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Hugoniot Measurements on Sylgard and HNAB via Ultrafast Time Domain Interferometry

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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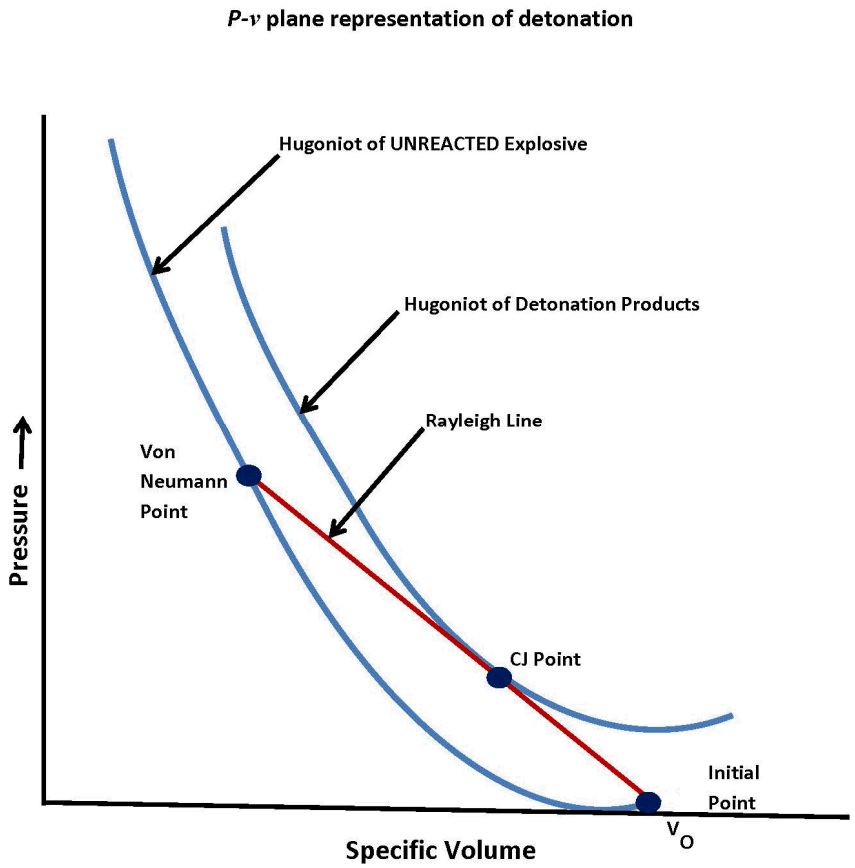
Motivation and Goals

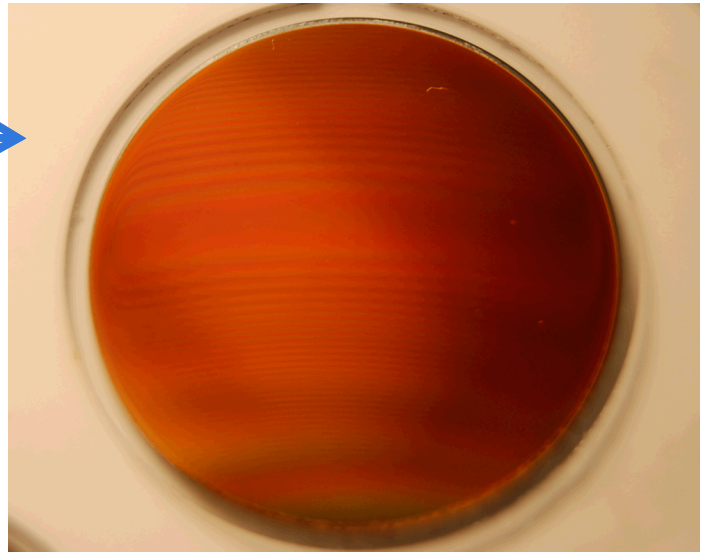
Experimentally-verified Equations of State (EOS) for energetic materials are typically limited to pressures well below detonation pressure.

We need sub-ns time resolution to measure shock and particle velocities of energetic materials before they react.



Why HNAB?

