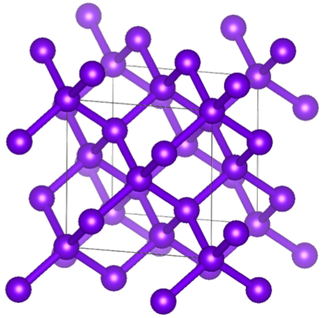
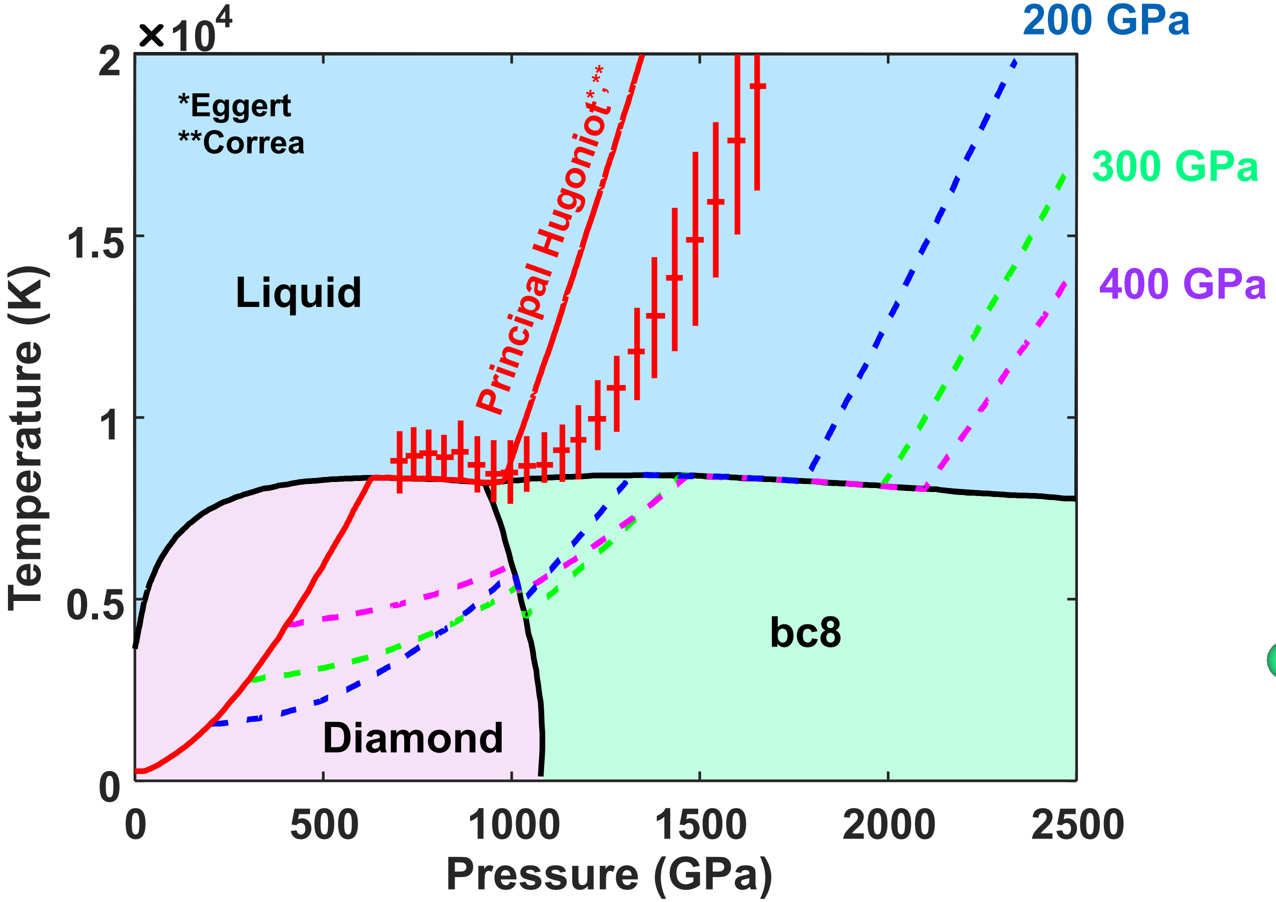
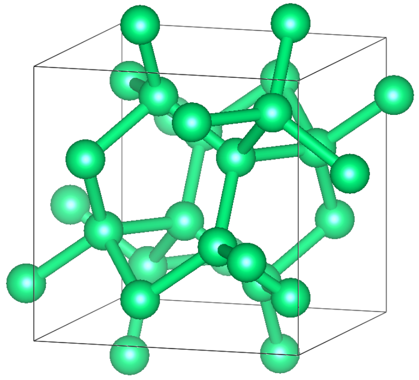
X-ray Diffraction of Double-Shocked Diamond

Diamond





bc8



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APS DPP
Fort Lauderdale, FL
21-25 October, 2019

Summary

We are developing double-shock x-ray diffraction (XRD) to detect phase transitions (melting/diamond-bc8)

- The melting properties of carbon at high pressures are important for designing ICF implosions and for modeling planetary interiors
- Velocimetry and pyrometry measurements* on double shocked diamond reveal that the melting temperatures at pressures between 0.6 TPa and 2.5 TPa are relatively flat
- Double shock XRD measurements explored the diamond phase diagram for first shocks ranging from 300-800 GPa and final shock pressures up to ~1 TPa

* Hicks *et al.* (unpublished)

Collaborators

G.W. Collins, **L. Crandall**, X. Gong, R. Saha, M. Huff, G. Tabak, Z. Sprowal, T.R. Boehly, M. Zaghoo, J.R. Rygg
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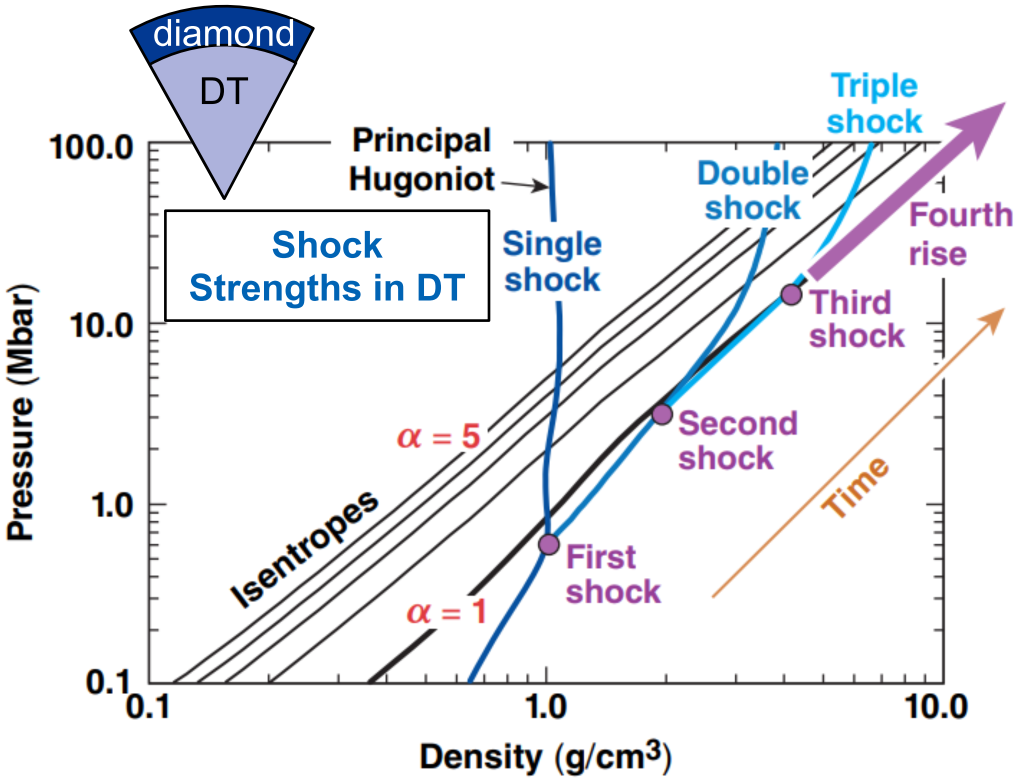
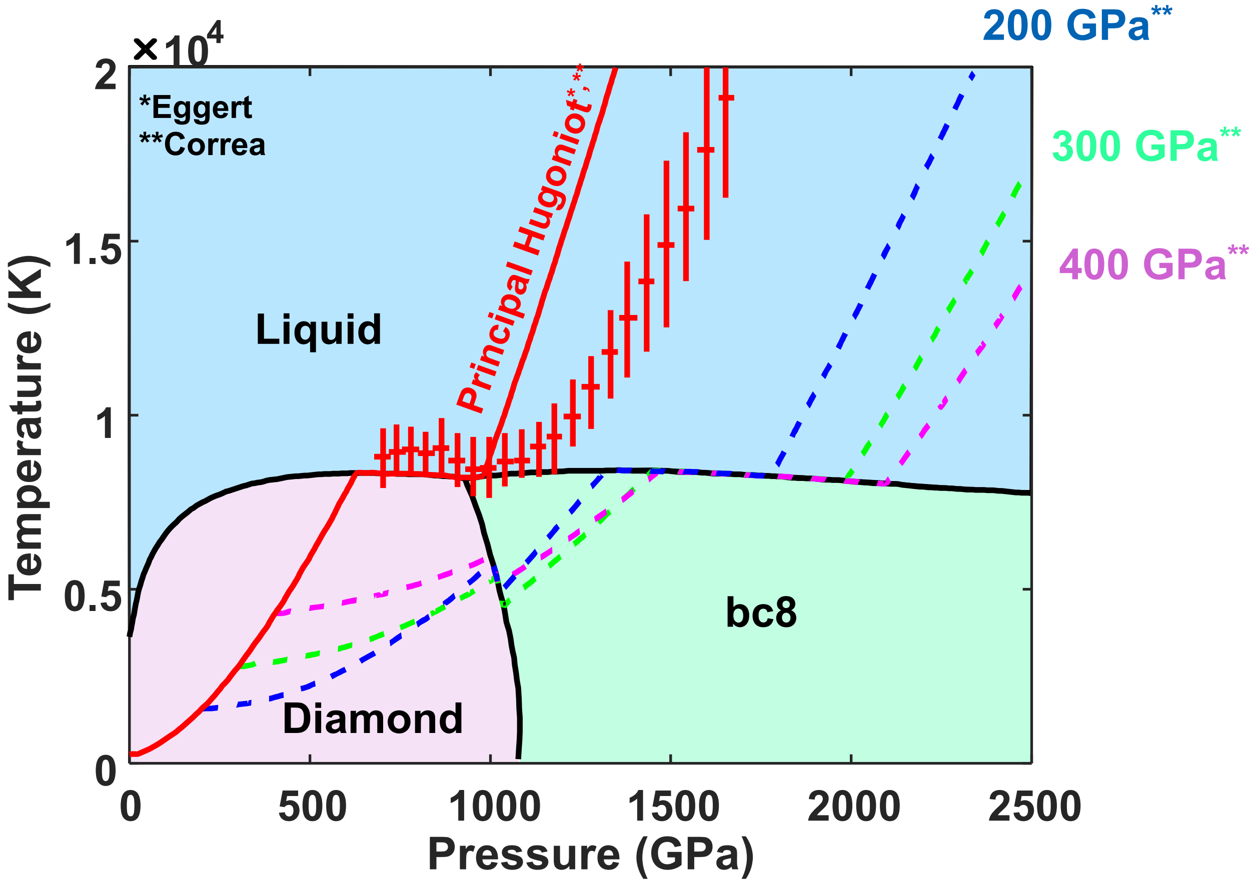
P.M. Celliers, D. Fratanduono, Y. Ping, J. Eggert, D. Munro, A. Jenei
Lawrence Livermore National Laboratory

D.G. Hicks
Swinburne University of Technology

The melting properties of diamond at high pressures are important for designing ICF implosions

