LAWRENCE LIVERMORE NATIONAL LABORATORY

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Materials at Extreme Compression

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Materials at Extreme Compression

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Lawrence Livermore National Laboratory

LLNL-PRES-XXXXXX

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We have built a broad base of academic collaborators

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- **Los Alamos Laboratory**
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- **University of California, Berkeley**
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- **Princeton University**
  - T. Duffy, J. Wang^, June Wicks^
- **University of Rochester**
  - T. Boehly, B. Yaakobi
- **Stanford University**
  - A. Gleason^^, W. Mao
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  - P. Loubeyre, S. Brygoo
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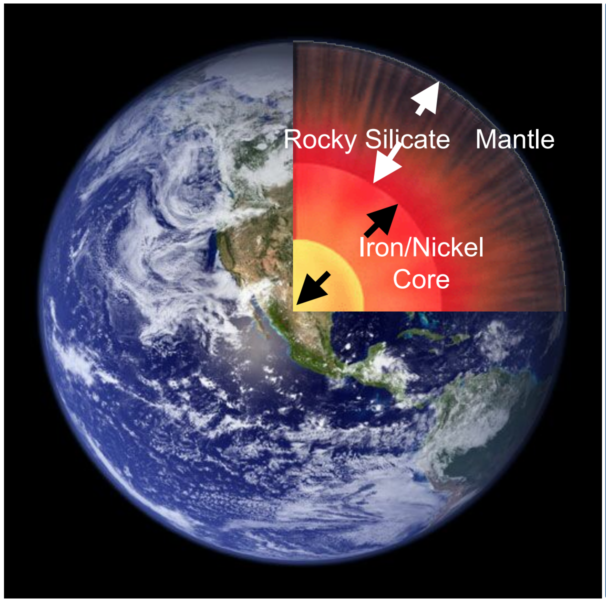
- **National Research Council of Canada**
  - D. Klug, Y. Yao
- **University of Edinburgh, Scotland**
  - M. McMahon, E. McBride^, R. Briggs^^
- **Additional Collaborators / Consultants**
  - Andrew Comley, Brian Maddox, Hye-Sook Park, and Bruce Remington
- **Plus farget fabrication, Omega and NIF facility and diagnostic teams.**

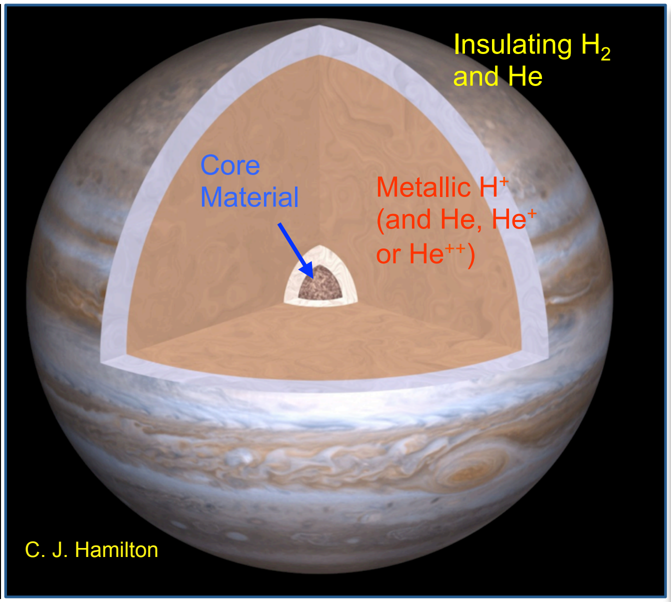
^Student
^^Post-Doc

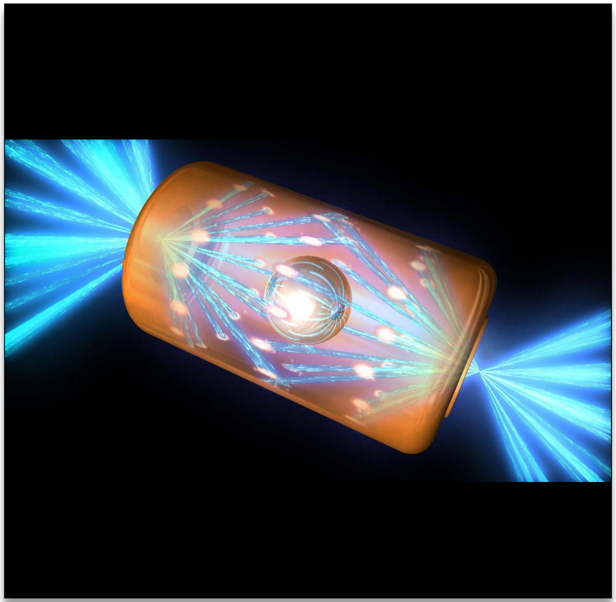
*Currently, University of Edinburgh
**Currently, Harvard University

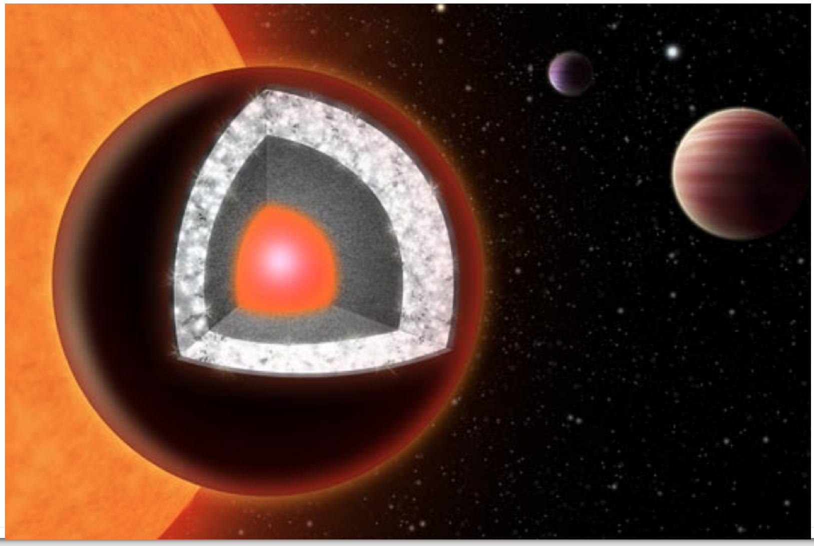
1 Mbar = 100 GPa = 0.1 TPa

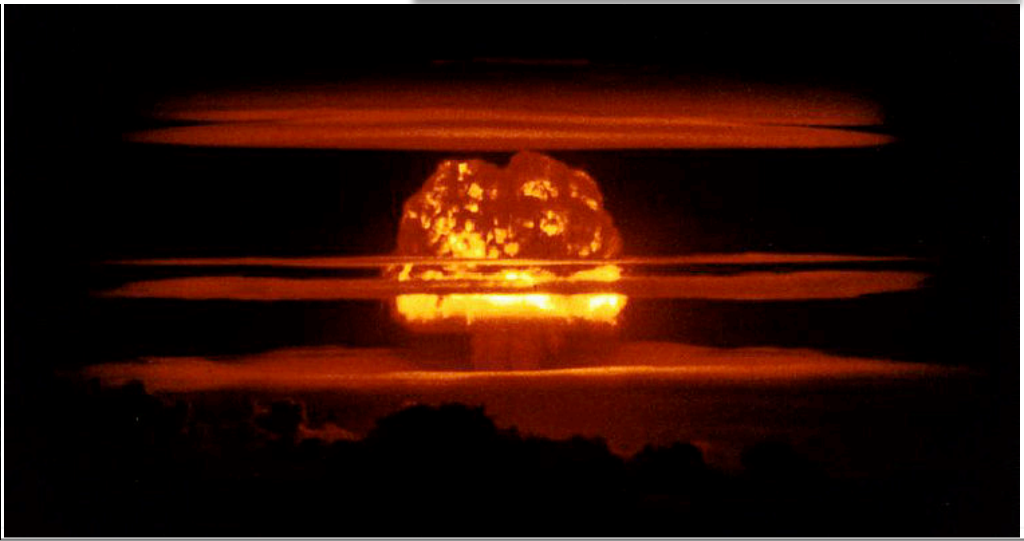
Matter at High Energy Density (HED) is found throughout our universe





