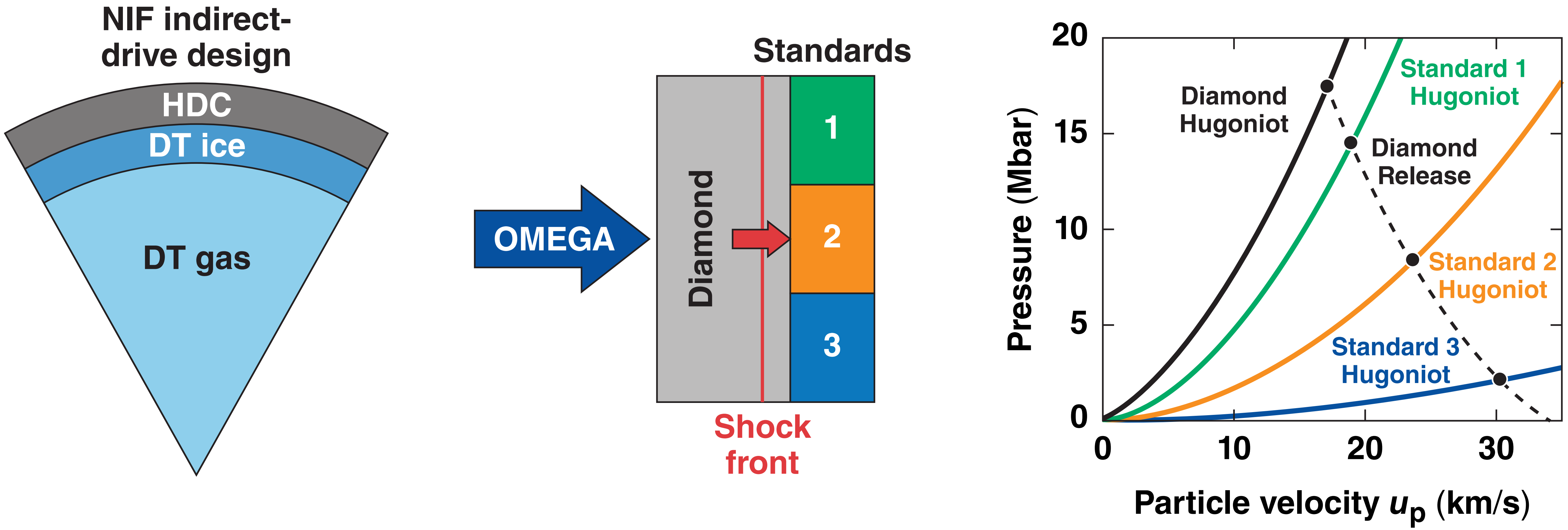
The Shock and Release Behavior of Diamond Compressed to 25 Mbar



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American Physical Society
Division of Plasma Physics
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Summary

The first inertial confinement fusion (ICF) relevant high-density carbon (HDC) data were measured on and off the Hugoniot

- The HDC Hugoniot is stiffer than expected by density-functional-theory molecular dynamics (DFT-MD) and is well represented using a porosity model
- Hugoniot and release measurements were obtained for both nanocrystalline HDC and single-crystal (SC) diamond using impedance matching
- A Grüneisen parameter of one in the liquid phase (>13 Mbar) was derived from the experimental data sets
- Experimentally determined analytical release models agree with the release data for both types of diamond

None of the current EOS models accurately describe the shock and release behaviors of both HDC and SC diamond over the entire experimental data set (8 to 26 Mbar).

E25581

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Outline

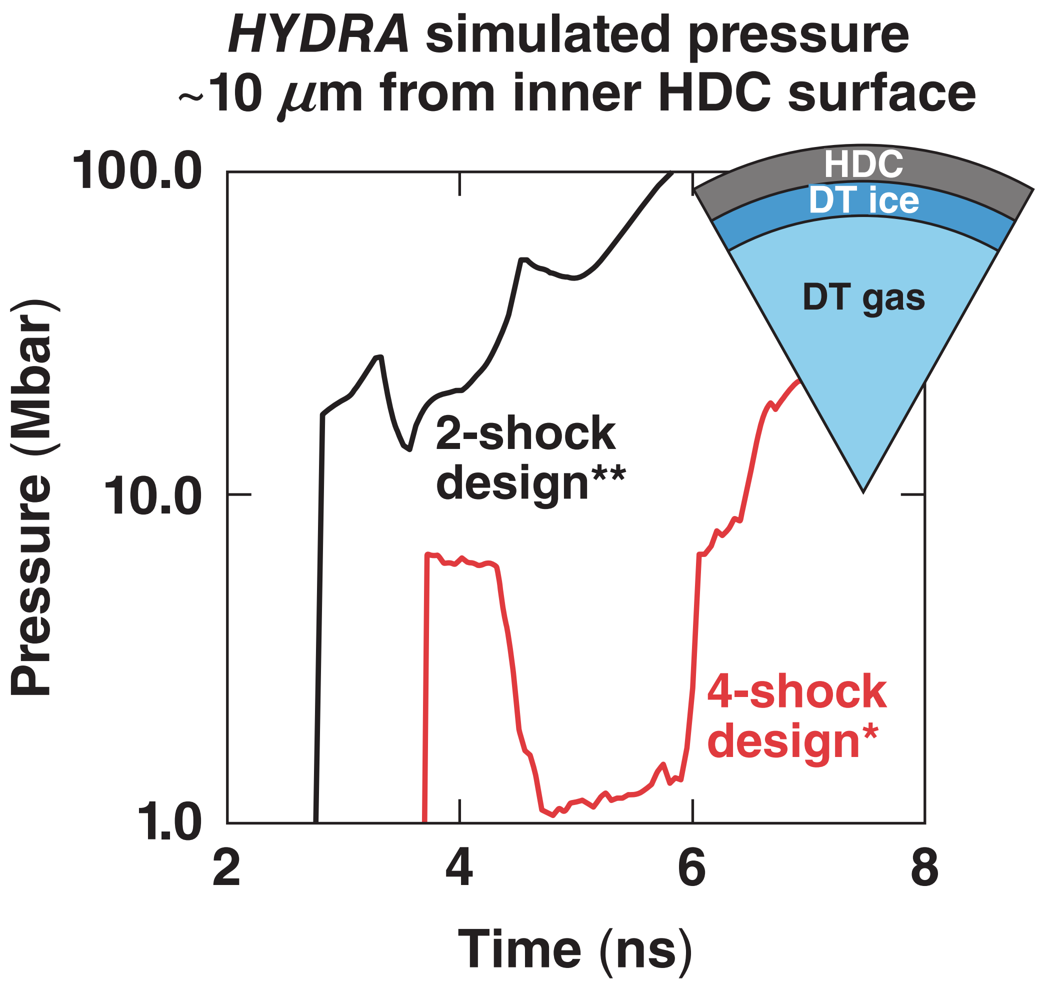
- Motivation
- Technique
- Hugoniot and release results
  - SC diamond
  - HDC

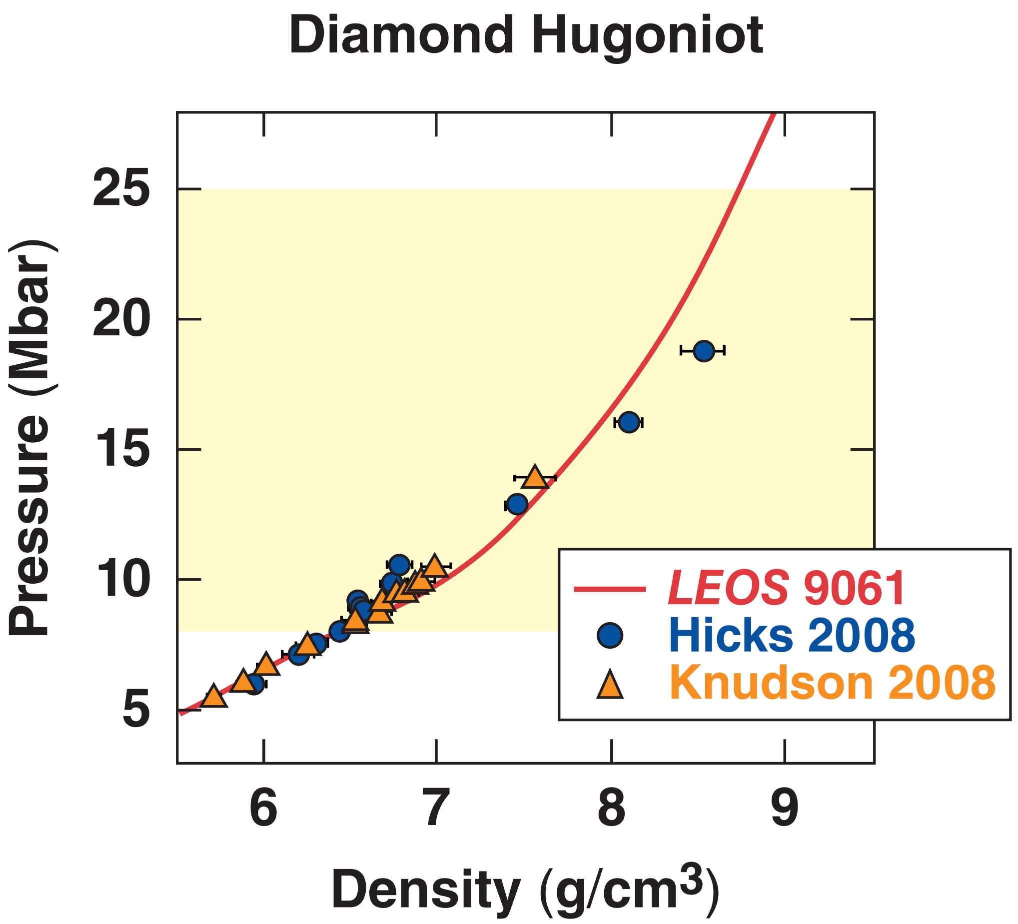
Outline

- **Motivation**
- Technique
- Hugoniot and release results
  - – SC diamond
  - – HDC

E25582a

The Hugoniot and release behaviors of HDC when shocked between 8 and 25 Mbar are important for ICF target designs





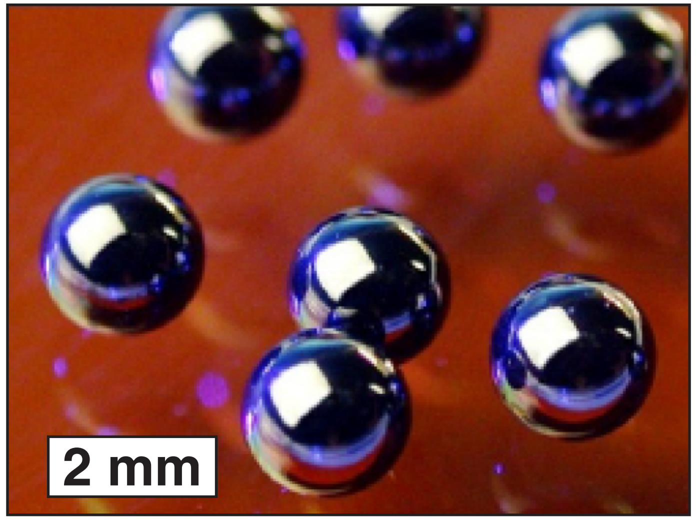
*D. Ho, Lawrence Livermore National Laboratory, private communication (2016).
**N. Meezan *et al.*, Phys. Plasmas 22, 062703 (2015).
L. F. Berzak Hopkins *et al.*, Phys. Plasmas 22, 056318 (2015).

