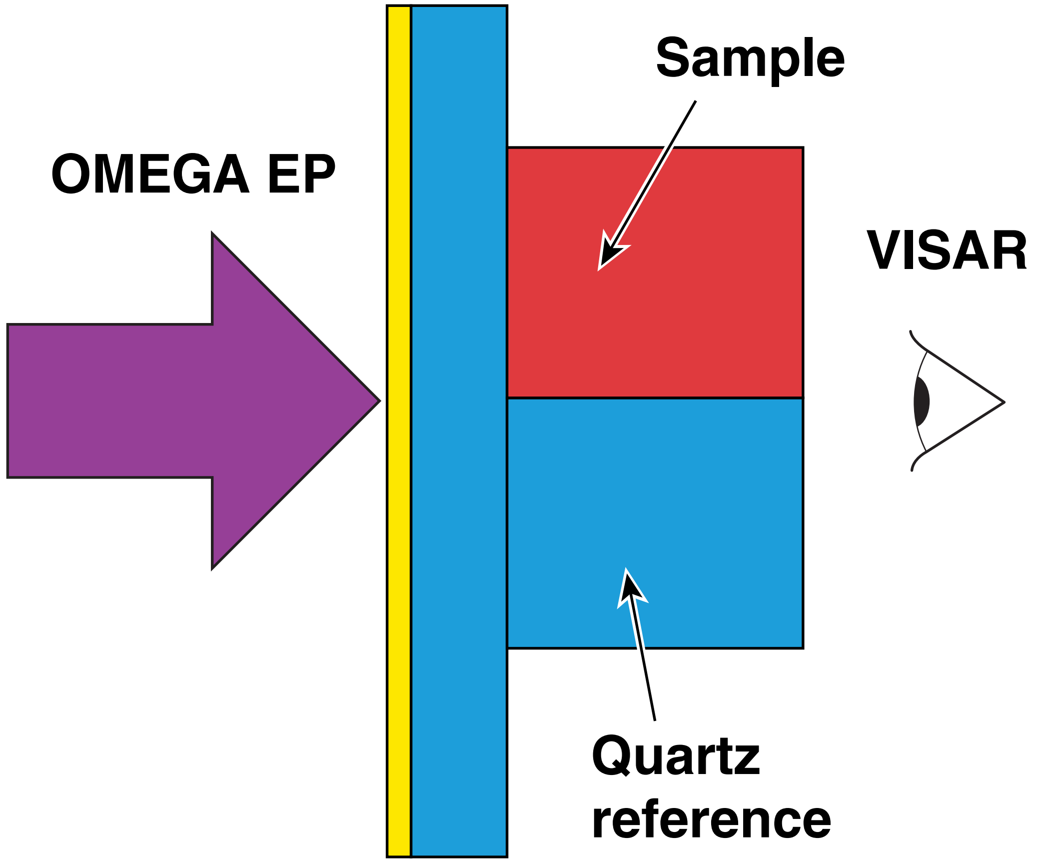
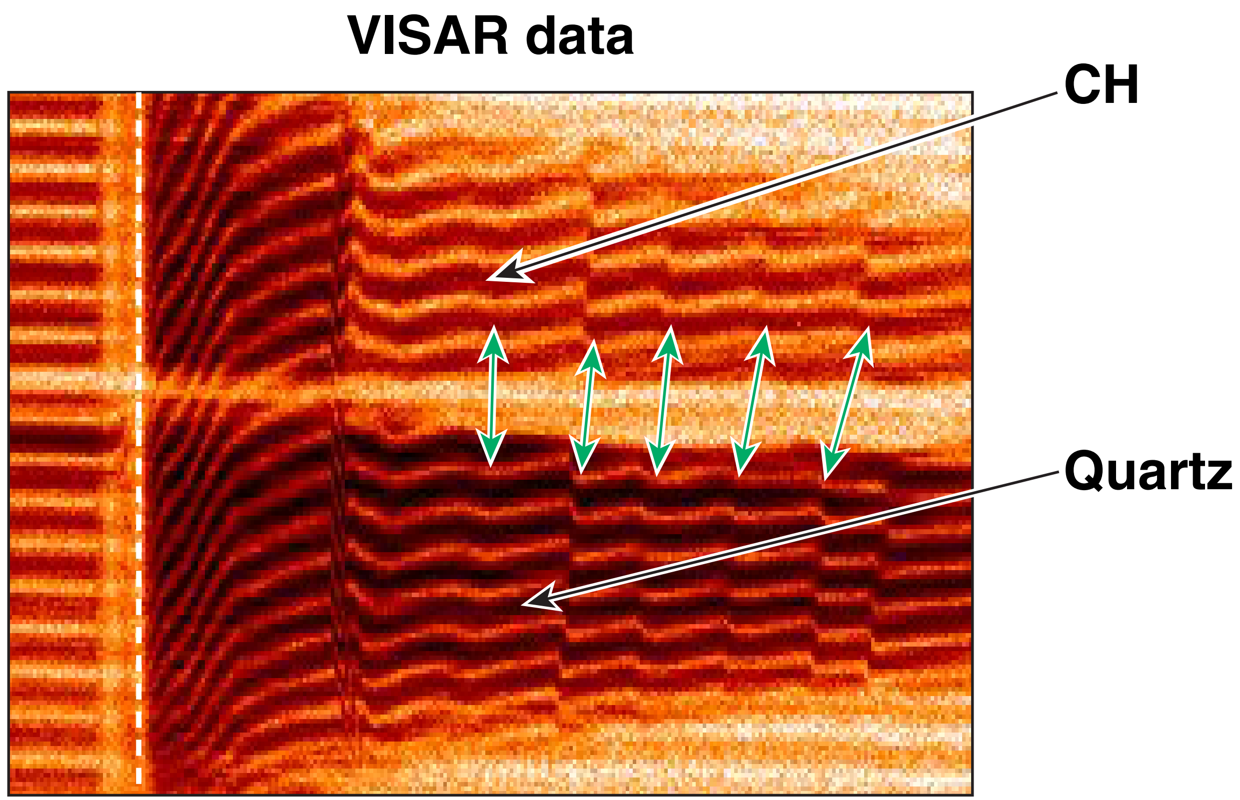
Measurements of Sound Velocity and Grüneisen Parameter in CH Shocked to 800 GPa





