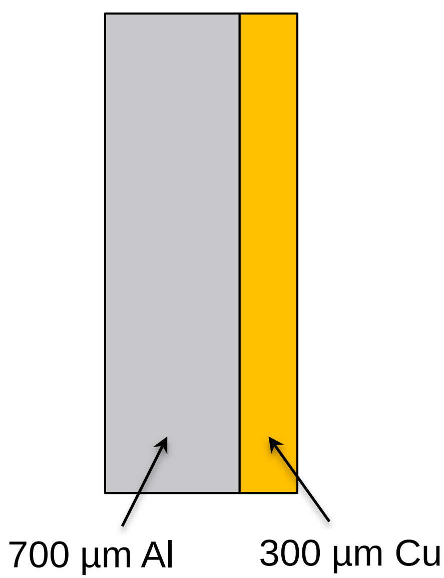
- Flyer velocities ranged from 7-17 km/s
- Experiments used asymmetric loads to launch 2 flyers with ~10% different velocities per shot

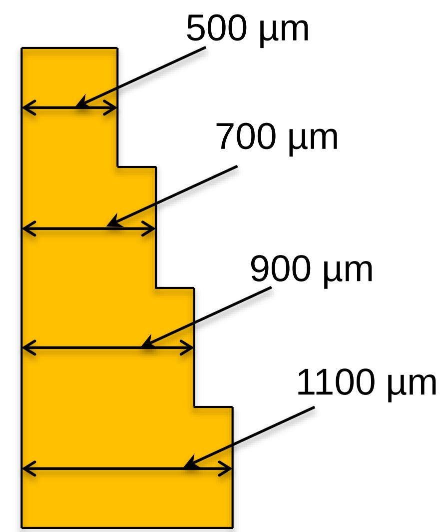


Target fabrication requires machining to tight tolerance and precise measurement

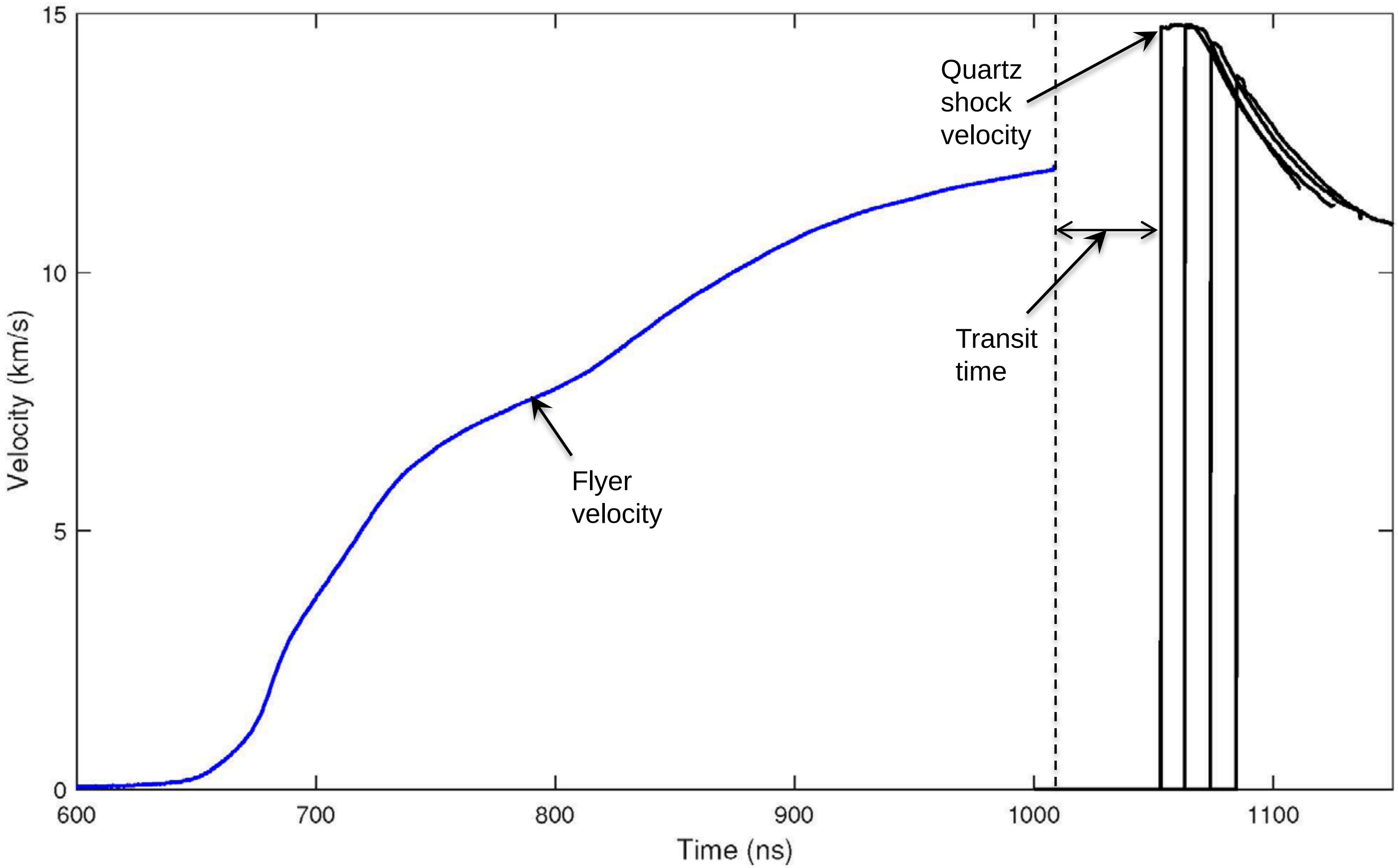
- Flyer plates were developed by plating Cu onto Al substrates and diamond-turning to desired thickness