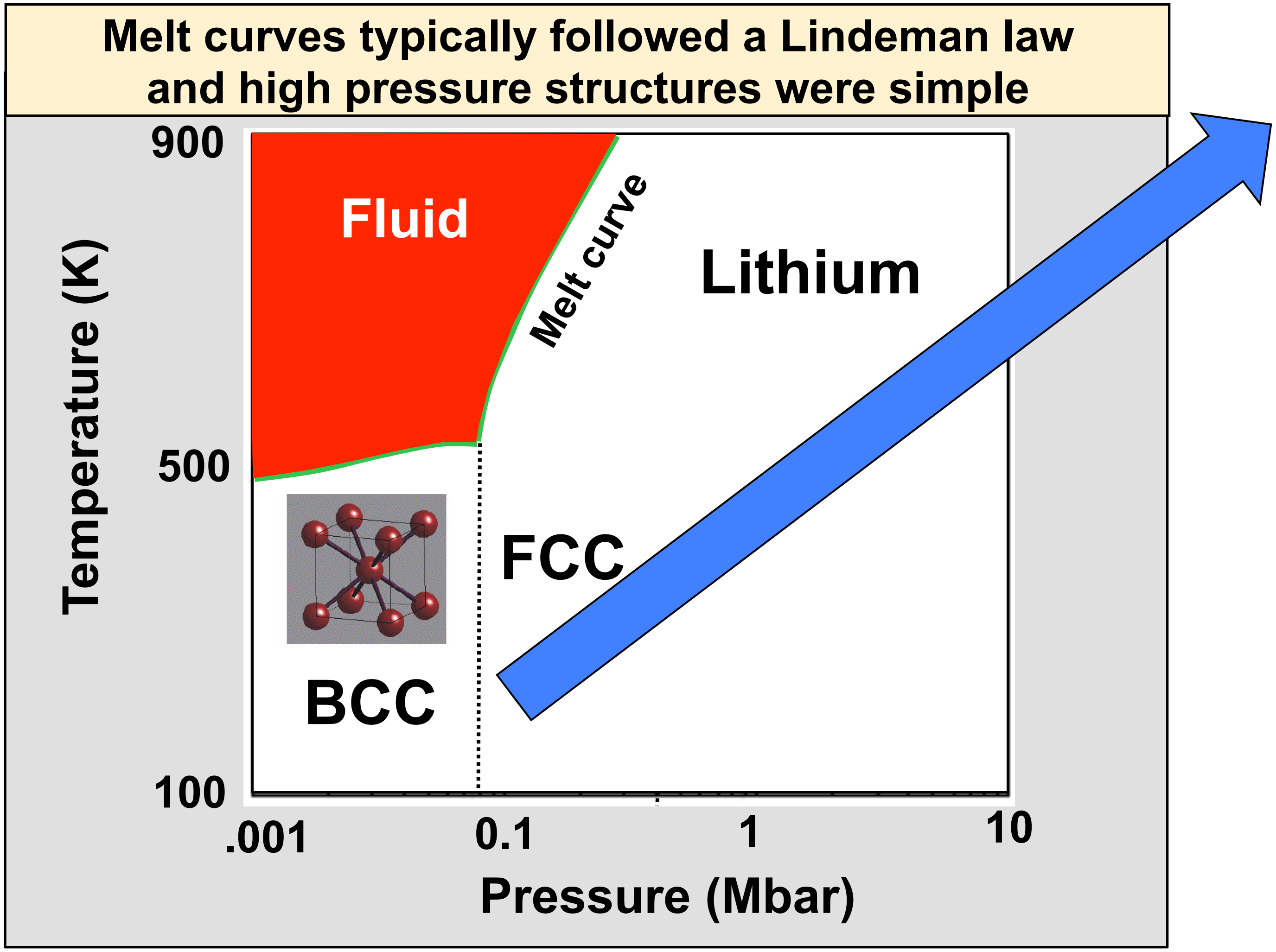






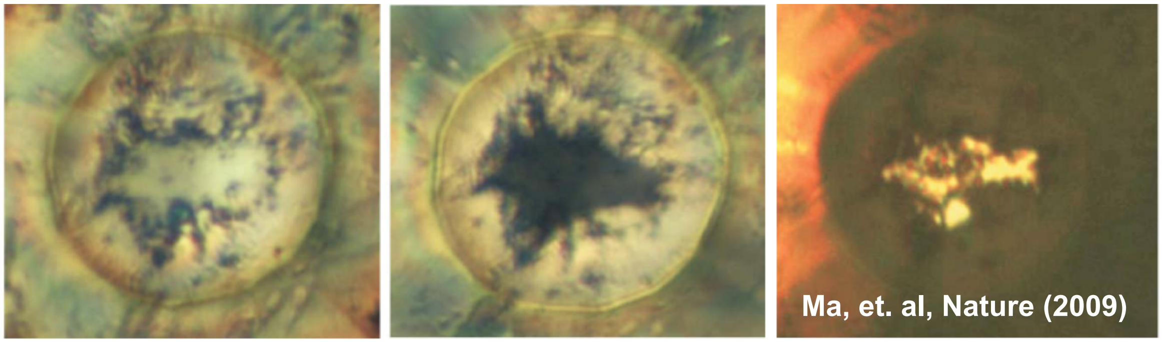
1 Mbar = 100 GPa = 0.1 TPa

Just a few years ago, ultra-high pressure phase diagrams were considered to be very simple



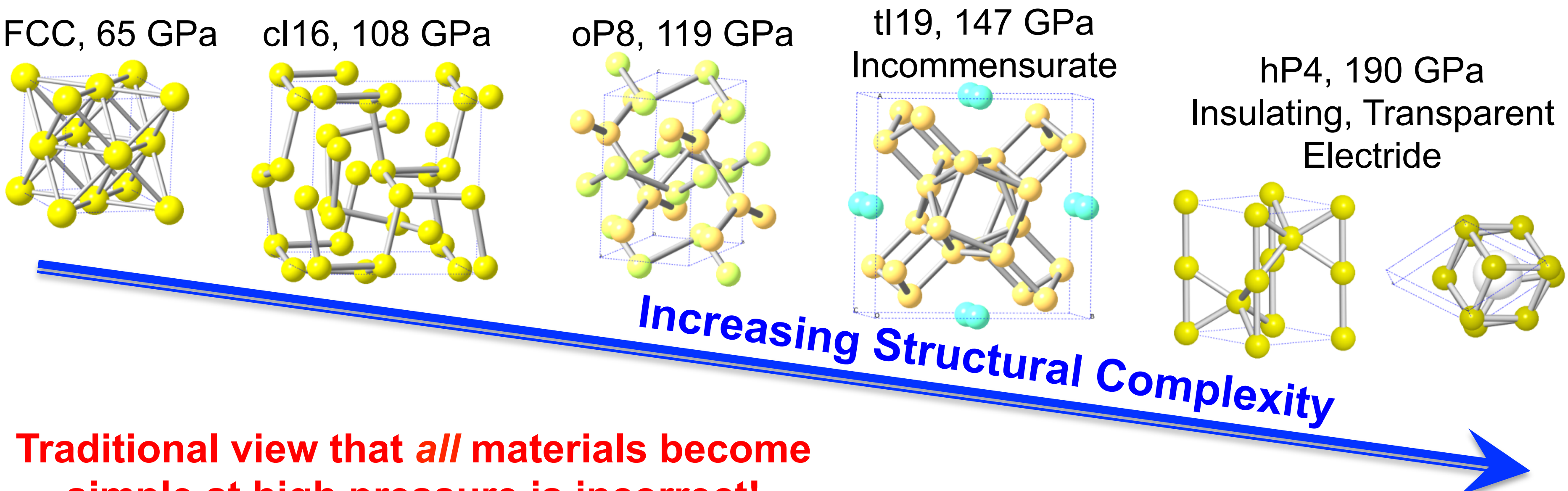
Physics Gets Simple!

