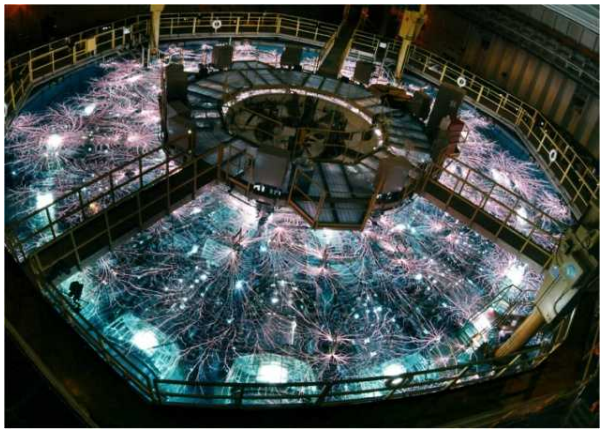
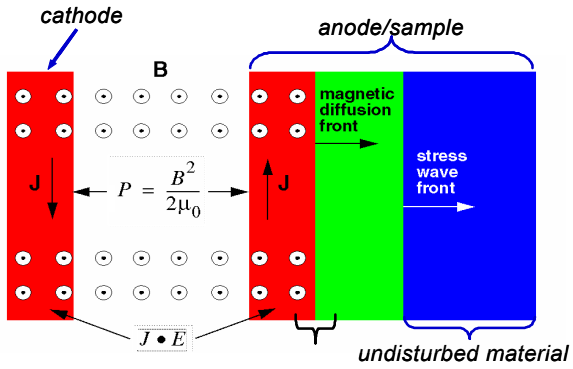
SAND2017-11741C

High Pressure Science at Sandia National Laboratories

Probing Materials under Extreme Conditions using Synchrotron Radiation
Argonne National Laboratory

Chris Seagle
Sandia National Laboratories, Albuquerque, NM





Chris Seagle, (505) 844-0934, ctseagl@sandia.gov

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SNL Facilities and Research Priorities

Z Machine:

- Ramp (isentropic) compression to ~5 Mbar
- Shock Compression (flyers to ~40 km/s)
- Shock-Ramp Compression (flyers <10 km/s)

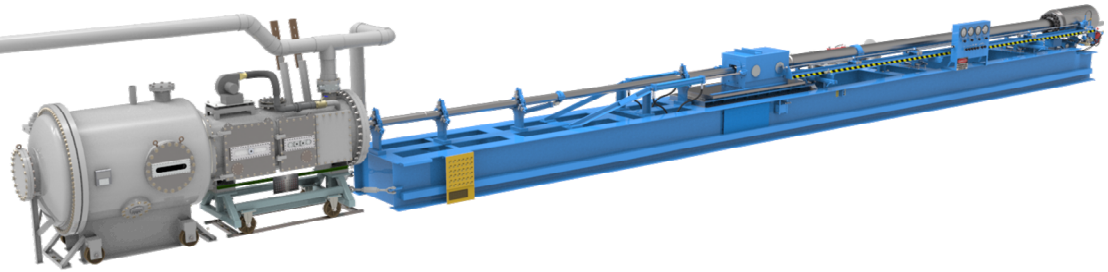
Dynamic Integrated Compression Experimental Facility

DICE:

- Small Air gun ~400 m/s
- VELOCE pulsed power ~3 MA
- THOR pulsed power (commissioning, ~10 MA)

STAR:

- Gas gun facility
- 2-Stage (~7 km/s)
- Powdergun (~2-3 km/s)
- Oblique gun (~1-2 km/s)
- Air gun (~800 m/s)
- Terminal Ballistics (~6 km/s)



STAR
Shock Thermodynamics Applied Research

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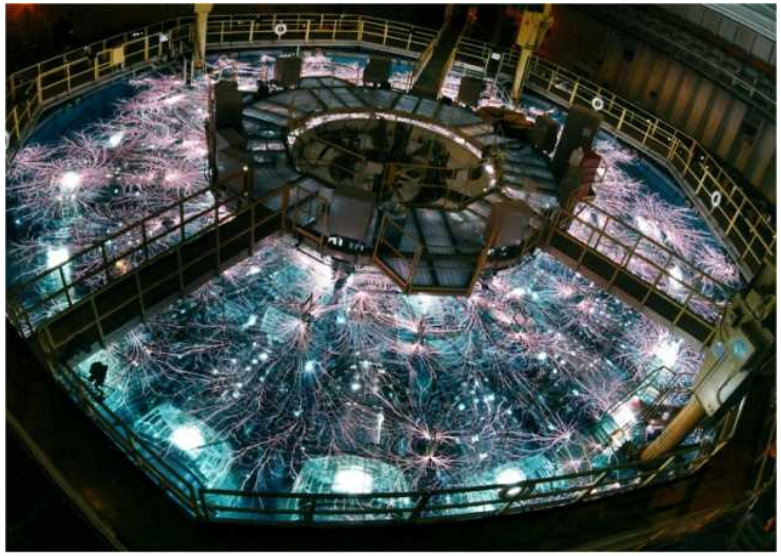
SNL Facilities and Research Priorities

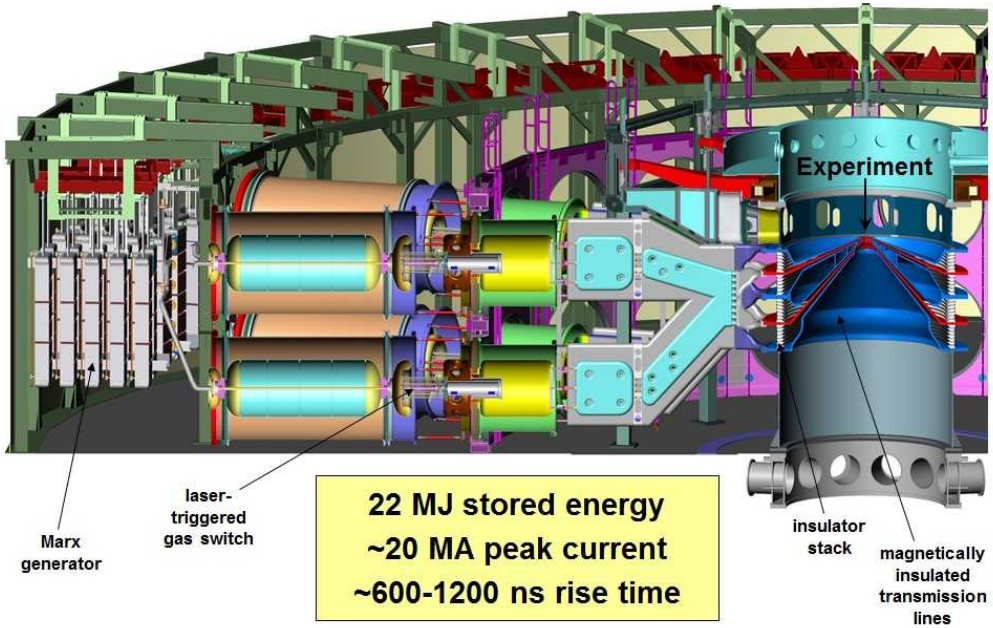
- Sandia dynamic material properties is focused on several areas of importance to national security:
  - Equations of State (metals, dielectrics, gasses, AM-materials)
  - Phase diagram and kinetics of phase transitions on dynamic loading
  - Strength of materials at high compression
  - Loading technique development
  - Initial condition control
  - Diagnostic development

SNL has active collaborations with other NNSA labs (LLNL, LANL) and academic collaborators through the fundamental science program: U. Washington, Carnegie Institution of Washington, U. Texas @ Austin, Harvard, U. Rostock.

