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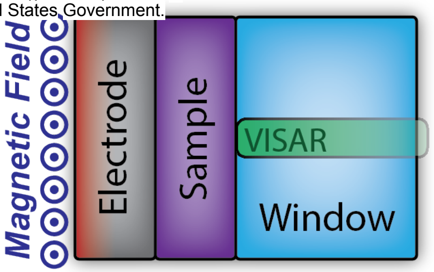
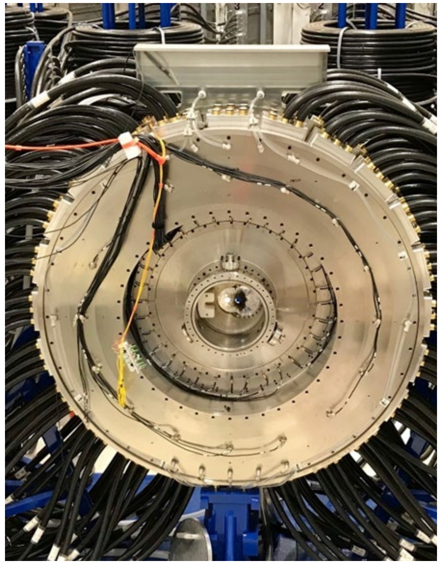


Ramp and Shock-Ramp Experiments on the SNL Pulsed Power Machines

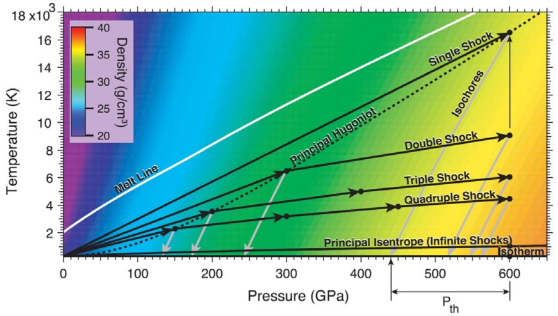


Justin Brown, Sakun Duwal,
Jean-Paul Davis

Z FUNDAMENTAL SCIENCE WORKSHOP

PLANETARY SCIENCE BREAKOUT - CA

August 9-10, 2021



U.S. DEPARTMENT OF ENERGY NNSA

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What is shockless/ramp compression?

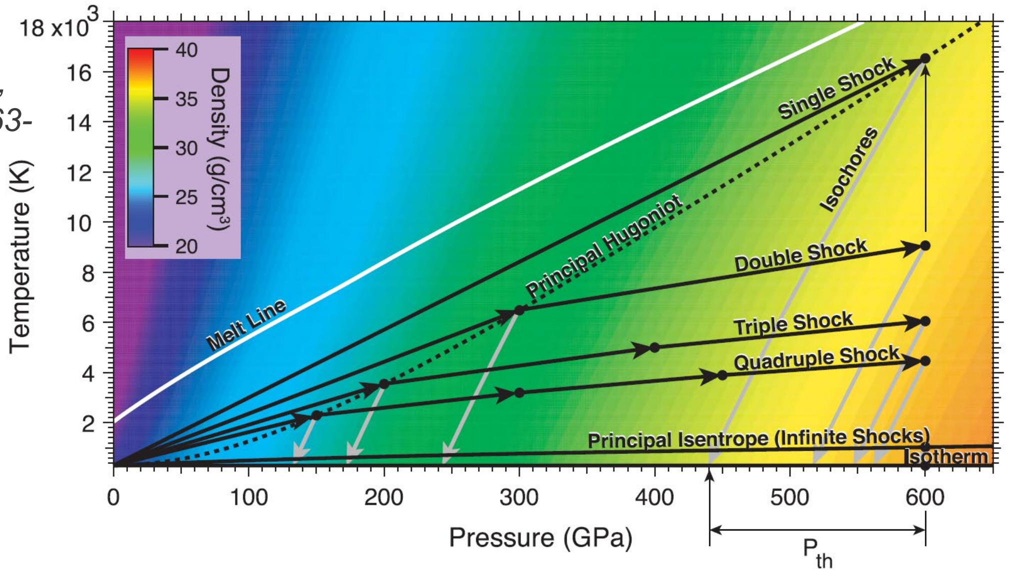
Continuous propagating stress wave that satisfies the Cauchy equations

$$\frac{d\rho}{\rho^2} = \frac{du}{\rho_0 C_L}$$ Conservation of mass

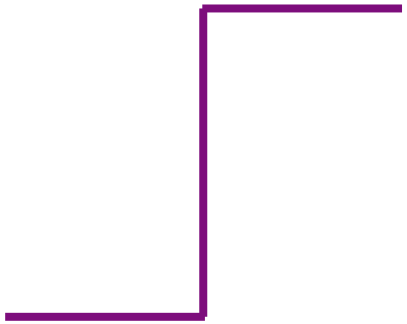
$$d\sigma_x = \rho_0 C_L du$$ Conservation of momentum

Limit of an infinite amount of tiny shocks

*Fratanduono et al, Science, **372**, 1063-1068 (2021)*



Rankine Hugoniot Jump Conditions



$$\frac{\rho - \rho_0}{\rho\rho_0} = \frac{u}{\rho_0 U_s}$$

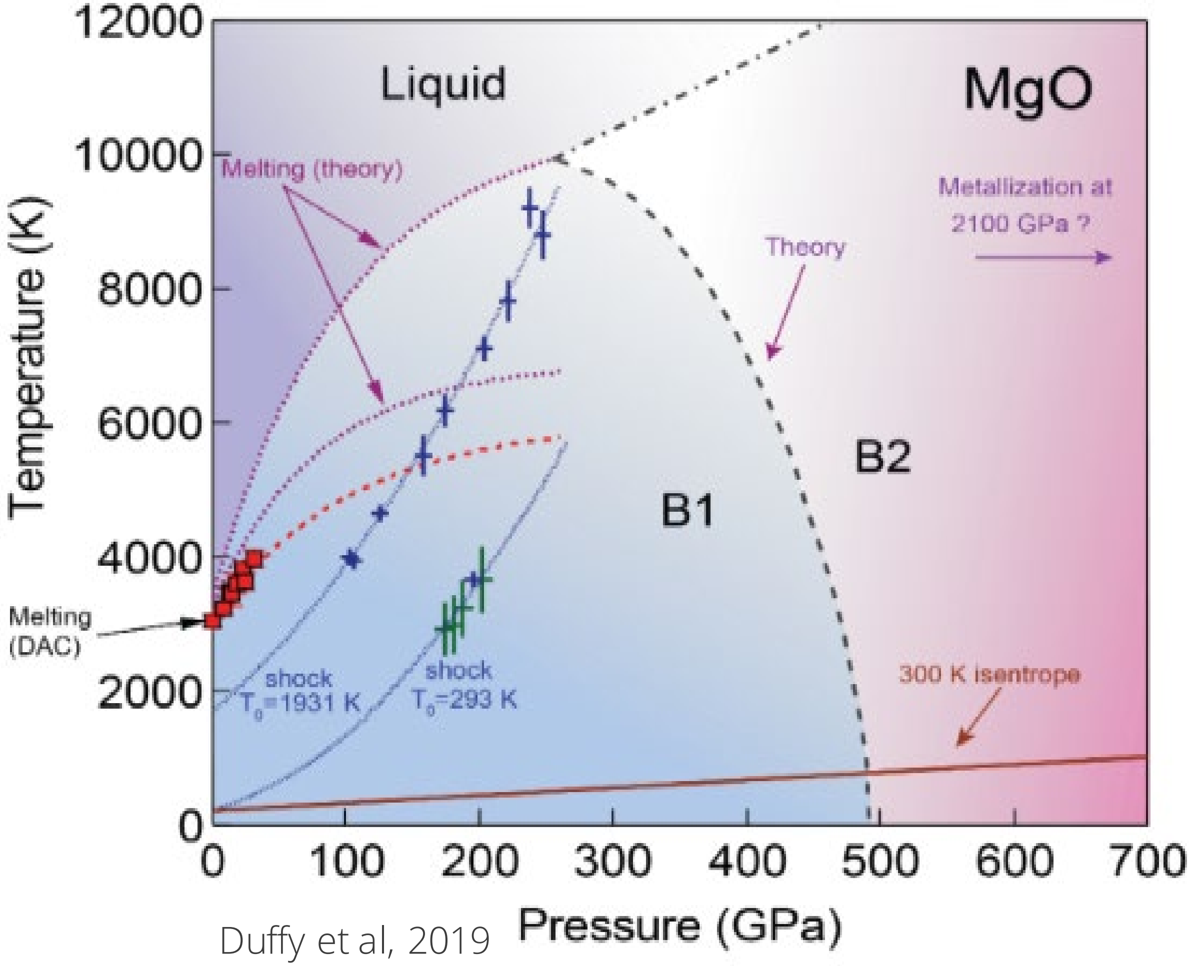
$$\sigma_x = \rho_0 U_s u$$

Why is ramp compression of interest?