Above 200 GPa Sodium becomes a large band-gap insulator! -- Electride --



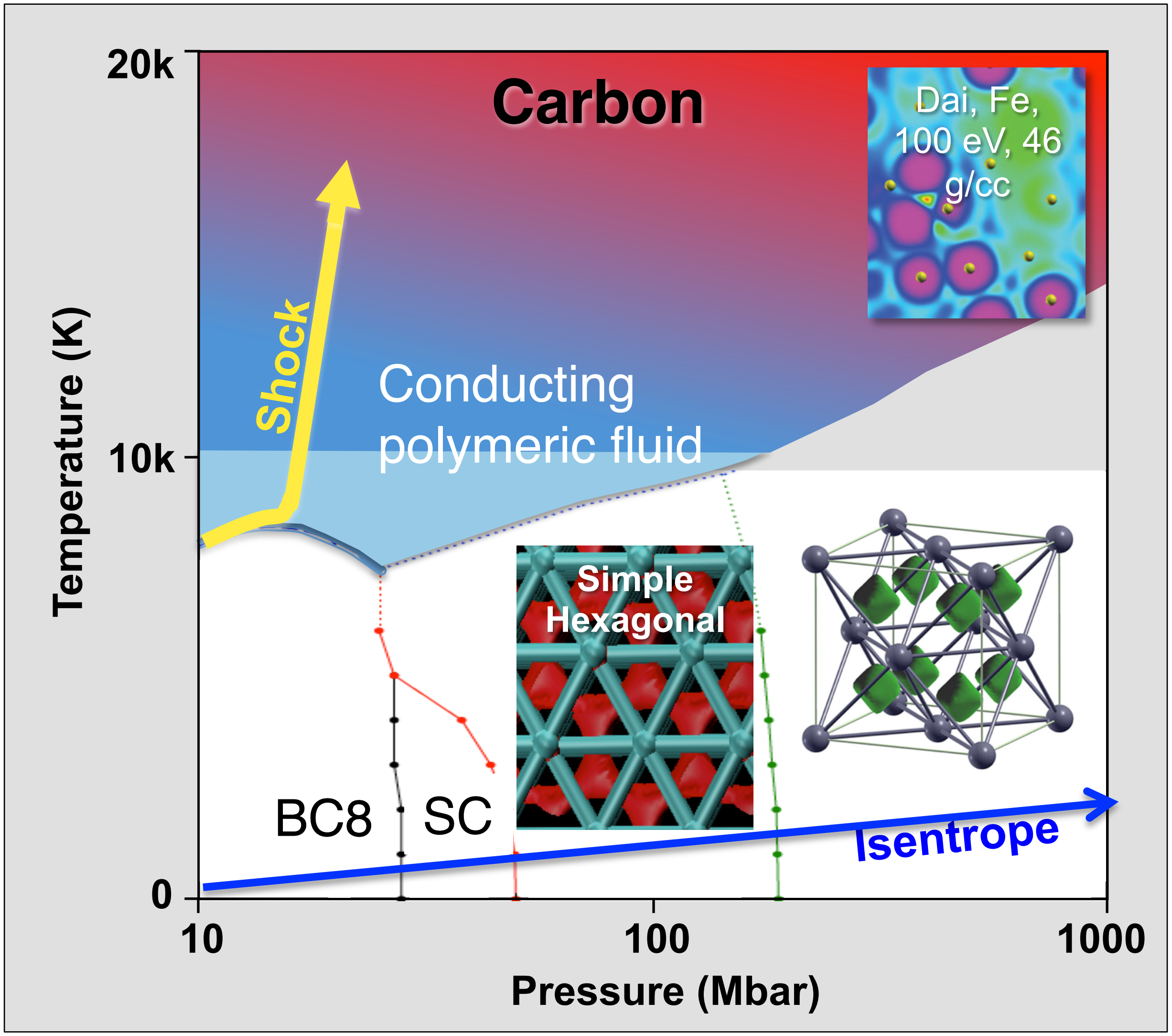
120 GPa 156 GPa 199 GPa

"... what the present results most assuredly demonstrate is the importance of pressure in revealing the limitations of previously hallowed models of solids"
–Neil Ashcroft (Nature, 2009).



Traditional view that *all* materials become simple at high pressure is incorrect!

Many materials are predicted to adopt complex structures in high pressure solid and fluid phases



Canales, PRL, (2012)
Hamel et al, 2014

1 Mbar = 100 GPa = 0.1 TPa

Using laser-driven compression and the NIF we are study Extreme-Compression (ρ/ρ_0>2) Science

We want to measure:

