SAND2006-6533C

Future Technologies Conference II

Material Dynamics Experiments on the Sandia Z Accelerator

Materials Technology Trends for Defense and National Security: Advancements in Assessment and Certification Technologies

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National Nuclear Security Administration

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- Jerry Kerley, Dennis Hayes, Jim Asay (Consultants)

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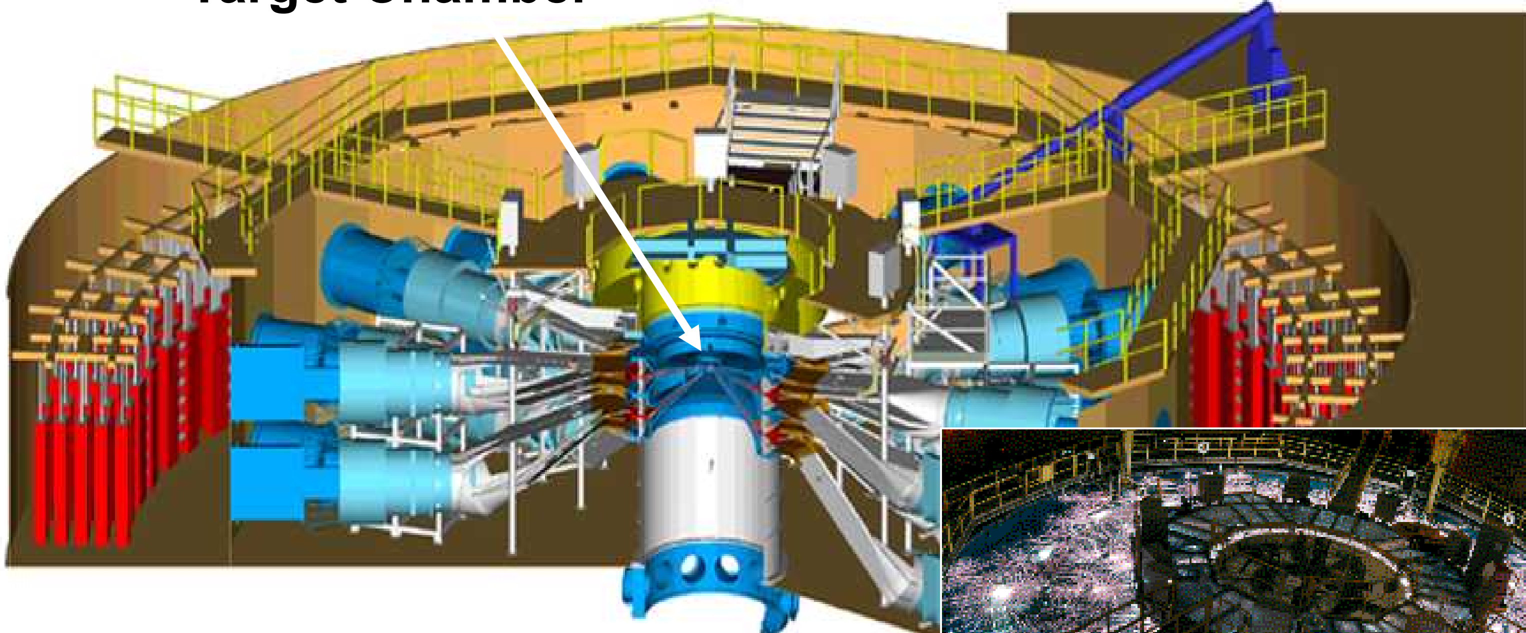
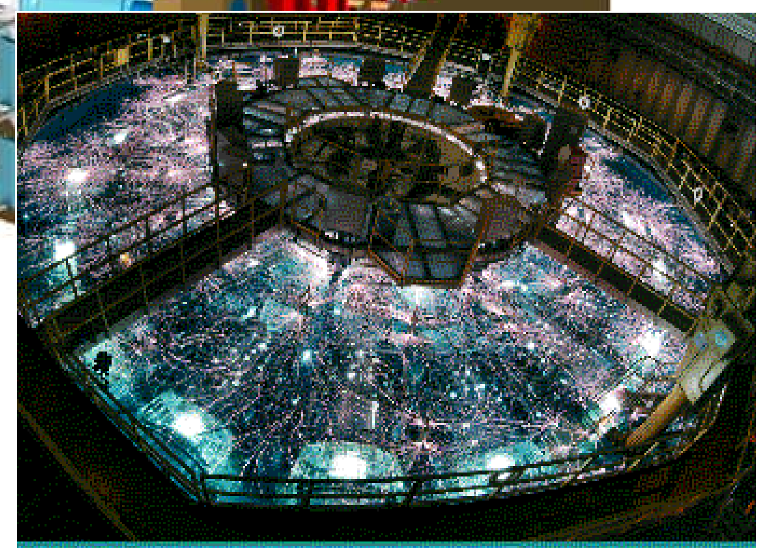
The Sandia Z Accelerator





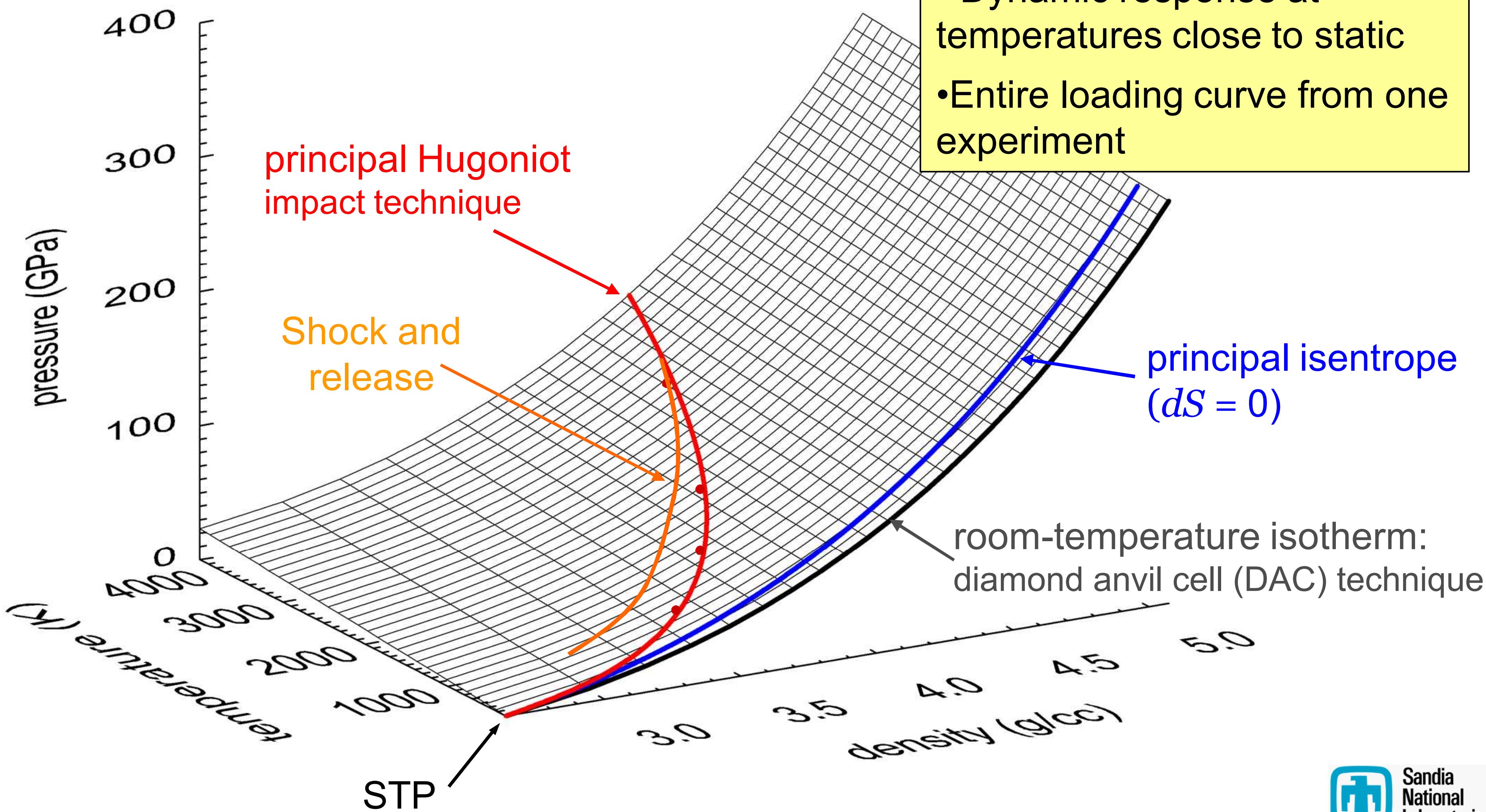
11.5 MJ stored energy

~20 MA peak current

~200-300 ns rise time

Ramp compression on Z enables access to large region of equation of state surface

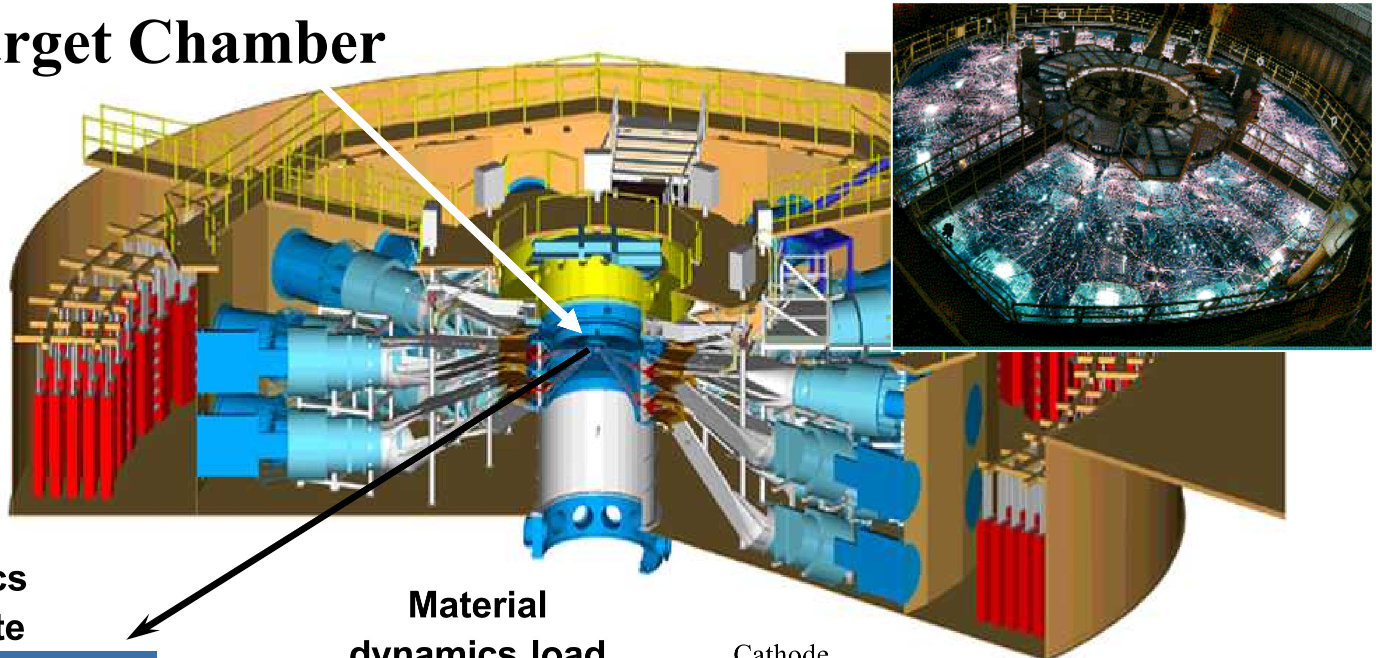
- Dynamic response at temperatures close to static
- Entire loading curve from one experiment



Sandia Z accelerator

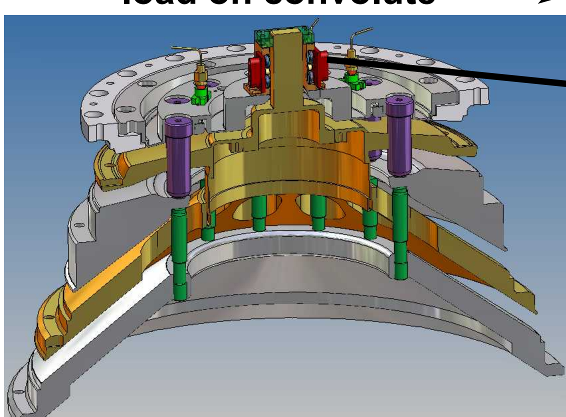
11.5 MJ stored energy
~22 MA peak current
~200 ns rise time

