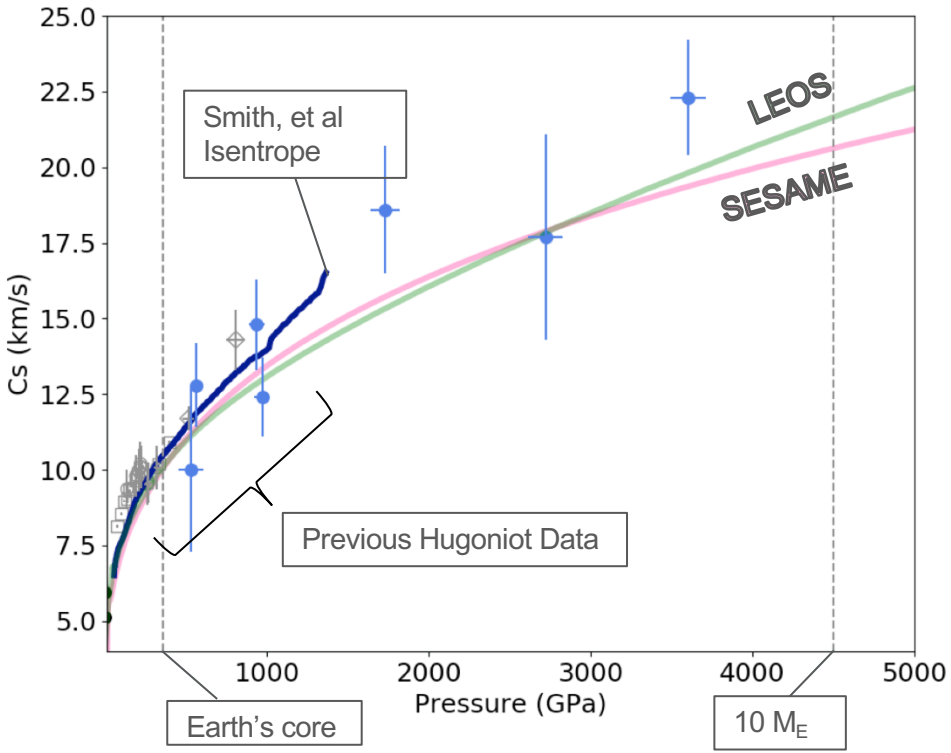
Measurements of Sound Speed in Iron Shock-Compressed to ~4000 GPa



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62nd Annual Meeting of the American Physical Society Division of Plasma Physics

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- At high pressure, the sound speed provides information about thermodynamic derivatives ($c_s^2 = \left.\frac{dP}{d\rho}\right|_s$) of the equation of state.
- The bulk sound speed is calculated with the Nonsteady Waves method* from transit times of pressure perturbations in shocked materials.
- Models for the sound speed in shocked iron predict comparable results with these measurements.

