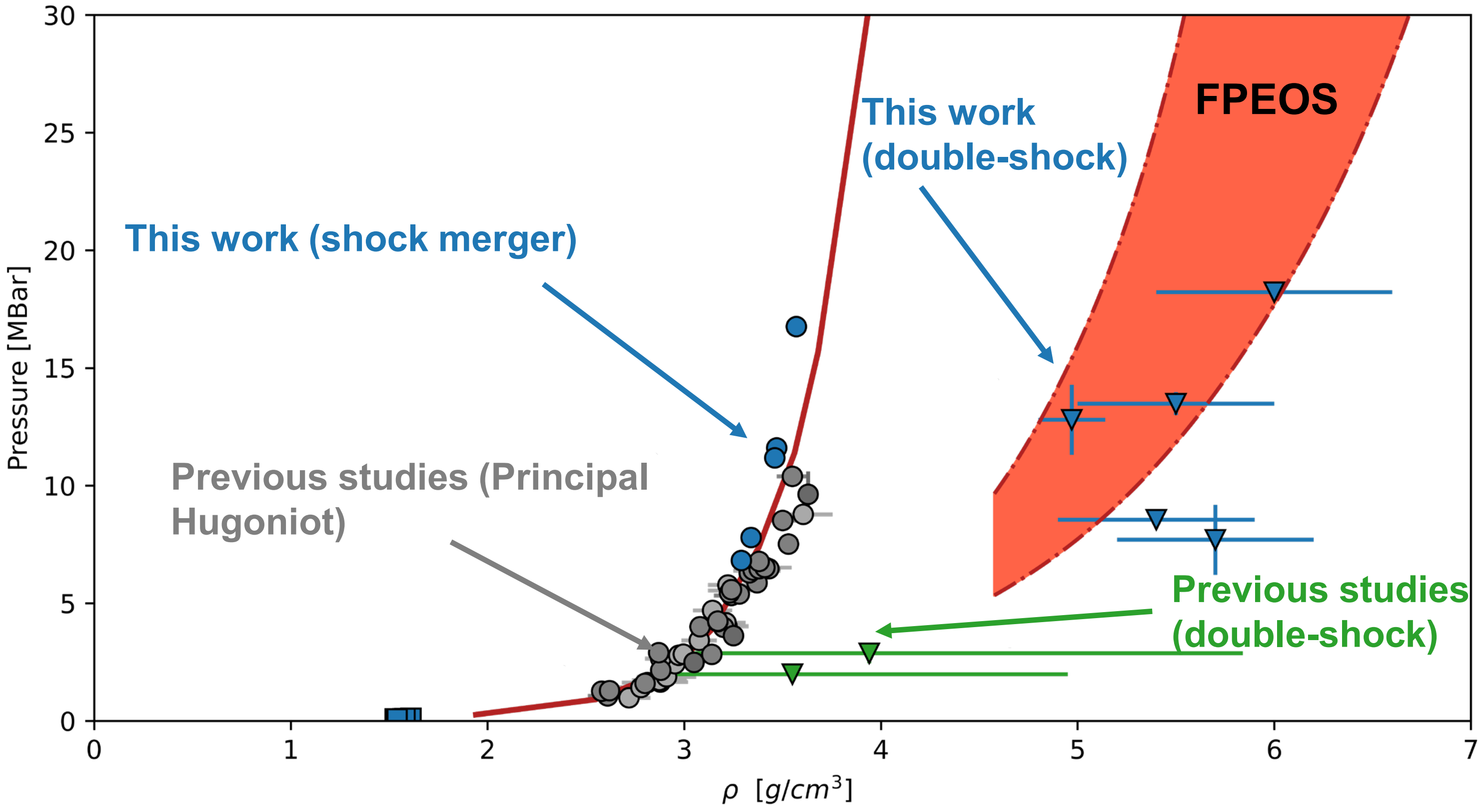
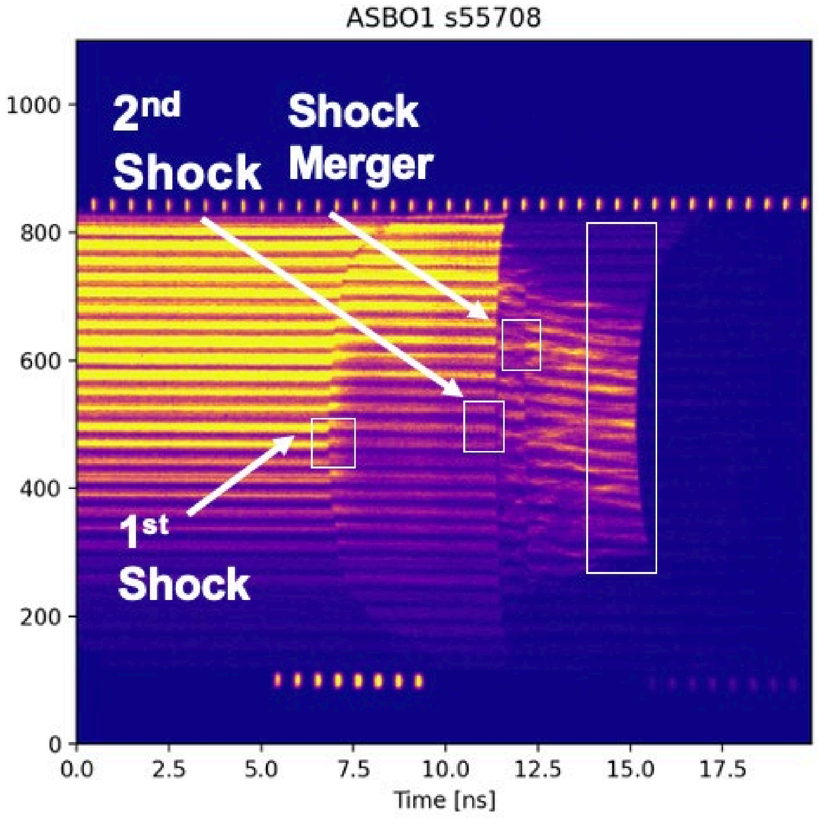
Properties of Double Shocked CH to 18 MBar





Zaire K. Sprowal
HEDx Group
University of Rochester Laboratory for Laser Energetics

APS Division of Plasma Physics Meeting
Spokane, Washington
October 21, 2022

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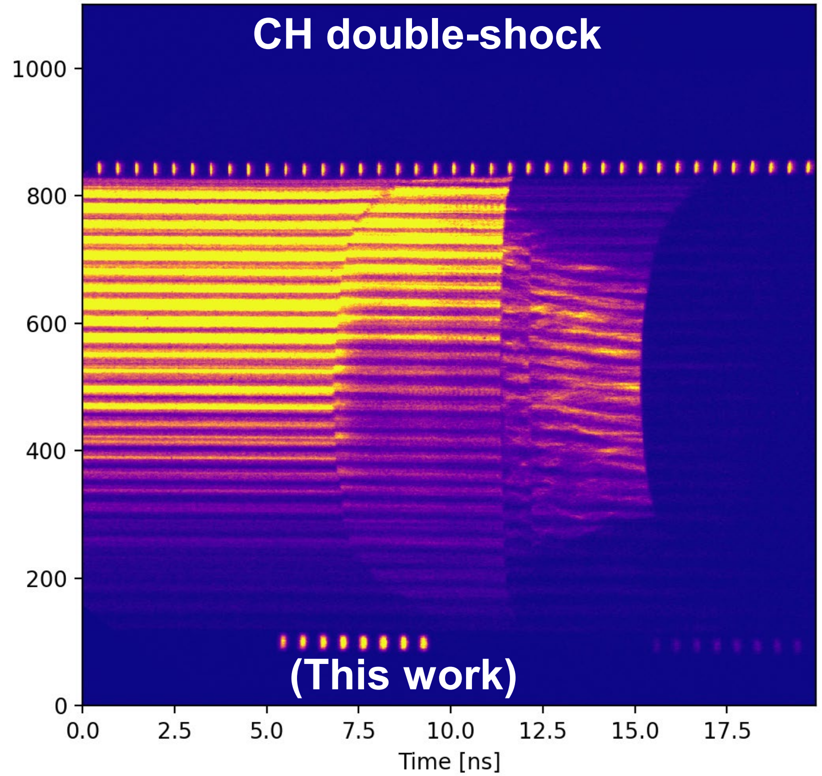

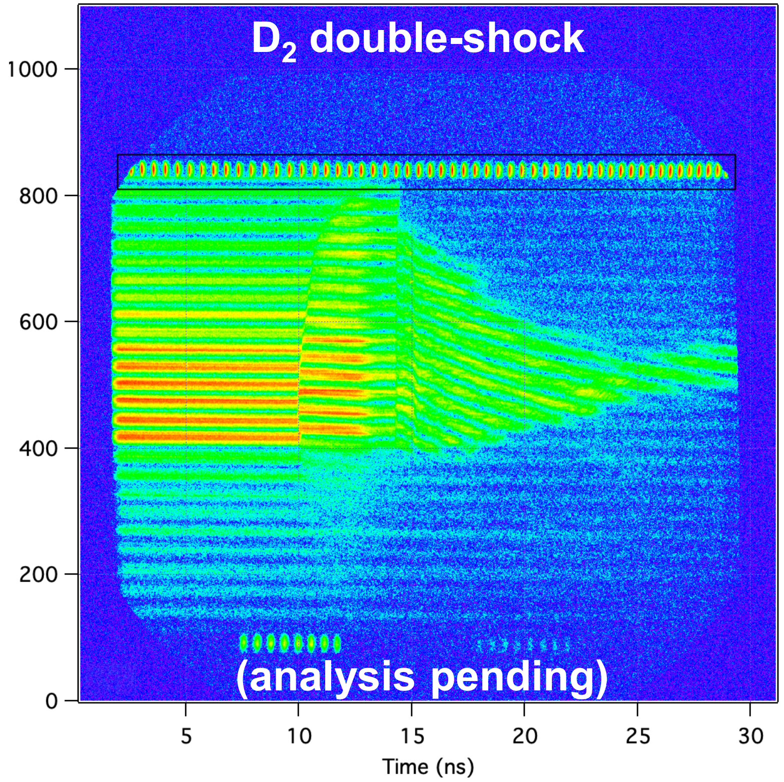

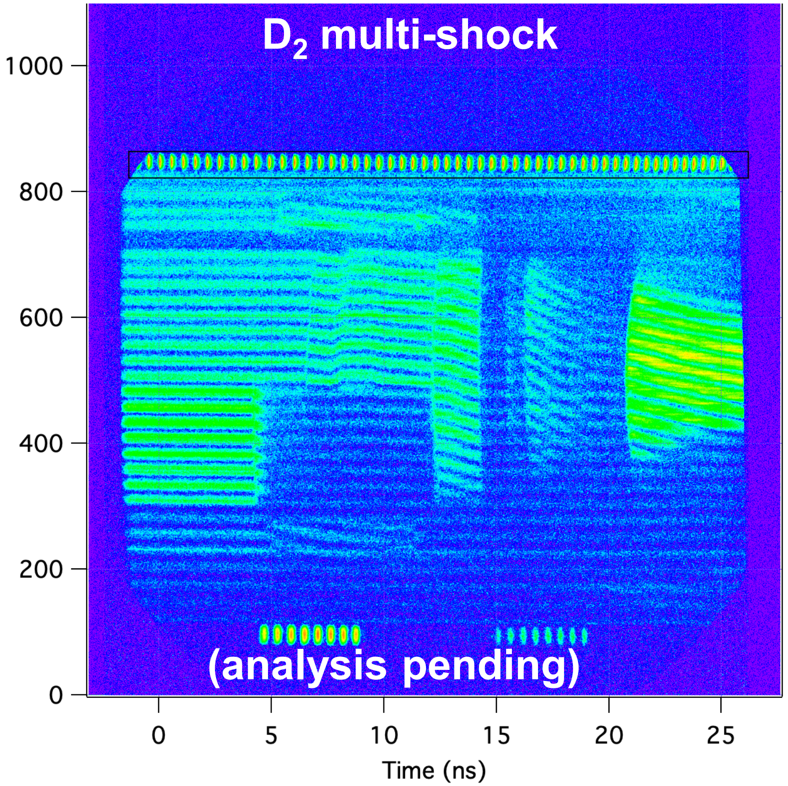

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Multi-shock compression facilitates unique access to high density states

- Double-shock states in CH were observed directly up to pressures of ~18 Mbar and densities of up to ~6.0 g/cc
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Collaborators

Z. K. Sprowal, L. E. Hansen, Margaret Huff, J. R. Rygg, T. R. Boehly, D. N. Polsin, S. Zhang, and G. W. Collins

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D. Hicks

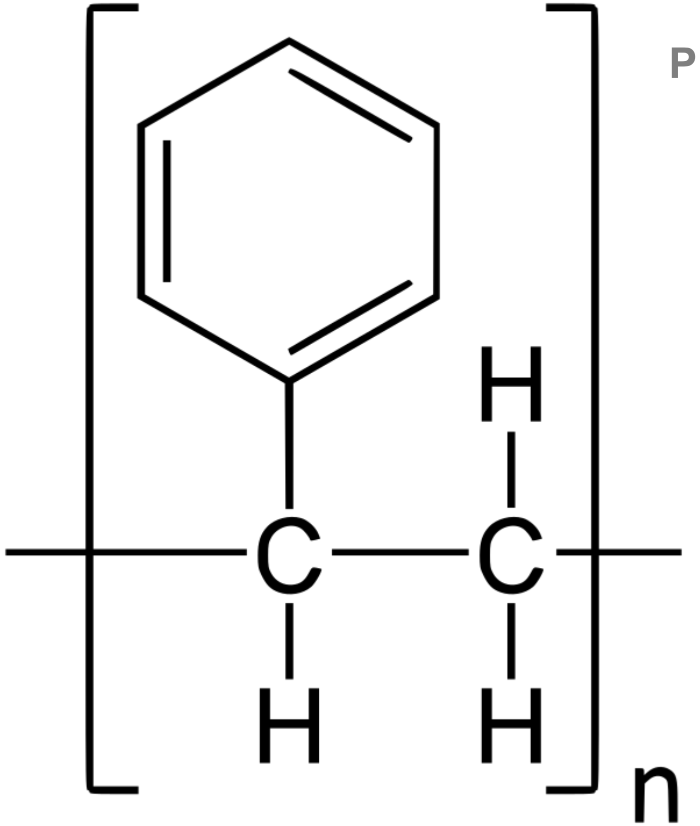
Swinburne University of Technology, Melbourne, Australia