Target Chamber

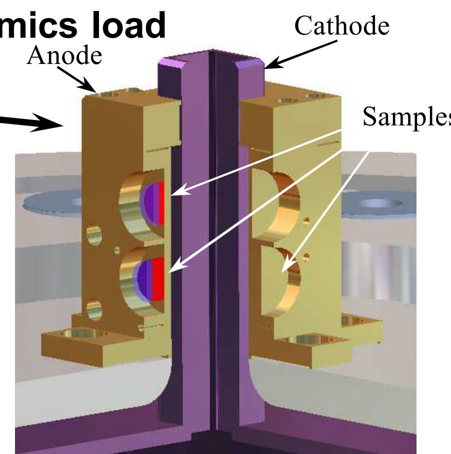


~ 6 m

Material dynamics load on convolute



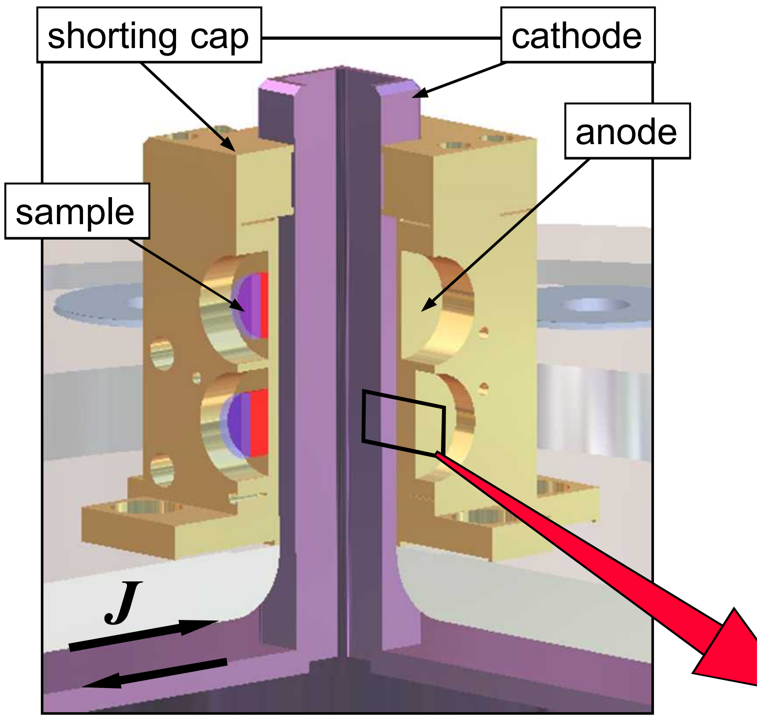
Material dynamics load

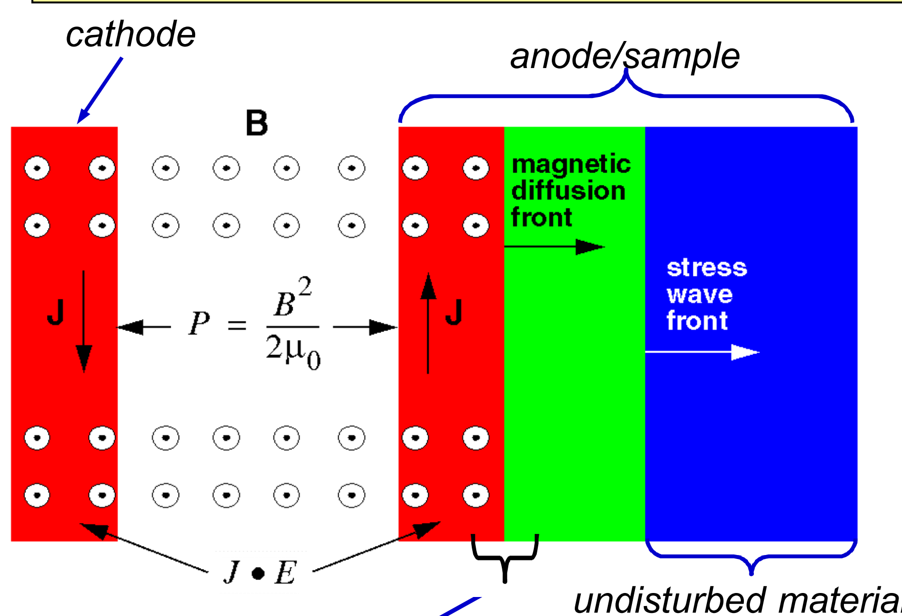


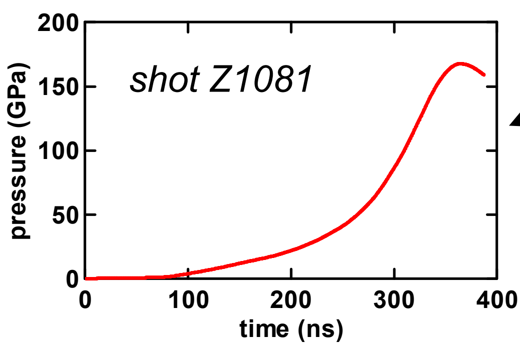
~ 4 cm

Magnetic drive on the Z accelerator can produce smooth ramp loading to very high pressures

- pulse of electric current through rectangular coaxial electrodes (shorted at one end) induces magnetic field
- $J \times B$ magnetic force transferred to electrode material







plasma – gas – liquid – solid

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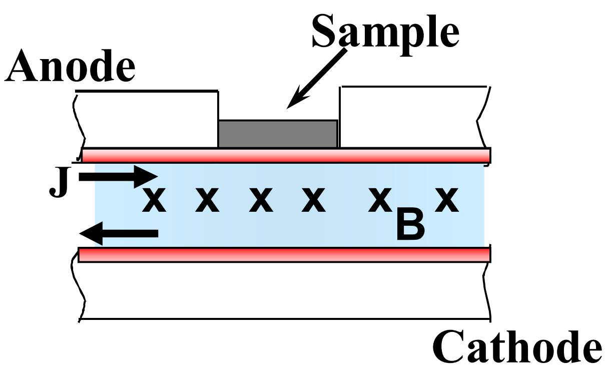
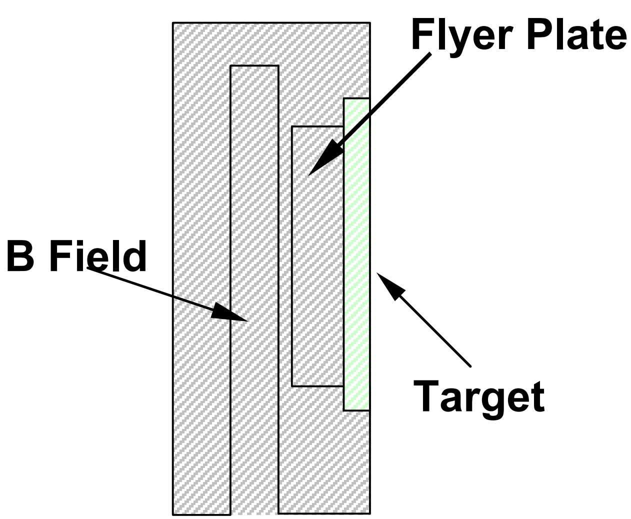
Techniques have been developed on Z for accurate EOS studies—both major advances



Isentropic Compression Experiments (ICE)*

Magnetically produced Isentropic Compression Experiments (ICE) to provide measurement of continuous compression curves to ~3 Mbar
- previously unavailable at Mbar pressures

* Developed with LLNL



Magnetically launched flyer plates

Magnetically driven flyer plates for shock Hugoniot experiments at velocities to ~ 34 km/s
- exceeds gas gun velocities by ~ 4X and pressures by ~ 7-8X with comparable accuracy

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Outline

- Motivation for developing this platform
- Isentropic Compression Experiments (ICE)
  - Isentropic compression of materials
  - Phase transition measurements
  - A-B material comparisons
- Hyper-velocity flyer plate experiments
  - Symmetric impact
  - Relative impact
  - Impedance match
- Conclusions

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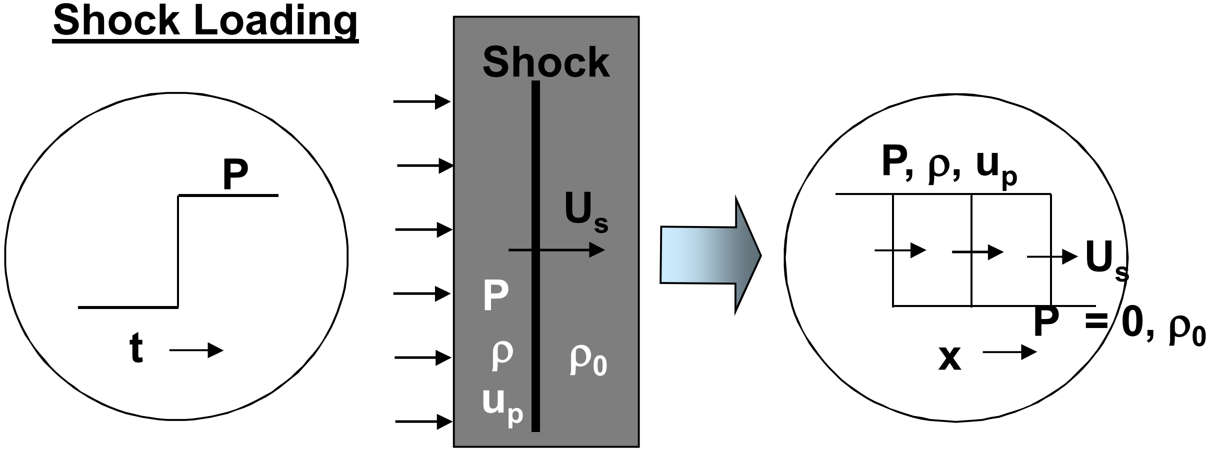
Wave analysis applied to an arbitrary wave results in differential form of jump conditions

Shock Loading

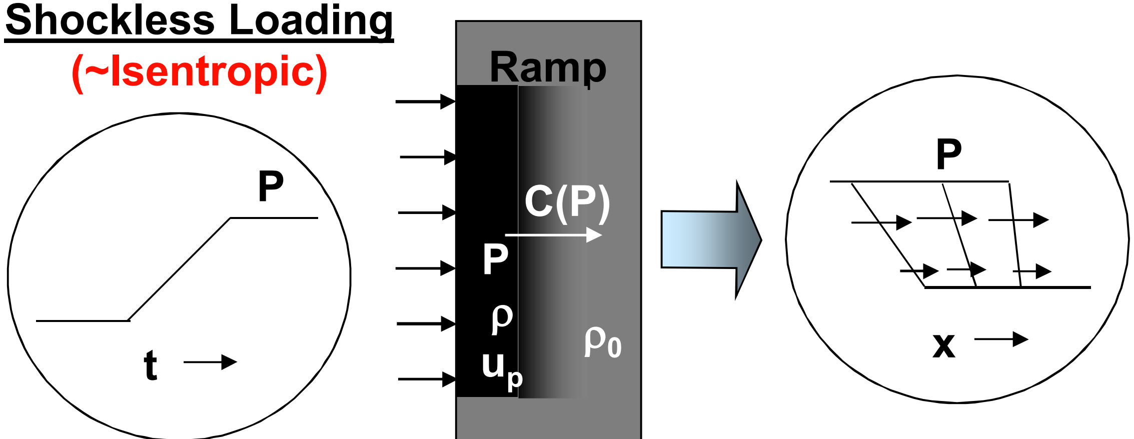


$$\left.\begin{aligned} P &= \rho_0\, U_s\, u_p \\ \rho_0/\rho &= 1 - u_p/U_s \end{aligned}\right\} \quad P_H(V)$$

Conservation of mass, momentum, and energy

Shockless Loading

(~Isentropic)



$$\left.\begin{aligned} \frac{\partial \sigma_x}{\partial x} &= -\rho_0 \frac{\partial u}{\partial t} \\ \frac{\partial u}{\partial x} &= \rho_0 \frac{\partial V}{\partial t} \end{aligned}\right\} \quad \sim P_S(V)$$