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59th Annual Meeting of the
American Physical Society
Division of Plasma Physics
Milwaukee, WI
23–27 October 2017

Summary

Our measurements of Grüneisen parameter and quantum molecular dynamics (QMD) simulations show the effect of energy sinks in shocked CH

- Sound-velocity measurements are made using an unsteady wave analysis relating the temporal shift between acoustic perturbations
- The Grüneisen parameter of the material behind the shock front is determined from its sound velocity and the slope of its Hugoniot curve
- The sound-speed measurements are predicted by most models
- The measured Grüneisen parameter exhibits a decrease at lower pressures, which is likely caused by dissociaton and ionization

Collaborators

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The high-pressure sound speed and Grüneisen parameter are important for inertial confinement fusion, EOS* measurements, and geophysics

- For shock-timing, shock mergers and rarefaction waves depend on sound speed in the shocked ablator material
- The release of shocked material is modeled by Mie–Grüneisen EOS

$$P - P_{\mathrm{H}} = \frac{\Gamma}{V}(E - E_{\mathrm{H}})$$

- The sound velocity $c_s^2 = \left(\frac{dP}{dV}\right)_v$ and Grüneisen parameter $\Gamma = V\left(\frac{dP}{dE}\right)_v$ define derivatives across the Hugoniot curve and can provide information about off-Hugoniot states