Stress-Density

Temperature

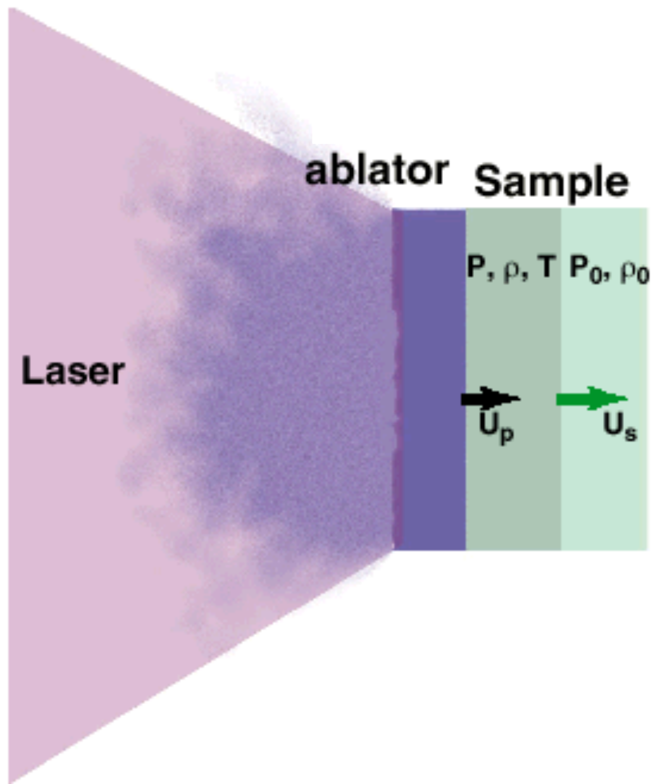
Structure

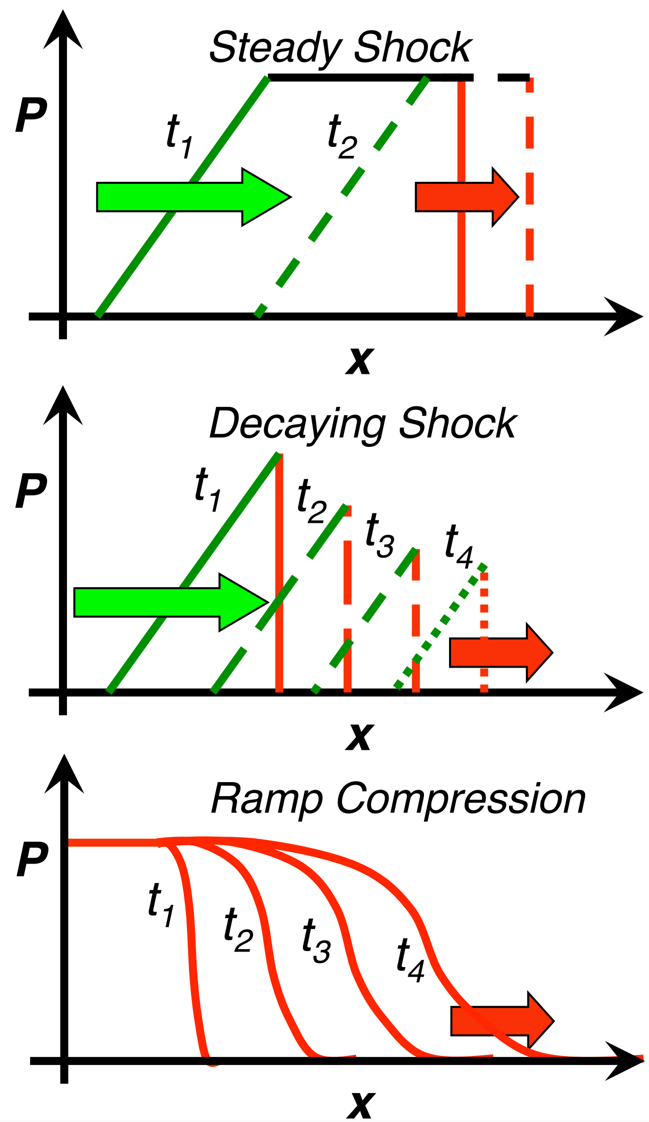
Solid-Solid Phase Transitions

Solid-Liquid Phase Transitions

1 Mbar = 100 GPa = 0.1 TPa

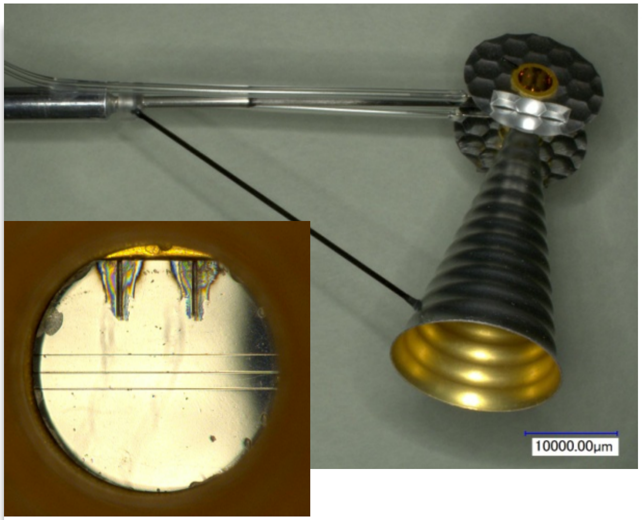
We use a shaped laser pulse to control the time-dependent laser ablation drive pressure

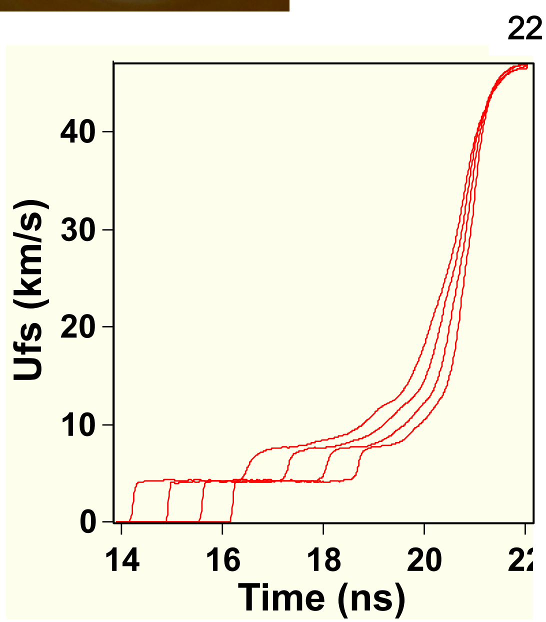


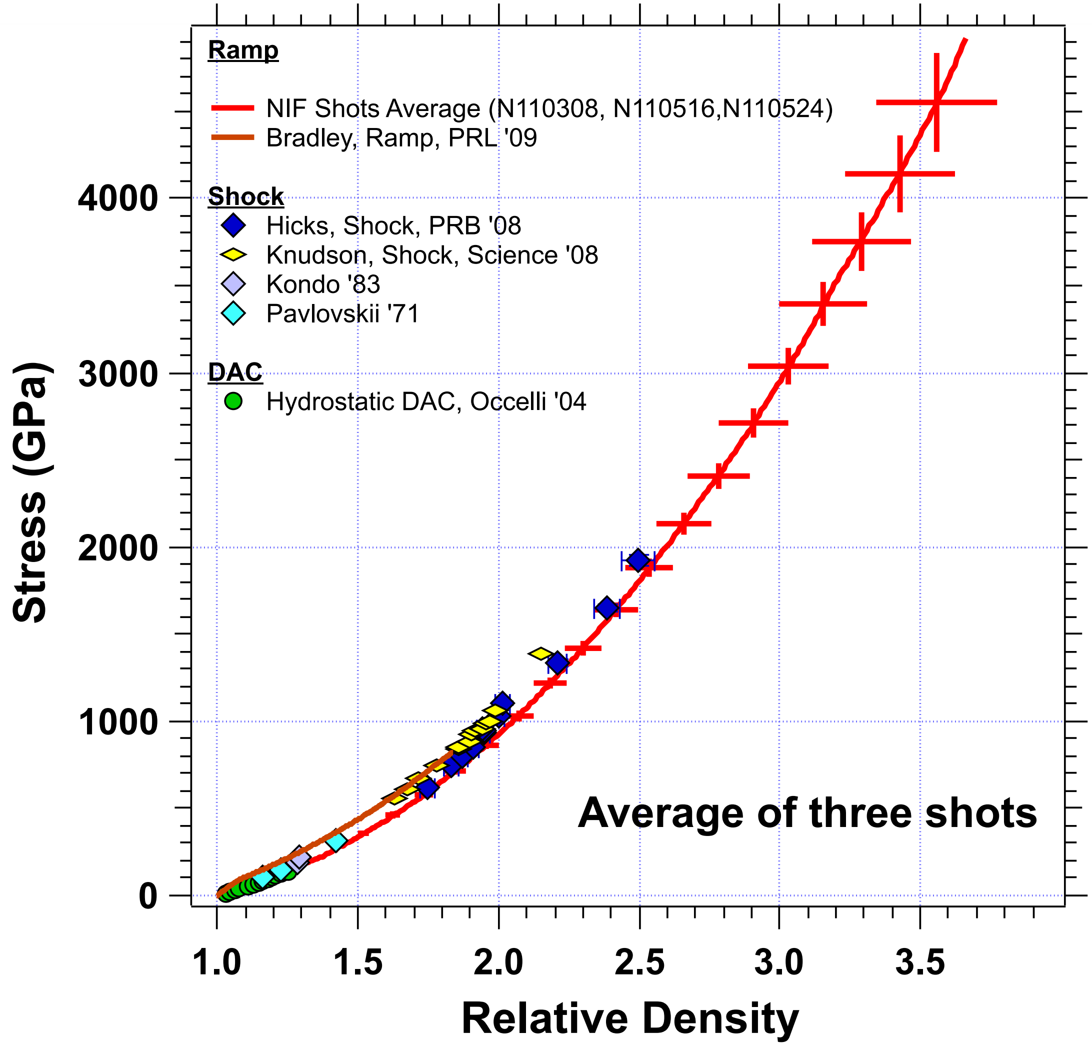


Steady Shocks -> Impedance Matching
Decaying Shocks -> *Us* vs *R*, *T*, Heat Capacity
Ramp Compression -> Lower Temperature

Ramp-compression EOS of nano-crystalline diamond to 50 Mbar.





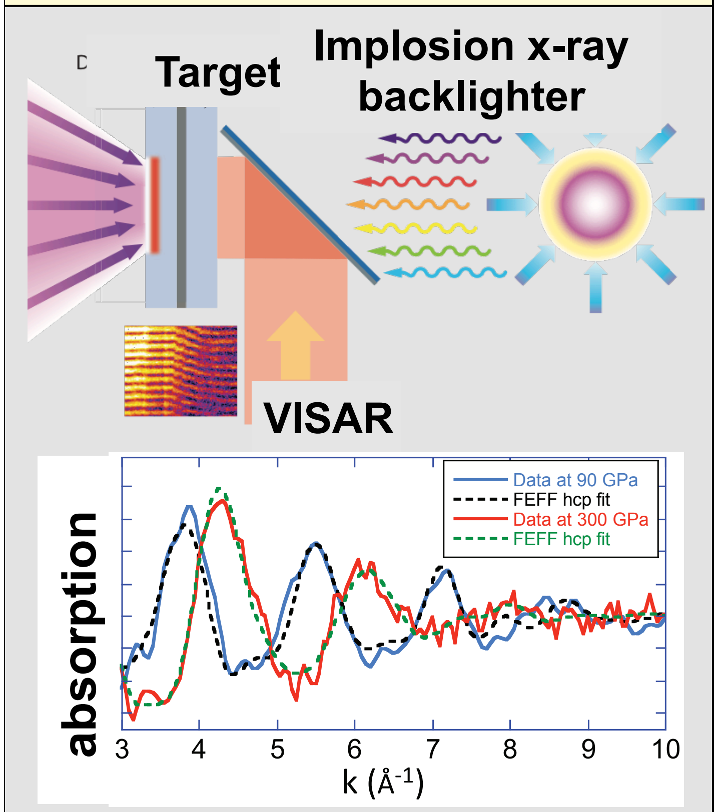


Smith, et. al, **Nature**, accepted for publication.