- Copper samples machined to have steps from 500-1100 µm
- Thickness measured to <2 µm





Flyer velocity, shock transit time, and quartz shock velocity measured with VISAR



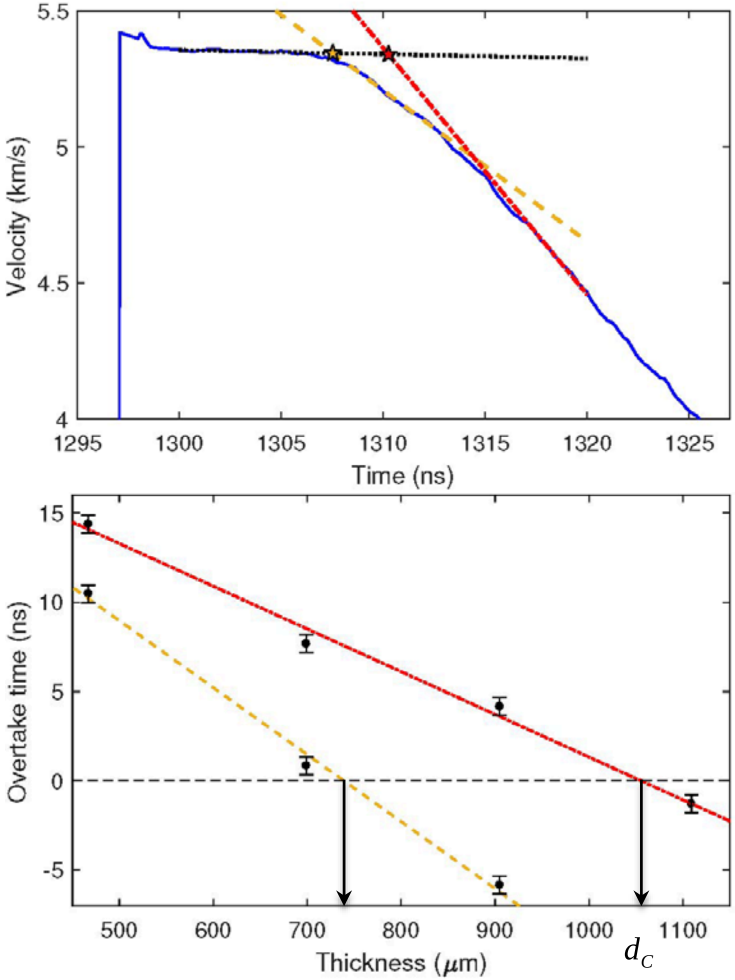
Longitudinal and bulk sound velocities determined from overtake of release wave

- Longitudinal and bulk overtake times measured for each step
- Overtake times interpolated for thickness at which overtake occurs
- Copper sound velocity given by:

Copper flyer thickness

$$C_L = \frac{d_C + d_F}{d_C - d_F} U_S$$

- Beryllium sound velocity relative to copper layer



Copper sound velocity constrained from 300-1100 GPa

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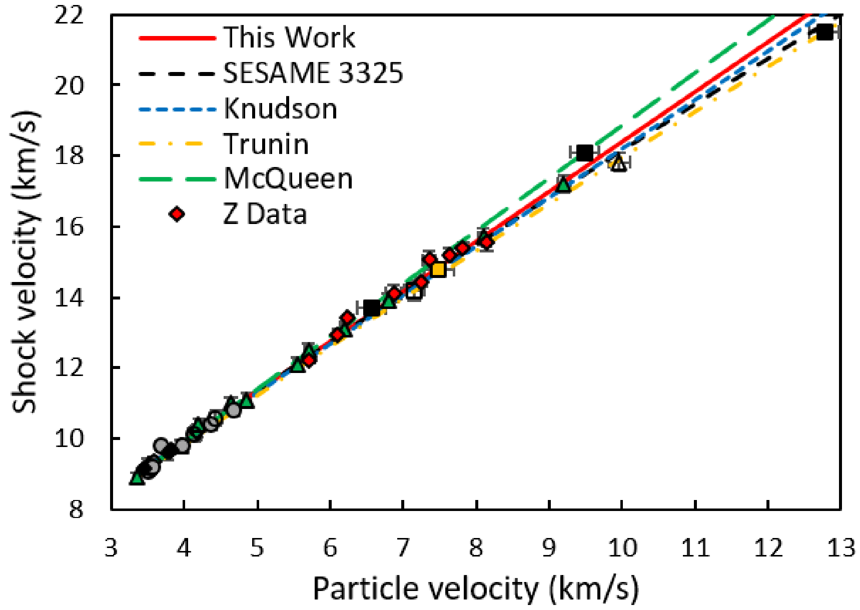
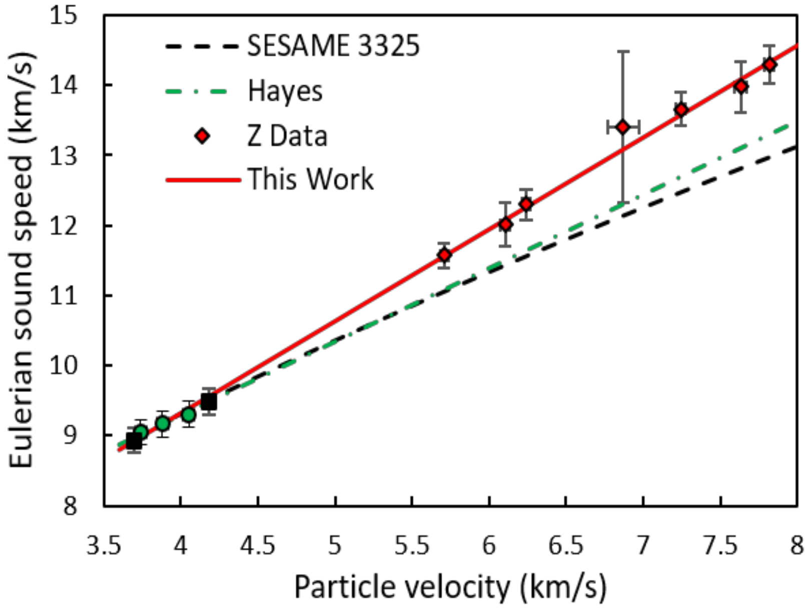
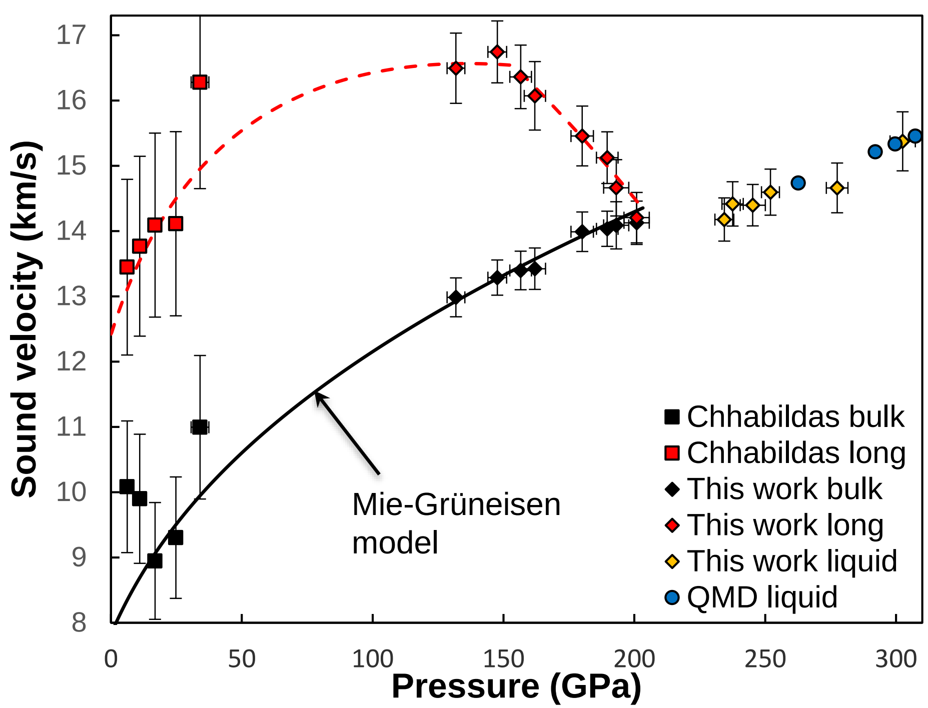
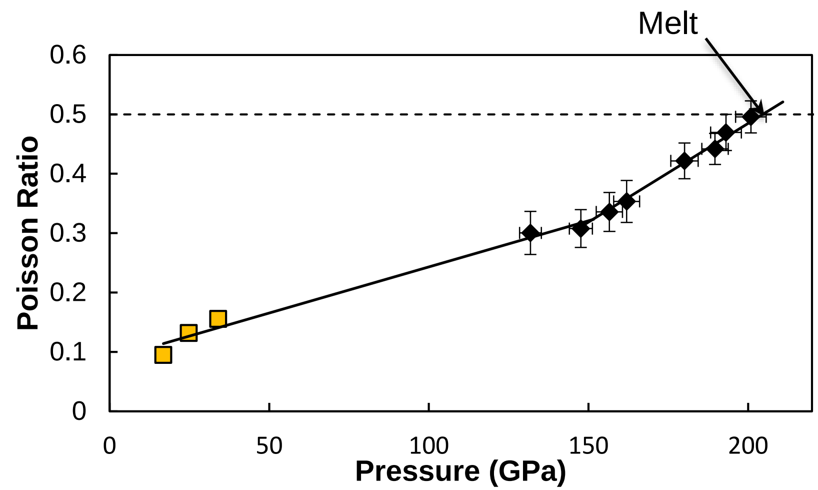