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

Collaborators

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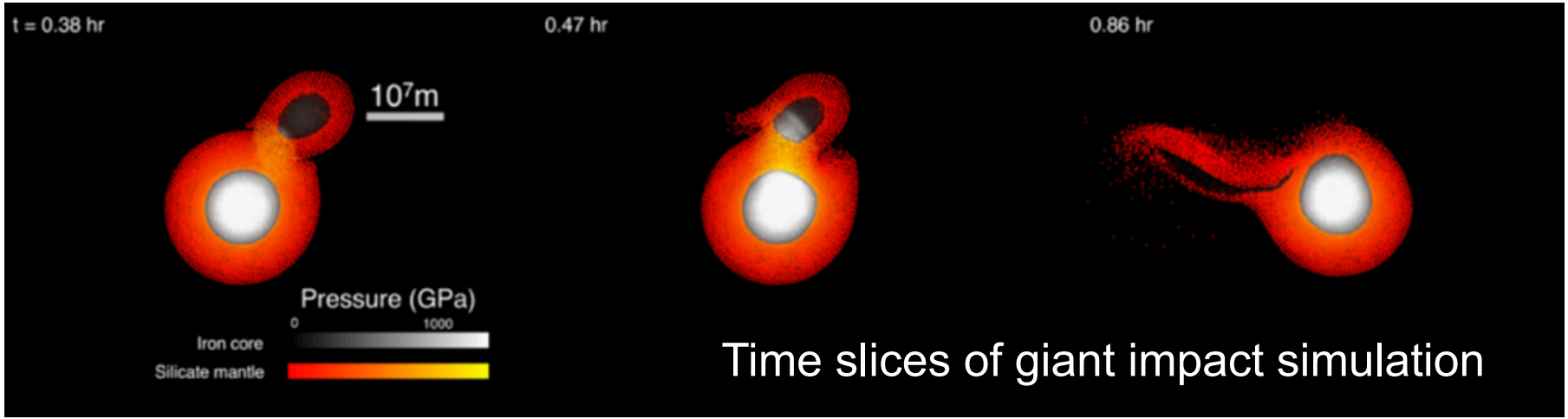
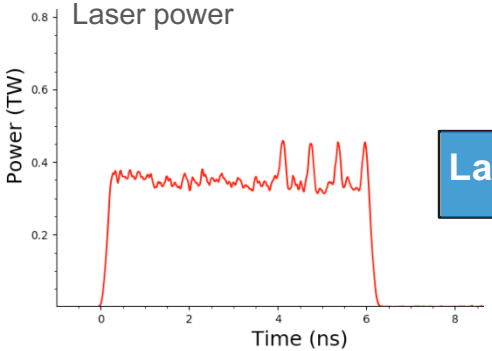
Giant Impact Events

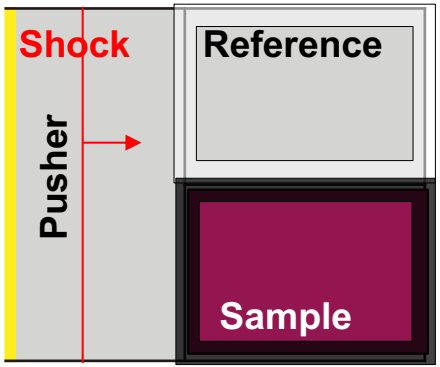
- Sound velocity determines the Mach number in giant impact simulations; a higher sound velocity could imply a stronger shock and more vaporization of iron

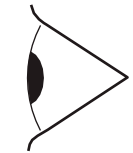


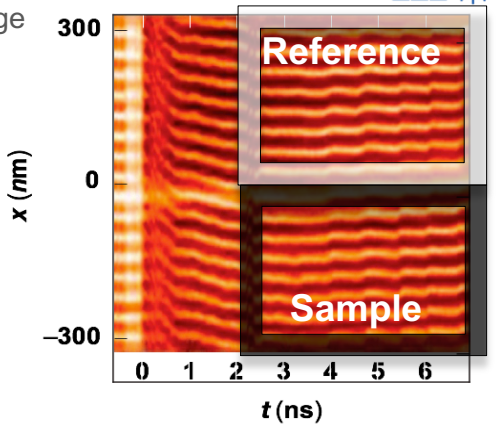
M. Nakajima, et al.

Modulations in the laser drive applied uniformly across a sample and reference are used to infer relative sound speed in the shocked samples

