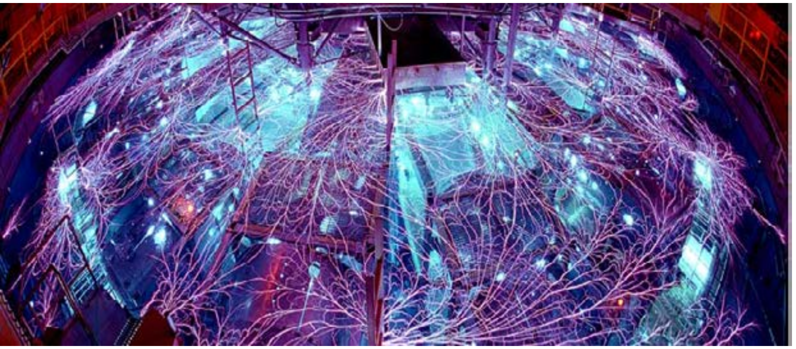
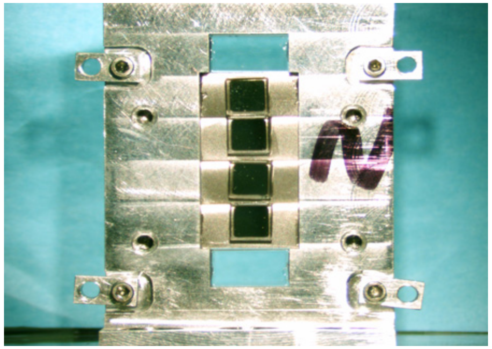
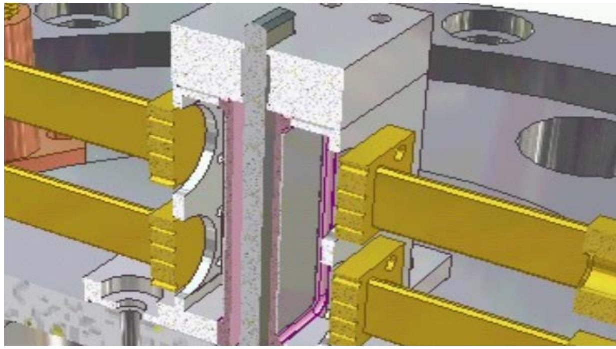
Exceptional service in the national interest

SAND2017-6792C







Sound velocity and strength of beryllium along the principal Hugoniot

Chad McCoy, Marcus Knudson, and Michael Desjarlais

Sandia National Laboratories, Albuquerque, NM

20th Biennial Conference of the APS Topical Group on Shock Compression of Condensed Matter

