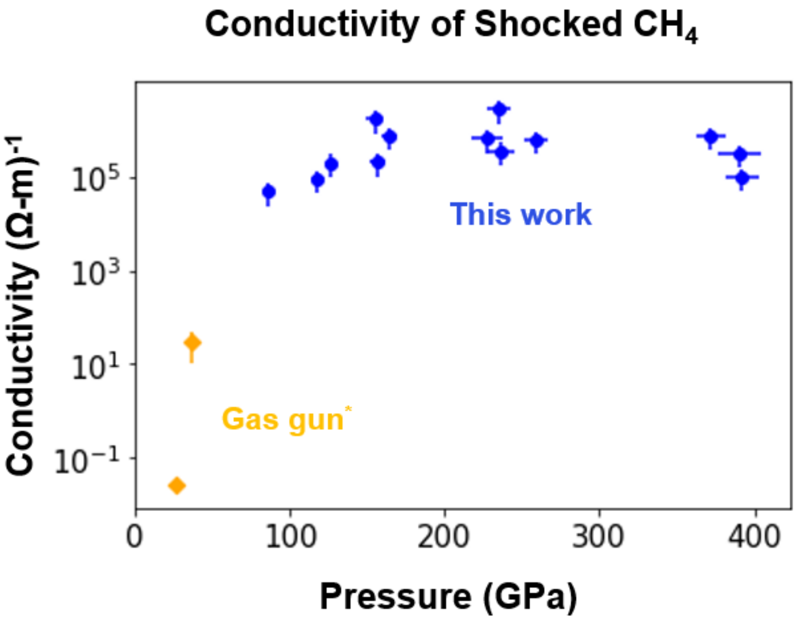
Equation of State and Metallization of Methane Shock-Compressed to 400 GPa



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Laboratory for Laser Energetics

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We present Hugoniot EOS and conductivity data on methane to 400 GPa

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- Methane is a major constituent of icy giant planets; its high-pressure behavior is important to evolutionary models
- Methane samples were precompressed in diamond-anvil cells to a range of initial densities (0.4-0.6 g/cc) and then shocked using the OMEGA* and GEKKO XII** laser facilities
- The compressibility of shocked methane changes at ~50-100 GPa
- We observed an insulator-conductor transition at the same conditions

* Laboratory for Laser Energetics, University of Rochester, Rochester, NY
** Osaka University, Osaka, Japan

Coauthors

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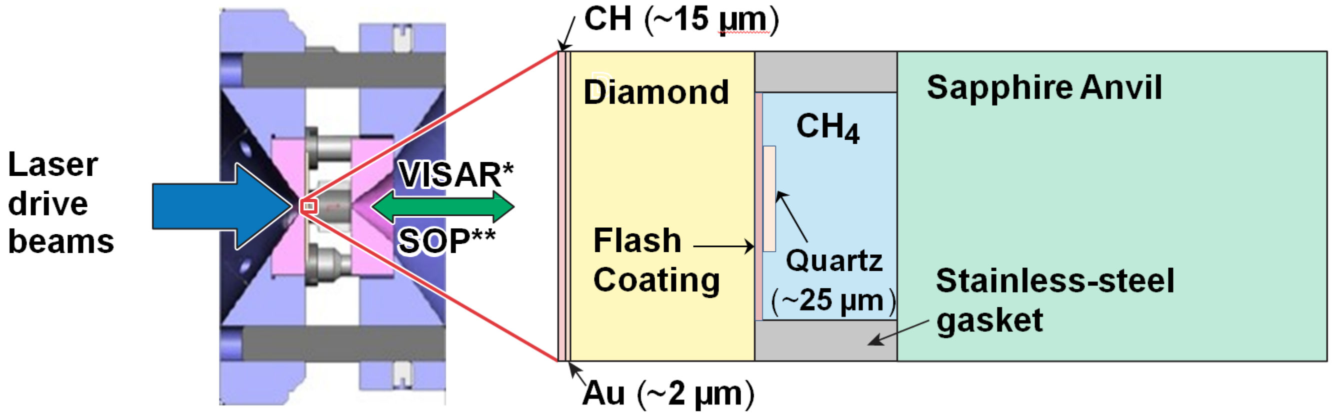
[6]University of California, Berkeley

