HYDRA simulations of radiating shock experiments

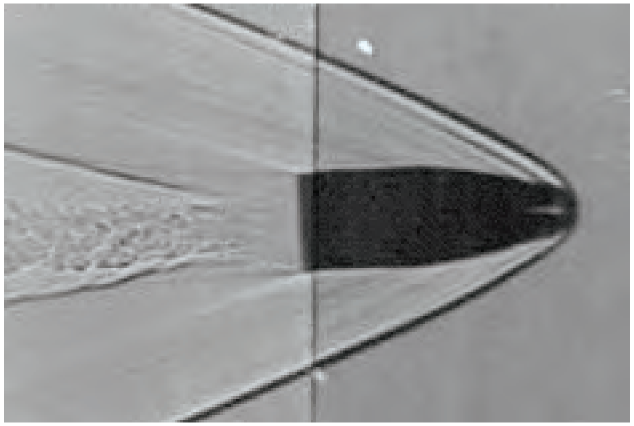
Forrest Doss

Acknowledging, R. P. Drake *(University of Michigan)*
H. F. Robey *(Lawrence Livermore National Laboratory)*

SSGF Annual Conference
July 14, 2009

This research was supported by the DOE NNSA under the Predictive Science Academic Alliance Program by grant DE-FC52-08NA28616, the Stewardship Sciences Academic Alliances program by grant DE-FG52-04NA00064, under the National Laser User Facility by grant DE-FG03-00SF22021, and by the Stewardship Science Graduate Fellowship program.

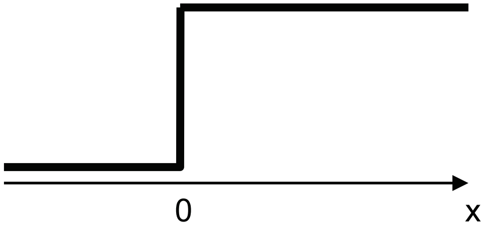
What is a shock?



- Characterized by high-speed, high-pressure fluid dynamics.

- Can be created by an object moving faster than the local speed of sound.

- Shocks take the form of a discontinuity in flow variables (speed, density, pressure, temperature, etc).



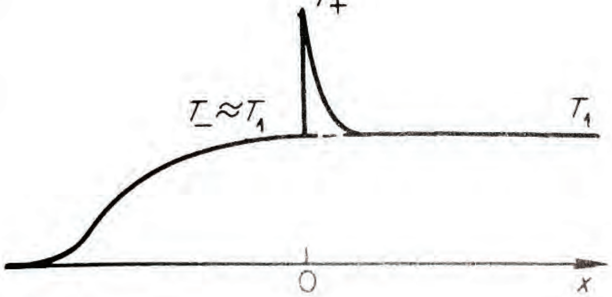
At high shock velocities and low densities, shock structure is changed by radiation

- **We may gauge the importance of radiation in the shock's frame by the ratio of energy emitted by blackbody radiation to the kinetic energy influx,**

$$R_{rad} = \frac{\sigma T^4}{\frac{1}{2}\rho {u_s}^3} \propto \frac{u_s^5}{\rho}$$

where *T* is the initial post-shock temperature, u_s is shock velocity, and ρ is pre-shocked mass density

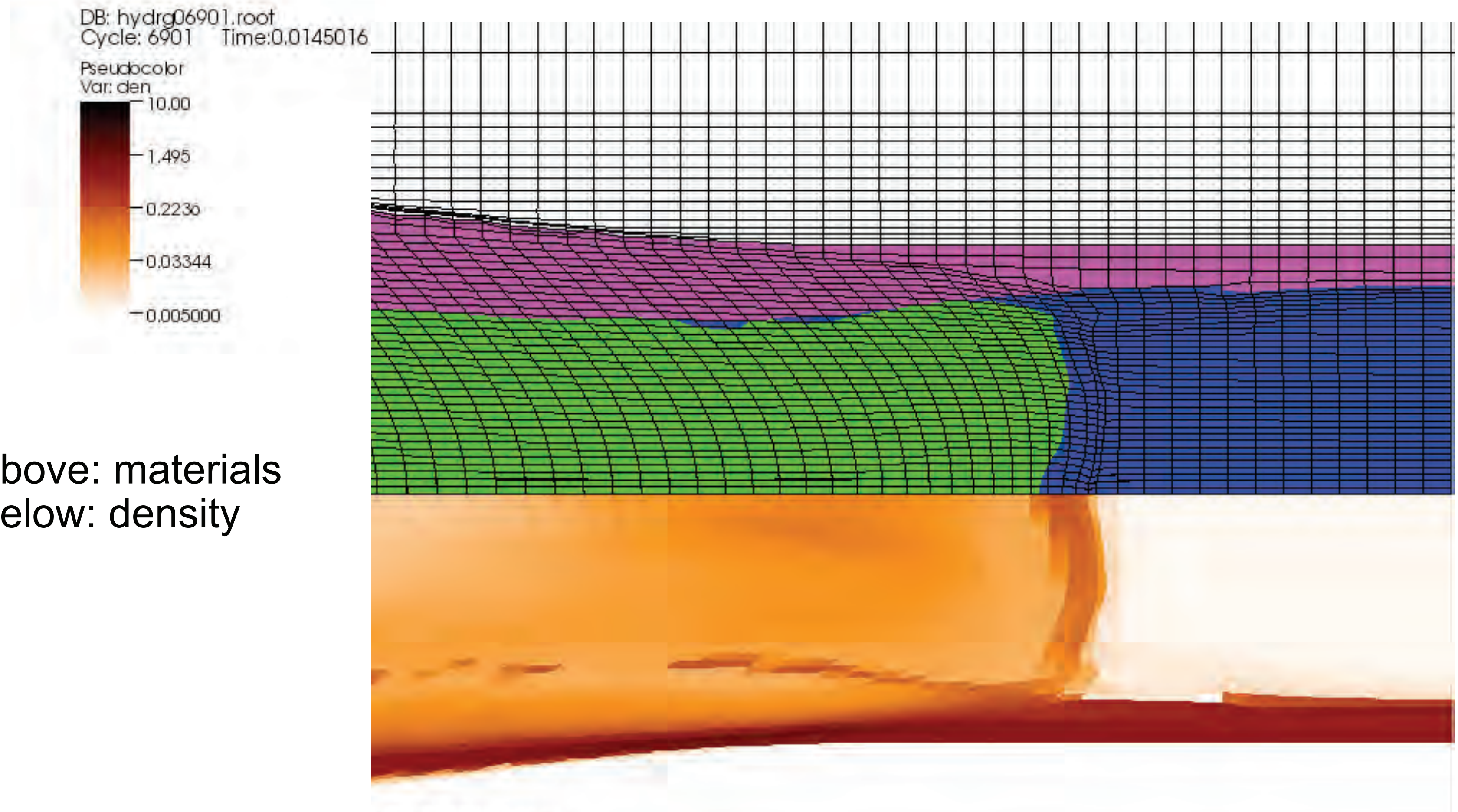
- **Shock structure is changed by the formation of a heated precursor and post-shock cooling [Zel'dovich pg 531]**