Z is Well Suited for Dynamic Compression Experiments in the High Energy-Density Regime

Shockless Compression experiments are possible to ~5 Mbar and >30 Mbar for Shock Compression Experiments





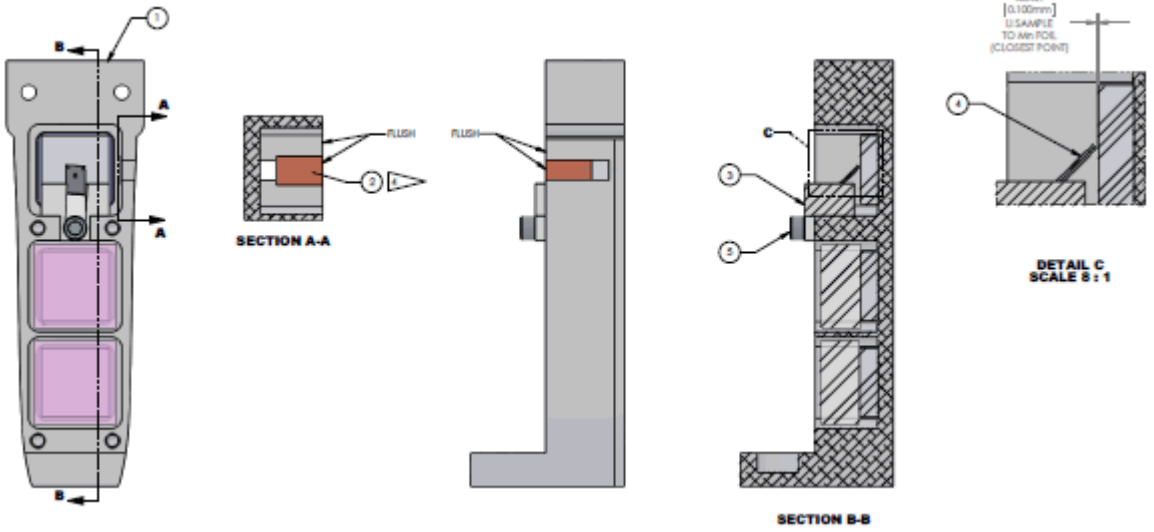
Temporally tailored pulseshapping capabilities allows a wide range of ramp, shock, and shock-ramp compression experiments

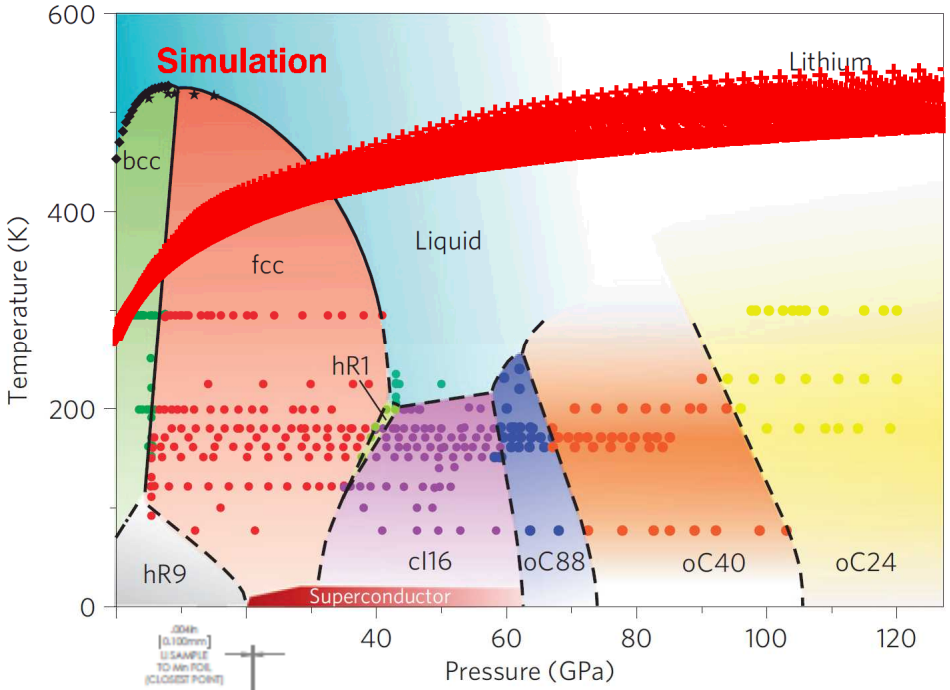
Rugged Diagnostic and Hardware Design Required

Ramp Compression of Lithium

Lithium has a complex phase diagram and is expected to melt on the principal isotherm and isentrope

Three experiments have been conducted on Z to identify signatures of melting and solidification based on velocimetry and x-ray scattering.