P. M. Celliers

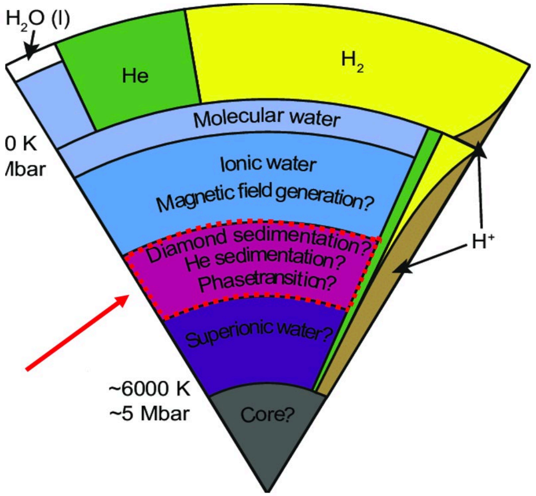
Lawrence Livermore National Laboratory, Livermore, CA, USA

CH has several practical applications ranging from ICF to Planetary Modeling

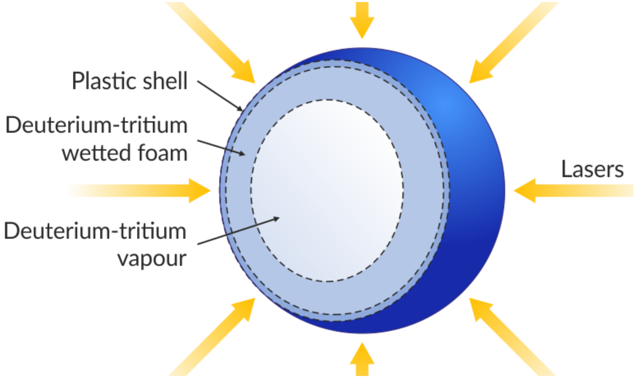
Polystyrene $(C_8H_8)_n$



Planetary Interiors



ICF



- Polystyrene is a synthetic polymer and one of the most ubiquitous plastics
- Polystyrene's 1:1 stoichiometric ratio of C:H makes it a suitable proxy material for studying planetary interiors
- It is also important for ICF research for its use in fusion capsules

Barrios et al. Phys. Plasmas 17, 056307 (2010)
Kraus et al. Phys. Plasmas 23, 056313 (2018)

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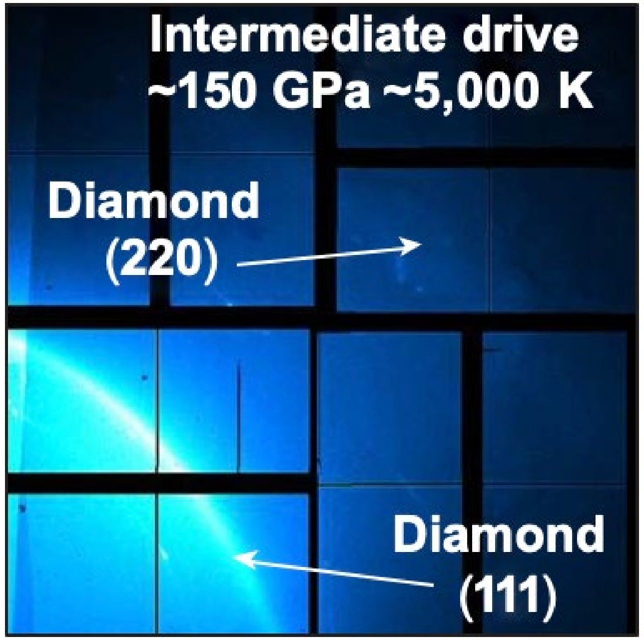

High-pressure chemistry of hydrocarbons relevant to planetary interiors and inertial confinement fusion

Cite as: Phys. Plasmas **25**, 056313 (2018); https://doi.org/10.1063/1.5017908
Submitted: 01 December 2017 . Accepted: 08 May 2018 . Published Online: 23 May 2018

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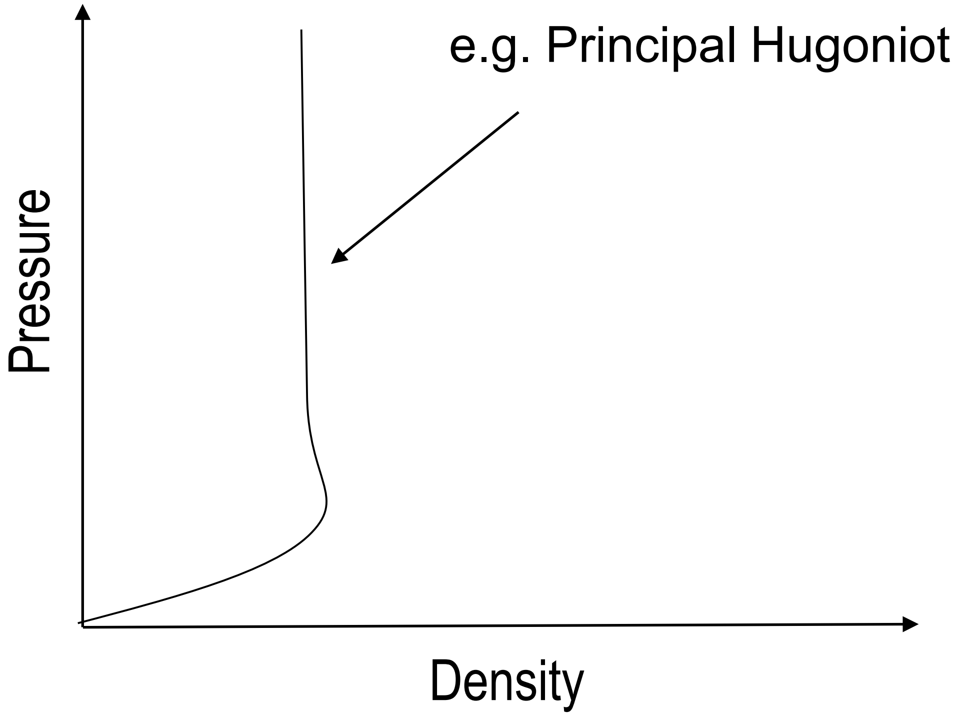
- It is also important for ICF research for its use in fusion capsules
- Recent experiments showing Diamond precipitation in CH has important consequences for both ICF and planetary modeling

Kraus et al. Phys. Plasmas 23, 056313 (2018)

A variety of experimental paths enable exploration of a material's phase space



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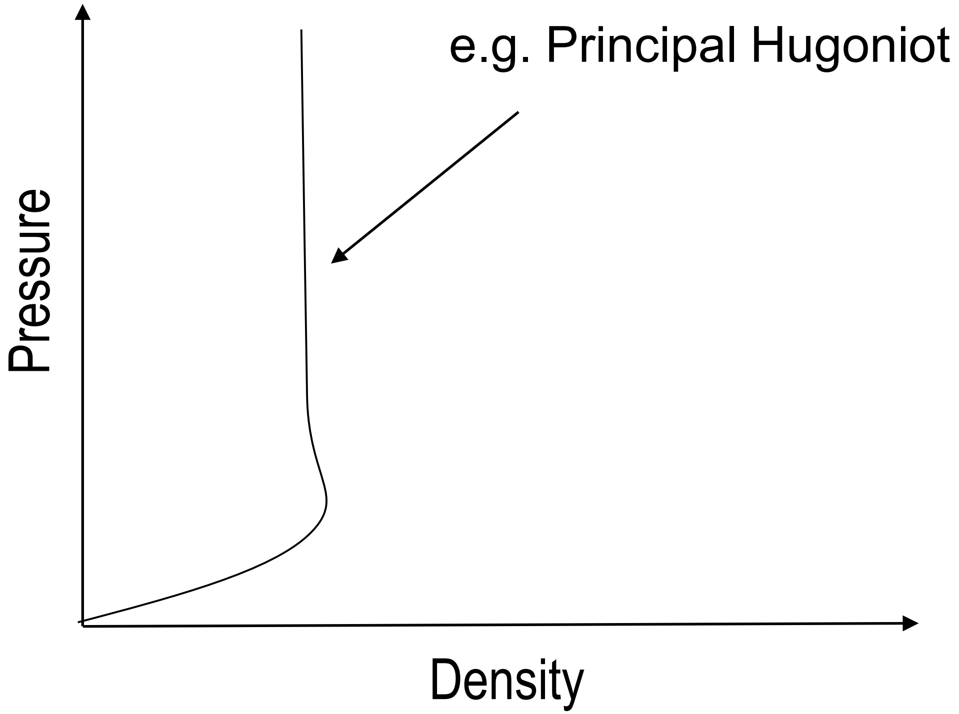

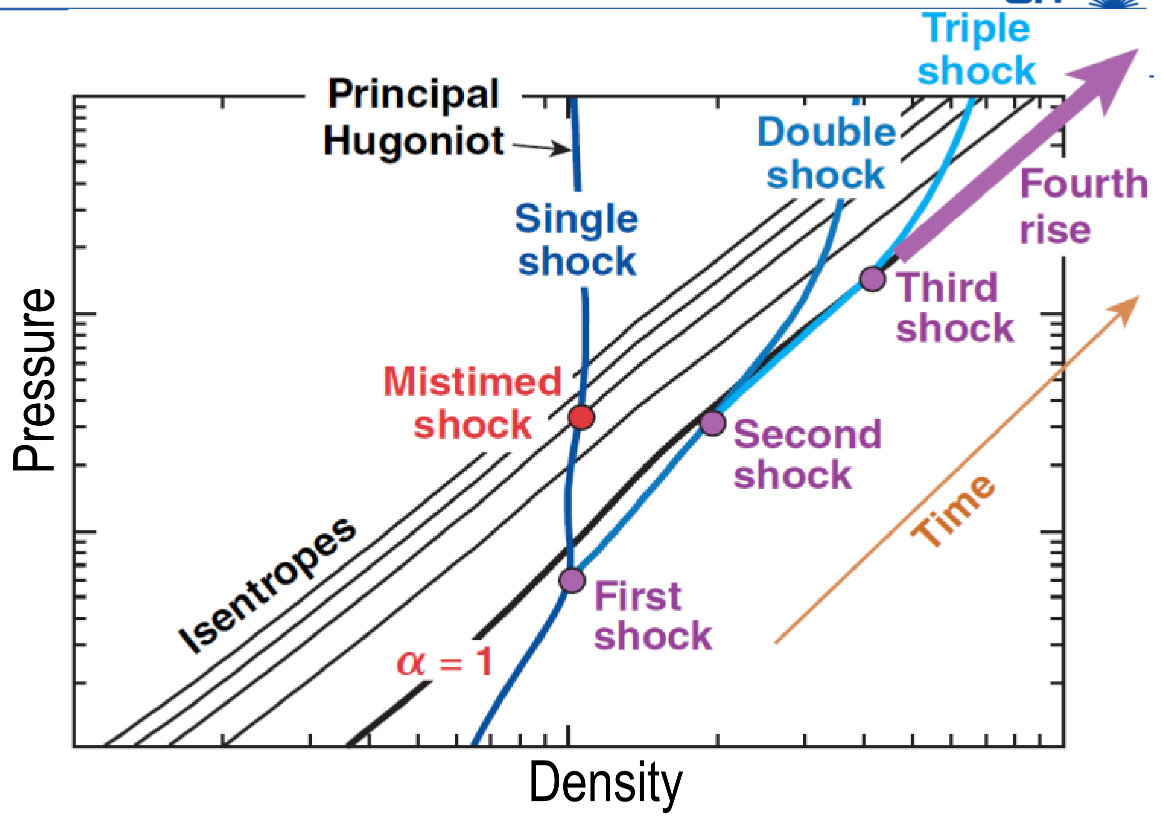

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- Multi-shock compression is a method for obtaining off-Hugoniot states