- **Additional modifications from changes in opacity**

- **Occur in astrophysics and can be created in laser-driven experiments**

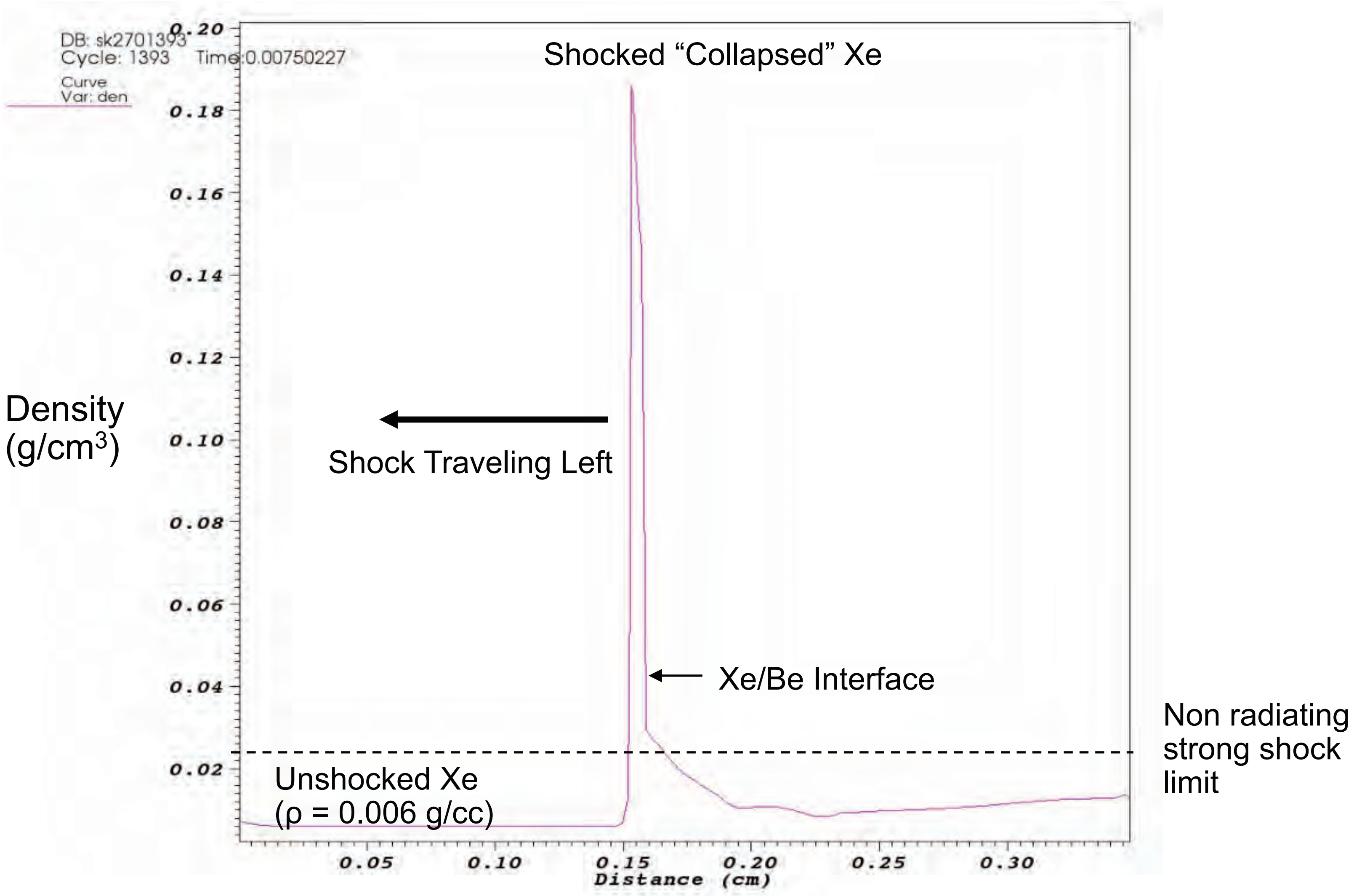
Radiating shocks have been simulated in 2D using HYDRA*