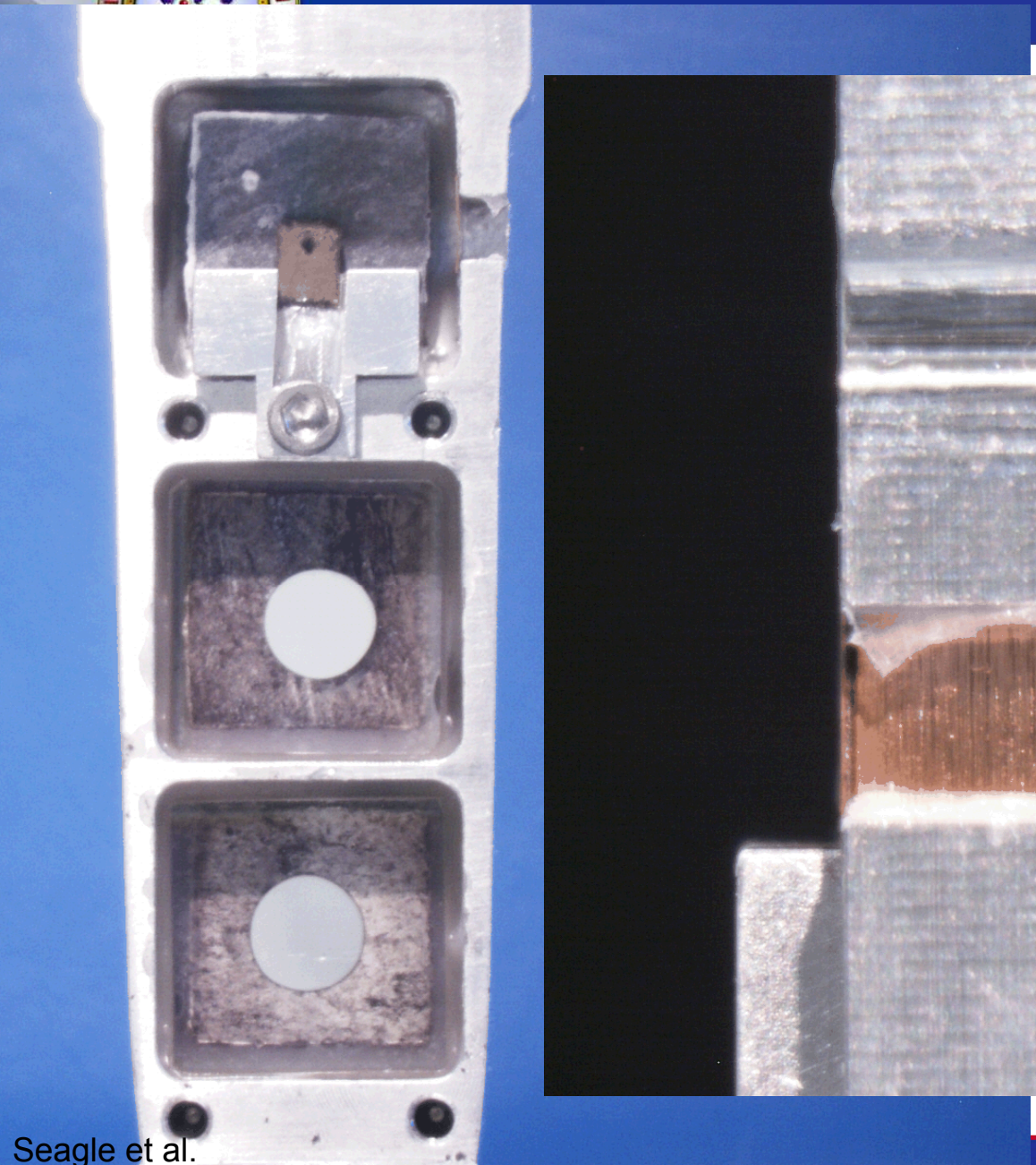


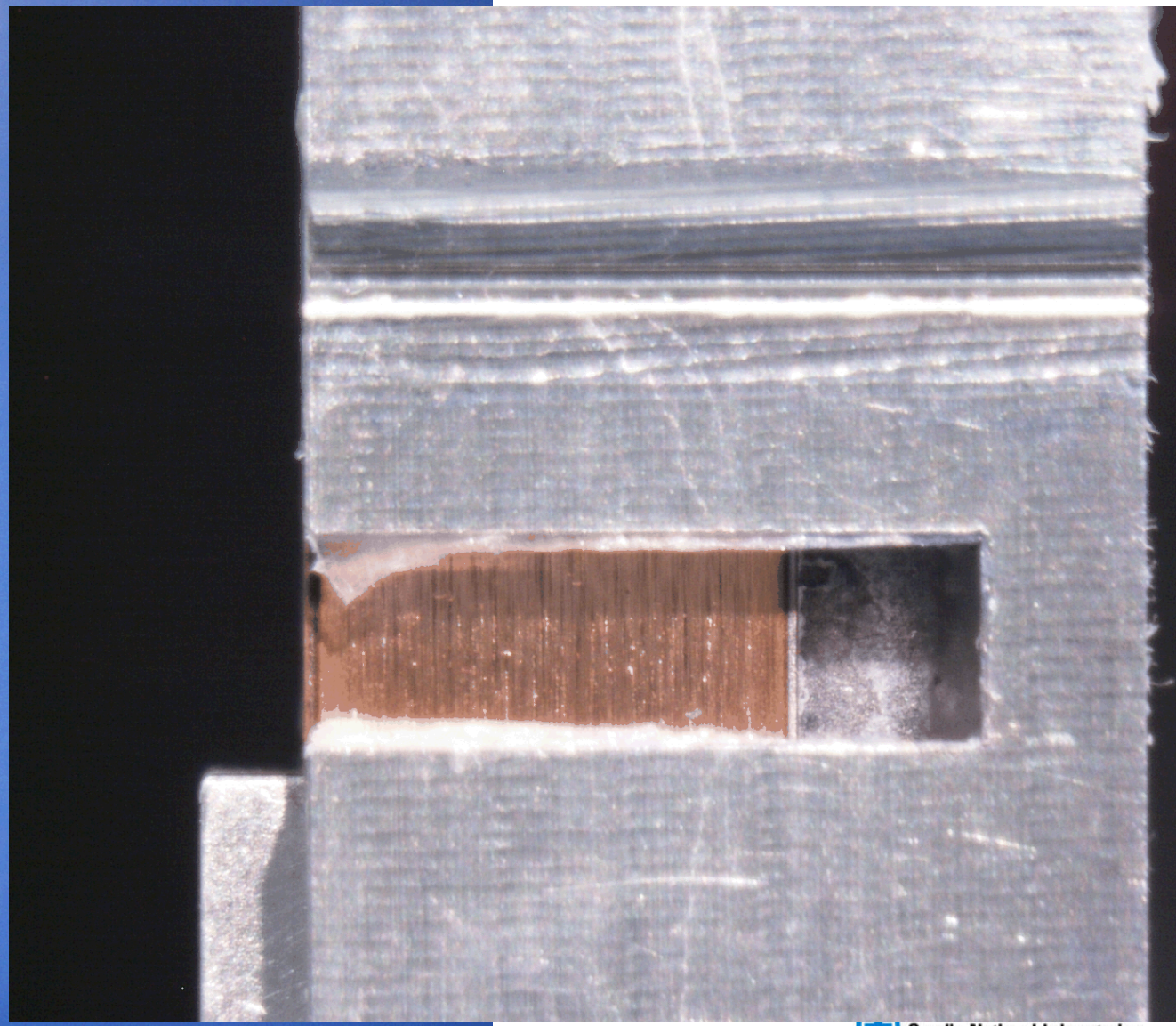
Guillaume et al. (Nature Phys 2011)

Spatially resolved elastic x-ray scattering was observed as a function of energy utilizing an Mn source generated from Z Beamlet.

Seagle et al.