*EOS: equation of state

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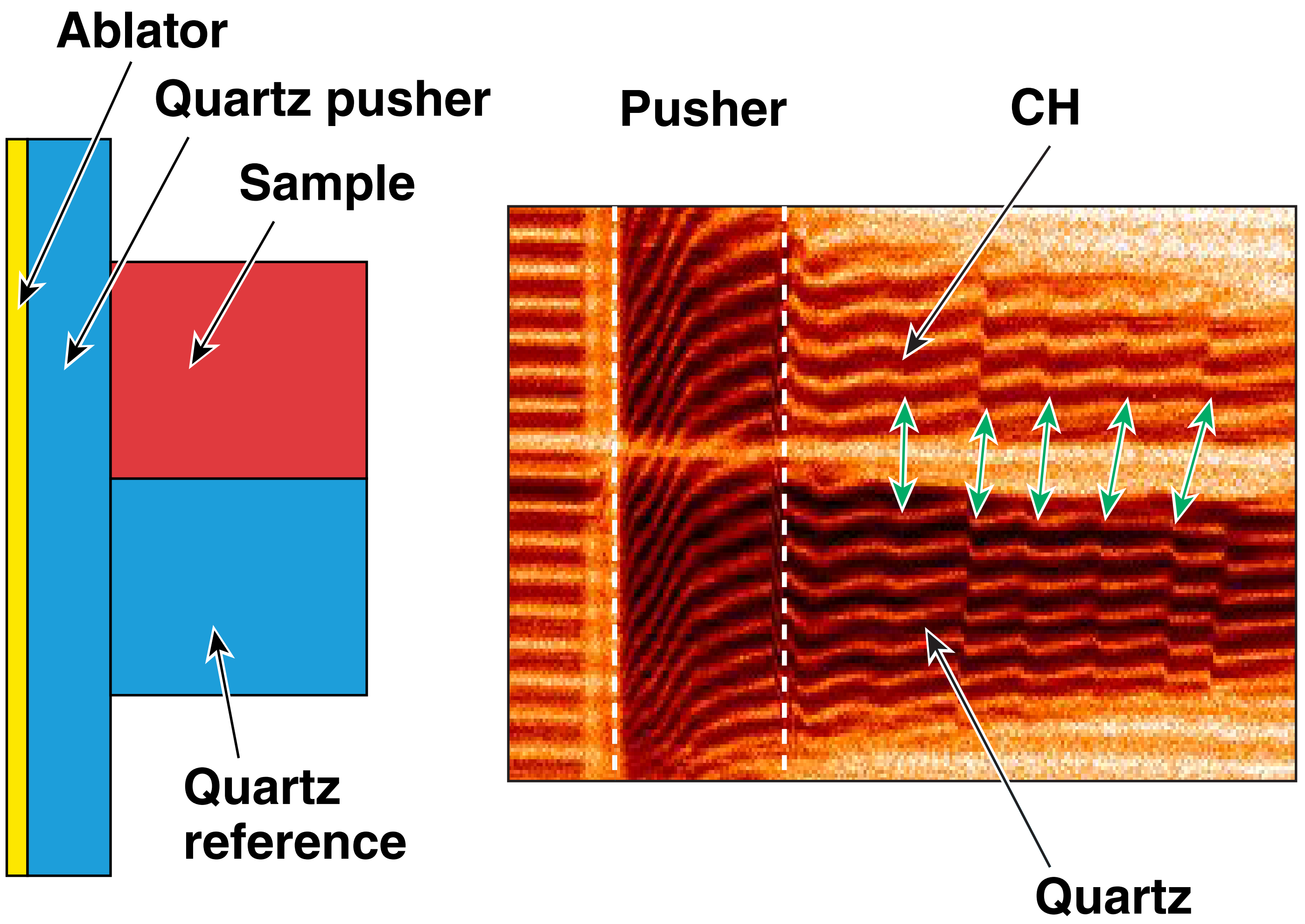