Above: materials
Below: density

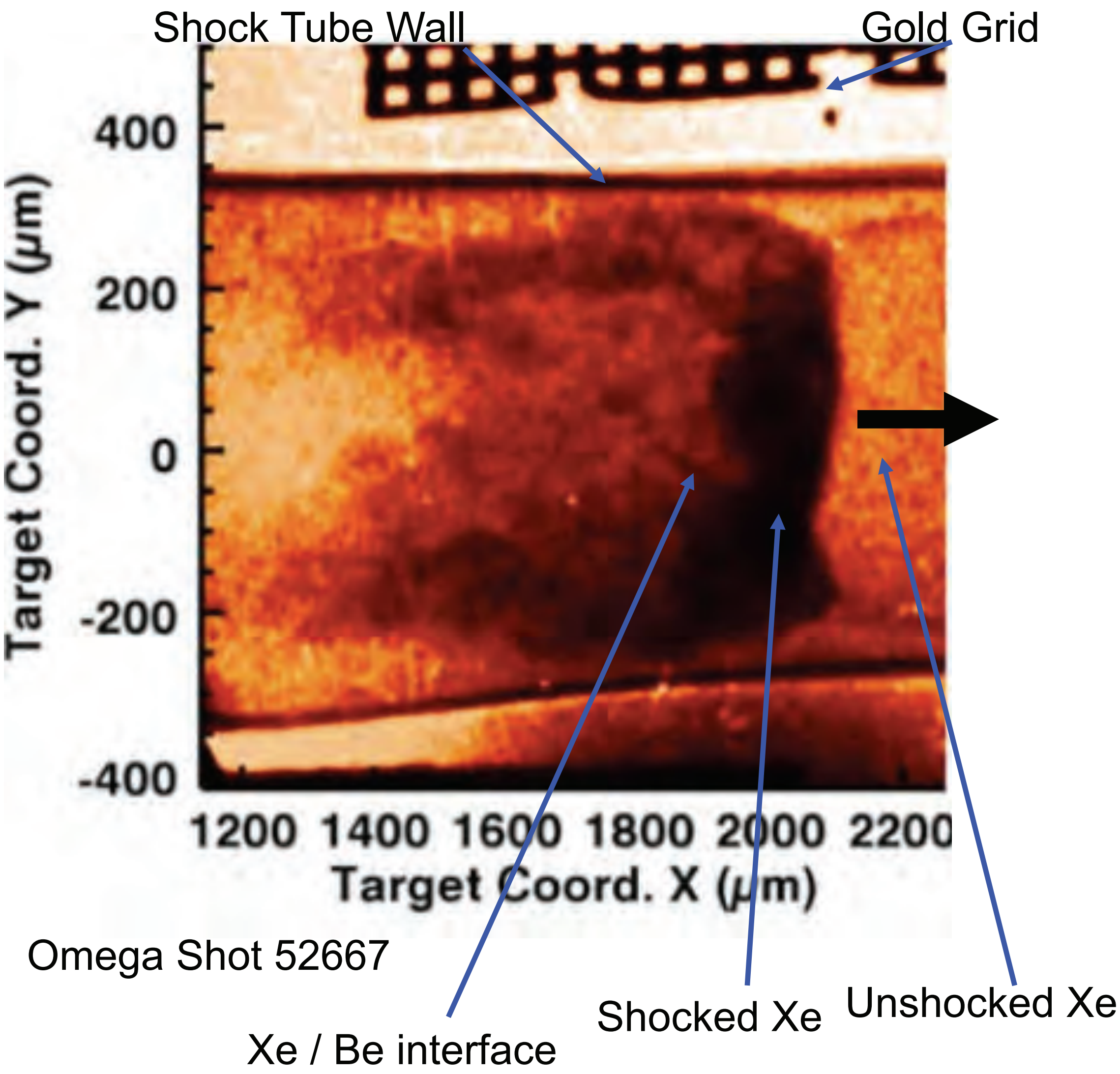
*** M. M. Marinak et al., *Phys. Plasmas* 8, 2275 (2001)**

Previous work had established one-dimensional radiating shock profiles



1D Simulation

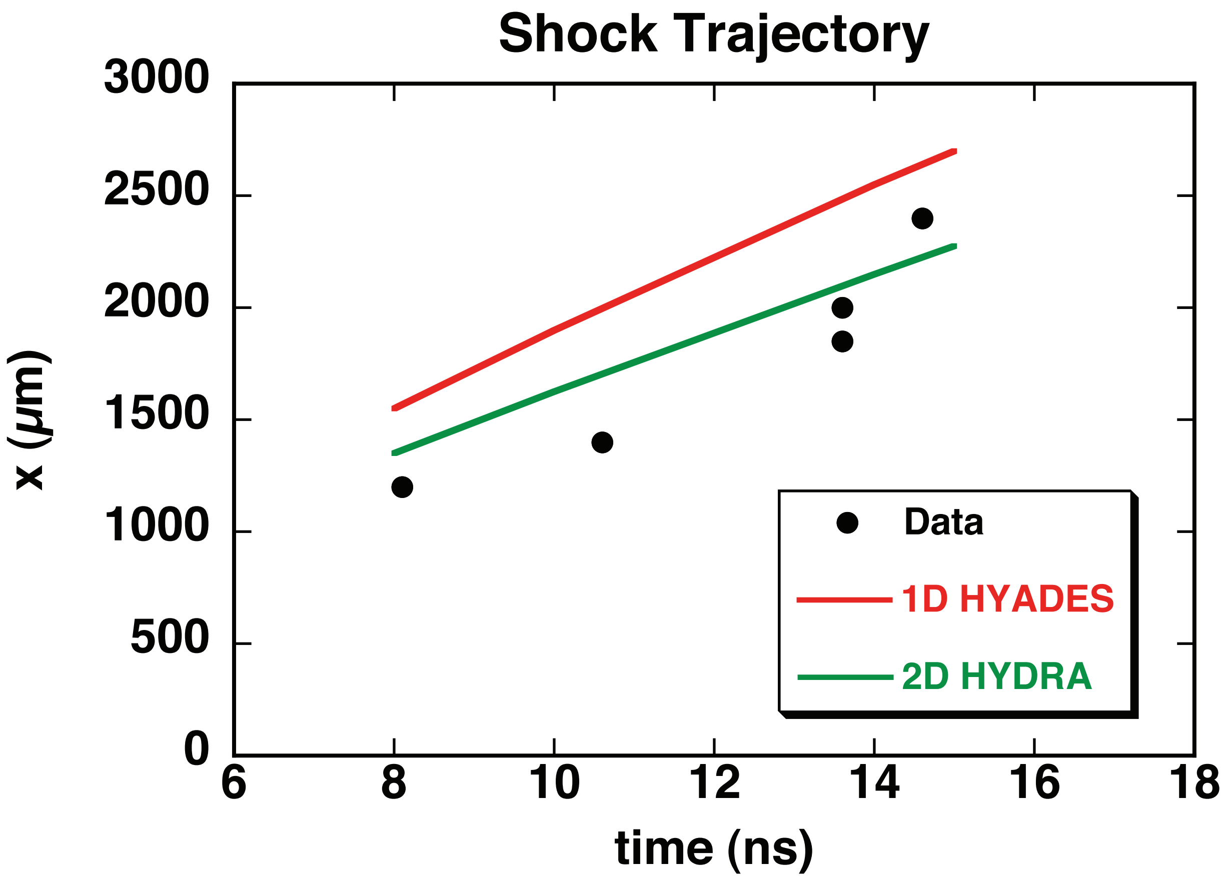
Experimentally, radiography measures shock features



Omega Shot 52667

- Shock is driven by 20 μm Be disc, t = 13 ns, shock traveling at ~110 km/sec.
- Shock has traveled 2 mm, compressed material to < 200 μm.
- Gold Grid serves as a spatial fiducial. Data from pre-shot metrology is used to diagnose lengths in target image.
- The mystery in these images: Why doesn't the shock front reach the walls of the shock tube?