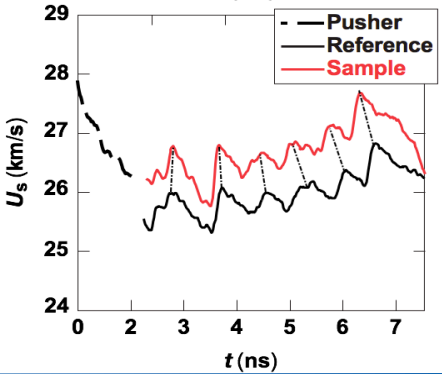








VISAR Lineout

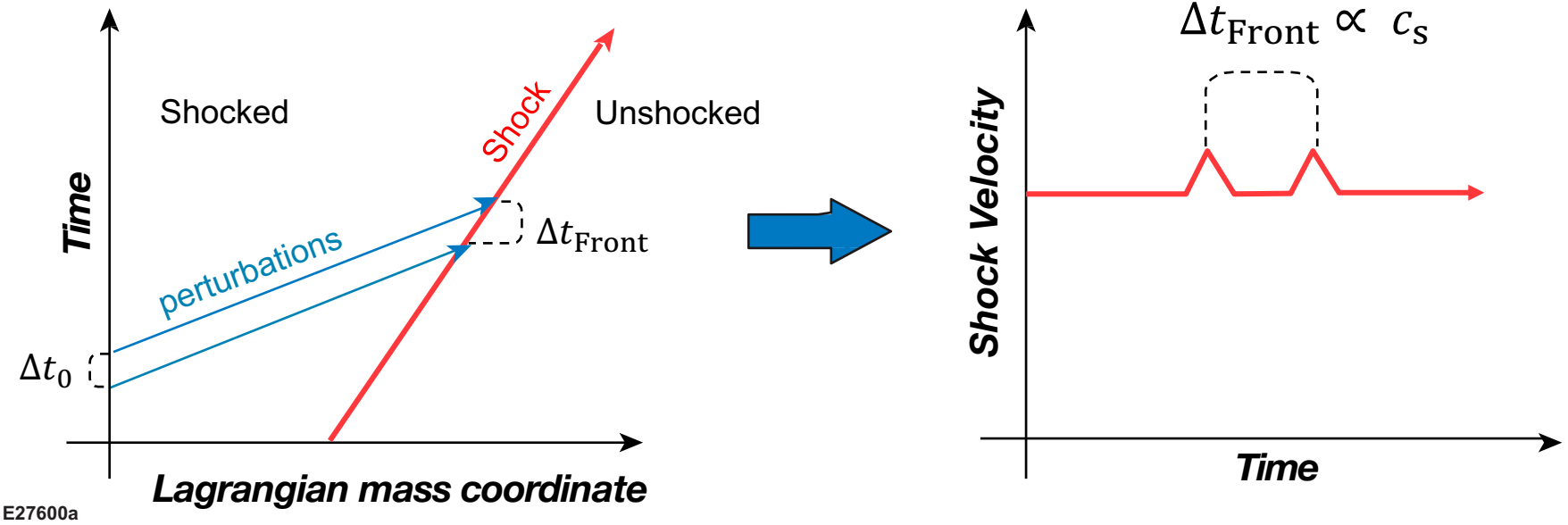


- Transit times are proportional to sound speed
- Referenced to quartz**

*Velocity interferometry system for any reflector

**C.A. McCoy *et al.*, J. Appl. Phys. 120, 235901 (2016).

Perturbations in drive pressure travel at the local sound velocity to catch up with the shock front



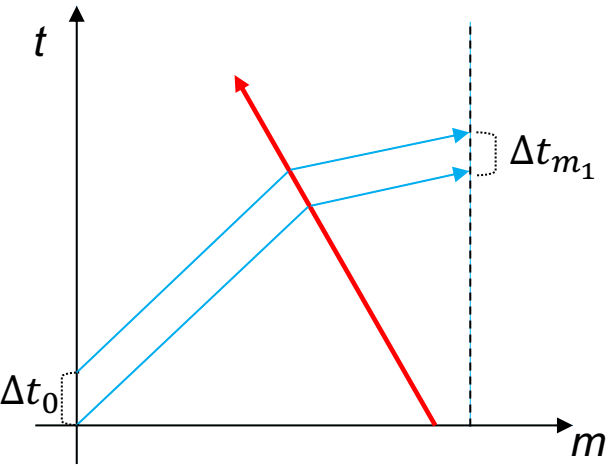
E27600a

Transmission coefficients for temporal and amplitude changes can be calculated for perturbations traversing regions of various states