*C. A. McCoy, M. D. Knudson, and S. Root, Submitted to Phys. Rev. B

Beryllium sound velocity results consistent with melt occurring at ~200 GPa

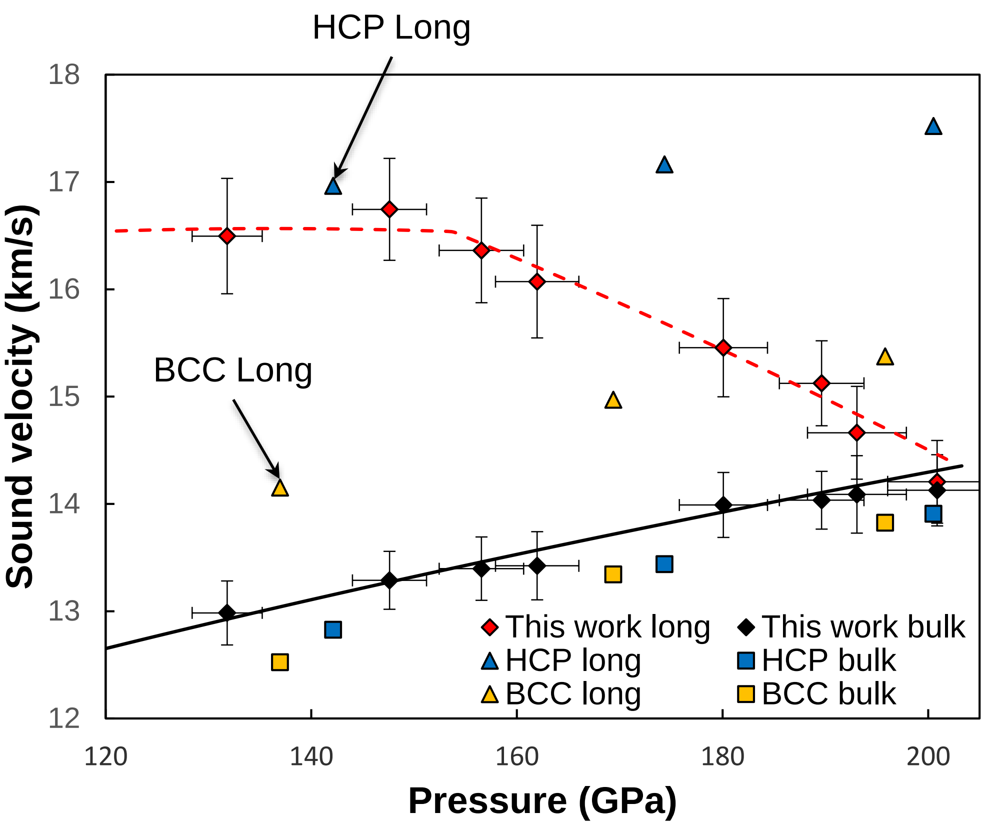


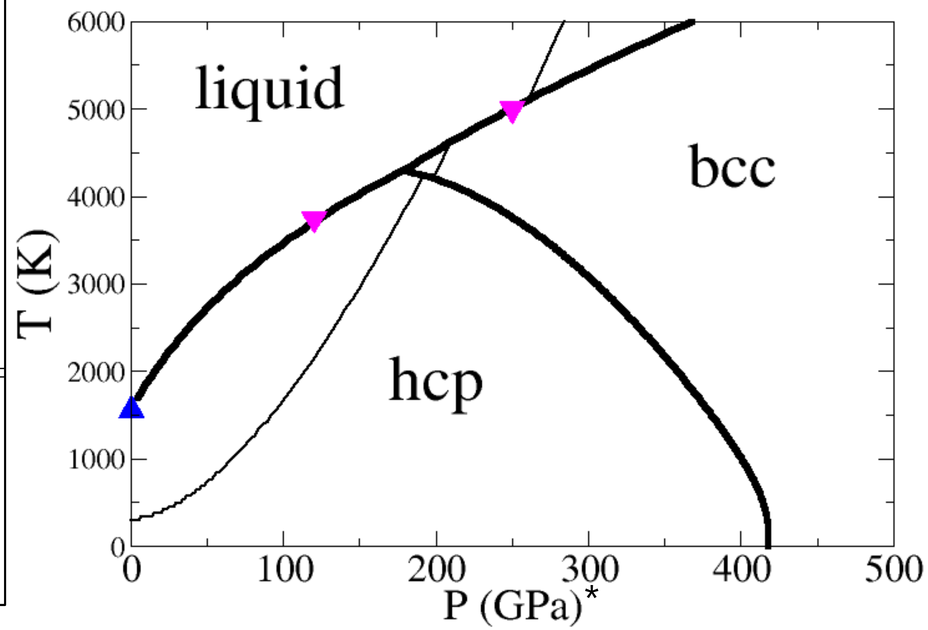


- Sound velocity agrees with Mie-Grüneisen EOS below melt
- Data above melt in good agreement with QMD results

*L. C. Chabildas, J. L. Wise, and J. R. Asay, AIP Conf. Proc. **78**, 422 (1982);

Comparison with QMD suggests that Be melts from HCP phase rather than BCC