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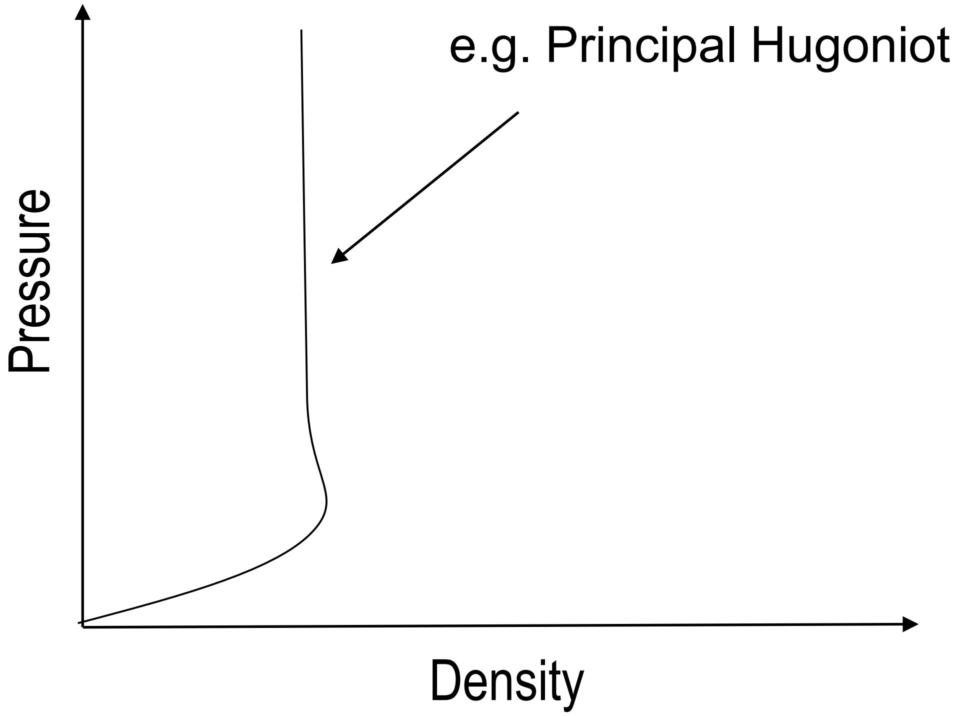
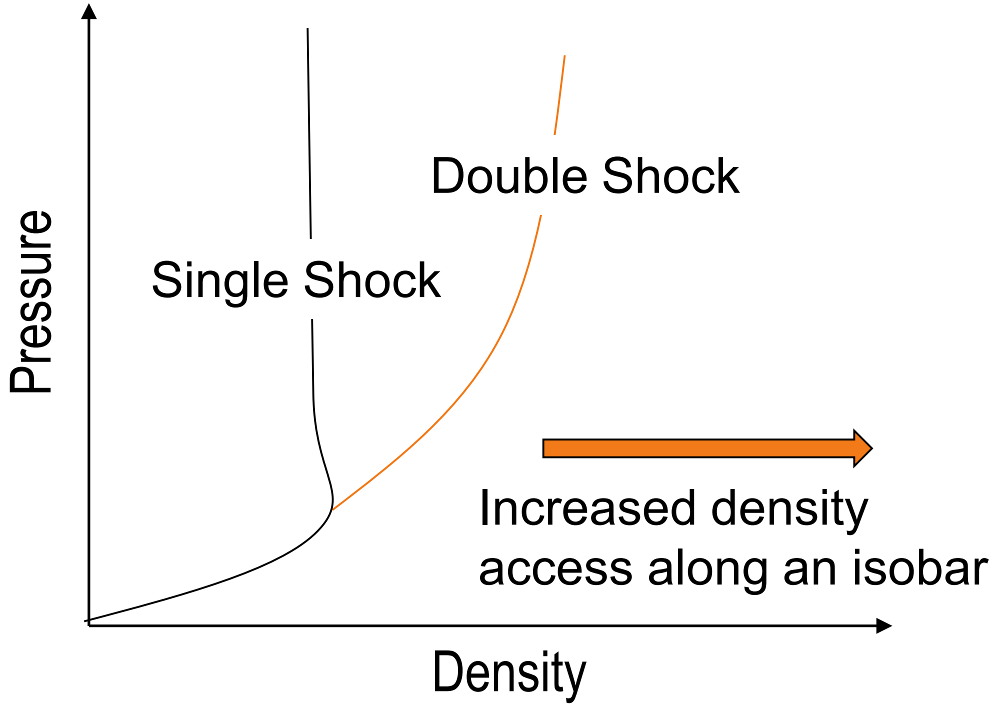
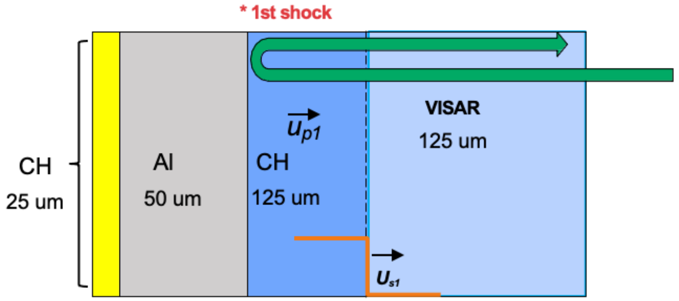




- The locus of states accessible by shocking a material is referred to as an Hugoniot
- Multi-shock compression is a method for obtaining off-Hugoniot states
- A specific class of multi-shock compression, **dynamic pre-compression (or double shock)**, is the focus of this work

Double-shock state (P_2,ρ_2) is observed directly and determined by self-impedance matching



Guargaglini et al. Phys. Plasmas 26, 042704 (2019)

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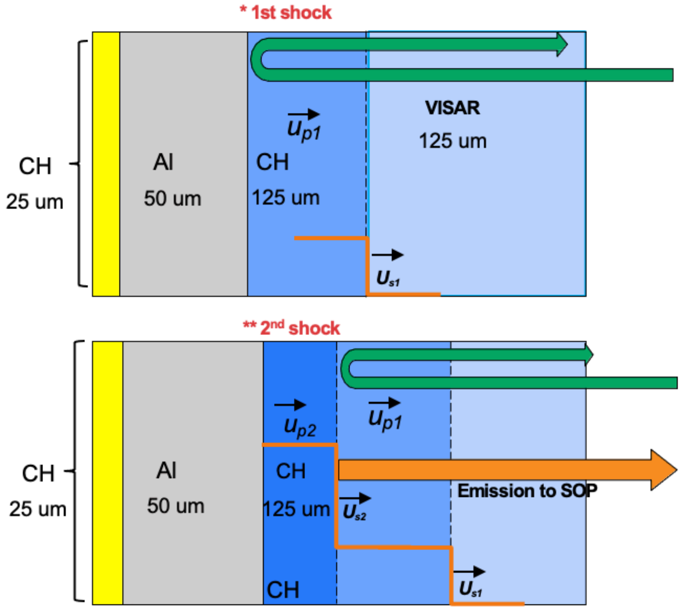

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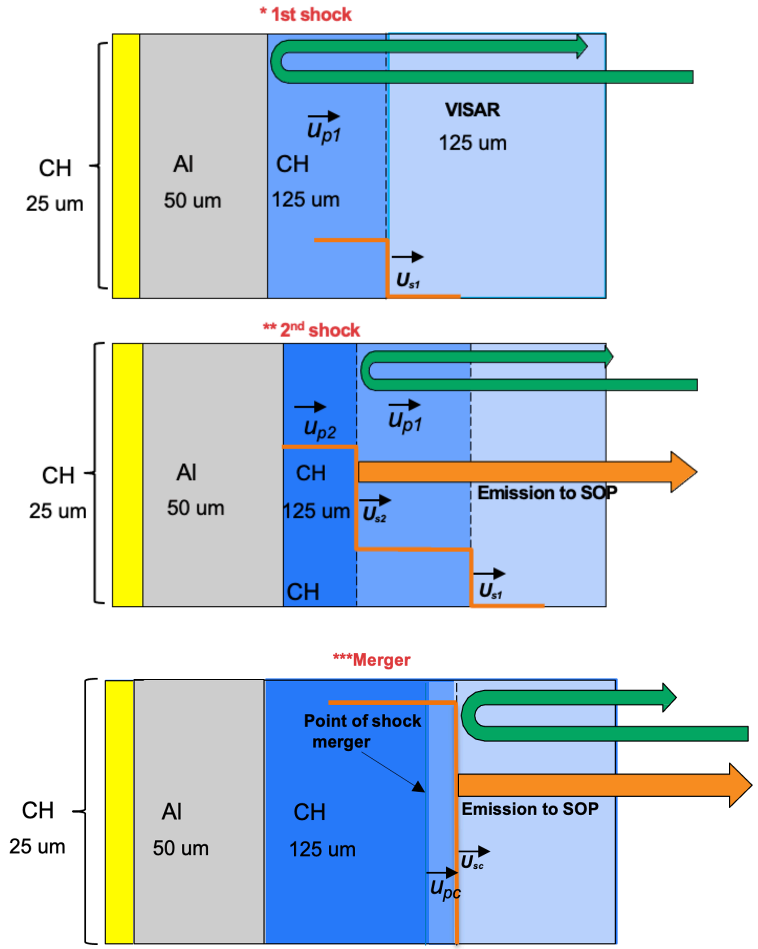

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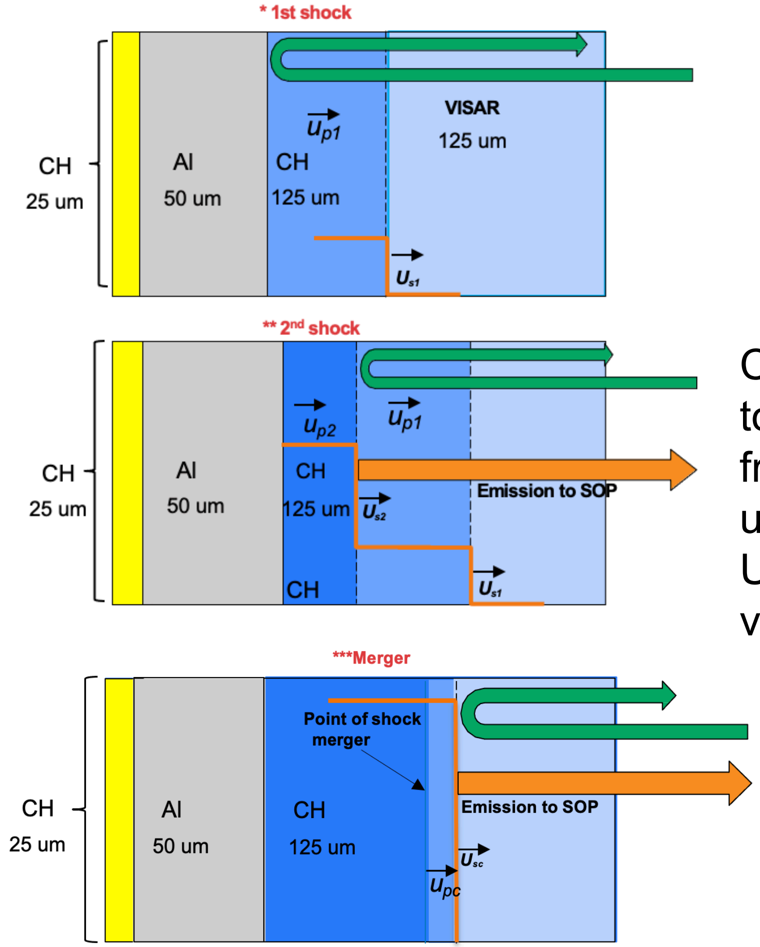

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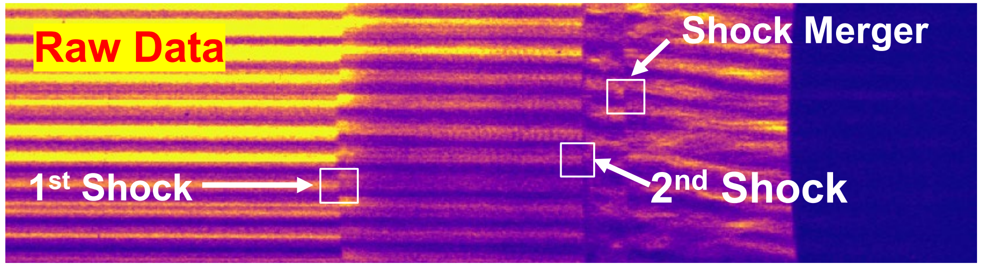
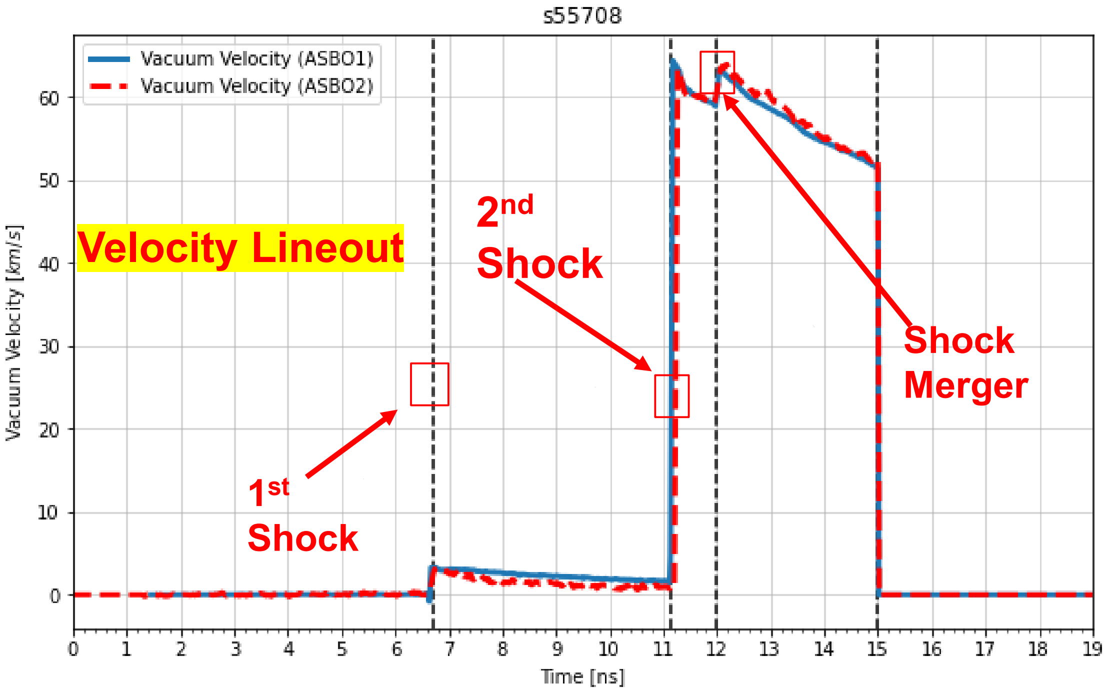
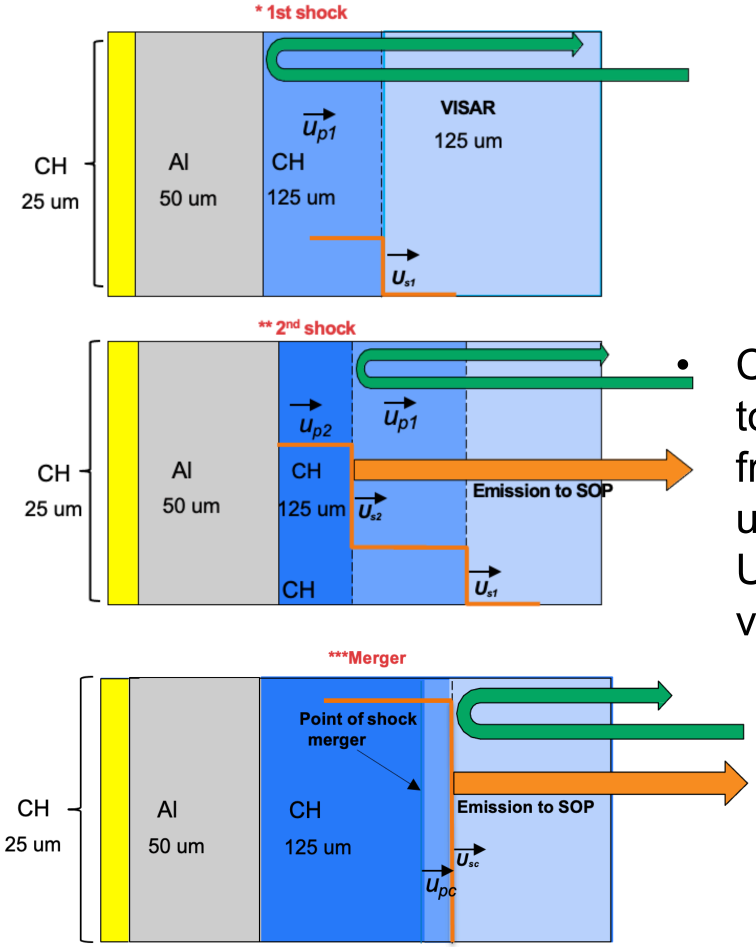
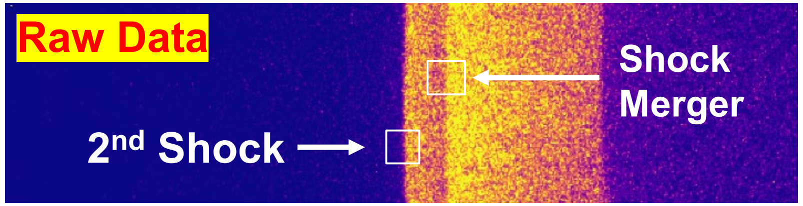