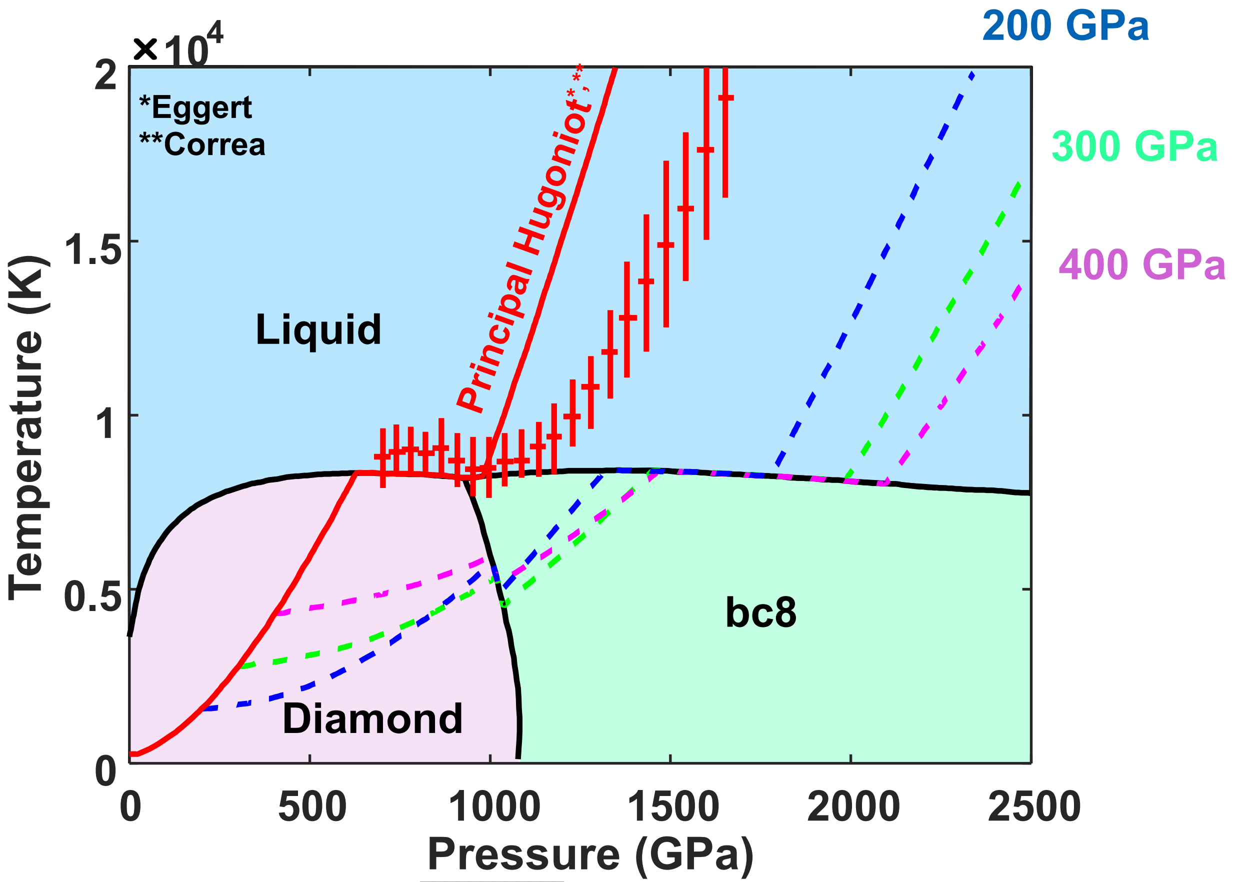




* Eggert *et al.*, Nat. Phys. 6, 20-43 (2010)
**Correa *et al.*, Proc. Natl Acad. Sci. USA 103, 1204-1208 (2006)

Phase transitions can be detected using x-ray diffraction on the secondary Hugoniot of diamond

- Double shock conditions access higher pressure states along the melt curve than states on the primary Hugoniot*
- At phase transitions, the Hugoniot is marked by plateaus caused by latent heat
- The bc8 structure at high pressures has been proposed but has not been observed with XRD***
- The diamond phase is stable to 2 TPa under ramp compression (preliminary)



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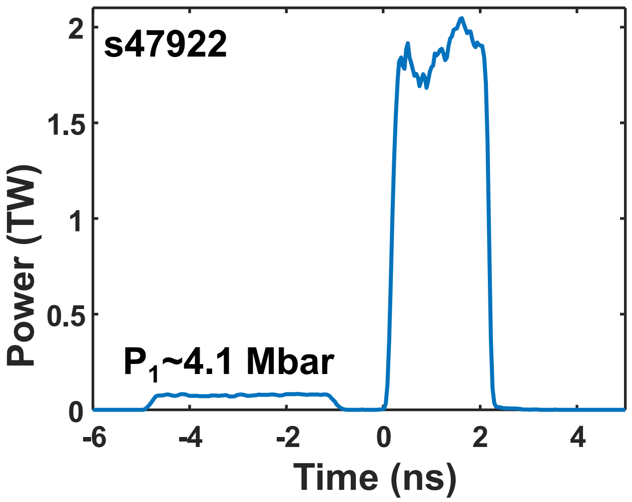
† Correa *et al.*, Proc. Natl Acad. Sci. USA 103, 1204-1208 (2006)
***Knudson *et al.*, Science 322, 5909, 1822-1825 (2008)

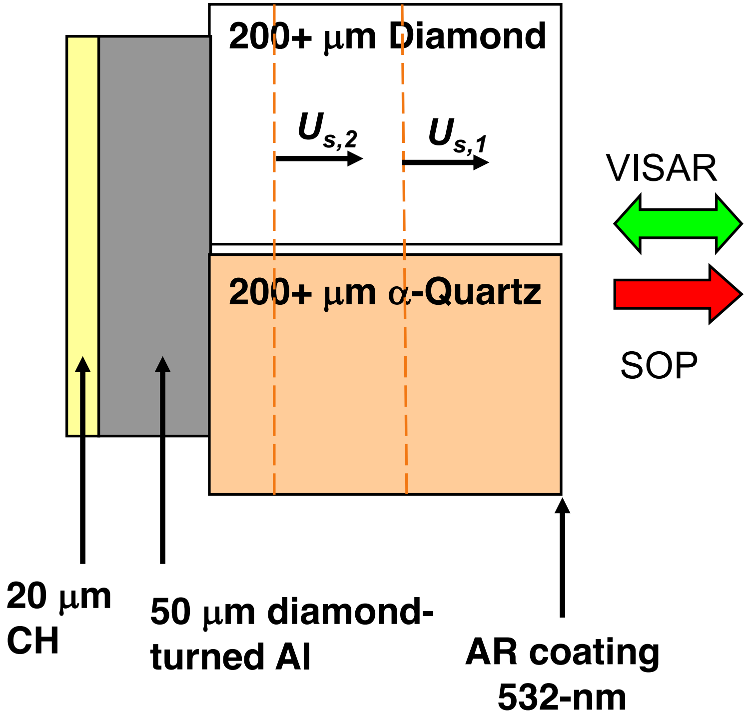
*L. Crandall

Double shock VISAR and SOP measurements use a step target design to determine the first shock pressures in diamond above the Hugoniot elastic limit

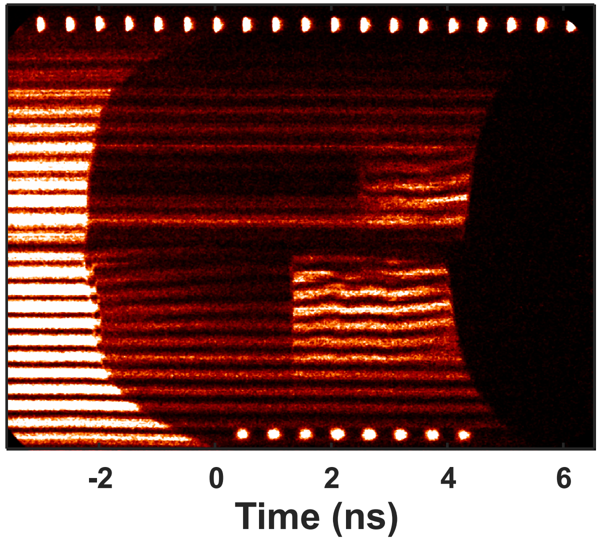
Laser Drive

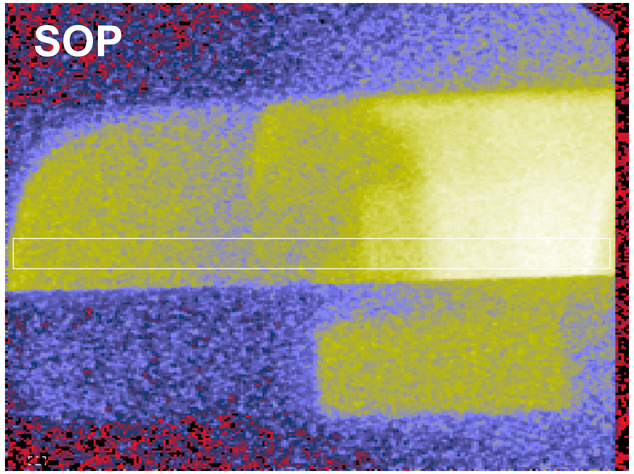


Target



VISAR1 Shot 47922

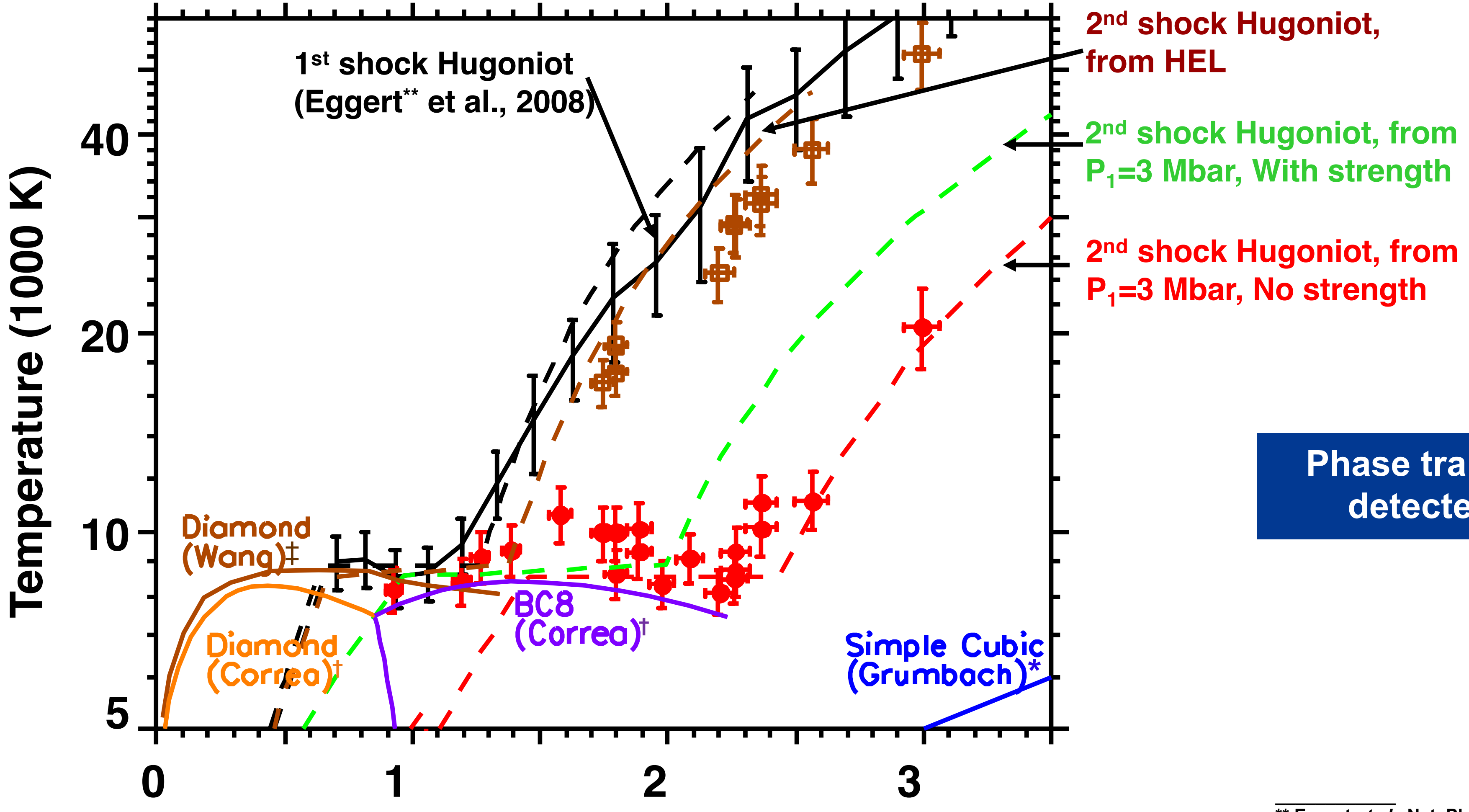




*Hicks (unpublished)

VISAR: velocity interferometer for any reflector
SOP: streaked optical pyrometry

Preliminary results* measured second shock pressures and temperatures to 2.5 TPa for first shock pressures between 300-400 GPa