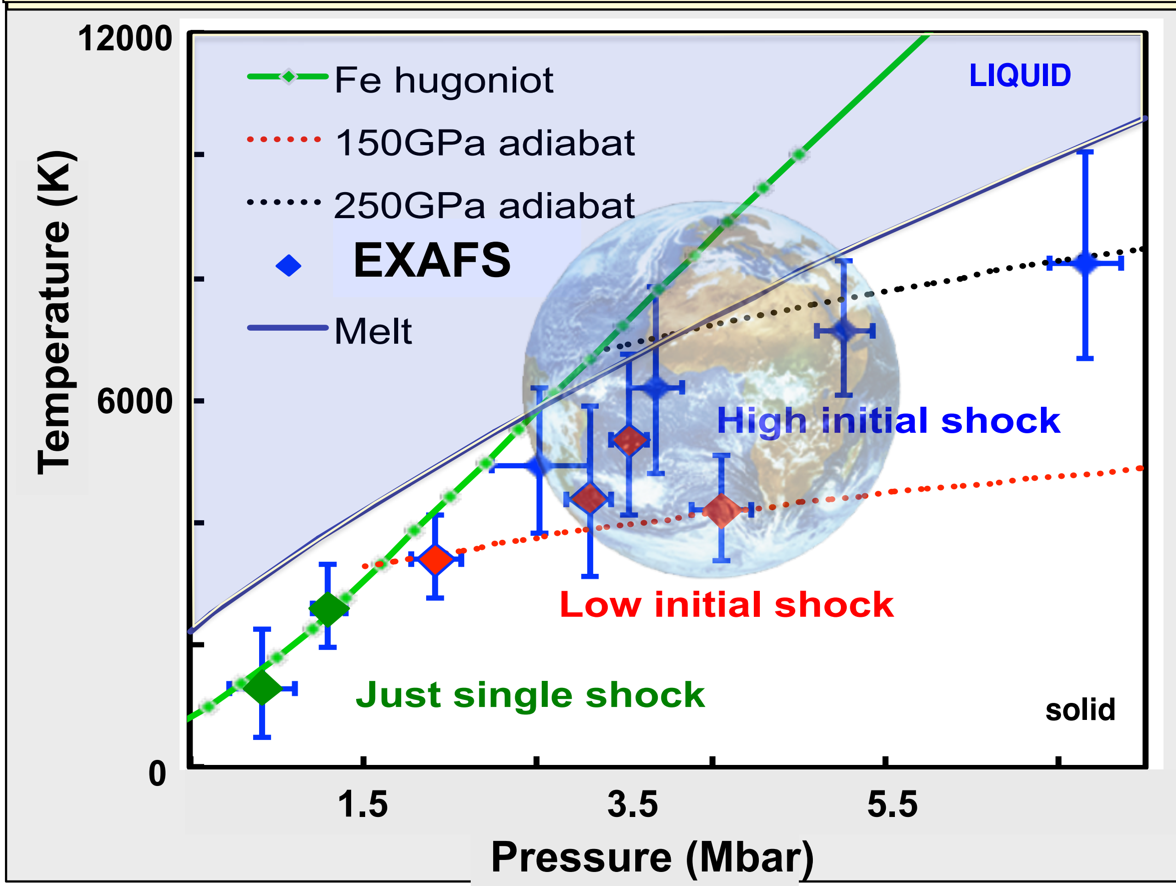
1 Mbar = 100 GPa = 0.1 TPa

Resolving x-ray absorption structure gives temperature along different compression paths

EXAFS data collected in 50 ps snapshot



T versus P data for Fe shows structure is HCP and information on Earth's core conditions



Y. Ping, et al., PRL, **111**, (2013).

Using the laser-driven compression and the NIF we will study Extreme Compression Science

We want to measure:

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Structure

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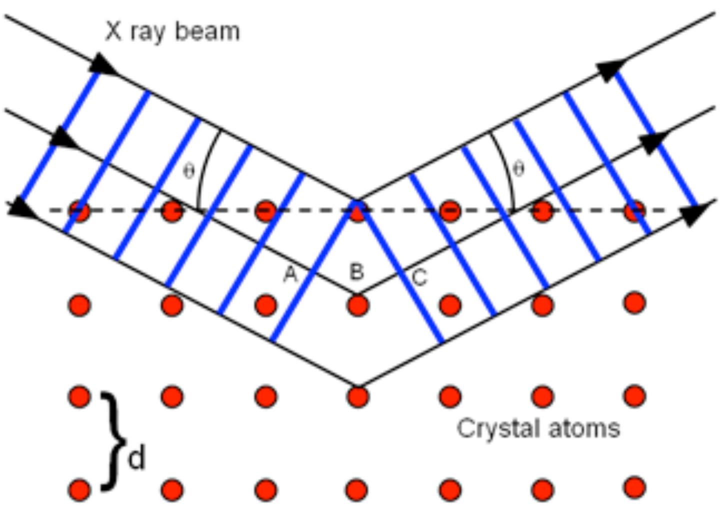
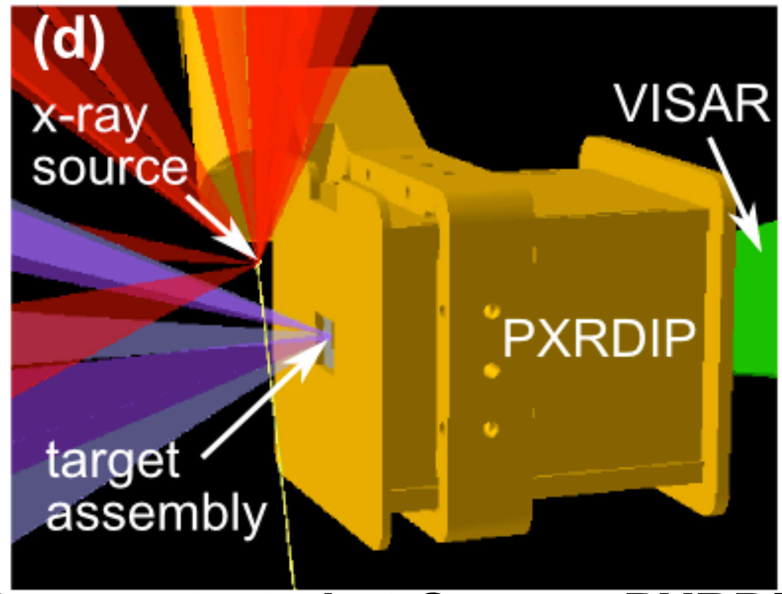
Using LDRD funding, we developed in-situ x-ray diffraction at Janus and Omega