*L. X. Benedict, *et al*, Phys. Rev. B 79, 064106 (2009).

Reverberating wave sound velocity measurements demonstrated on OMEGA

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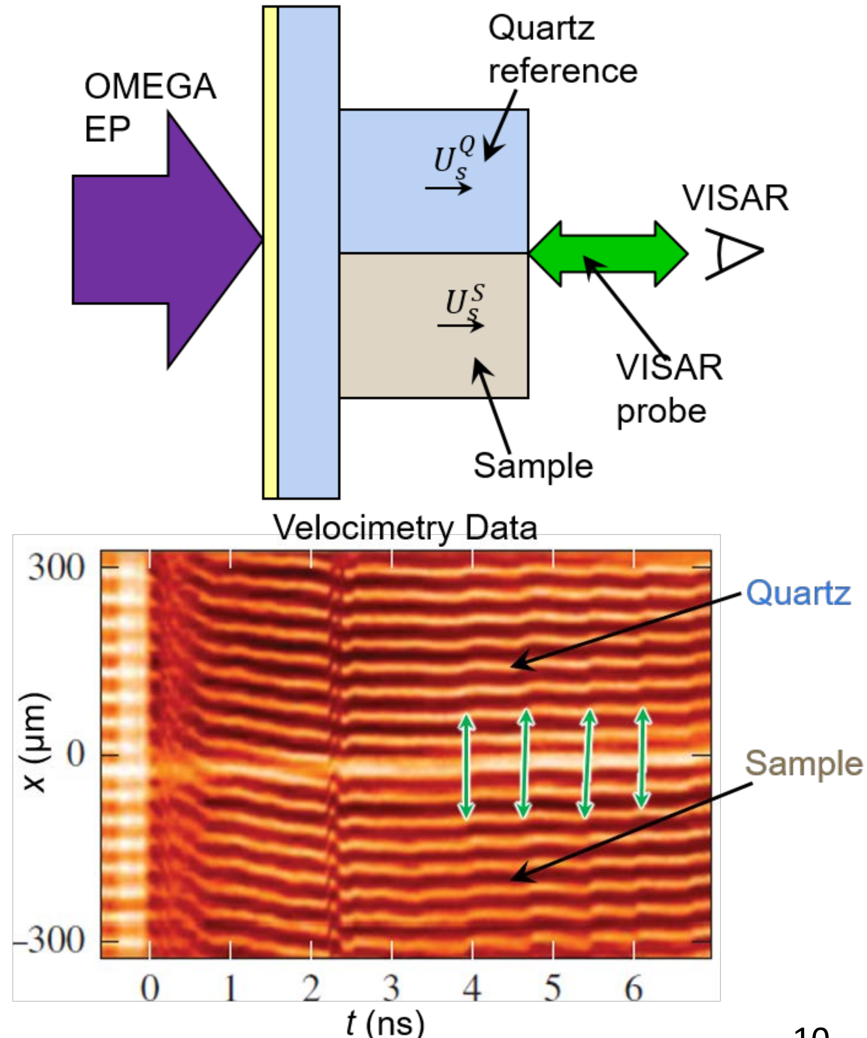
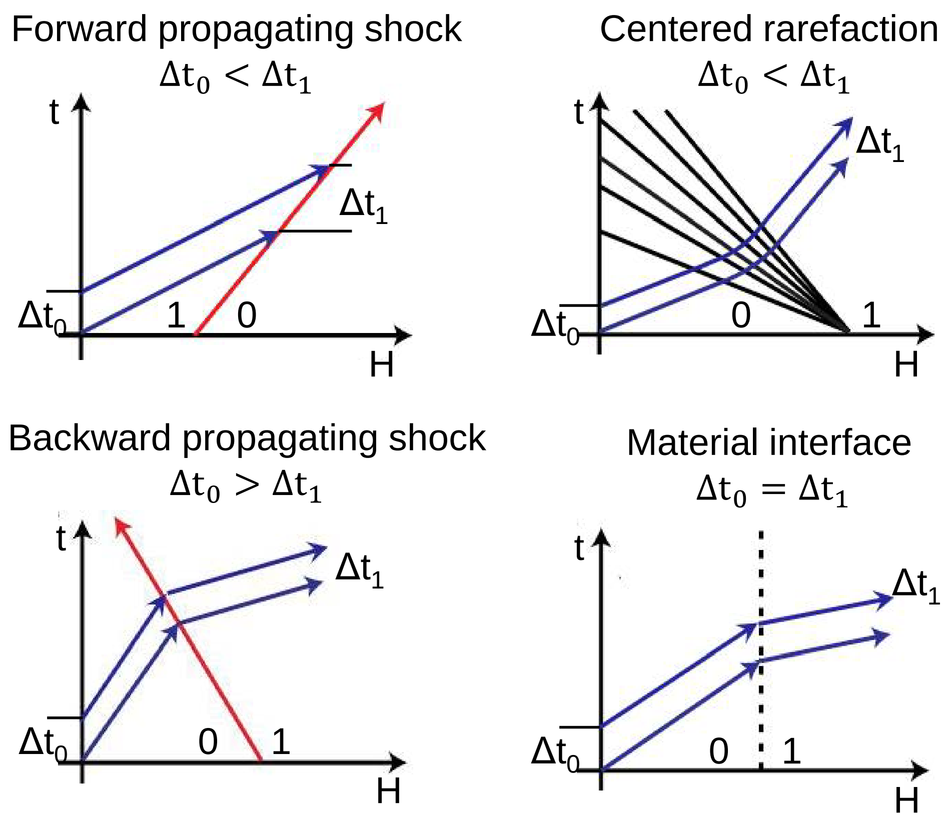
- Thin ablator generated reverberating shock between higher impedance baseplate and laser drive
- Shock velocity in both quartz reference and sample tracked using line-imaging VISAR
- Reverberations produce perturbations to shock velocity which can be related between sample and quartz reference