[7]Swinburne University of Technology

Methane samples were precompressed in diamond-anvil cells (DAC's) and shocked at the OMEGA and GEKKO XII laser facilities

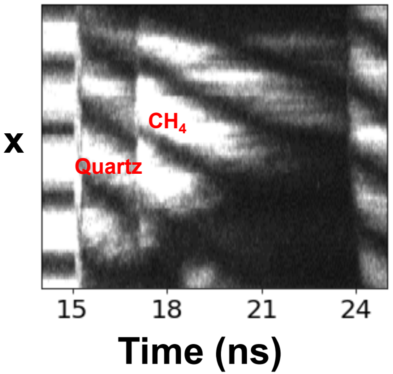


- CH4 was precompressed to 0.3-1 GPa, corresponding to initial densities of 0.4-0.6 g/cc
- Shock velocity, reflectivity, and self-emission were measured using the velocity interferometer system for any reflector (VISAR*) and streak optical pyrometry (SOP**)
- Quartz was used as a material standard for the Hugoniot and temperature measurements

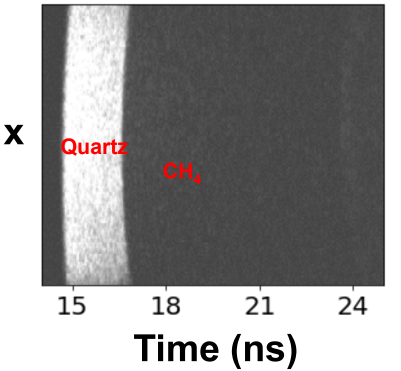
* Velocity Interferometry System for Any Reflector
** Streak Optical Pyrometry

VISAR and SOP simultaneously measured the shock velocity and self-emission of the target, respectively

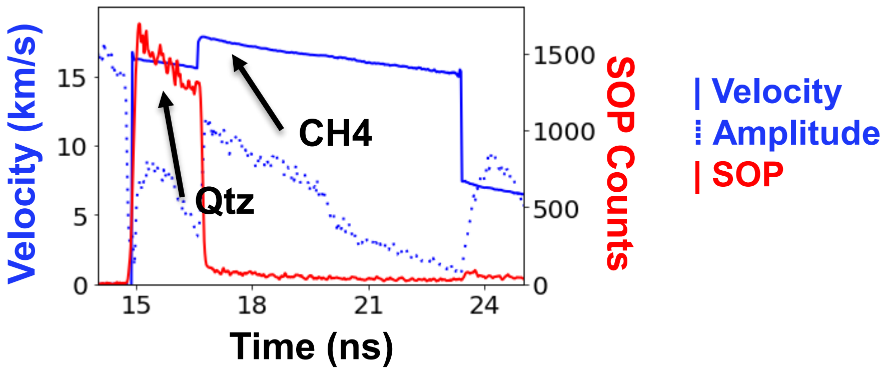
VISAR* Streak Record



SOP** Streak Record



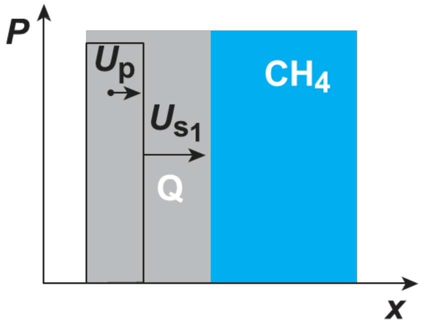
Combined VISAR and SOP plots

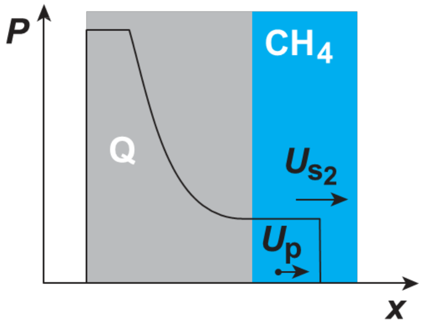


- EOS is derived from shock velocities in quartz and methane via impedance matching
- Methane self-emission is referenced to quartz for temperature measurements
- VISAR fringe amplitude provides the reflectivity (referenced to quartz) and this is used to model both quartz and methane as a gray-body