- Compression path is close to the isentrope
  - Better constraint of the room temperature isotherm
  - Can probe extreme pressures without melting

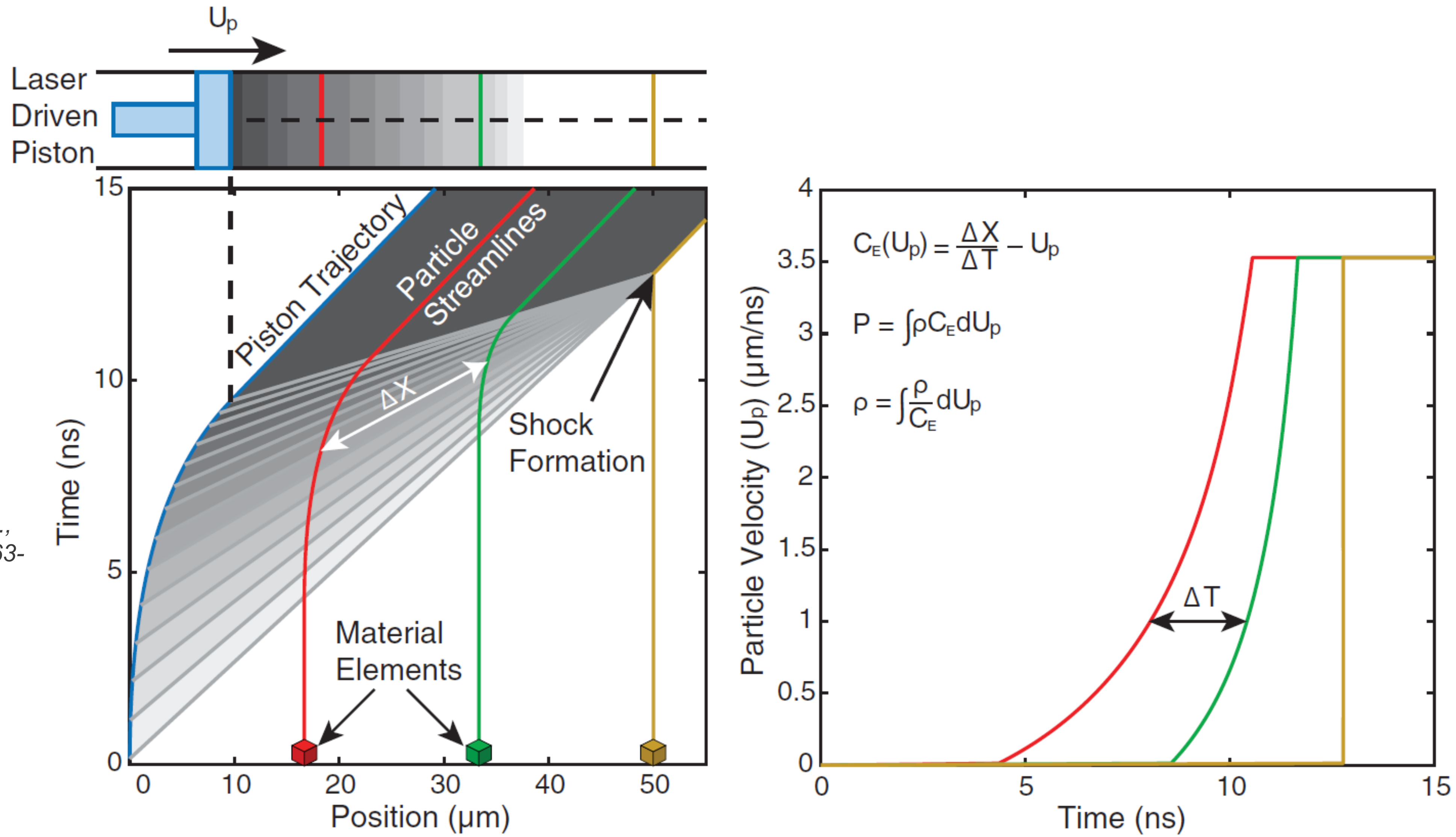
- Since the wave is continuous, you get the entire loading path from a single experiment!
  - Can often "see" physics in the wave profile measurements

The B1-B2 transformation in MgO can be studied using ramp compression



Duffy et al, 2019

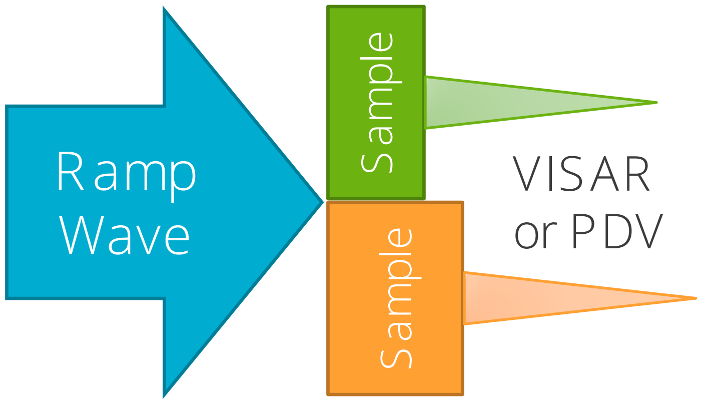
Ramp compression requires precise control of the input wave to avoid shock formation

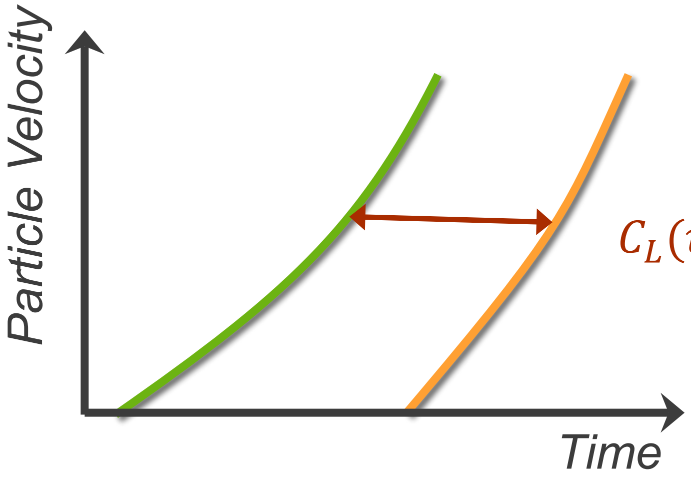


Fratanduono et al., Science, ***372***, *1063-1068 (2021)*

The basic concept for a ramp experiment is easy

Measure the velocities at multiple sample thicknesses, calculate the wavespeed and integrate…