E25669

The HDC used as a NIF ablator has different material properties than SC diamond that could affect its response to shock compression

SC diamond	HDC
$\rho_0 = 3.52$ g/cm^3	$\rho_0 \approx 3.36$ g/cm^3
<110> orientation	nanocrystalline
diamond lattice	grain sizes < 10 nm
transparent	translucent

HDC capsules*



*C. Dawedeit *et al.*, Diamond and Related Materials 40, 75 (2013)

E25677

Outline

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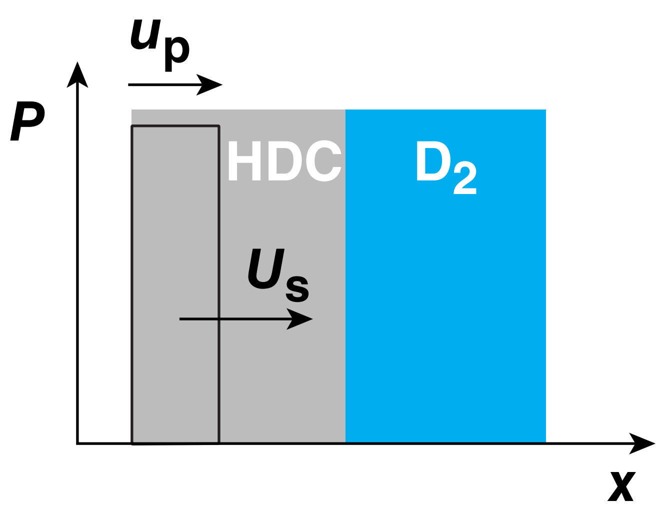
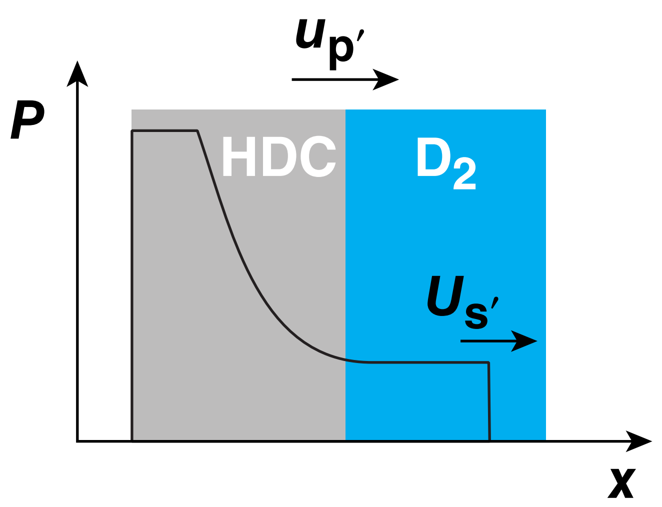
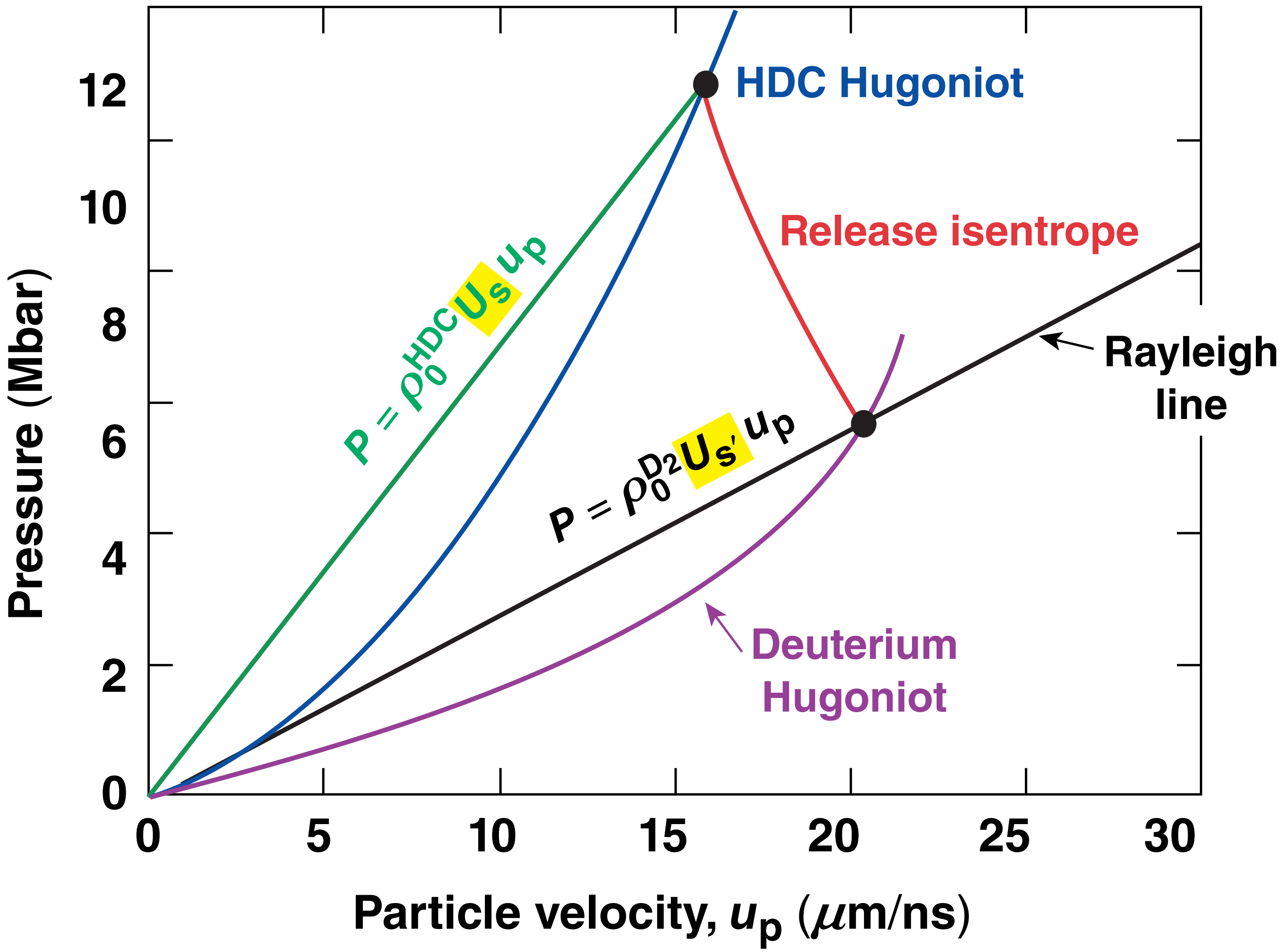
- **Technique**
- Hugoniot and release results
  - SC diamond
  - HDC

