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Nanosecond freezing of gallium under extreme effective cooling rates. Part 1: Experiments

PRESENTED BY

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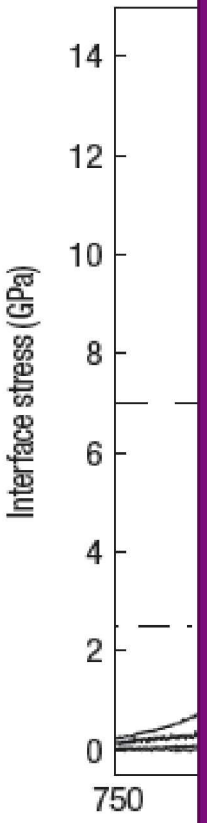
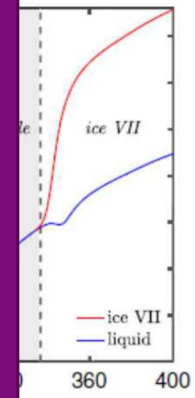
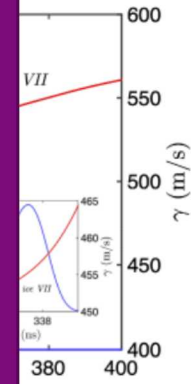
Motivation for these experiments stems from previous work on water