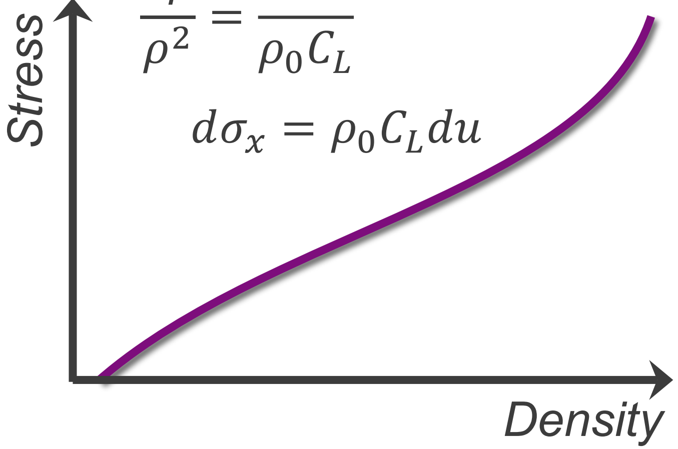




$$C_L(u) = \frac{\Delta x}{\Delta t}$$

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

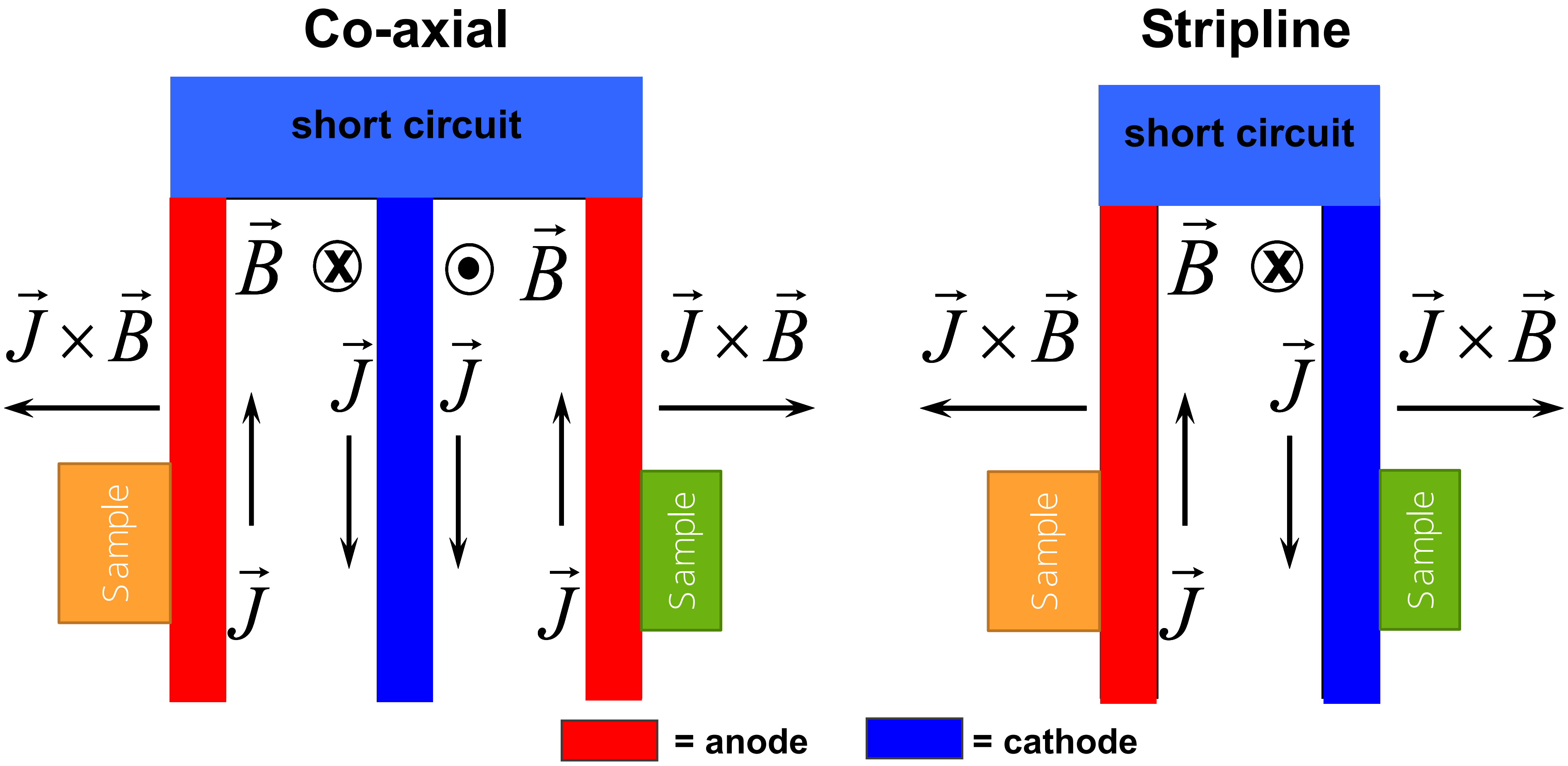
$$d\sigma_x = \rho_0 C_L du$$



But this assumes the velocities are ***in-situ***. In reality we always make the measurements at an interface. Let's ignore this for now…

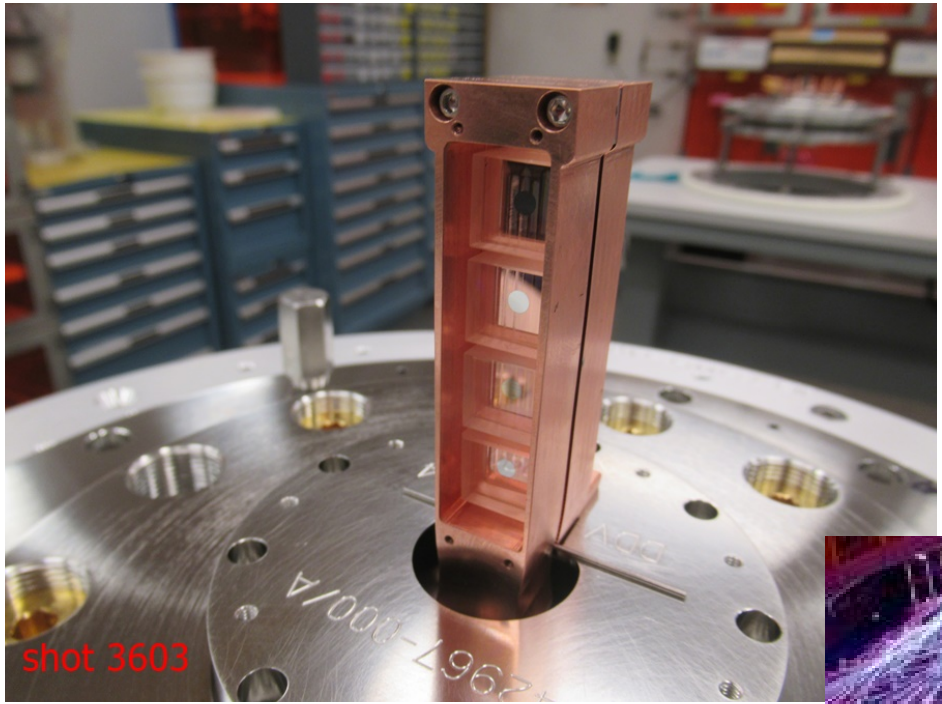
The unique current pulseshaping capabilities at Z and Thor make them well suited to ramp compression

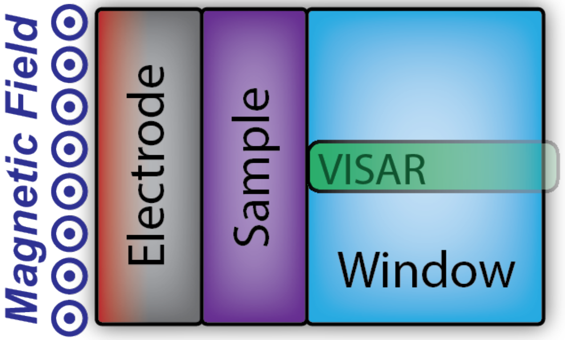
You've already seen how the magnetic pressure can be used to launch flyer plates. Here, we design the geometry and current pulse to produce a shockless compression.

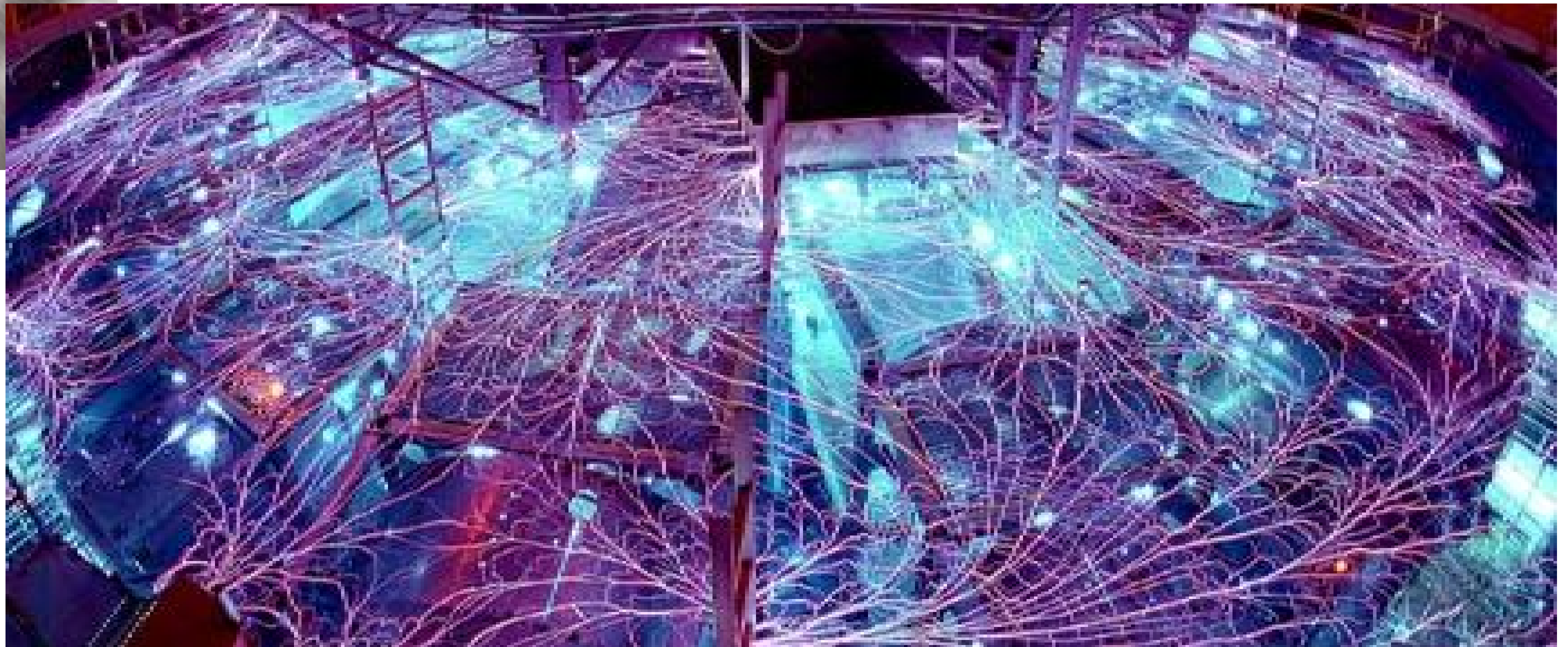


Typical specs for a Z ramp compression experiment

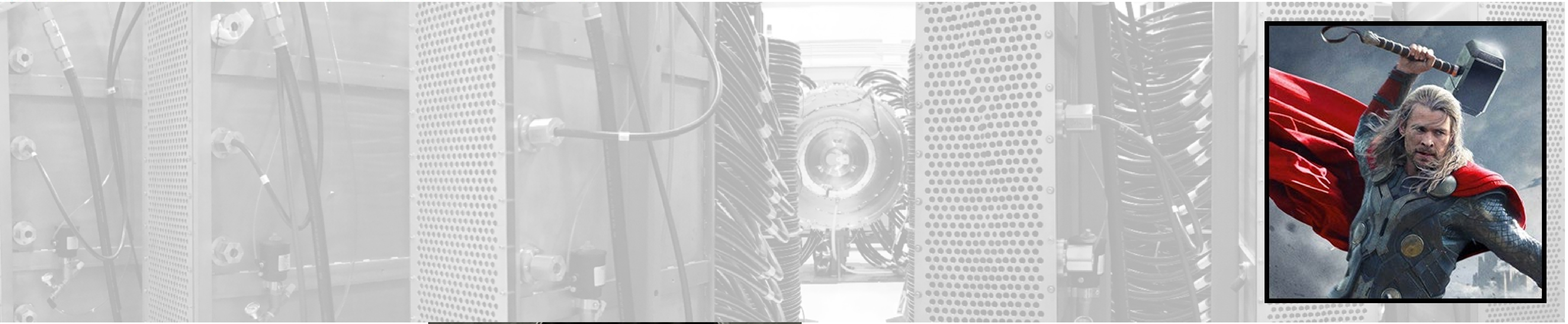
- Cu or Al panels
  - Usually Cu as material models are believed to be better
- 4 locations available for samples or 'drives'
  - Samples are typically 8mm squares, ~1mm thick
- Peak pressures ~5MBar
- Current rise times: 500 – 1200 ns