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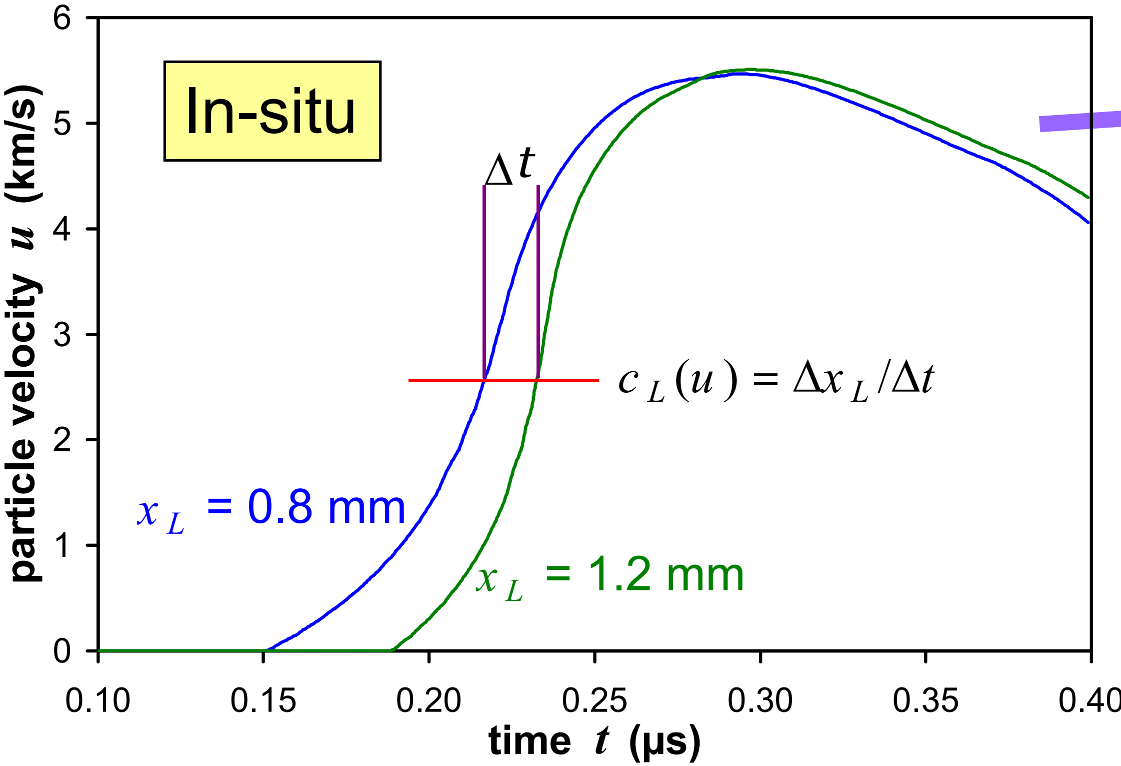
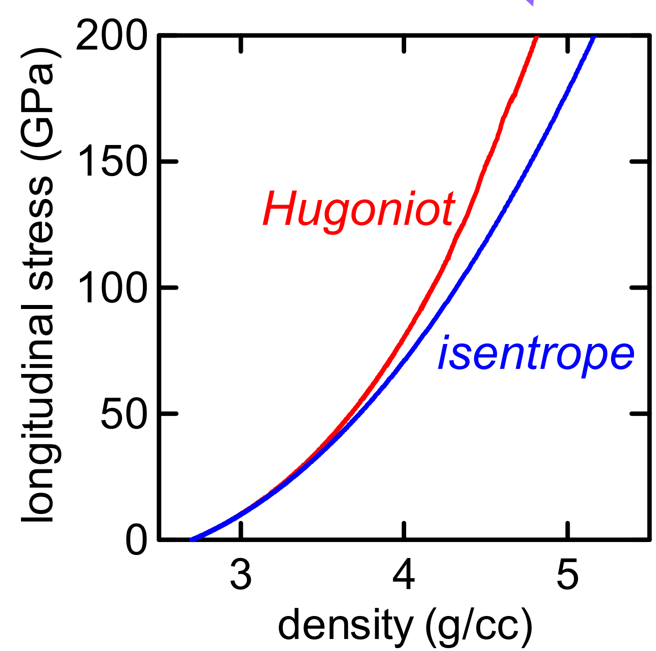
P-ρ response can be obtained by measuring the evolution of the ramp wave



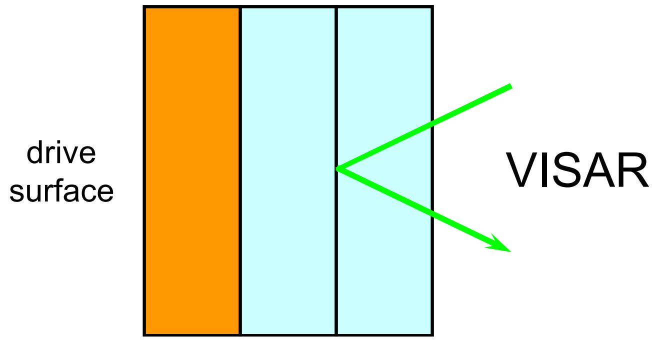
$$d\sigma_x = \rho_0 c_L du$$

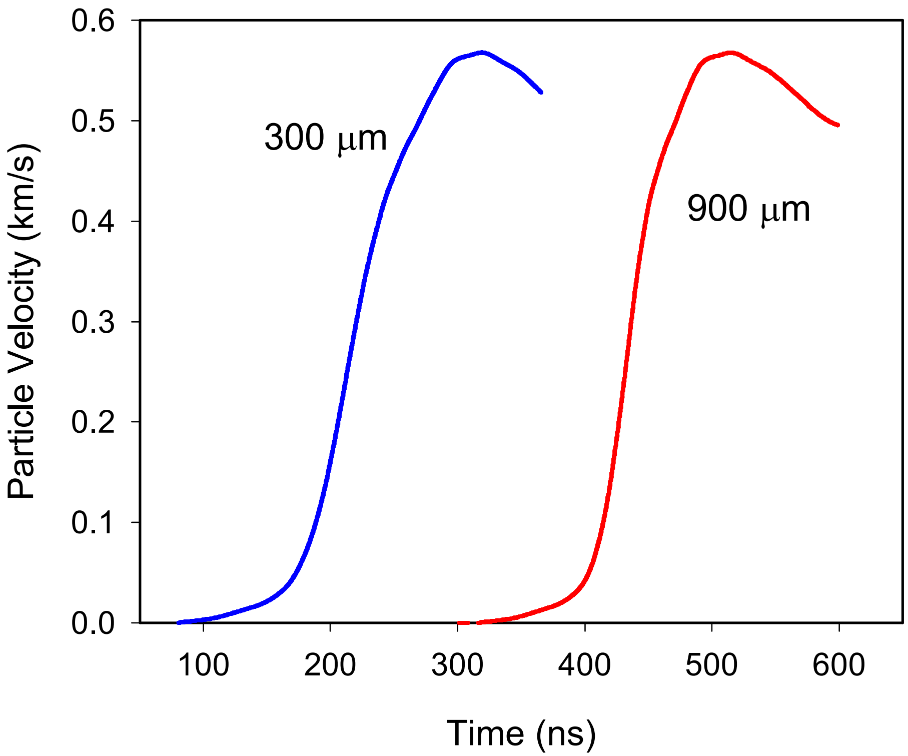
$$\frac{d\rho}{\rho^2} = \frac{du}{\rho_0 c_L}$$

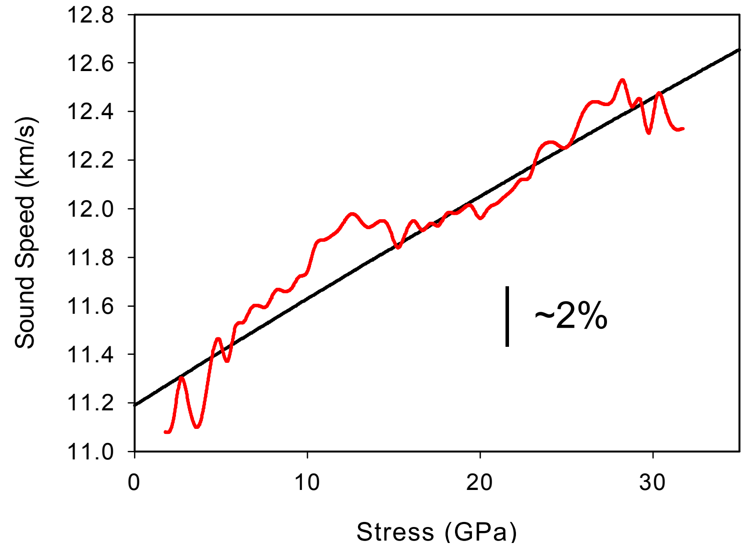


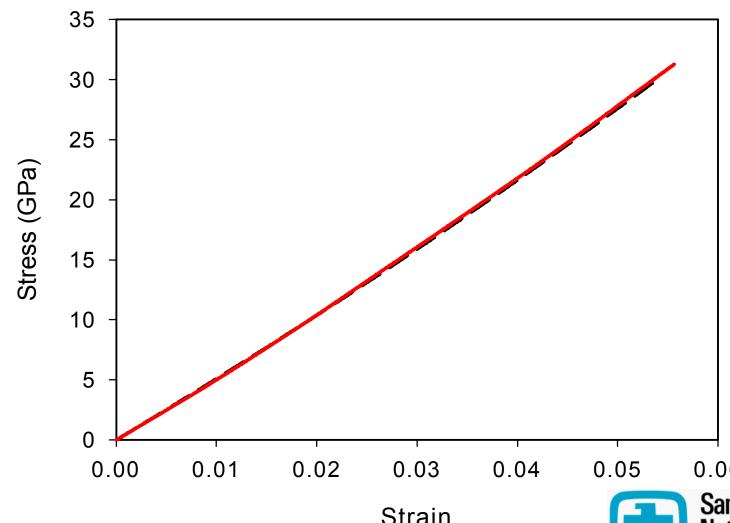
- requires a single, simple right-going wave
- compression is usually quasi-isentropic due to dissipative phenomena (plastic work, viscosity, thermal conduction, *etc.*)