Dolan et al., Nature Physics, 2007



Myint et al., Physical Review Letters, 2018



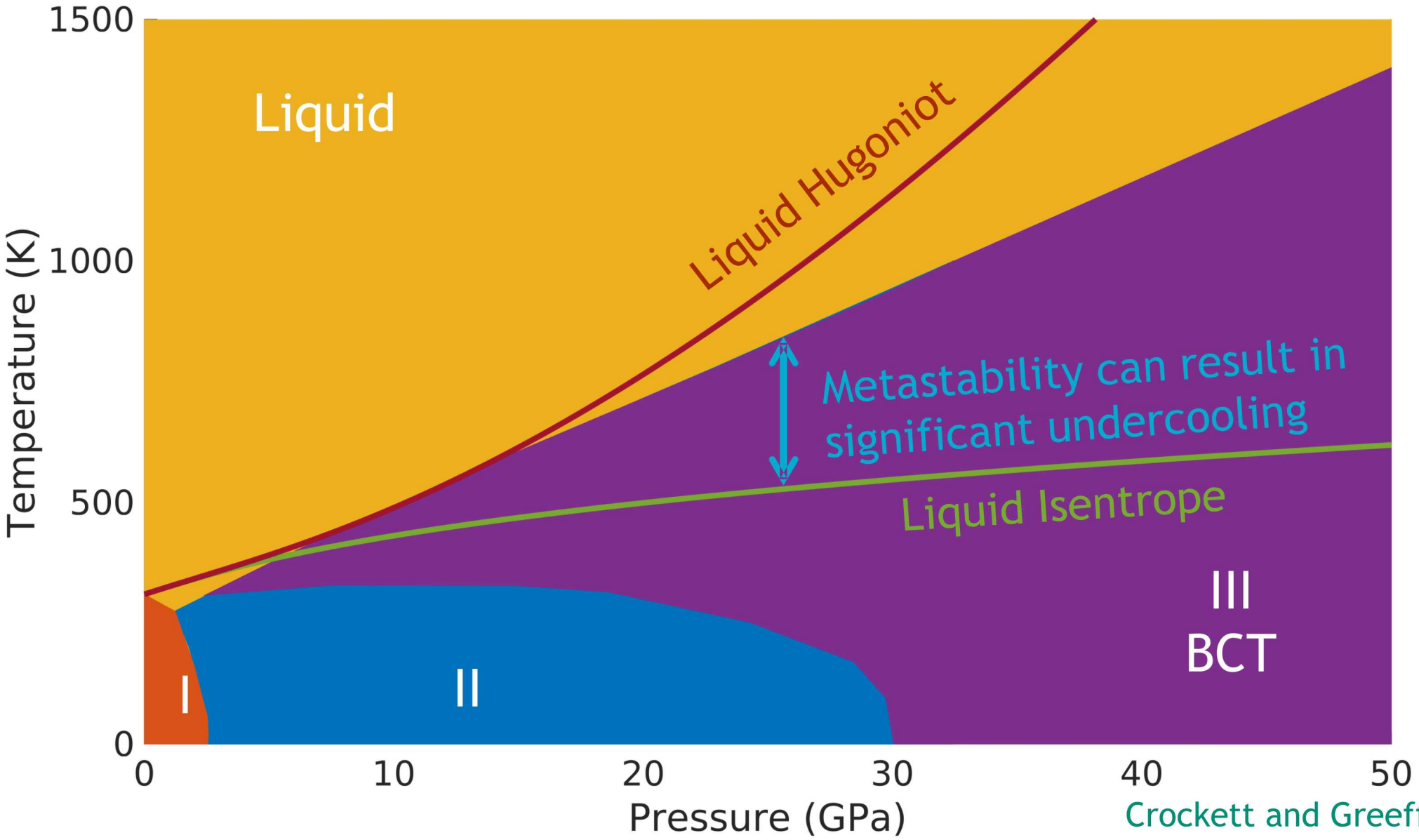


Will a metal exhibit similar rapid dynamic solidification?

Can the theory used to model water be extended to make accurate predictions for metals?

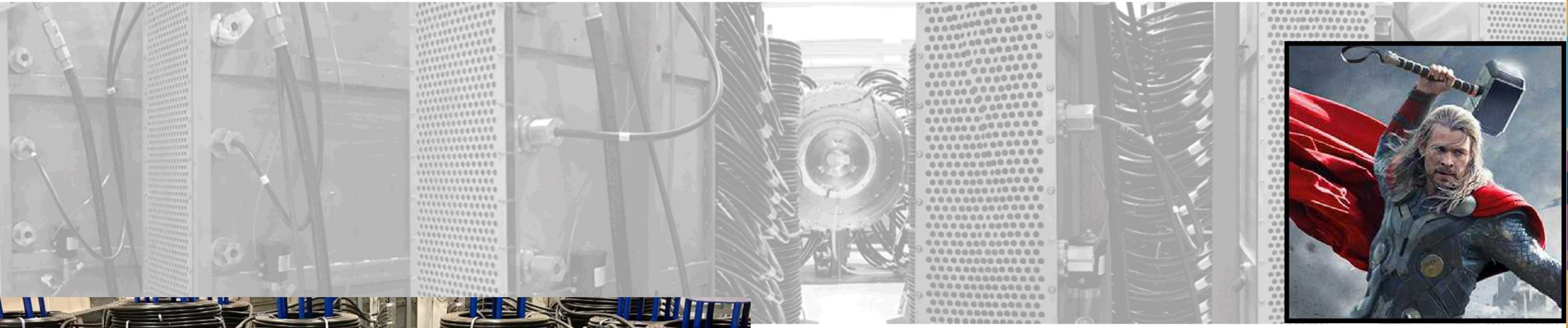
A thin (on theory shocklessly compressed to 14 GPa over 150 ns. is capable of simulating the experiments.

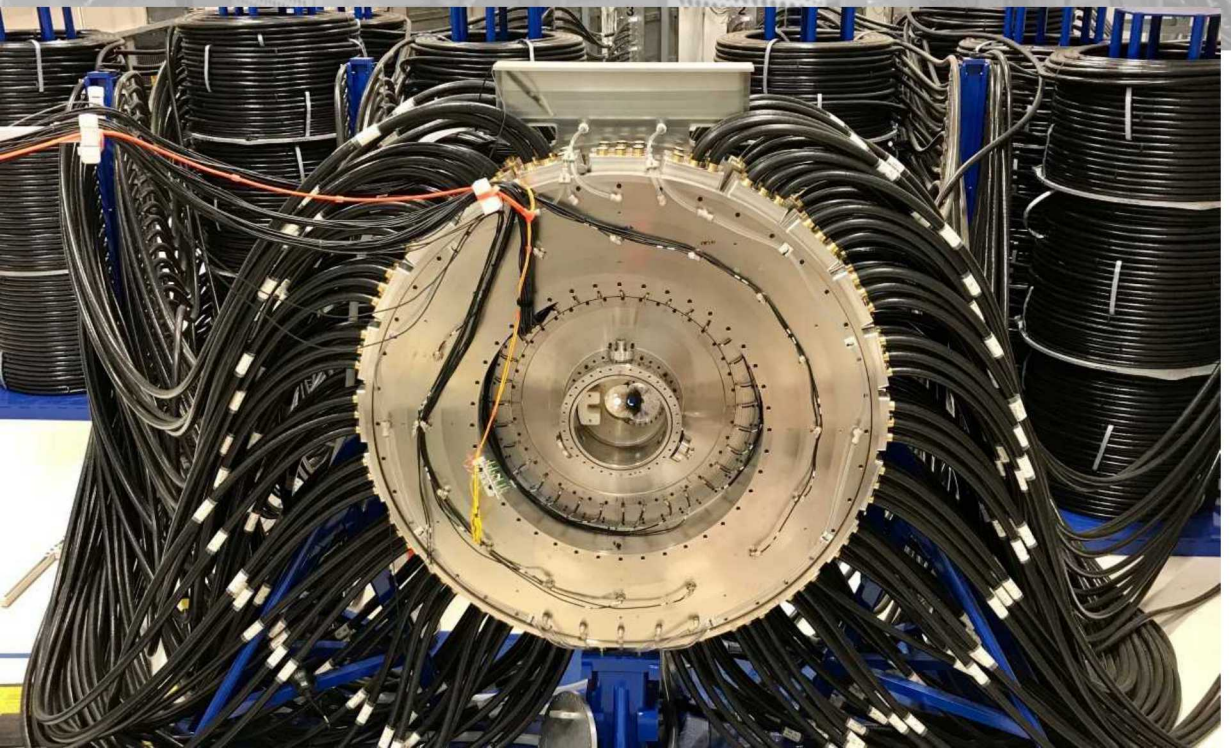
Gallium has a low melting temperature, making it well suited for this study