View of assembled lithium panel and x-ray scattering window





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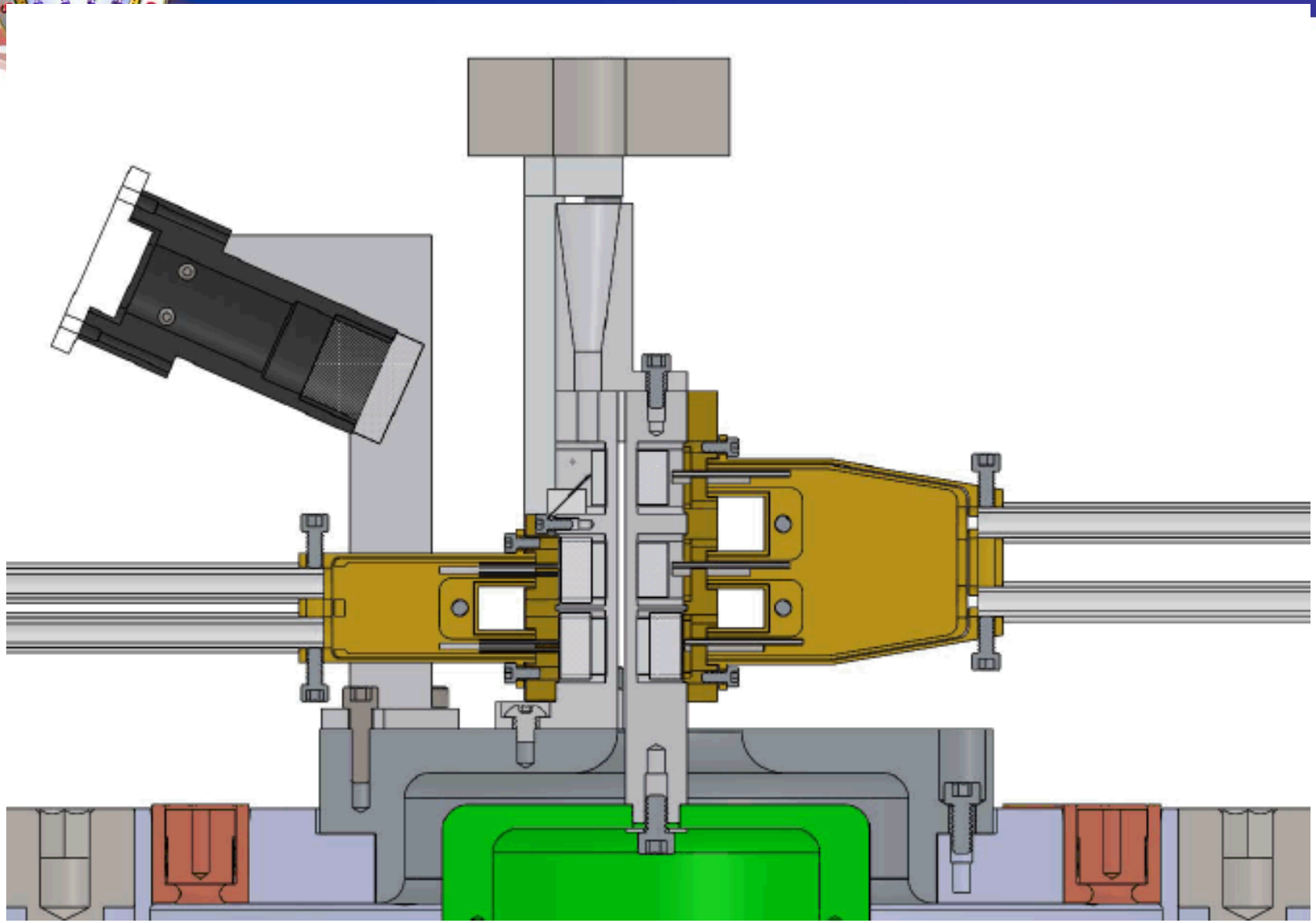

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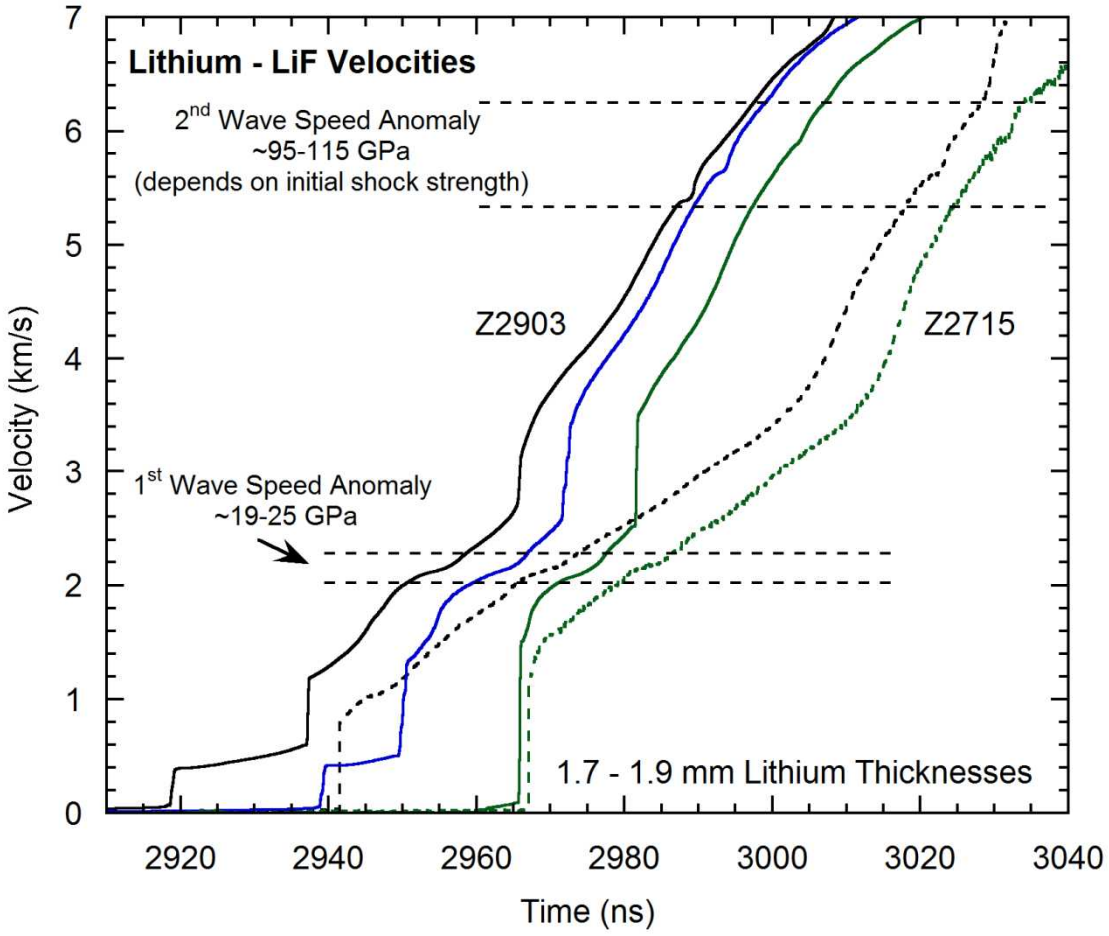
Velocimetry

- "Typical" phase transitions manifest as a pull-back in velocity followed by acceleration (densification)
- Two clear pull backs are observed on ramp-compressed lithium
  - 19-25 GPa, observed in every sample, likely melting
  - 95-115 GPa, observed in most samples, less pronounced in samples which exhibited a higher initial shock (on a higher temperature isentrope). Most likely associated with solidification.