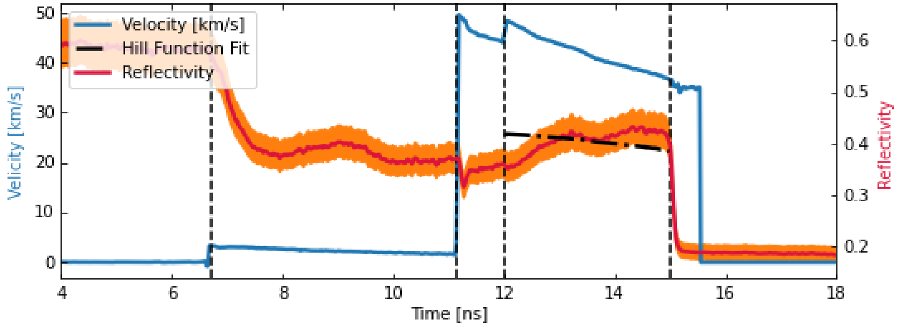


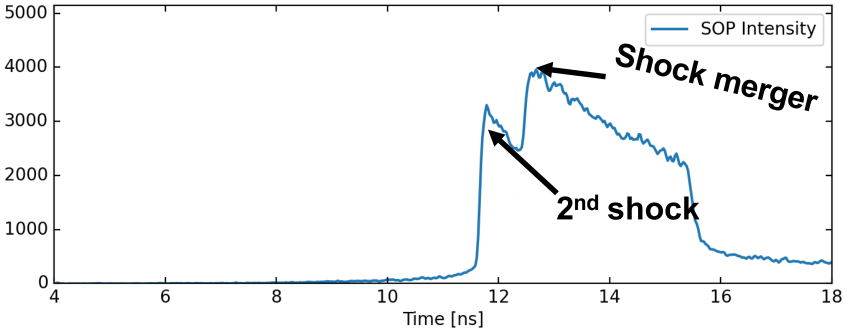


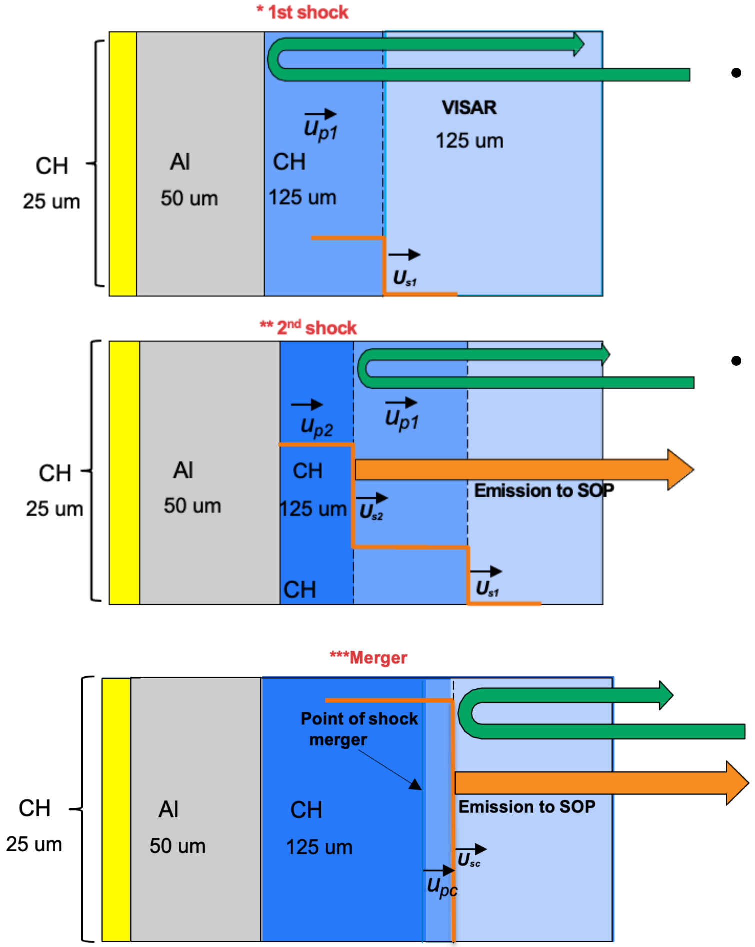
- Conservation relations are used to obtain pressure and density from primary observables u_{p1},U_{s2} (second shock velocity), U_{sc} (merger/coalescence velocity)

Temperature of double-shock and merger states is measured using optical pyrometry





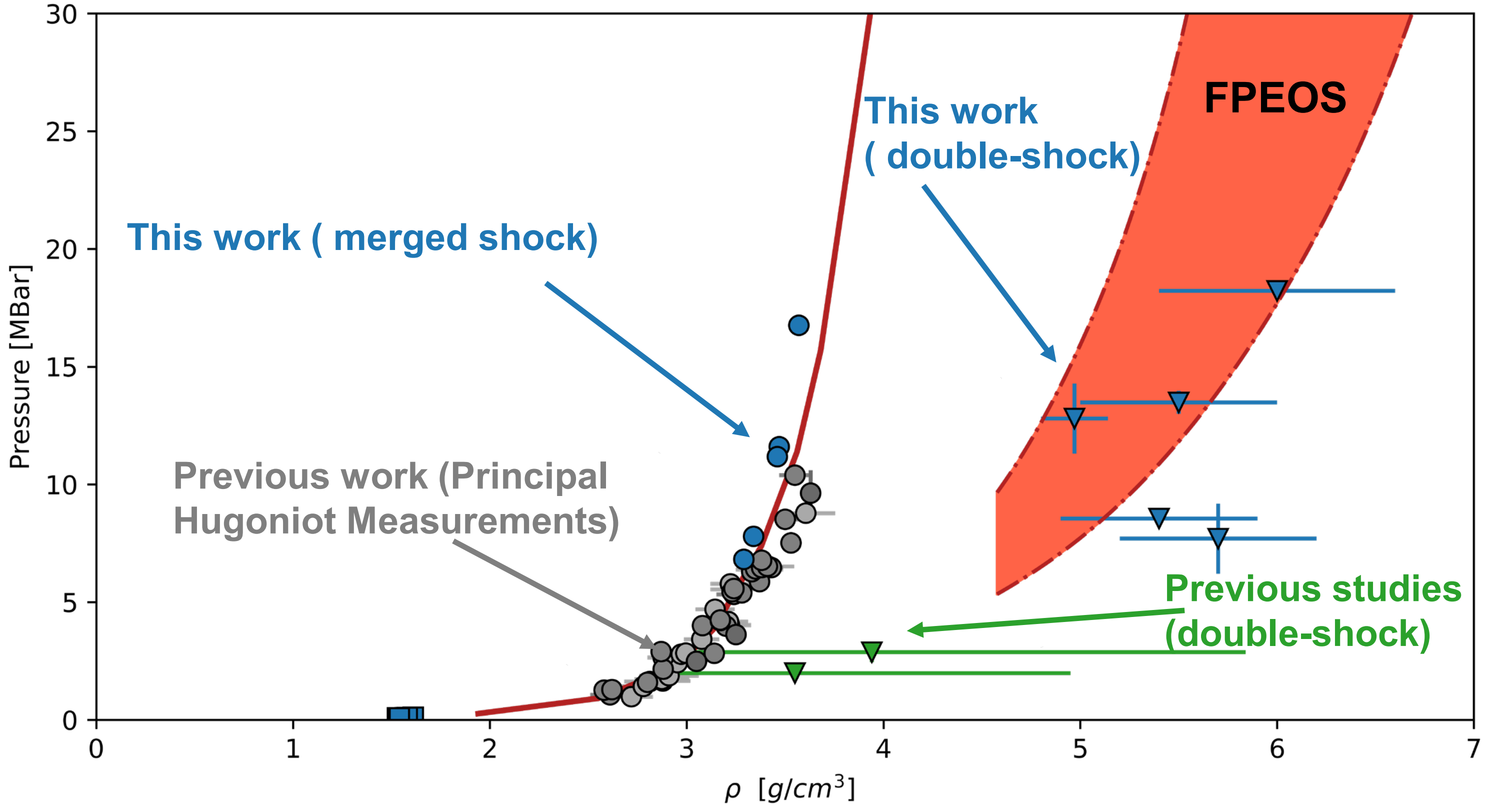




- Transparent (weak) shocks in CH have temperatures below the detection threshold of SOP (~3000 K)
- Thus, the intensity from the SOP raw data and emissivity obtained from VISAR are used to obtain a grey-body temperature of the double shock and merger states only

$$T = \frac{T_0}{ln\left[1 + \frac{(1 - R)A}{I_{SOP}}\right]}$$

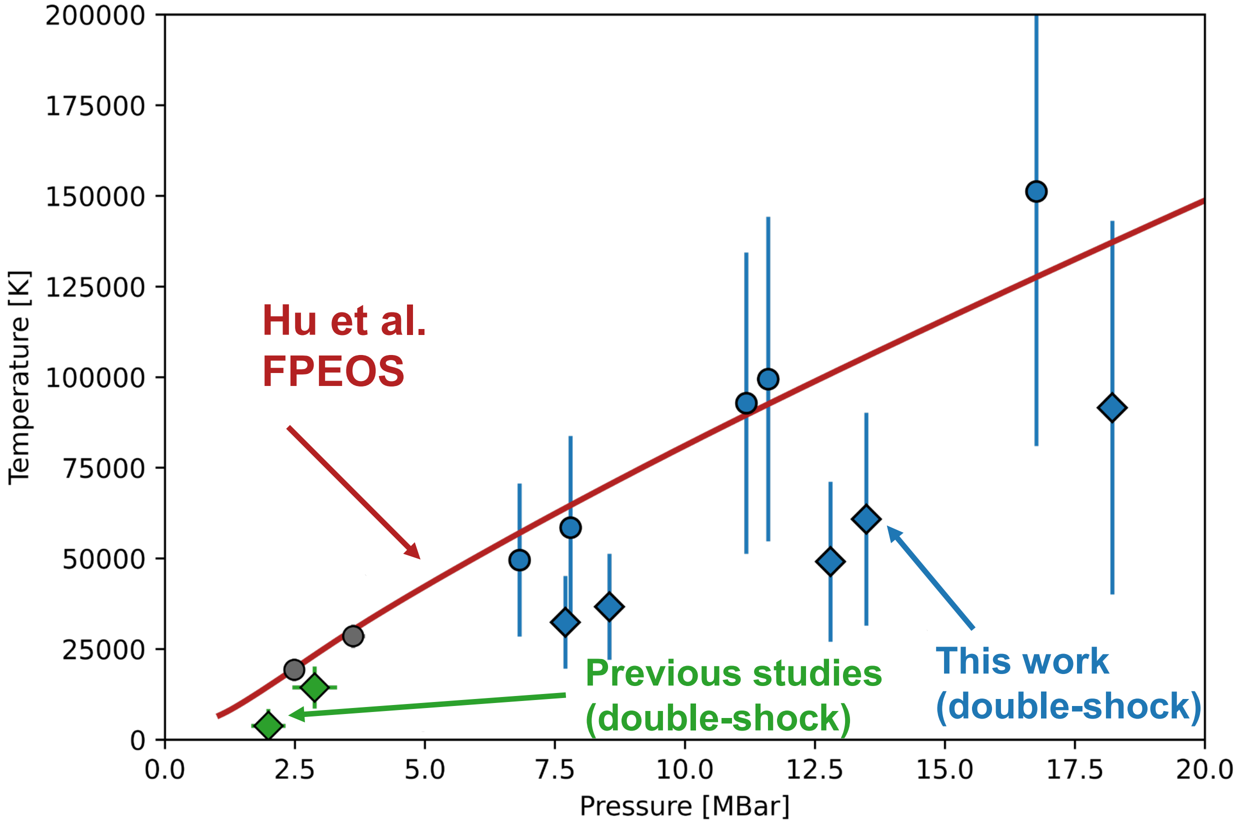
Some double shock states show greater compression than predicted by existing models



