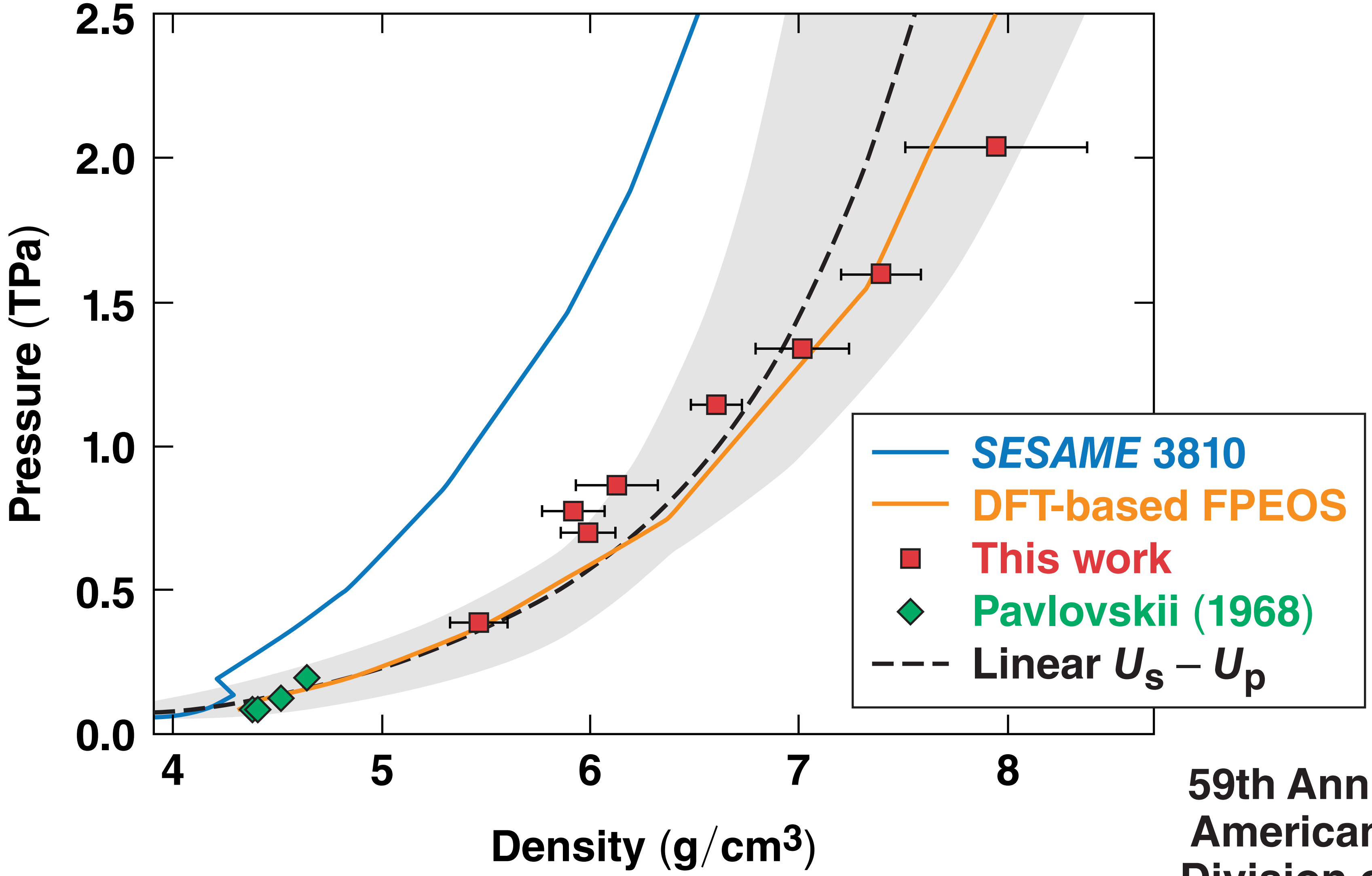
Hugoniot Measurements of Silicon Shock Compressed to 21 Mbar



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Summary

Laser-driven shocks were used to measure the silicon Hugoniot to 21 Mbar (2.1 TPa)

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- Silicon is of interest in high-energy-density (HED) physics, inertial confinement fusion (ICF) targets, geophysics, planetary science, and astrophysics
- First-principles calculations* predict "softer" behavior than older, widely used models
- Impedance matching was used to measure pressure and density in opaque silicon
- Our data indicates silicon is more compressible than predicted by *SESAME* 3810
- Results show limited agreement with density functional theory above 5 Mbar

*S. X. Hu *et al*., Phys. Rev. B 94, 094109 (2016).