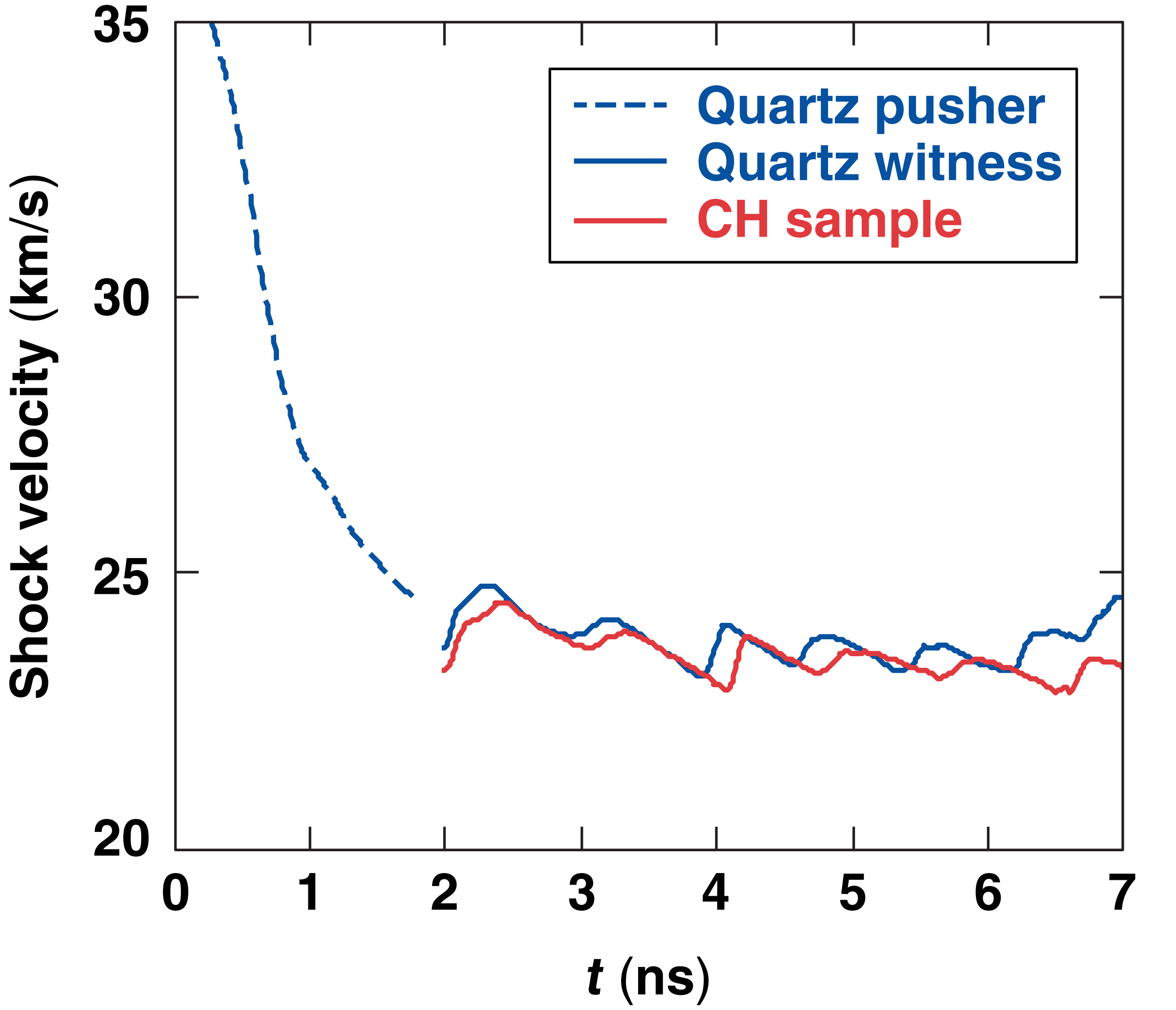
Pressure perturbations propagate at the local sound speeds in the shocked quartz witness and CH sample