- The measured double shock states vary from showing good agreement to being measured at ~14% denser than the FPEOS** predicted locus of double shock states
- This predicted range fell between (14.4 GPa,1.72 g/cm^3) < P_1,ρ_1 < (20.8 GPa,2.34 g/cm^3), for the first shock state

Zhang et al. A Phys. Rev. E 96 (2017) 013204
Zhang et al. J. Chem. Phys. 148 (2018) 102318
Militzer at al. Physical Review E 103 (2021) 013203

Temperatures of double-shock states exhibit the same general behavior as their corresponding hugoniot states, albeit at significantly cooler



- In fact, the temperature of the double shock states were consistently 50-60% cooler than the subsequent merger (hugoniot) shock states
- These temperatures for the double shock fell between ~25 kK – 75 kK

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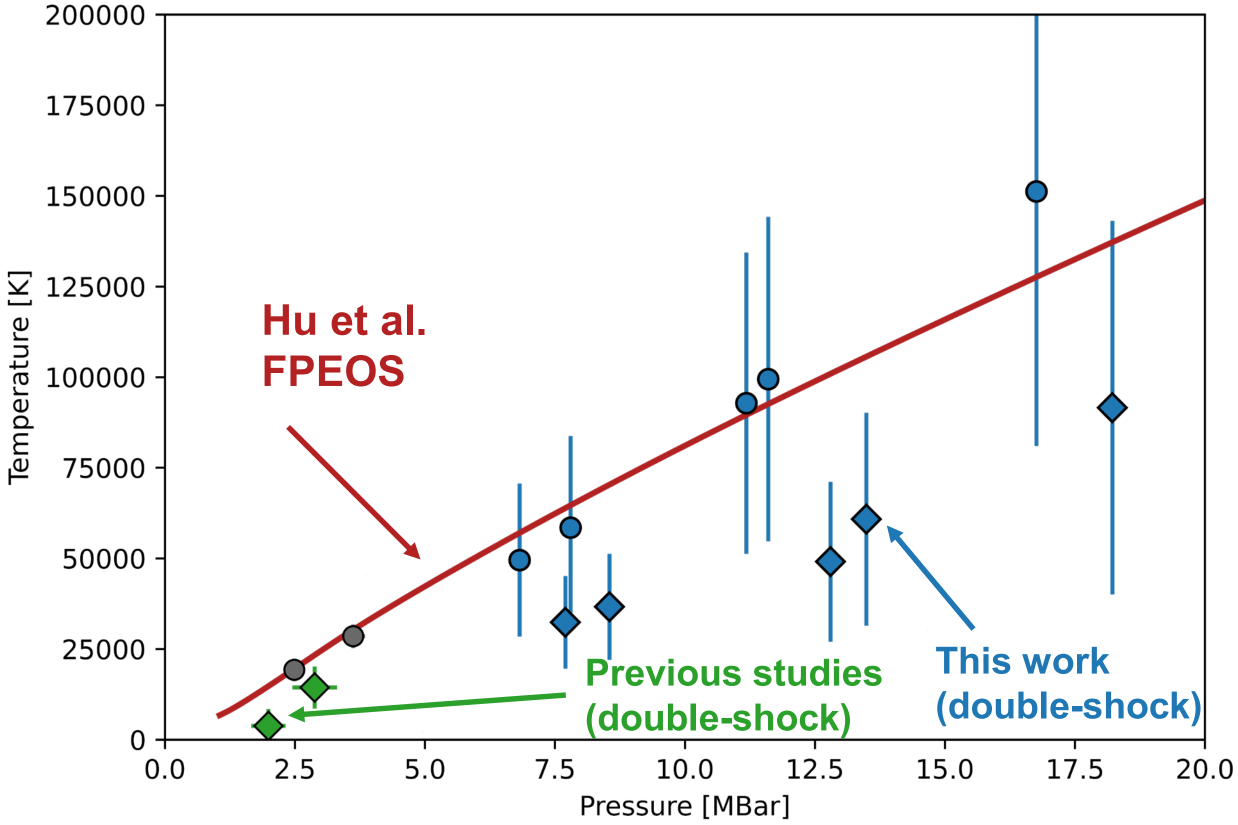

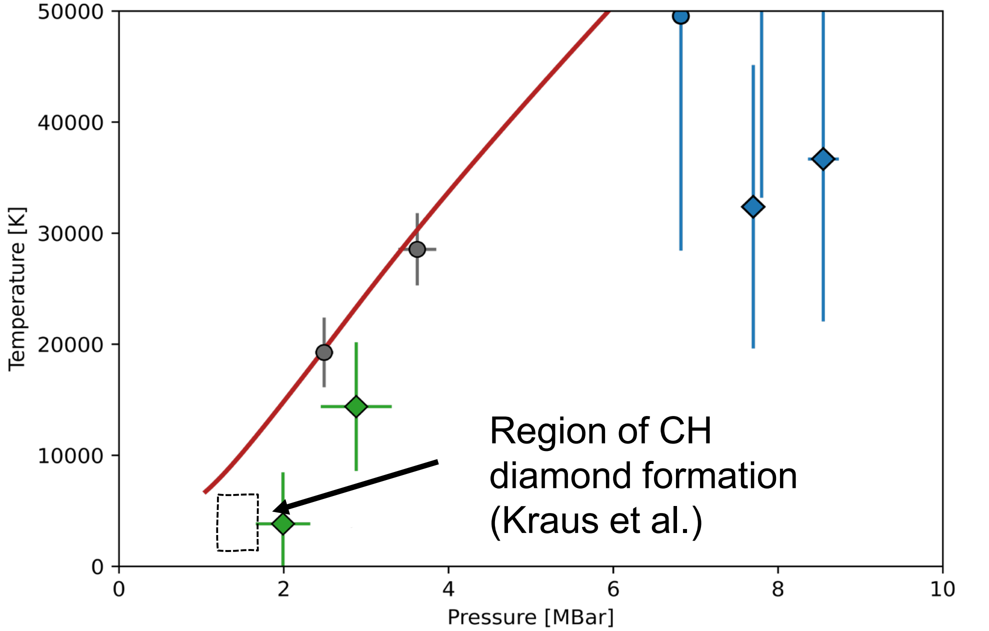

- The temperature of the double shock states were consistently 50-60% cooler than the subsequent merger (hugoniot) shock states
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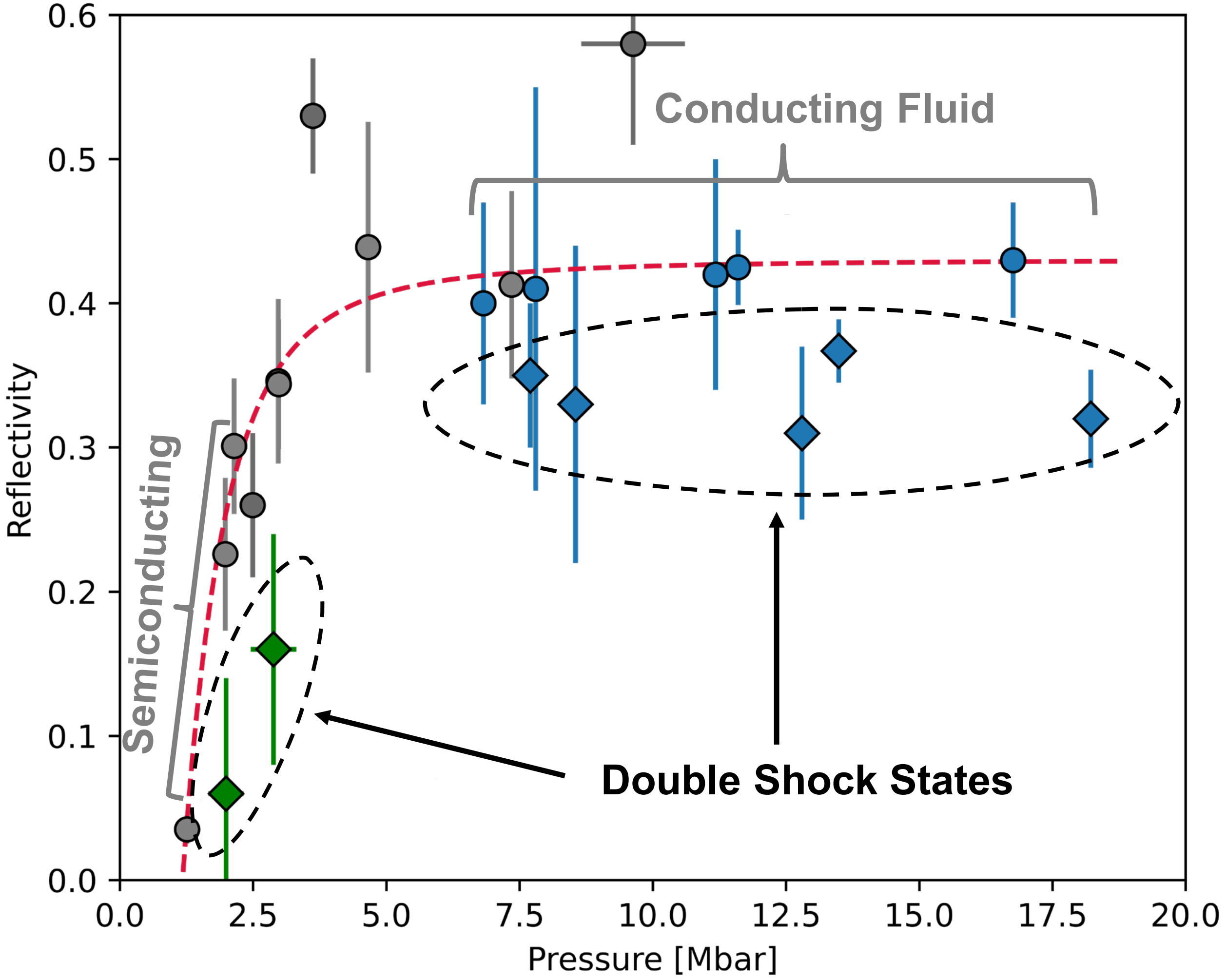
Reflectivity of states on the CH principal hugoniot saturate at ~40% while for double shock states we observe reflectivity between ~30 – 40%



- These data occupy a range of states traversing band gap closure to the conducting fluid regime of CH
- That the reflectivity of (singly) shocked CH follows H_2 through an overlapping temperature range suggests that hydrogen drives the behavior of the reflectivity
- However, the double-shock appears to diminish this effect, as the relative “drop” in reflectivity for these states hovers closer to the reflectivity of pure carbon (diamond) observed in the literature
- Moreover, the double shock platform may offer a unique opportunity to explore the high pressure / high density chemical behavior of hydrocarbons at these conditions

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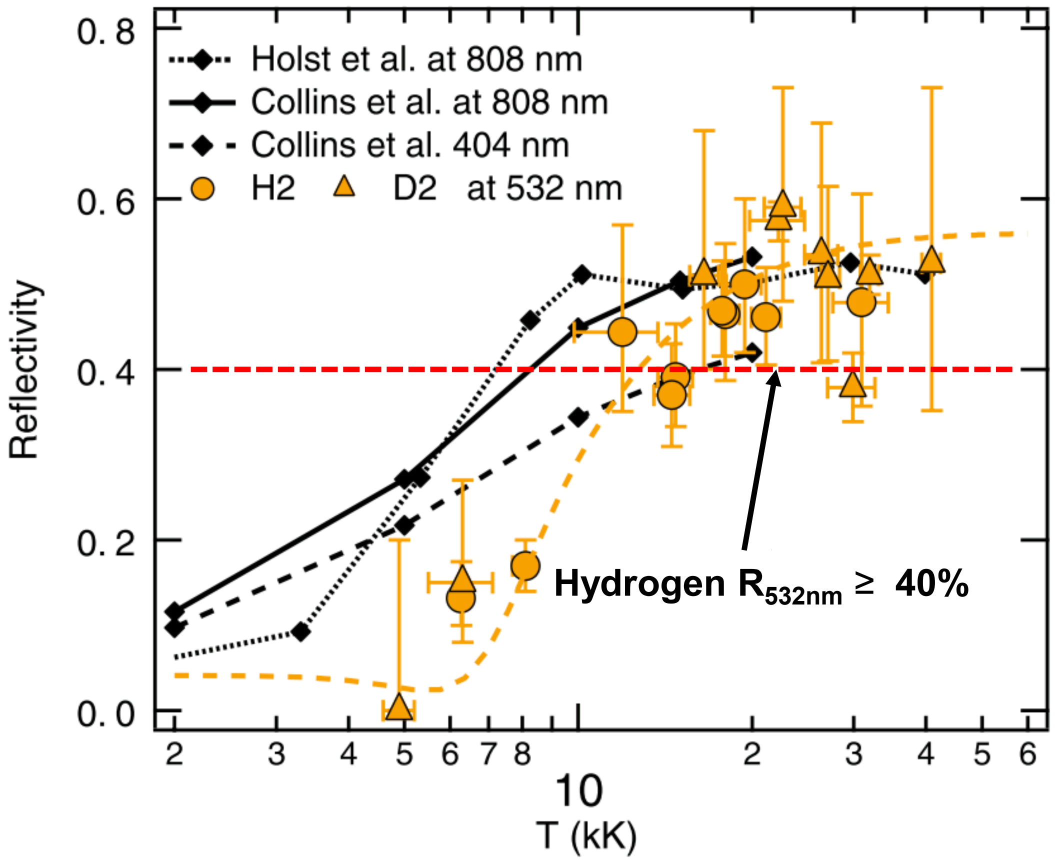