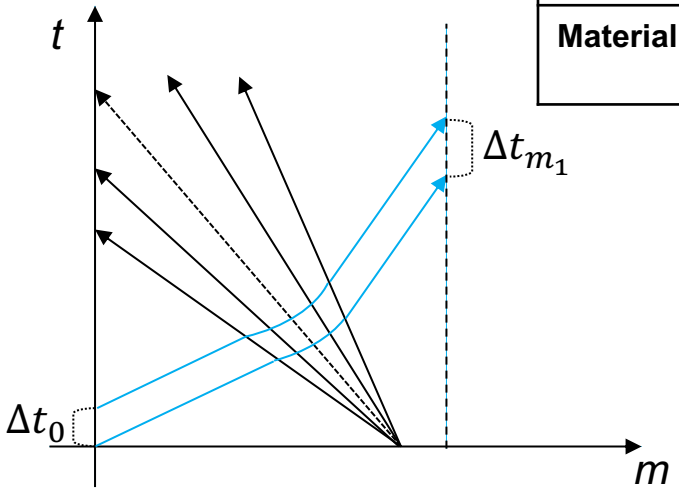
- Sound-speed calculations depend on only the temporal coefficients
- Coefficients depend on the Mach number of the two regions

Receding shock	$\frac{\Delta t_{\text{Front}}}{\Delta t_0} = \frac{1}{1 - M_1}$
Counter-propagating shock	$\frac{\Delta t_{m1}}{\Delta t_0} = \frac{1 + M_1}{1 - M_0}$
Rarefaction	$\frac{\Delta t_{m1}}{\Delta t_0} = \frac{1 + M_1}{1 - M_0}$
Material interface	$\frac{\Delta t_{m_1}}{\Delta t_0} = 1$