* Velocity Interferometry System for Any Reflector
** Streak Optical Pyrometry

The impedance-matching method relies on the shock and release behaviors of a known standard





Rankine–Hugoniot equations

$$\frac{\rho}{\rho_0} = \frac{U_s}{U_s - U_p}$$

$$P - P_0 = \rho_0 U_s U_p$$

$$E - E_0 = \frac{1}{2}(P + P_0)\left({}^{1}/_{\rho_0} - {}^{1}/_{\rho}\right)$$

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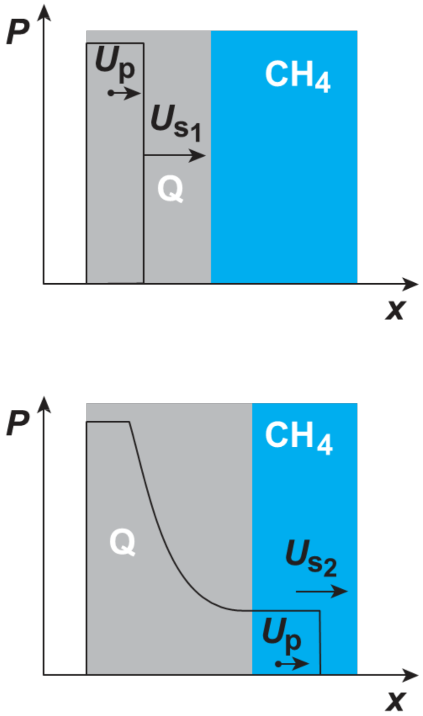

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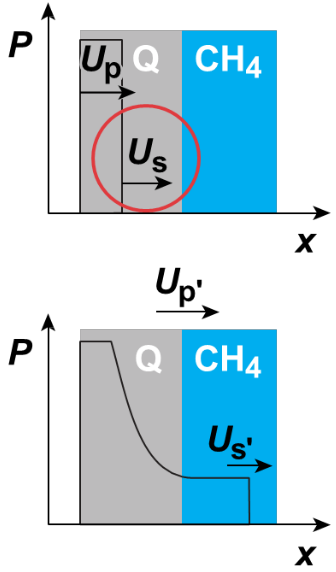
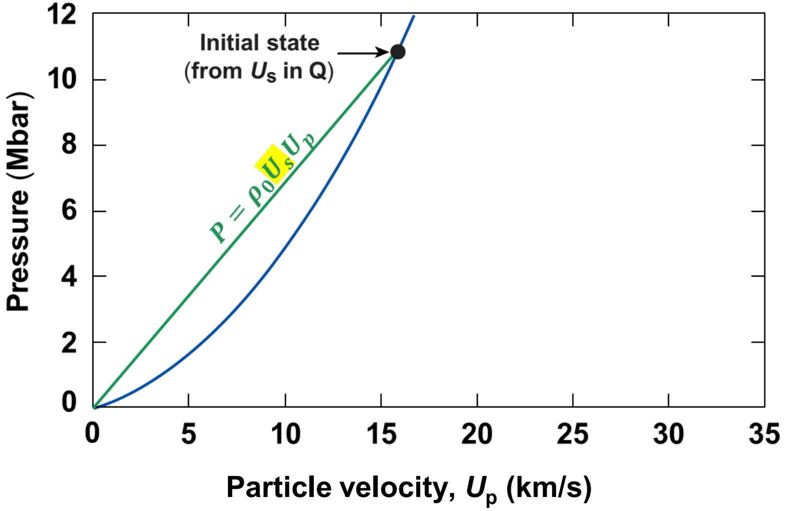
Equation-of-state data are obtained from the impedance-matching technique





S. Brygoo *et al.*, J. Appl. Phys. 118, 195901 (2015).
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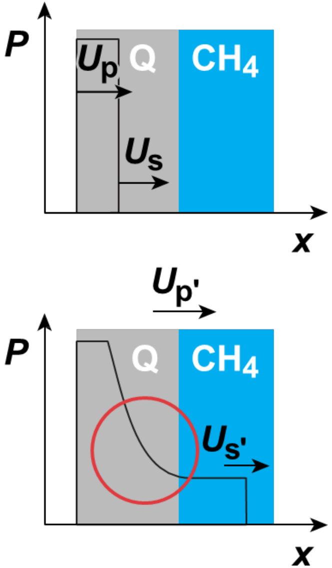