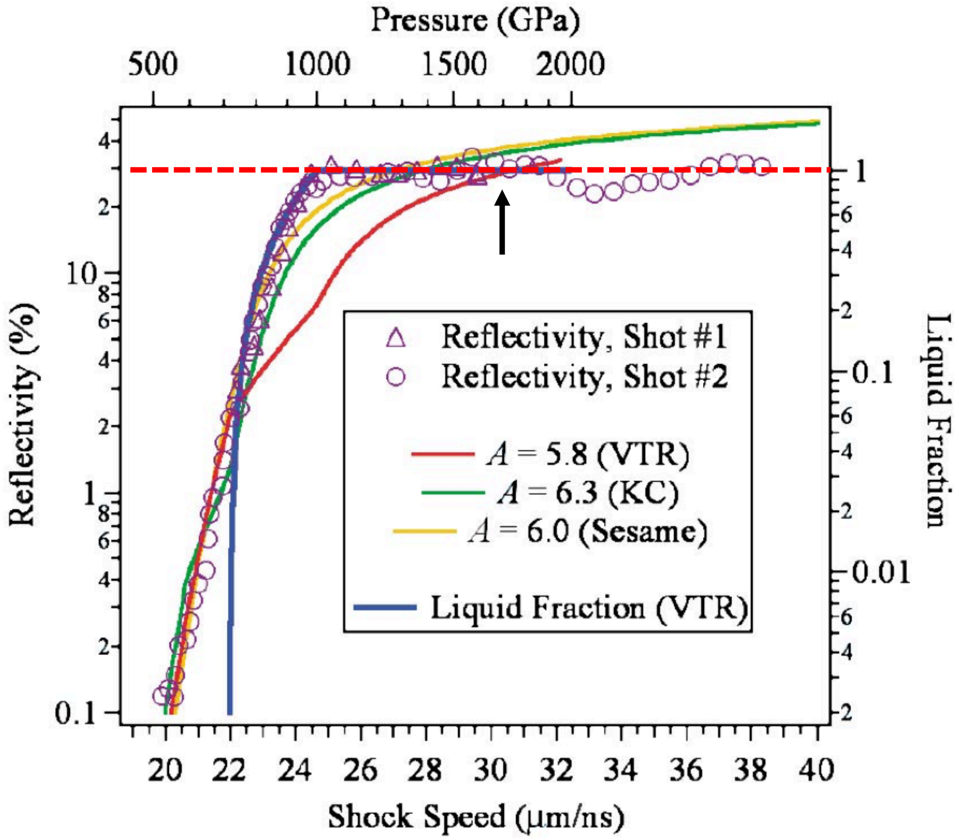

D. K Bradley, et al. Phys. Rev. Lett. **93**, 195506

Loubeyre, Brygoo et al. Phys. Review B 86, 144115 (2012) Extended

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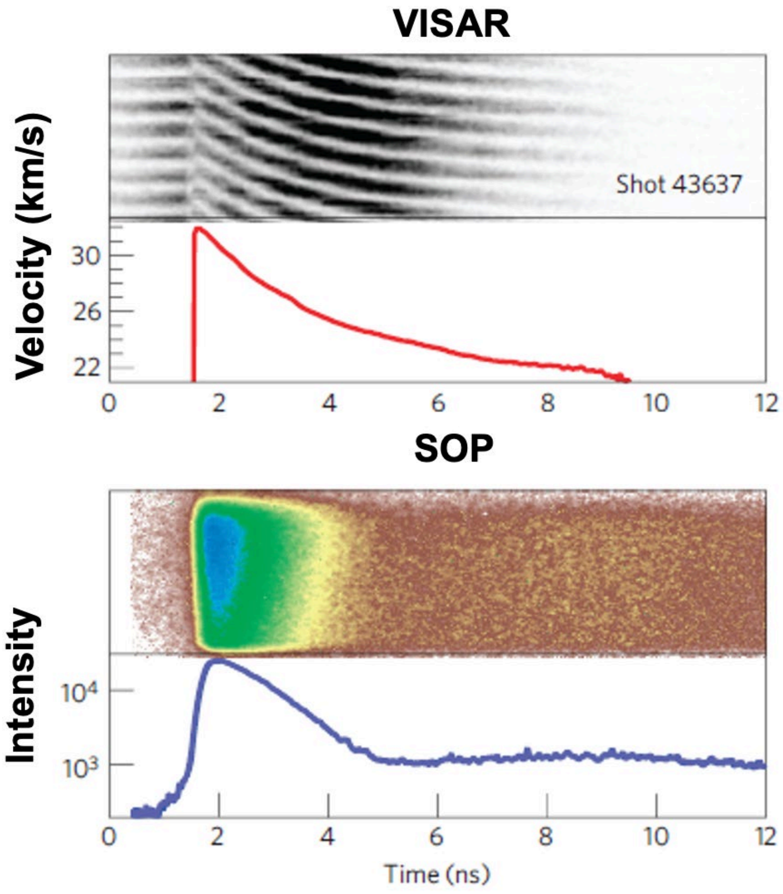
BACKUP SLIDE

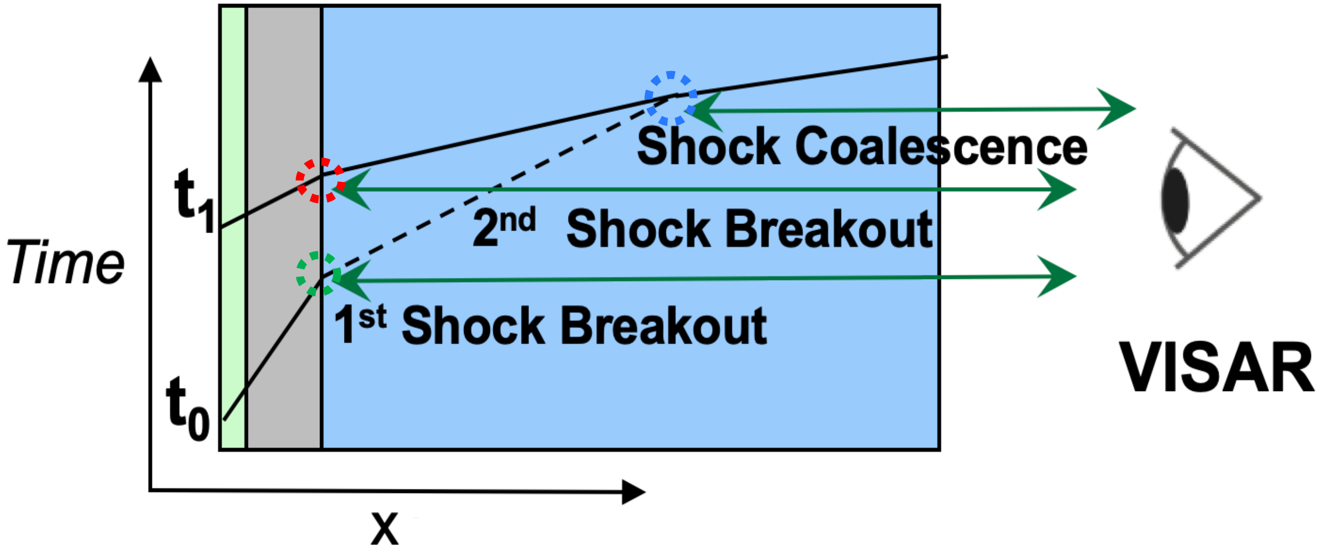
The VISAR/SOP system is the principal diagnostic for HEDP shock experiments

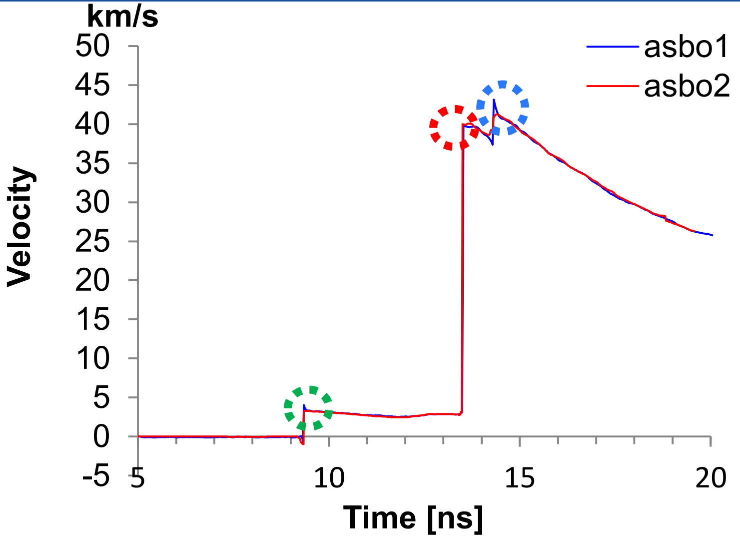


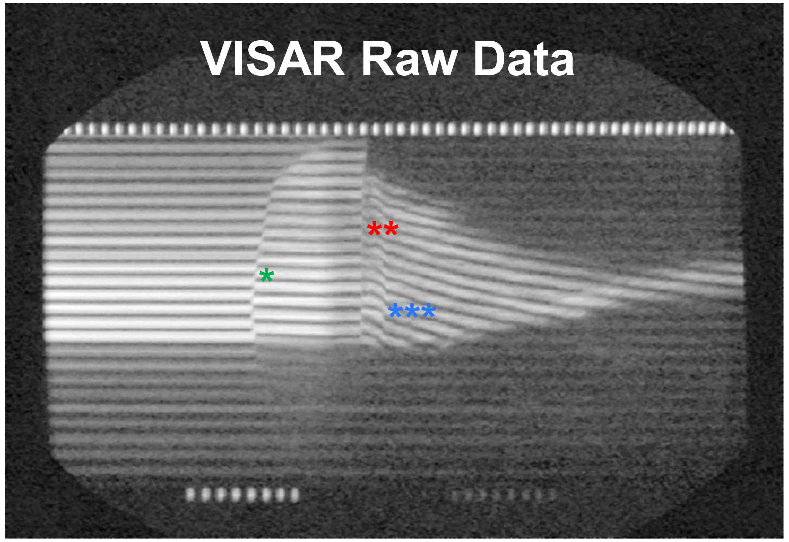
***Velocity interferometer for any reflector**
****Streaked Optical Pyrometer**

- The VISAR diagnostic tracks changes in the velocity of reflective surfaces (free surfaces, interfaces, and strong shocks)
- The SOP diagnostic measures the self-emission of shock surfaces which allows us to measure temperature