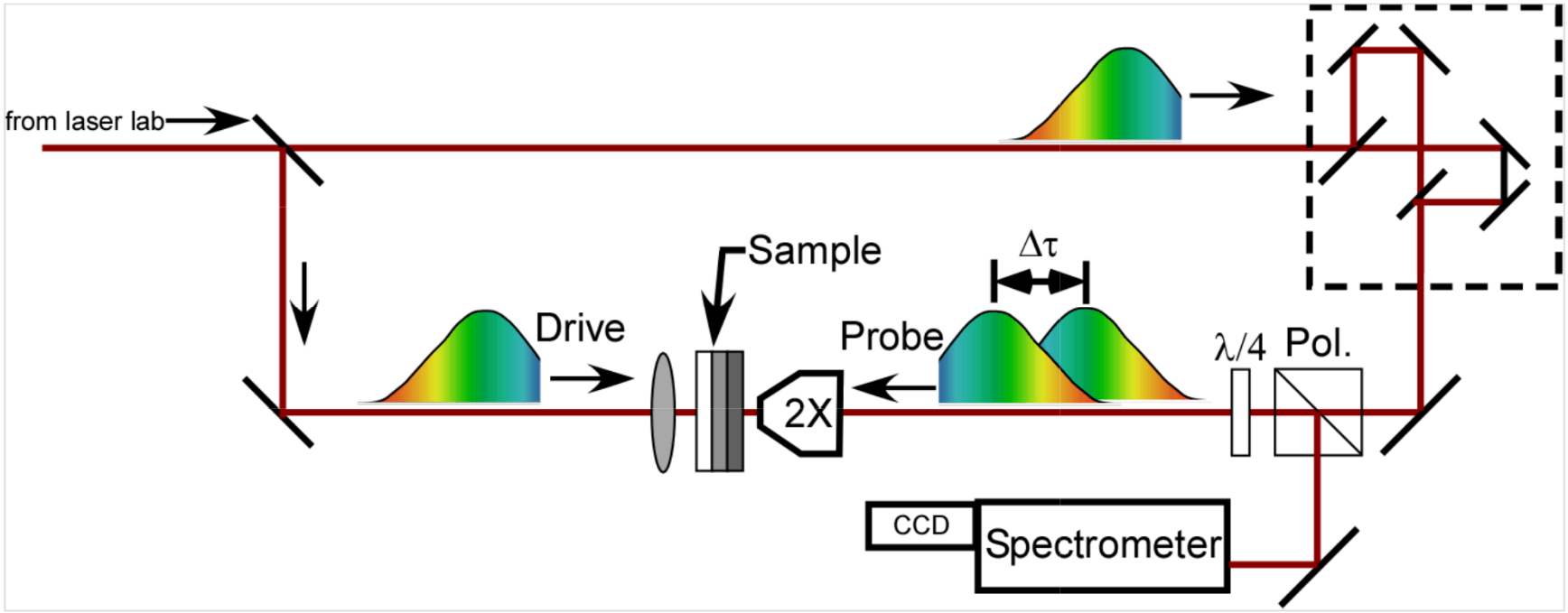
HNAB can be vapor-deposited as a fully-dense amorphous thin film.



Over a matter of weeks, it crystallizes into several different forms.

The amorphous and crystallized films are chemically identical and have almost identical densities. Microstructure is the major difference, making it a model system for studying the effects of microstructure on performance and sensitivity.