Simulation with 2D HYDRA provides better agreement on shock trajectory than 1D HYADES

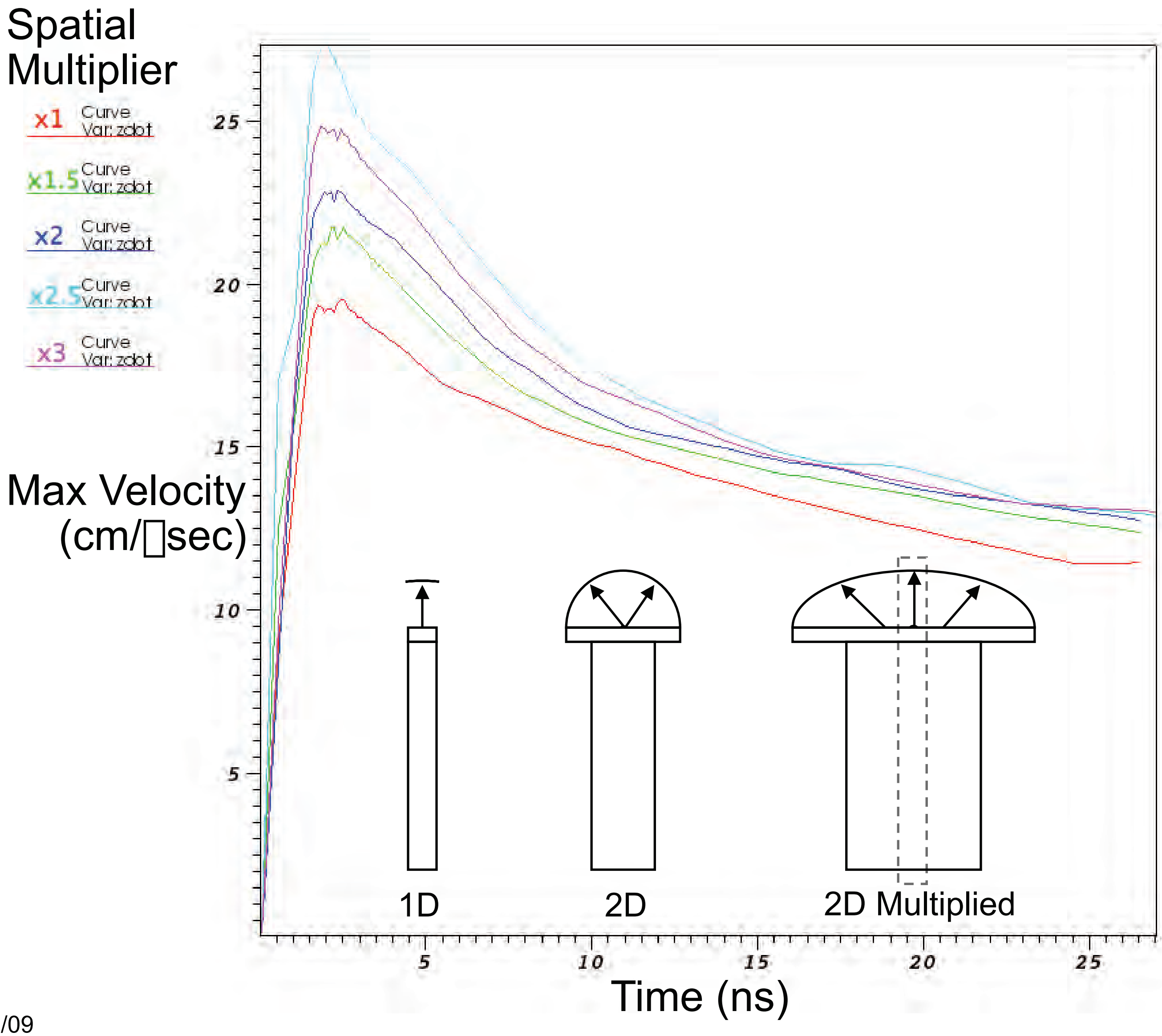


- Points are shock positions recorded by calibrated radiography.

- Each data point is a separate shot.

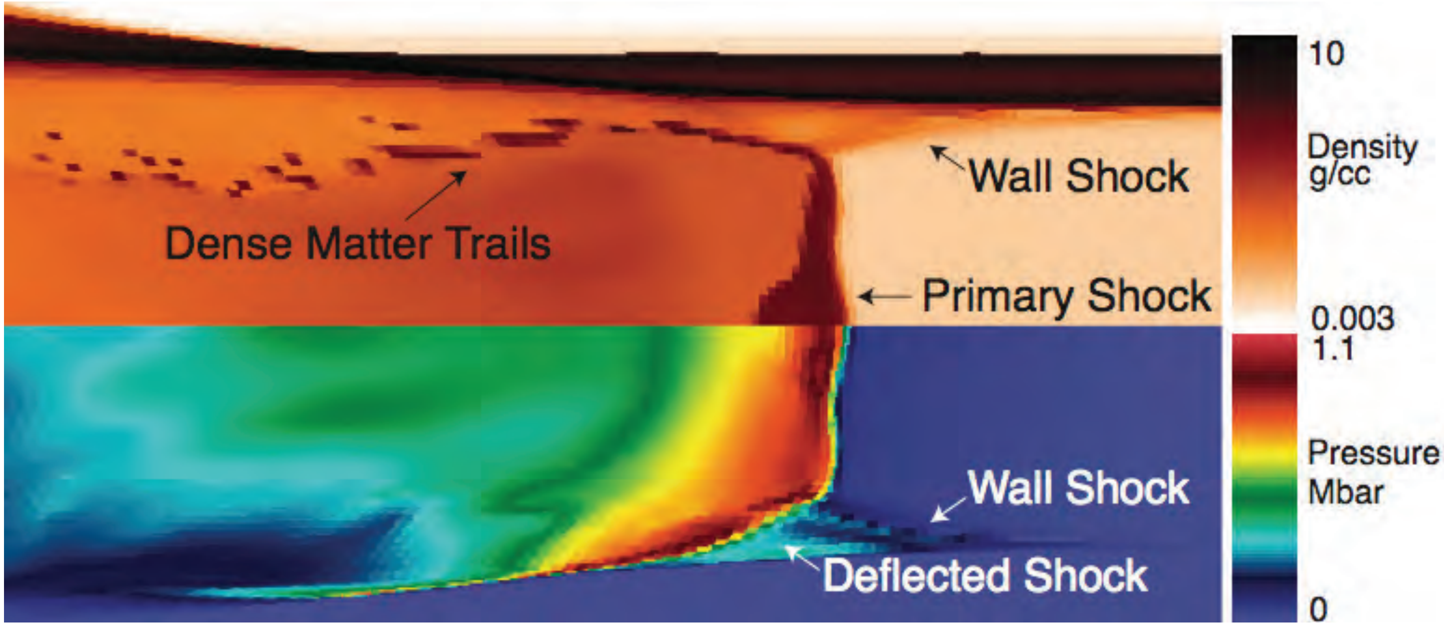
- Shot-to-shot variability in the drive energy, gas density, ablator thickness contributes to scatter.