Simple example - Isentropic compression experiment in single crystal Sapphire

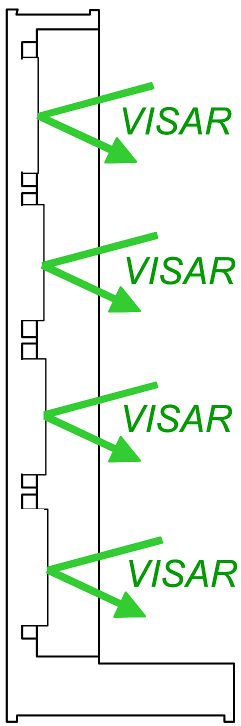


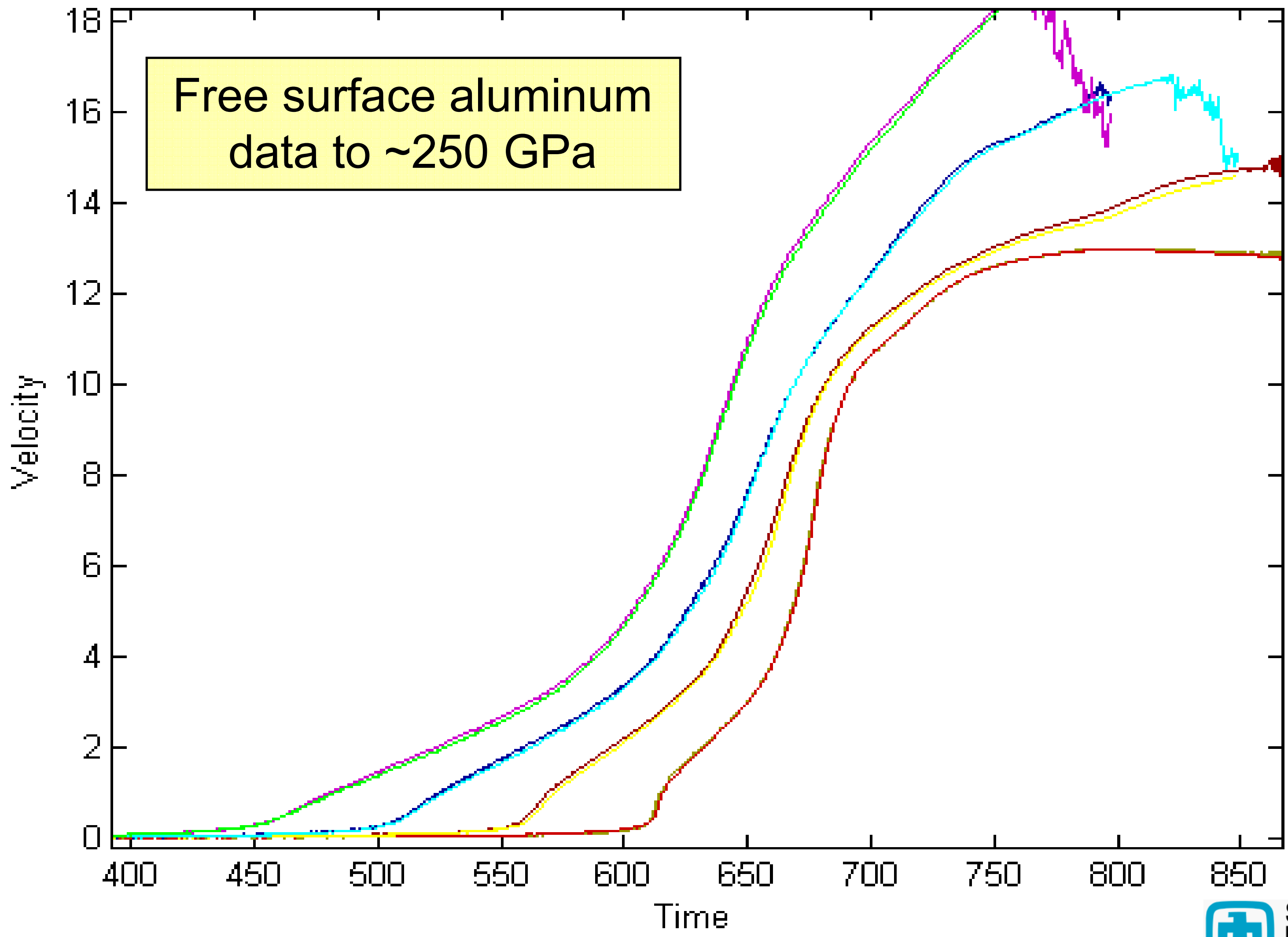






Pulse shaping and MHD modeling has enabled loading of aluminum to ~250 GPa at > 1.8 mm





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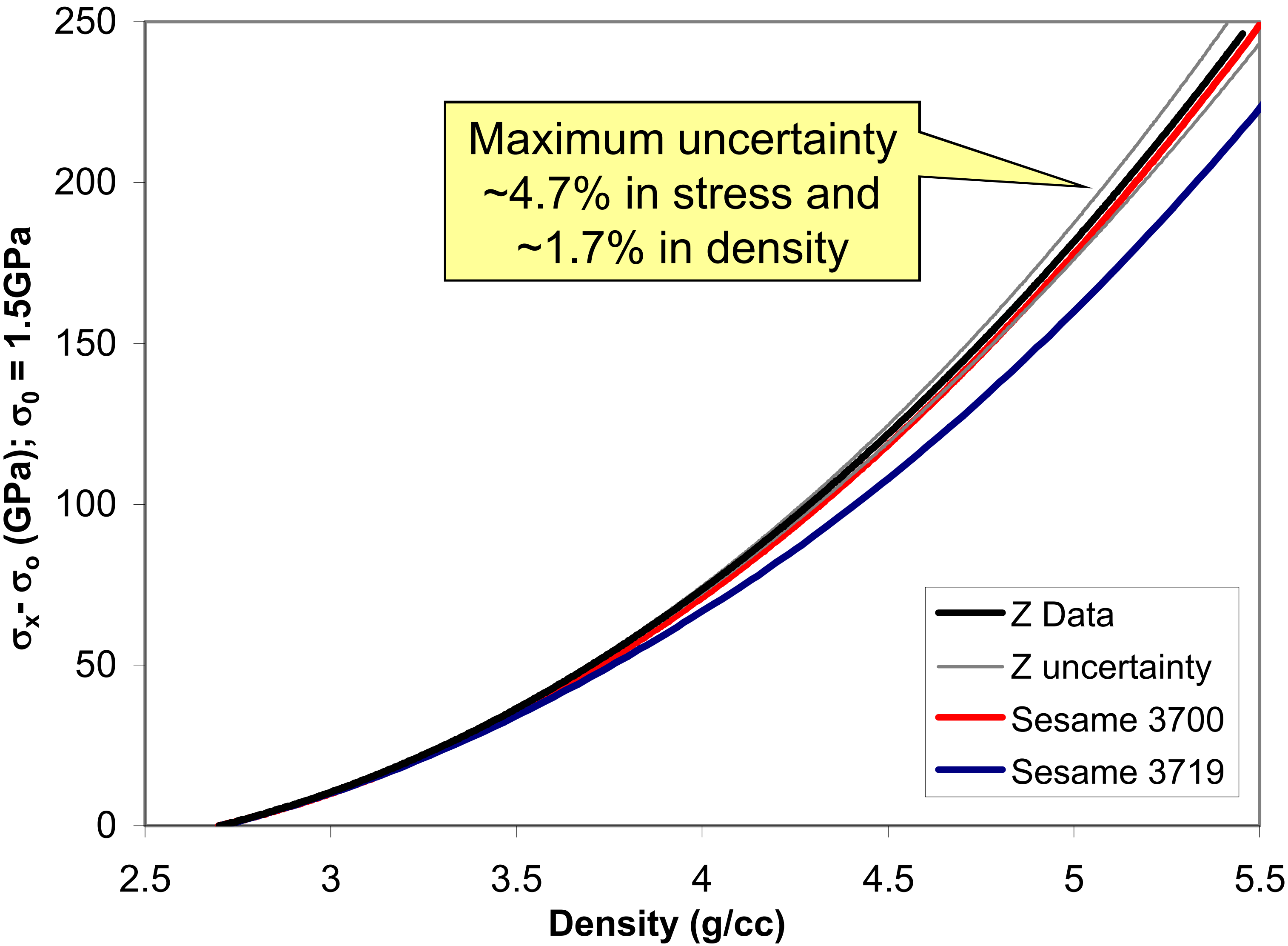
ICE technique has been used to infer the isentrope of aluminum to ~250 GPa



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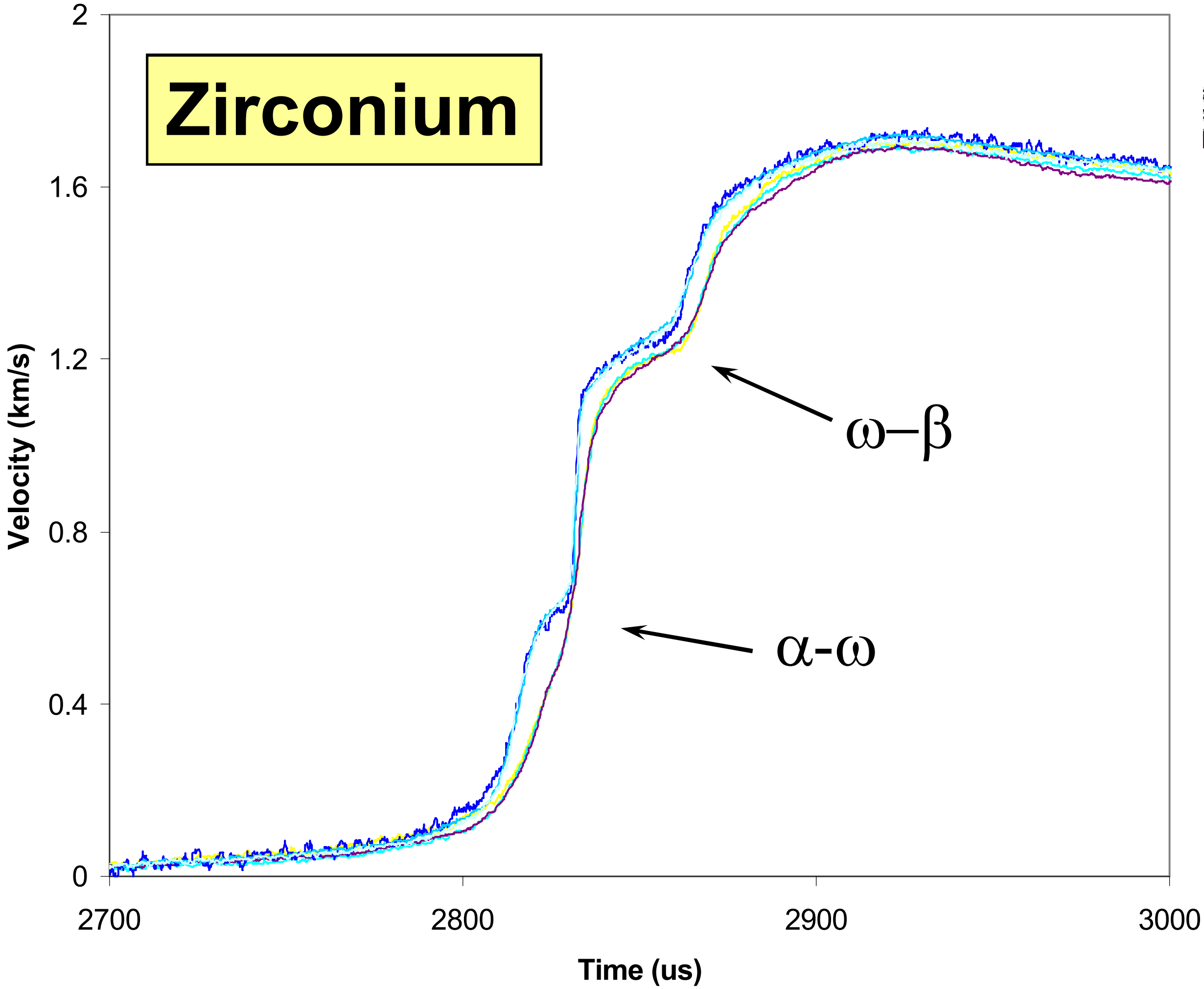
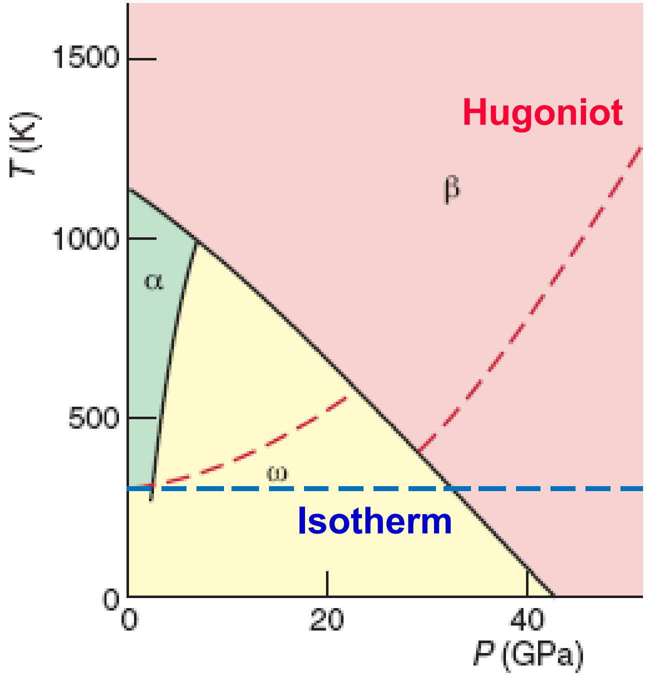
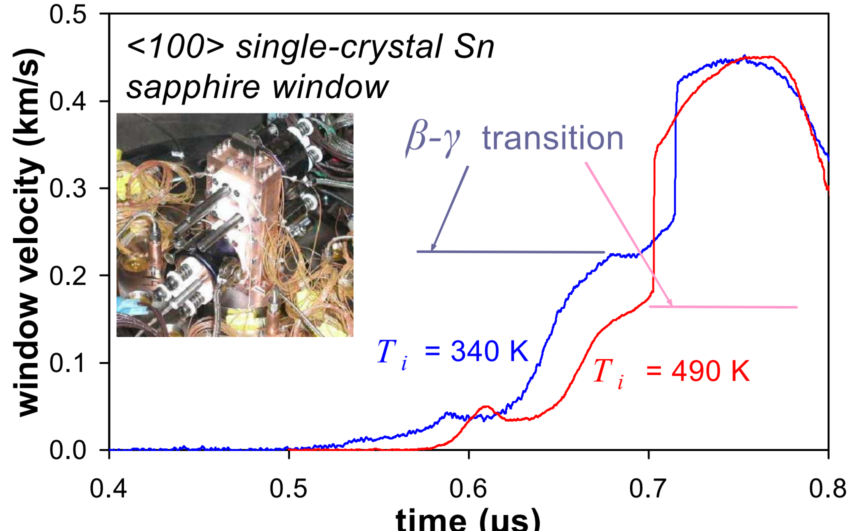
Phase transition data have been obtained on various impure samples of Zr