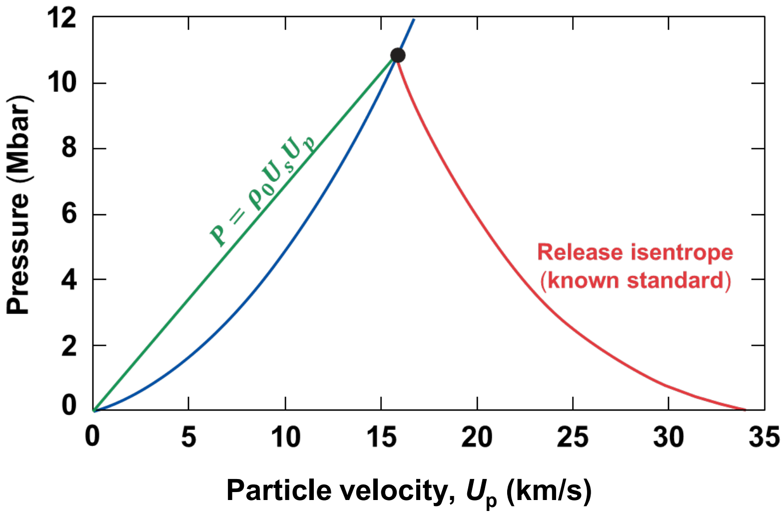

Mie–Grüneisen linear reference model

$$P_S - P_H = \frac{\Gamma}{V}(E_S - E_H)$$

$$U_p = U_{p1} + \int_{P1}^{P} \frac{V dP_S}{c_S}$$

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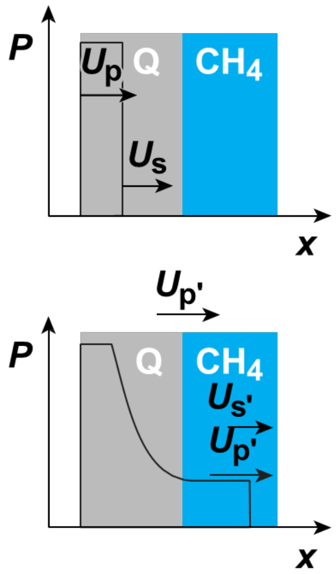