Convergence to 1D results is explored by varying tube and drive radial parameters



- Radial dimensions are multiplied.
- Laser irradiance is kept constant.

2D simulations in HYDRA revealed new behavior

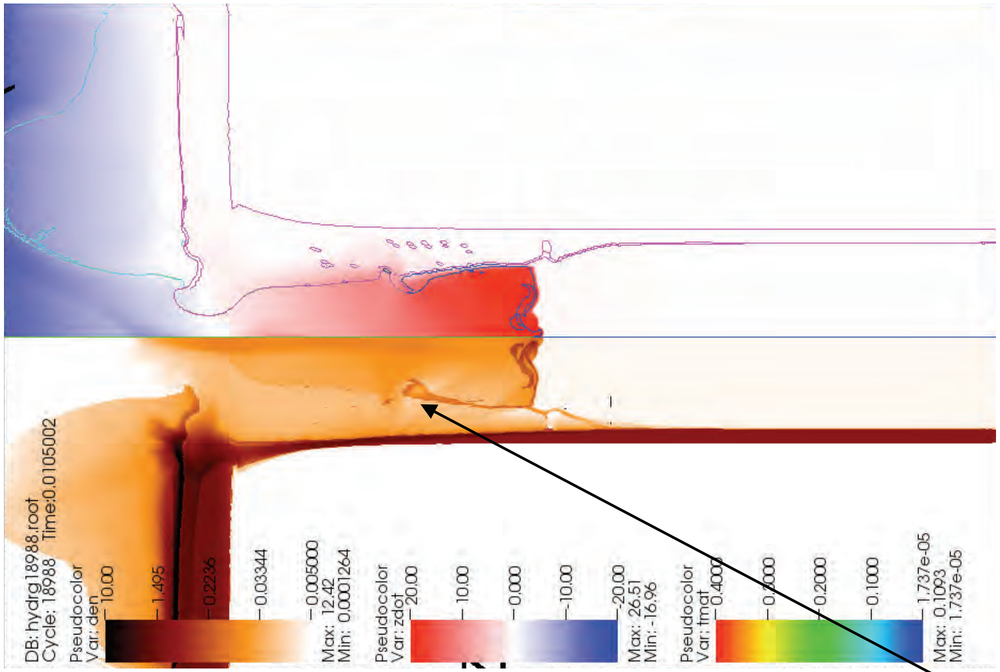


High resolution HYDRA* simulation

- The shock tube is typically much denser and stronger than the interior material. Normally, the shock tube's evolution has small effects on material ahead of the shock.
- This assumption breaks down in HED systems.
- Radiation from the shock induces plastic ablation, forming a radial blast wave in the tube.

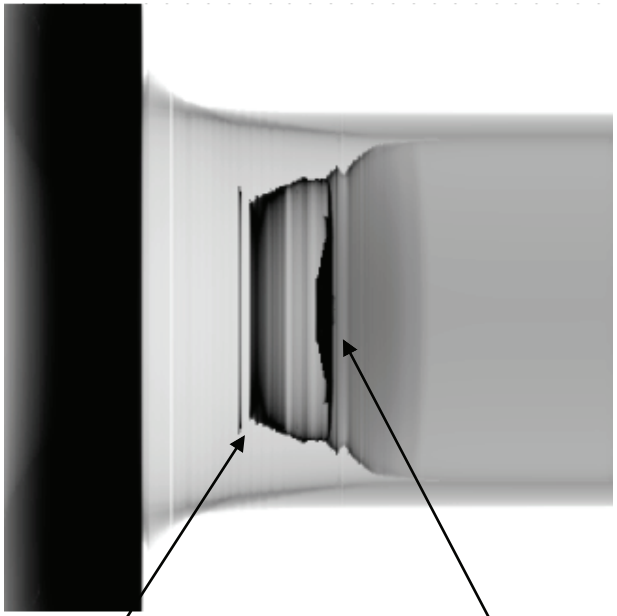
* M. M. Marinak et al., *Phys. Plasmas* 8, 2275 (2001)

Wall shocks control the primary shock morphology



A simulation with exaggerated wall shock

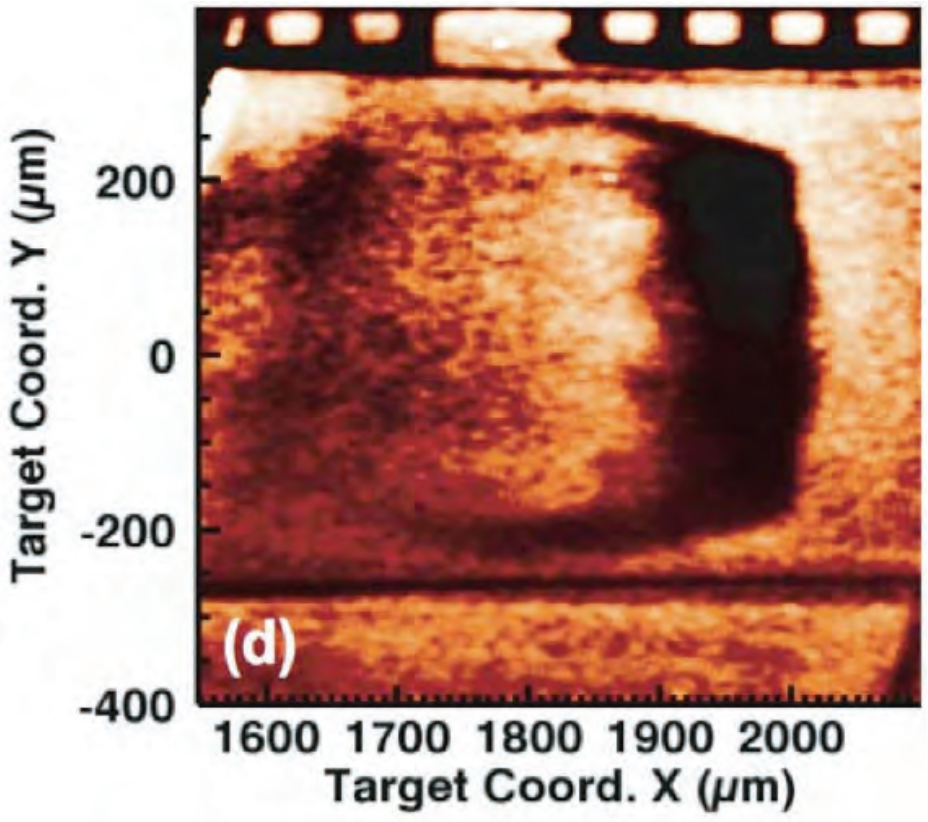
Simulated Radiograph



Dense Xe collected behind shock by oblique shock interactions

Primary shock

Effects of the wall shock are indirectly seen in early radiating shock experiments