The difference in arrival times is used to infer sound speed.

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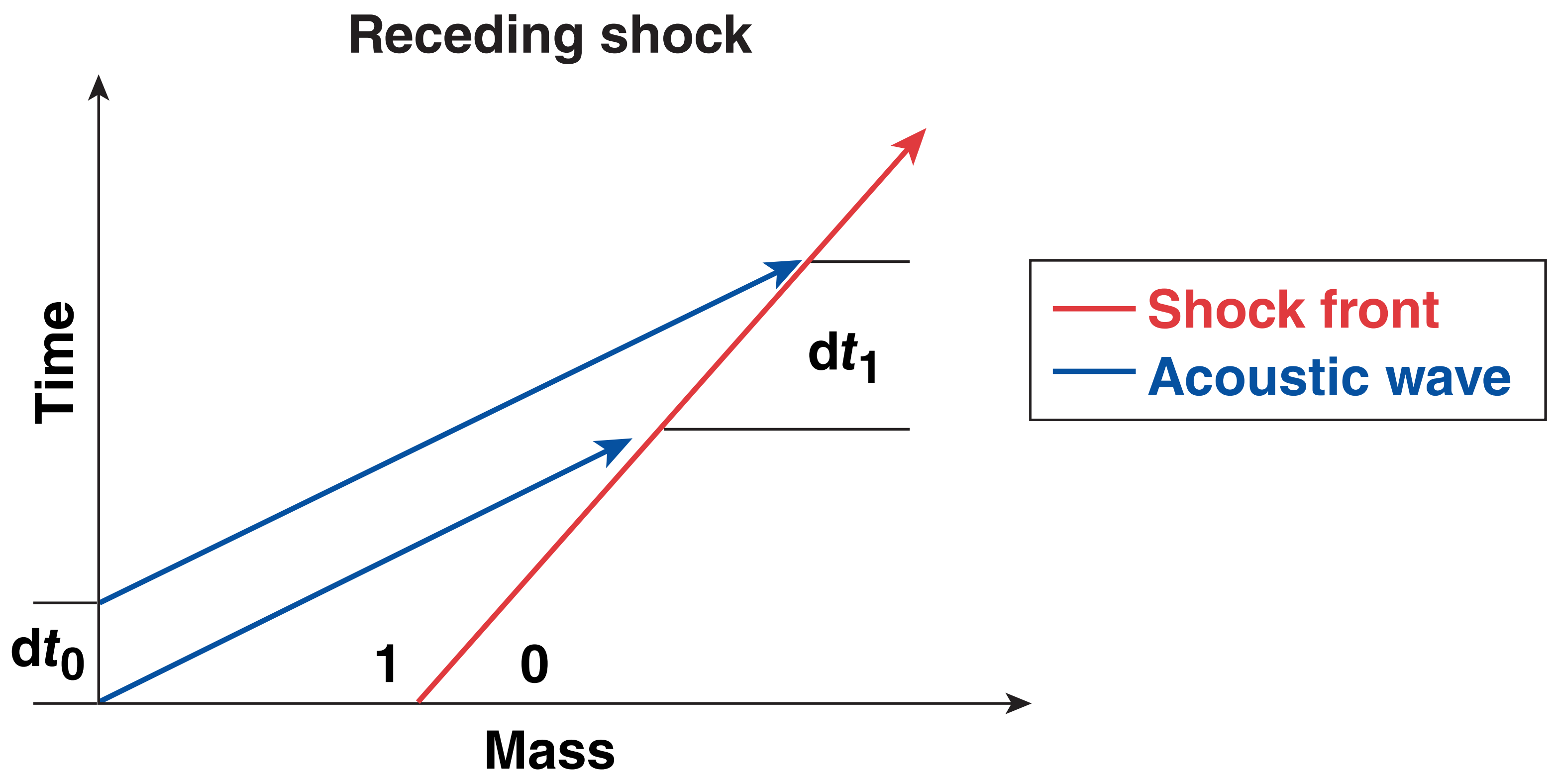
Unsteady wave analysis* is used to propagate acoustic waves through shocked material



- Equations describing time dilation of acoustic disturbances across regions of flow are dependent on Mach numbers
- For example, a receding shock is given by: $$\frac{dt_1}{dt_0} = \frac{(1+M_1)}{(1+M_0)}$$

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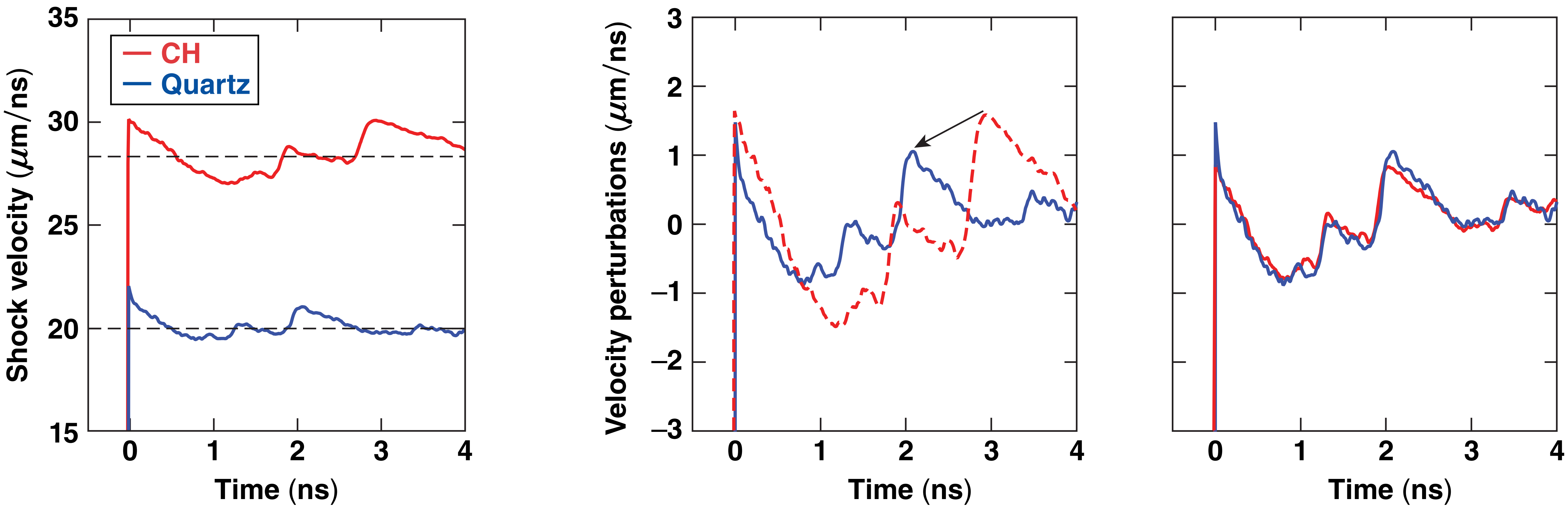
*D. E. Fratanduono *et al.*, J. Appl. Phys. 116, 033517 (2014).