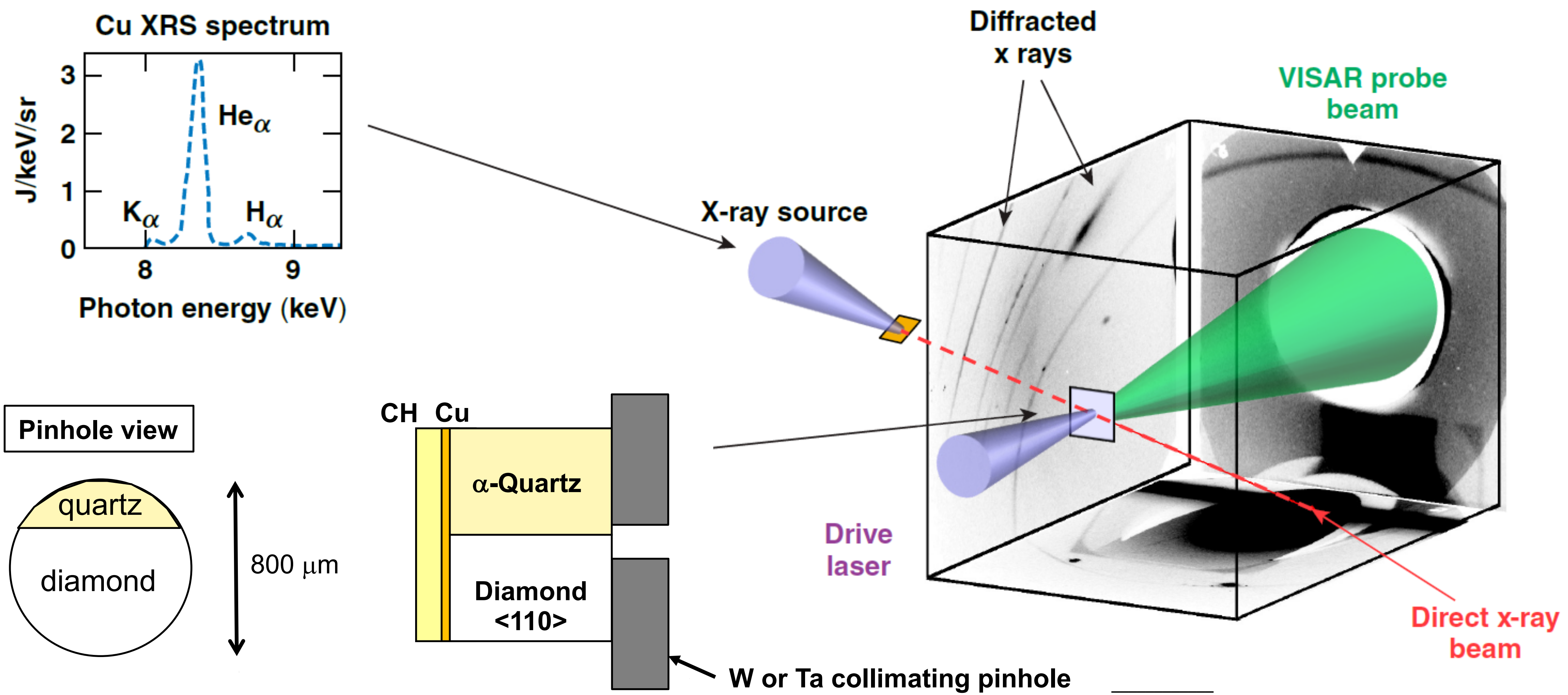


Phase transitions can be detected using XRD

*Hicks (unpublished)

** Eggert *et al.*, Nat. Phys. 6, 20-43 (2010)
‡Wang et al., Phys. Rev. Lett. 95, 185701 (2005)
†Correa *et al.*, Proc. Natl Acad. Sci. USA 103, 1204-1208 (2006)
*Grumbach *et al.*, Phys. Rev. B 54, 15730 (1996)

The powder x-ray diffraction image plate (PXRDIP*) platform is used to record diffraction patterns on OMEGA EP



* J. R. Rygg et al., Rev. Sci. Instrum. 83, 113904 (2012).

Impedance matching is used to determine the first shock pressures in the diamond (300-800 GPa)

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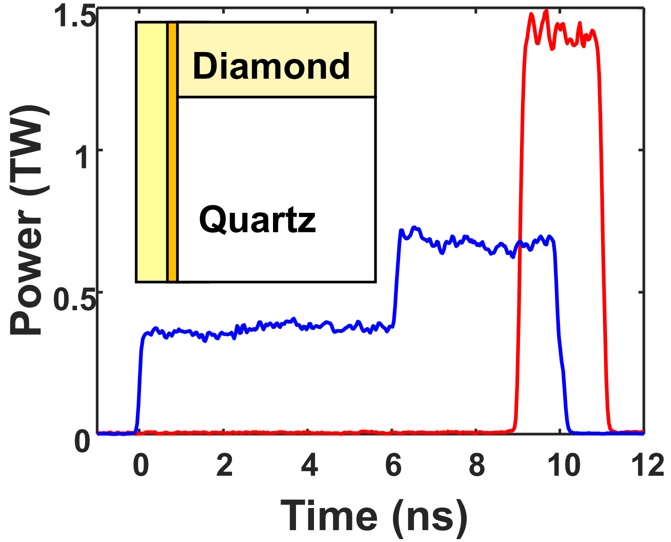
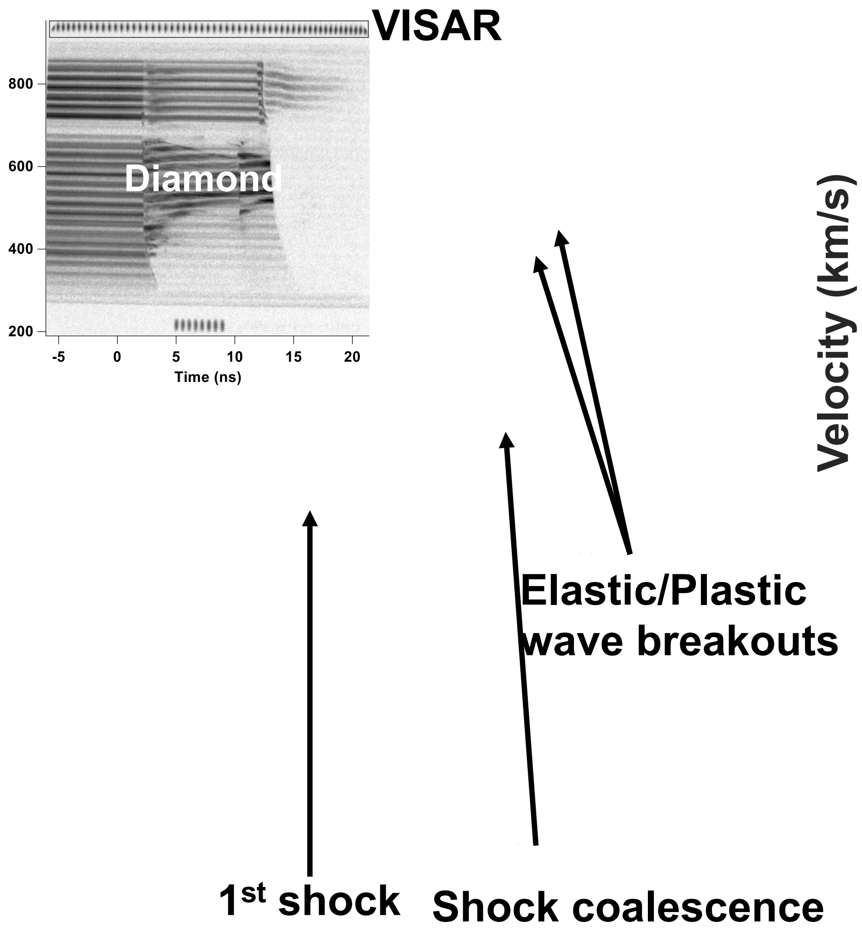
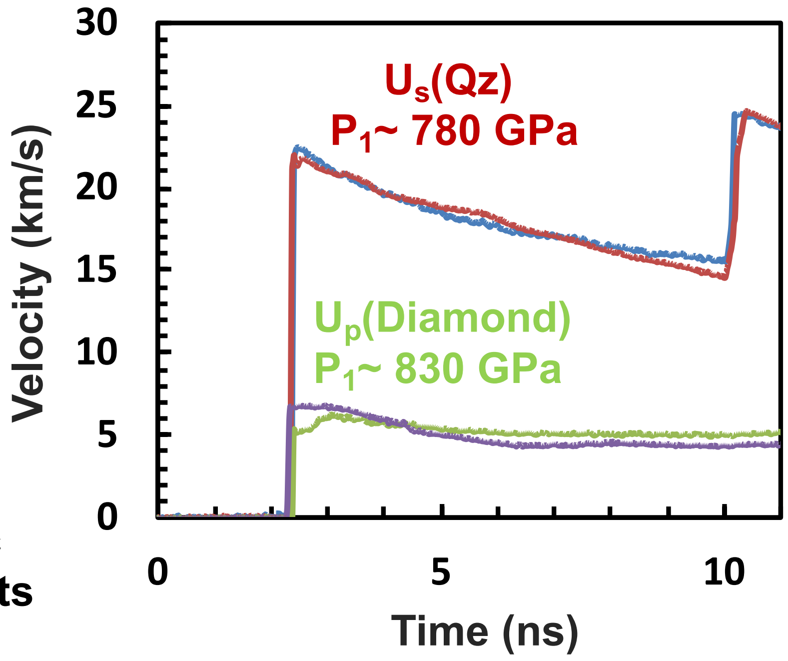




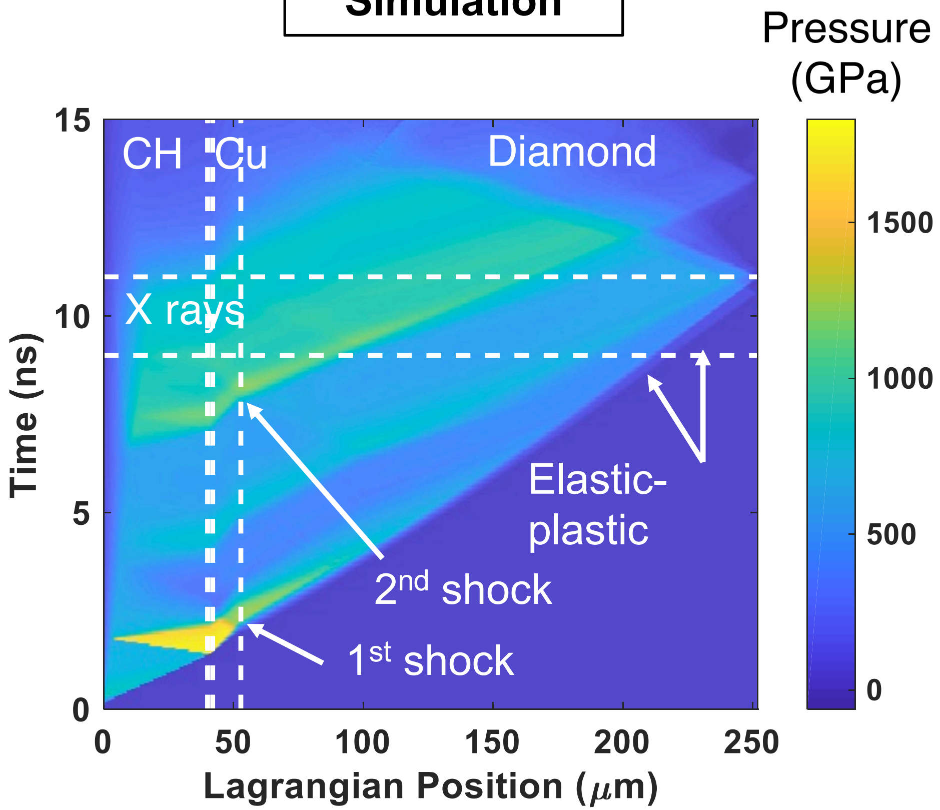


s31305

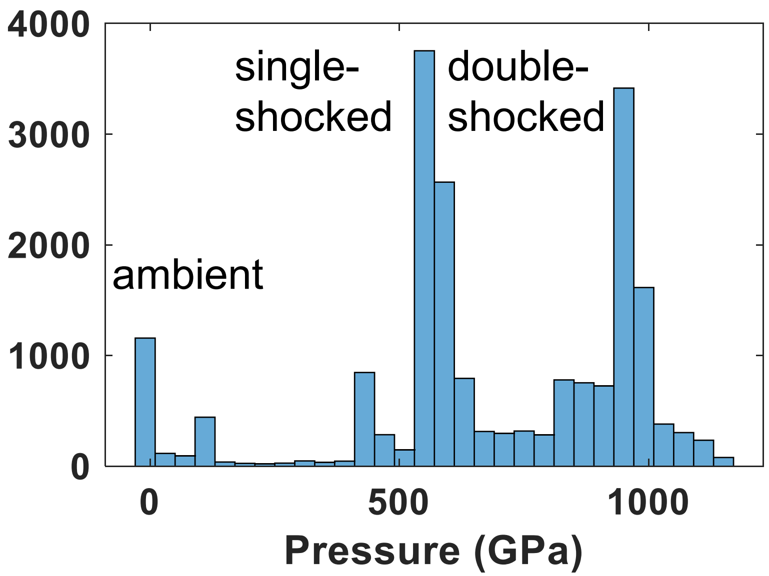
LLNL AnalyzeVISAR code (Marius Millot) was used to process the VISAR / SOP data.