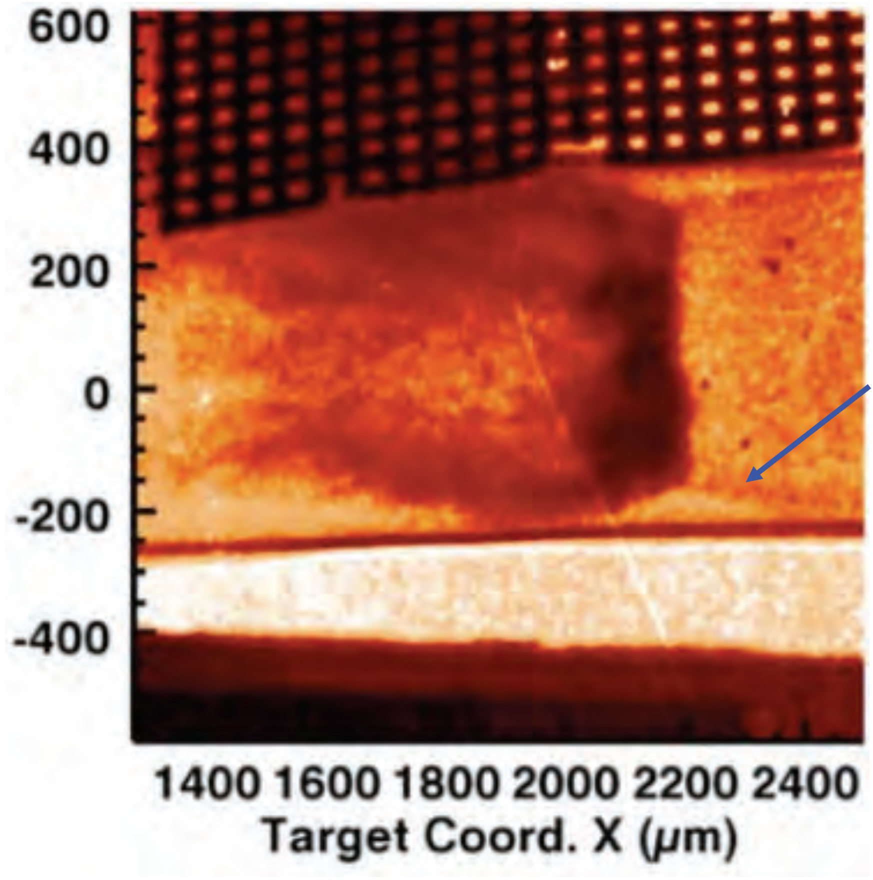


20□m disc Reighard shot
Average velocity 140 km/s

Wall shock induced features which can be seen in experiments of this generation include:

- Dense Xenon collected behind the primary shock
- Edge displacement
- Curvature of the trails
- Angle of primary shock at kink.

Later experiments, with improvements in radiography, show clear evidence of the wall shock