Collaborators

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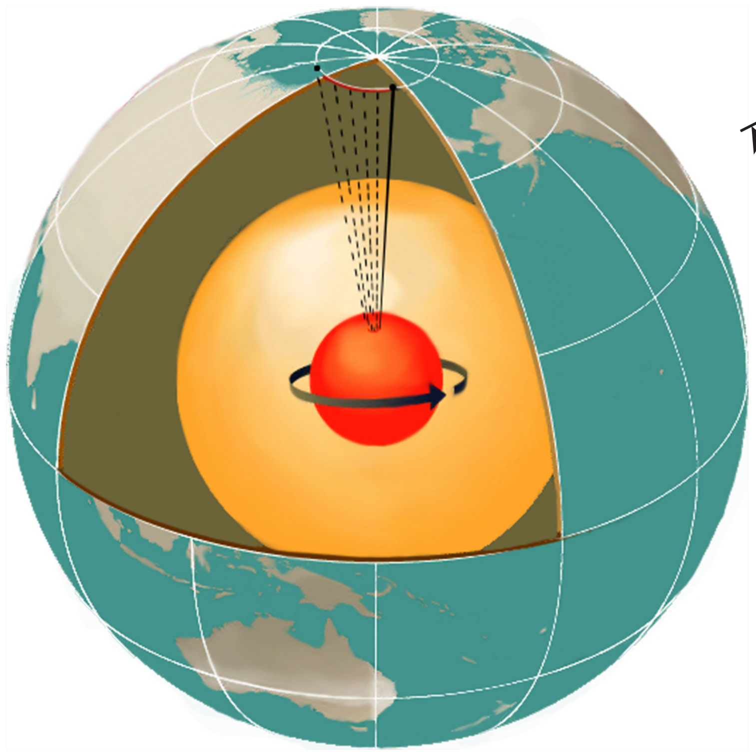
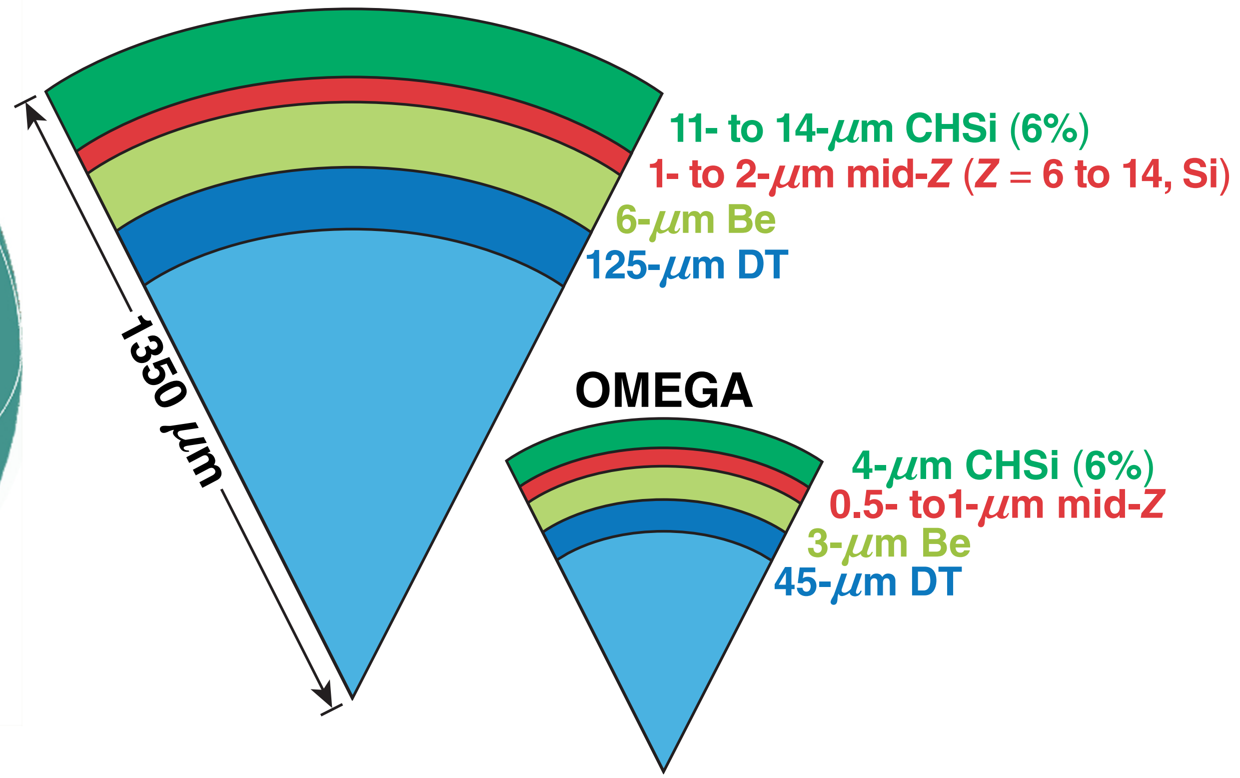
Silicon is important to HED physics, such as planetary science and ICF capsules

- The high-pressure silicon equation of state (EOS) is crucial to understanding the dynamics of silicon-rich planets (i.e., earth)
- Silicon is used in ICF capsules to reduce fuel preheat and laser–plasma instability (LPI) effects