Crockett and Greeff, SCCM, 2009

To isentropically compress Ga we used Sandia's newest pulsed power machine: Thor



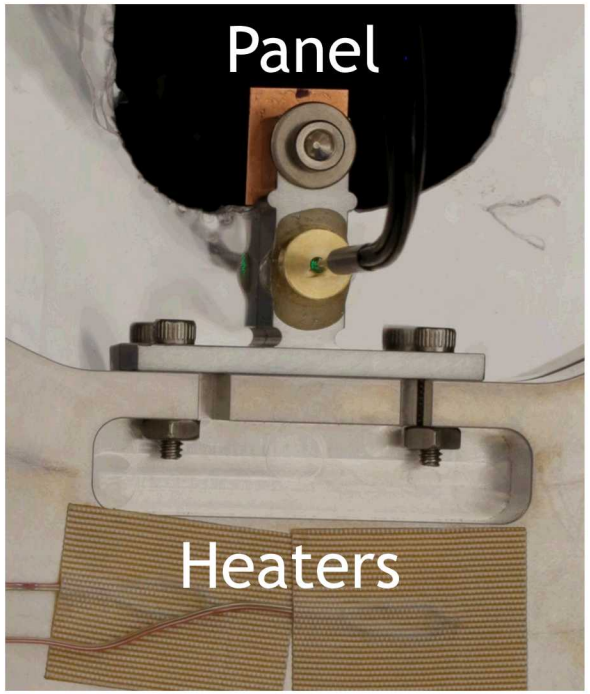


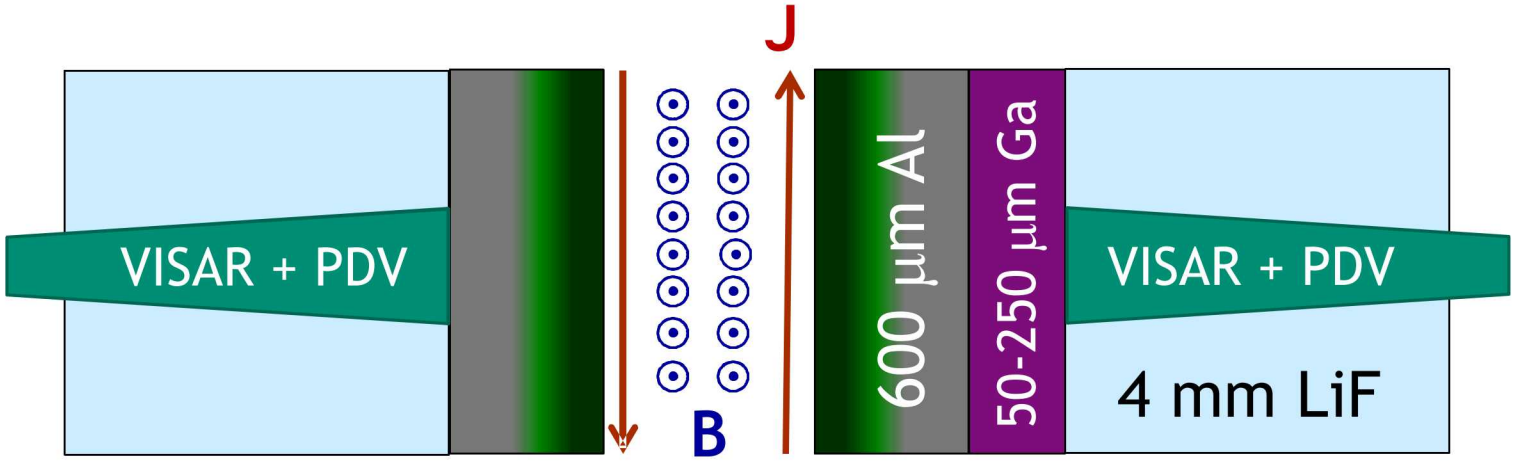
Stores 51 kJ of electrical energy with exquisite current pulseshaping

- Loading rates of ~10^6 – 10^7 /s
- Peak stresses of ~ 40 GPa

Relatively inexpensive and can be fired multiple times per day.