Wall Shock

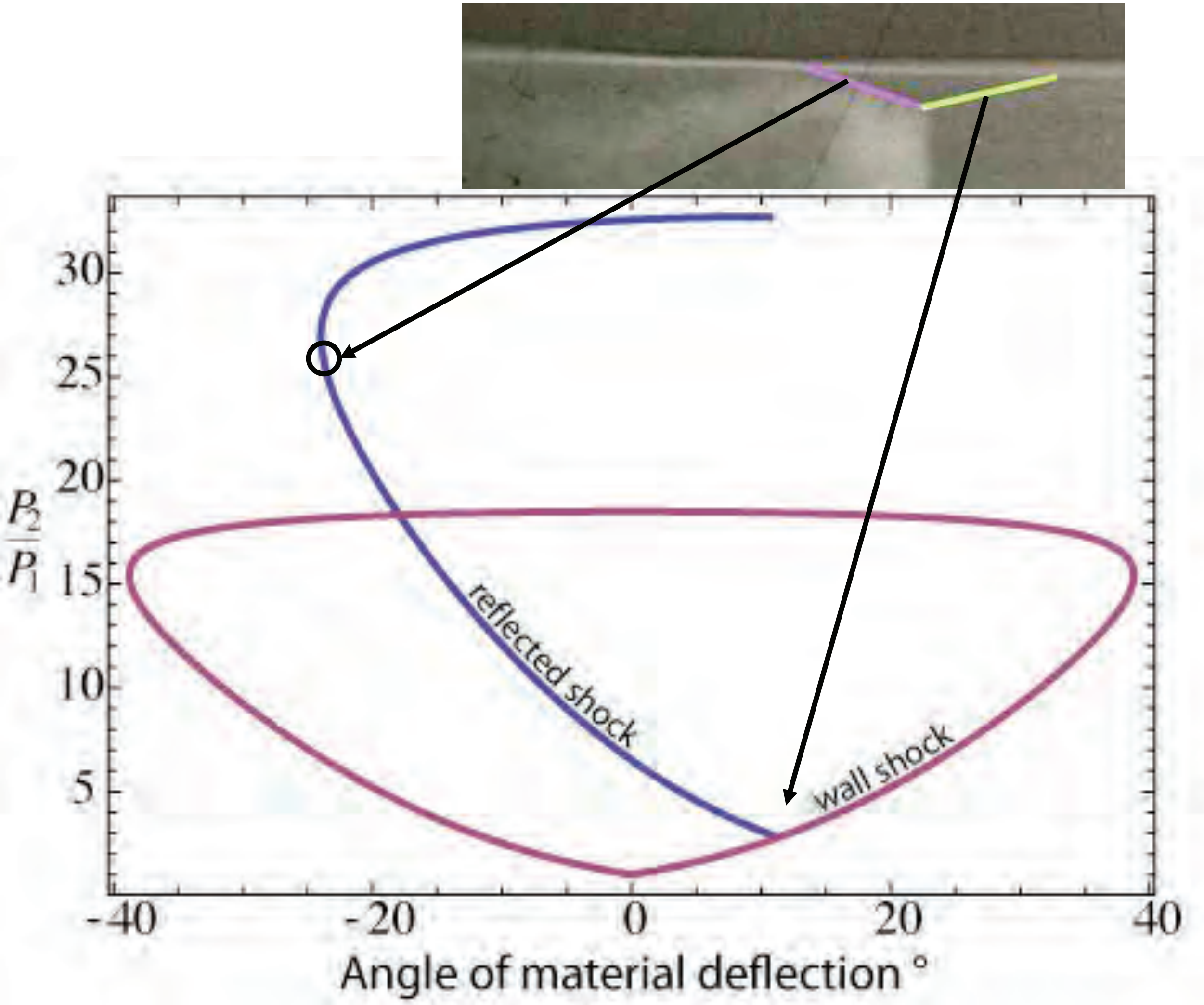
Omega Shot 52665

Wall shock induced features in the modern data include:

- Finite displacement of shock edges from tube walls
- Angle of primary shock deflection at kink
- Angle of wall shock off of wall
- Curvature and thicknesses of the trails
- Dense Xenon collected behind the primary shock.

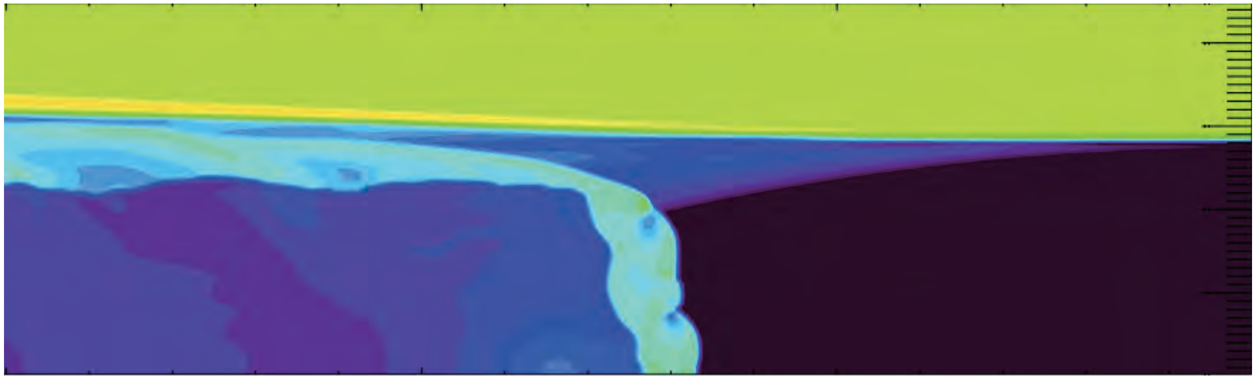
Measurements of deflection angles constrain primary shock Mach number

- The method of shock polars plots possible angular deflections of material against the pressure increase across the shock, with Mach number as a parameter.
- The material interface angles measured from the radiograph translate directly to the θ coordinates of points of intersection.
- Only particular Mach numbers will consistently link the angles of intersection.
- Coupled with a velocity diagnostic, this gives speed of sound in the radiative preheat region.



$$\tan(\theta_j - \theta_i) = \frac{\left(\frac{P_j}{P_i} - 1\right)}{\gamma M_i^2 + 1 - \frac{P_j}{P_i}} \sqrt{\frac{2\gamma M_i^2}{(\gamma + 1)\frac{P_j}{P_i} + \gamma - 1} - 1}$$