Planetary science*



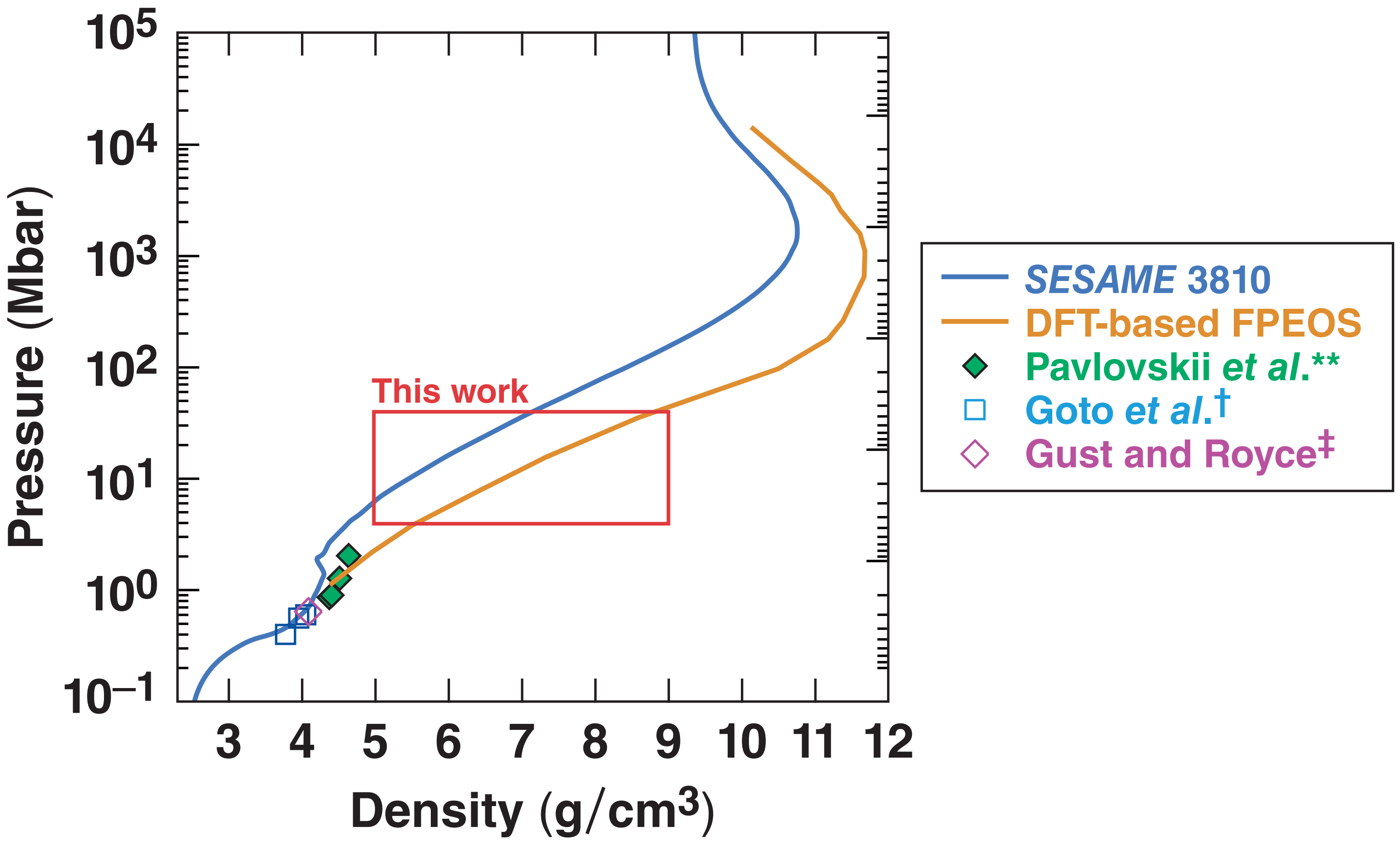
ICF capsule**



*http://www.nasa.gov/sites/default/files/images/607068main_world-unlabeled.jpg
**V. N. Goncharov *et al.*, Phys. Plasmas 21, 056315 (2014).

Modern DFT calculations are significantly different from the standard *SESAME*

- The silicon *SESAME* EOS table was constructed based on a chemical picture of matter
- Below 1 Mbar, *SESAME* 3810 was constrained by Hugoniot data from 1997
- Above 1 Mbar, it was constructed so the Hugoniot was "similar" to germanium
- The first-principles predicted shock density is ~20% higher*



DFT: density functional theory
FPEOS: first-principles equation of state

*S. X. Hu *et al.*, Phys. Rev. B 94, 094109 (2016).
**M. N. Pavlovskii, Sov. Phys.-Solid State 9, 2514 (1968).
†T. Goto, T. Sato, and Y. Syono, Jpn. J. Appl. Phys. 21, L369 (1982).
‡W. H. Gust and E. B. Royce, J. Appl. Phys. 42, 1897 (1971).