Velocity-perturbation profiles are transformed (using *F* and *G*) to match reference material; these provide sound speed

$$\delta u_W(t-t_1) = G\delta u_S\left[(t-t_1)F^{-1}\right]$$



$$M_{S2,d} = 1 - \frac{(1-M_{S1,d})(1+M_{R1,d})}{F(1+M_{R1,u})}$$

$$C_s = \frac{p}{U_p\rho} M_{S2,d}^{-1}$$

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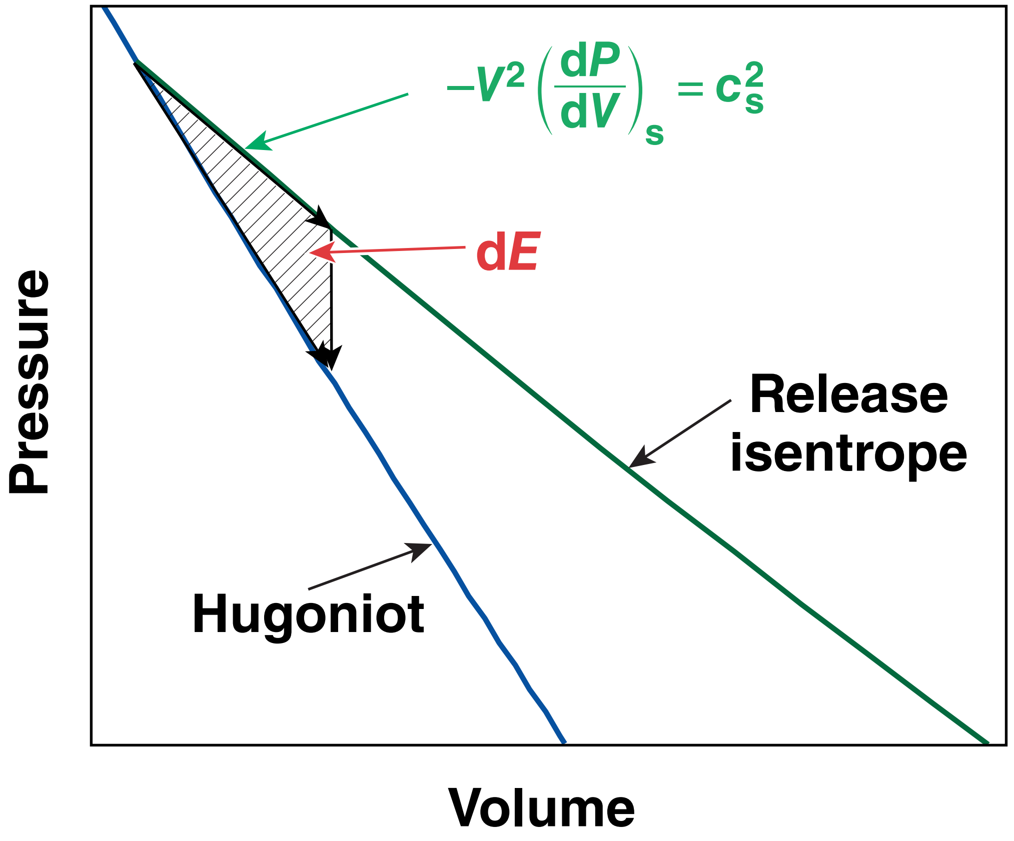
The Grüneisen parameter is determined from the sound velocity and the slope of the Hugoniot curve