At the time of the x-ray exposure, the diamond is double-shocked, single-shocked, and unshocked

Hydrodynamic Simulation



Pressure Distribution



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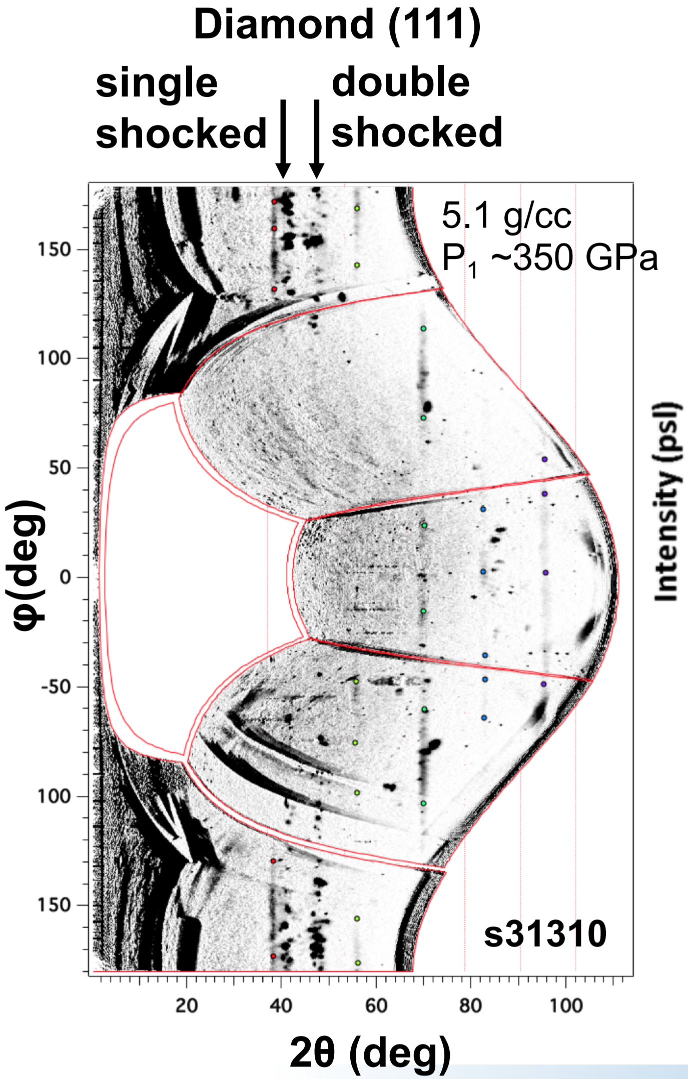
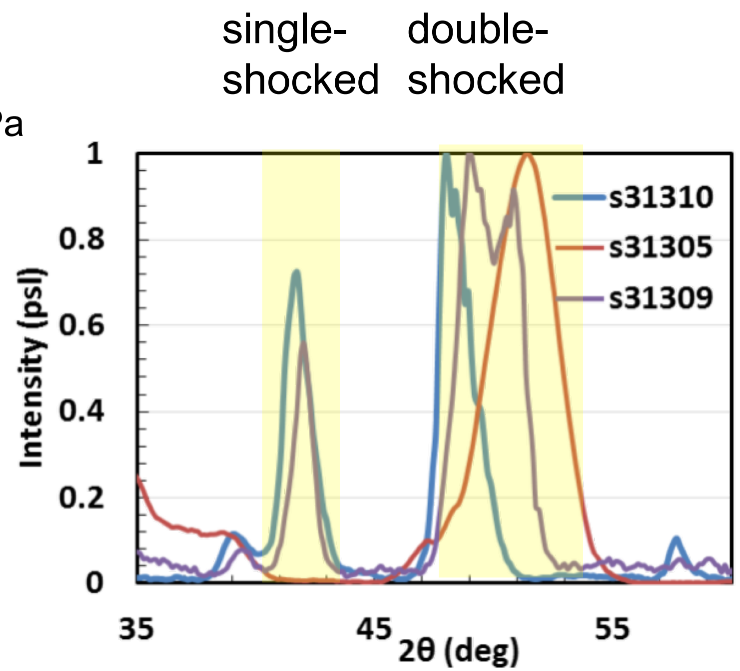
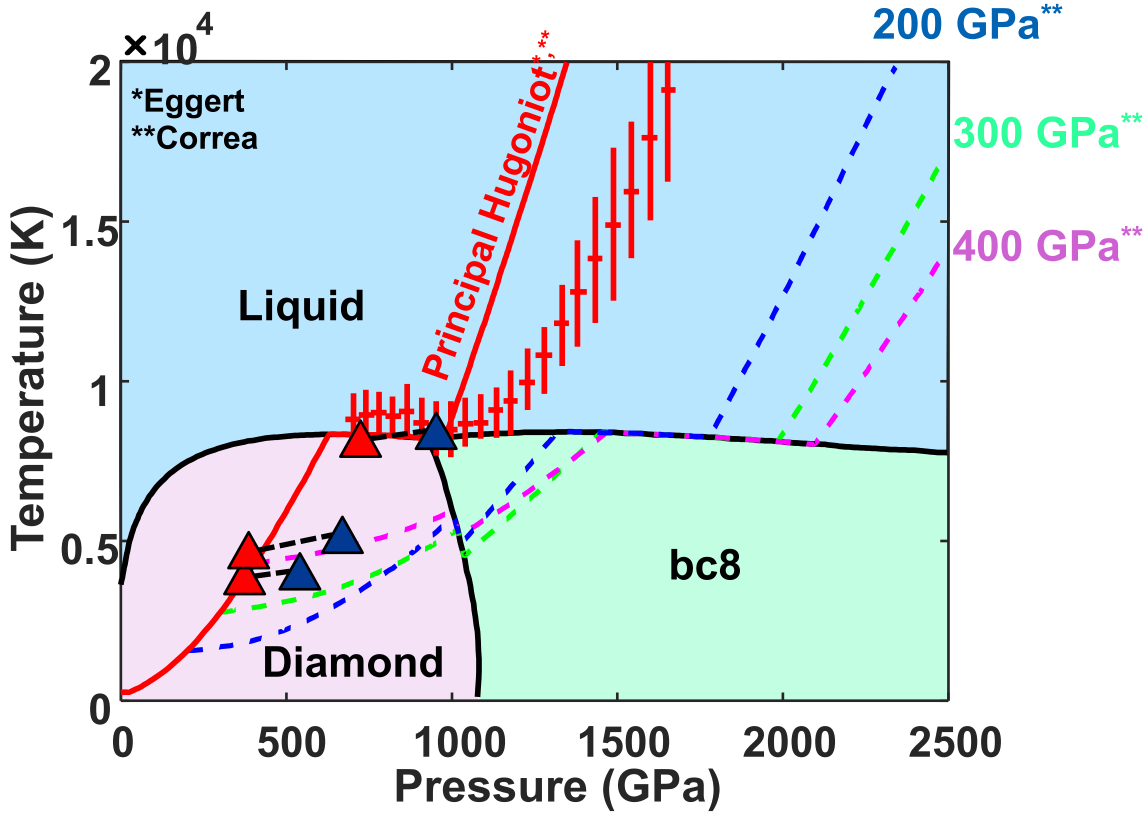
Diffraction data was collected for first shocks between 350-850 GPa and final pressures up to ~1 TPa







UNIVERSITY of ROCHESTER

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UR LLE

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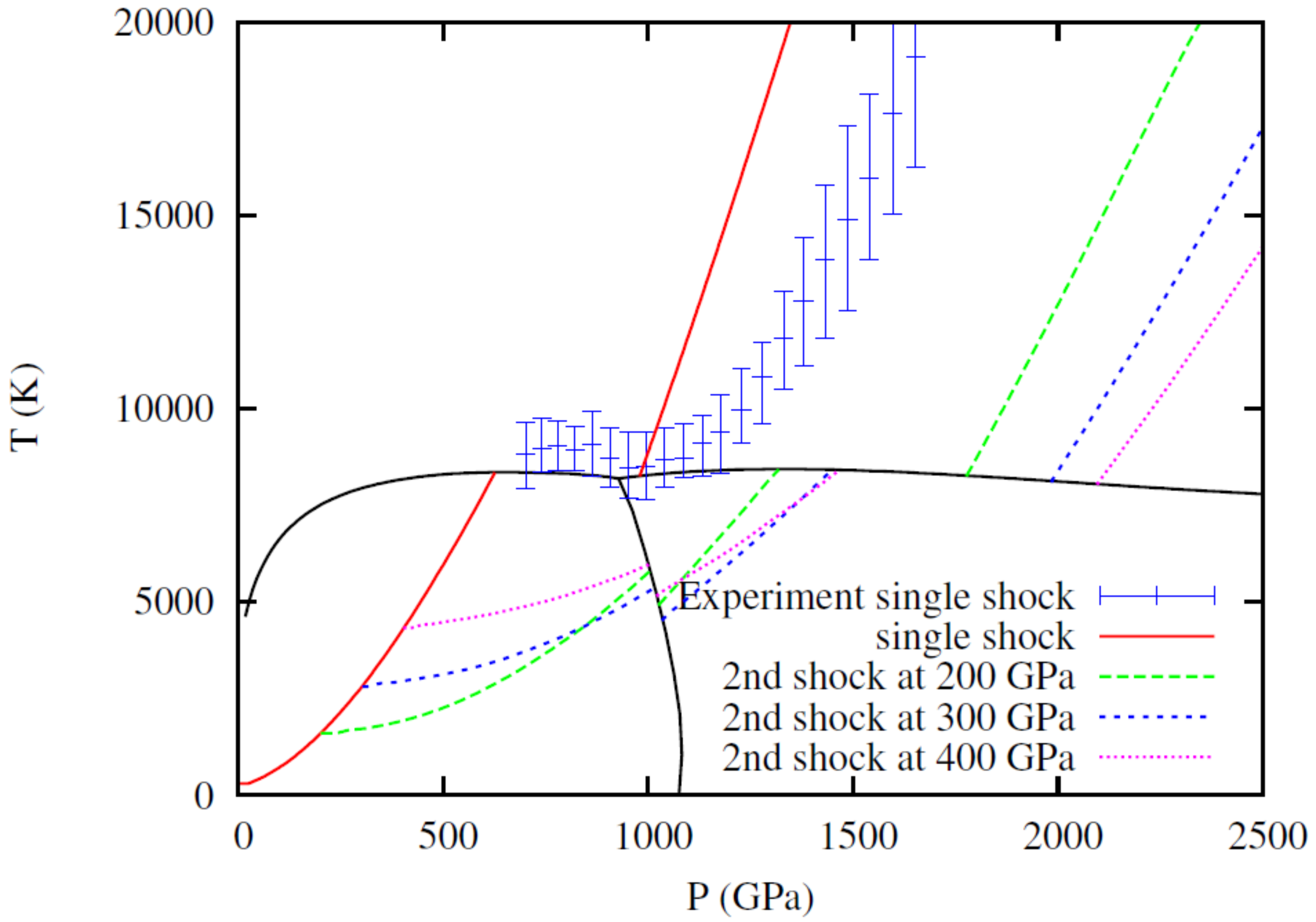
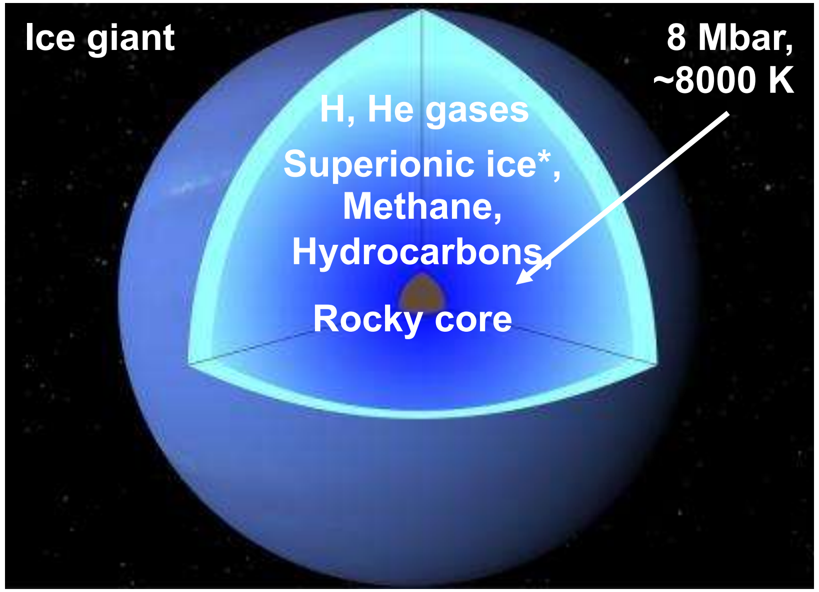
Summa