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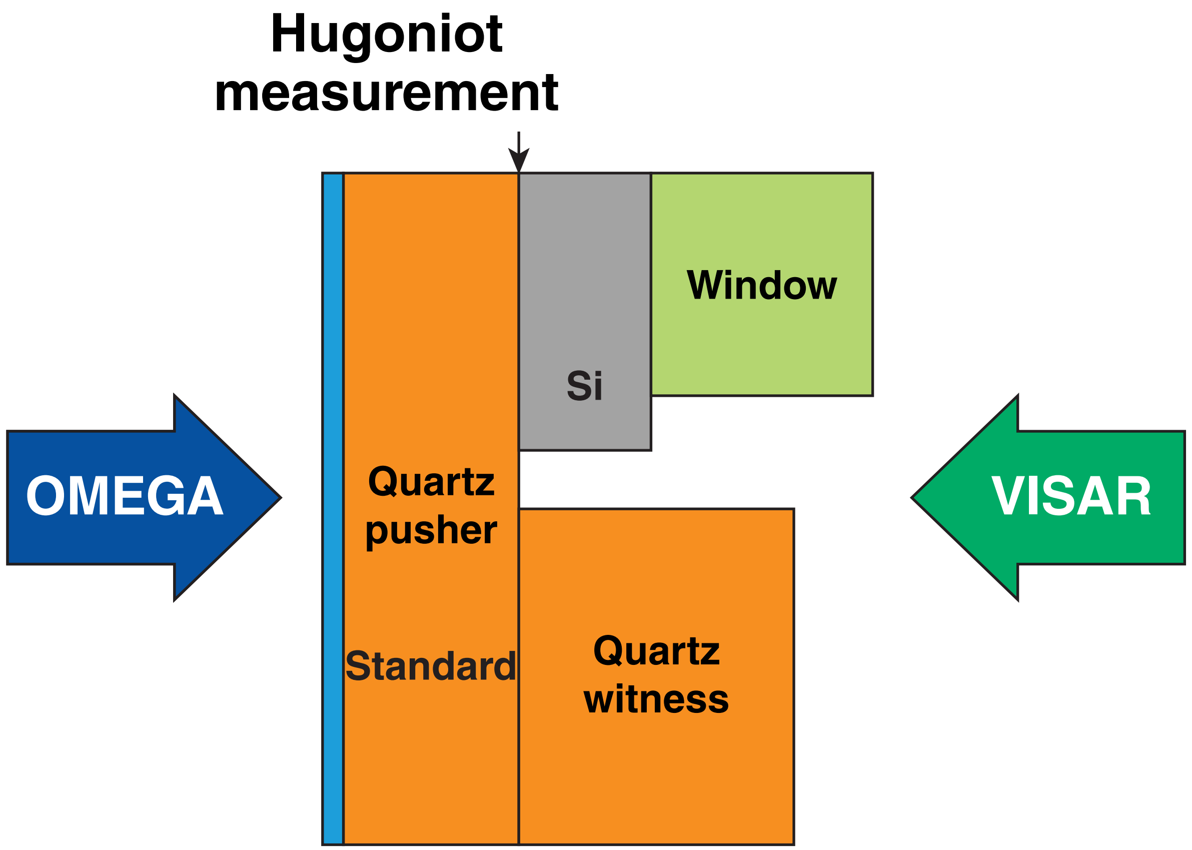
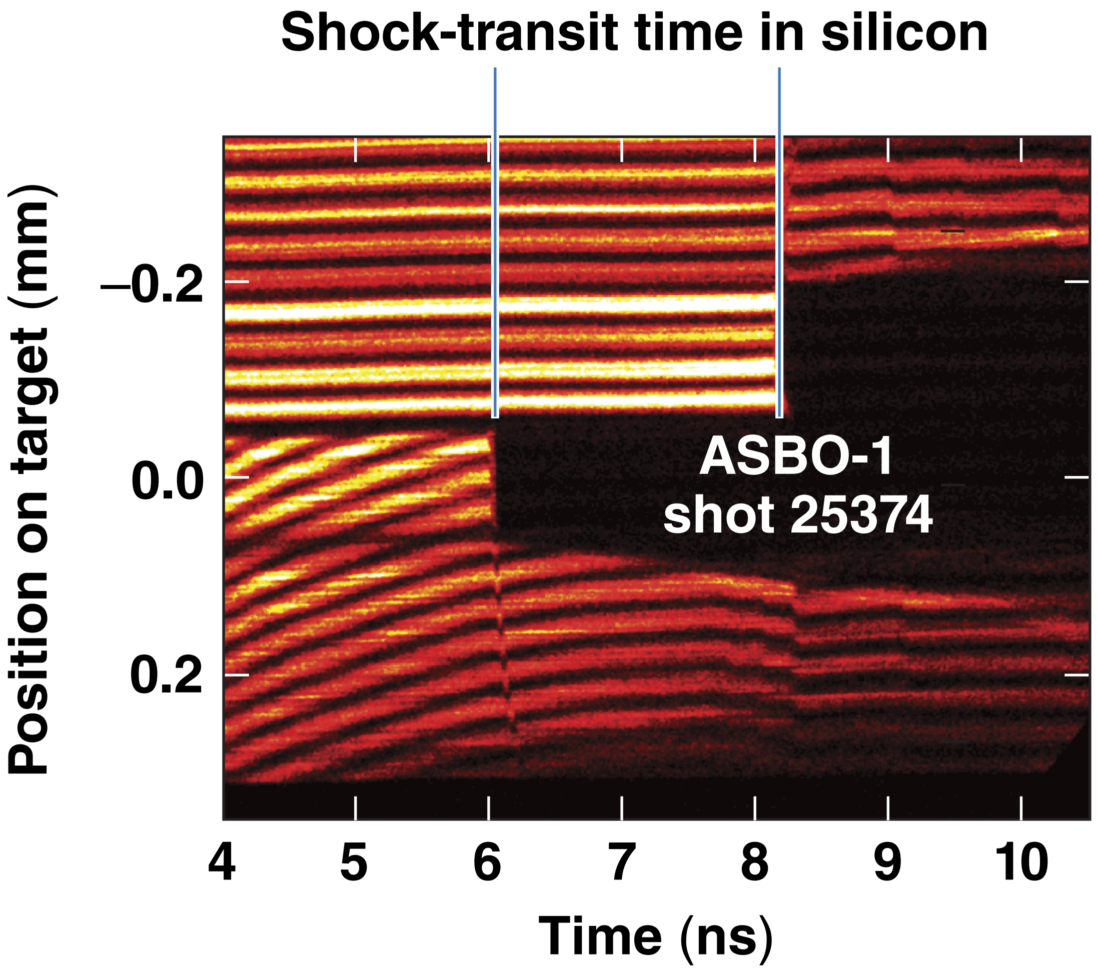
EOS measurements of opaque samples (Si) use transit times for velocity, requiring sophisticated corrections to reduce errors*