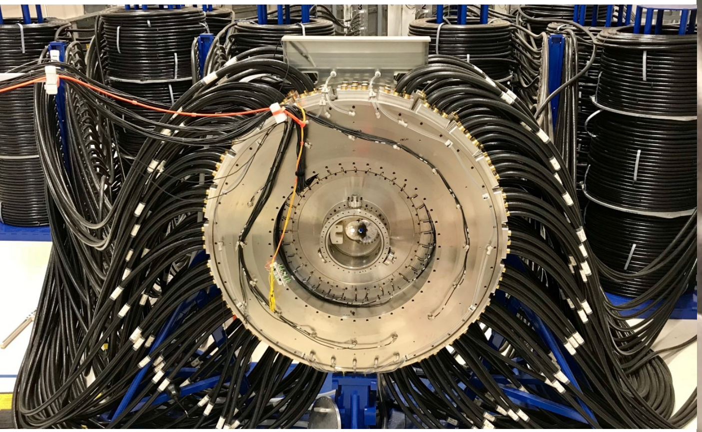






Typical specs for a Thor ramp compression experiment

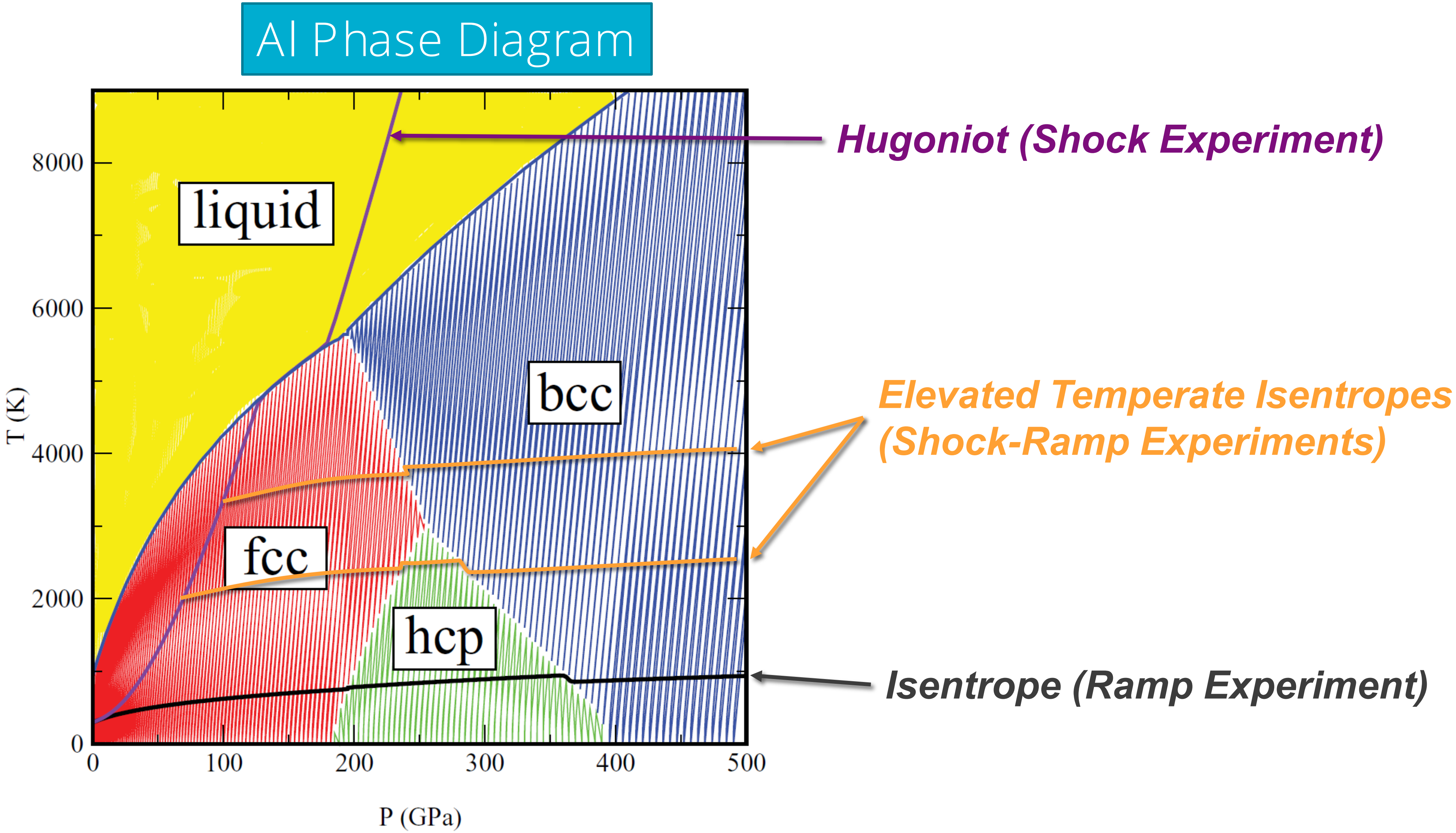




- Cu or Al panels
  - Al used more often since it is more efficient
  - 1 location available for samples or 'drives'
  - Samples are typically 6-10mm disks, ~1mm thick
- Peak pressures: ~20 Gpa
- Current rise times: ~250 – 500 ns

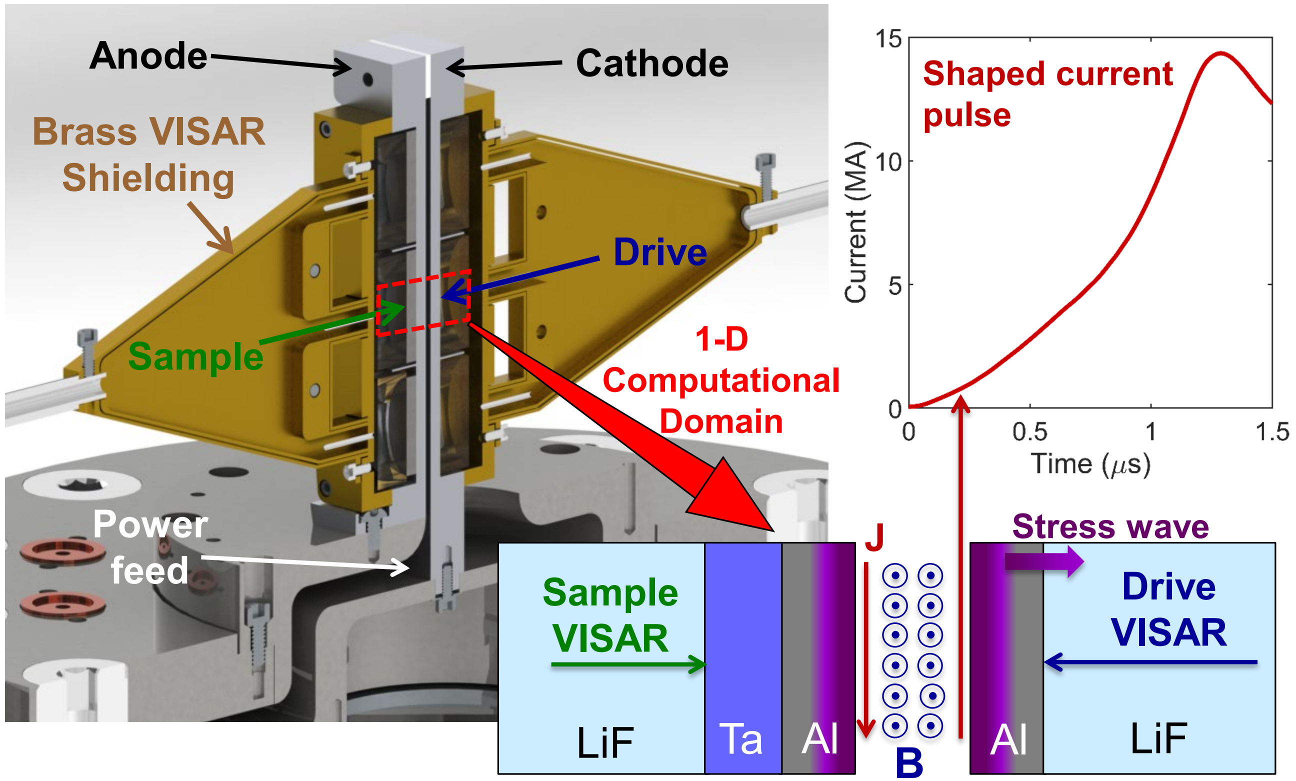
Z can also be used for shock-ramp experiments to explore elevated temperature isentropes