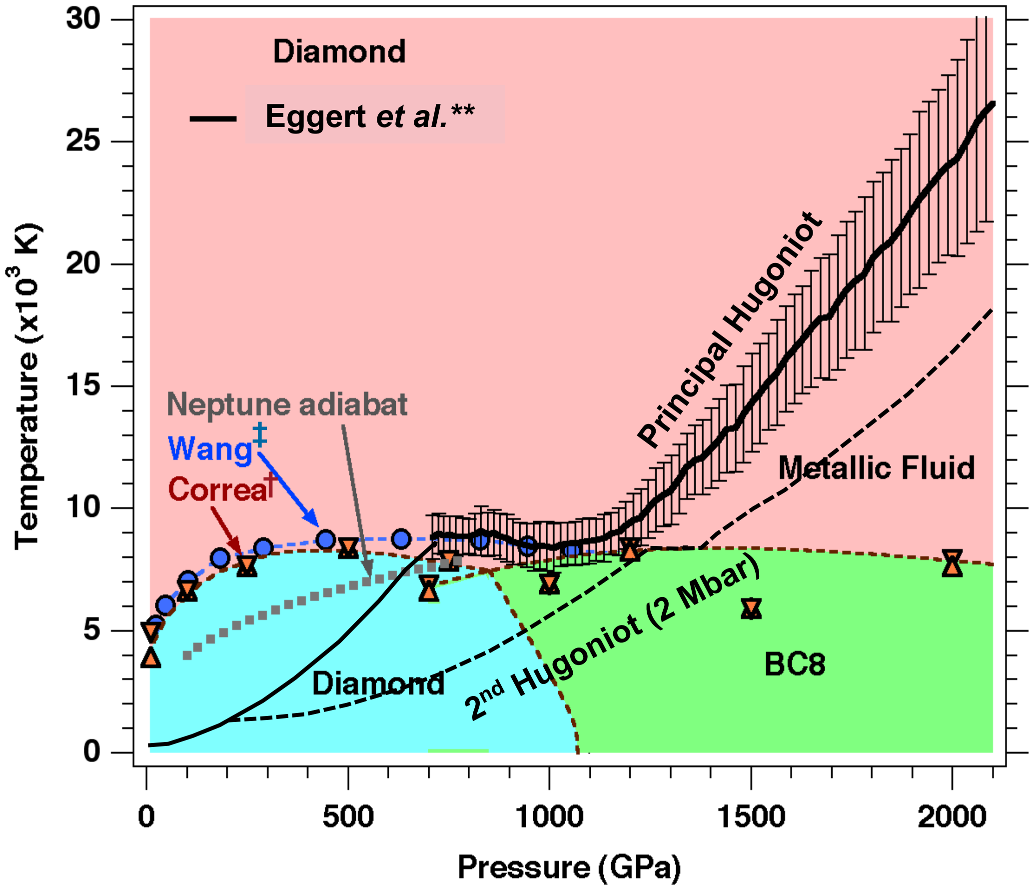


20000
15000
10000
5000
0
T (K)
0
500
1000
1500
2000
2500
P (GPa)
Experiment single shock
single shock
2nd shock at 200 GPa
2nd shock at 300 GPa
2nd shock at 400 GPa

Motivation

The low-temperature, high-pressure phases of carbon are important for evolution models for solar (Uranus, Neptune) and extrasolar planets and white dwarfs





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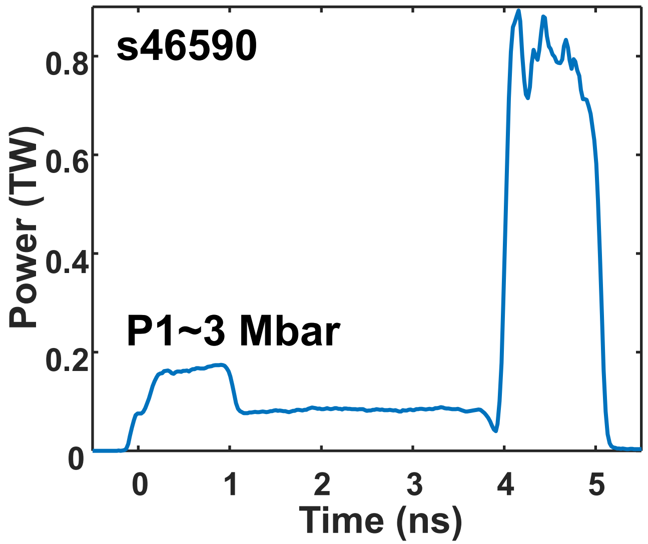
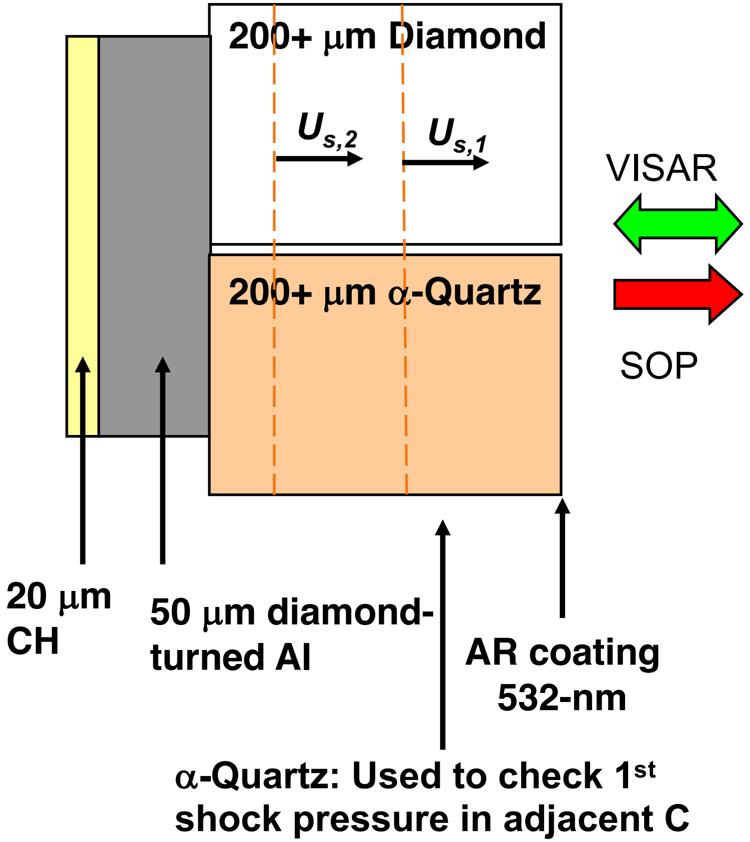
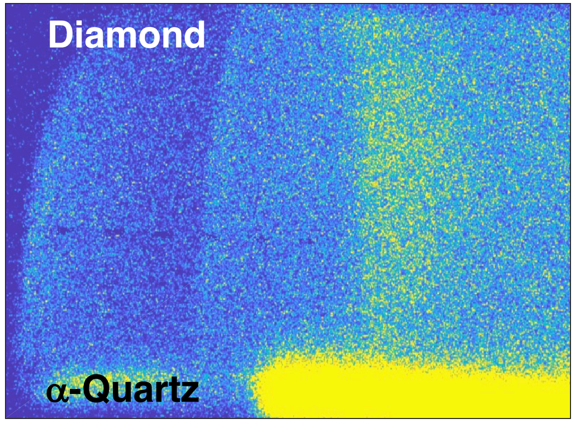
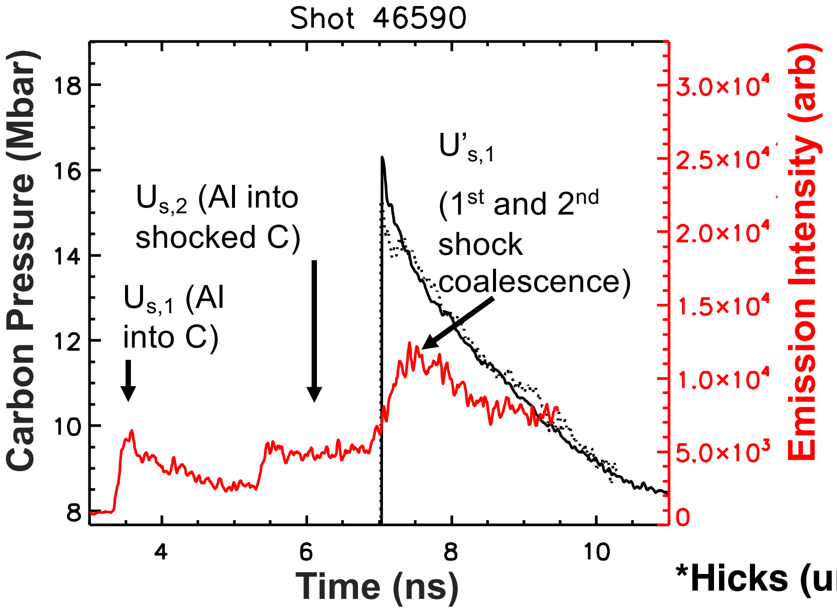
Two-shock experiments* observed several temperature jumps at shock catch-up









VISAR: velocity interferometer for any reflector
SOP: streaked optical pyrometry

*Hicks (unpublished)

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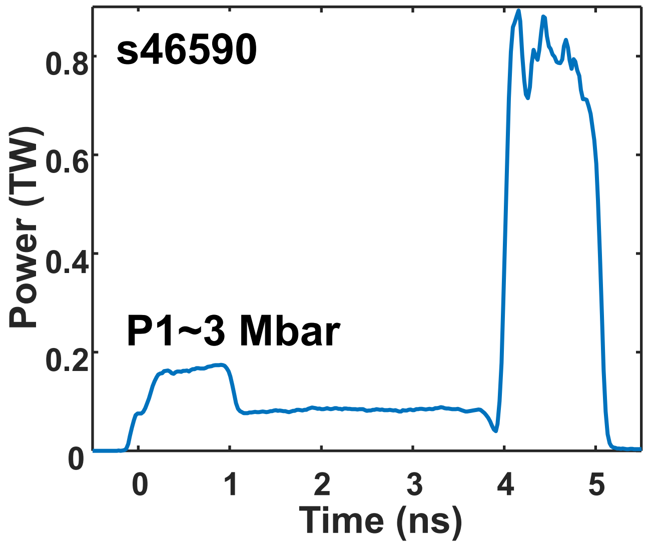