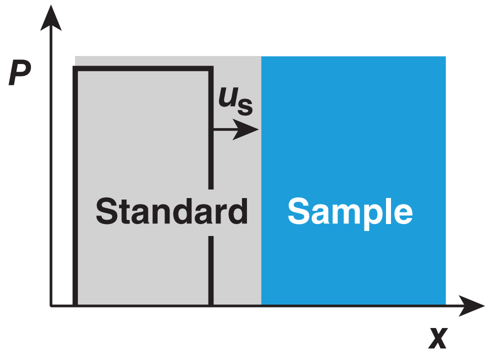


- Instantaneous shock velocities in silicon are determined using a nonsteady wave correction*

VISAR: velocity interferometer system for any reflector
ASBO: active shot breakout
*D. E. Fratanduono *et al*., J. Appl. Phys. 116, 033517 (2014).

Method

The impedance-matching technique determines the pressure and particle velocity in a sample relative to a known standard

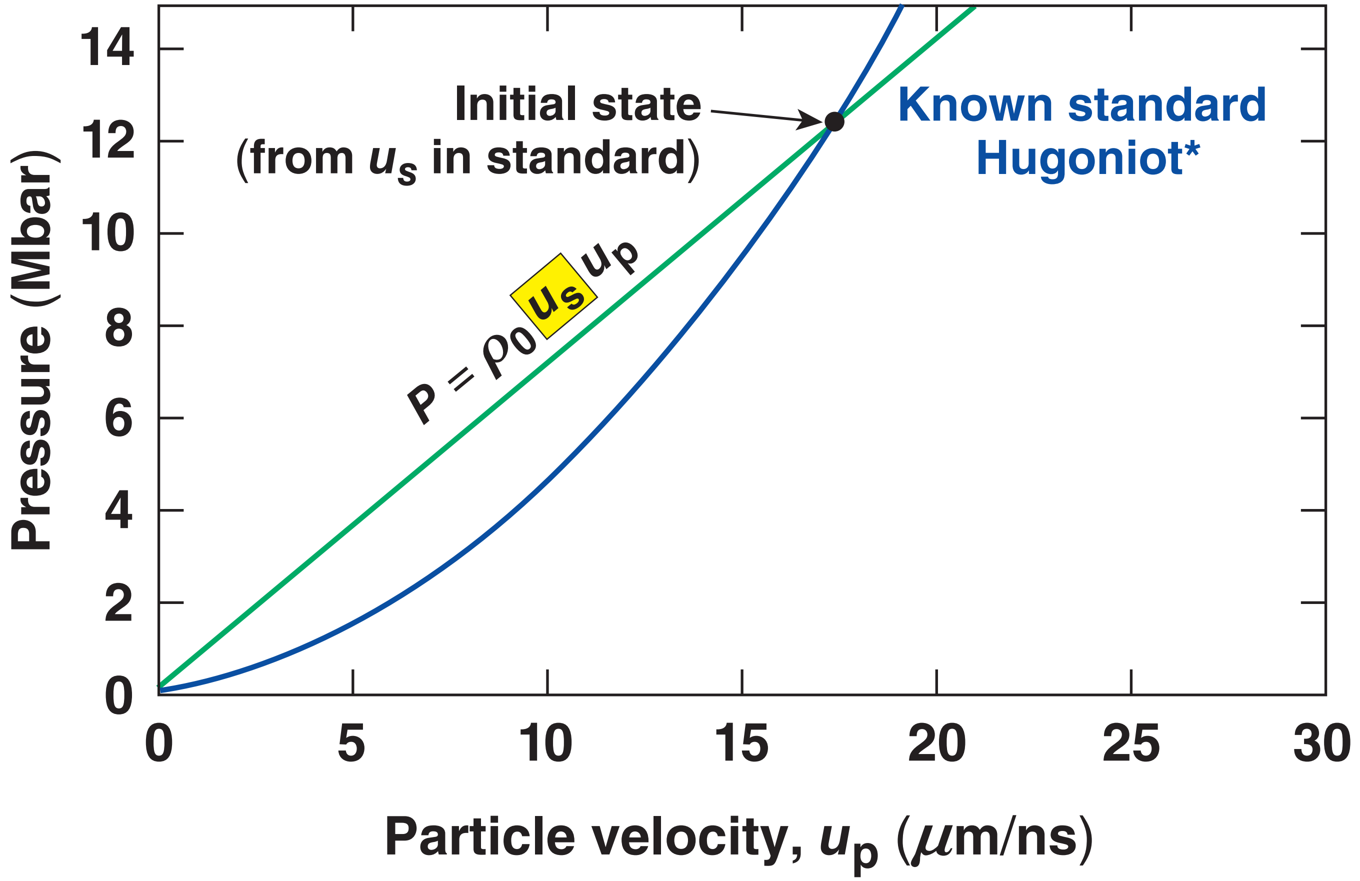


Rankine–Hugoniot relations

$$\rho_0 u_s = \rho_1 (u_s - u_p)$$

$$P_1 - P_0 = \rho_0 u_s u_p$$

$$\left[(\varepsilon_1 - \varepsilon_0) + \left(u_p^2/2\right)\right]\rho_0 u_s = P_1 u_p$$



*M. D. Knudson and M. P. Desjarlais, Phys. Rev. Lett. 103, 225501 (2009).