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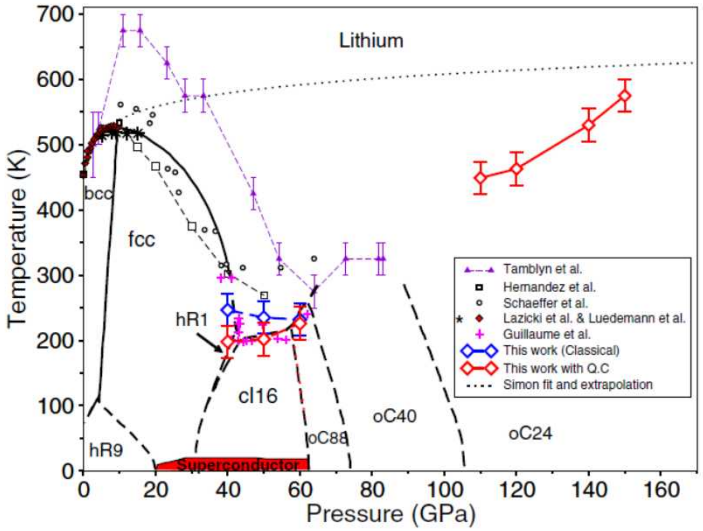
Seagle et al.

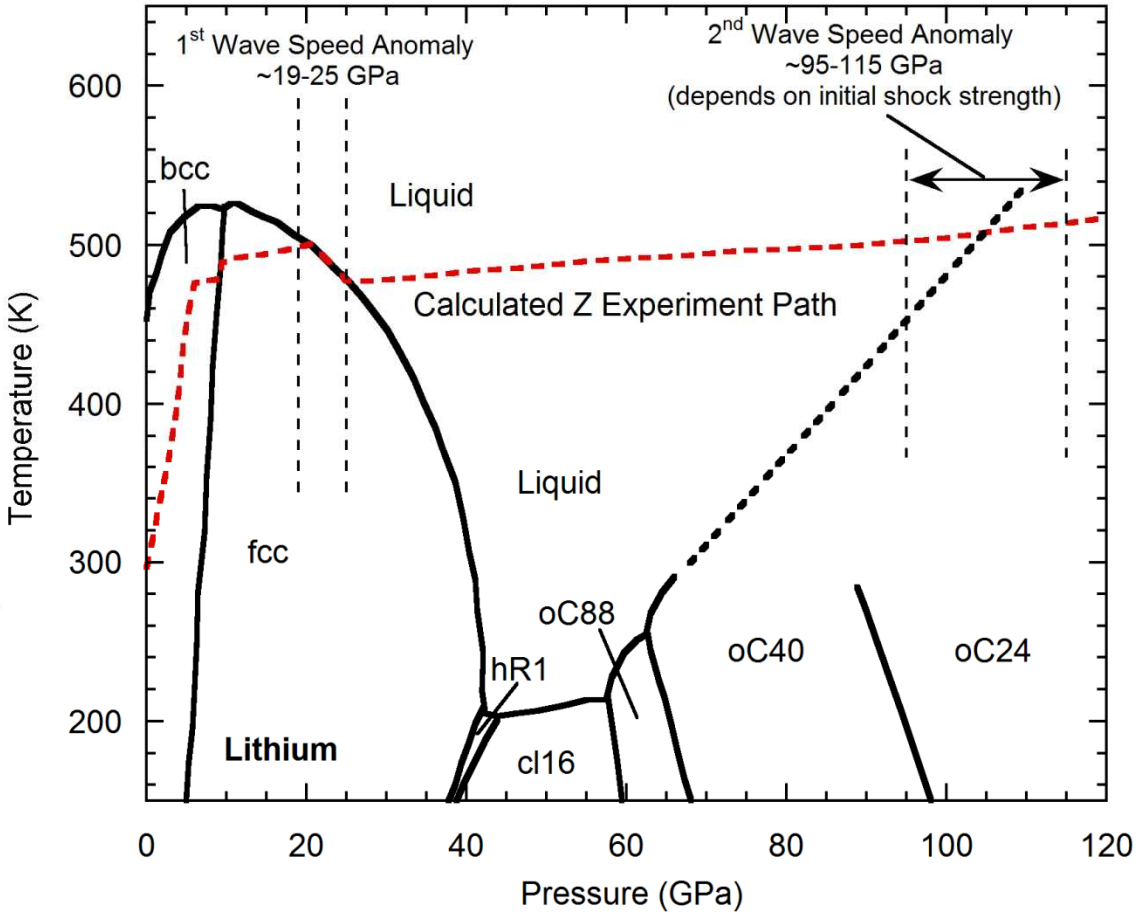
Post-shot simulations

- The initial shocks were unintentional, but of small magnitude (<8 GPa).

- The calculated experimental path crosses the bcc-fcc boundary at low pressure, coasts along the melt line for ~6 GPa, and reaches peak pressures where solidification may occur.



Elatresh et al. Phys. Rev. B, 2016



Seagle et al.