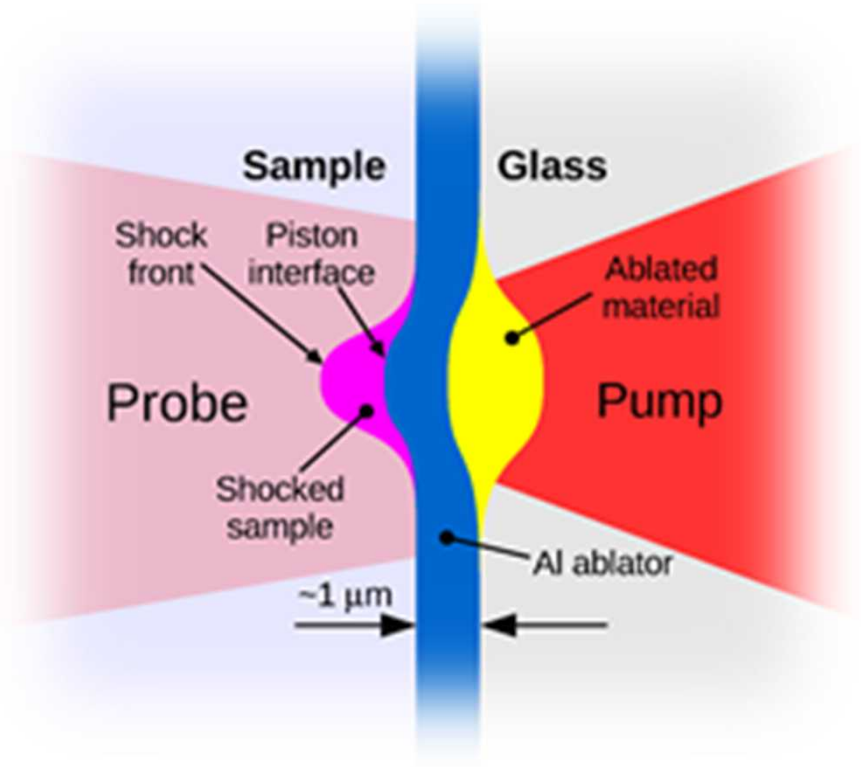
Ultrafast Time Domain Interferometry

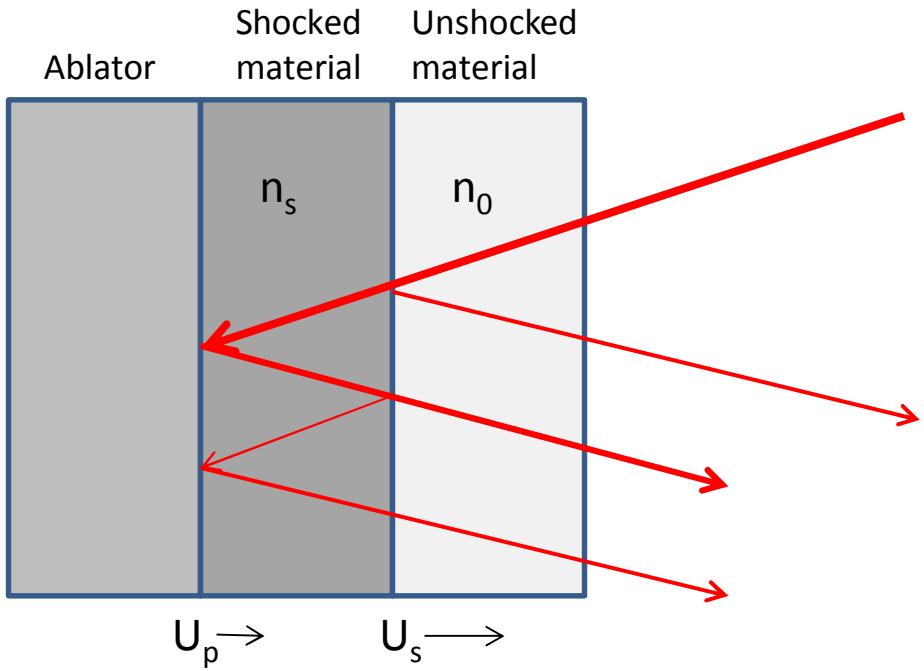


We achieve picosecond time resolution by encoding time onto wavelength and measuring wavelength with a slow spectrometer. Pulse are ~300-400 ps long with separation of ~10 ps.

Timing jitter is minimized by using the same laser pulse to drive the shock and probe U_P and U_S from the other side of the target.