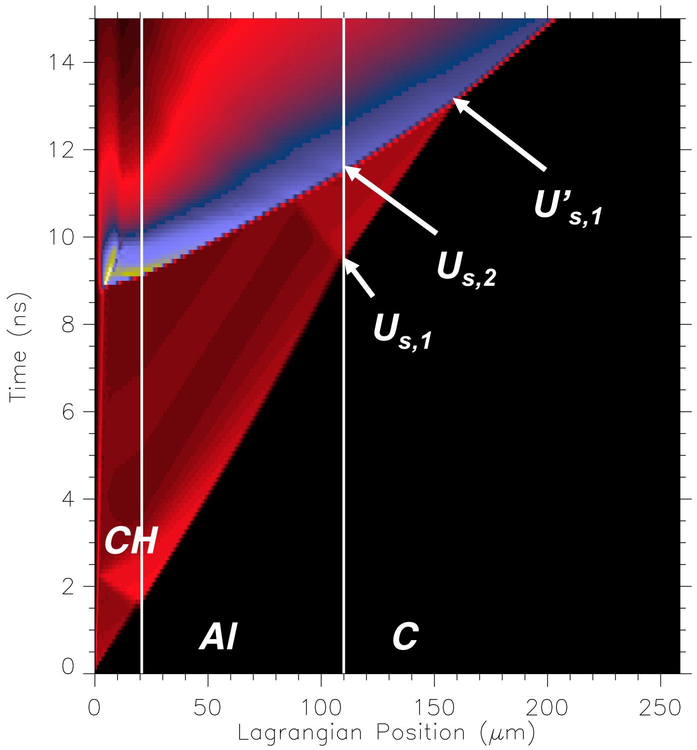

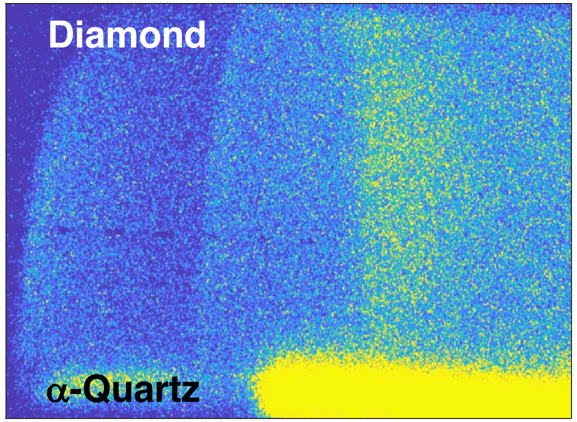

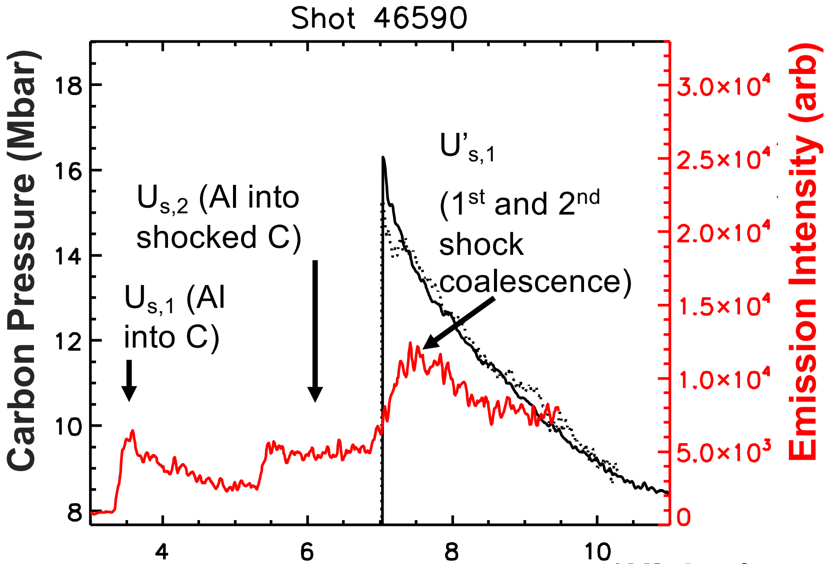

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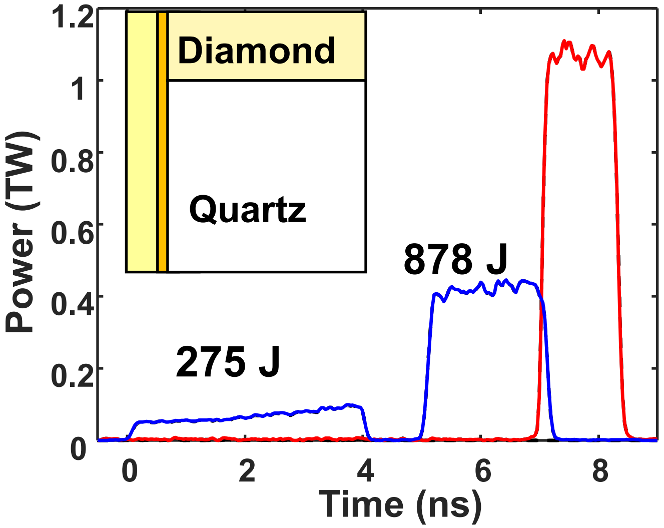
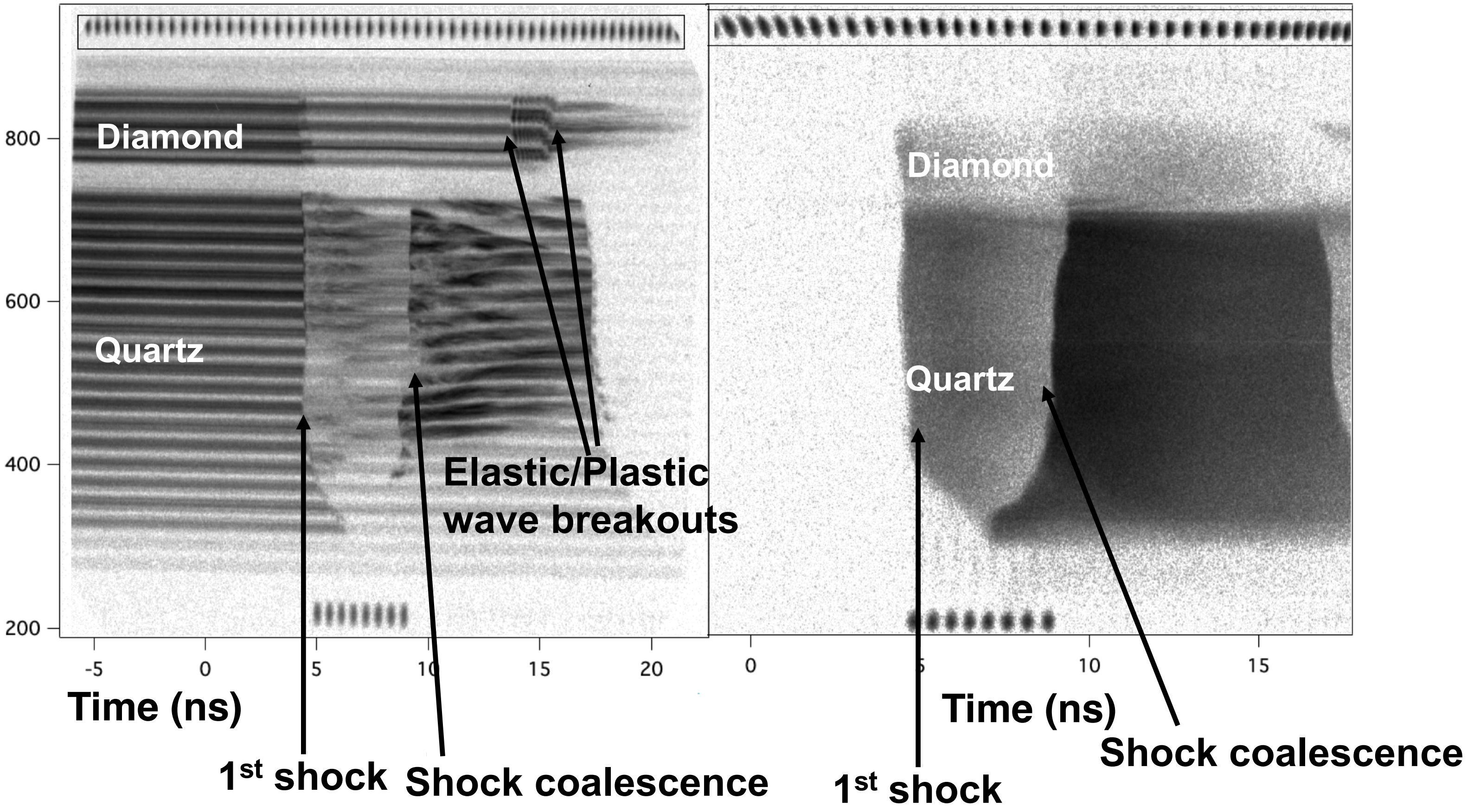
A first shock pressure of 2.2 Mbar in the diamond in measured from the adjacent quartz; the second shock pressure is less than 10 Mbar





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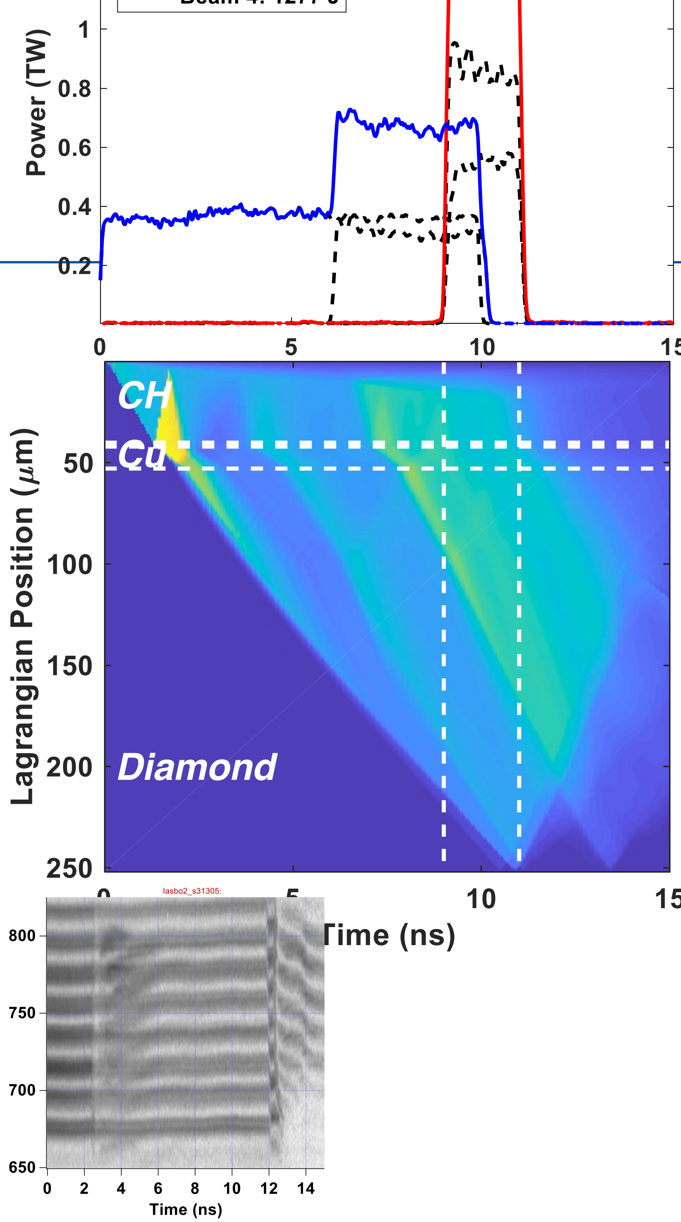
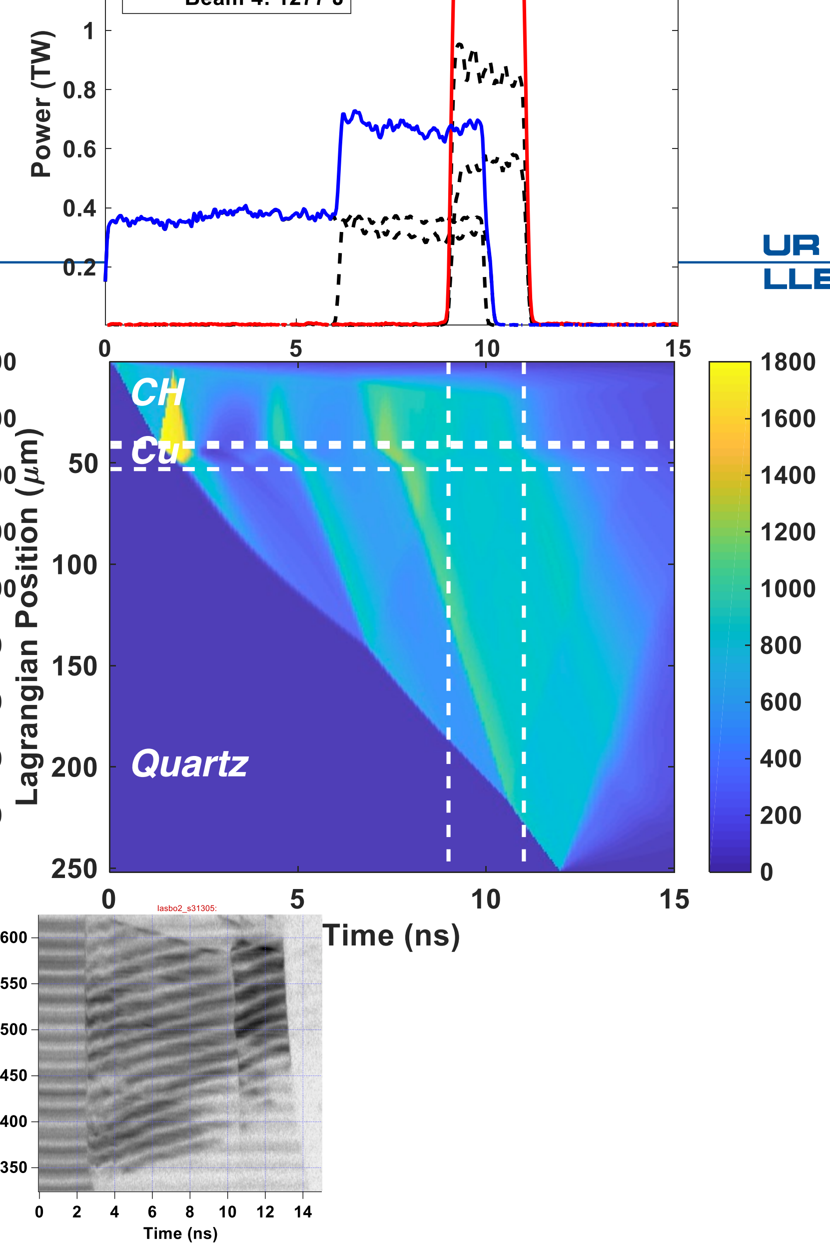
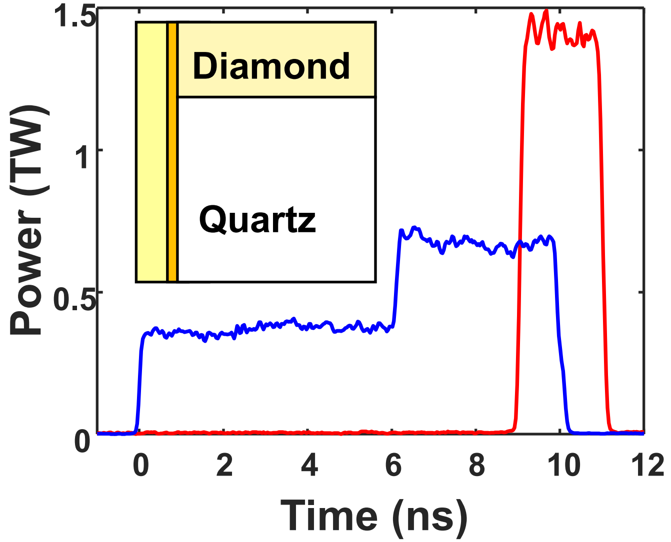
LLNL AnalyzeVISAR code (Marius Millot) was used to process the VISAR / SOP data.