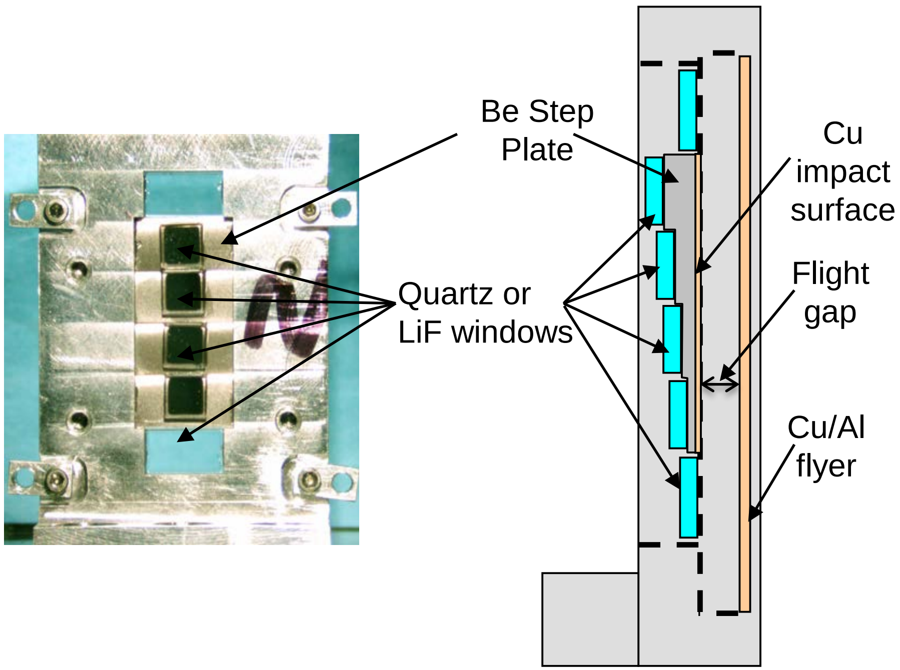
July 9-14, 2017; St. Louis, MO

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

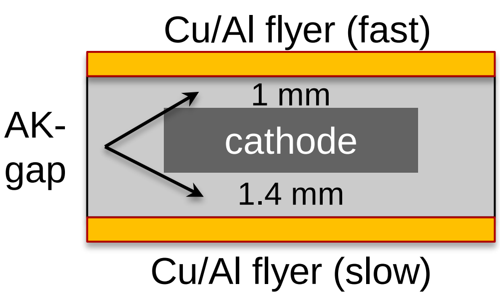
Summary

- Knowledge of the beryllium equation of state is necessary for ICF and MagLIF target physics
- Measured sound velocity along the principal Hugoniot from ~130-300 GPa
  - Data is consistent with Be melting from the HCP phase at ~200 GPa