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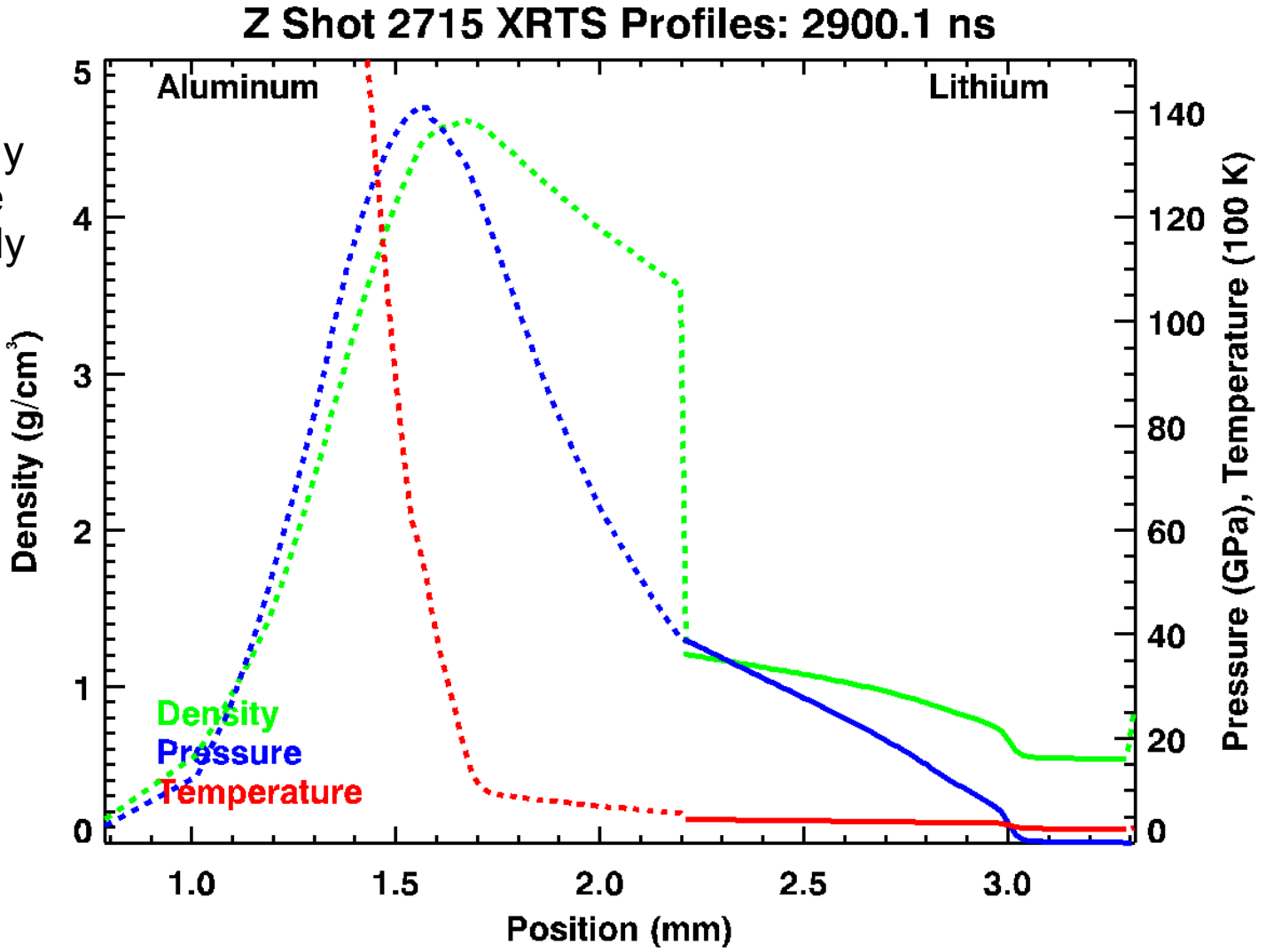
Spatial profile at x-ray probe time suggests possibility of observing bcc, fcc, and liquid lithium

Two experiments utilized an essentially identical x-ray probe time, which was early (conservative): both produced nearly identical scattering features.

A third shot probed late in time in an attempt to see the fourth (solid) phase, unfortunately no scattering was observed.



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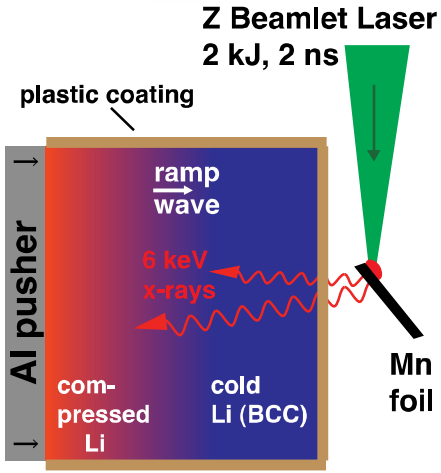
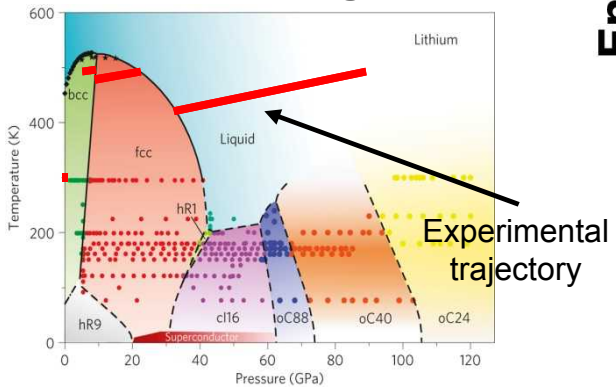
An x-ray scattering experiment was successfully performed on Z with compressed Lithium metal.

Experimental Setup

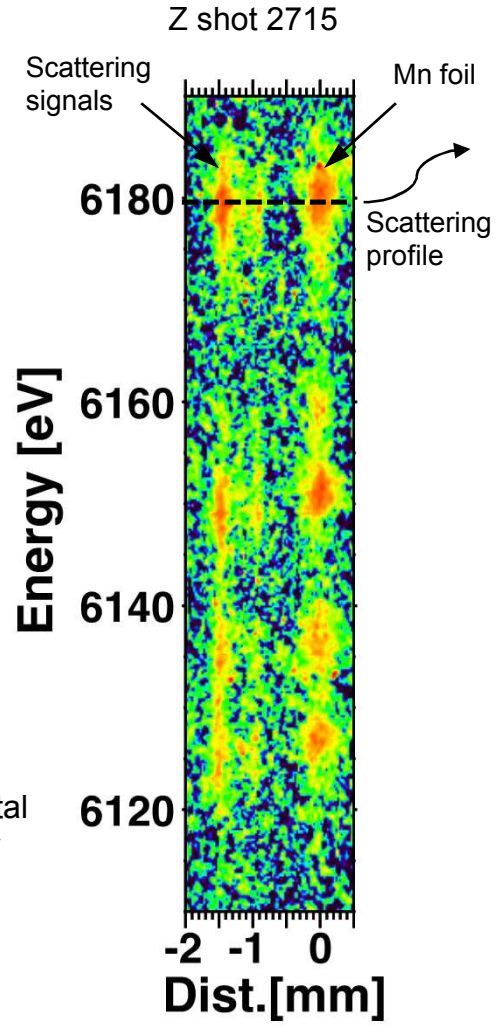


Li Phase Diagram

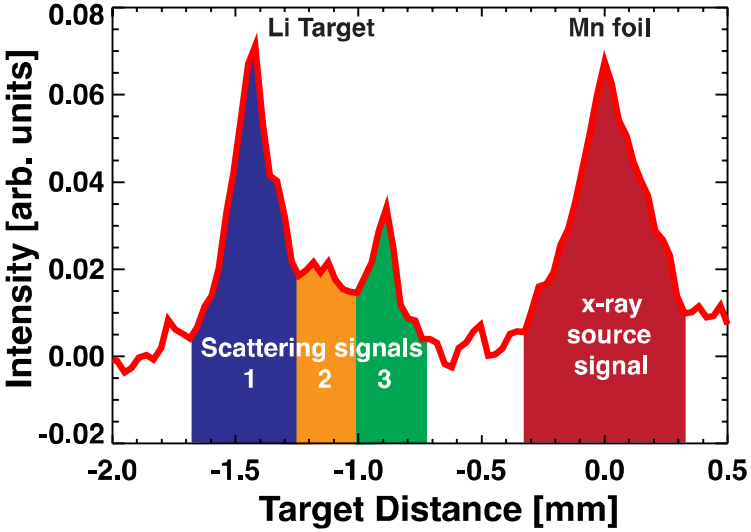


Guilliame et al. Nature Physics. **7**, 211 (2011)

Data Image



Spatial Profile of Scattering



Comments

- Experiment was designed to undergo phase transitions: BCC➔FCC➔Liquid.
- A spatial variation in the scattered x-ray signal was observed.
- Preliminary identification of phases based on comparison with QMD simulation.