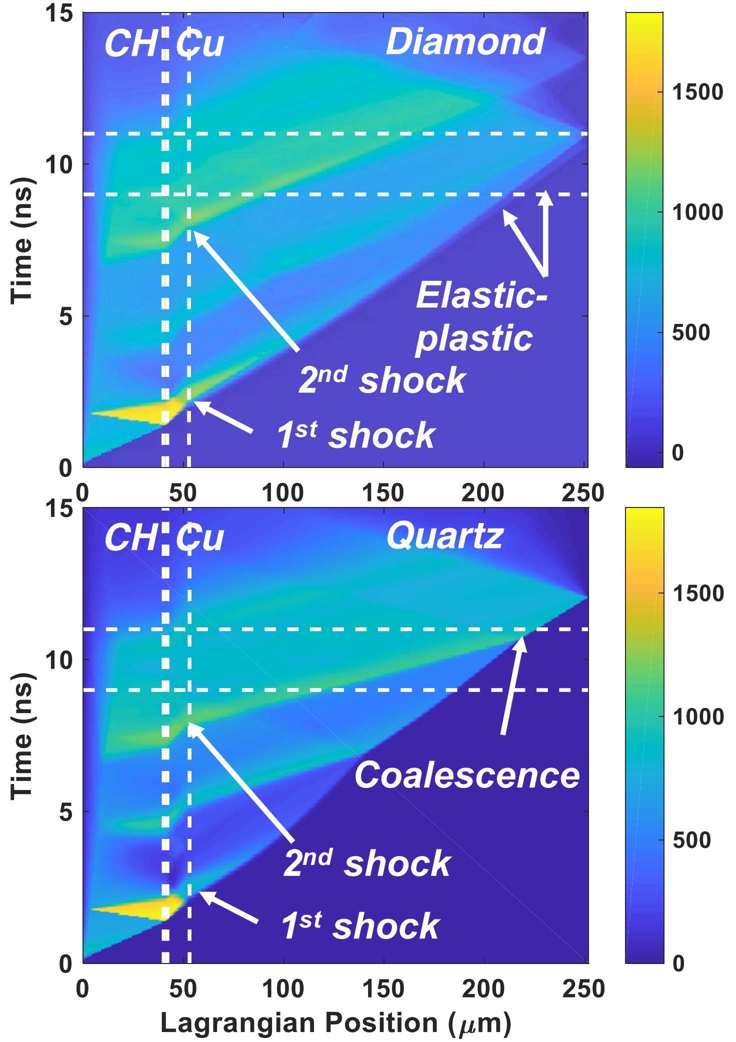

Power (TW)
Lagrangian Position (μm)
CH
Cu
Diamond
Time (ns)
Time (ns)

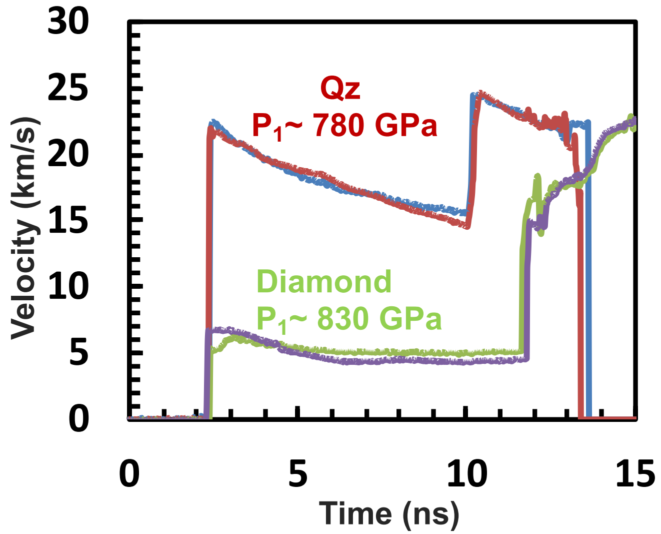

Power (TW)
Lagrangian Position (μm)
CH
Cu
Quartz
Time (ns)
Time (ns)

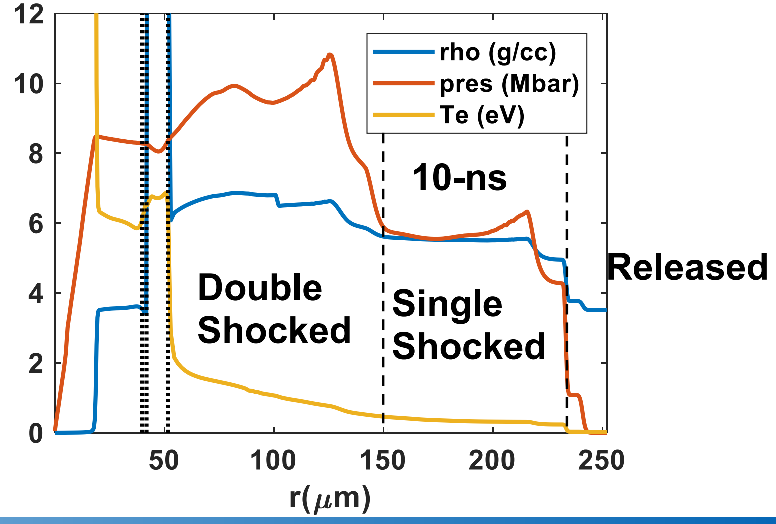
s31305

At the time of the x-ray exposure, the diamond is double-shocked, single-shocked, and released



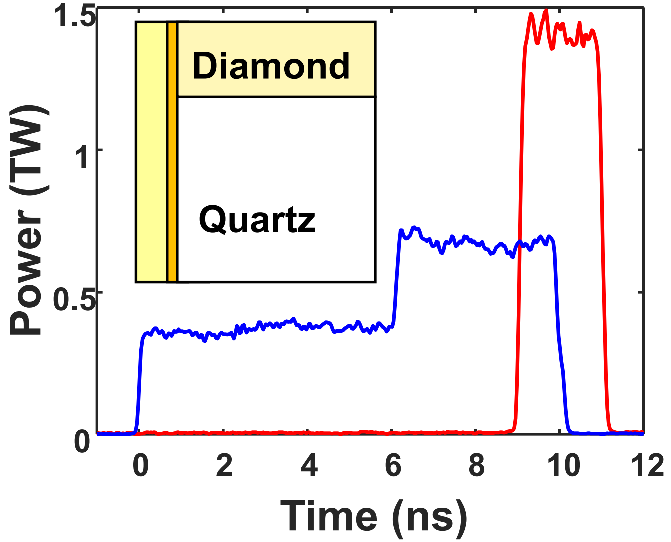




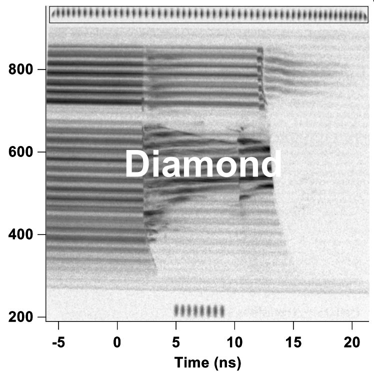


s31305

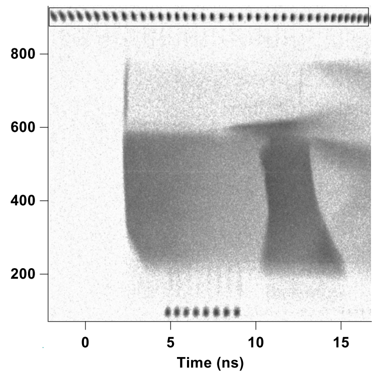
A first shock pressure in the diamond is measured from the adjacent quartz



VISAR



SOP



No coalescence

Elastic/Plastic wave breakouts

1st shock

Shock coalescence

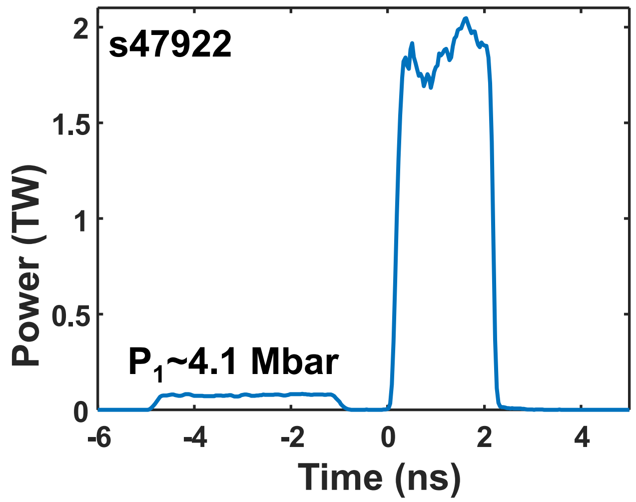
1st shock

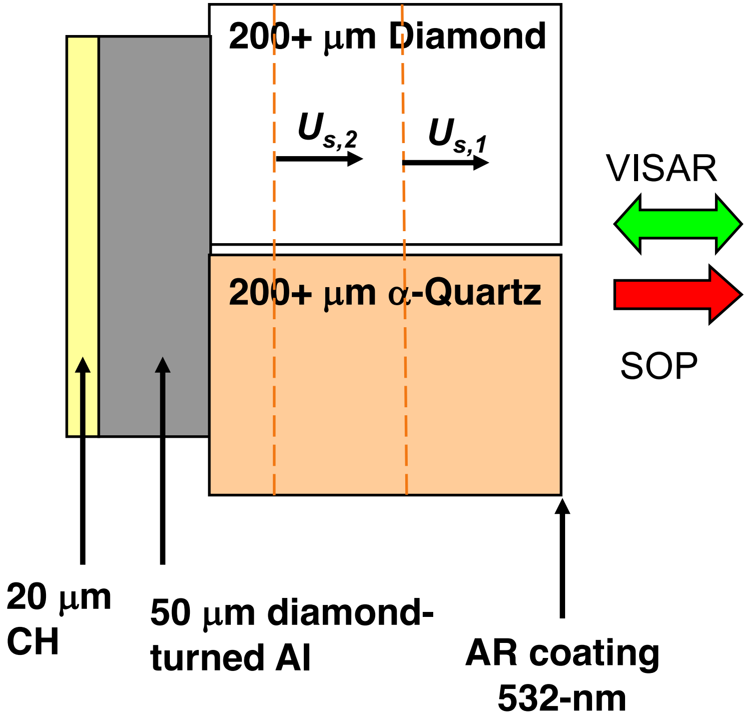
Shock coalescence

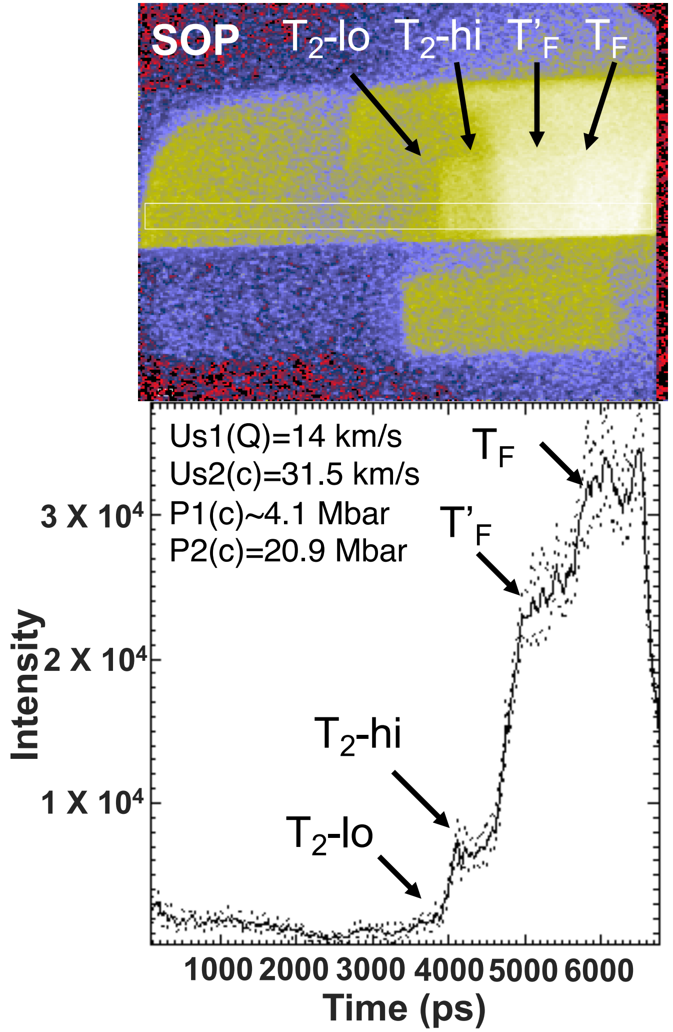
LLNL AnalyzeVISAR code (Marius Millot) was used to process the VISAR / SOP data.