Experimental configuration





"Drive" measurement

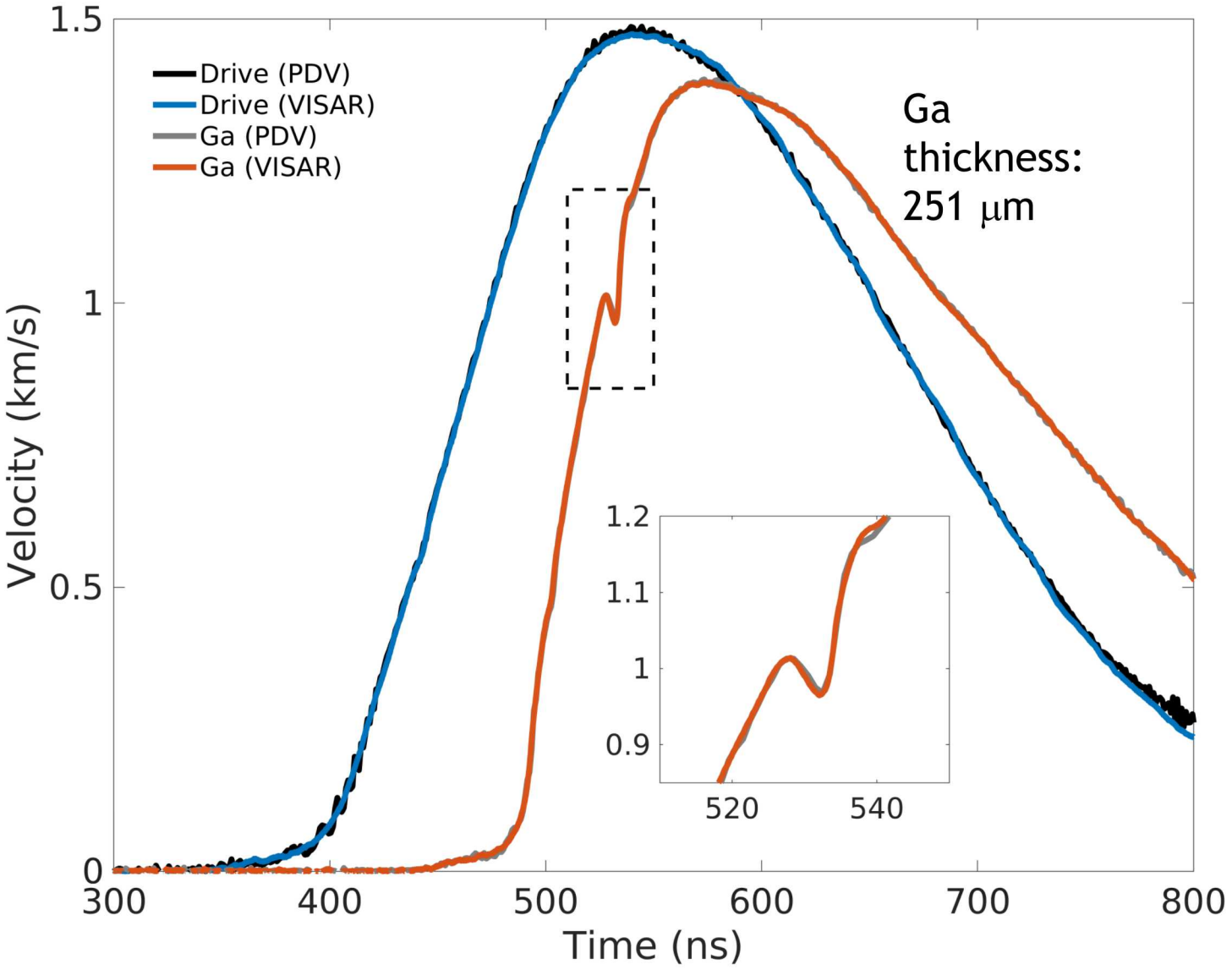
Sample measurement

Aluminum electrodes and LiF windows
- Impedance matched for uniform sample loading
- Anodized Al panel to avoid liquid Ga embrittlement
  - Type IIB (<20 µm thick)