Counter-propagating Shock



Rarefaction



Mach number

$$M_n = \frac{P_n}{u_n \rho_n c_{s,n}}$$

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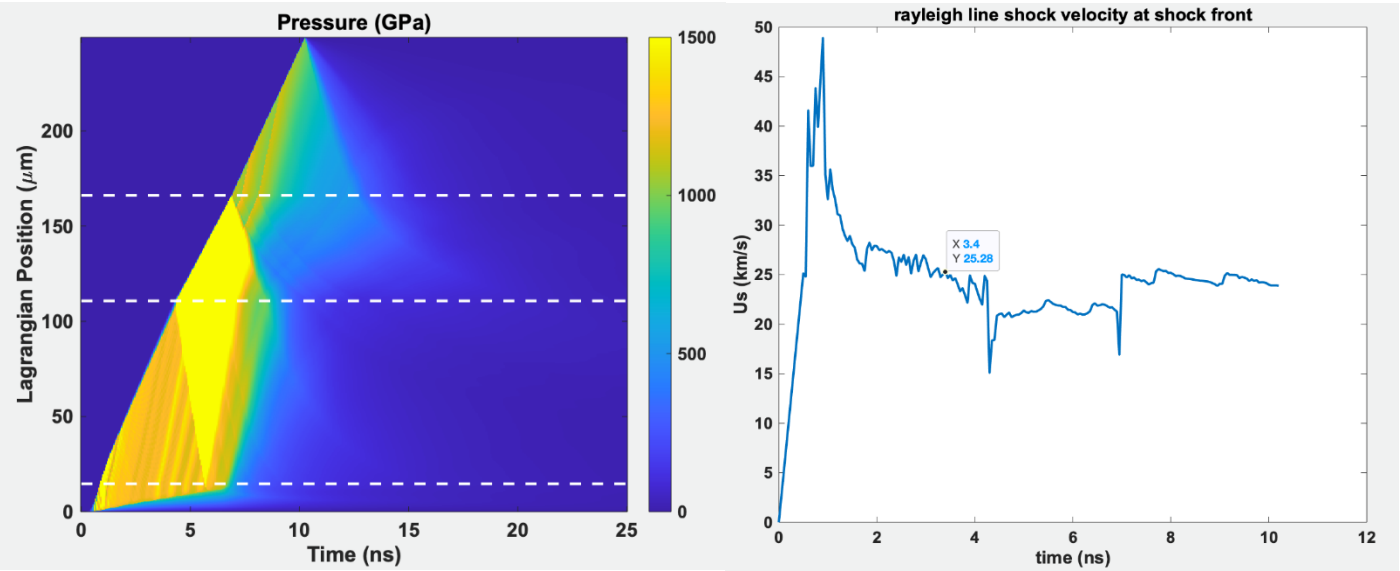
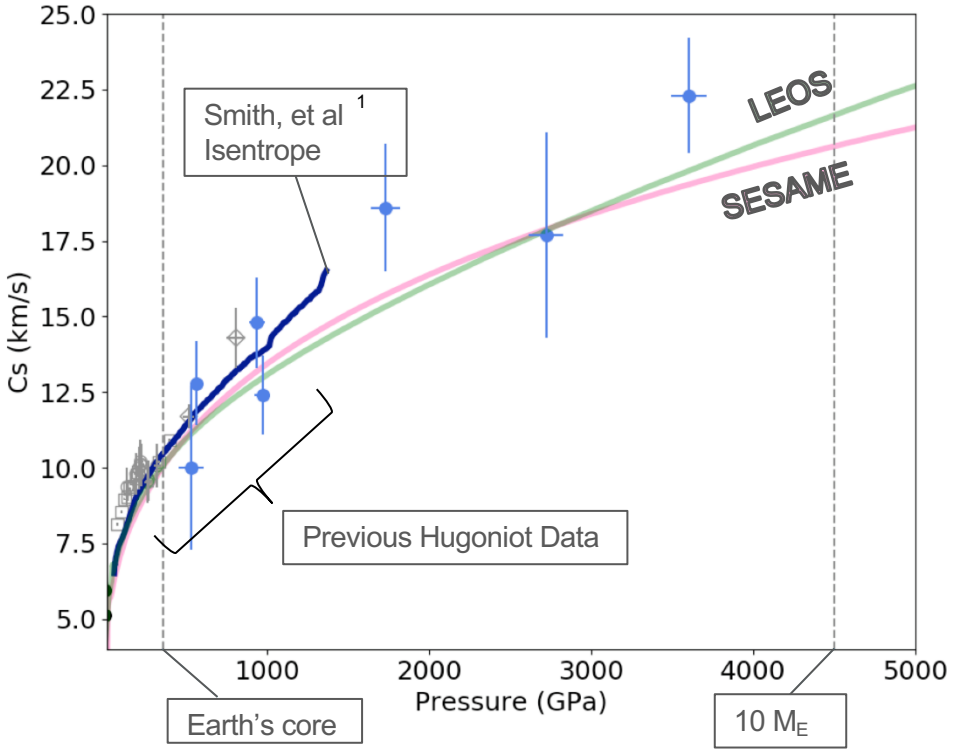
HYADES simulations validate the Nonsteady Waves technique to extract sound speed



- A 1d hydrocode provides a simulated shock velocity
- Analysis using the Nonsteady Waves method recovers the sound speed along the Hugoniot

The sound speed was measured in shock-compressed iron to 3700 GPa



This work

previous sound speed data on the Hugoniot [2]

1 R. F. Smith, et al., *Nature*, 2, 452–458, (2018)

2 J. H. Nguyen and N. C. Holmes, *Nature* 427,339 (2004).
J. M. Brown and R. G. McQueen, *J. Geophys. Res.*, 91(B7), 7485–7494 (1986).
Sakaiya,et al, *Earth Planet. Sci. Lett.* 392, 80-85, (2014).

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Thank you for your time

Please email any comments or questions to mhuf@lle.rochester.edu, I will be happy to respond.