UTDI: Material interaction model



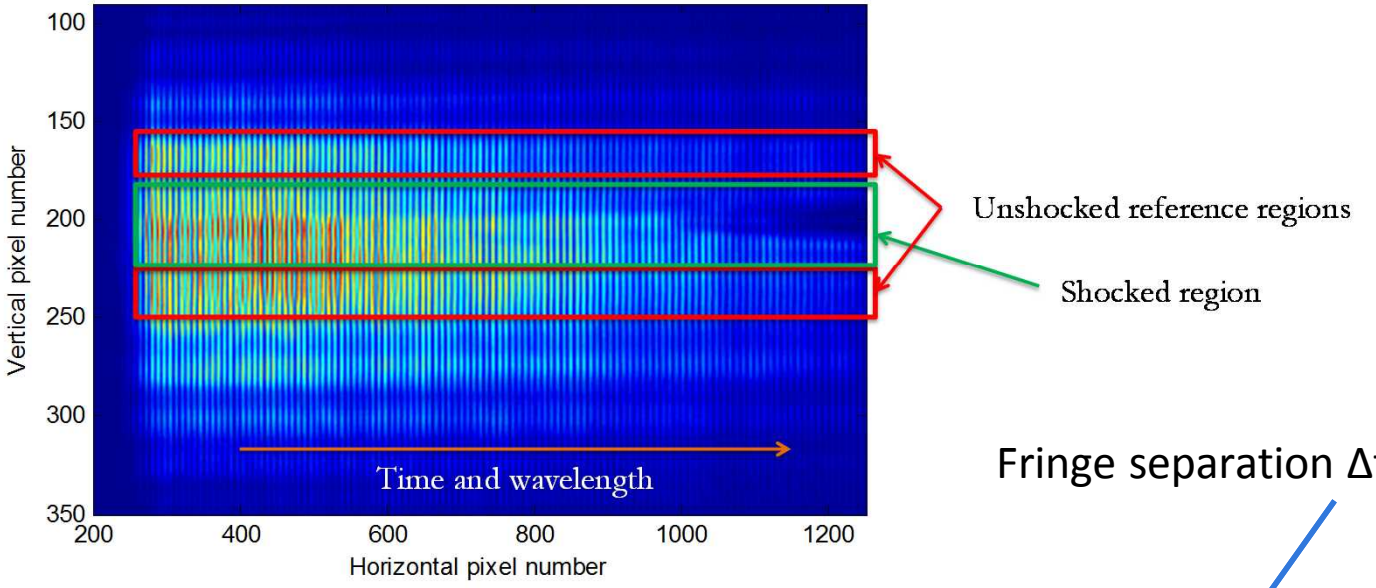


Shocks are nominally 1D. 20-30 µm spot size, <1 µm surface displacement.

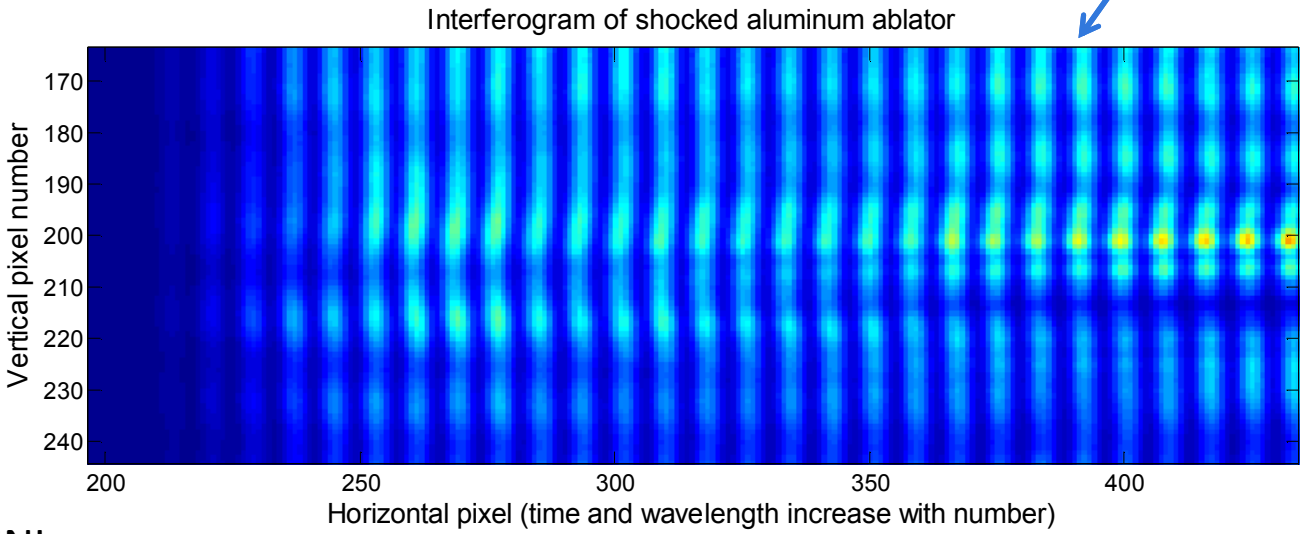
Displacement of ablator and shock are greatly exaggerated for clarity.

Because $U_S > U_P$, the shock front and ablator form an expanding etalon and the interference of reflections changes with time!