E25582b

EOS data are obtained using the impedance-matching technique*



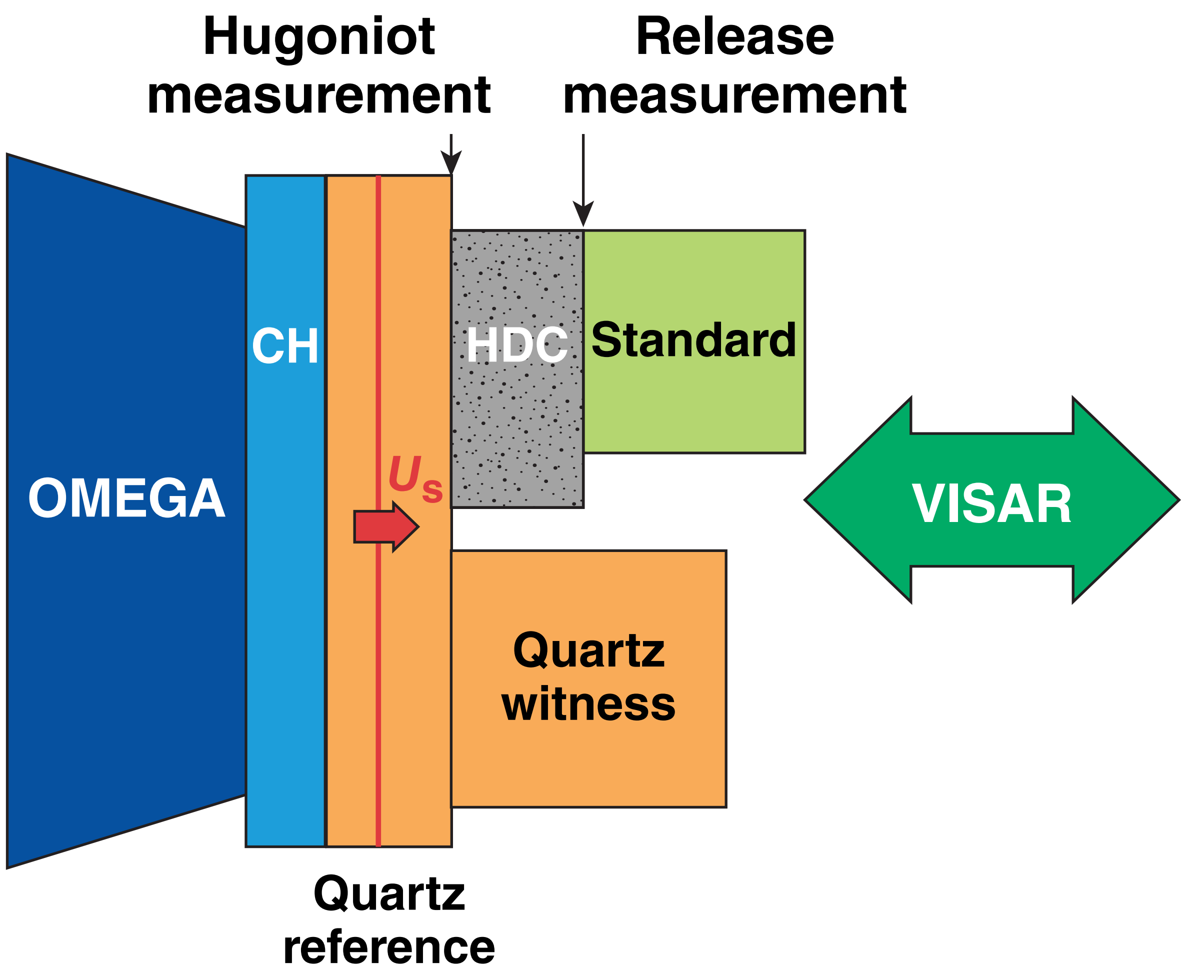


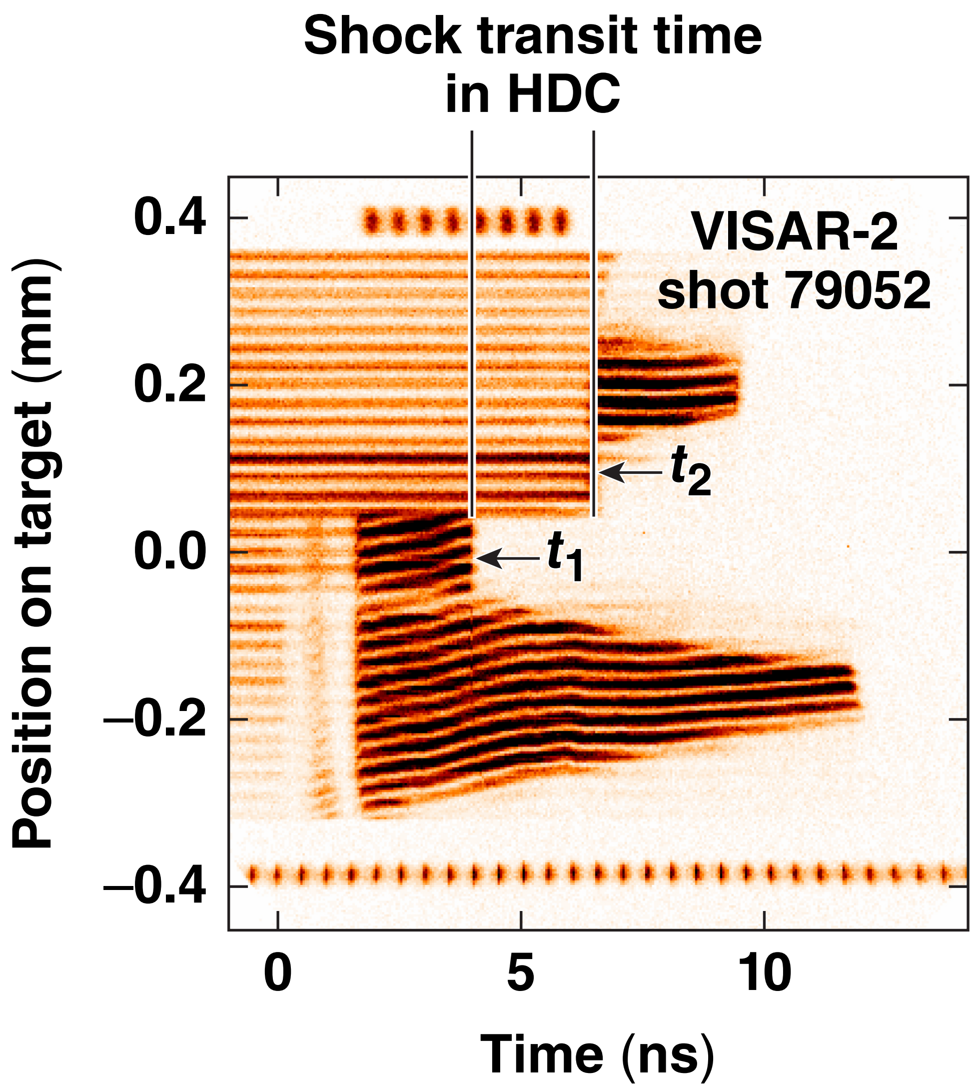


* Ya. B. Zel'dovich and Yu. P. Raǐzer, in Physics of Shock Waves and High-Temperature Hydrodynamic Phenomena, edited by W. D. Hayes and R. F. Probstein (Academic Press, New York, 1966).

E12433r

A velocity interferometer system for any reflector (VISAR)* was used to measure shock velocities and transit times in stepped targets

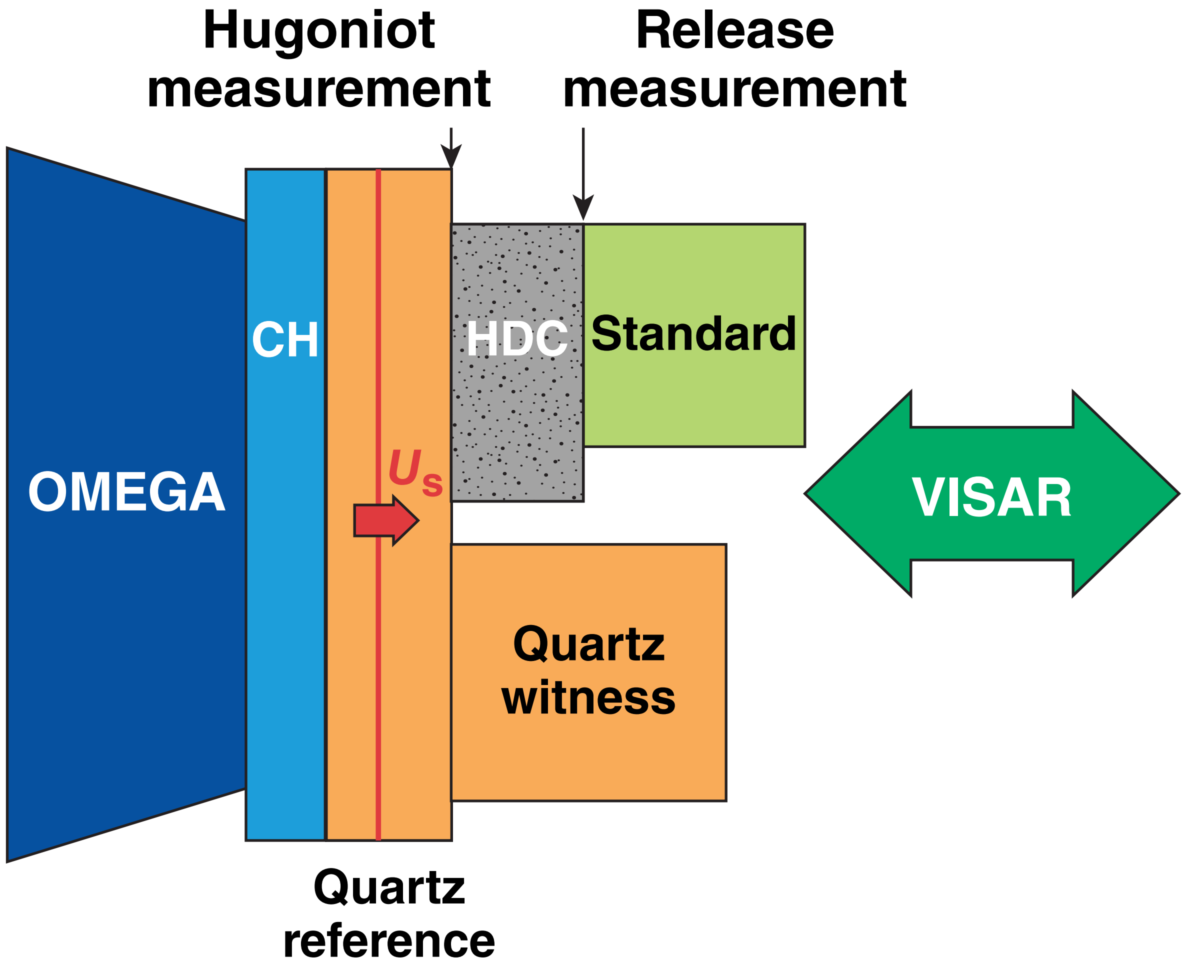


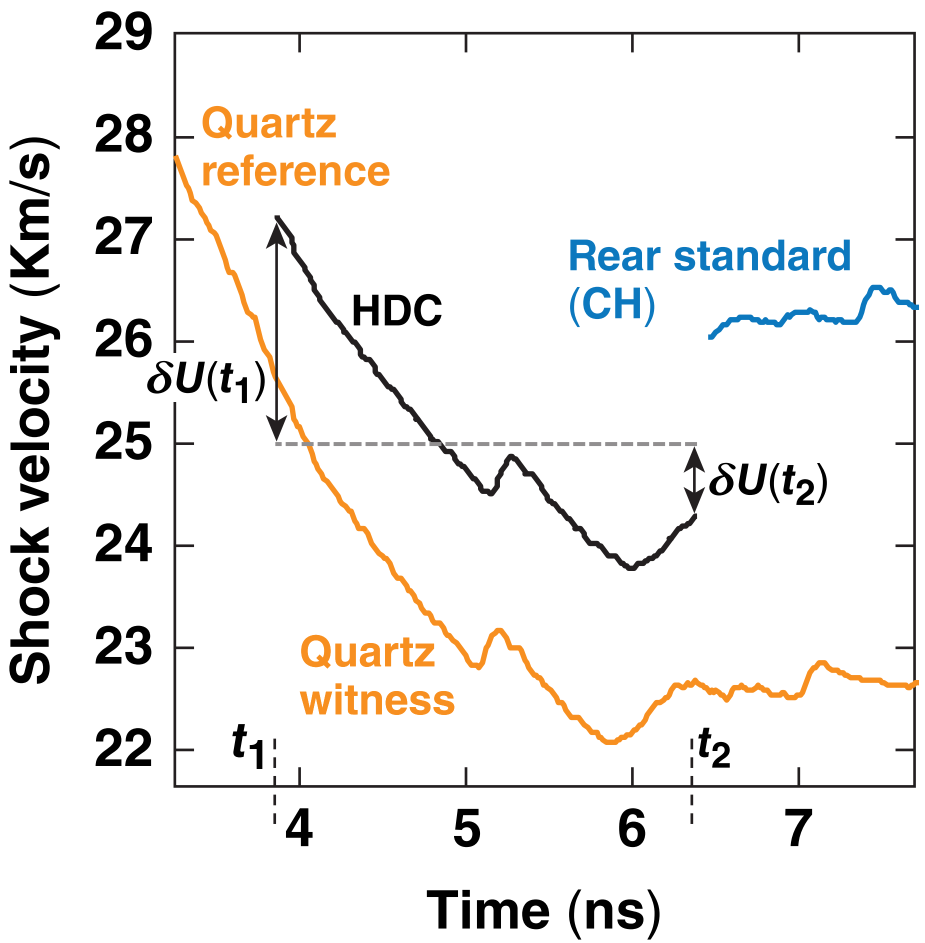


*P. M. Celliers *et al.*, Rev. Sci. Intrum. 75, 4916 (2004).