[*] C. A. McCoy, *et al*, J. Appl. Phys 120, 235901 (2016).

Acoustic disturbances interact with multiple features in a typical target



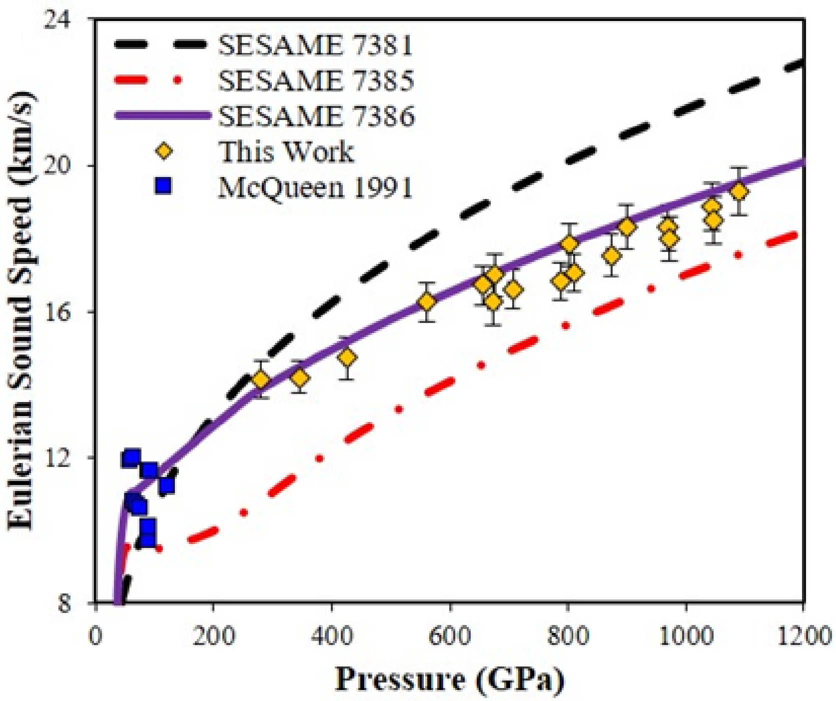
- Acoustic wave
- Shock front
- Rarefaction
- Interface