Panels heated to ~34°C
- Well controlled initial temperature

Shot variations:
- Current pulse (loading rate and peak pressure)
- Ga sample thickness

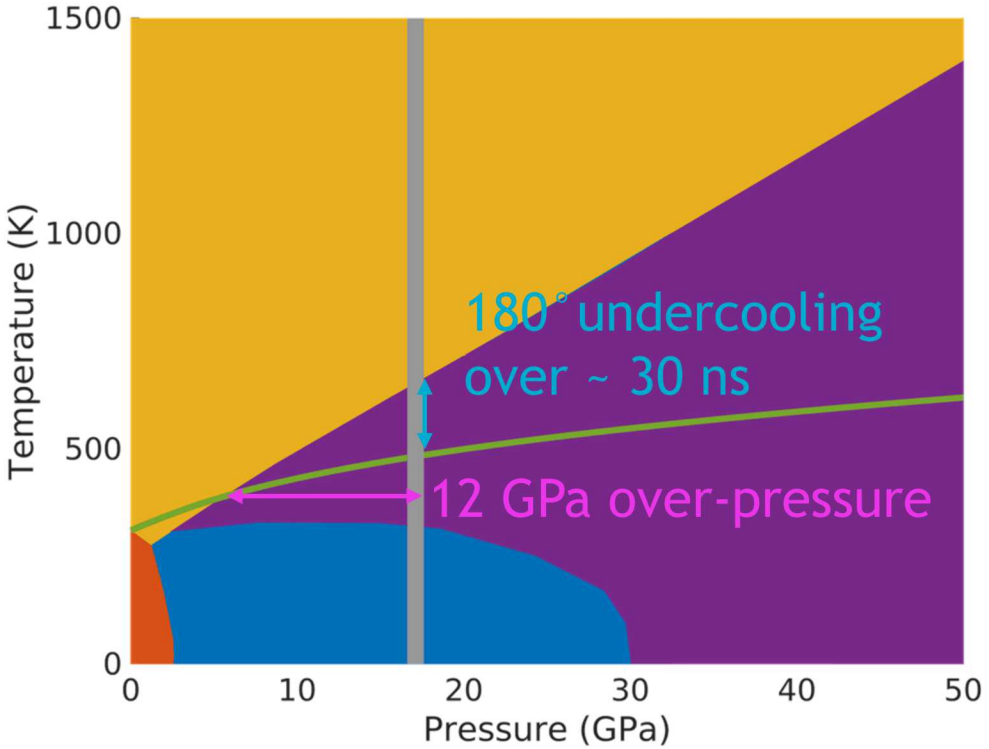
Example of a typical experiment



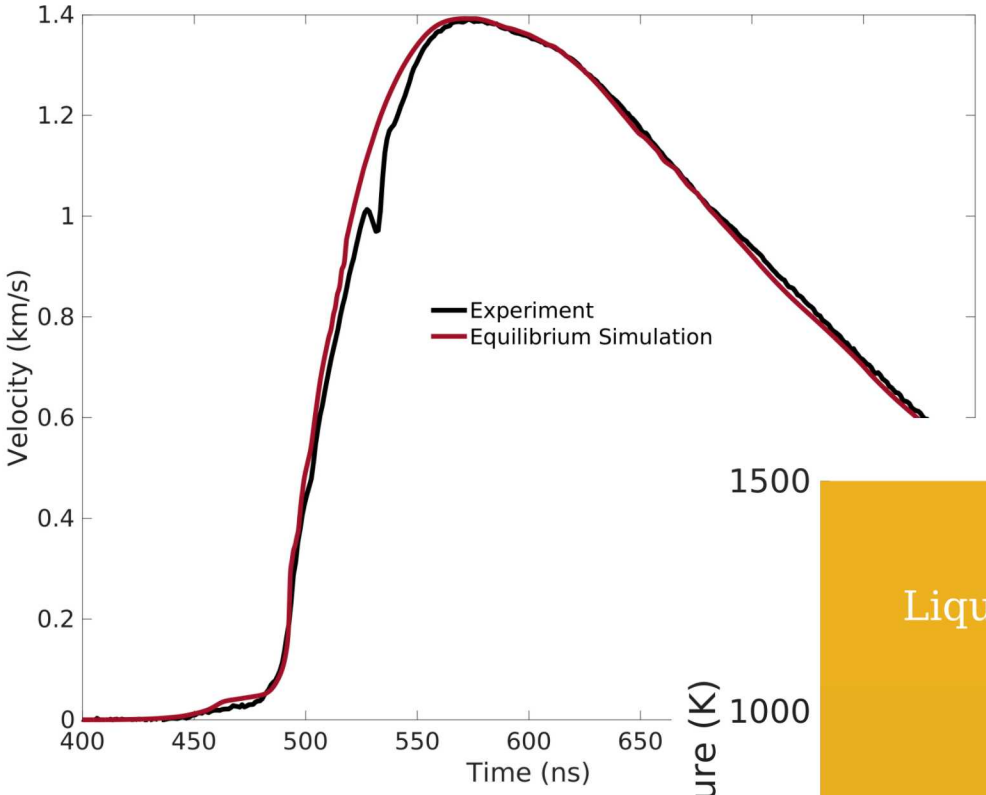
VISAR and PDV agree to within expected errors