E23267e

A correction* is applied to the average shock velocity in HDC to compensate for the nonsteady drive

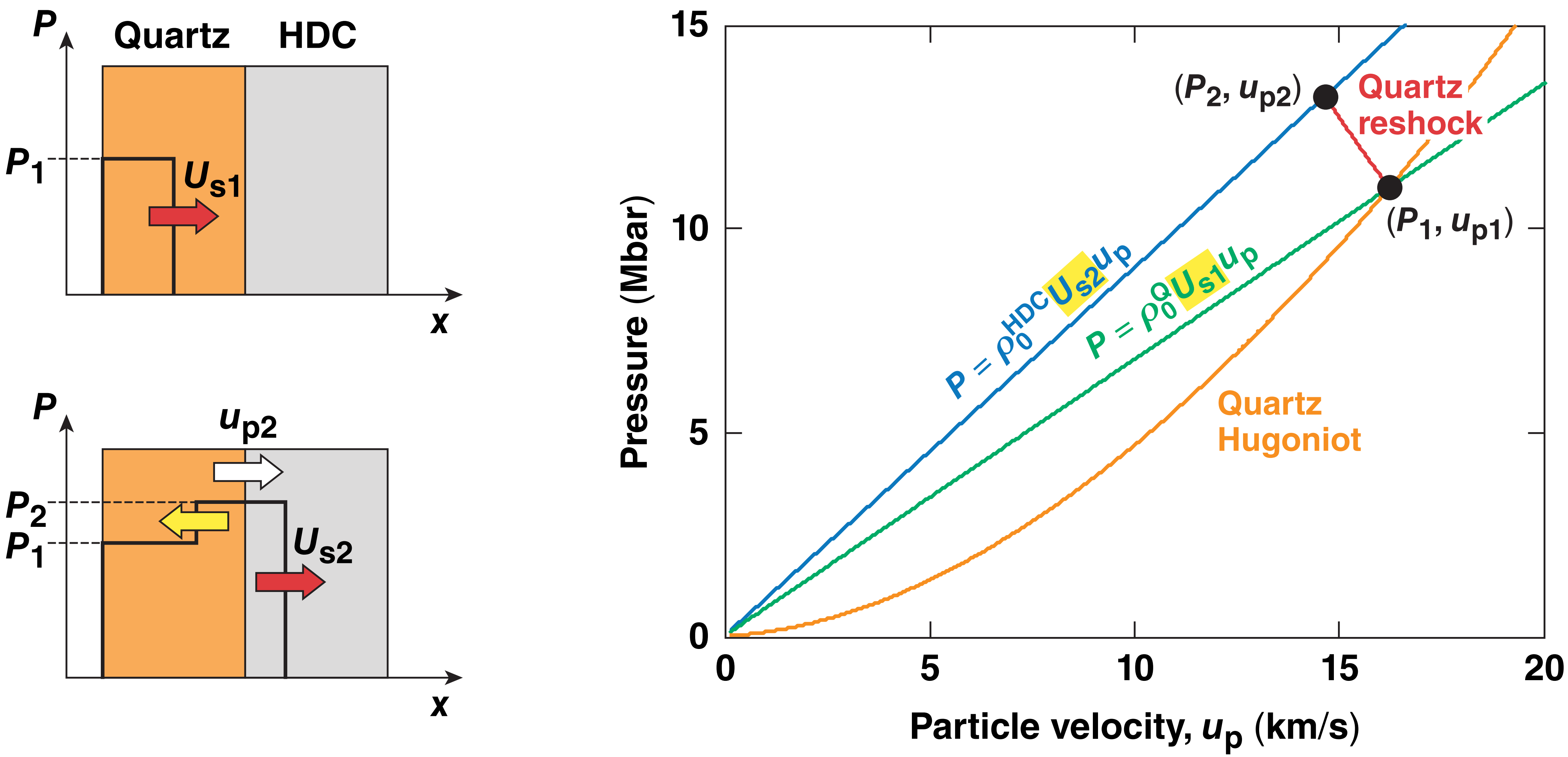




*D. E. Fratanduono *et al.*, J. Appl. Phys. 116, 033517 (2014).

E23267f

The HDC Hugoniot is measured by impedance matching with a quartz standard

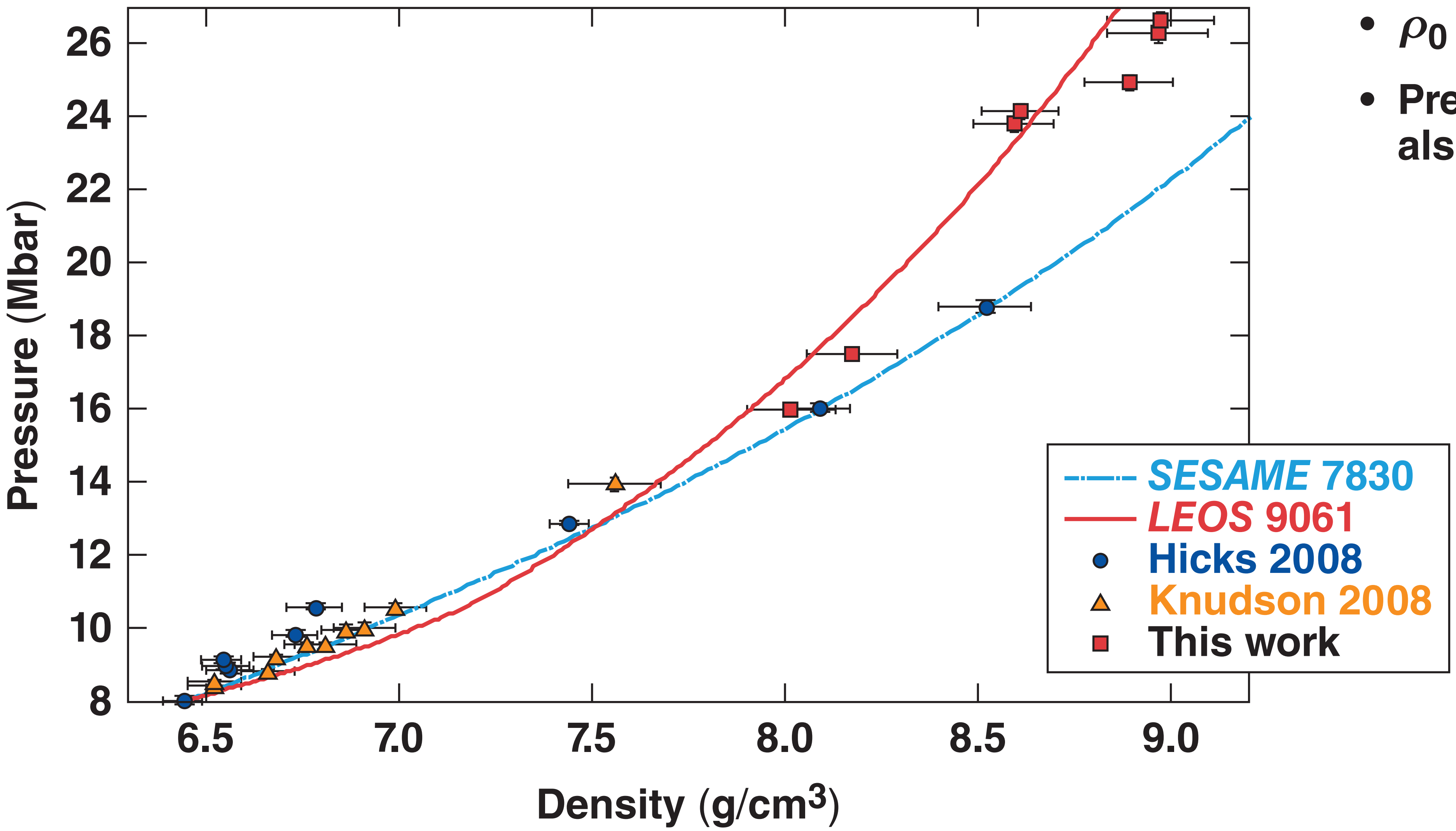


E25584

Outline

- Motivation
- Technique
- **Hugoniot and release results**
  - SC diamond
  - HDC

New high-pressure Hugoniot data for SC diamond match the density-functional-theory molecular-dynamics (DFT-MD) EOS model* (*LEOS* 9061)