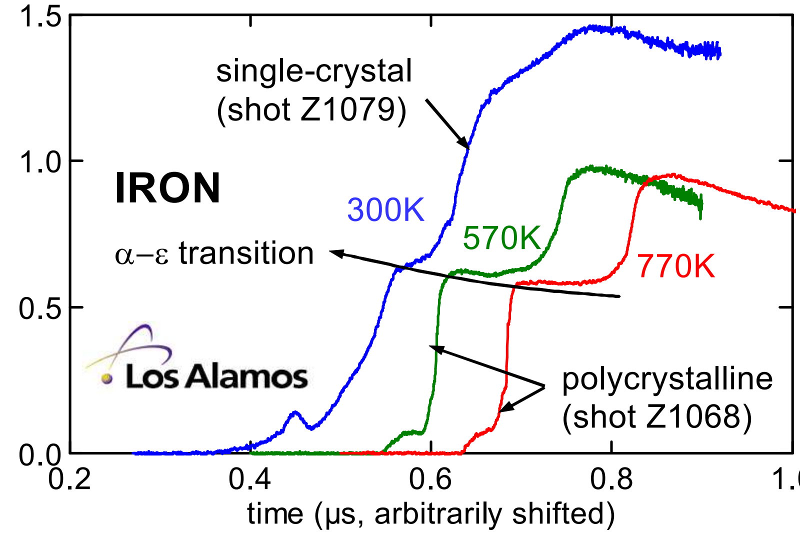


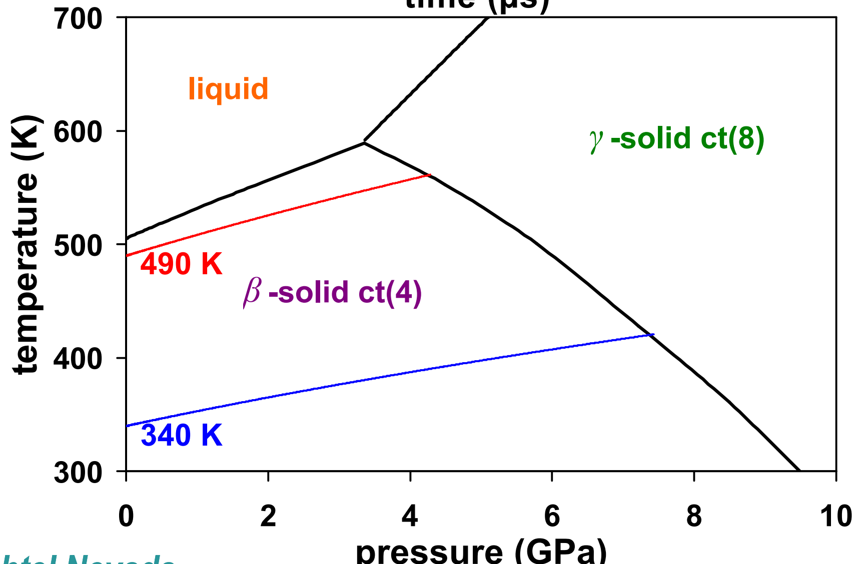


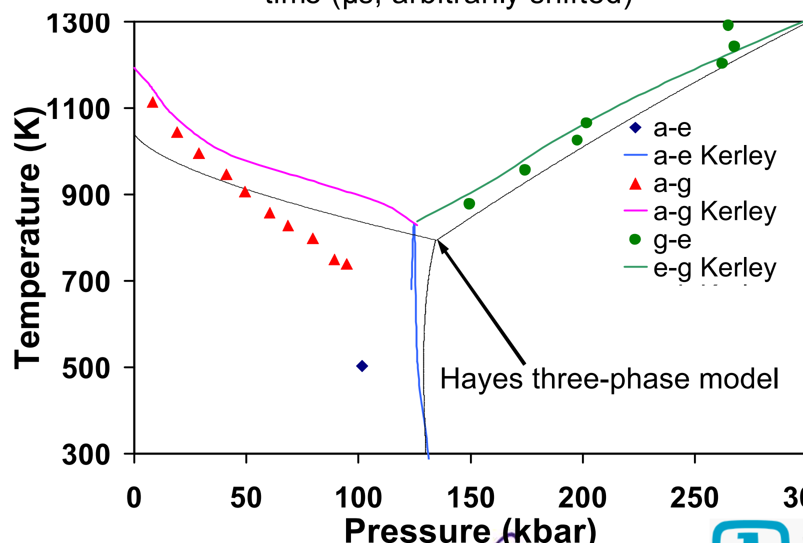
Significant differences in the α-ω phase transition observed for different oxygen impurity levels

Preliminary data on pre-heated solids show clear temperature effect on phase transition









Bechtel Nevada

Los Alamos

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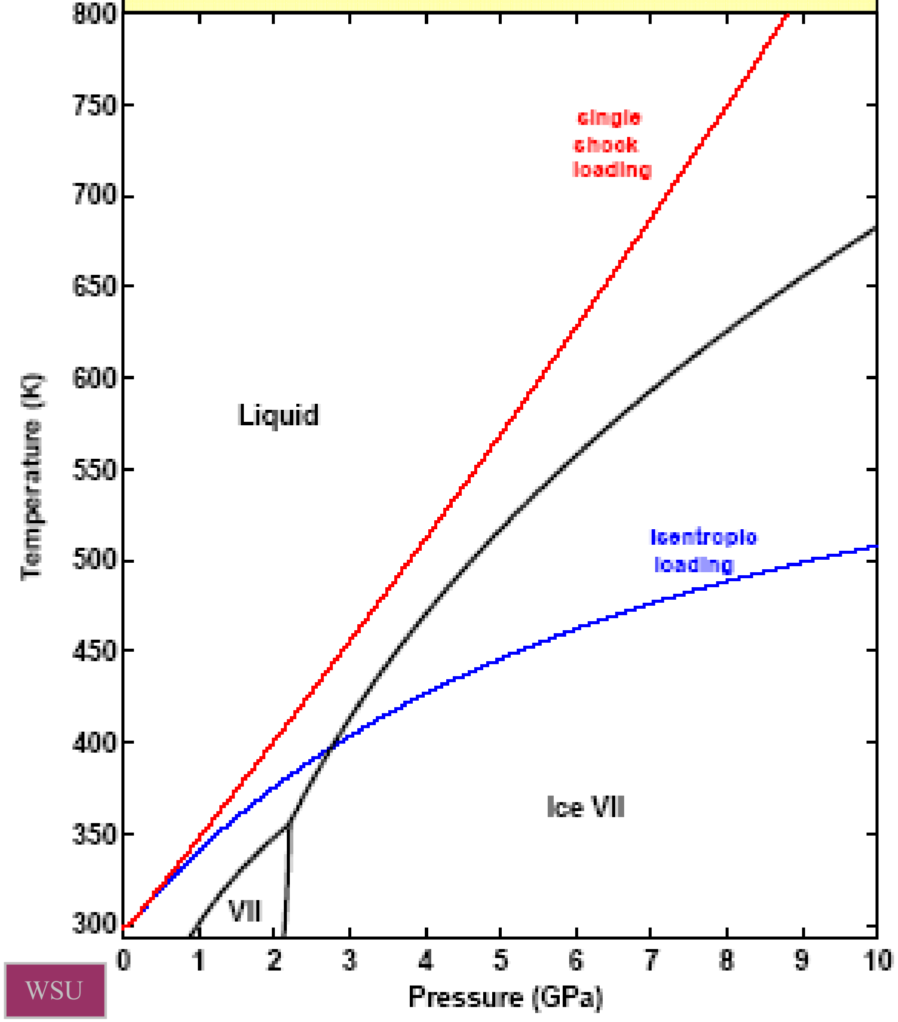
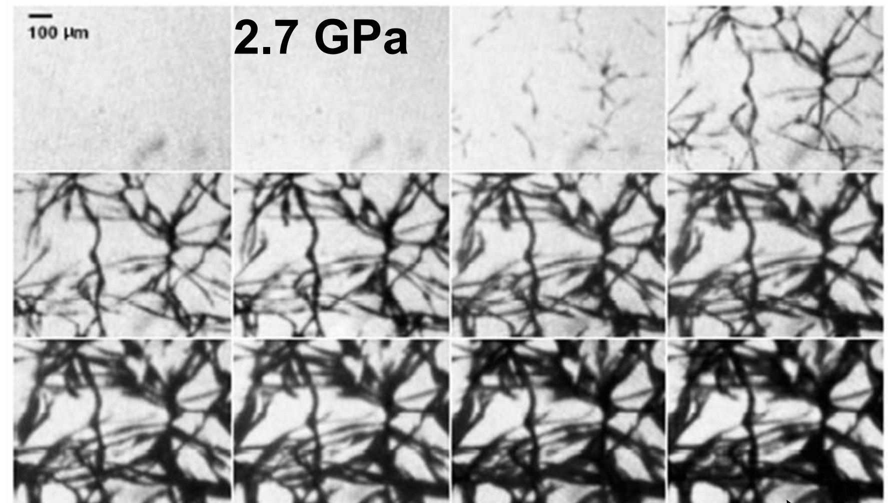
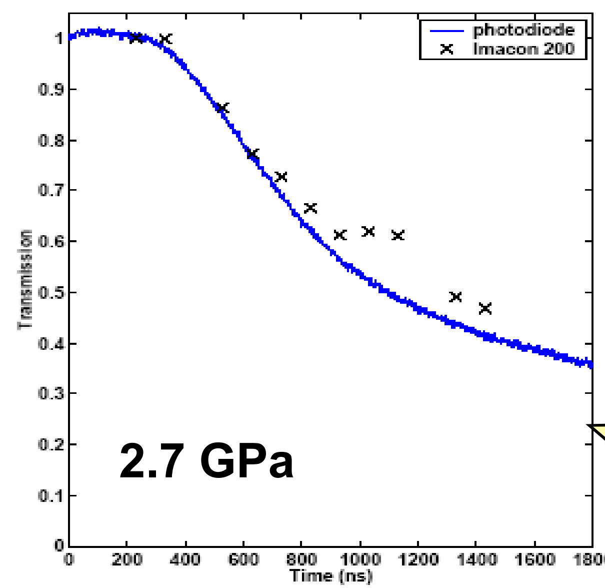
Transmission measurements in compressed water showing rapid solidification