Sjostrom et al, PRB, ***94****, 144101 (2016)*

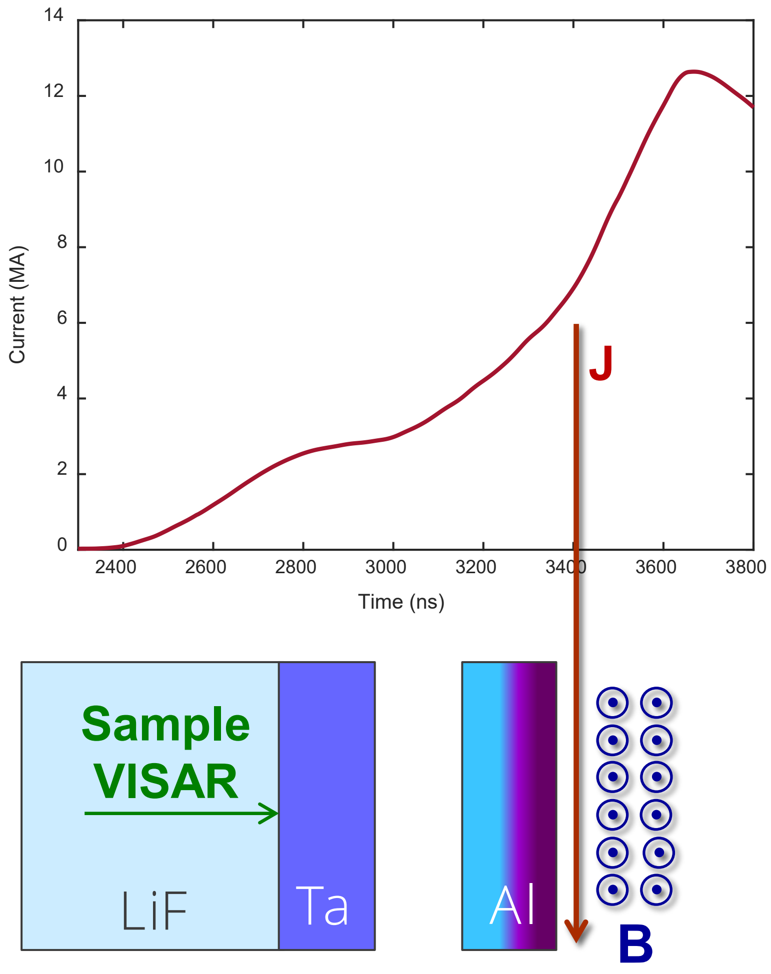


Z can also be used for shock-ramp experiments to explore elevated temperature isotherms

Ramp Configuration



Shock-Ramp Configuration



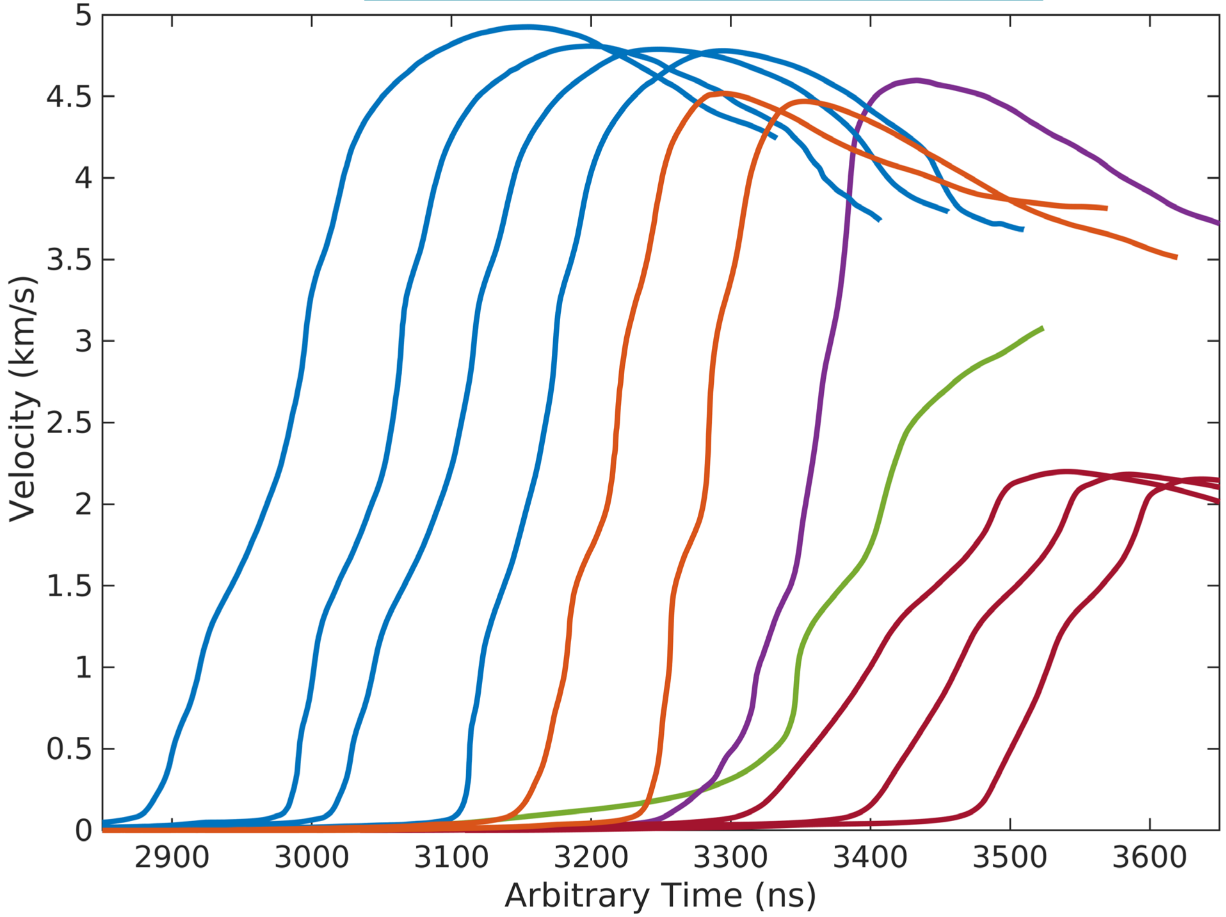
Three practical examples are next

- Platinum ramp on Z
- Tin ramps on Z and Thor
- Shock-ramp of cerium

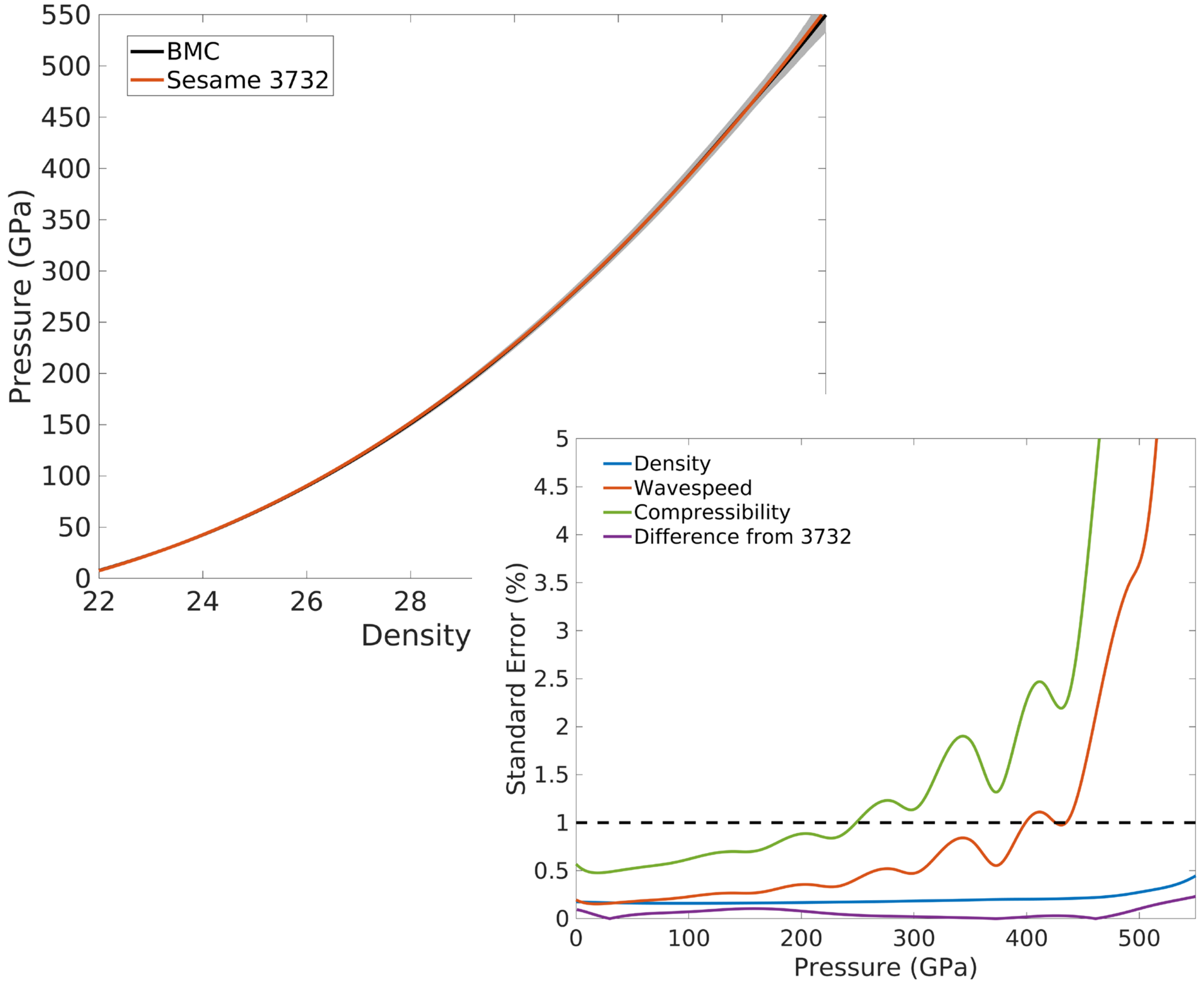
Any Questions So Far?