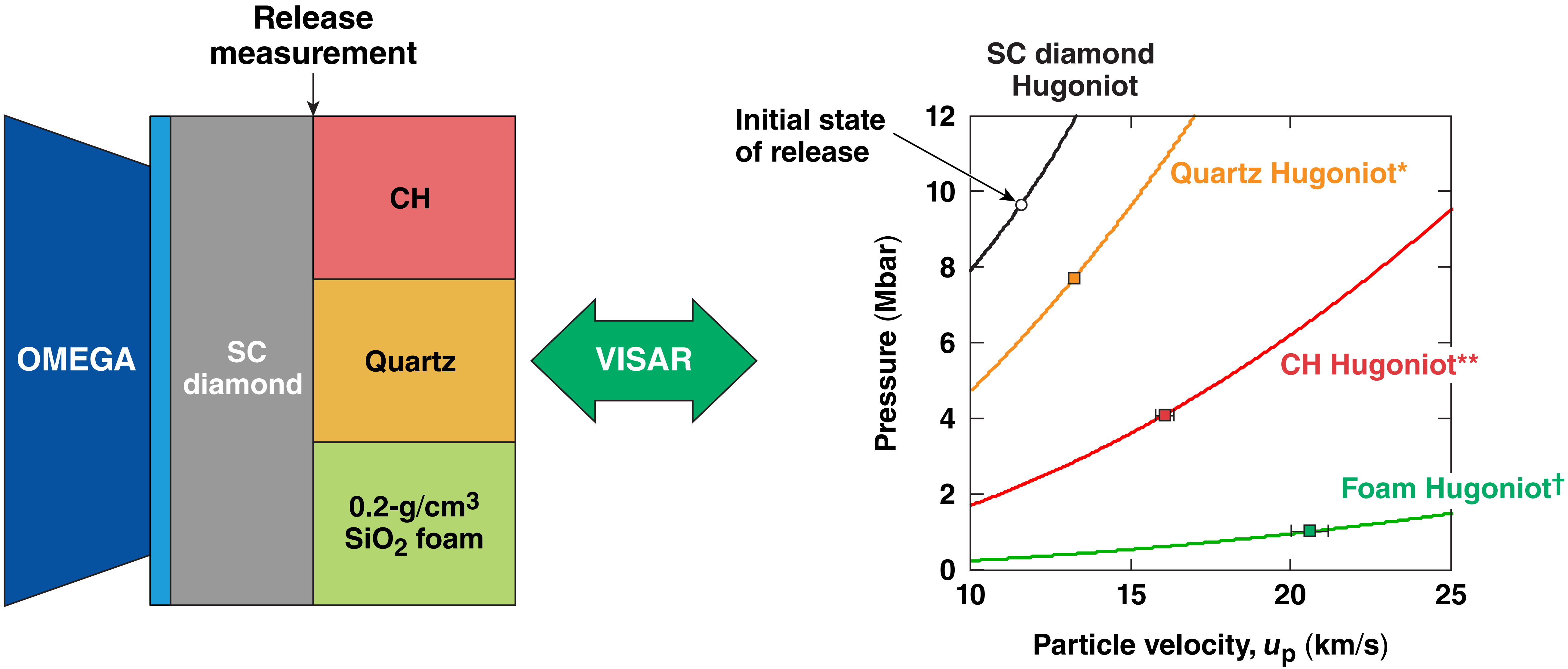


- ρ_0 = 3.52 g/cm^3
- Preliminary NIF data up to 75 Mbar also favor *LEOS* 9061

*L. X. Benedict *et al.*, Phys. Rev. B 89, 224109 (2014).

E25540

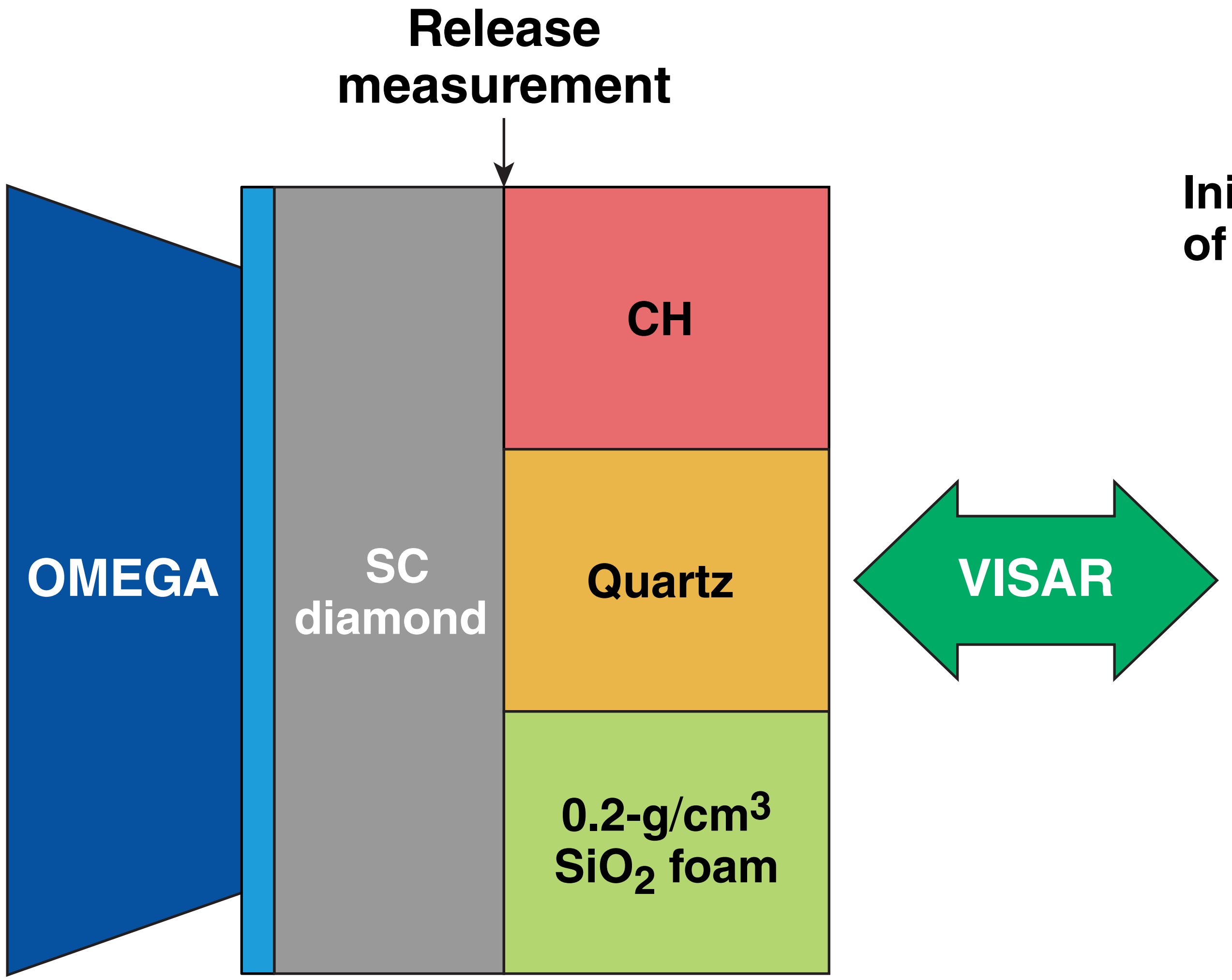
High-precision SC diamond release data were acquired using multiple standards

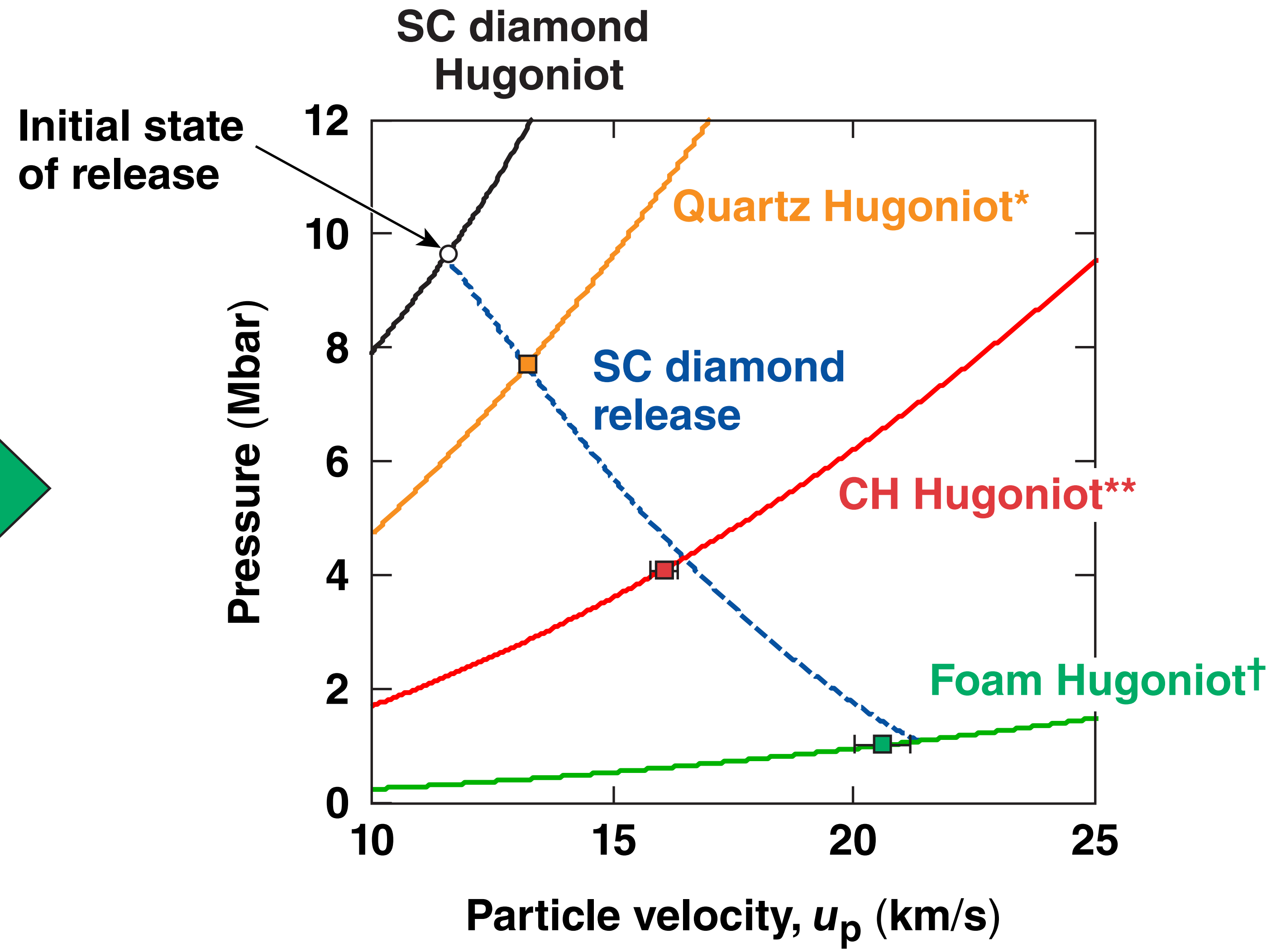


*M. D. Knudson and M. P. Desjarlais, Phys. Rev. B 88, 184107 (2013).
**M. A. Barrios *et al.*, Phys. Plasmas 17, 056307 (2010).
†M. D. Knudson and R. W. Lemke, J. Appl. Phys. 114, 053510 (2013).