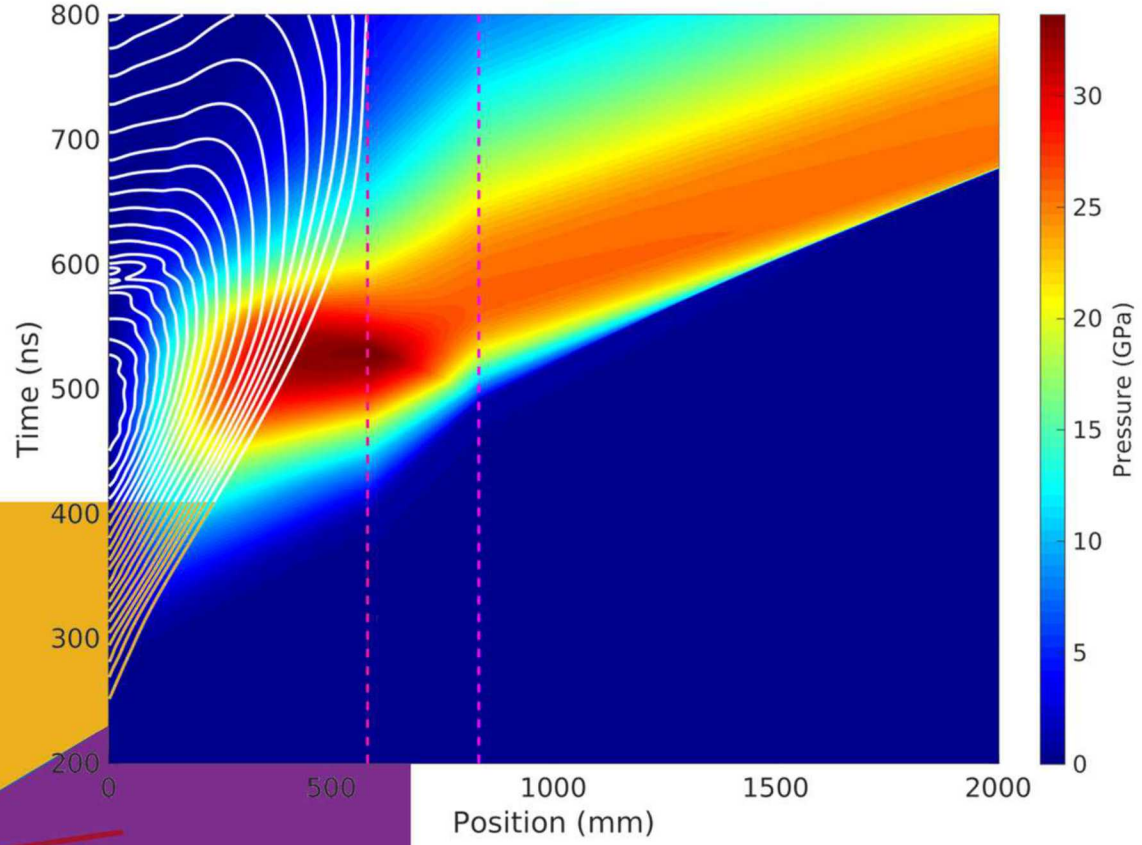
Signature in velocity profile suggests solidification in ~5 ns