A significant amount of Pt data has been collected on Z to 5.5 MBar: 11 profiles over 7 experiments

VISAR Measurements

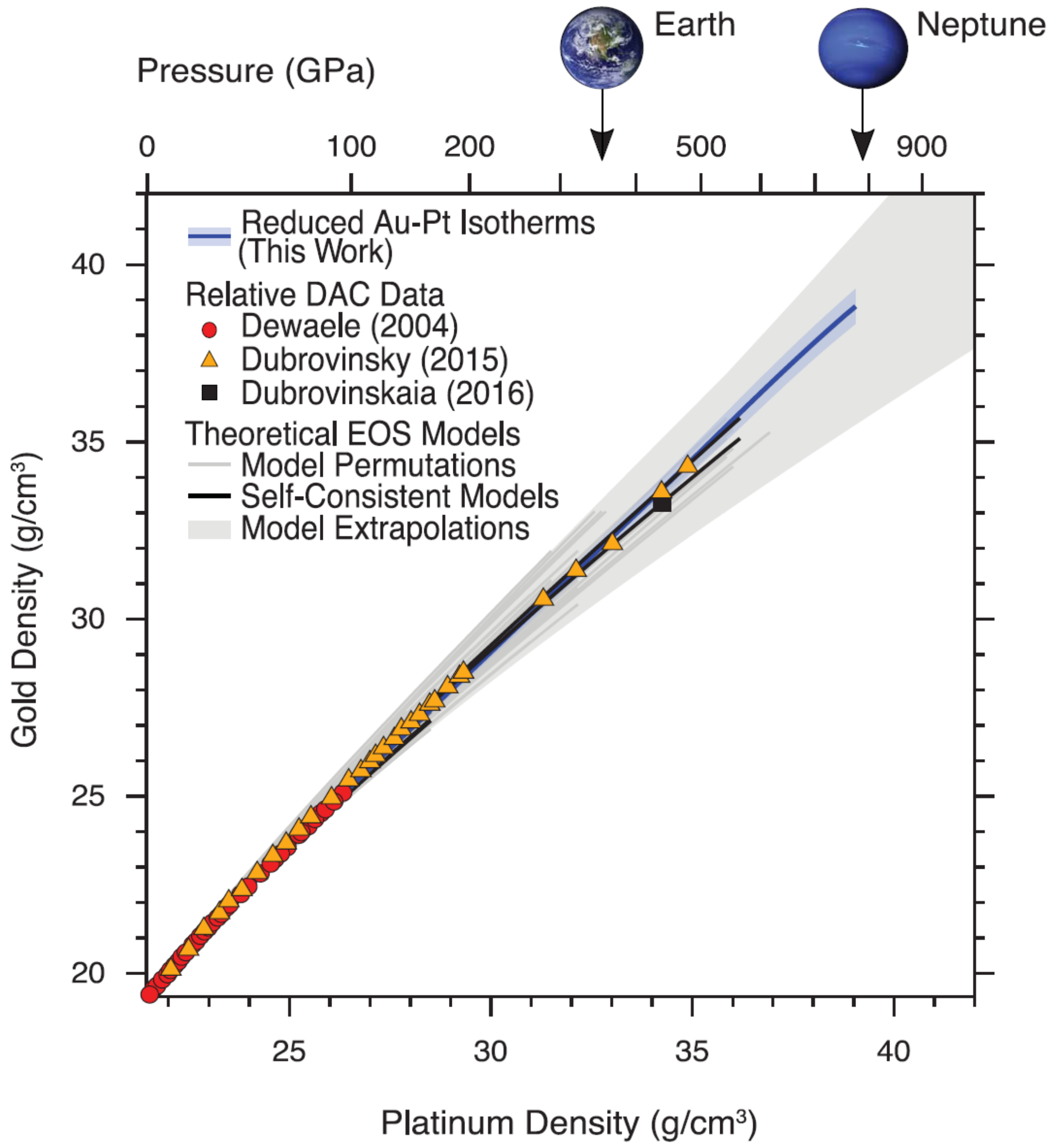


Extracted Isentrope

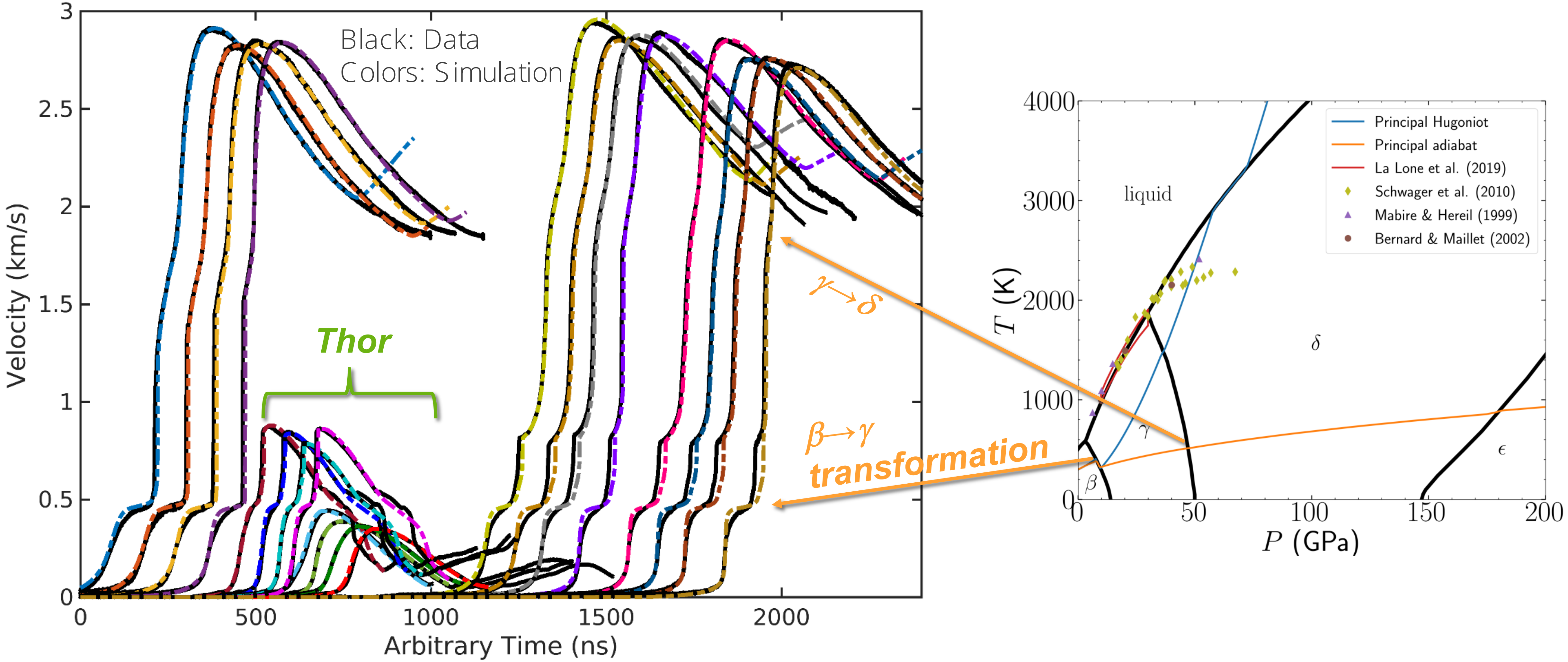


Precision of Z was combined with the higher pressures at NiF to produce Pt and Au standards to 800 GPa