  - HCP-BCC transition not identified from sound velocity data
- Lagrangian technique was developed to relate shock velocity measurement to window interface velocity
  - Technique used with quartz windows to make wave profile measurements in Be
- Shear modulus and yield strength rapidly decrease ~50 GPa prior to onset of melt

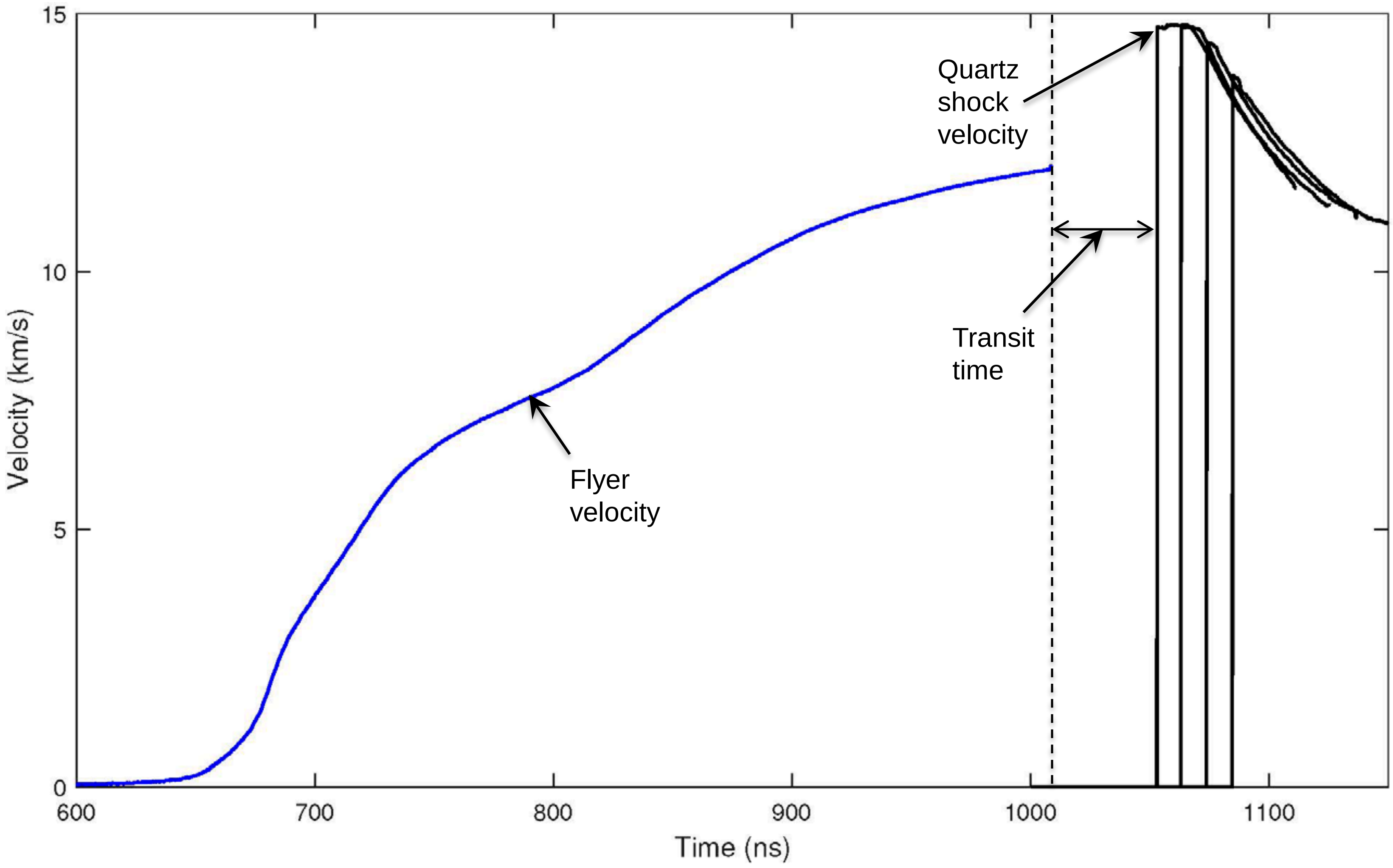
Stepped beryllium targets were impacted with multilayered flyer plates