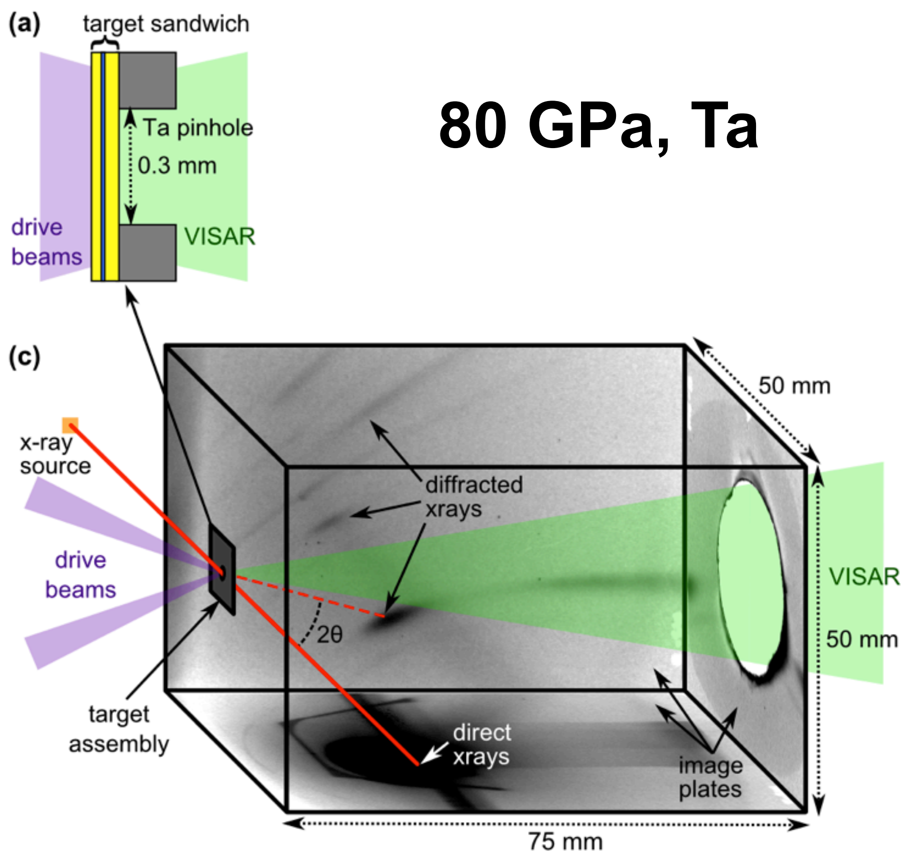


Demonstrated at Omega, PXRDIP

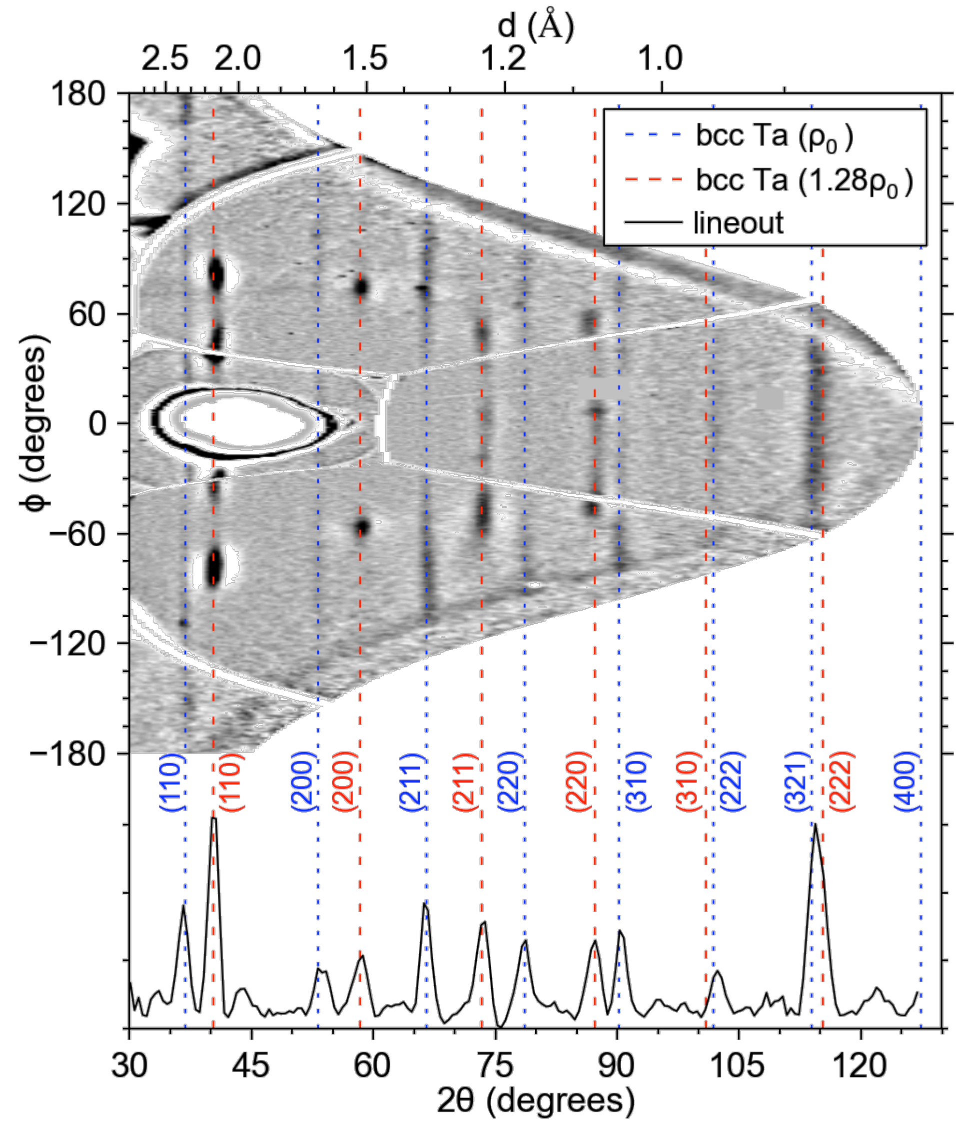
(Powder X-Ray Diffraction Image Plates)

1 Mbar = 100 GPa = 0.1 TPa

In situ diffraction provides conclusive crystal structure. Demonstrated at Omega



80 GPa, Ta



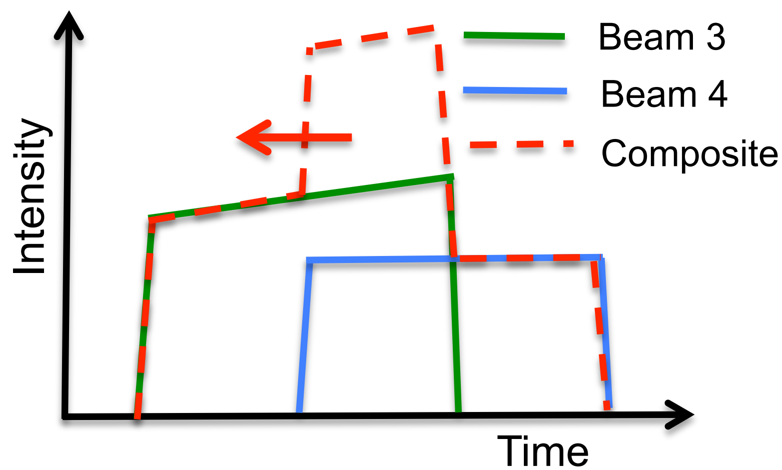
Rygg, et al., RSI, **83,** 113904 (2012)