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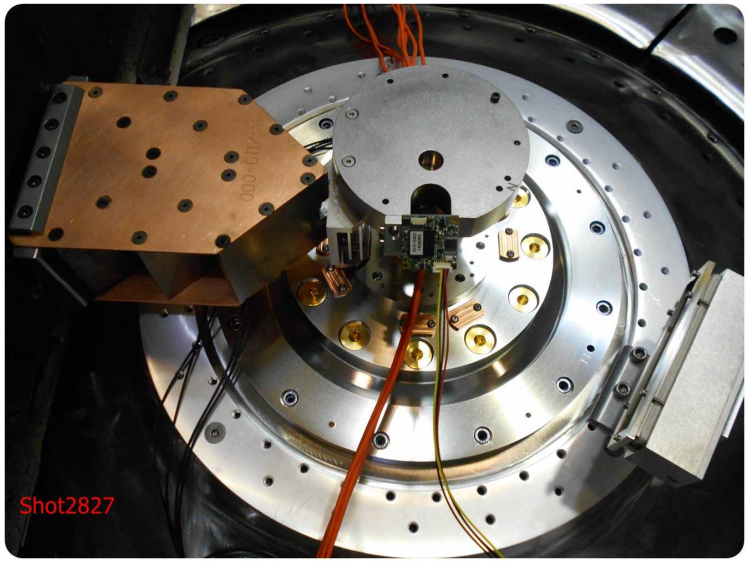
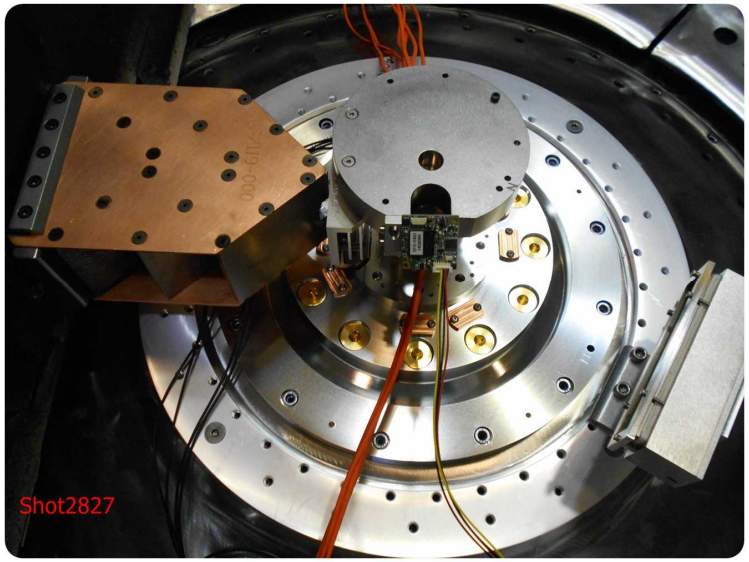
Hardware Before