UTDI: A Homodyne Interferometer like VISAR

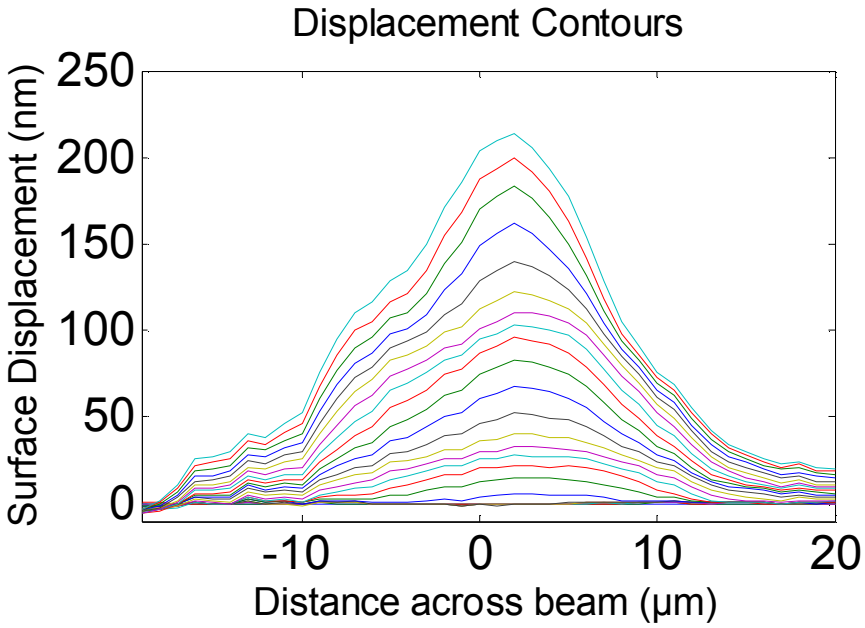


Fringe separation $\Delta t = 1/\Delta f \sim 10$ ps

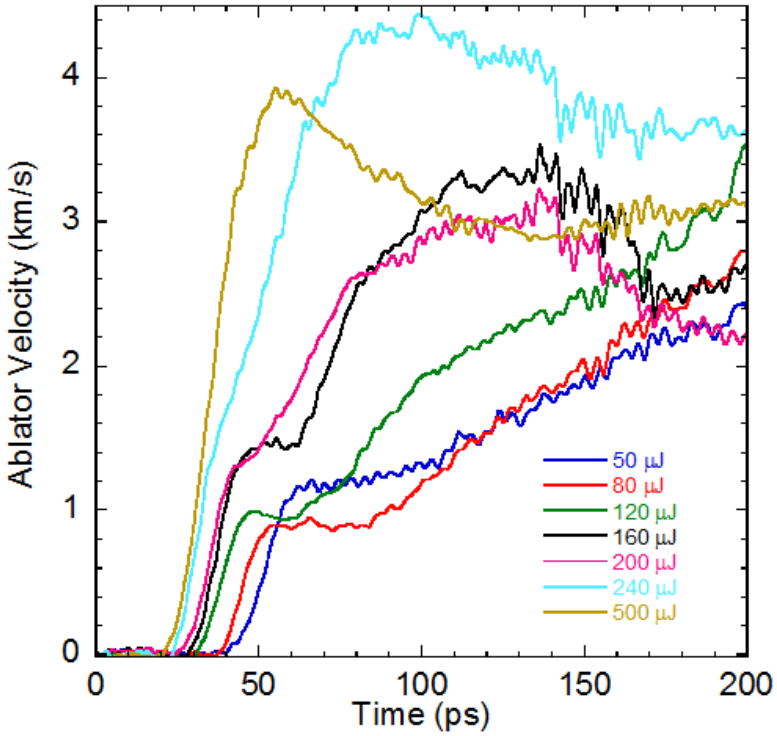


Data from SNL

Bare aluminum ablator data



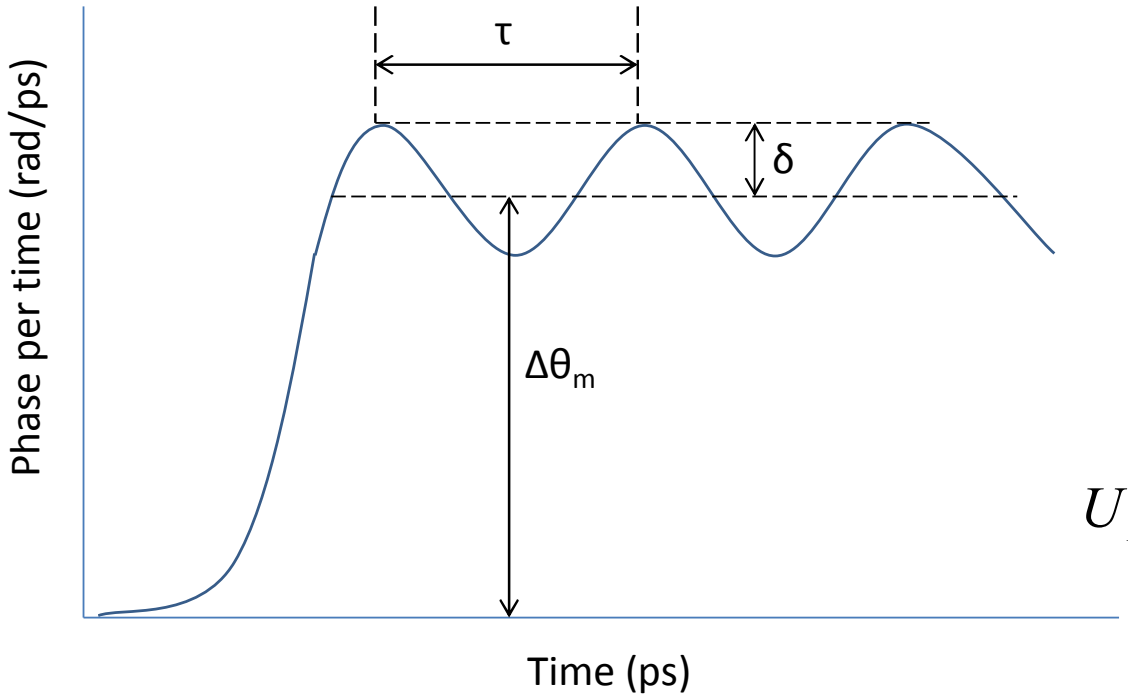
Contours generated by integrating velocity over