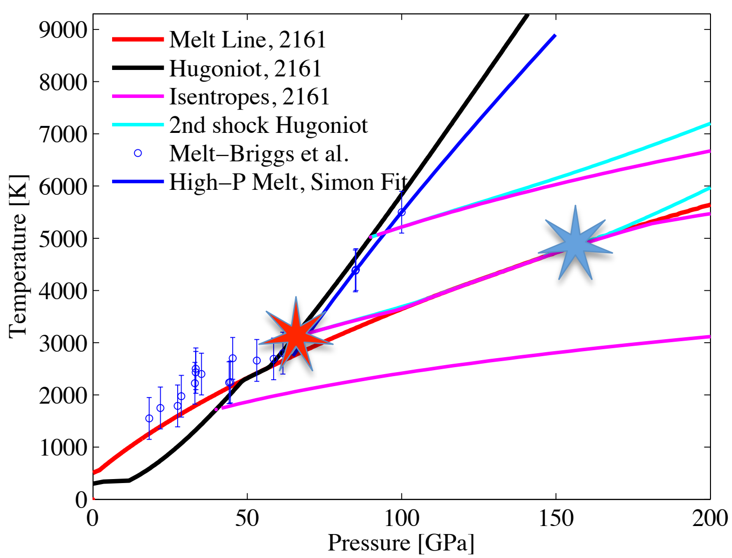
De-warped image plate data

1 Mbar = 100 GPa = 0.1 TPa

We have observed Shock-Melt – Refreeze for first time ever in Sn at Omega

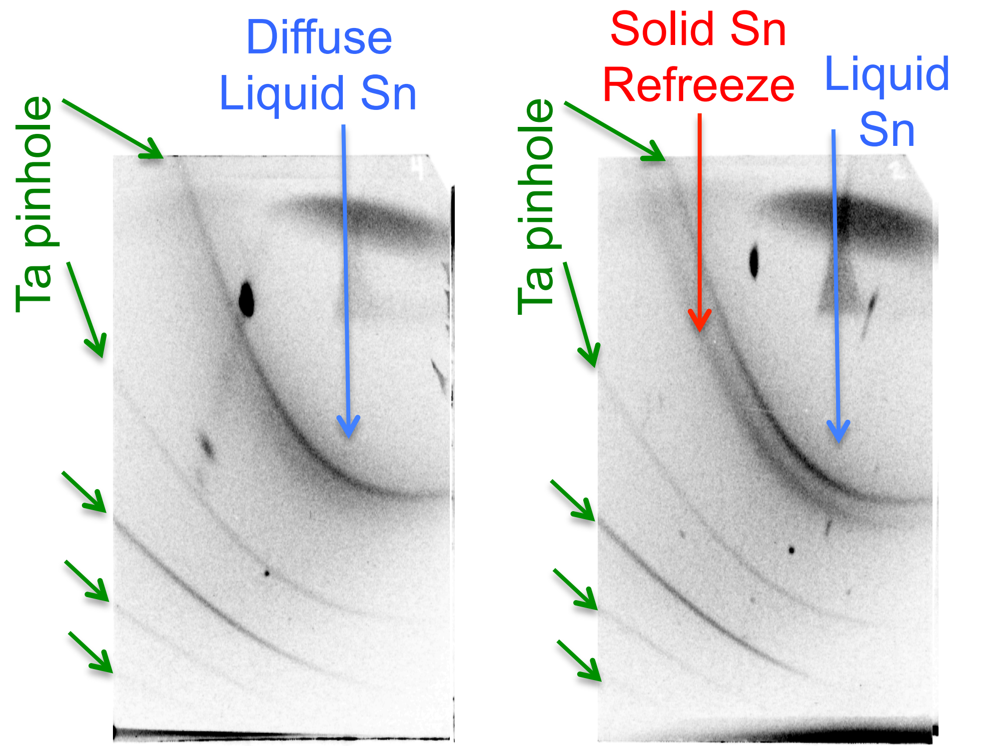
[May 28, 2014]





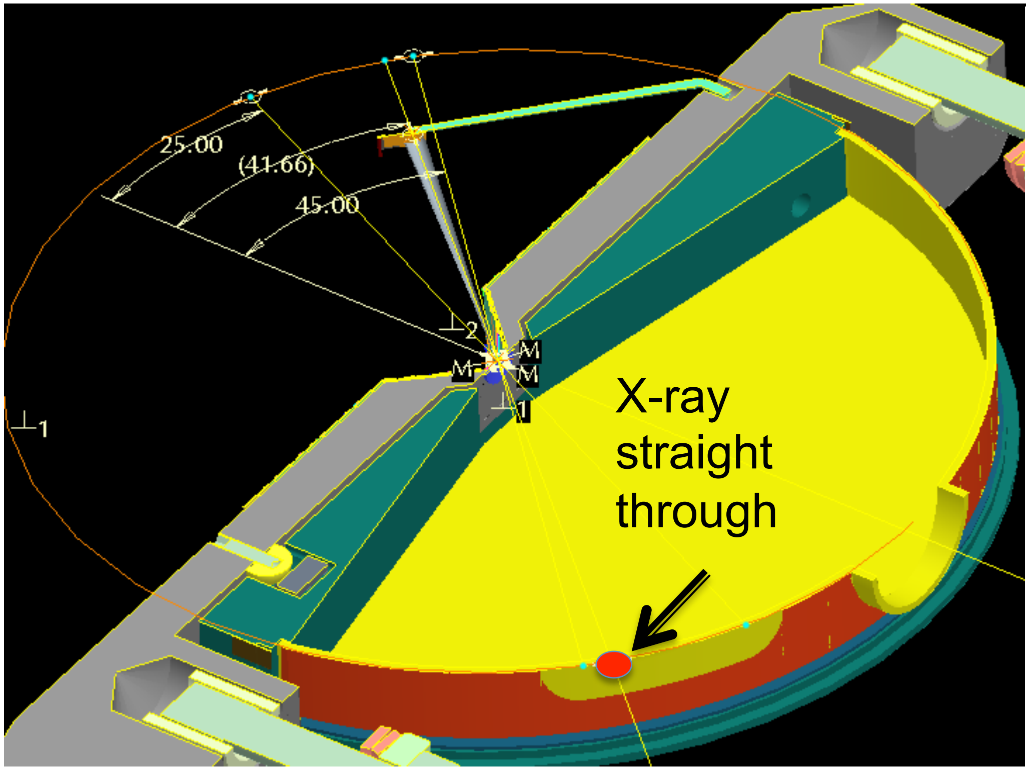
Shot 18450
Long Delay
=> All Liquid

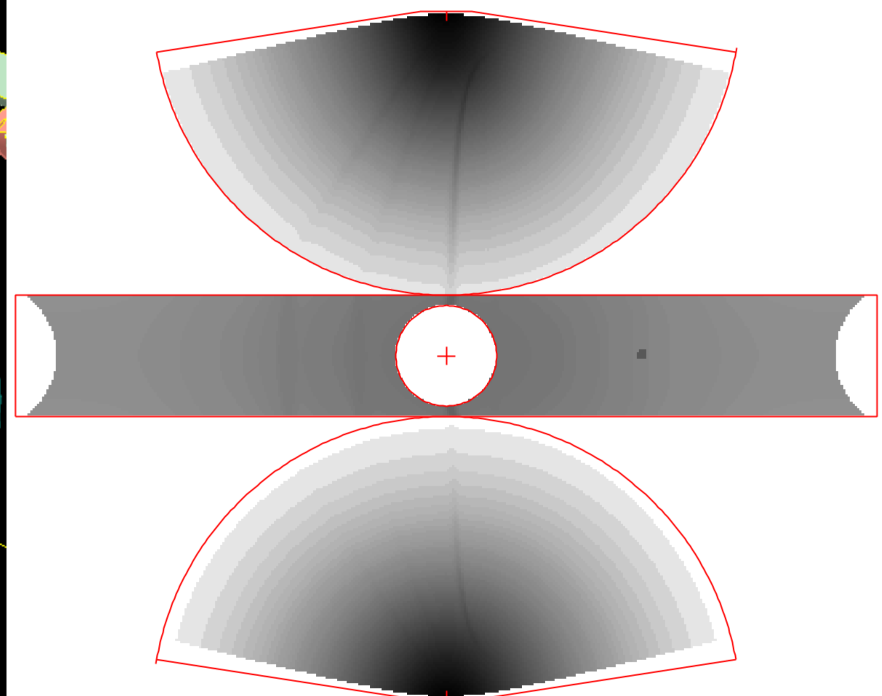
Shot 18452
Reduced Delay
=> Liquid + Refreeze



Rick Kraus, Federica Coppari

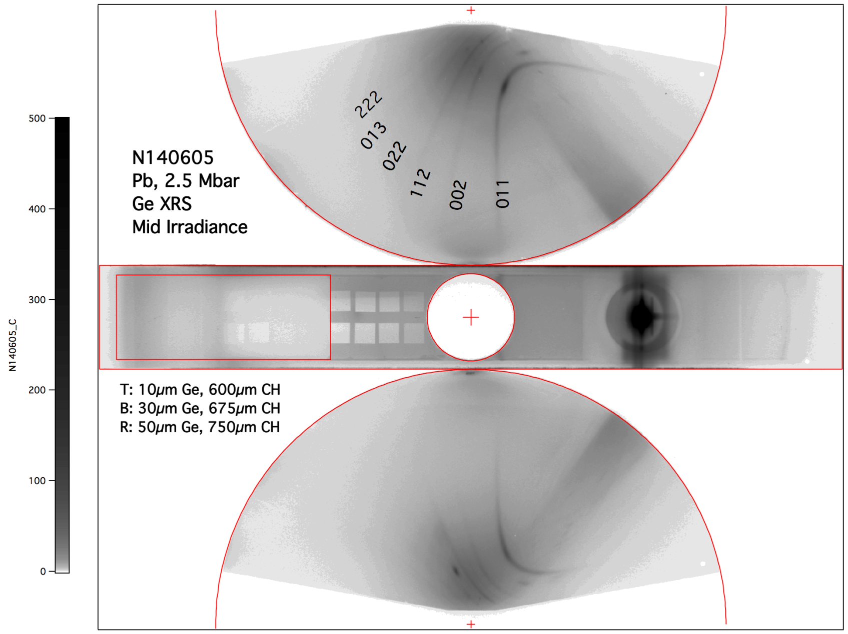
We are fielding diffraction on NIF (13 shots so far) TARDIS (TARget Diffraction In Situ) diagnostic