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Method

When the shock crosses the interface, the standard will release to a P and u_p supported by the standard's Hugoniot

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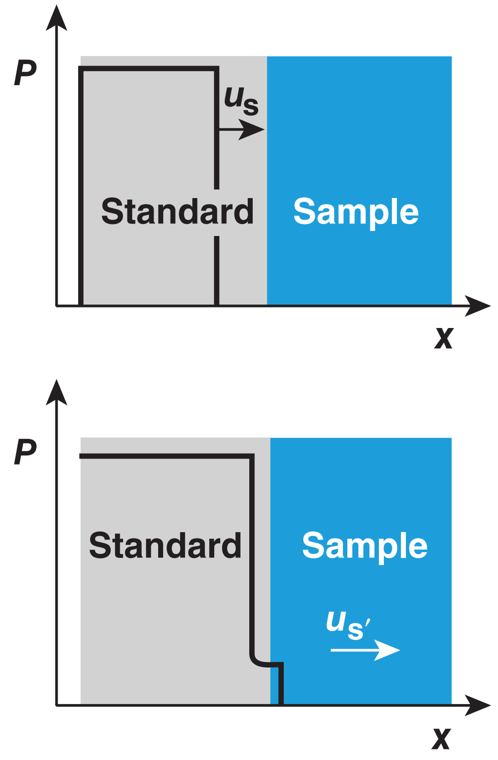

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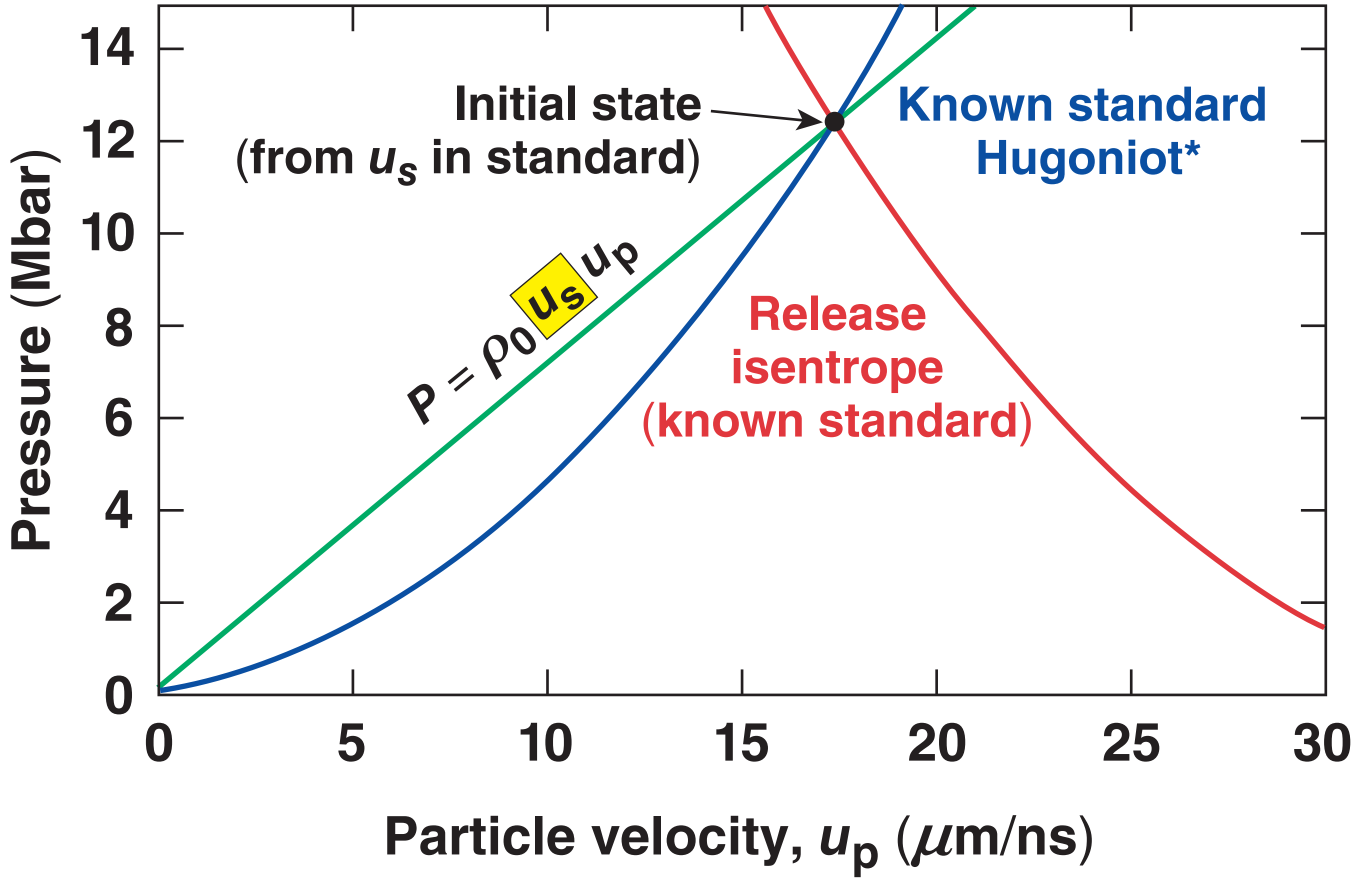

*M. D. Knudson and M. P. Desjarlais, Phys. Rev. Lett. 103, 225501 (2009).