*Fratanduono et al, Science, **372**, 1063-1068 (2021)*

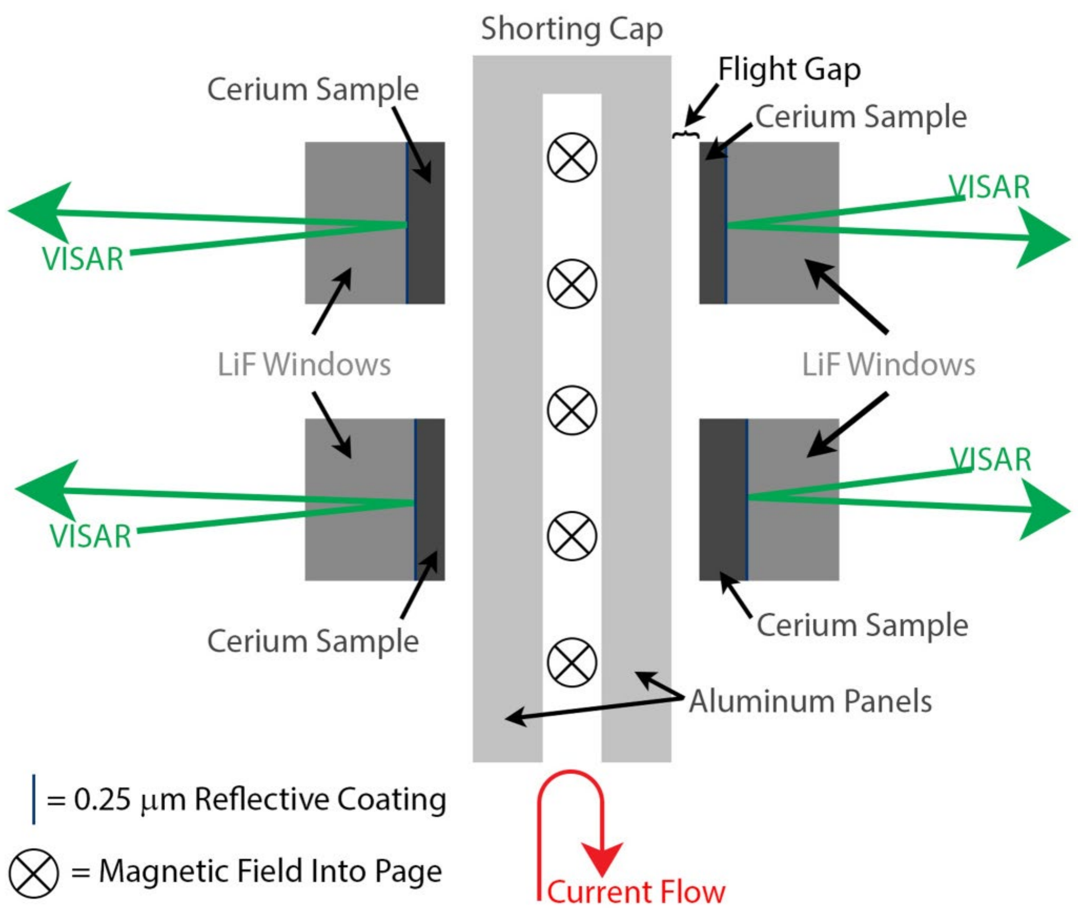


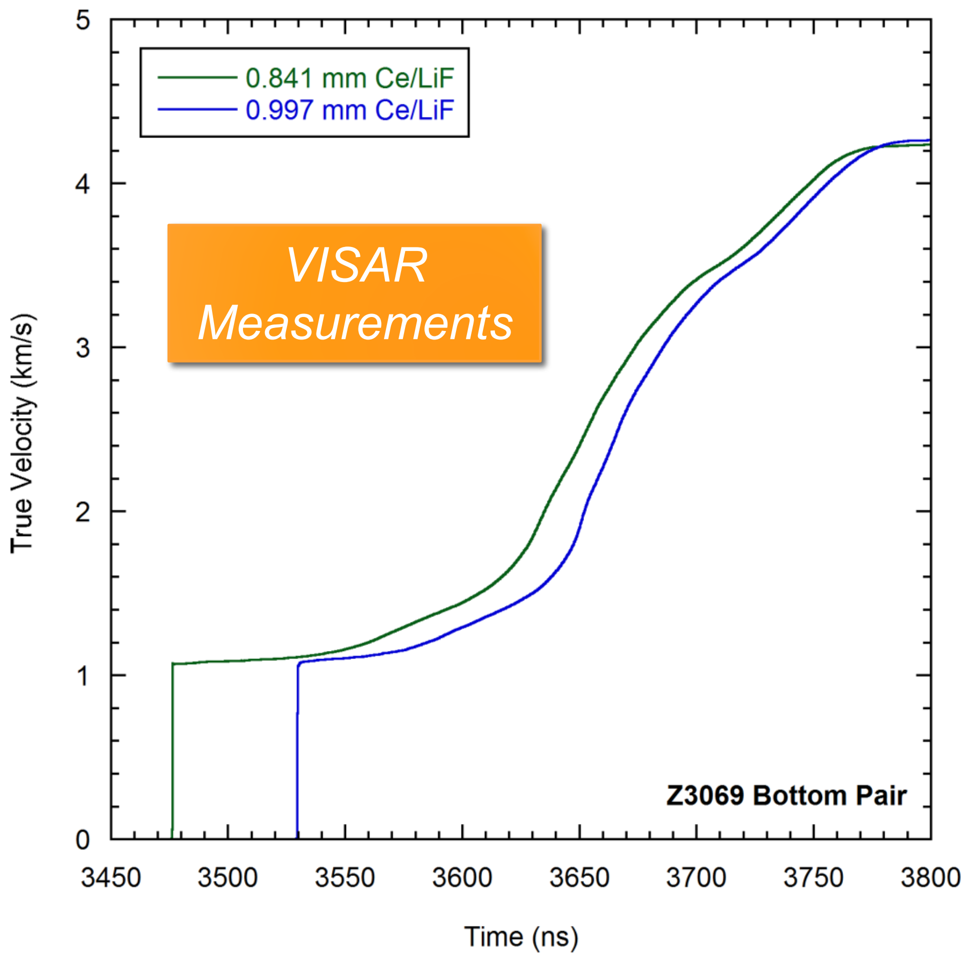
Recent data on Tin to explore phase-transformation kinetics and strength



Shock-Ramp Compression of cerium on Z to explore shock melting and ramp solidification