E24117c

High-precision SC diamond release data were acquired using multiple standards

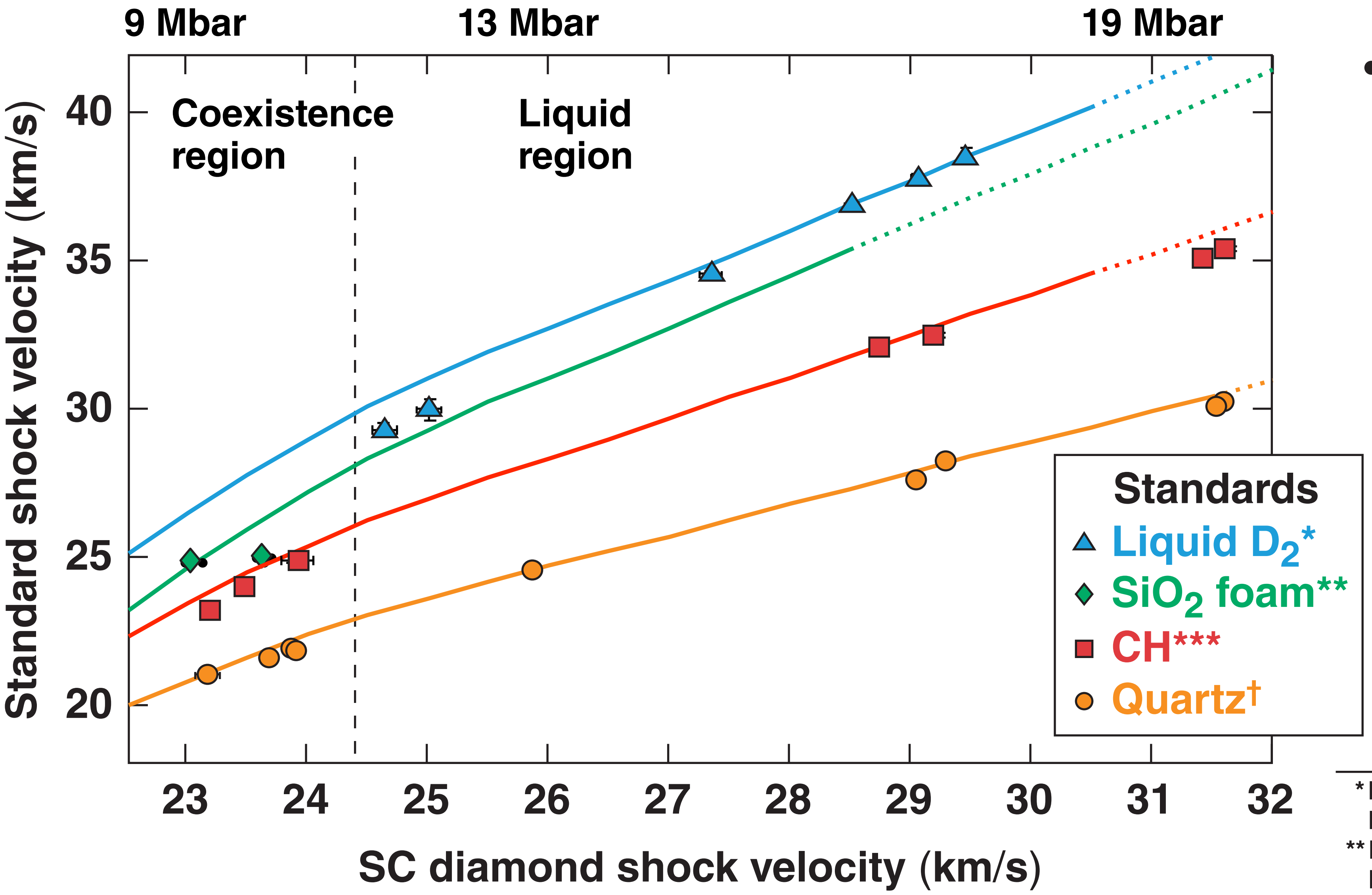




*M. D. Knudson and M. P. Desjarlais, Phys. Rev. B 88, 184107 (2013).
**M. A. Barrios *et al.*, Phys. Plasmas 17, 056307 (2010).
†M. D. Knudson and R. W. Lemke, J. Appl. Phys. 114, 053510 (2013).

E24117d

The SC diamond release from higher pressure (>13 Mbar) is best modeled using DFT-MD (*LEOS* 9061)

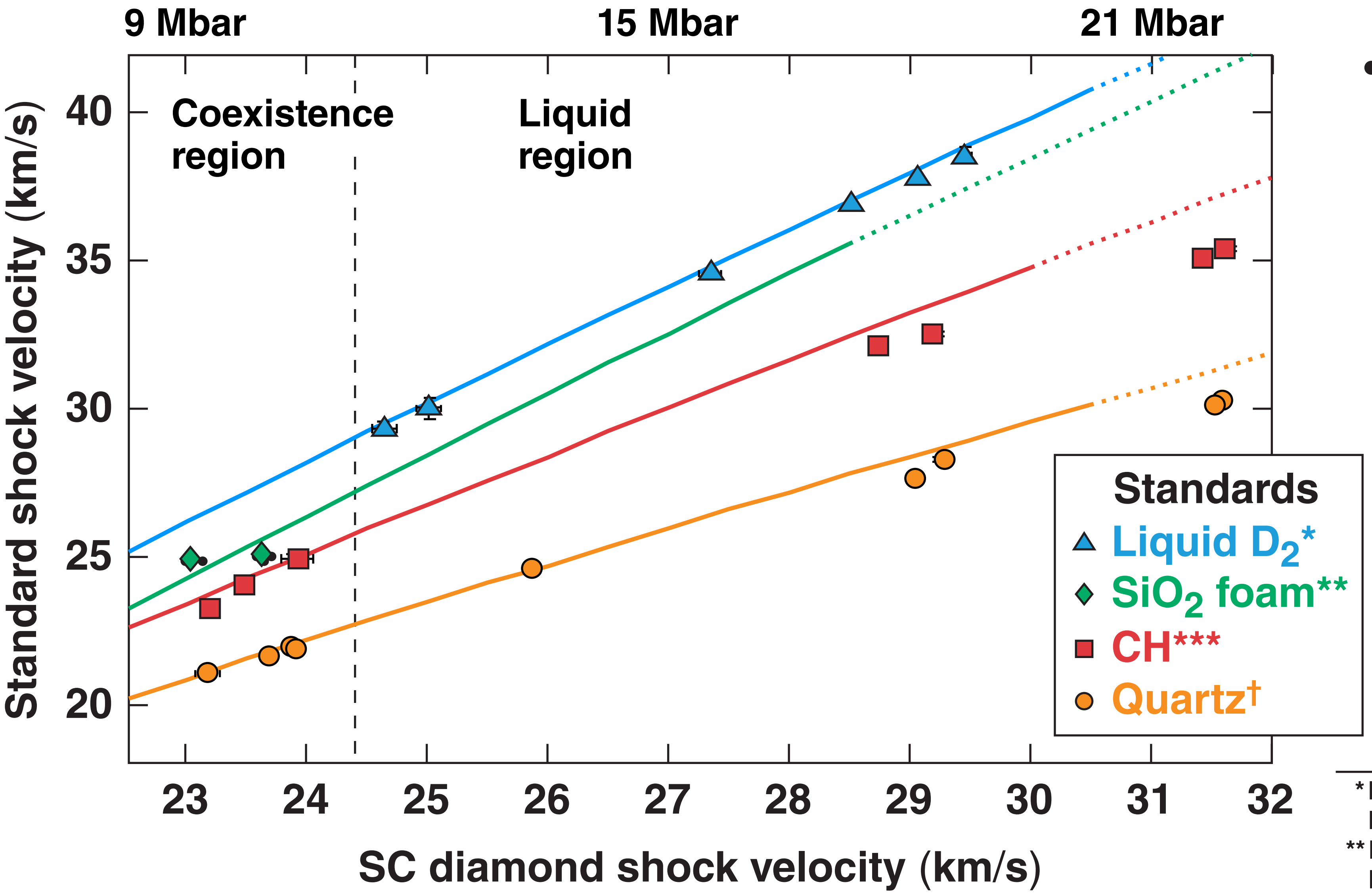


- SC diamond Hugoniot and release curves generated using
  - *LEOS* 9061

*D. G. Hicks *et al.*, Phys. Rev. B 79, 014112 (2009); M. D. Knudson and R. W. Lemke, J. Appl. Phys. 114, 053510 (2013).
**M. D. Knudson, M. P. Desjarlais, and A. Pribram-Jones, Phys. Rev. B 91, 224105 (2015).
***M. A. Barrios *et al.*, Phys. Plasmas 17, 056307 (2010).
†M. D. Knudson and M. P. Desjarlais, Phys. Rev. B 88, 184107 (2013).

E25586a

The SC diamond release from lower pressure (9 to 15 Mbar) is accurately modeled using *SESAME* 7830



- SC diamond Hugoniot and release curves generated using
  - *SESAME* 7830

*D. G. Hicks *et al.*, Phys. Rev. B 79, 014112 (2009);
M. D. Knudson and R. W. Lemke, J. Appl. Phys. 114, 053510 (2013).
**M. D. Knudson, M. P. Desjarlais, and A. Pribram-Jones, Phys. Rev. B 91, 224105 (2015).
***M. A. Barrios *et al.*, Phys. Plasmas 17, 056307 (2010).
†M. D. Knudson and M. P. Desjarlais, Phys. Rev. B 88, 184107 (2013).