- Flyer velocities ranged from 7-13 km/s
- Experiments used asymmetric loads to launch 2 flyers with ~10% different velocities per shot

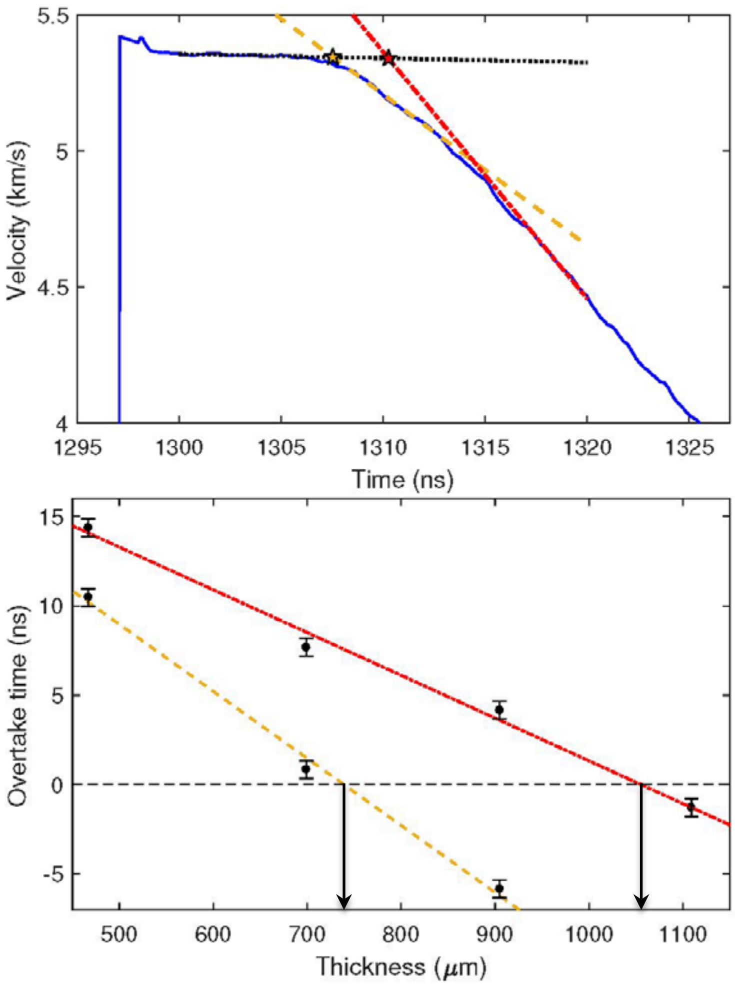


Flyer velocity, Be transit time, and quartz shock velocity measured with VISAR

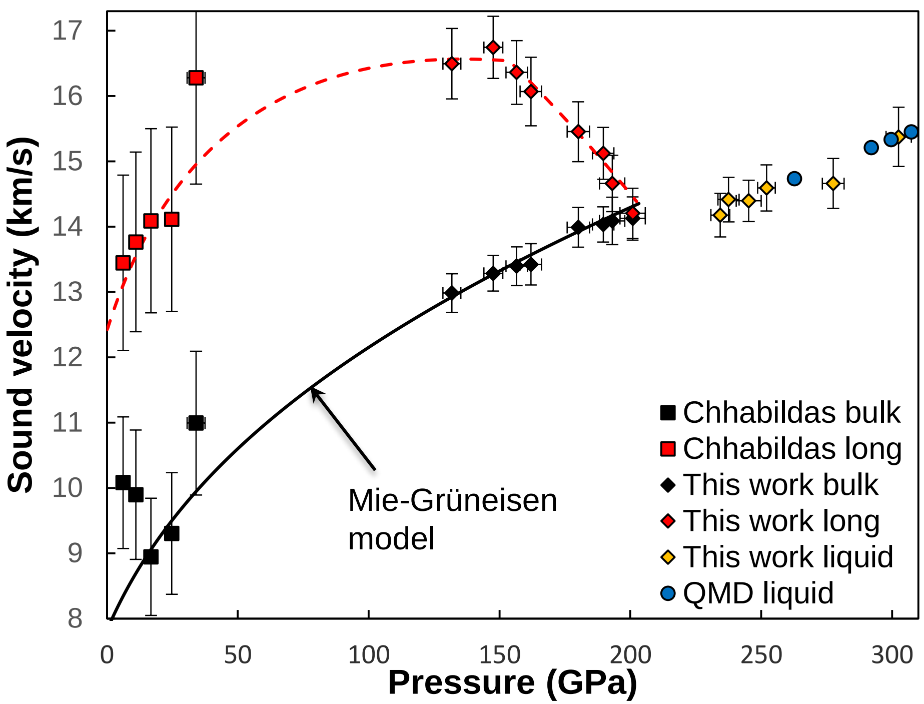


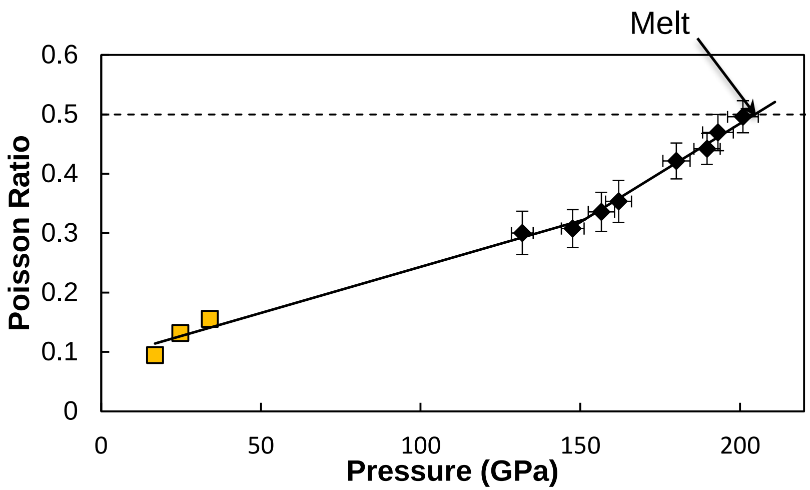
Longitudinal and bulk sound velocities determined from overtake of release wave

- Longitudinal and bulk overtake times measured for each step
- Overtake times interpolated for thickness at which overtake occurs
- Sound velocity calculated relative to copper layer on flyer and target