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Method

The intersection of the standard's release isentrope and the sample's Rayleigh line determines the sample's P and u_p

Rankine–Hugoniot relations

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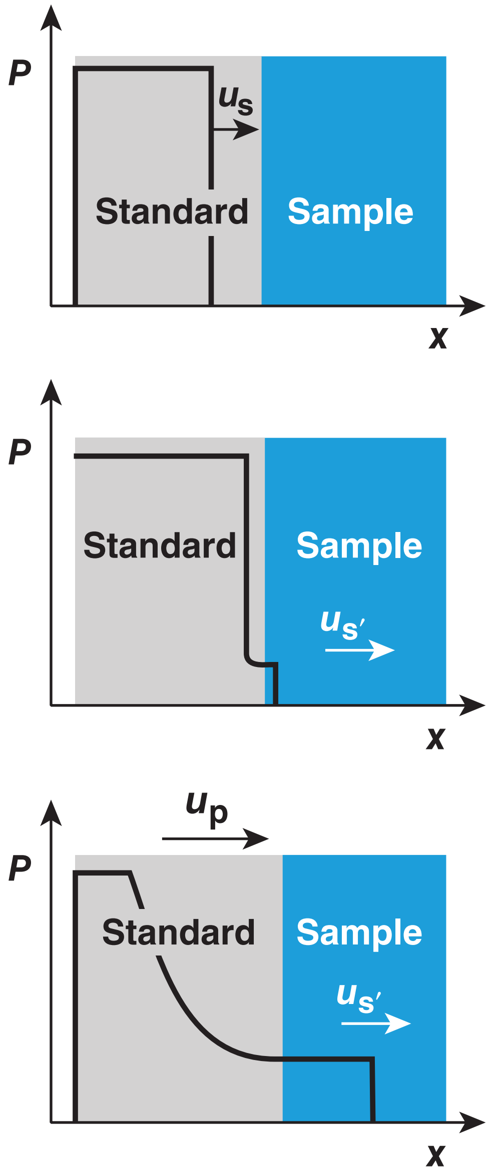