Double-shock experiments require a carefully tailored sequence of two shocks





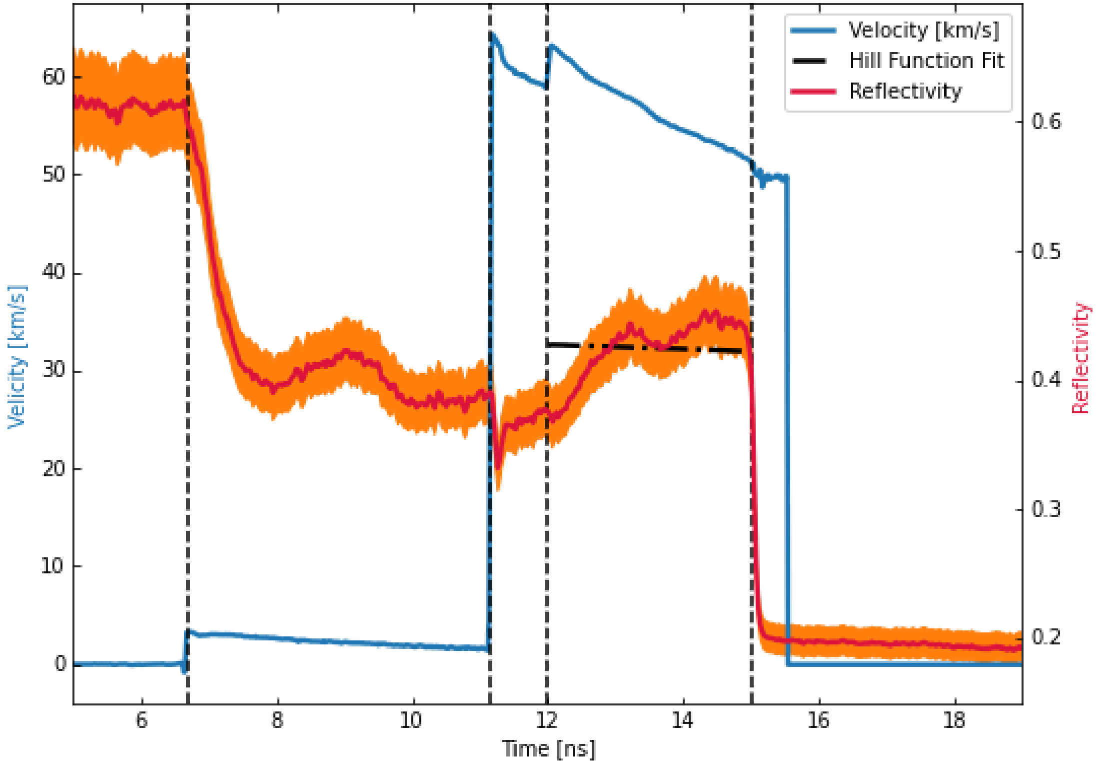


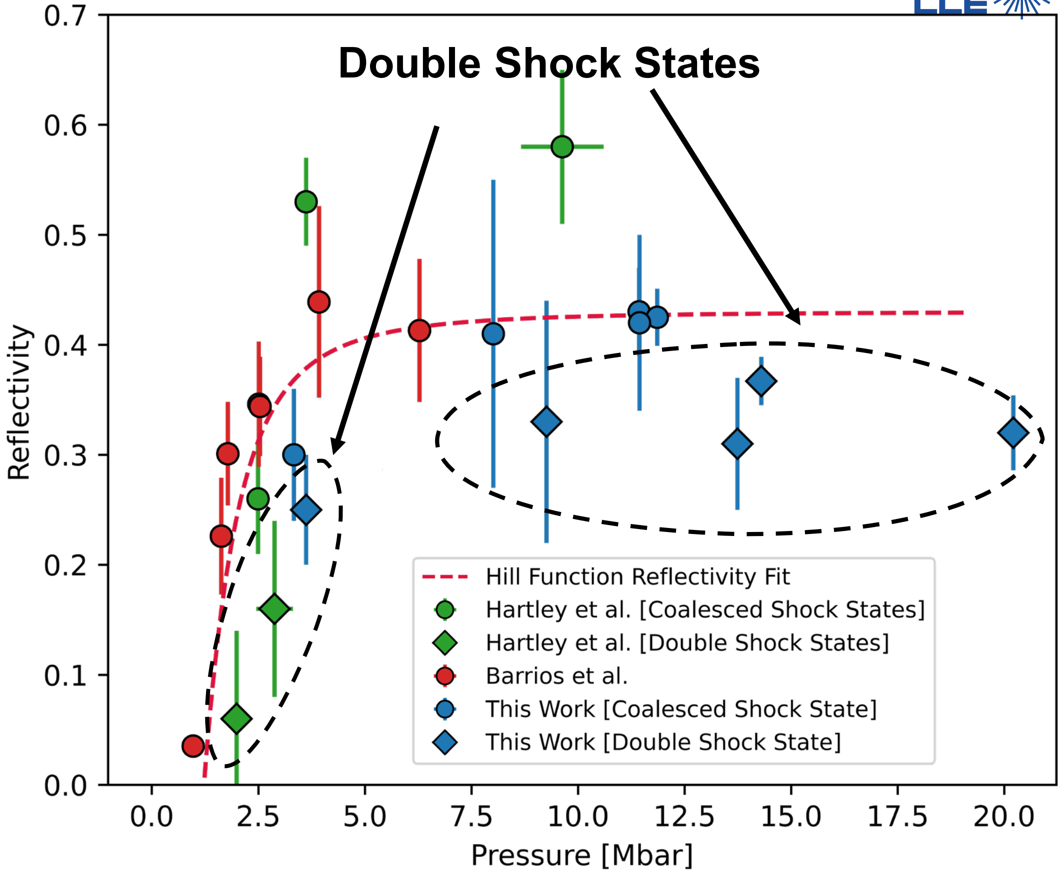
Typical laser pulses are pairs of ~1 ns square pulses separated by some time τ

Rygg 2010 - Unpublished

BACKUP SLIDE

A Hill Function was fit to existing Reflectivity Data for CH and used to calibrate the VISAR intensity





- We obtain measurements for the reflectivity of the double and coalesced shocks by averaging the calibrated VISAR signal in each respective region of interest

BACKUP SLIDE

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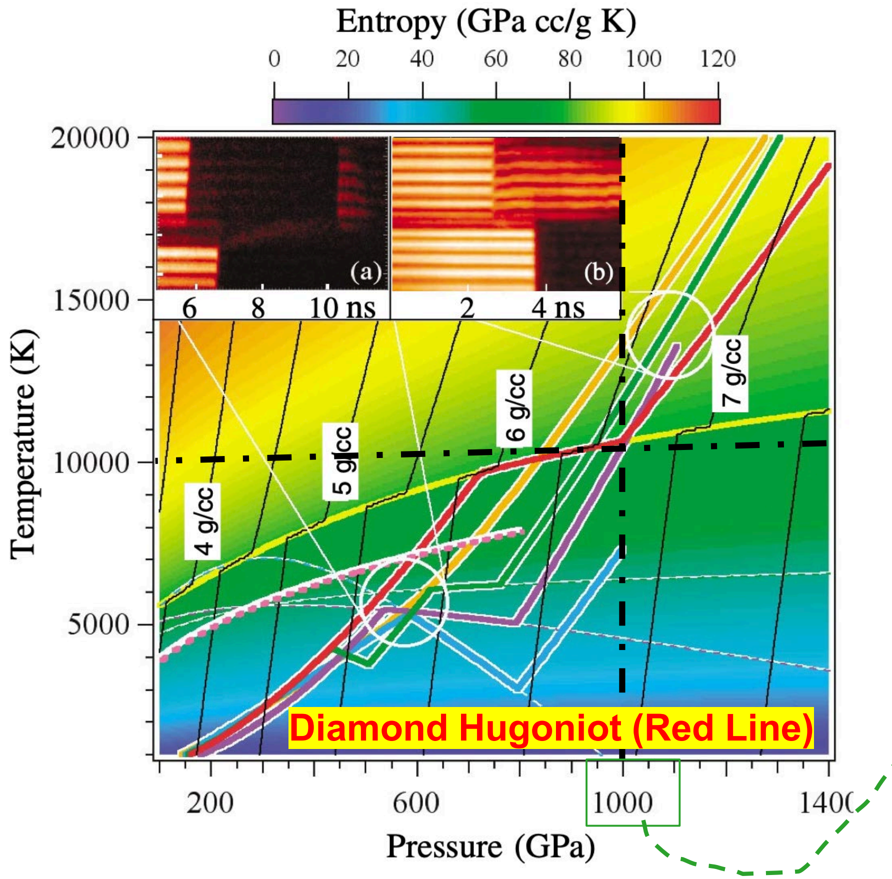

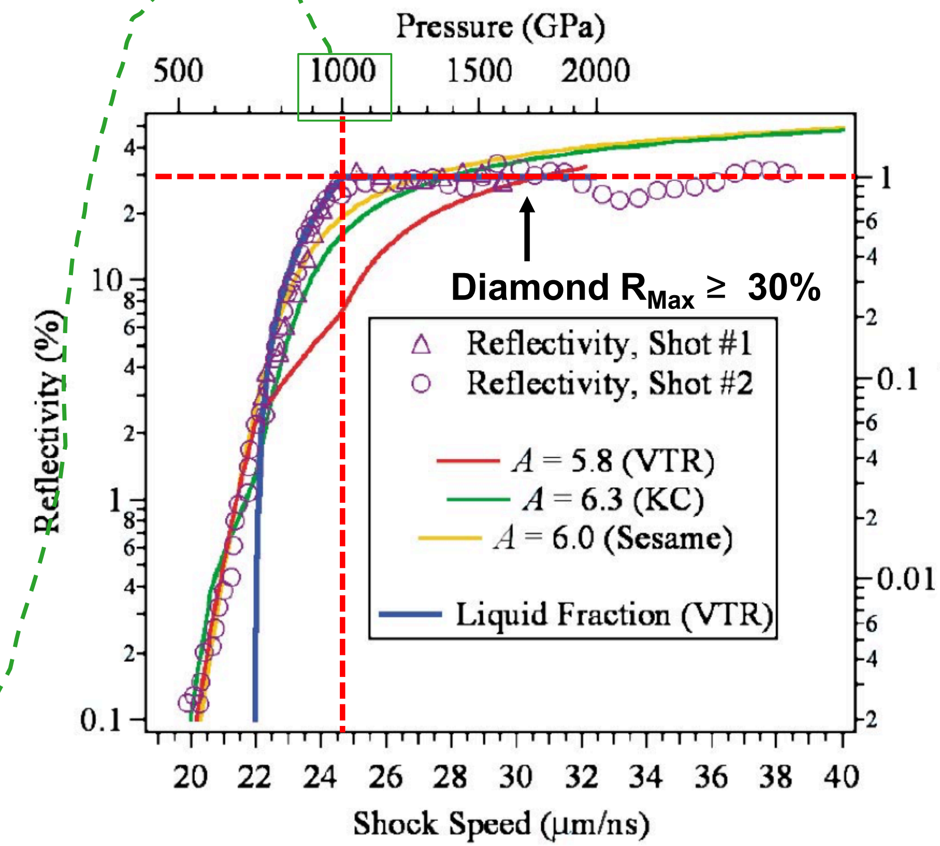

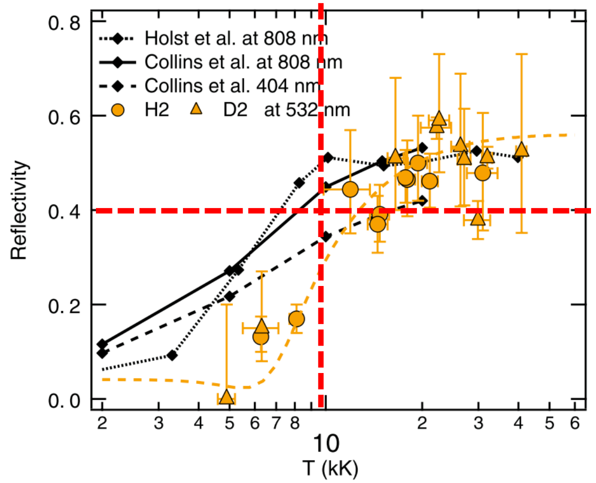

Bradley et al. 2010

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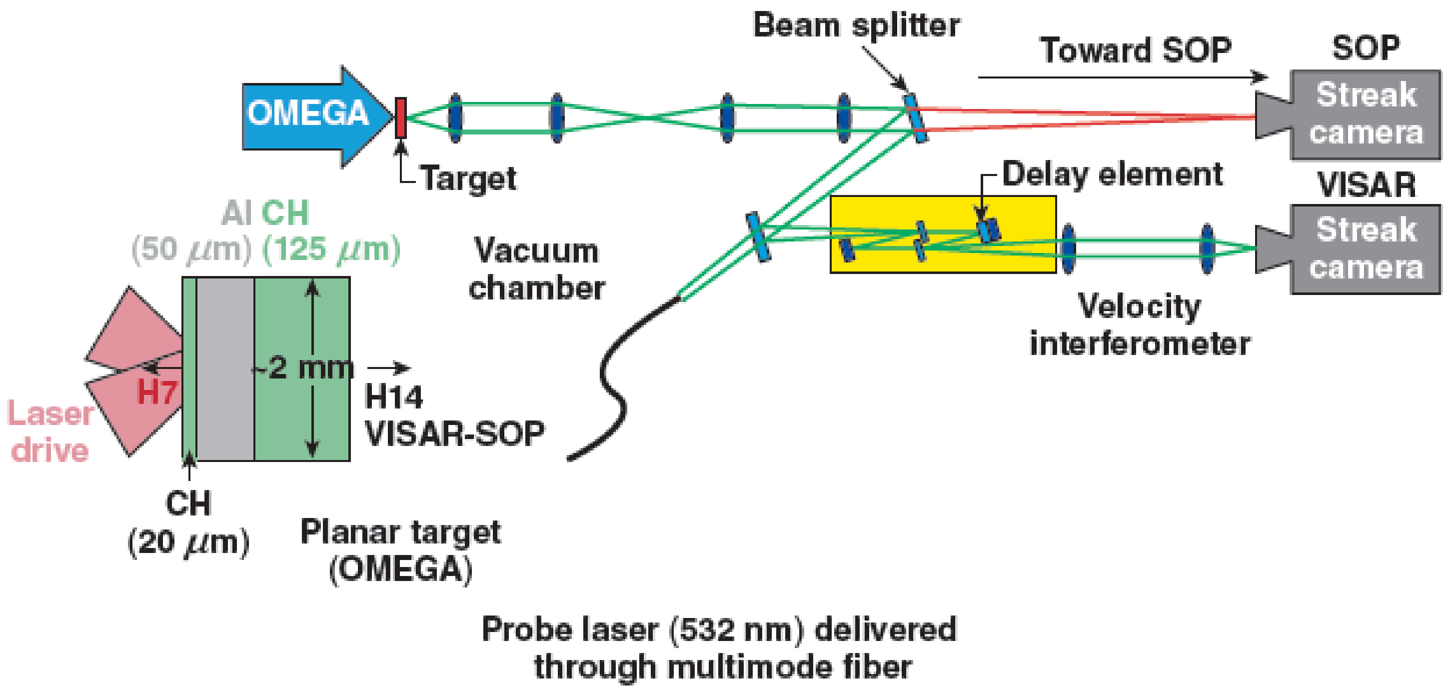

- VISAR (Velocity Interferometer for Any Reflector) tracks changes in the velocity of reflective surfaces
- SOP (streaked optical pyrometer) measures the self-emission of shock surfaces
- Modeling the shock surface as a grey body allows us to obtain a measurement for temperature

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Double-shock (P_2,ρ_2) state is determined by a self-impedance matching technique

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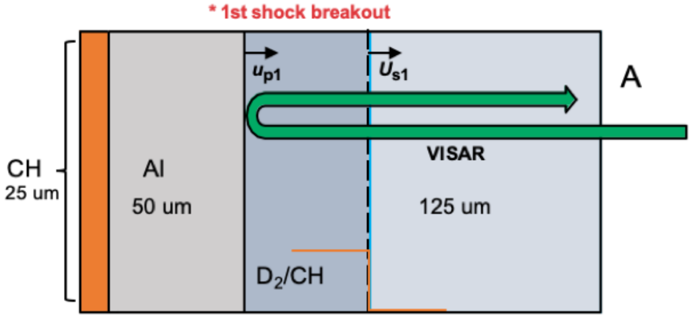

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Guargaglini et al. Phys. Plasmas 26, 042704 (2019)

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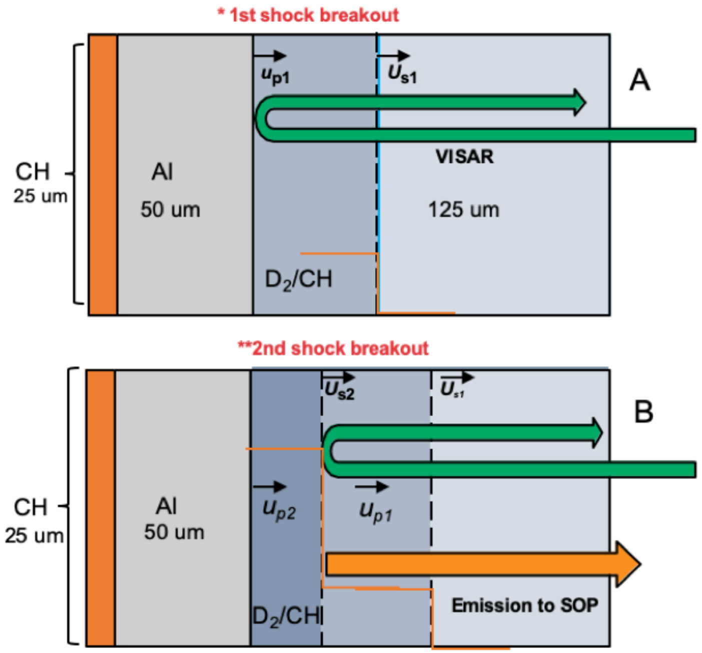