Sound velocity results consistent with melt occurring at ~200 GPa

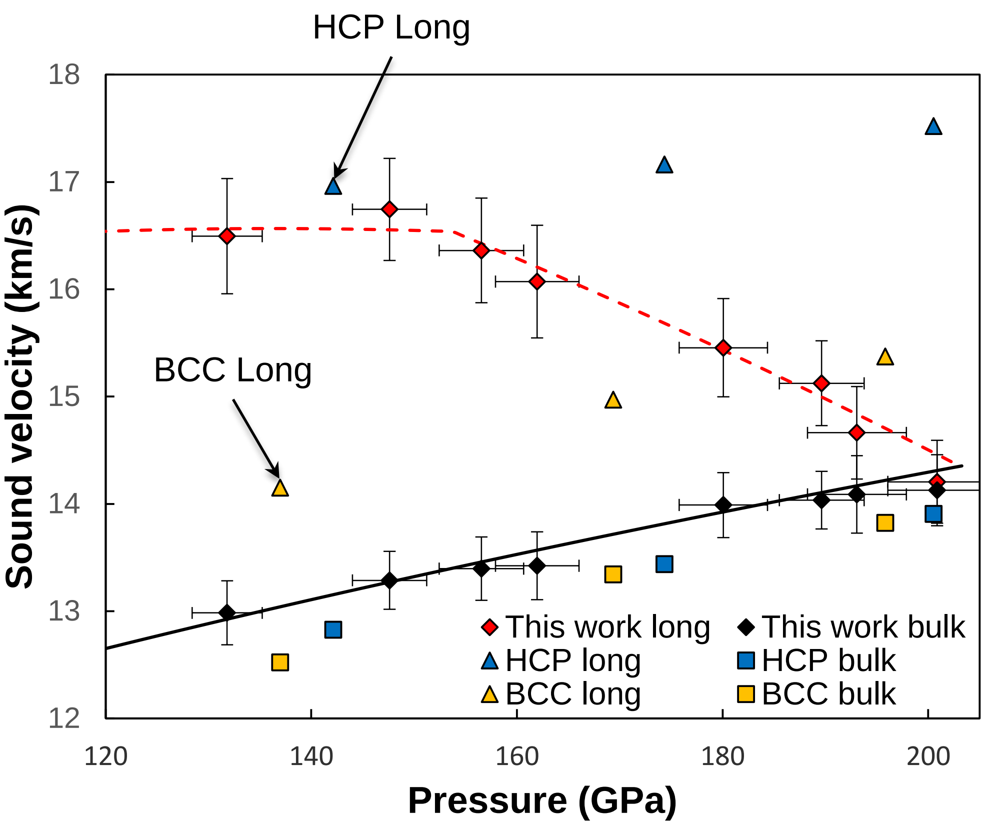


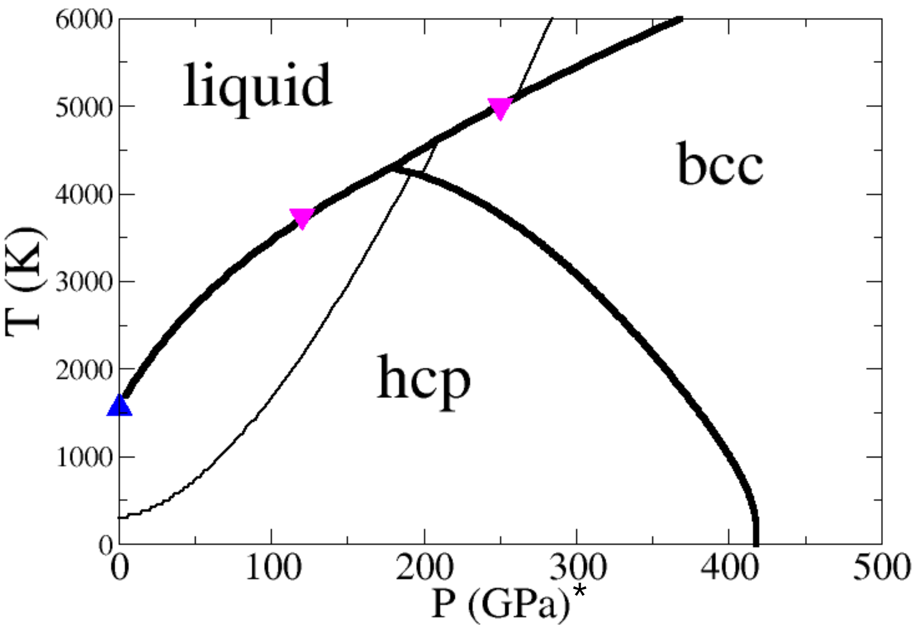


- Sound velocity agrees with Mie-Grüneisen EOS below melt
- Data above melt in good agreement with QMD results