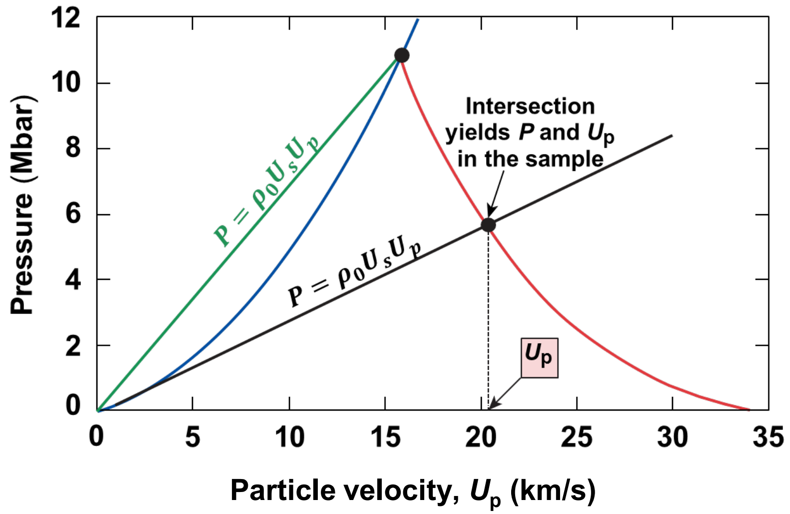

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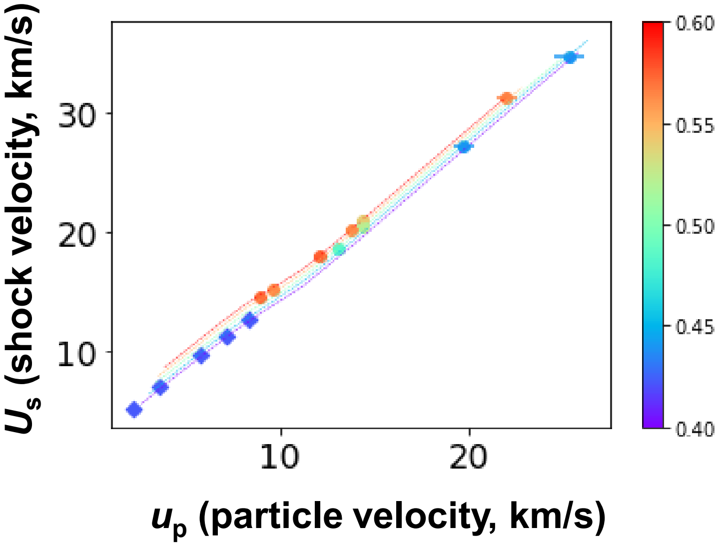
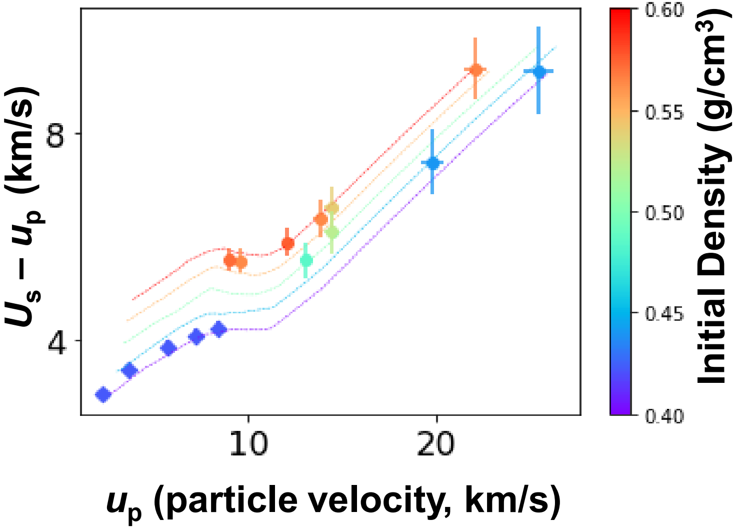
The shock and particle velocities show a change in slope at high pressures

Shock Velocity (U_s) versus Particle Velocity (u_p) in CH_4





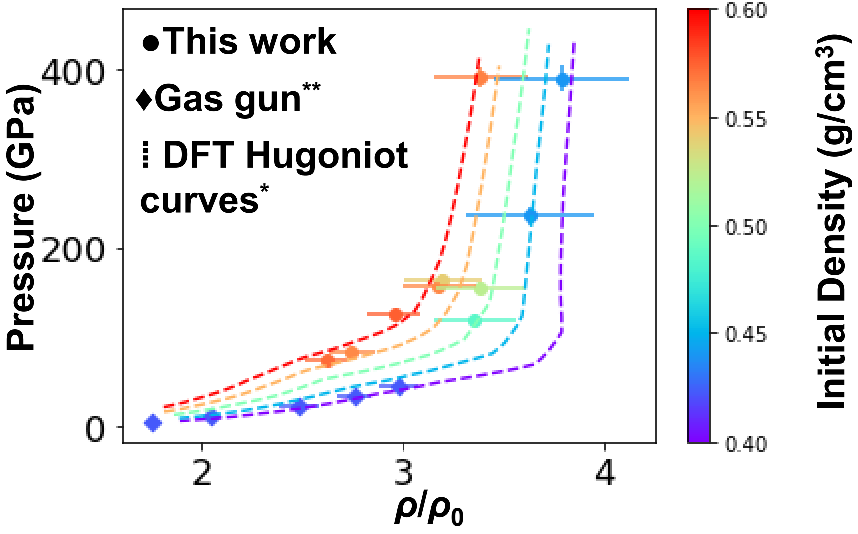
- ●This work
- ♦Gas gun**
- ⁞ DFT Hugoniot curves*