time for various time steps. Each controur is ~8 ps apart.



Free-surface ablator velocity profile changes markedly with drive energy.

Data from SNL

Canonical UTDI signal



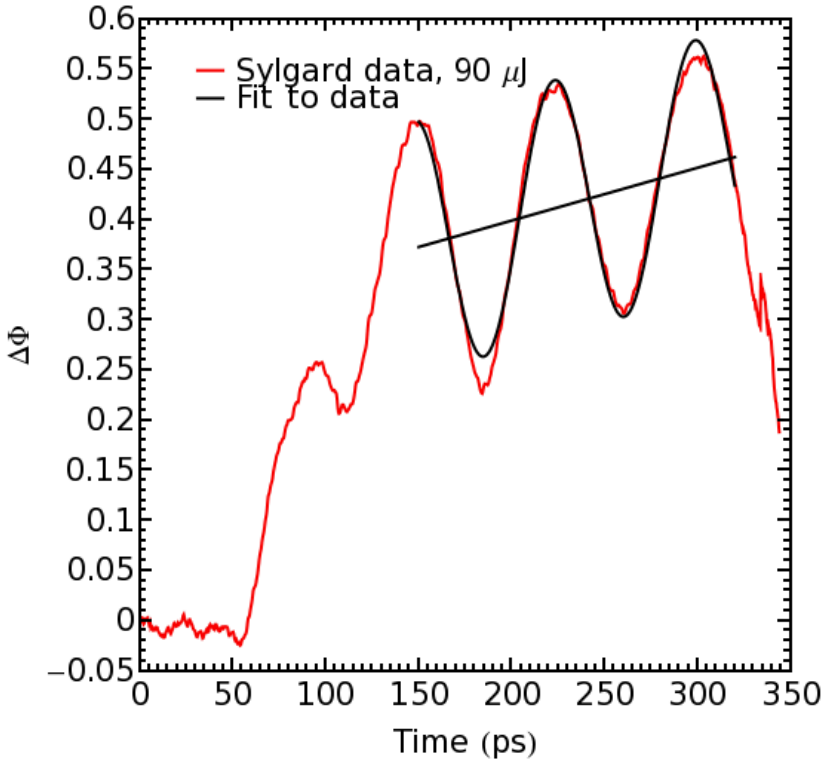
$$U_s = \frac{\lambda}{4\pi n_0}\left[\frac{\Delta\theta_m}{\Delta t} + \frac{2\pi}{\tau}\right]$$