- The sound velocity c_s gives the slope of an isentrope at a point where it intersects the Hugoniot curve
- Two slopes define an infinitesimal pressure–volume area, providing d*E* for

$$\Gamma = V\left(\frac{dP}{dE}\right)_V$$

- From the definition of the Grüneisen parameter:

$$\Gamma = \frac{2\left[V\left(\frac{dP}{dV}\right)_H + \frac{c_s^2}{V}\right]}{P_H + \left(\frac{dP}{dV}\right)_H (V_0 - V_H)}$$



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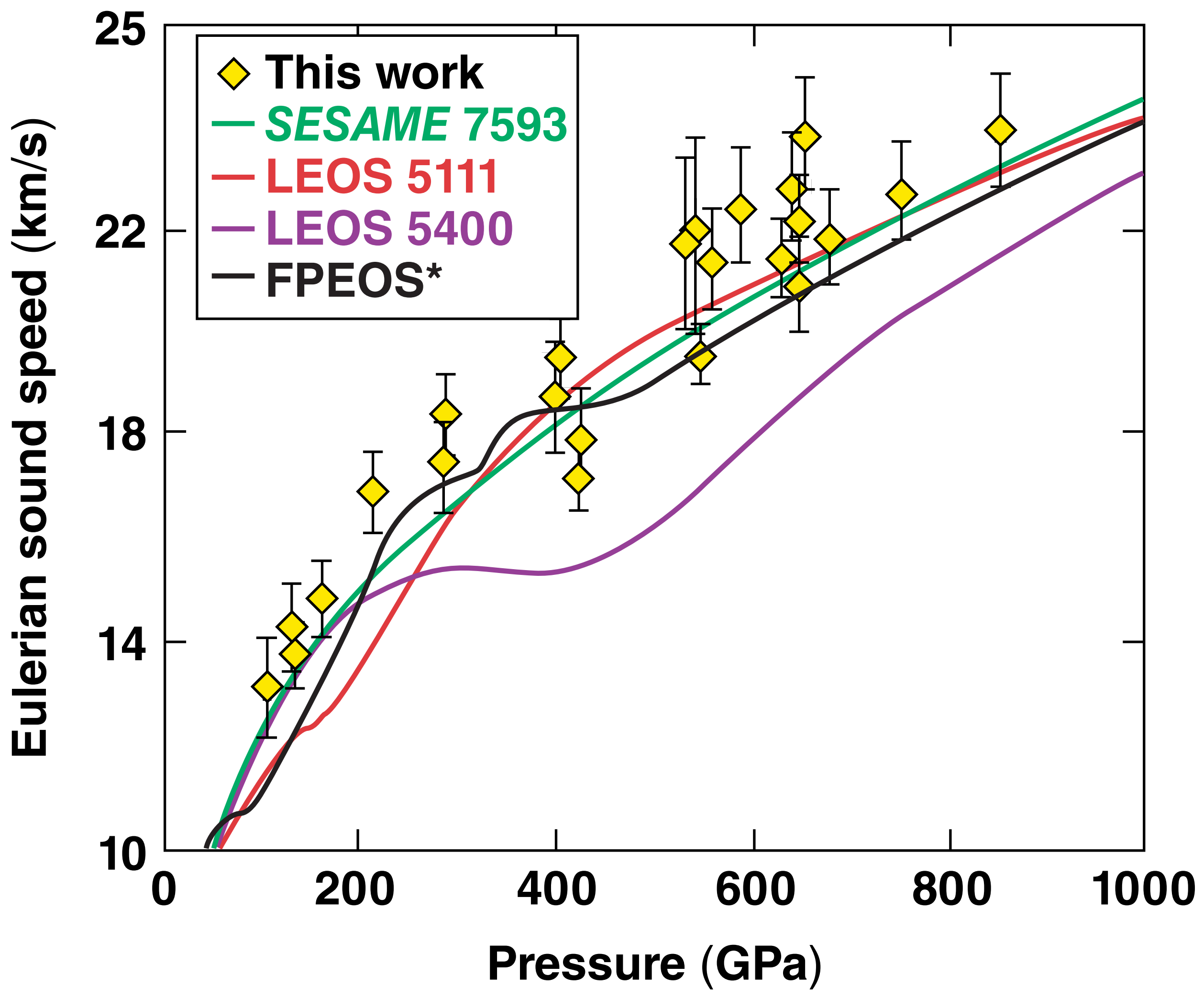
Most models adequately model sound speed of shock-compressed CH



*FPEOS: first-principles equation of state;
S. X. Hu, BI2.00003, this conference (invited);
S. X. Hu *et al.*, Phys. Rev. E 92, 043104 (2015).