H_2O Phase Diagram





Framing camera images



Integrated optical transmission

WSU

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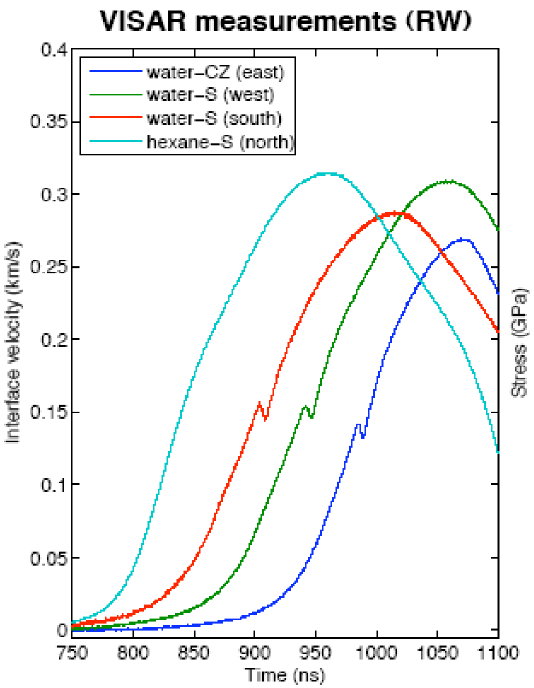
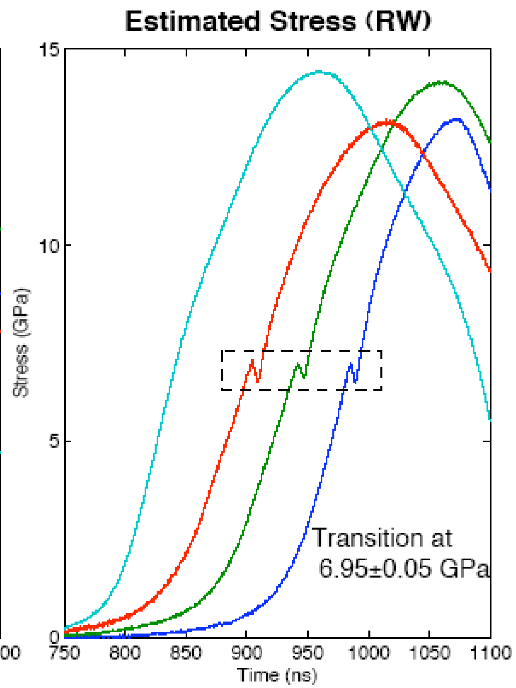
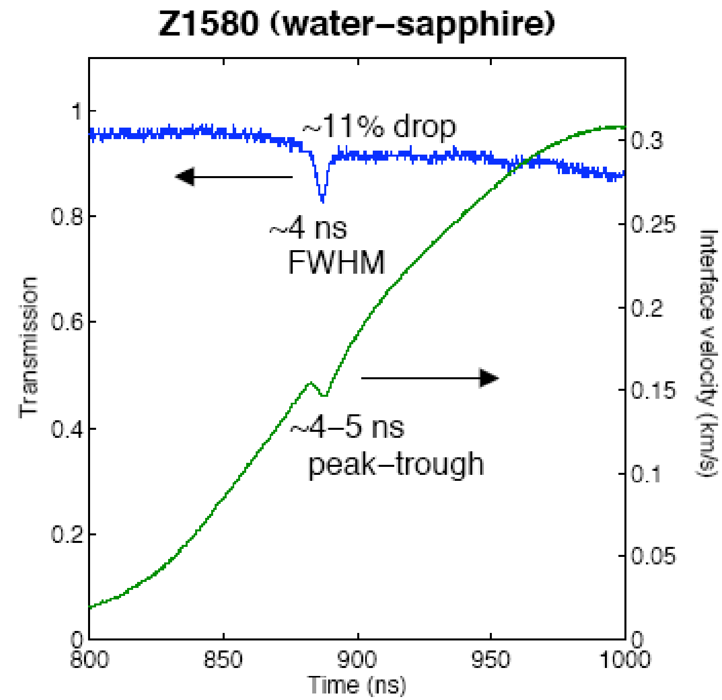
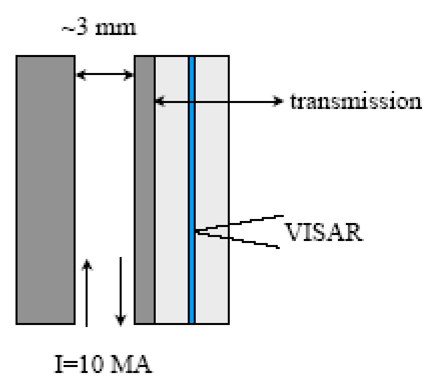
Recent experiments on Z indicate extremely rapid solidification possible in water







- Ramp compression experiments (Z)
  - 0.02 mm water samples
  - Sapphire and cubic zirconia windows
  - Aluminum drive panel
  - Hexane used as a control



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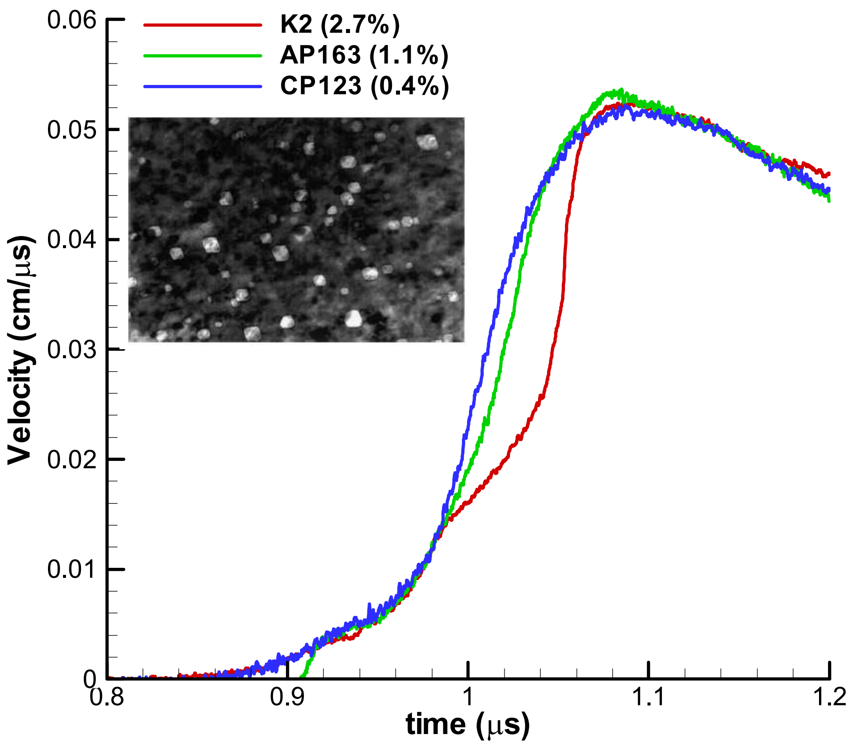
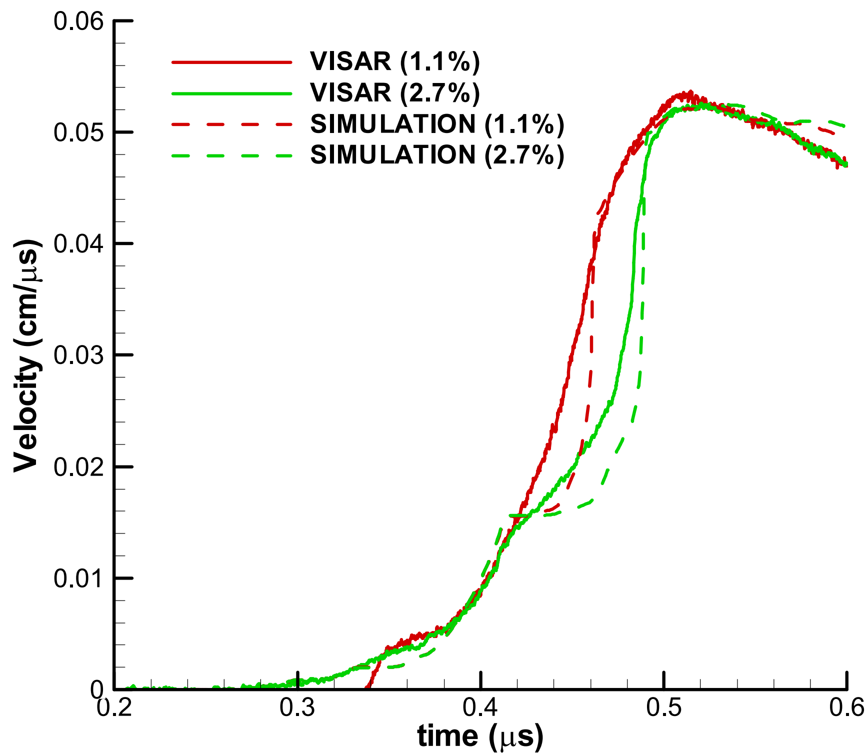
ICE has been used to examine radiation damage in irradiated stainless steel

800 μm Irradiated Stainless Steel





- Technique clearly shows where voids collapse
- Demonstrates utility of ICE for investigation of subtle material differences

D.B Reisman, et al., J. Appl. Phys. **93**, 8952 (2003)

From David Reisman, LLNL

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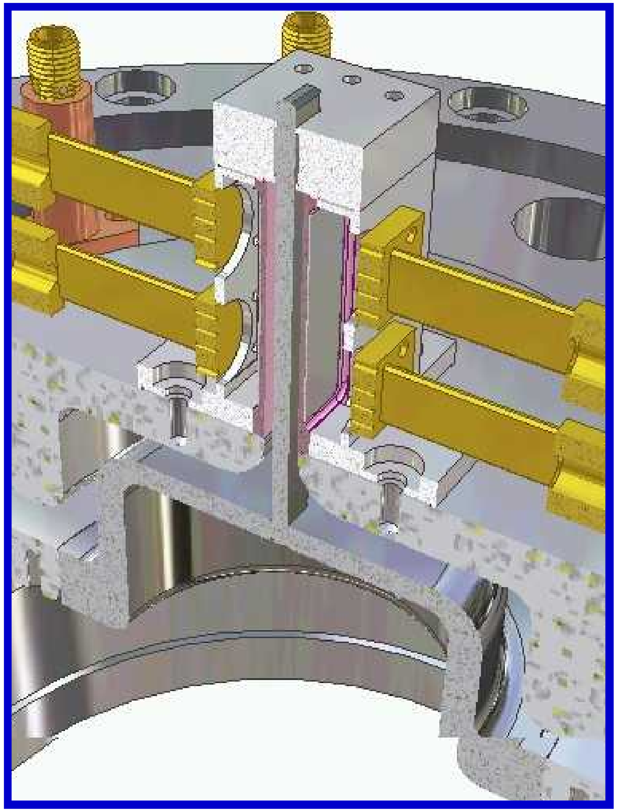
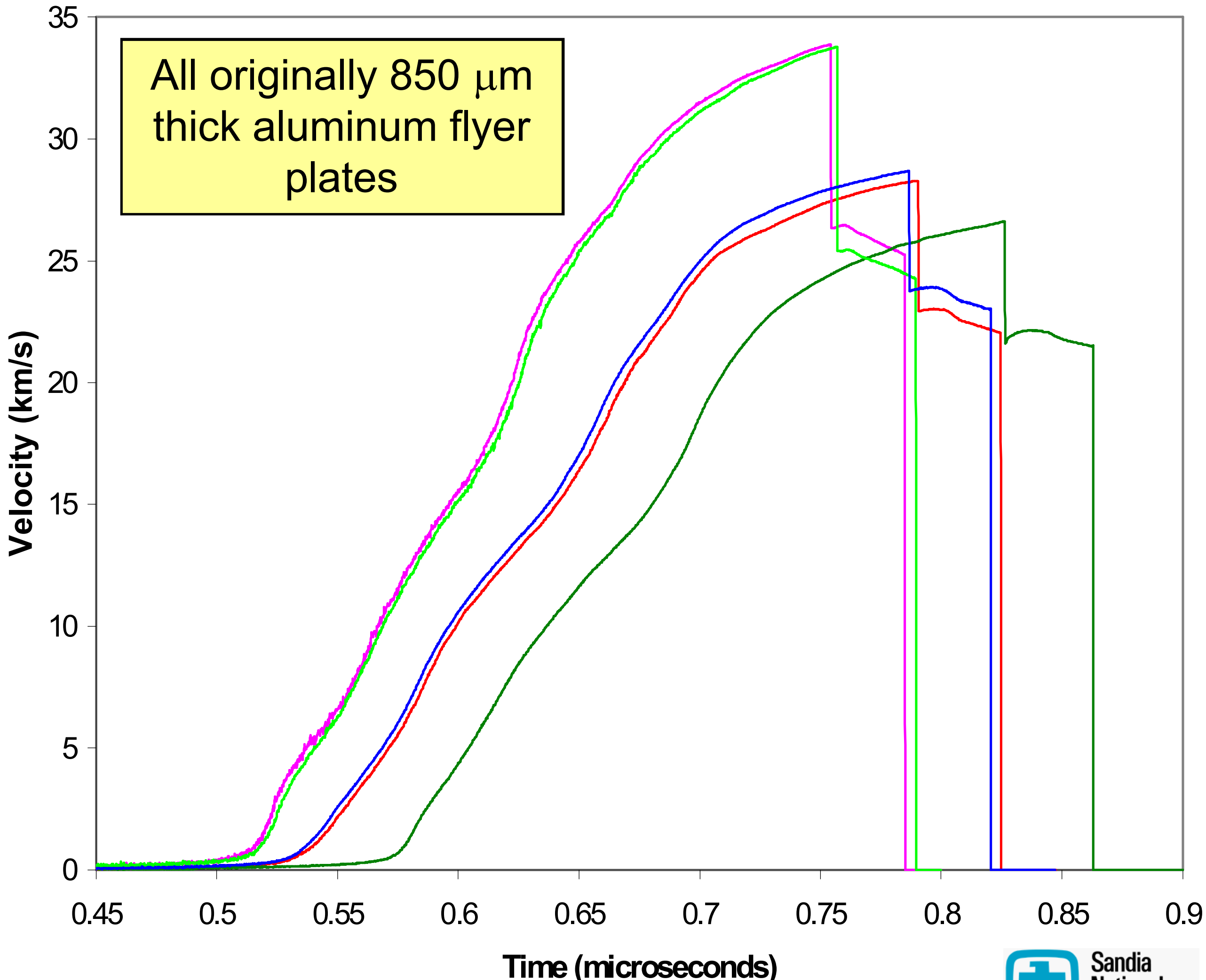
Outline