$$n_s = n_0 + \frac{\tau\delta n_0}{2\pi\Delta t - \tau\delta}$$

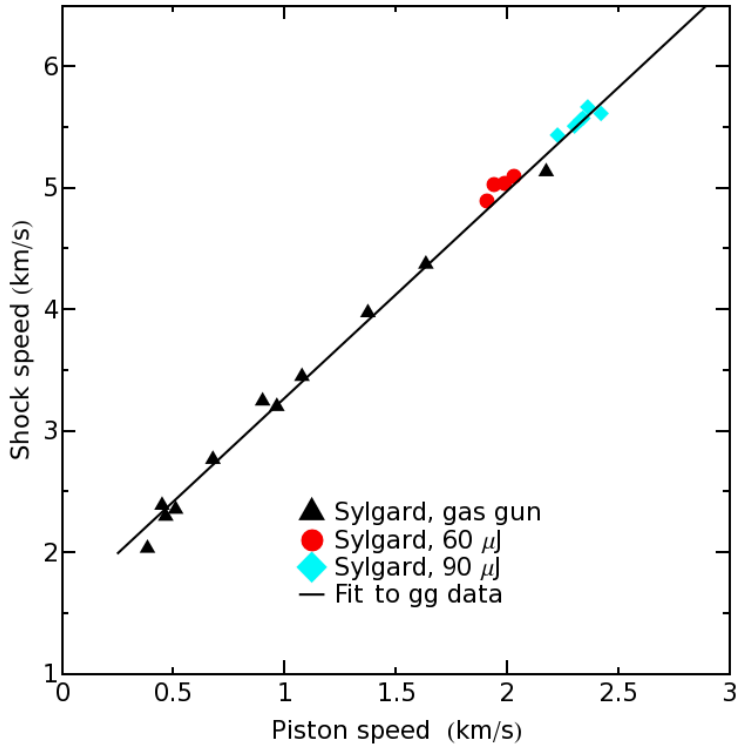
$$U_P = \frac{\lambda}{4\pi n_0}\left[\frac{\Delta\theta_m}{\Delta t} + \frac{2\pi}{\tau}\left(1 - \frac{n_0}{n_s}\right)\right]$$

Expanding etalon between the ablator and shock front causes oscillation in phase of reflected light. The offset, amplitude, and period of oscillation are related to U_P, U_S, and n_S. Besides the fitted parameters, we must also know the pulse separation, Δt, and the unshocked index of refraction, n_0.

Sylgard Hugoniot data



Phase data with region fit to model.

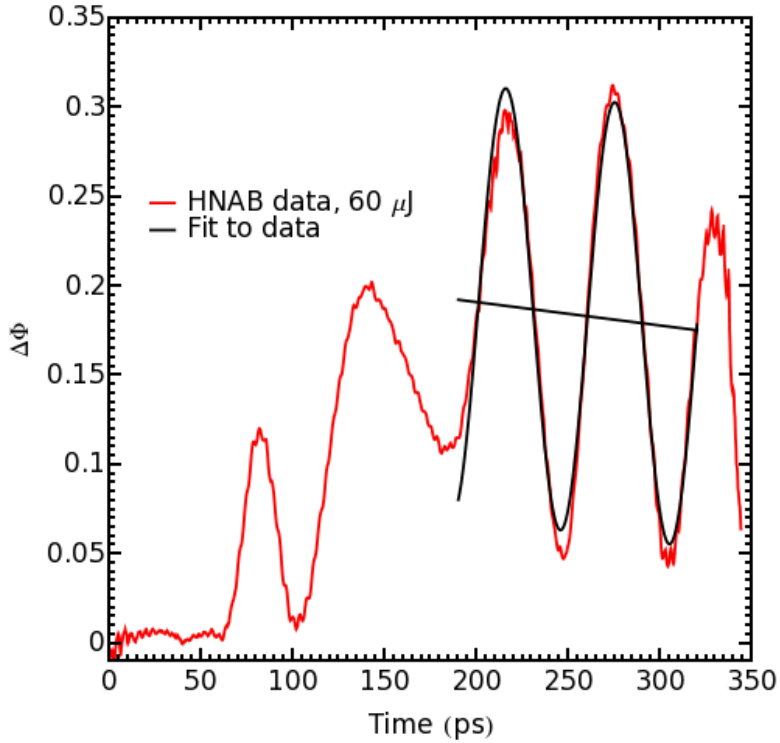


Sylgard Hugoniot compared to gas gun data from Marsh.