- Change in slope at U_s~15 km/s suggests a microscopic change in methane

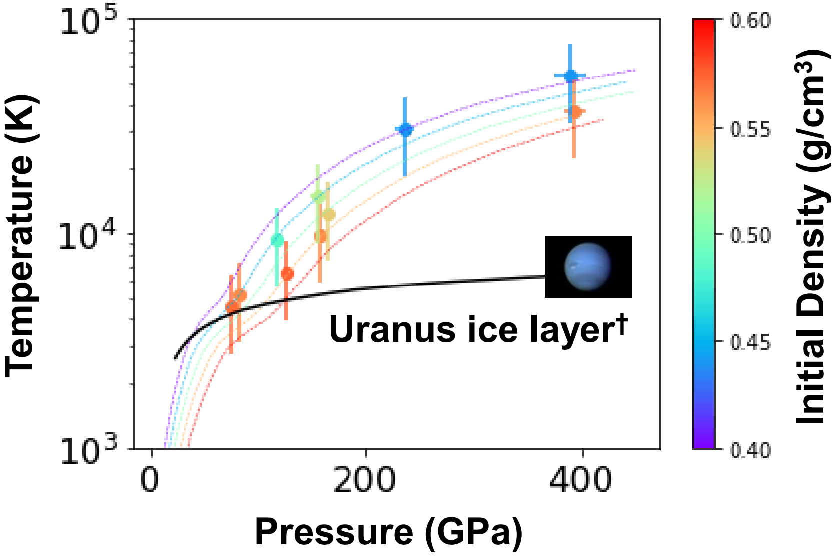
* B. L. Sherman *et al.*, Phys. Rev. B 86, 224113 (2012).
** W. J. Nellis *et al.*, J. Chem. Phys. 75, 3055 (1981).

Pressure and temperature data reveal the compressibility and thermal response of shocked methane

Pressure versus Compression Ratio



Temperature versus Pressure



- Methane compression saturates at roughly ~100 GPa

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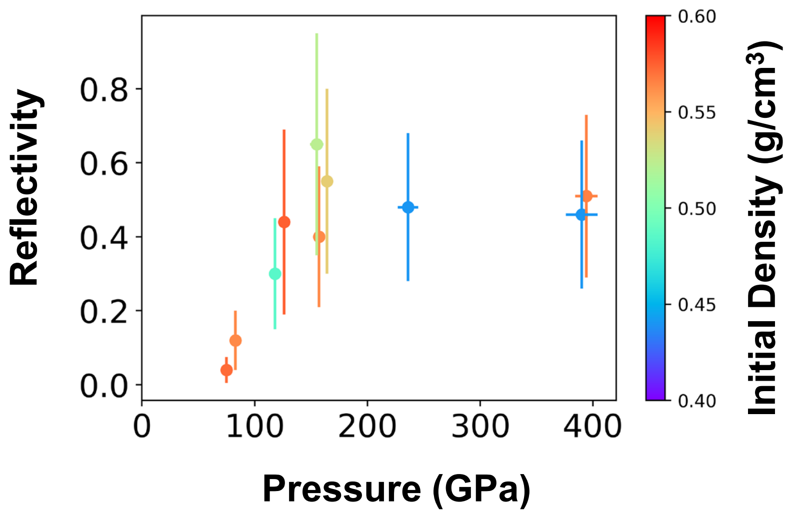
At the pressures where the compressibility changed we also observe a saturation in reflectivity