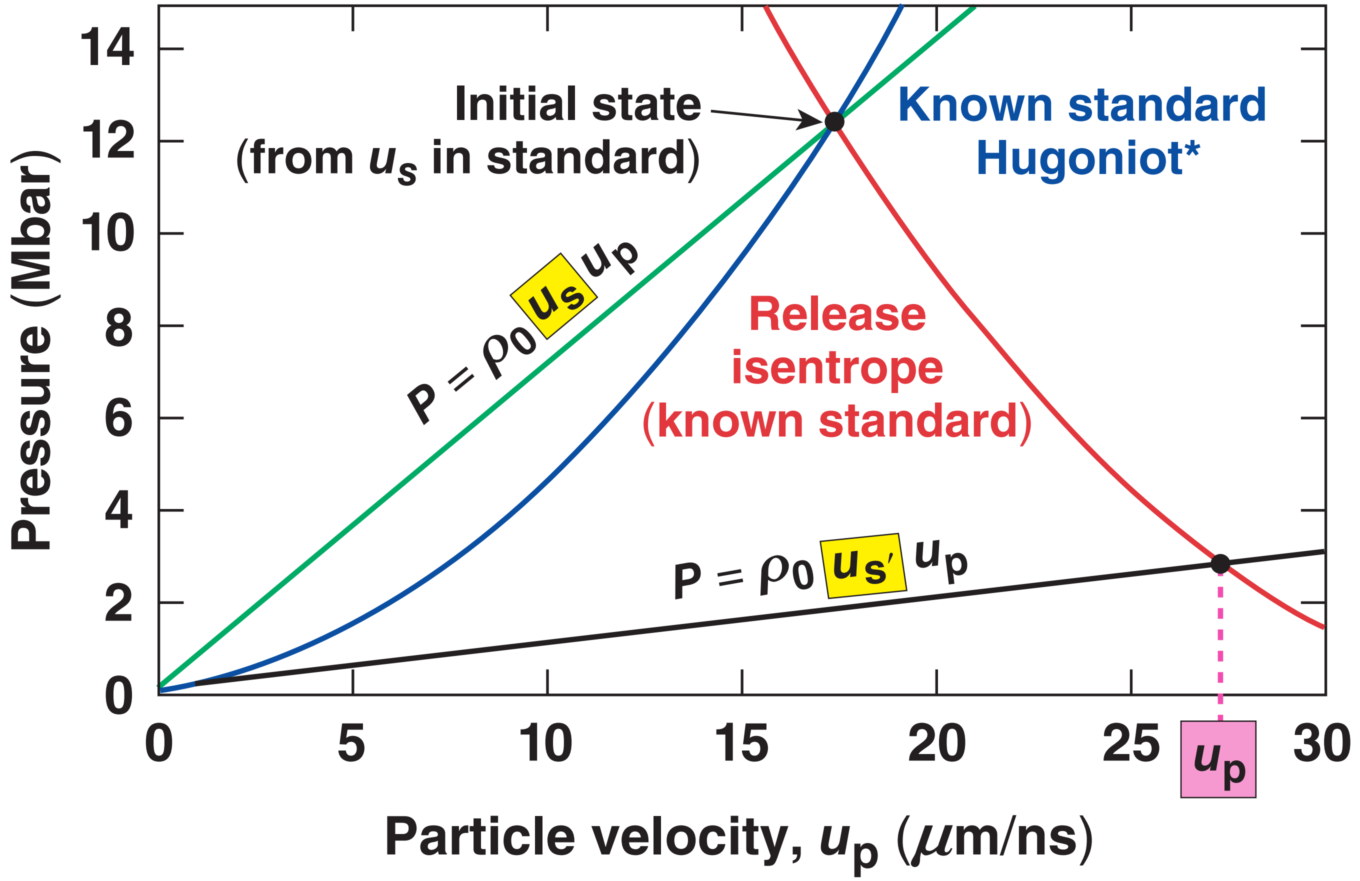

*M. D. Knudson and M. P. Desjarlais, Phys. Rev. Lett. 103, 225501 (2009).

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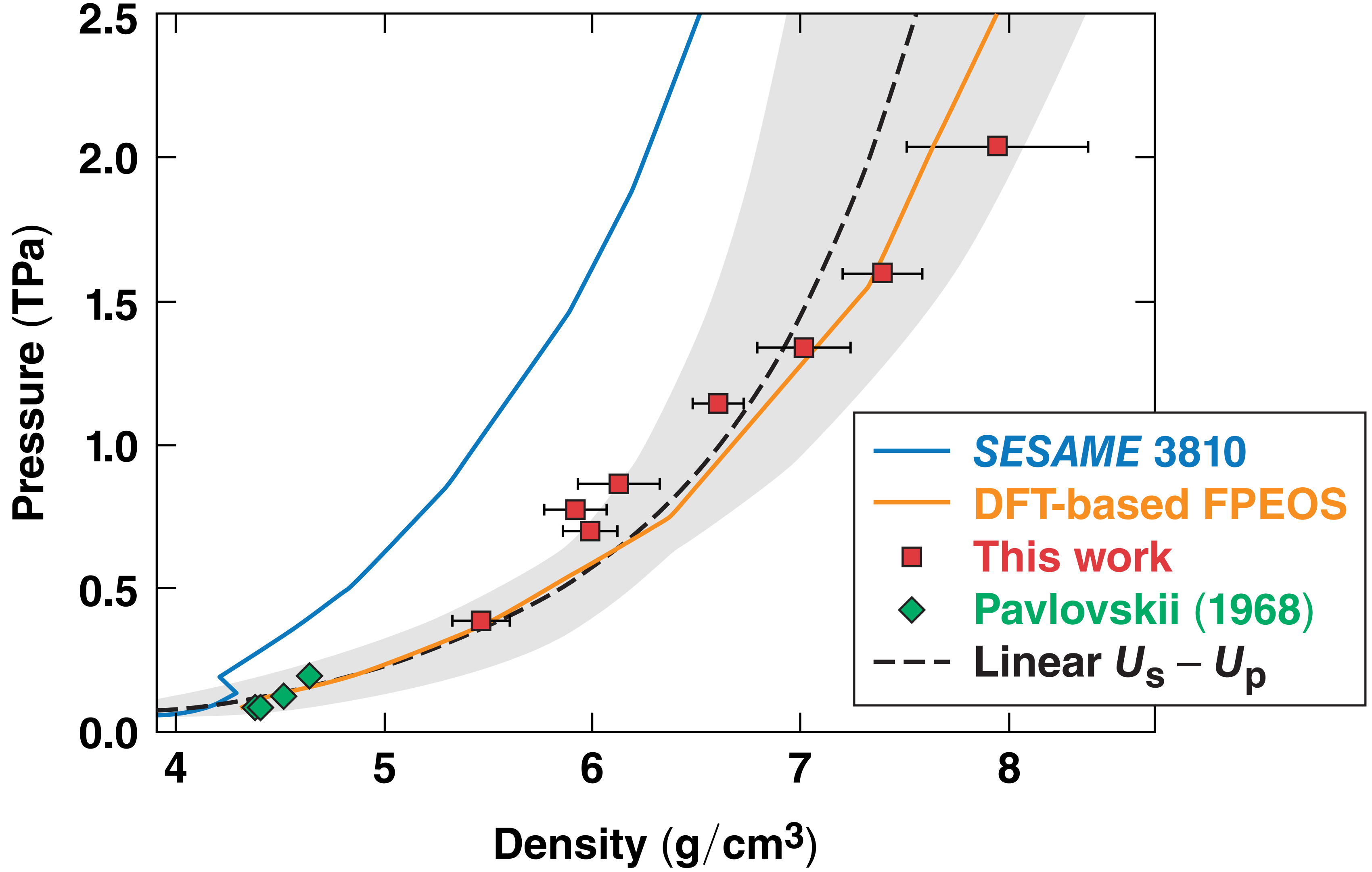
Results indicate that the density functional theory more adequately describes silicon's behavior above 2 Mbar



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