s31305

For first shocks ~4 Mbar, four distinct events are observed in the self-emission







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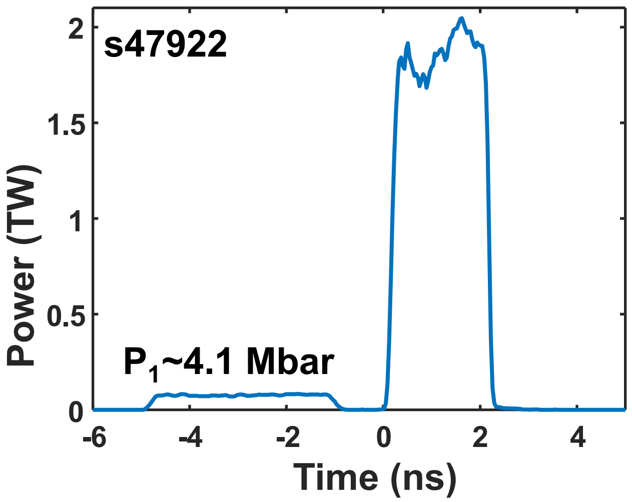
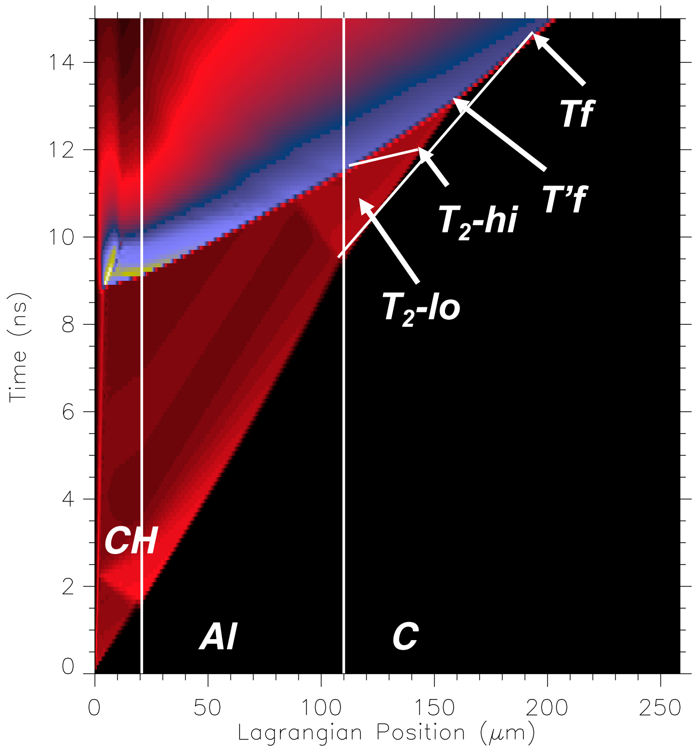
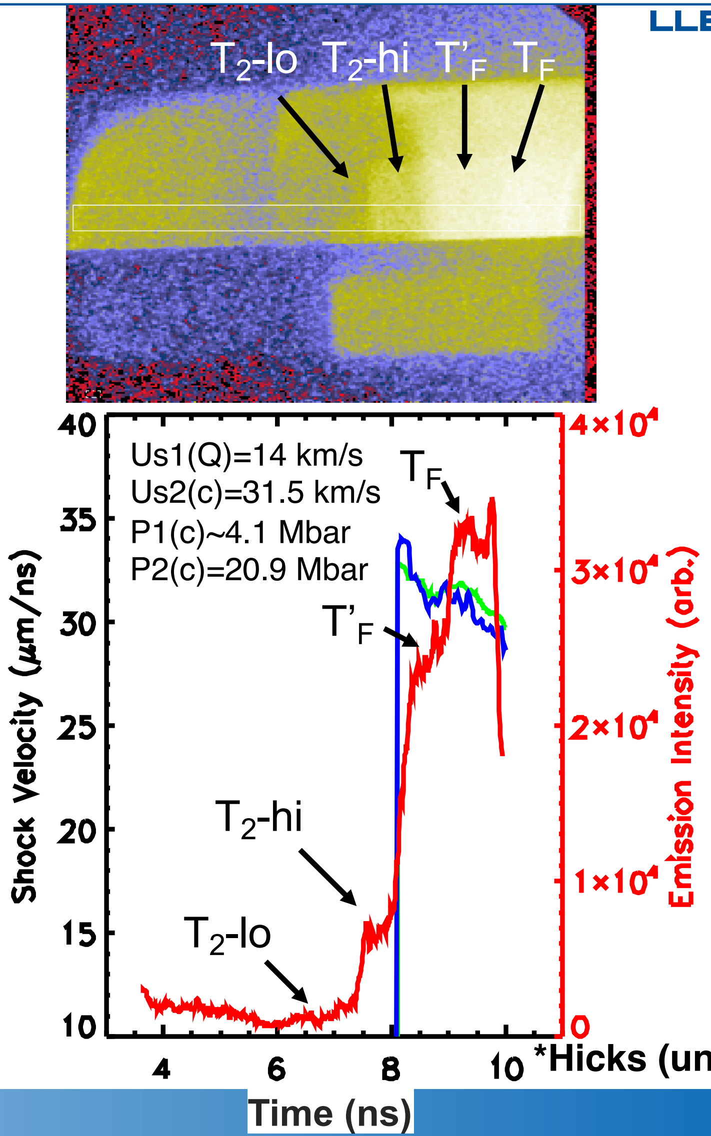
*Hicks (unpublished)

The wave-splitting can be explained by either strength or a phase transition







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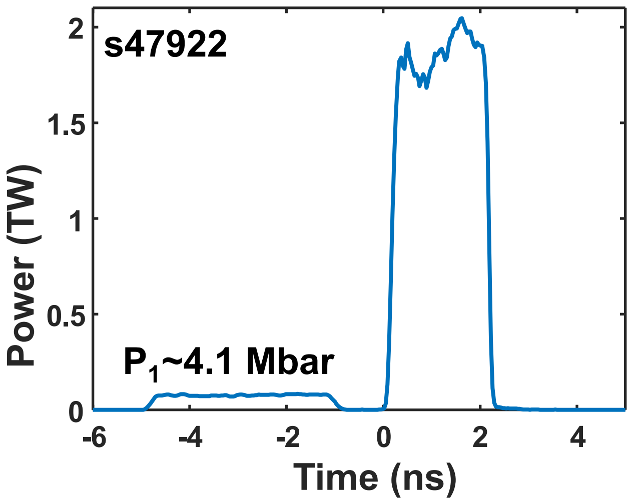
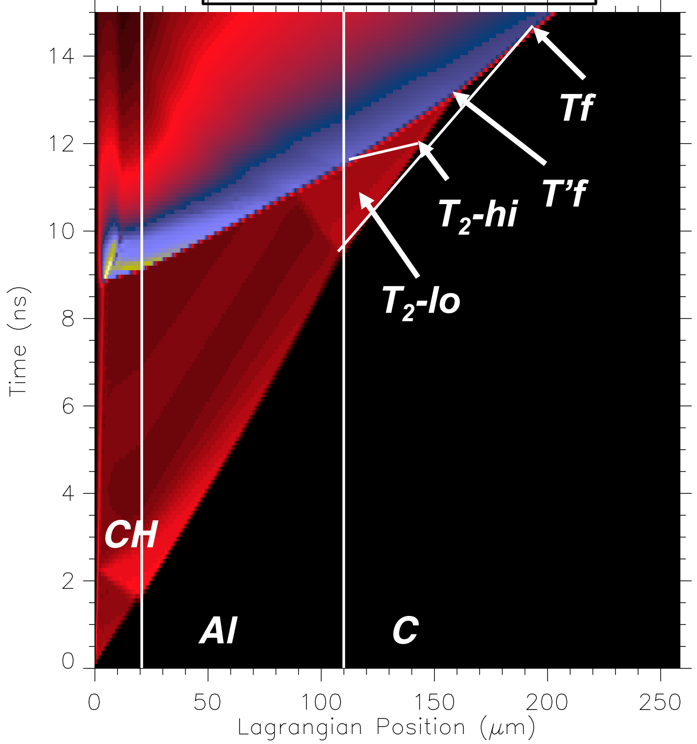
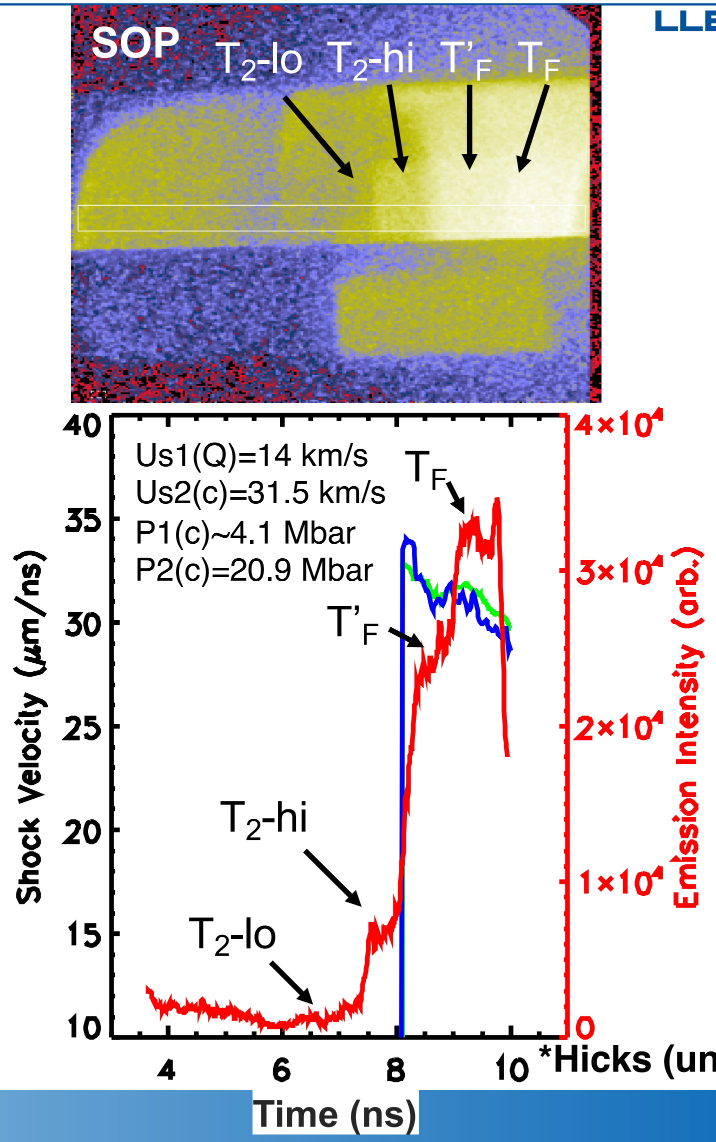
Laser Drive



Hydrodynamic Simulation





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Impedance matching