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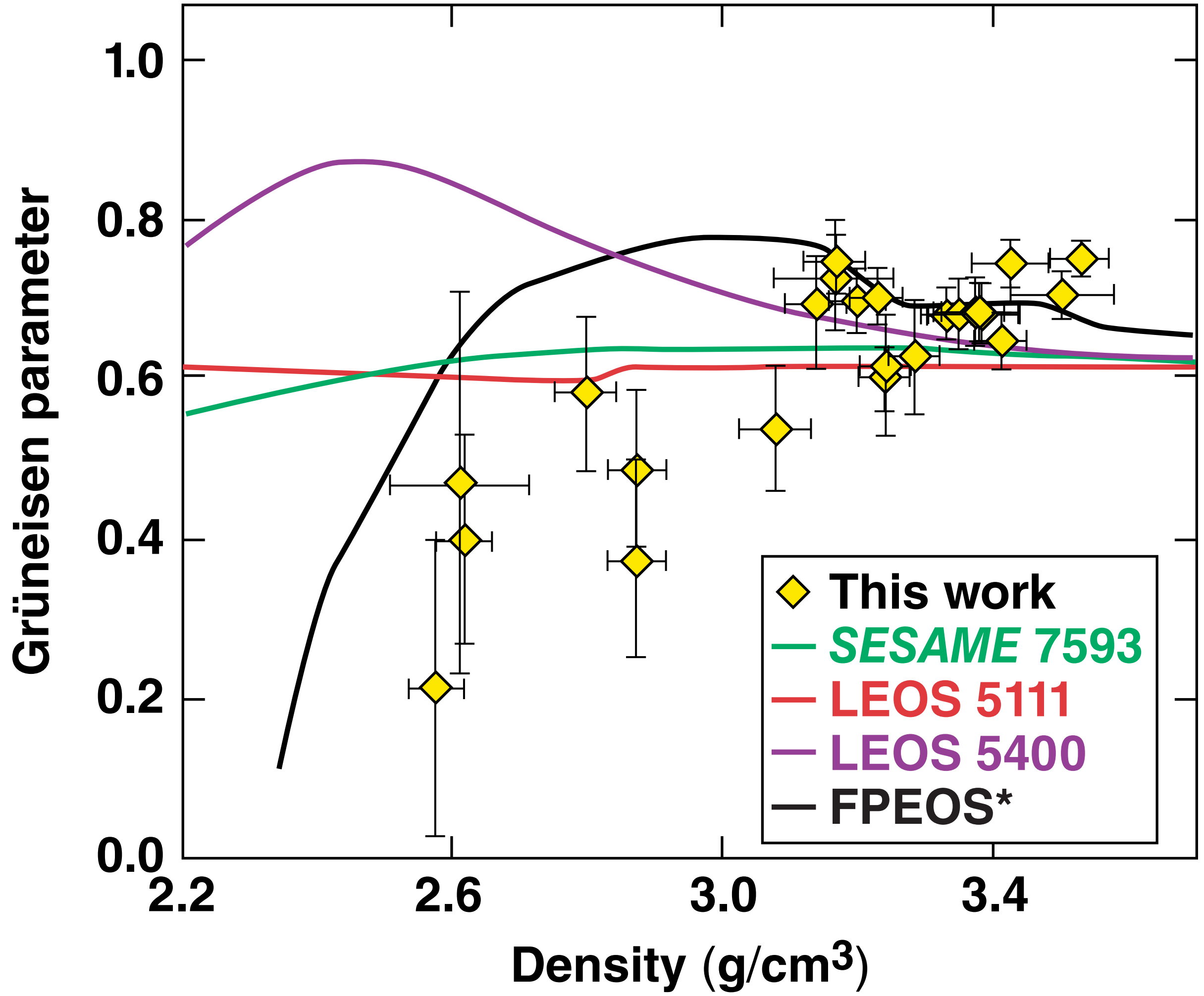
Only first-principle QMD predicts the decreasing Grüneisen parameter at 100 to 400 GPa



Reduced Γ is indicative of energy sinks; i.e., dissociation and ionization.

*S. X. Hu, BI2.00003, this conference (invited); S. X. Hu *et al.*, Phys. Rev. E 92, 043104 (2015).

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Our measurements of Grüneisen parameter and quantum molecular dynamics (QMD) simulations show the effect of energy sinks in shocked CH

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