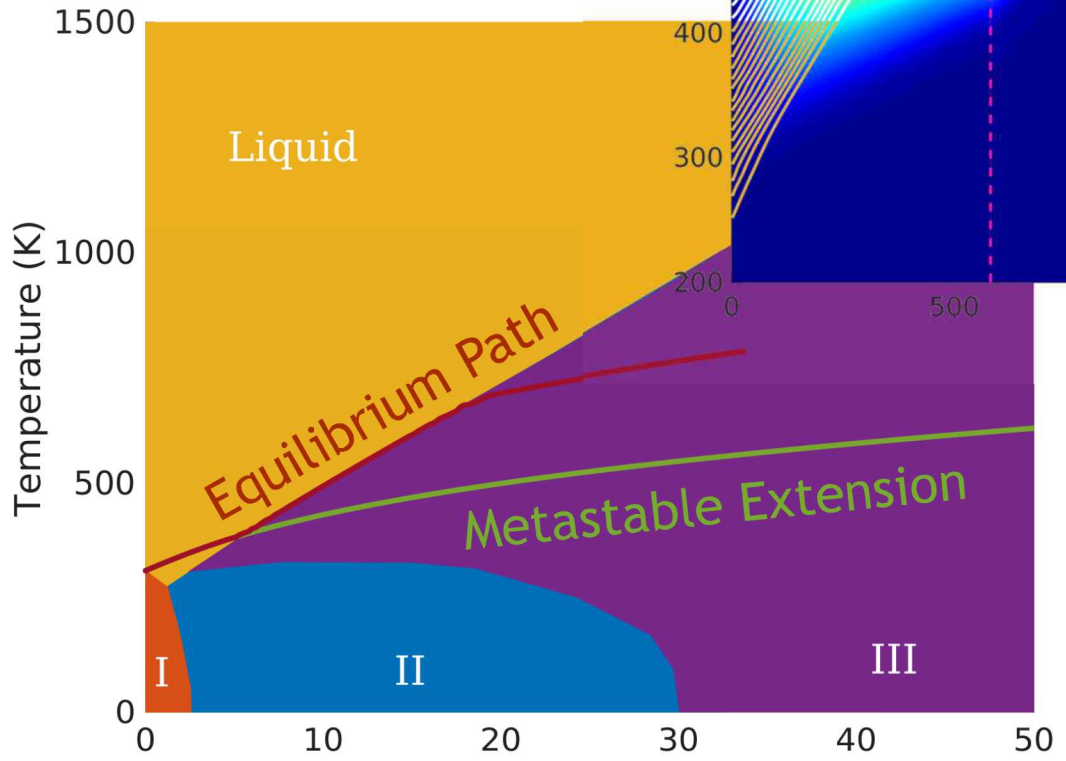
No obvious evidence of re-melting on release