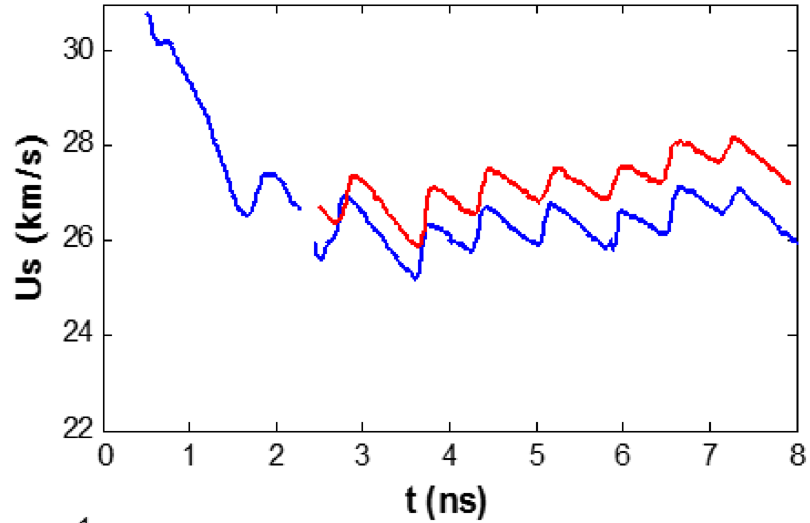
The interaction of the acoustic disturbances with target features is dependent on the Mach number

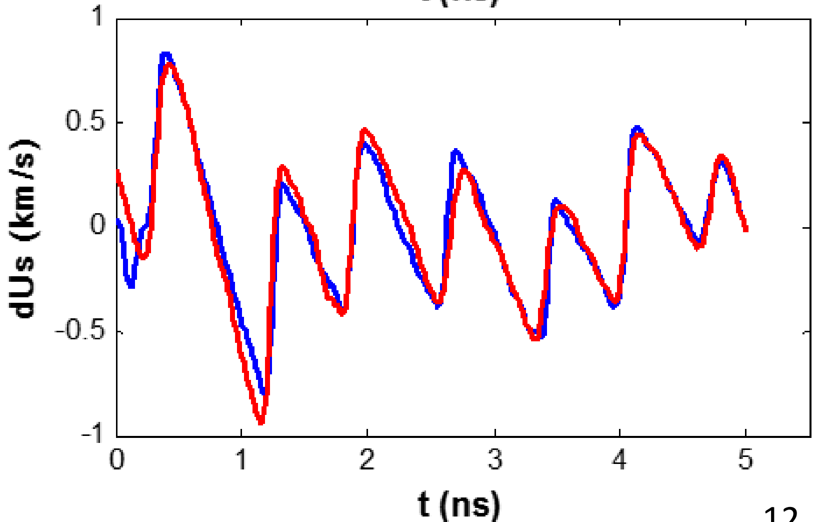
For example, a backward propagating shock is given by:

$$\frac{\Delta t_1}{\Delta t_0} = \frac{1 + M_{S,1}}{1 + M_{S,0}}$$

Matching perturbation profiles provides measurement of sound velocity

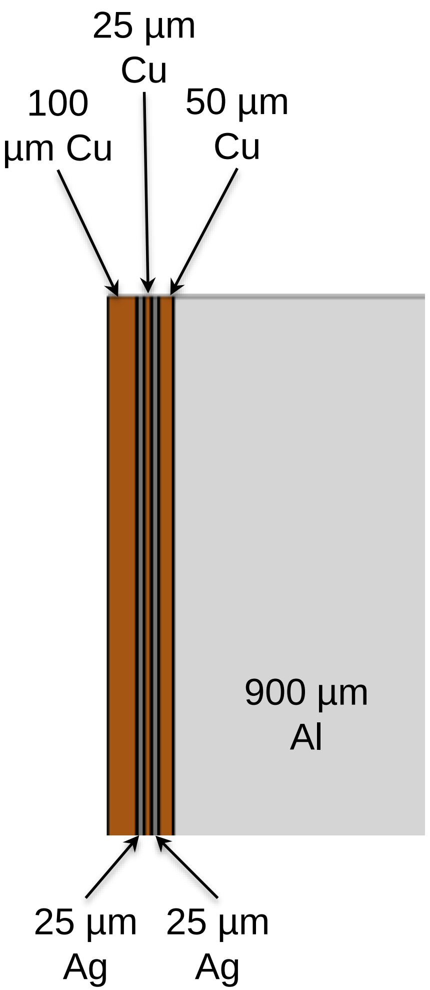


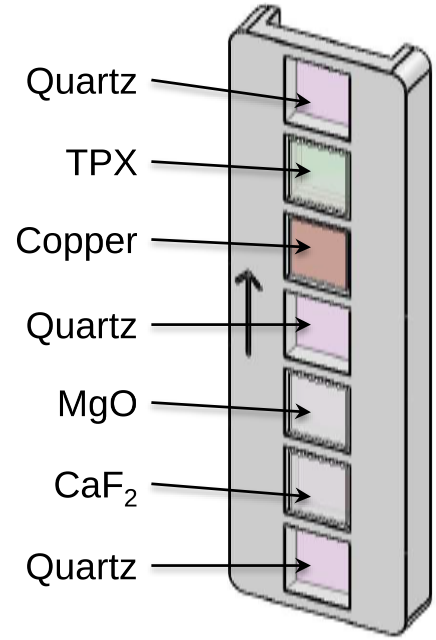




Reverberating wave technique for Z being developed using multilayered flyers

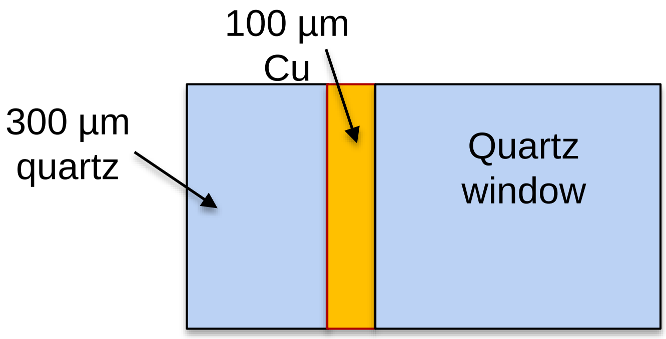
- Technique can study 4 samples simultaneously
  - Maintains quartz reference adjacent to each sample
- Flyer fabricated by plating and machining each layer to specified thickness then machining Al to final size
  - Drive uniformity concern due to stress on flyer and plating/machining each layer

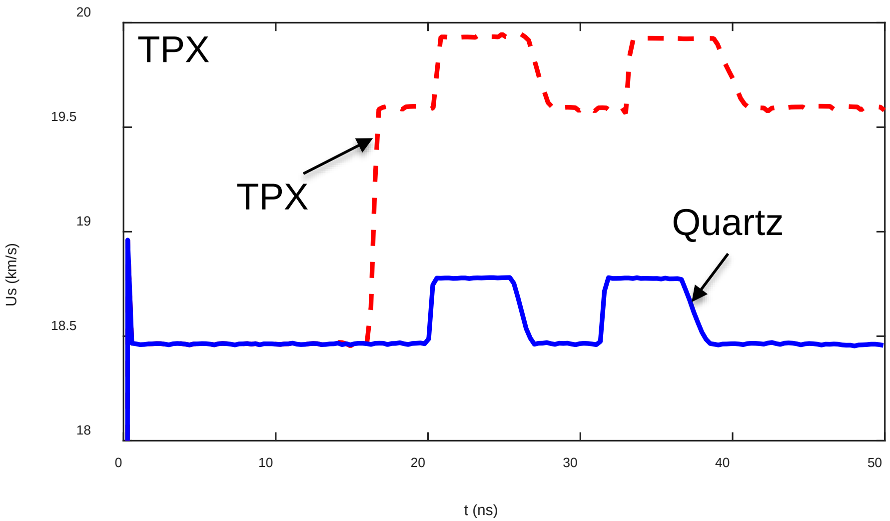


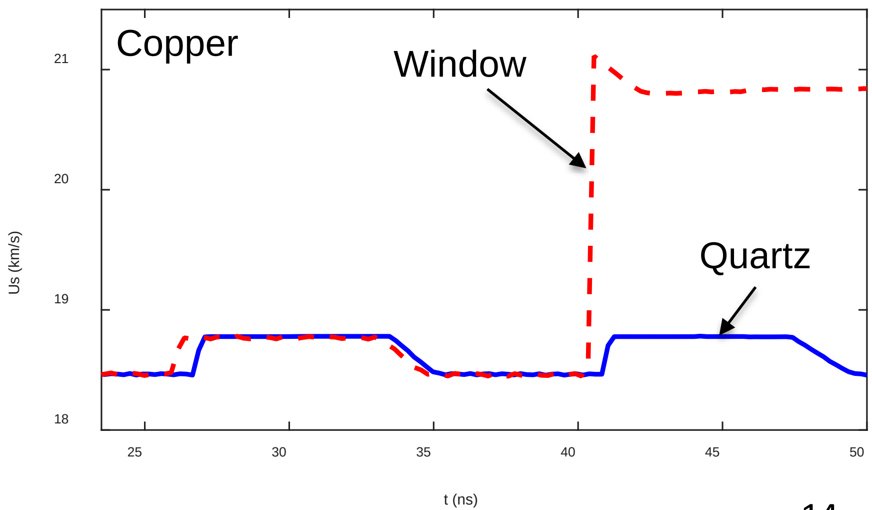


Simulations of Z experiment demonstrate uniform controlled perturbations

- Alternating Cu/Ag layers produce perturbations to shock velocity of ~2%
- Sample thicknesses determined to maximize perturbations for copper sample
  - Experiment valid until overtake of reflected wave







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Acknowledgements

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Thomas R. Boehly, Michelle C. Gregor, Danae N. Polsin, Dayne E. Fratanduono, Peter M. Celliers, Gilbert W. Collins, and David D. Meyerhofer

Z experiments:

Marcus D. Knudson, Michael P. Desjarlais, Seth Root, J. Michael Winey, and Yogendra M. Gupta