- Motivation for developing this platform
- Isentropic Compression Experiments (ICE)
  - Isentropic compression of materials
  - Phase transition measurements
  - A-B material comparisons
- Hyper-velocity flyer plate experiments
  - Symmetric impact
  - Relative impact
  - Impedance match
- Conclusions

Flyer plate velocity between ~5 to 34 km/s achievable with 1 to 4 flyer plates per experiment

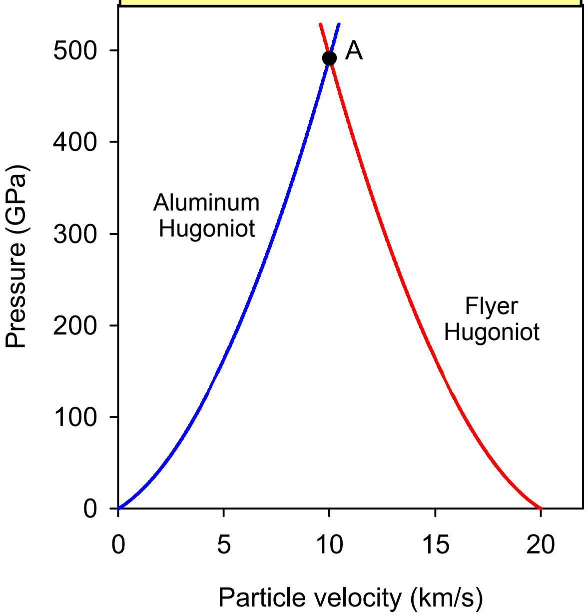


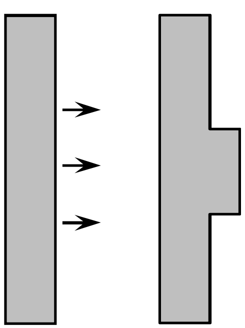
Peak velocity controlled by geometry and charge voltage



Common methods of obtaining Hugoniot measurements in plate impact experiments

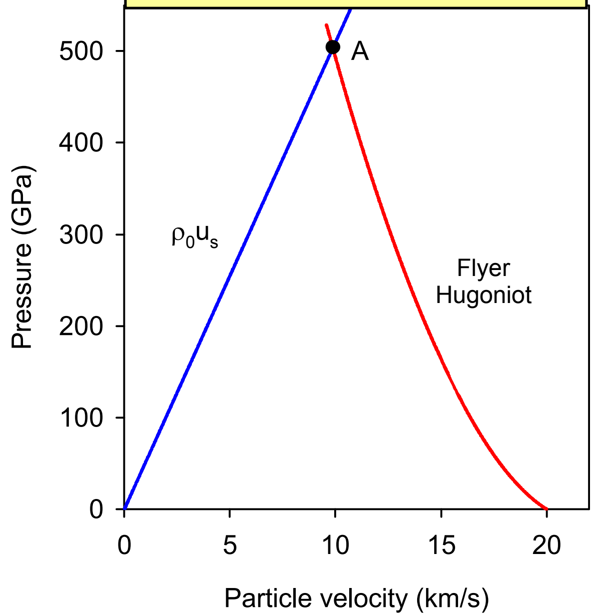
Symmetric Impact

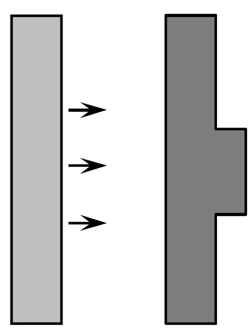




Flyer and target same material

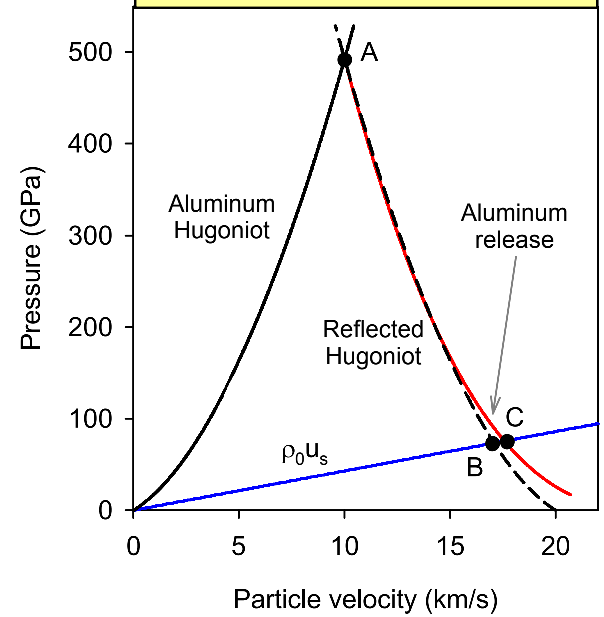
Relative Impact

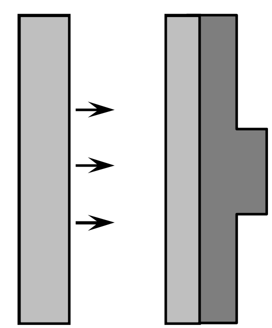




Flyer and target different material

Impedance Match

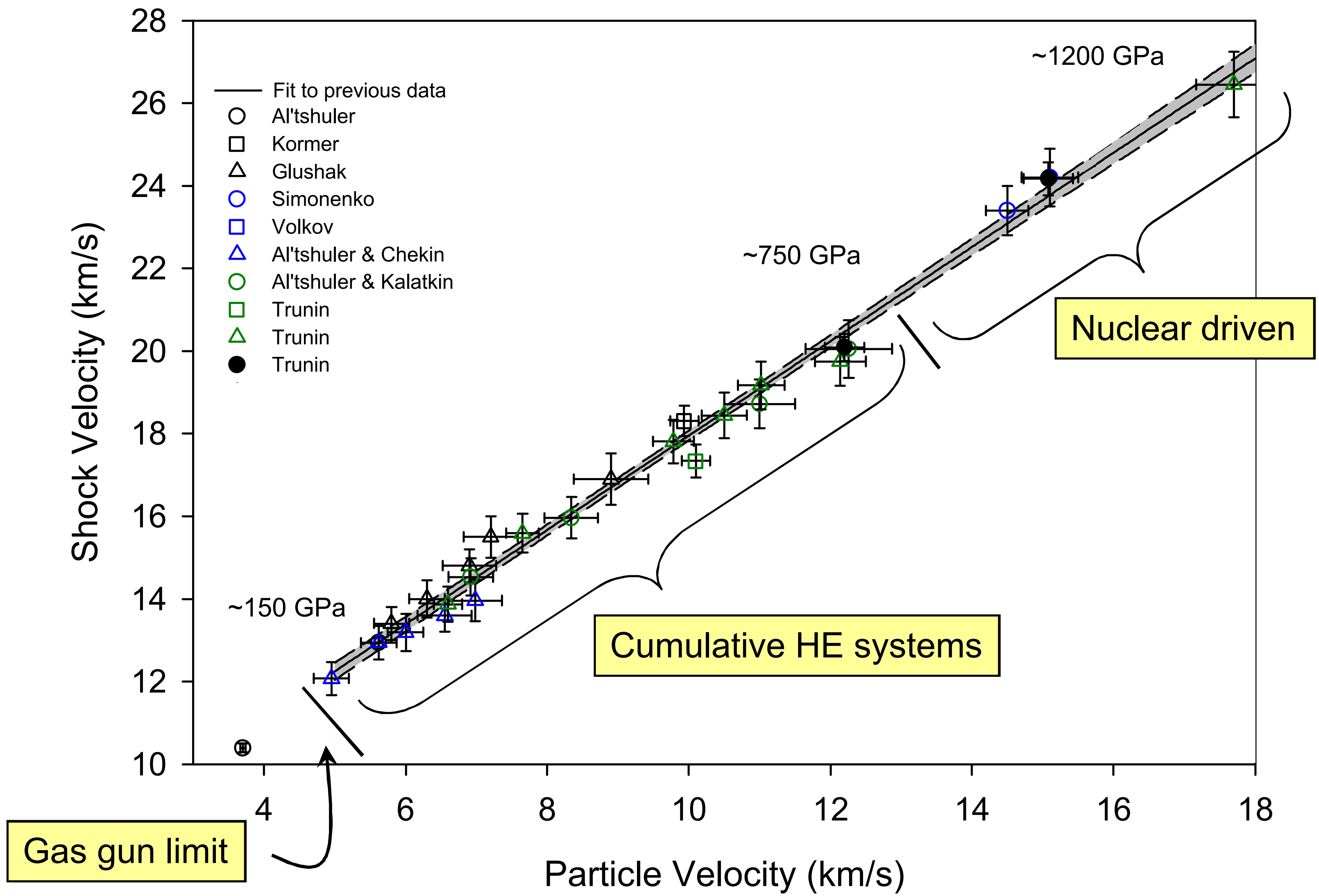




Target is composite

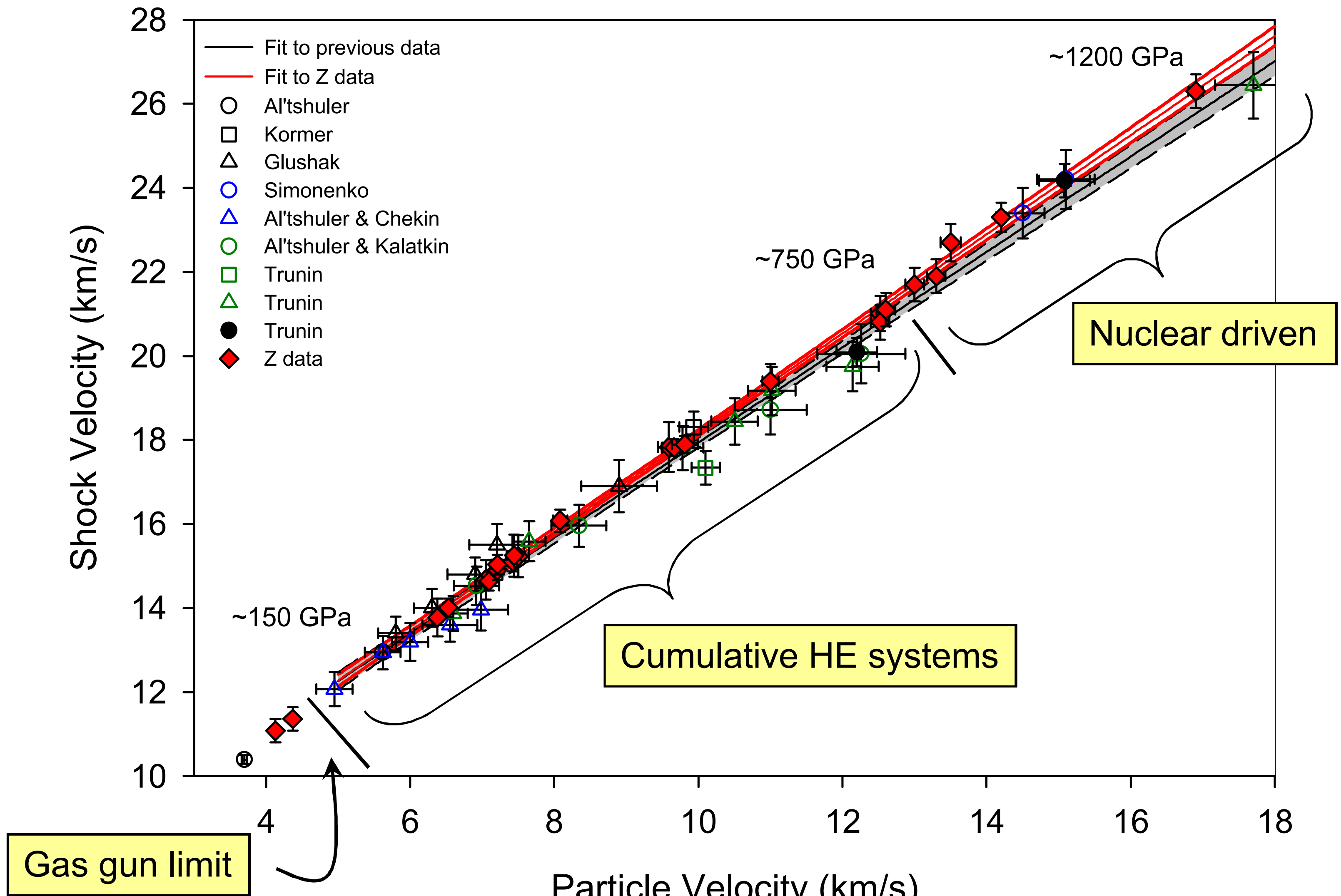
Recent data have improved our understanding of the high pressure EOS of aluminum