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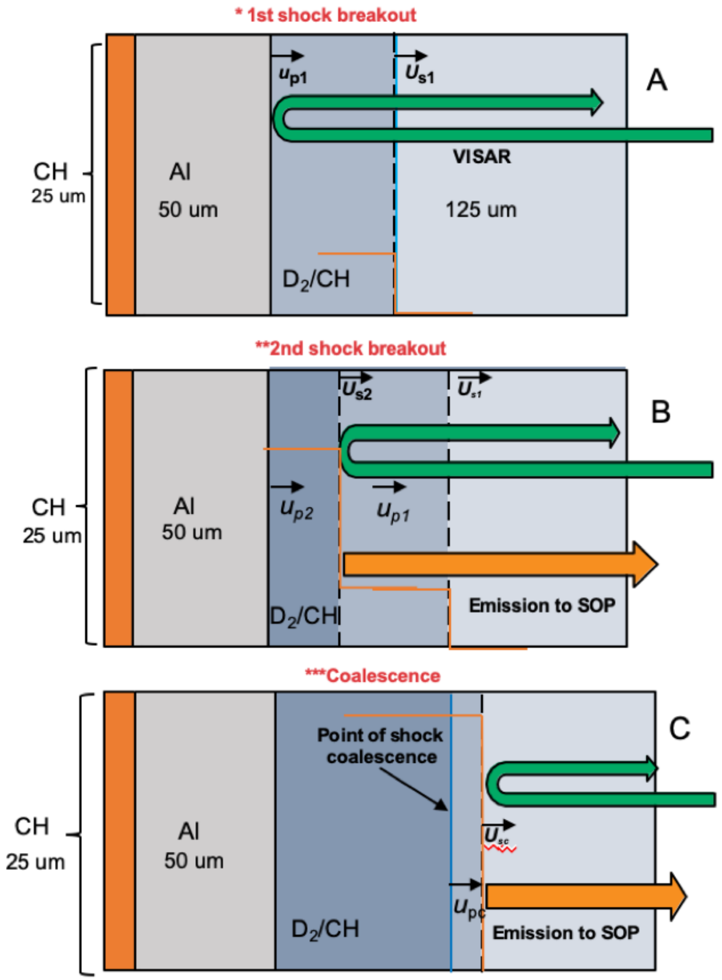

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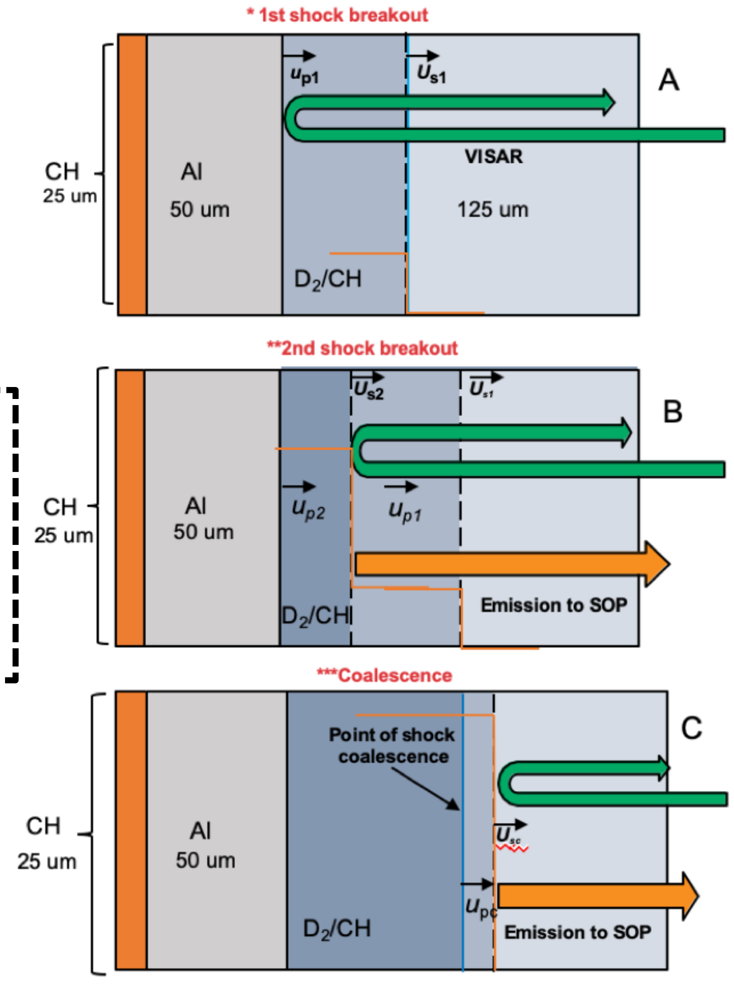
$$P = \rho_0 U_{s1} \boxed{u_{p1}}$$

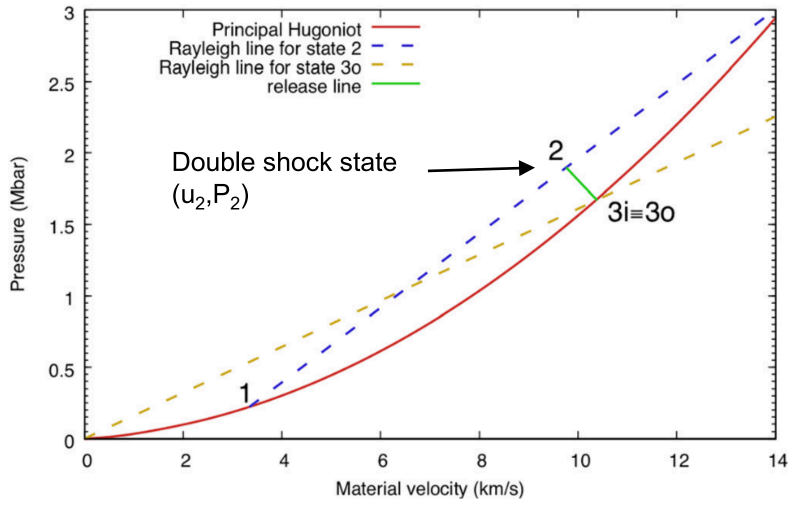
$$\frac{\rho_2}{\rho_1} = \frac{\boxed{U_{s2}} - u_{p1}}{\boxed{U_{s2}} - u_{p2}}$$

$$P(u_p) = P_1 + \rho_1 (\boxed{U_{s2}} - \boxed{u_{p1}})(u_p - \boxed{u_{p1}})$$

$$\frac{\rho_c}{\rho_0} = \frac{\boxed{U_{sc}}}{\boxed{U_{sc}} - u_{pc}}$$

$$P(u_p) = \rho_0 \boxed{U_{sc}} u_p$$

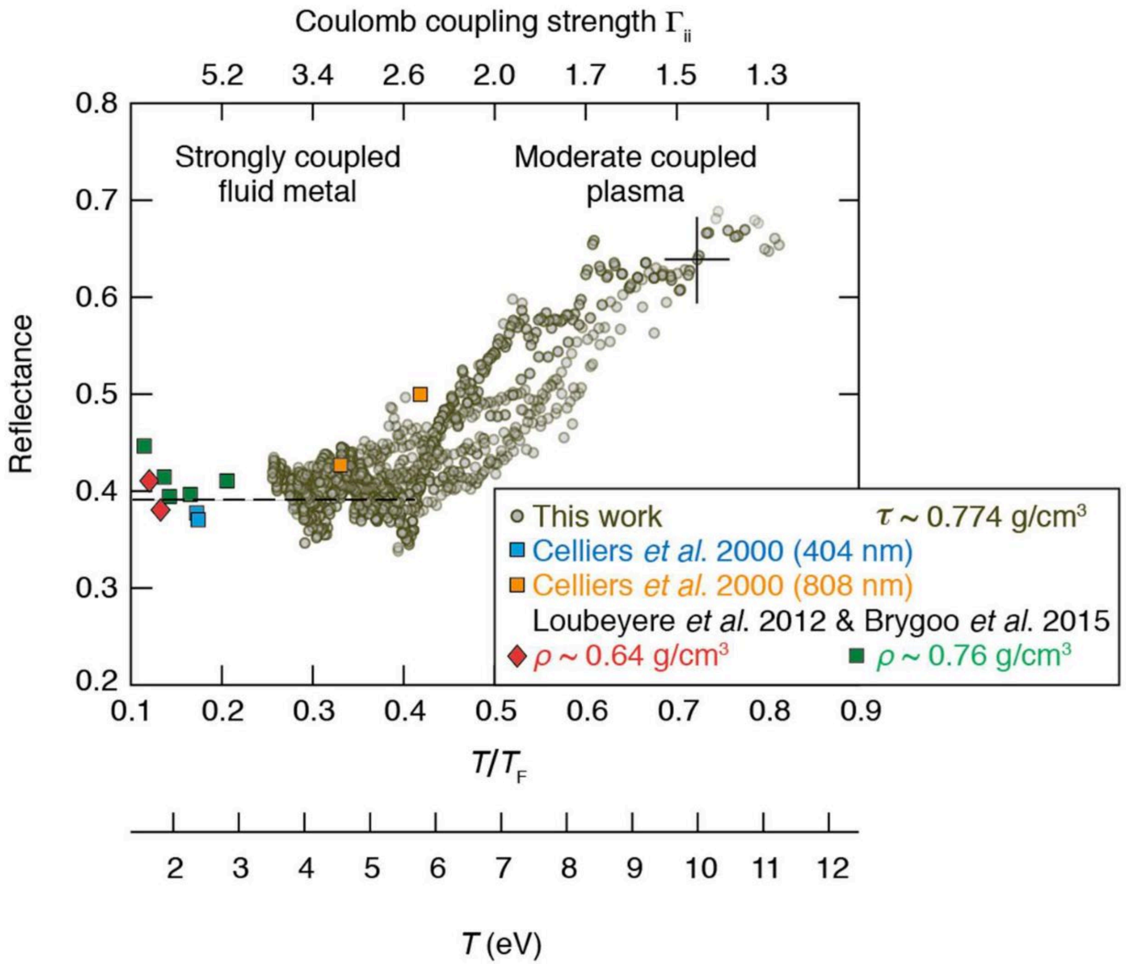




We perform the self-impedance matching method in the $P(U_p)$ plane to obtain (u_2,P_2), the double-shock state

Guargaglini et al. Phys. Plasmas 26, 042704 (2019)

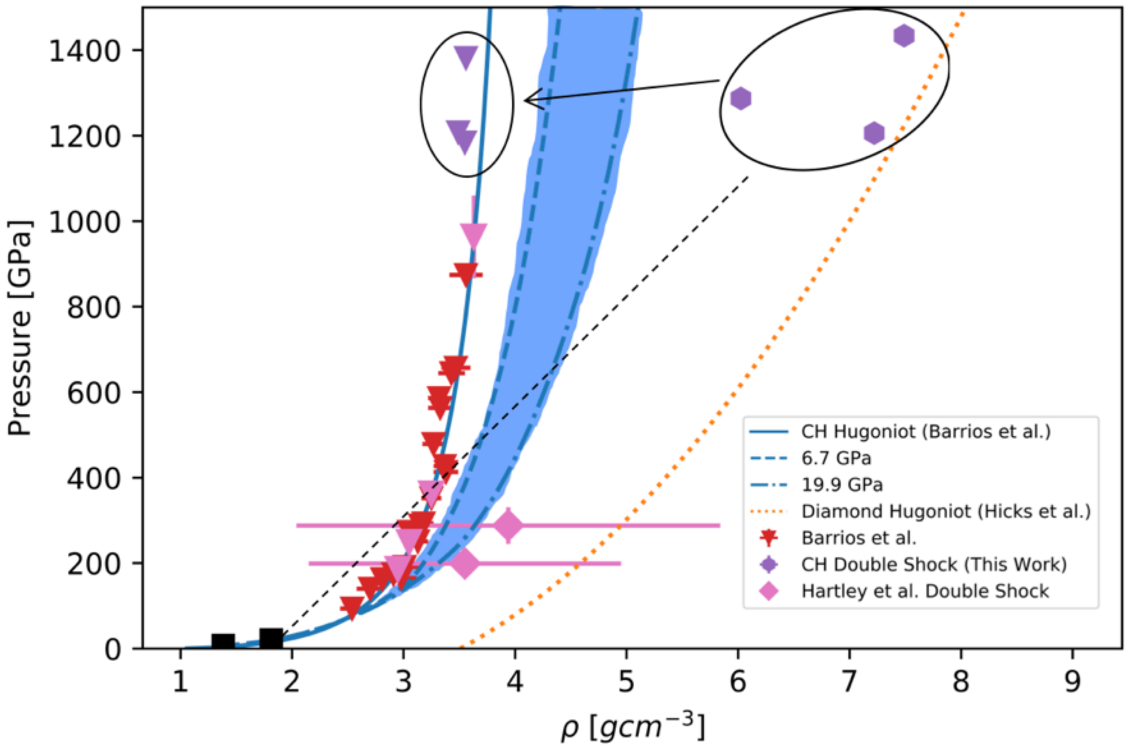
- A recent study in D_2 has shown the transition from a fermi-degenerate state to a classical plasm to occur at $T/T_F \sim 0.4$
- Double-shock method will allow us to measure this transition at higher densities



BACKUP SLIDE

Does the deviation from predicted off-Hugoniot (P_2,ρ_2) persist at lower pressures?

- Fill in more double-shock data points in lower pressure-density
- Refine technique and constrain error on data points.
- Compare our data to more and newer EOS models.



Celliers et al. Science 17 Aug 2018