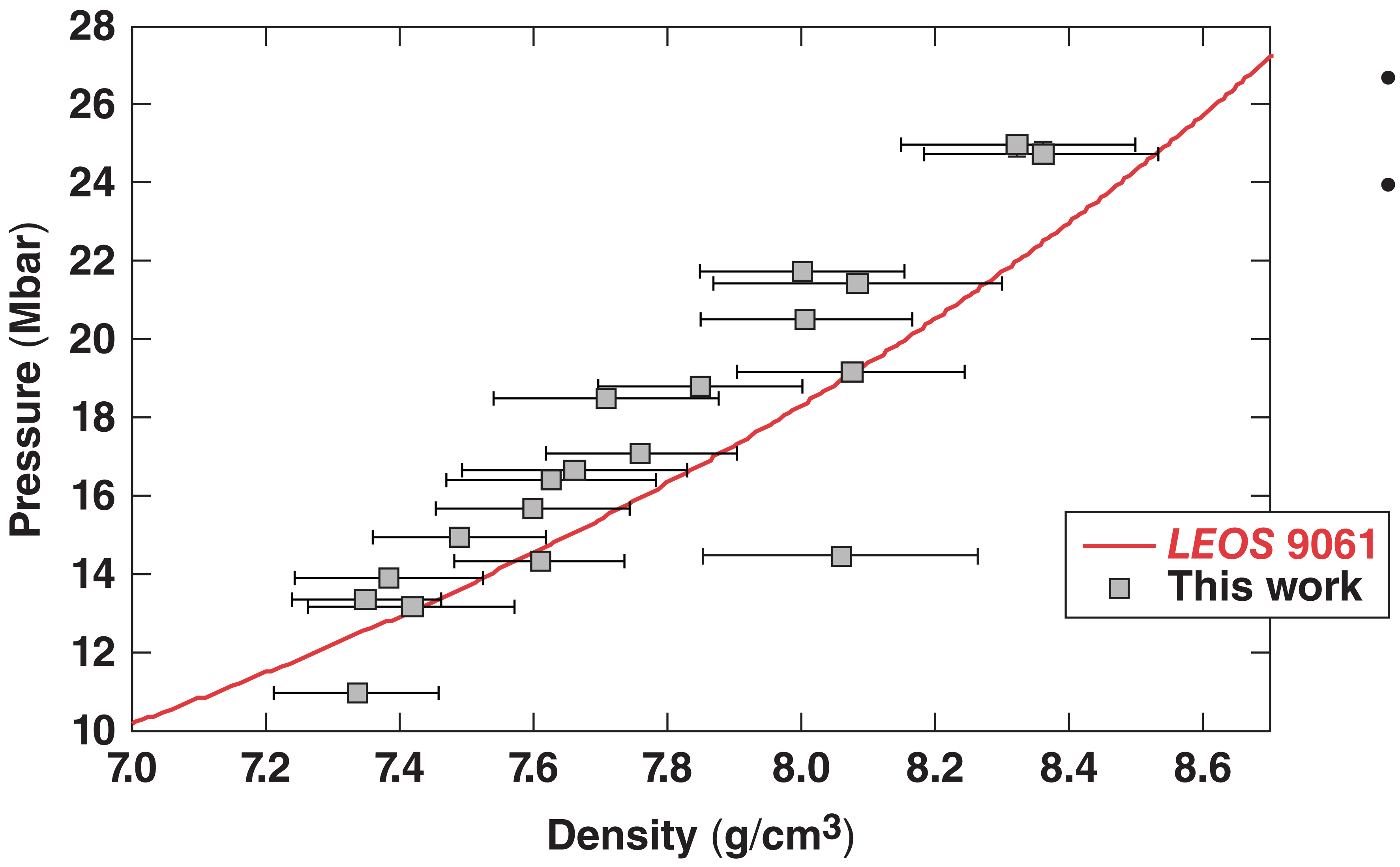
E25586

Outline

- Motivation
- Technique
- **Hugoniot and release results**
  - SC diamond
  - **HDC**

E25582d

The HDC Hugoniot between 11 and 26 Mbar is stiffer than the DFT-MD EOS model* (*LEOS* 9061)



- $\frac{\rho_0^{SC}}{\rho_0^{HDC}} = 1.05$
- The SC diamond data agree with *LEOS* 9061

*L. X. Benedict *et al.*, Phys. Rev. B 89, 224109 (2014).

E25539

The HDC Hugoniot is well-represented using a porosity model with $\Gamma = 1.03$

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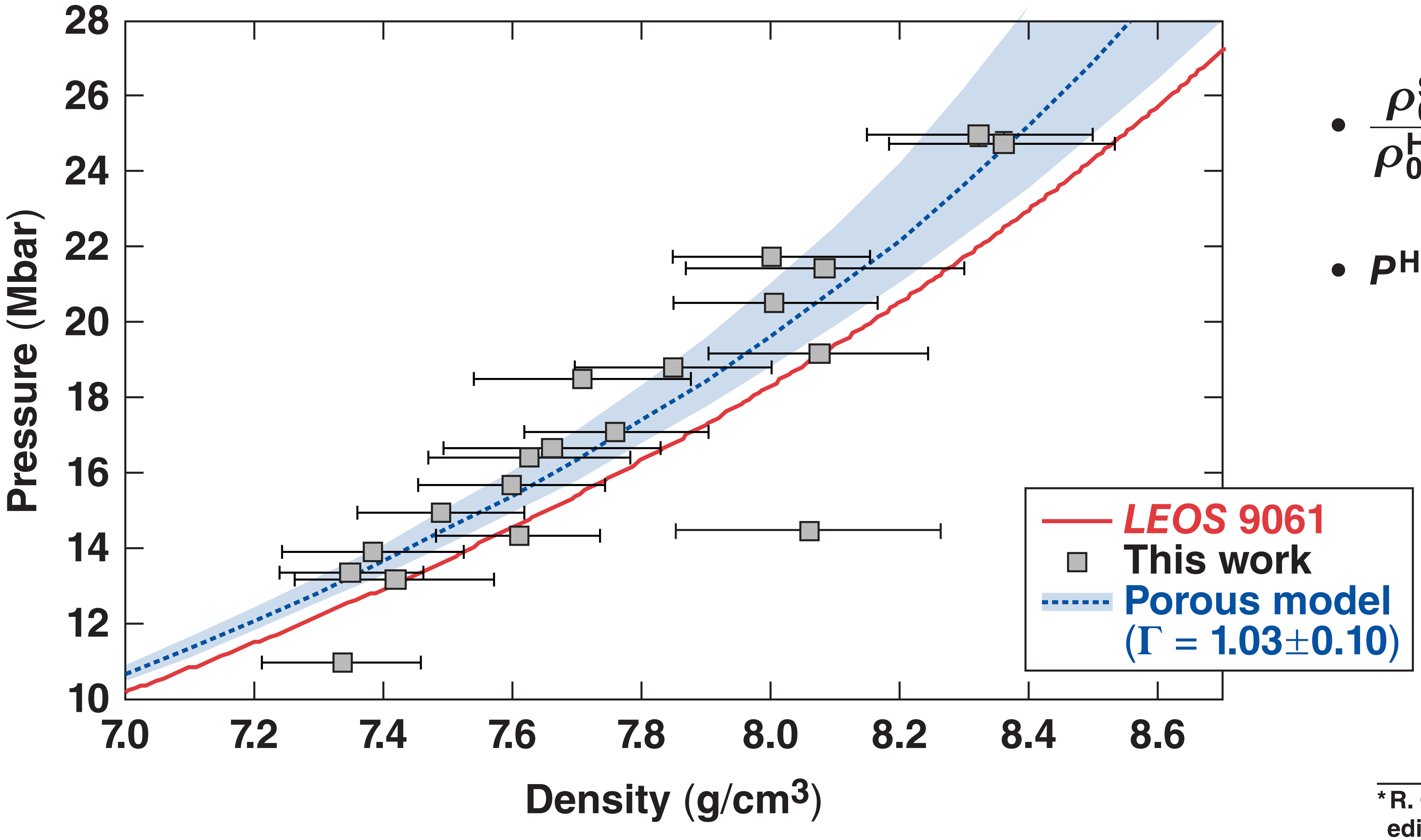


Porosity model*

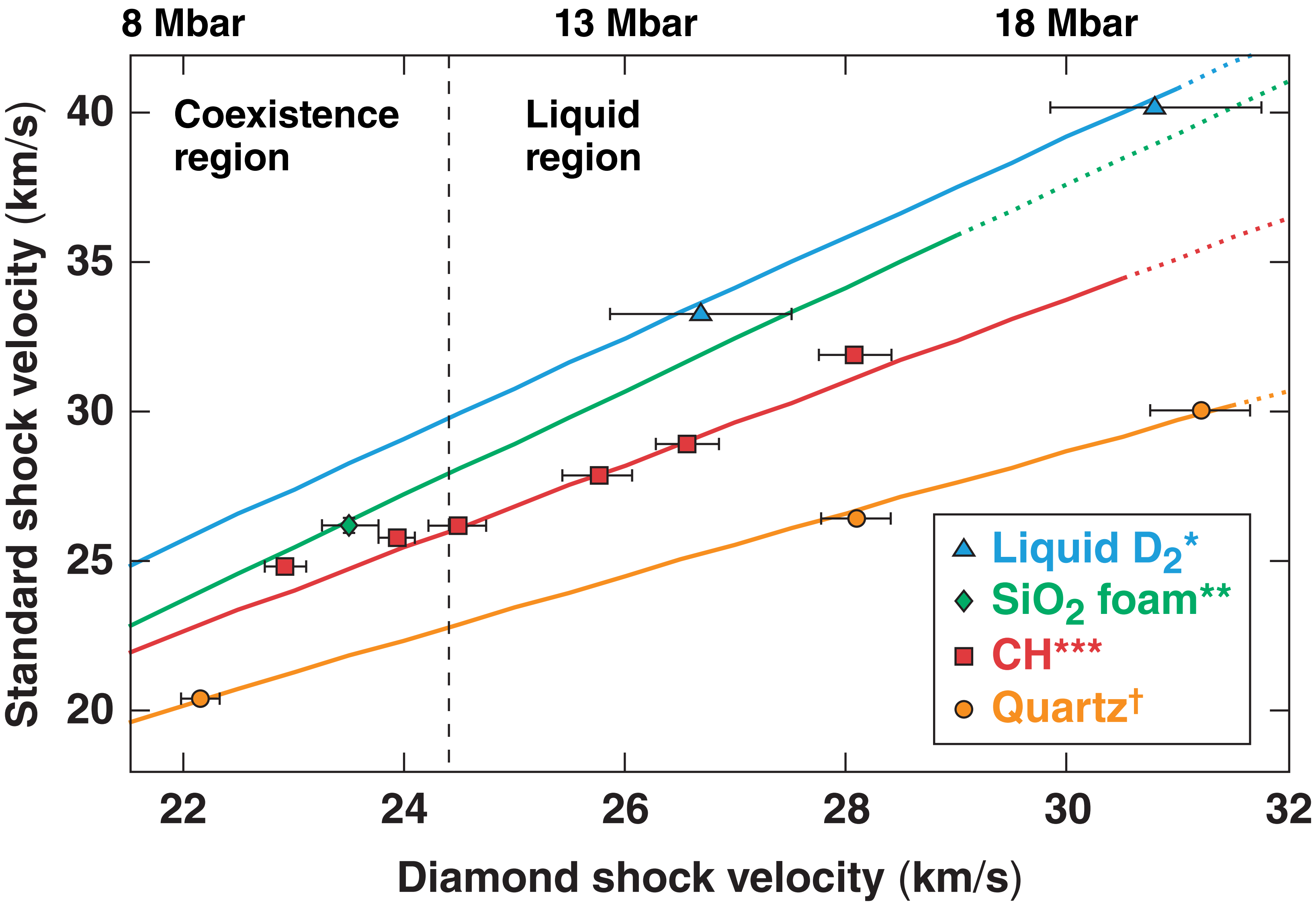
- $\dfrac{\rho_0^{SC}}{\rho_0^{HDC}} = 1.05$
- $P^{HDC} = P^{SC} \dfrac{1 - \frac{\Gamma}{2}\left(\frac{\rho}{\rho_0^{SC}} - 1\right)}{1 - \frac{\Gamma}{2}\left(\frac{\rho}{\rho_0^{HDC}} - 1\right)}$

Increased entropy from the initial pore collapse may affect the adiabat.