Symmetric impact



Symmetric impact

Recent data have improved our understanding of the high pressure EOS of aluminum



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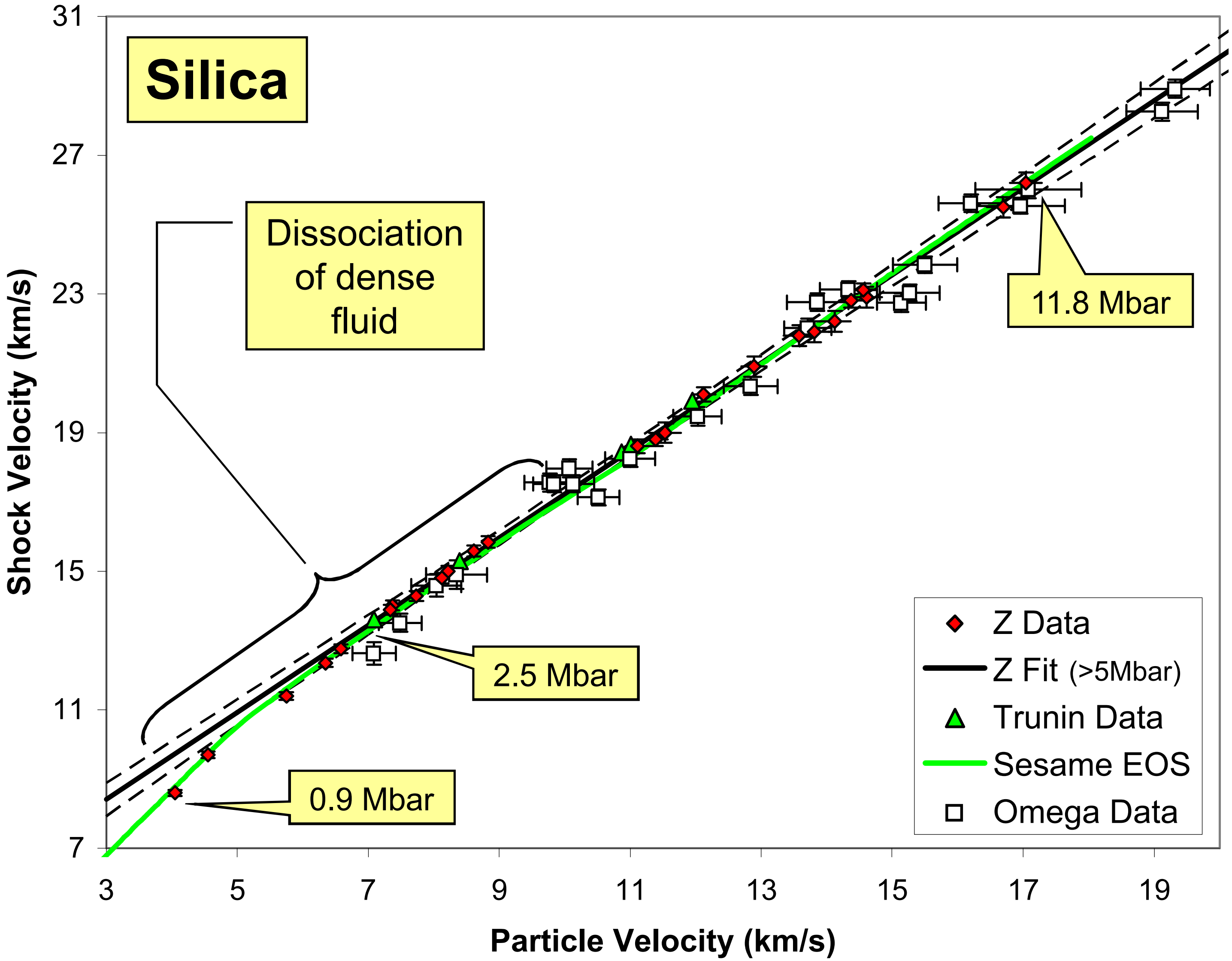
Relative impact

Hugoniot data for silica illustrates the accuracy and precision achievable on Z



High pressure response of Silica is of fundamental importance to geophysics

Quartz is becoming the standard of choice for high pressure laser Hugoniot measurements

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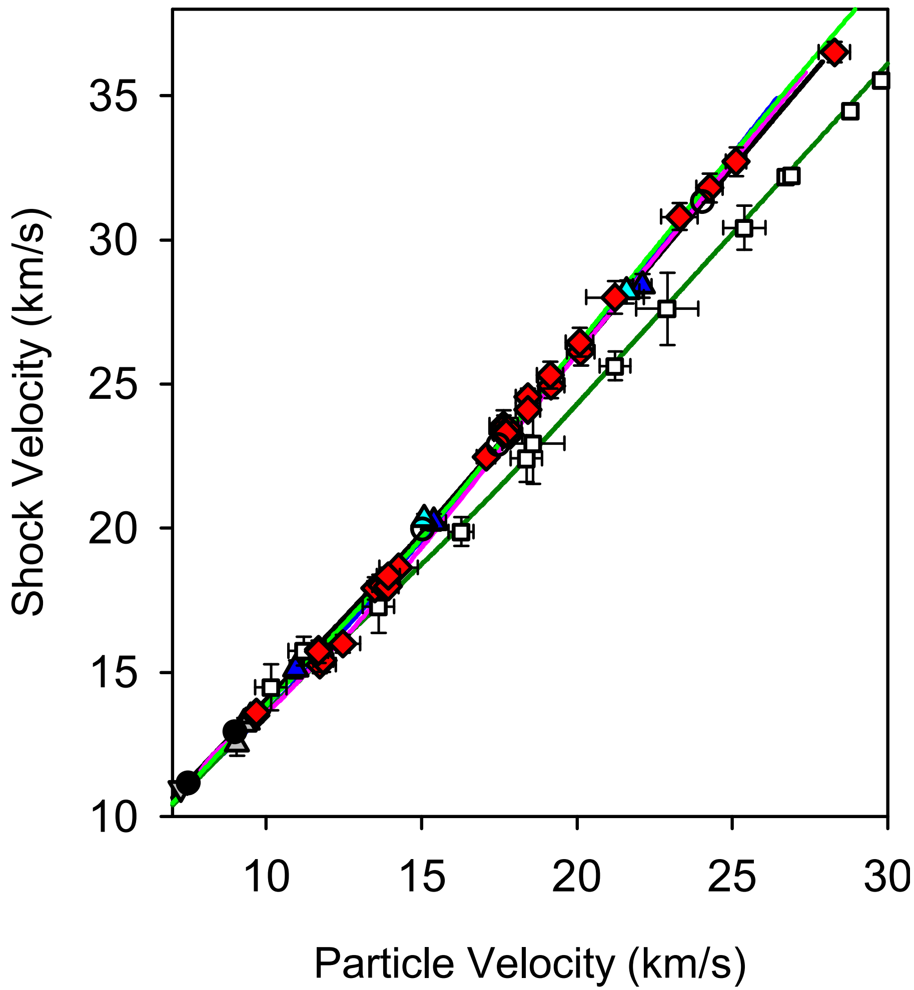
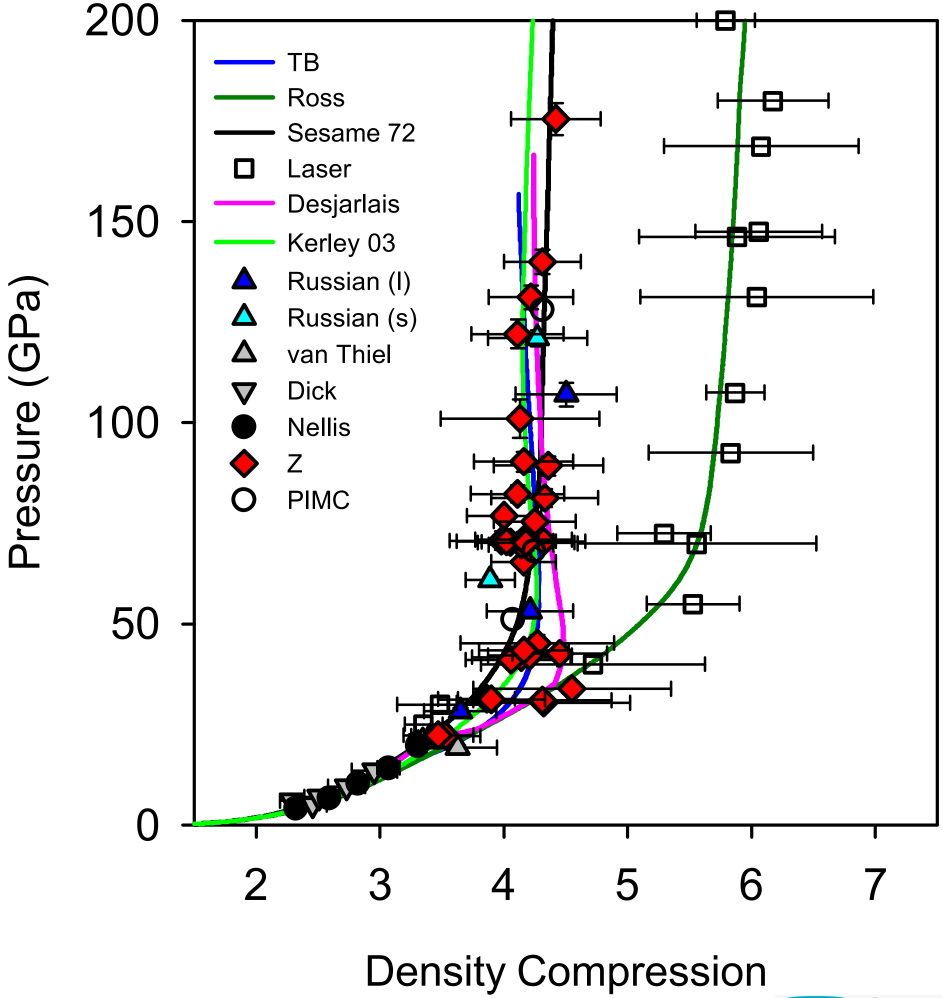
Impedance match

Data to 1.8 Mbar obtained on liquid D_2 to help resolve discrepancy in high-pressure response





M.D. Knudson, et al., Phys. Rev. Lett. **87**, 225501 (2001); Phys. Rev. B **69**, 144209 (2004)

Conclusions

- Isentropic compression experiments have been performed to ~300 GPa
  - P-V response
  - Phase transformation
  - Material strength
  - Constitutive properties
- Flyer plate experiments have been performed to ~34 km/s
  - Ultra-high pressure Hugoniot
  - Shock and release
  - Shock melting
- Enabling exciting new experiments in material dynamics