"Conventional" simulations of this experiment





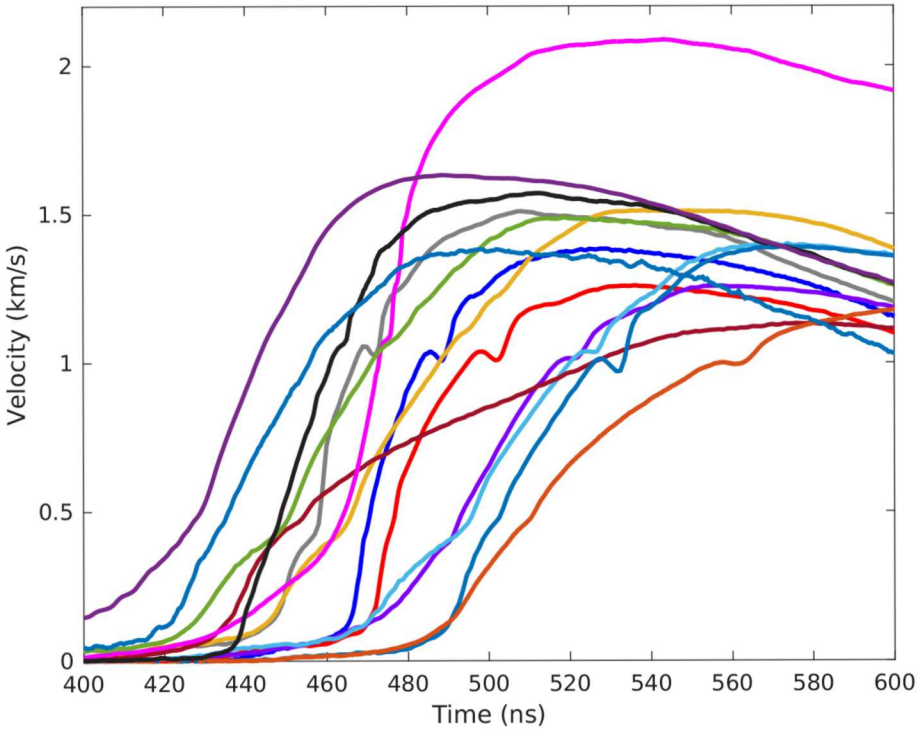


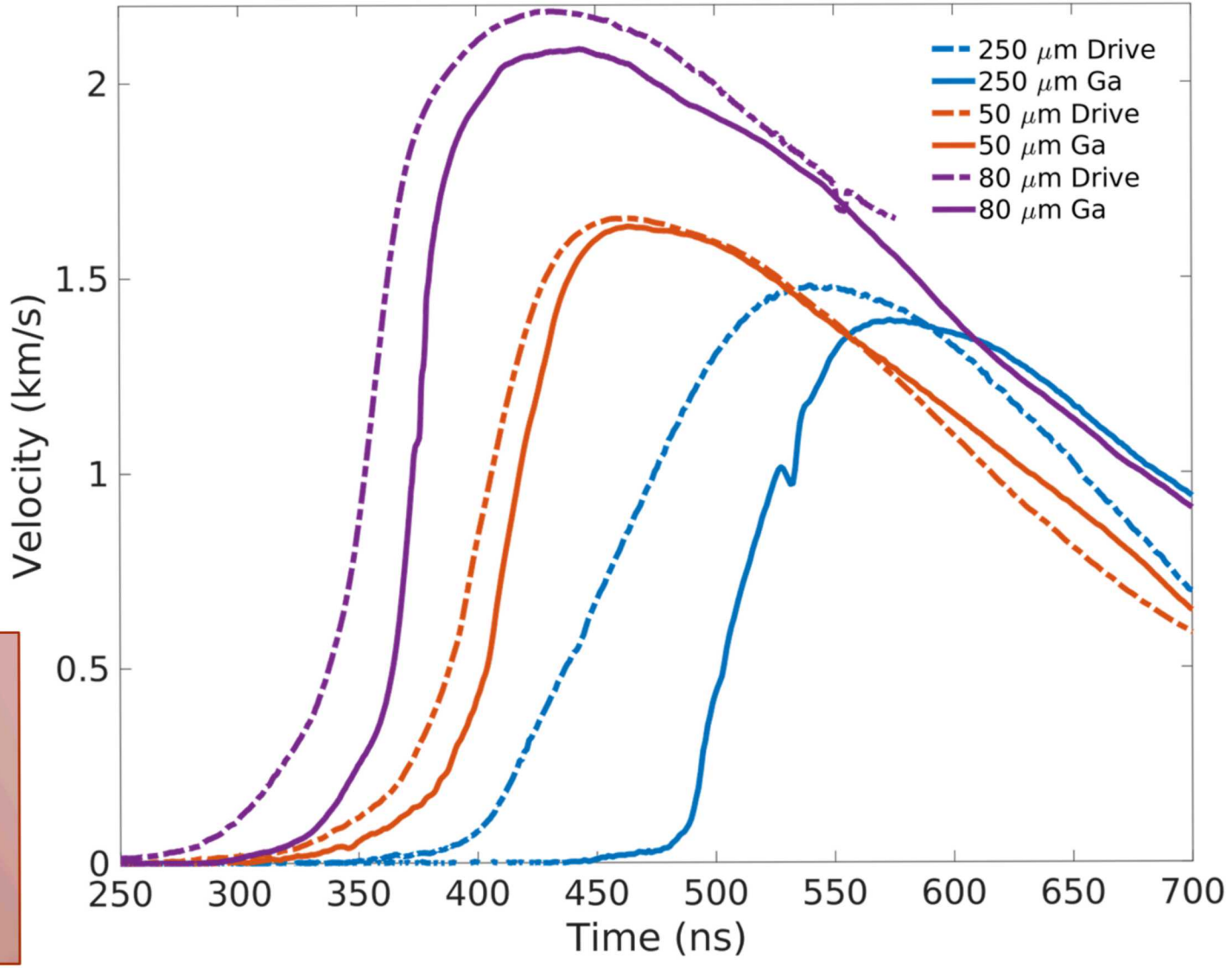
Simulations with the equilibrium multi-phase EOS do no exhibit signature of solidification

Waves do not reverberate quickly enough, so there is a pressure gradient across the Ga sample

- Sample is too thick

We have conducted 13 experiments which suggest a complicated coupling between the kinetics, cell size, and applied loading





Only through the modeling presented in the next talk have we been able to put together a comprehensive picture of what is happening in these experiments.

Future Experimental Work

X-ray diffraction is being implemented on Thor this year

- Well-suited for these types of solidification experiments

Experiment on Z scheduled in September

- Z has 400 times the stored energy of Thor
  - Can access lower loading rates and higher peak pressures
- Predictions are being performed with the LLNL model to optimize the design

Explore effects of heterogeneous nucleation by coating the window interface with different metals (crystal structures)

- BCT to encourage nucleation