*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



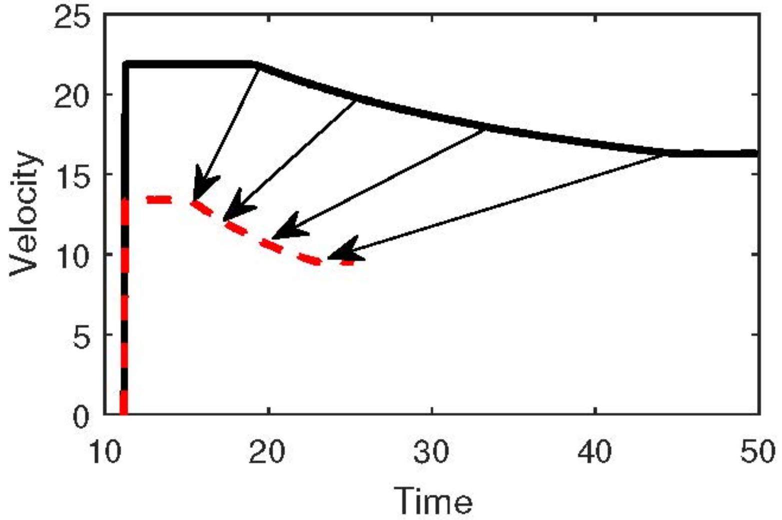


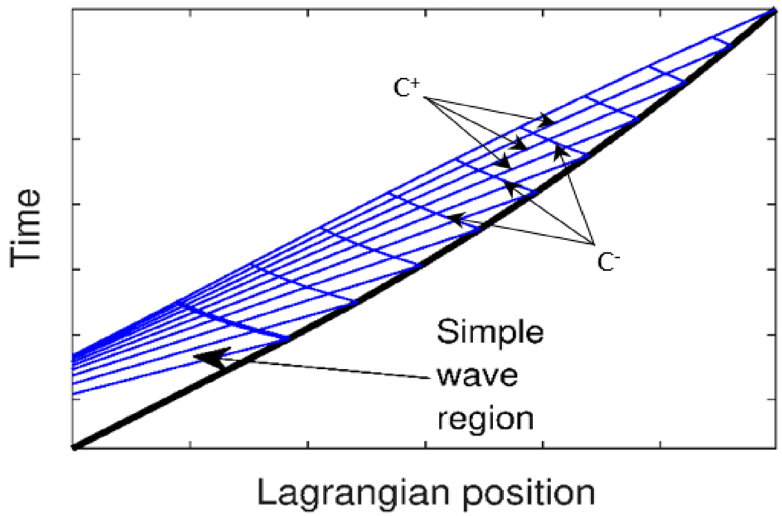
*L. X. Benedict, *et al*, Phys. Rev. B 79, 064106 (2009).

A Lagrangian technique was developed to determine interface profile from shock velocity

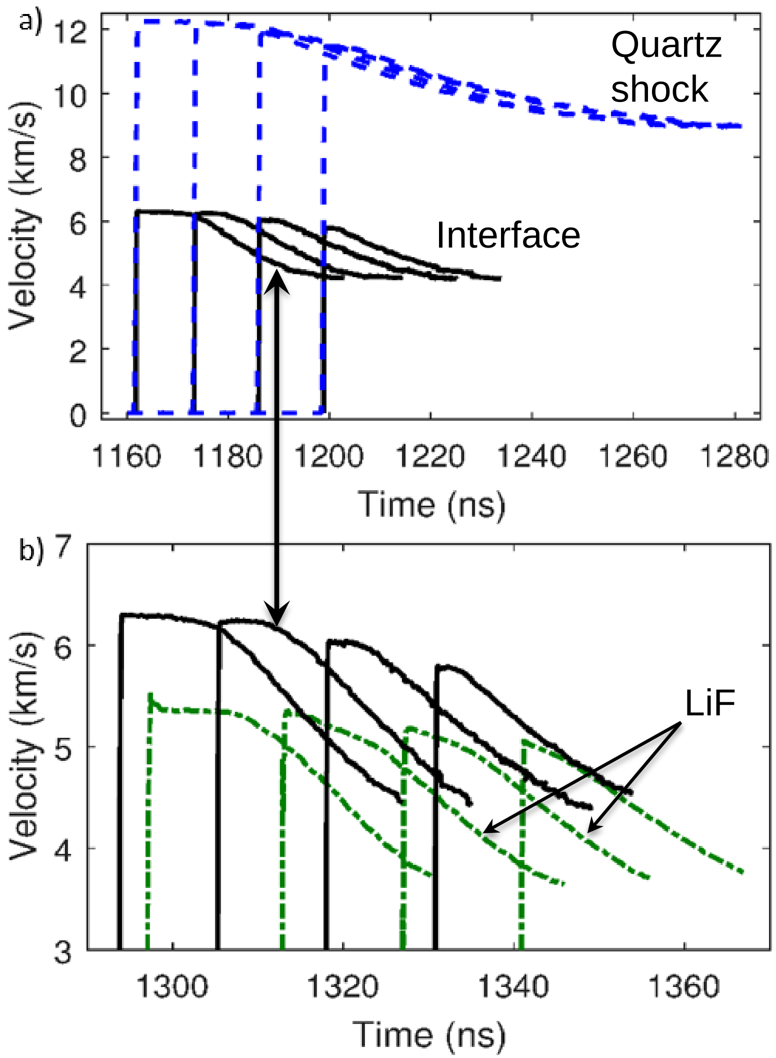
- C^+ characteristics propagated backwards from shock front to interface
- Sound velocity at intersection of C^+ and C^- characteristics calculated from release at Lagrangian coordinate
- Particle velocity at interface calculated from Riemann invariants:

$$u_p = \frac{R^+ + R^-}{2}$$





Quartz windows extend the regime where wave-profile measurements are possible



- LiF is transparent under shock compression to ~200 GPa
  - Be melt ~200 GPa → ~225 GPa in LiF/quartz
- Shock in quartz reflective above 150 GPa
  - Quartz sound velocity in Lagrangian frame is determined from release model*

*M. D. Knudson and M. P. Desjarlais, Phys. Rev. B **88**, 184107 (2013)

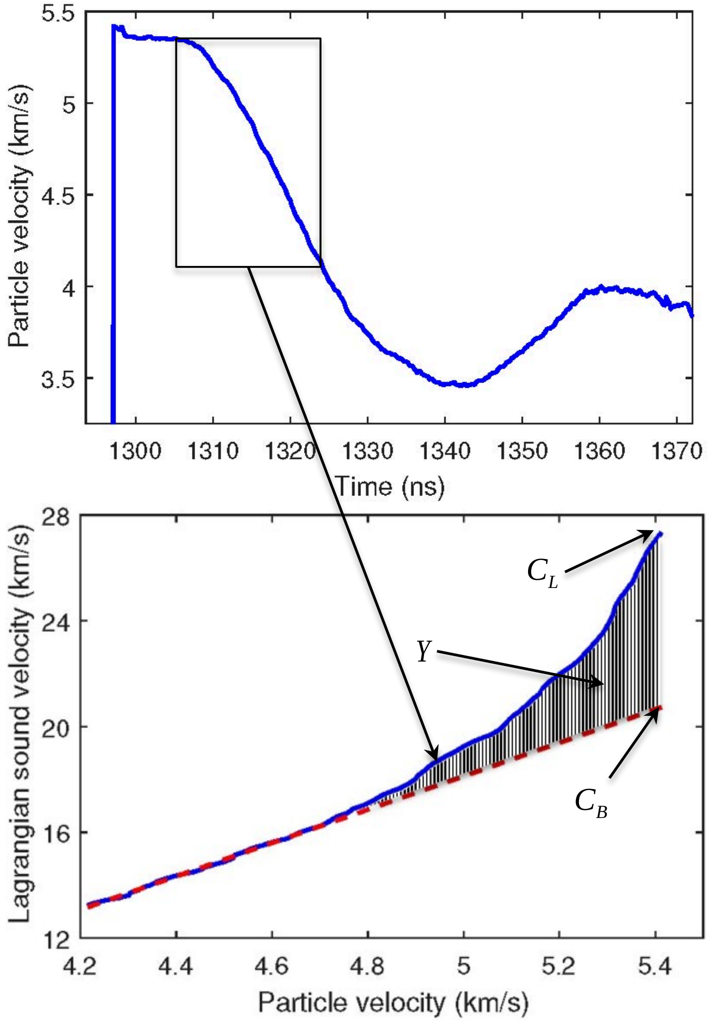
Beryllium strength estimated from wave profile measurements