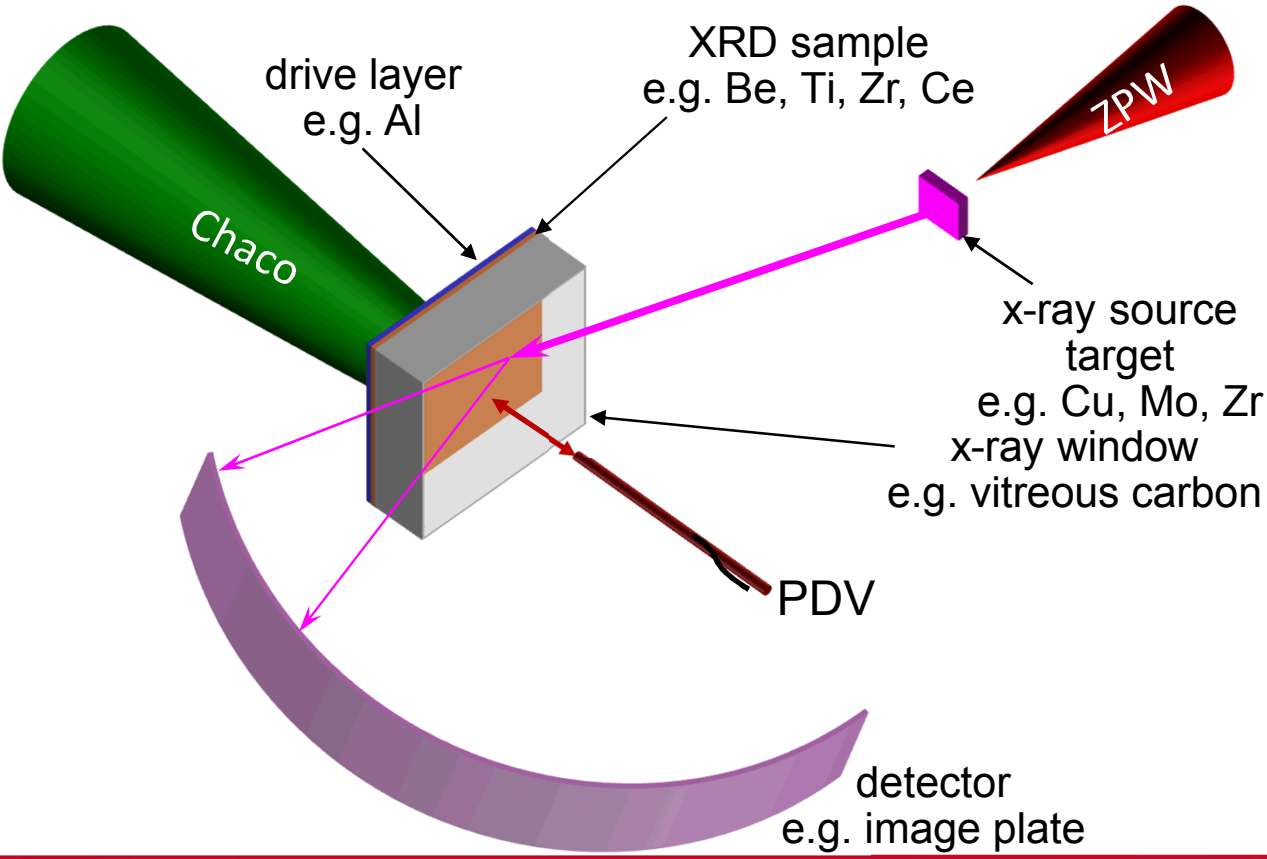


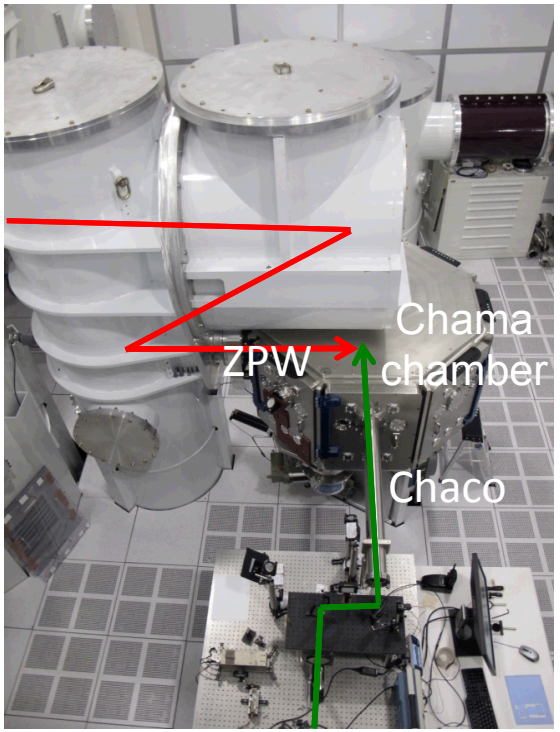
Hardware After



Overview of XRD LDRD project

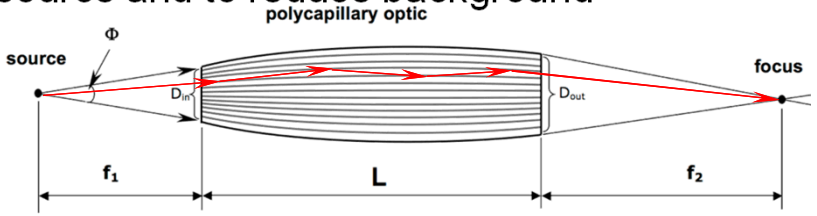
1. Chaco laser (50 J, 8 ns) to drive polycrystalline samples to tens of GPa pressure
2. Z-Petawatt (ZPW) laser (200 J, 100 ps) to develop >10 keV x-ray source suitable for diffraction
3. Perform integrated x-ray diffraction experiments to measure dynamic phase changes
4. Reproduce and predict phase transition dynamics with simulations

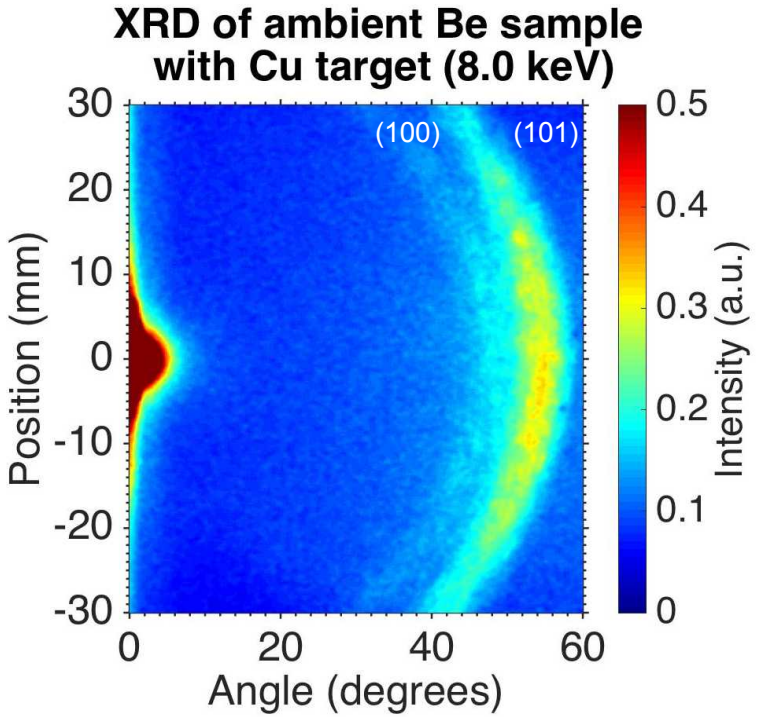


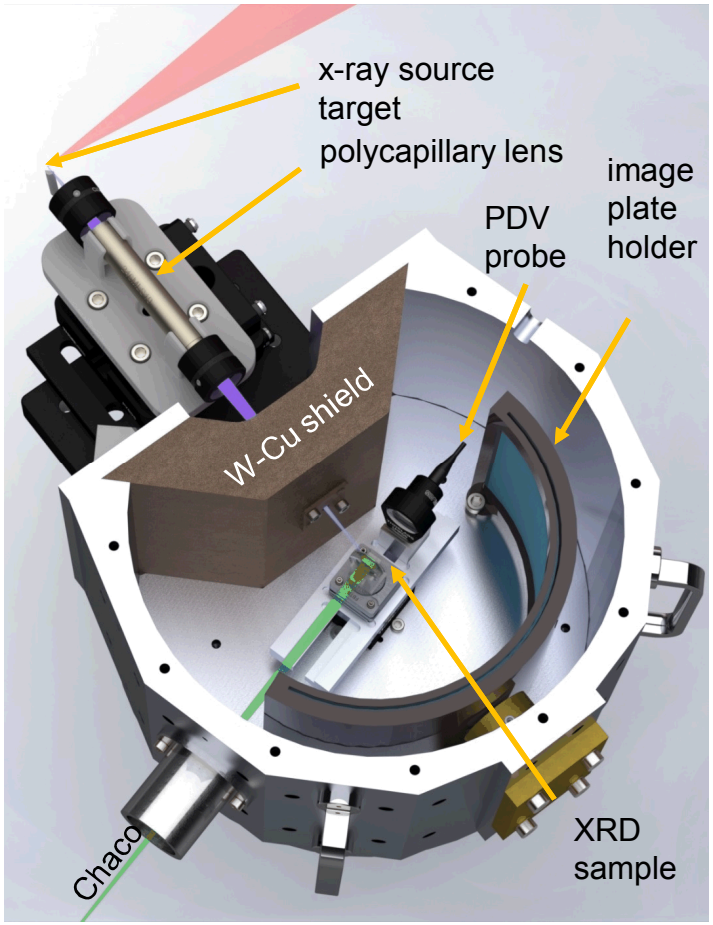


PACMAN - Phase And Crystallography Measurement ANalyzer

- X-ray polycapillary lens to increase x-ray flux from source and to reduce background







Areas for Potential Collaboration

- **Melting at High Pressure (e.g. Lithium)**
- **Static/Dynamic studies of sub-solidus phase transitions (see P. Kalita)**
- **Optical properties, melting, and phase/EoS of transparent “windows”**
  - **Current work on LiF, MgO, Sapphire, Tungsten hexafluoride, other high acoustic impedance materials(?).**

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Thanks!

Questions?