*R. G. McQueen *et al.*, in High-Velocity Impact Phenomena, edited by R. Kinslow (Academic Press, New York, 1970); R. F. Smith *et al.*, Nature 511, 330 (2014).

E25539a

A Mie-Grüneisen EOS model with Γ = 1.03 describes the HDC release data



Mie Grüneisen EOS

$$P - P_H = \frac{\Gamma}{V}(E - E_H)$$

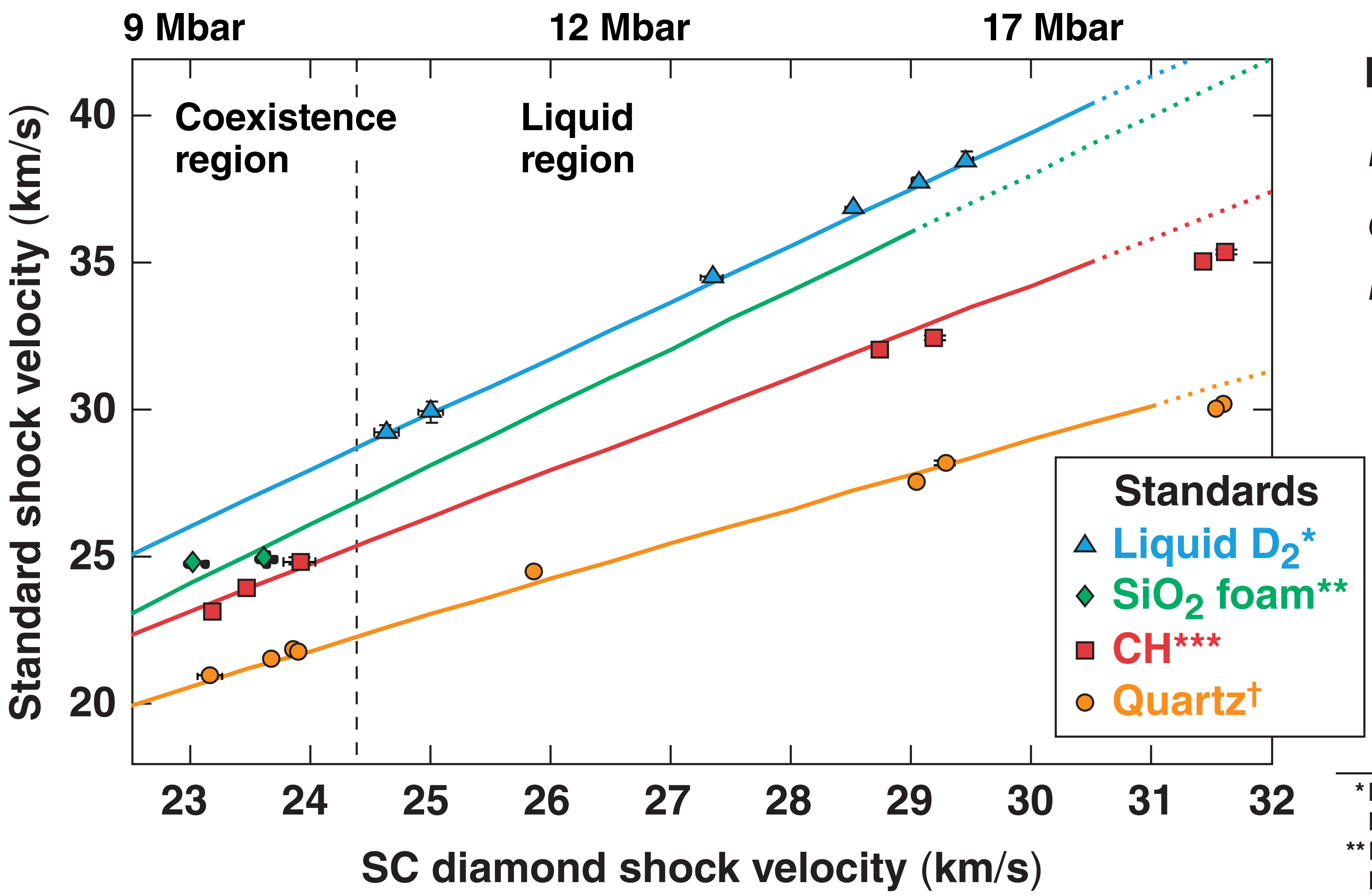
$$dE = -PdV$$

P_H: HDC porosity model

*D. G. Hicks *et al.*, Phys. Rev. B 79, 014112 (2009); M. D. Knudson and R. W. Lemke, J. Appl. Phys. 114, 053510 (2013).
**M. D. Knudson, M. P. Desjarlais, and A. Pribram-Jones, Phys. Rev. B 91, 224105 (2015).
***M. A. Barrios *et al.*, Phys. Plasmas 17, 056307 (2010).
†M. D. Knudson and M. P. Desjarlais, Phys. Rev. B 88, 184107 (2013).

E25541

A Mie-Grüneisen EOS model with $\Gamma = 1.03$ also describes the SC diamond release data



Mie Grüneisen EOS

$$P - P_H = \frac{\Gamma}{V}(E - E_H)$$

$$dE = -\mathrm{PdV}$$

P_H: linear $U_s - u_p$ fit to all SC diamond data

* D. G. Hicks *et al.*, Phys. Rev. B 79, 014112 (2009);
M. D. Knudson and R. W. Lemke, J. Appl. Phys. 114, 053510 (2013).

** M. D. Knudson, M. P. Desjarlais, and A. Pribram-Jones, Phys. Rev. B 91, 224105 (2015).

*** M. A. Barrios *et al.*, Phys. Plasmas 17, 056307 (2010).

† M. D. Knudson and M. P. Desjarlais, Phys. Rev. B 88, 184107 (2013).

E25736

The first inertial confinement fusion (ICF) relevant high-density carbon (HDC) data were measured on and off the Hugoniot

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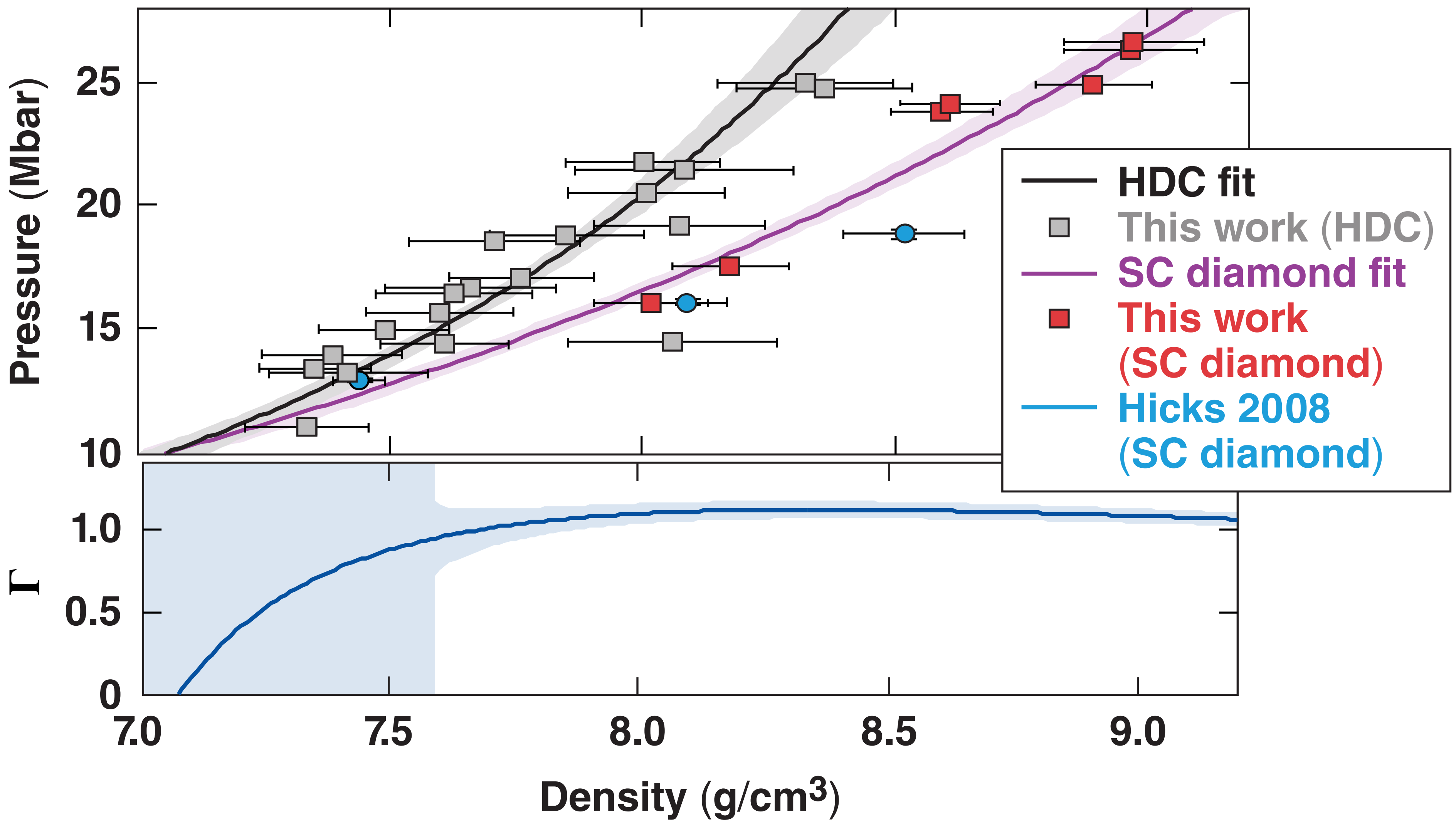
- Experimentally determined analytical release models agree with the release data for both types of diamond

None of the current EOS models accurately describe the shock and release behaviors of both HDC and SC diamond over the entire experimental data set (8 to 26 Mbar).

A Grüneisen parameter for liquid carbon was derived from the two experimentally determined Hugoniots



$$\Gamma = \frac{1}{\rho}\left(\frac{\partial P}{\partial E}\right)_{\rho}$$

$$\Gamma \approx \frac{1}{\rho}\left(\frac{P^{HDC} - P^{SC}}{E^{HDC} - E^{SC}}\right)_{\rho}$$

E25743