- *In-situ* velocities determined using incremental impedance match technique*
- Shear modulus calculated from sound velocities

$$G = \frac{3}{4}\frac{\rho_0^2}{\rho}\left(C_L^2 - C_B^2\right)$$

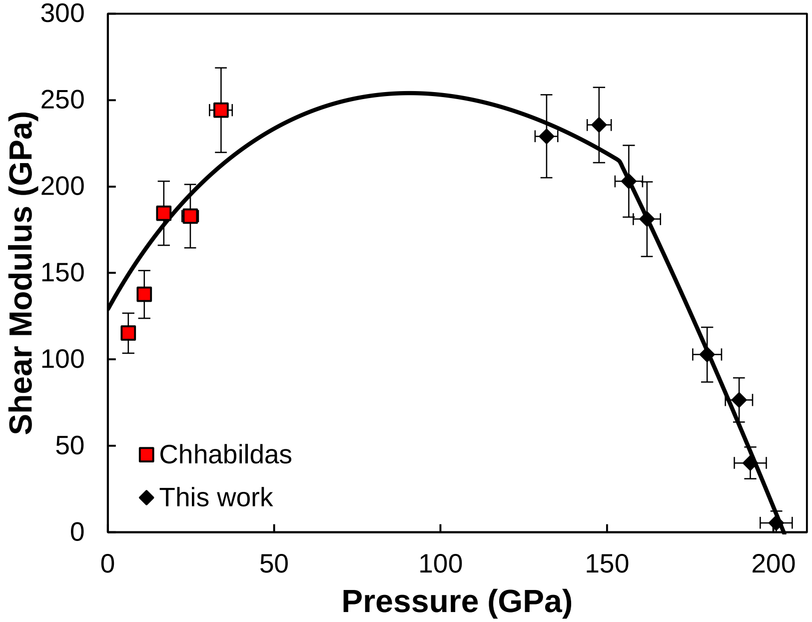
- Yield strength determined from

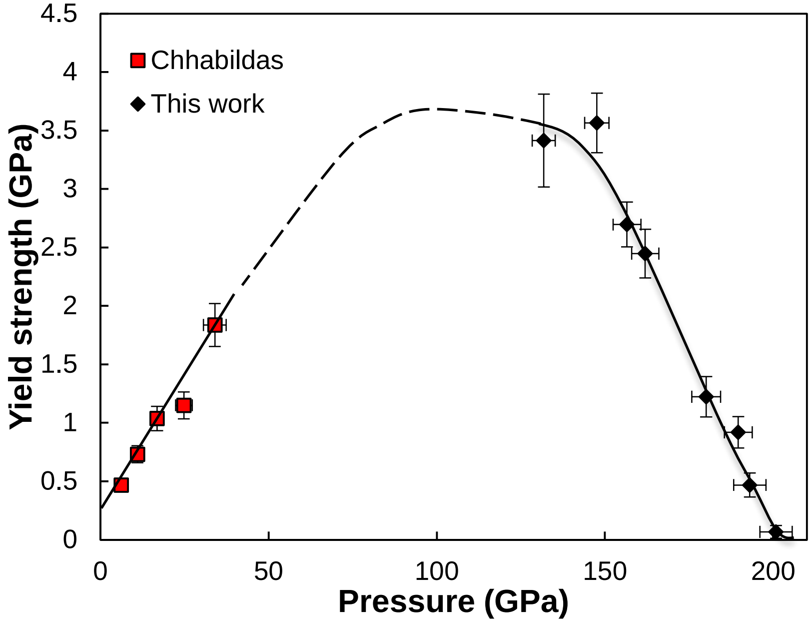
$$Y = -\frac{3}{4}\int \frac{C_L^2 - C_B^2}{C_L} du$$



*J. Lipkin and J. R. Asay, J. Appl. Phys. **48**, 182 (1977)

Shear modulus and yield strength significantly decrease ~50 GPa prior to melt





Summary

- Knowledge of the beryllium equation of state is necessary for ICF and MagLIF target physics
- Measured sound velocity along the principal Hugoniot from ~130-300 GPa
  - Data is consistent with Be melting from the HCP phase at ~200 GPa
  - HCP-BCC transition not identified from sound velocity data
- Lagrangian technique was developed to relate shock velocity measurement to window interface velocity
  - Technique used with quartz windows to make wave profile measurements in Be
- Shear modulus and yield strength rapidly decrease ~50 GPa prior to onset of melt