Reflectivity versus Pressure in Shocked CH_4



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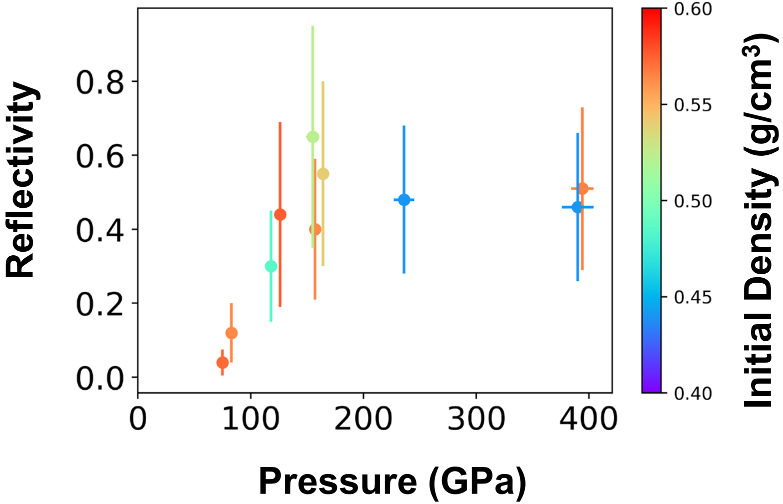
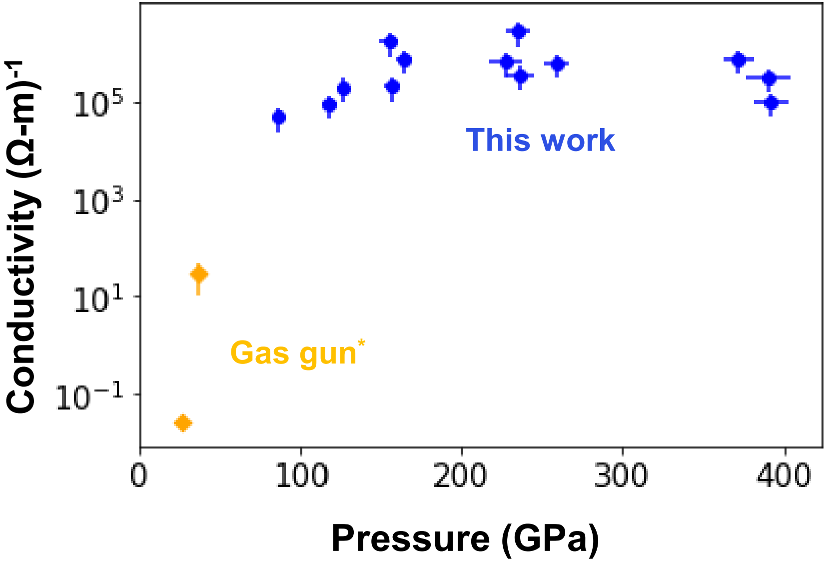


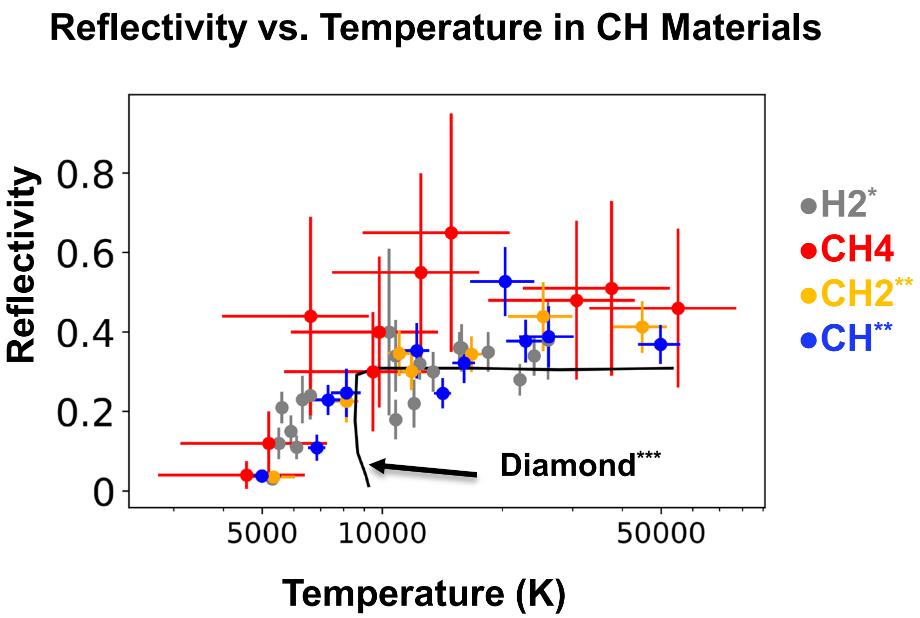
Conductivity of Shocked CH_4



- There is an insulator-conductor transition at ~50-100 GPa

* W. J. Nellis *et al.*, J. Chem. Phys. 115, 1015 (2001).

Hydrogen and CH compounds experience reflectivity onset at roughly the same temperatures



- The conductivity onset in CH materials appears to be temperature activated

* S. Brygoo *et al.*, J. Appl. Phys. 118, 195901 (2015).
** M. Barrios *et al.*, Physics of Plasmas 17, 056307 (2010).
*** J. Eggert *et al.*, Nature Physics 6, 40-43 (2010).

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