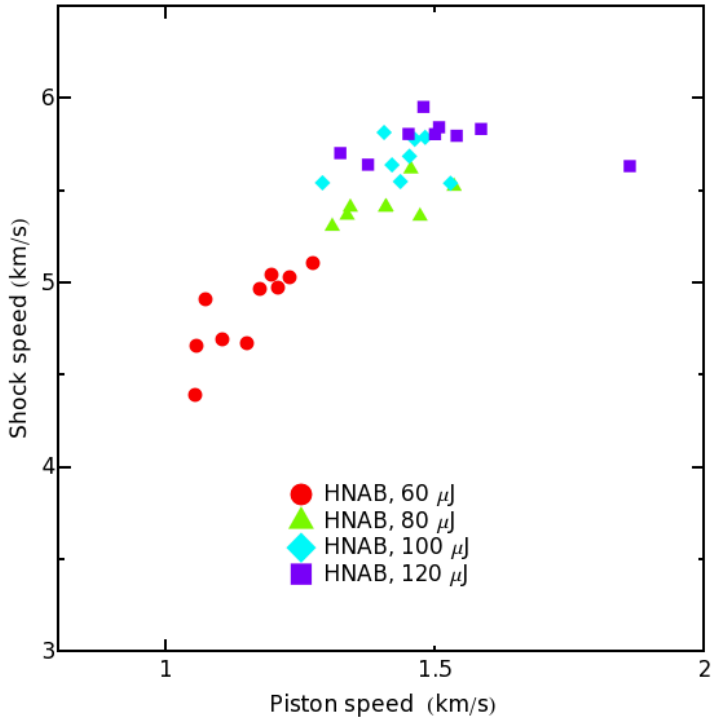
Data from LLNL

Marsh, Stanley P. LASL Shock Hugoniot Data. pp. 482,618, U. of California Press: Berkeley, CA, 1980.

HNAB Hugoniot data



Phase data with region fit to model.



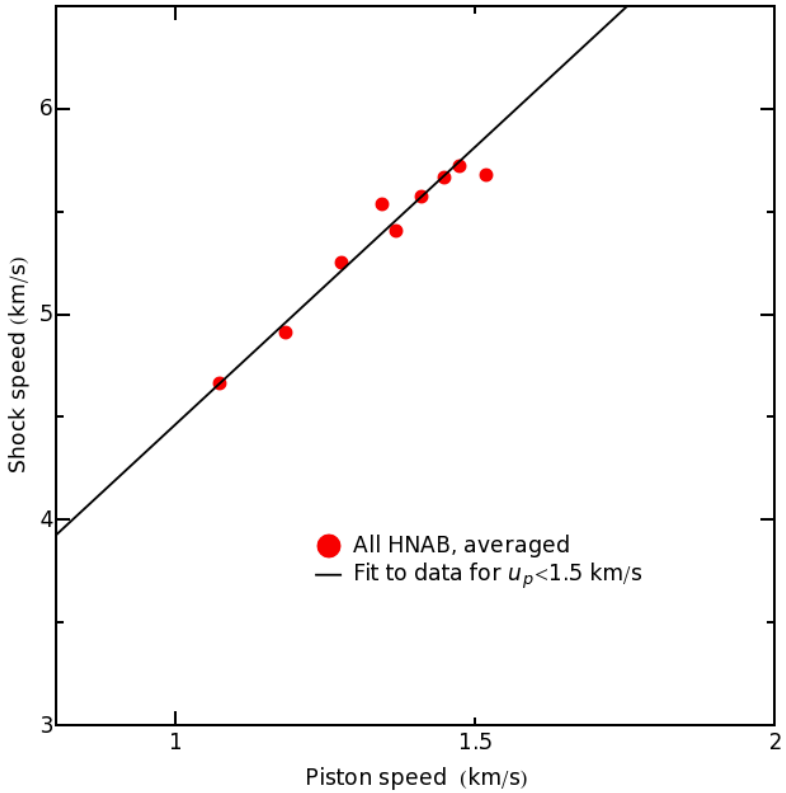
Hugoniot data for crystallized HNAB II assuming an unshocked index of refraction of 1.8.

Data from LLNL

HNAB Hugoniot details

HANB II crystals have an index of refraction of 1.5, 1.7, or 1.8, depending on the orientation of the crystal with respect to the light. In our analysis, we assume 1.8.

HNAB II is polycrystaline with crystals oriented randomly. Which index do you pick?



HNAB data from LLNL after binning into groups of 5, averaging, and eliminating one outlier.
Best fit line: $U_S = 2.70U_P + 1.77$ [km/s]

McCrone, W. C. "Crystallographic Study of Hexanitroazobenzene (HNAB)" SAND75-7067, 1967.

Future Work

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Characterize unshocked index of refraction of HNAB in crystallized and amorphous states to get more accurate Hugoniots.

Develop pulse-shaping techniques to drive sustained, steady shock in materials.

Perhaps develop a new model for analysis that relaxes requirements on steady-state shocks.