*Seagle et al., PRB, **102**, 054102 (2020)*

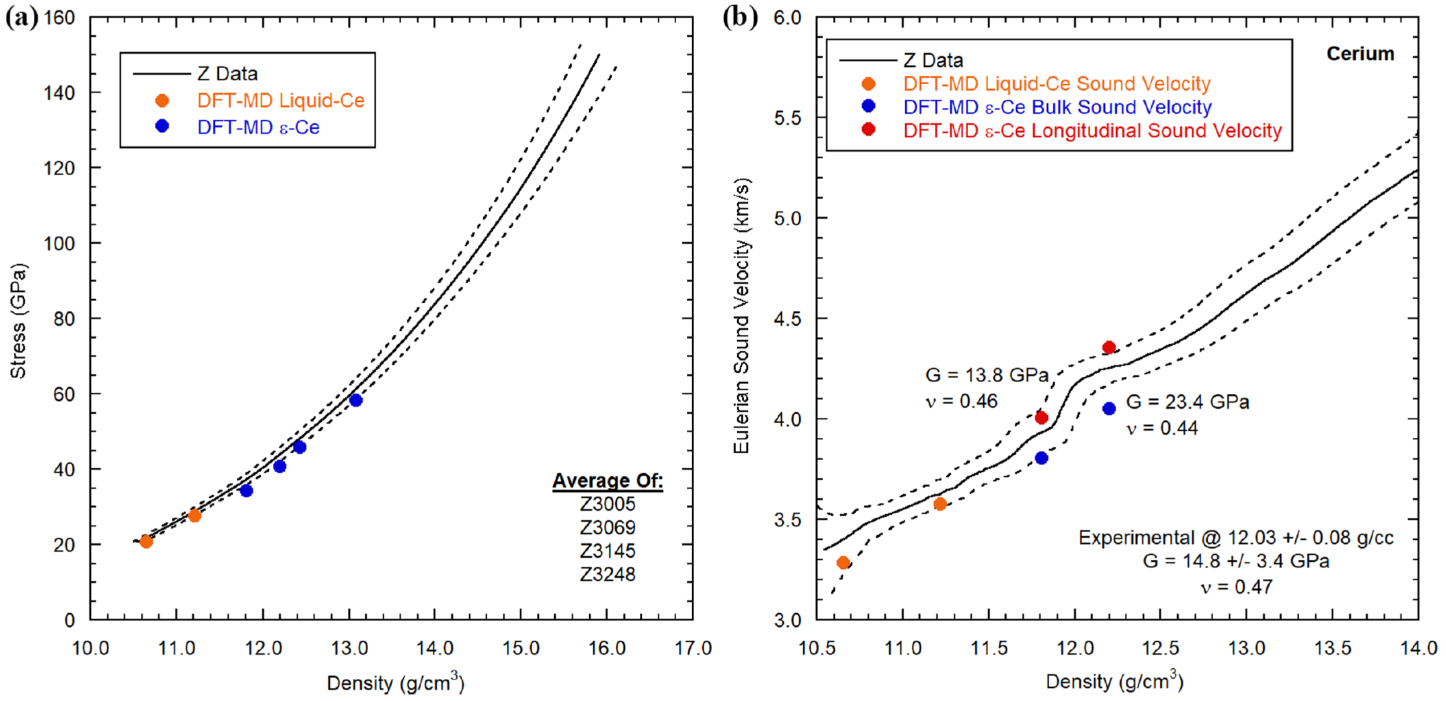




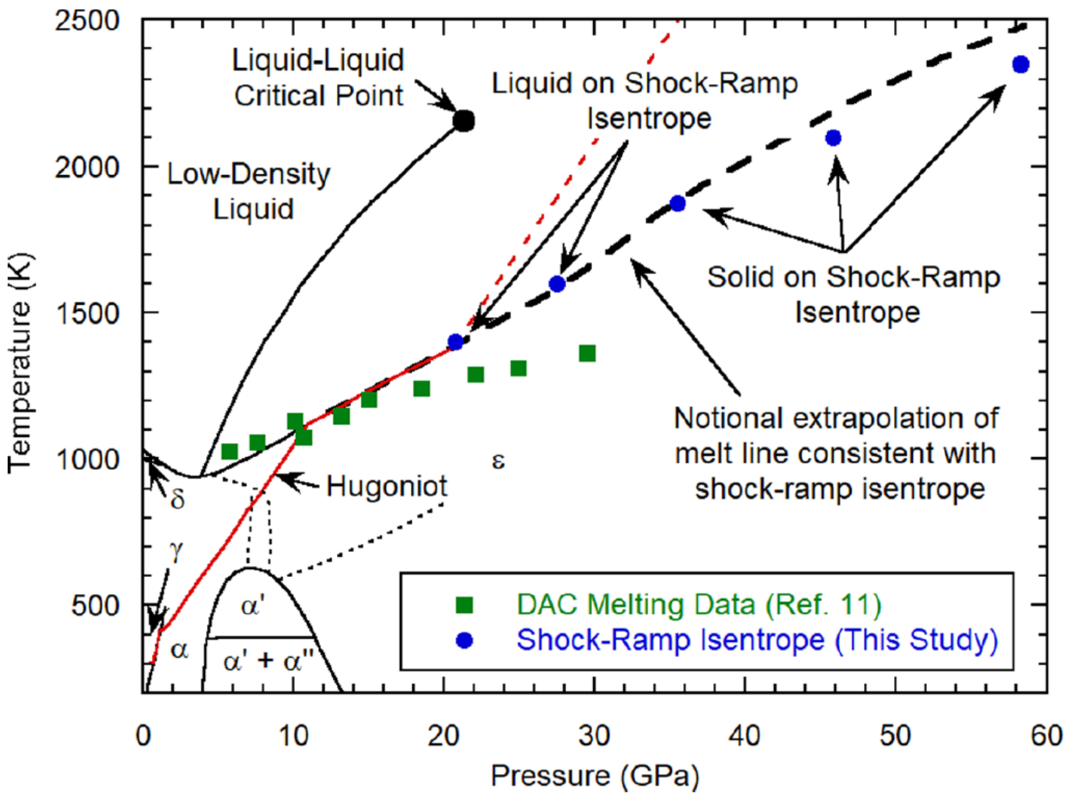
Shock-Ramp Compression of cerium on Z

*Seagle et al., PRB, **102**, 054102 (2020)*

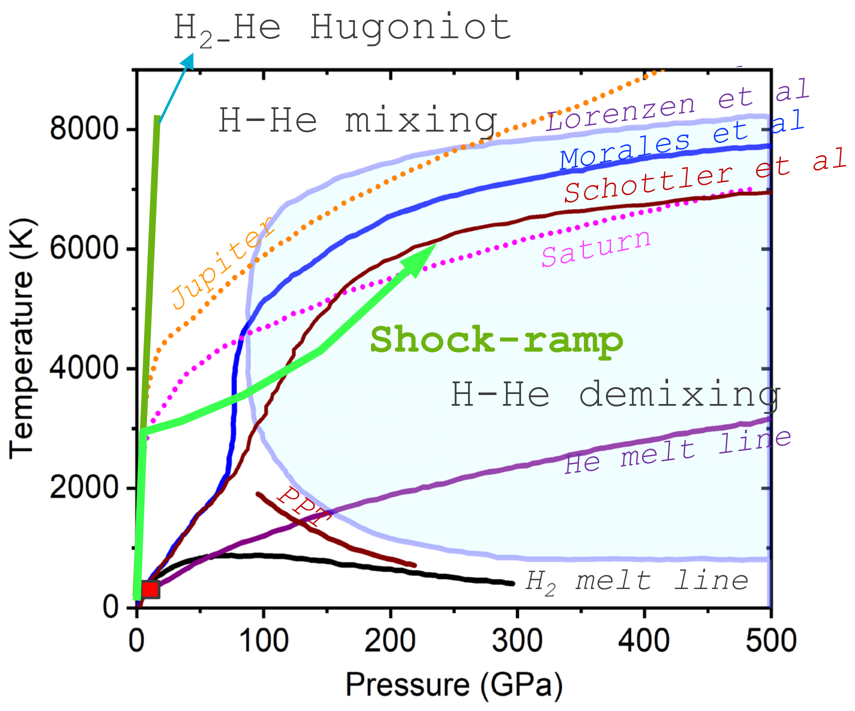
Data is consistent with DFT-MD and suggests solidification of Ce is observed



PT path based on DFT-MD

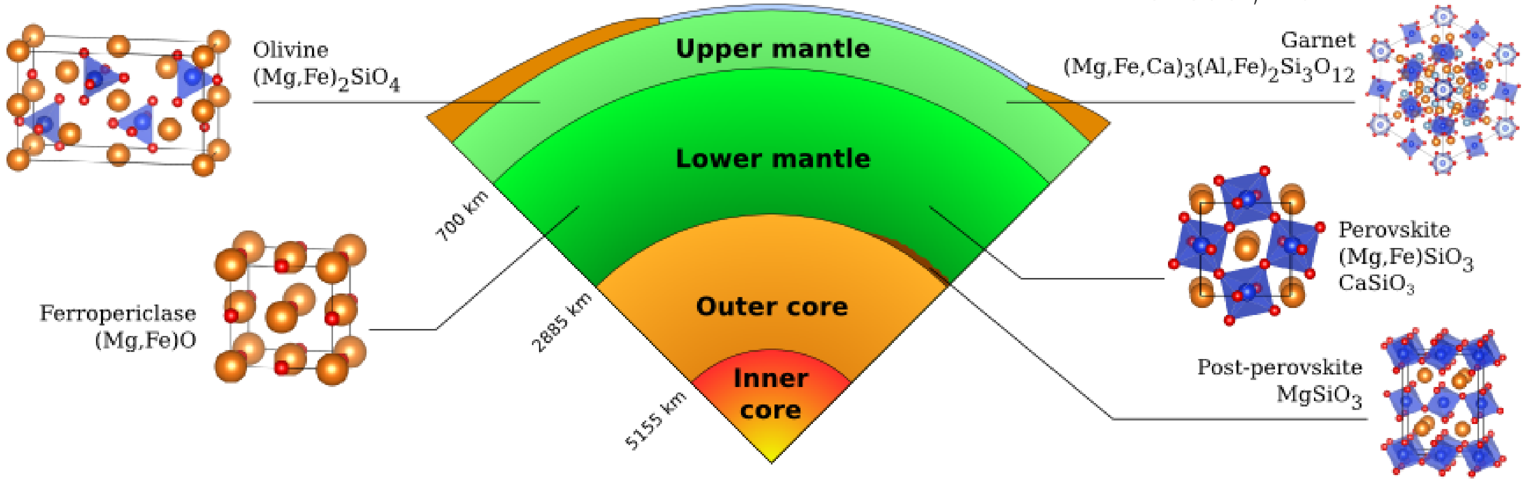


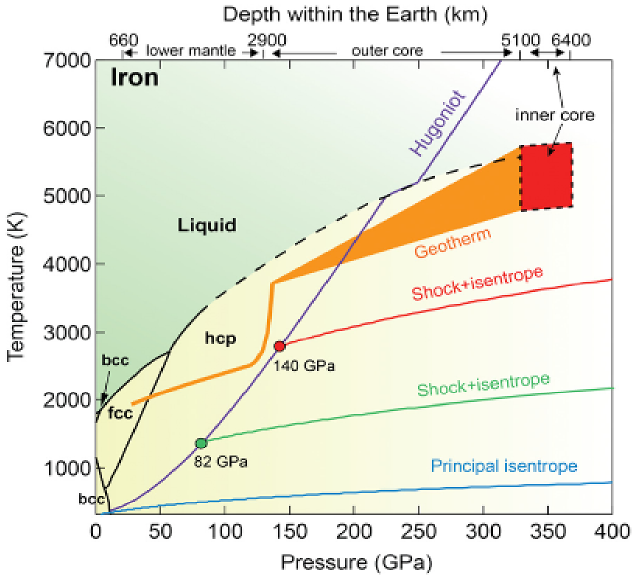
ZFS-centric applications



- H_2 and He major components of Jupiter and Saturn
- Studying EOS of H_2-He mixtures imperative for successful modeling of gas giant planets
- Shock ramp allows us to reach the proposed de-mixing region, probe along the planetary isentropes

Hirel et al, 2012





Wang et al. JAP 2013

- Shock ramp provides access to conditions found inside planets → insights to planetary formation and evolution
- Allows us to investigate dominant constitutes of Earth's core, such as Fe, MgO, $MgSiO_3$, or (MgFe)O (*see Hannah Bausch's talk on 08/10, Materials Science breakout session)*

Questions?