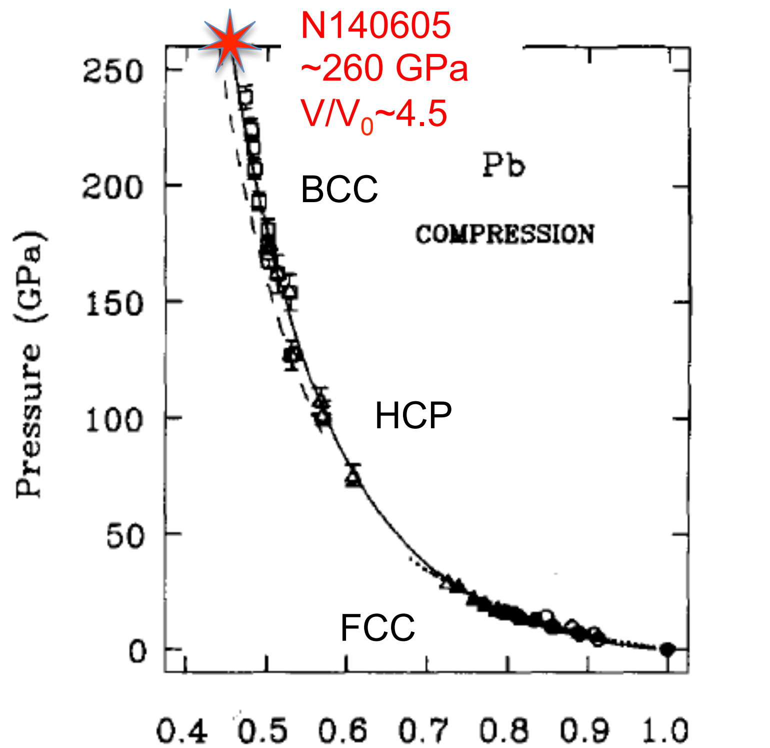




Three image plates collect the diffraction data

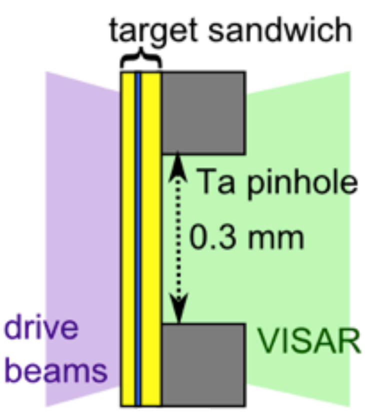
Last week we observed at least 9 diffraction lines from Pb at ~2.5 Mbar, and the (undriven) Ta pinhole

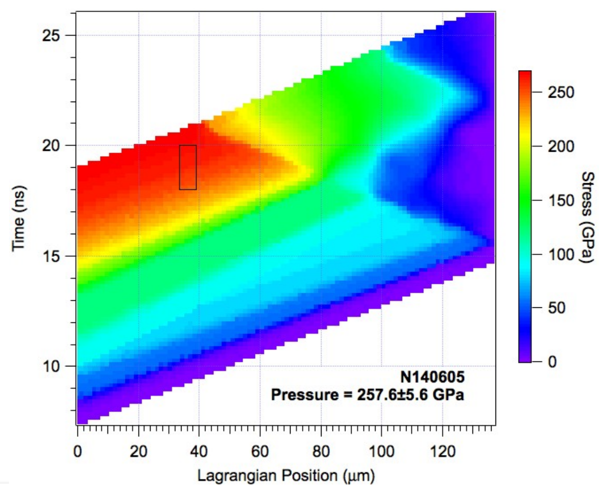




HIGH-PRESSURE PHASE TRANSITION AND EQUATION OF STATE OF LEAD TO 238 GPa

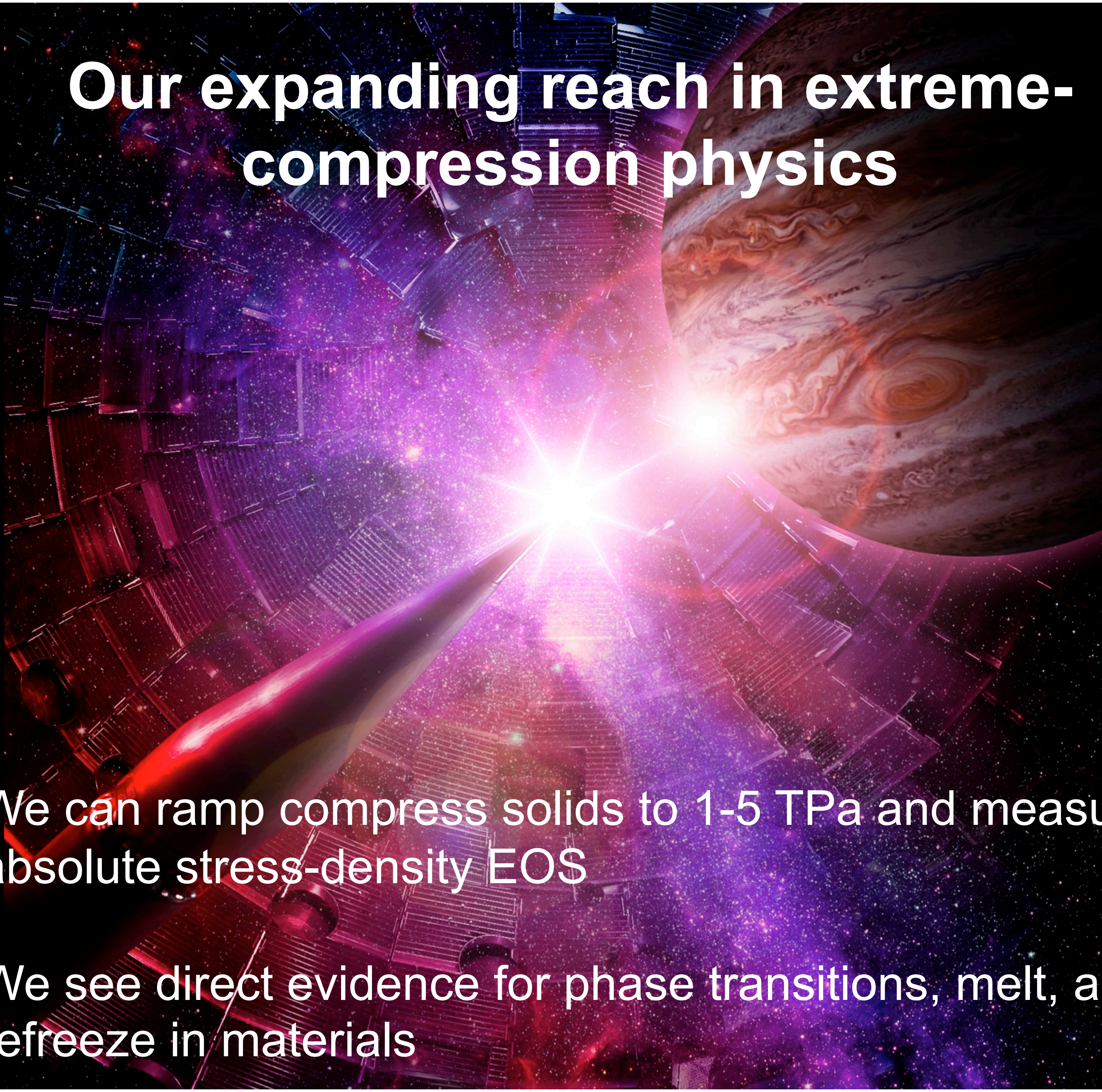
H.K. Mao*, Y. Wu**, J.F. Shu*, J.Z. Hu*, R.J. Hemley* and D.E. Cox†





Our observation of BCC phase suggests that we can study equilibrium solid phase diagrams on the NIF

Our expanding reach in extreme-compression physics



We can ramp compress solids to 1-5 TPa and measure absolute stress-density EOS

We see direct evidence for phase transitions, melt, and refreeze in materials