Later simulation efforts have extended the state of knowledge

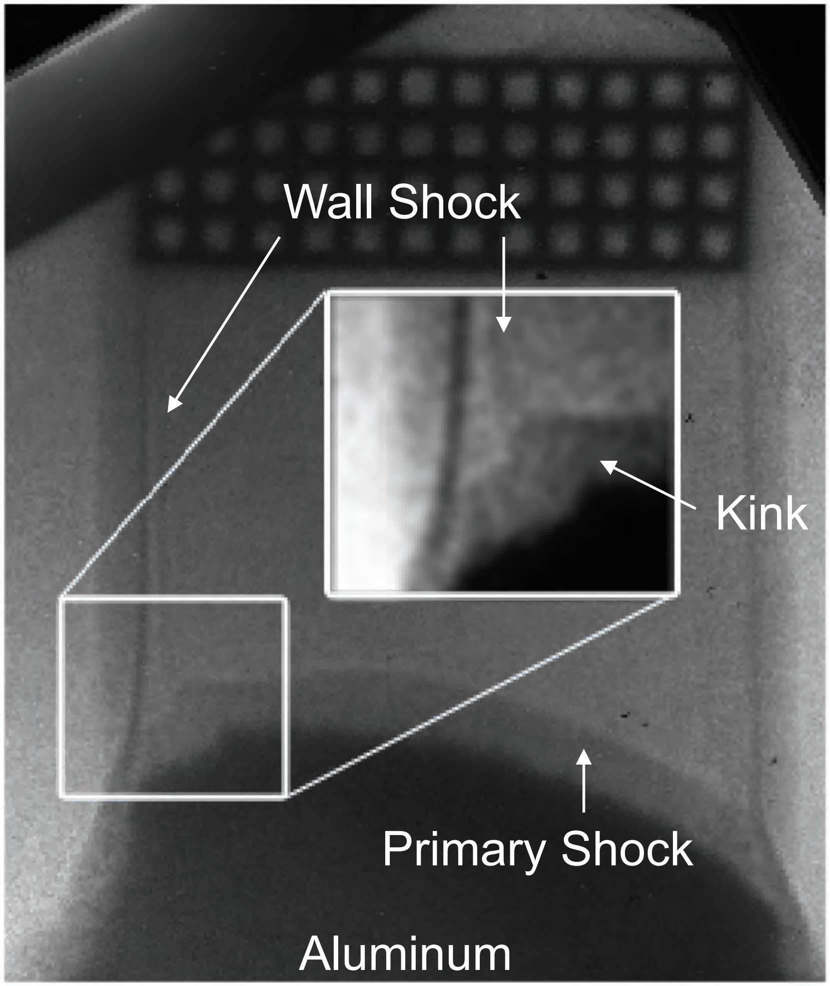


2D CRASH simulation, showing (log scaled) density

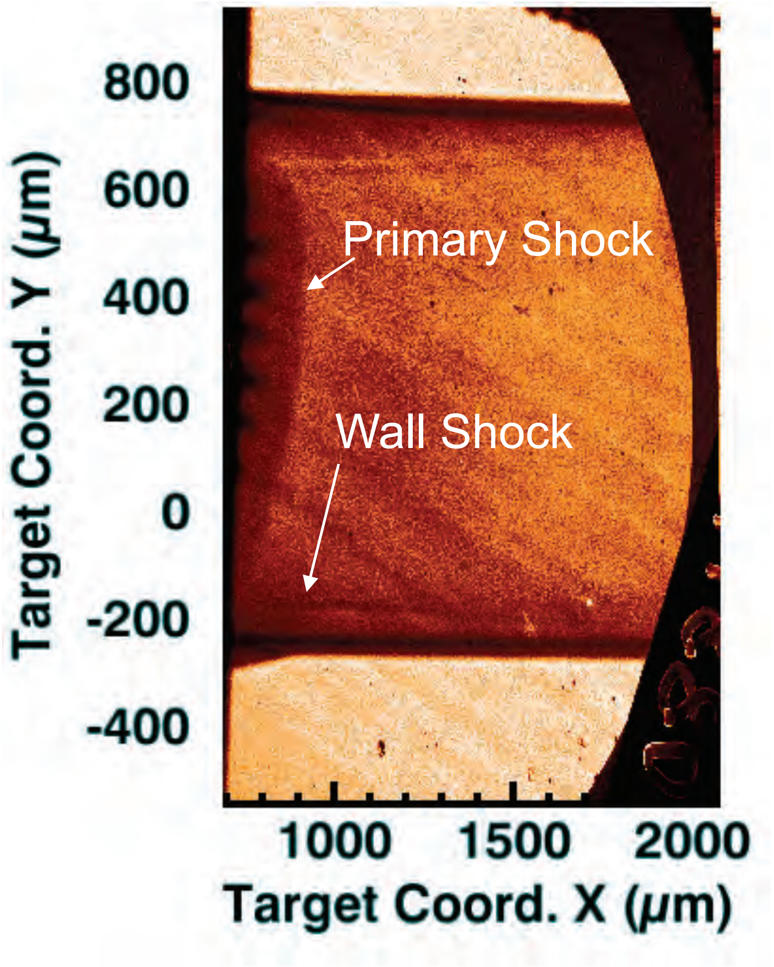
- The Center for Radiative Shock Hydrodynamics (CRASH) at the University of Michigan, as part of the Predictive Sciences Academic Alliances Program (PSAPP), has been creating a new code to study these systems.

- CRASH will have a much better grasp on uncertainties in the system, and will support the move to complicated 3D simulations.

Wall shocks have since been seen in other laser-driven experiments



NEL Al jet experiment
040520-001

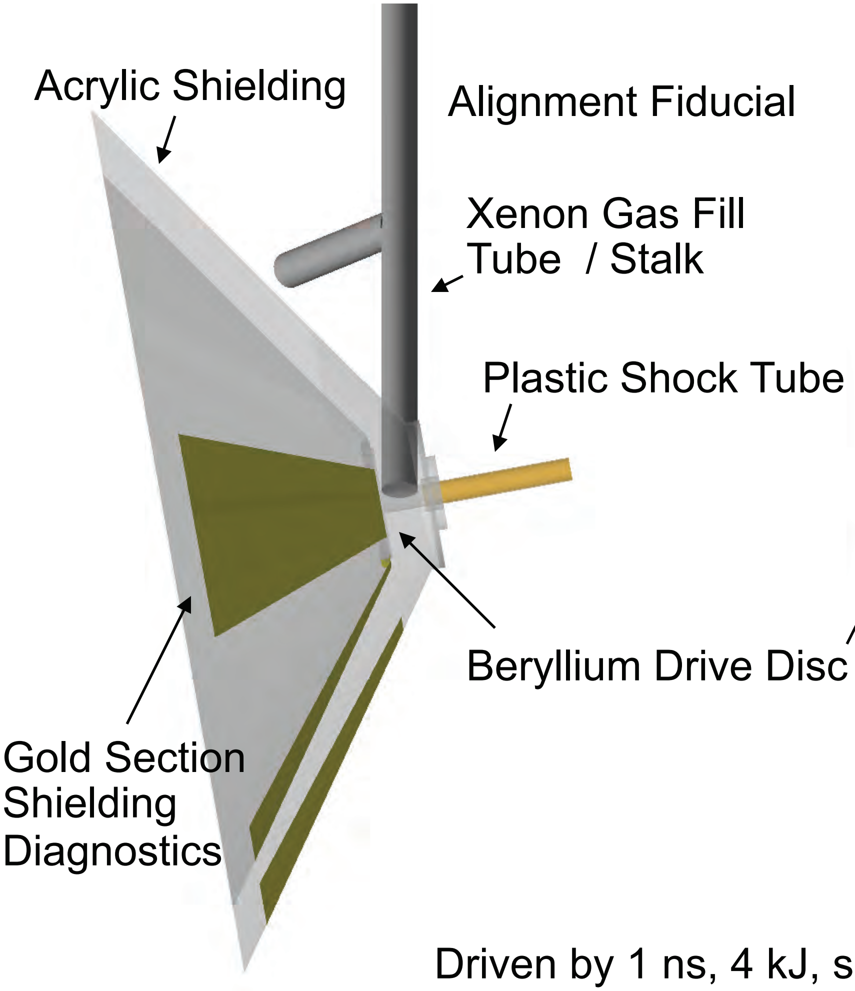


Omega SNRT
experiment 41880

Summary

- The radiative precursor of a sufficiently fast shock causes the evaporation of tube material ahead of the shock.
- The radiative precursor of a sufficiently fast shock causes the evaporation of tube material ahead of the shock. The resulting expansion wave drives a converging wall shock into the gas volume. This acts as a dynamic constriction of the tube, and modifies the edge conditions experienced by the primary shock.
- Wall shock radiography allows for indirect measurement of Mach numbers, velocities, sounds speeds, temperatures.
- Wall shocks in experiments in which the principal shock waves themselves should not be radiative have also been seen, in which the wall shocks have been launched by some other factor, possibly laser preheat.

Experiments are conducted in directly driven Xenon filled shock tubes on the Omega laser



Acrylic Shielding

Alignment Fiducial

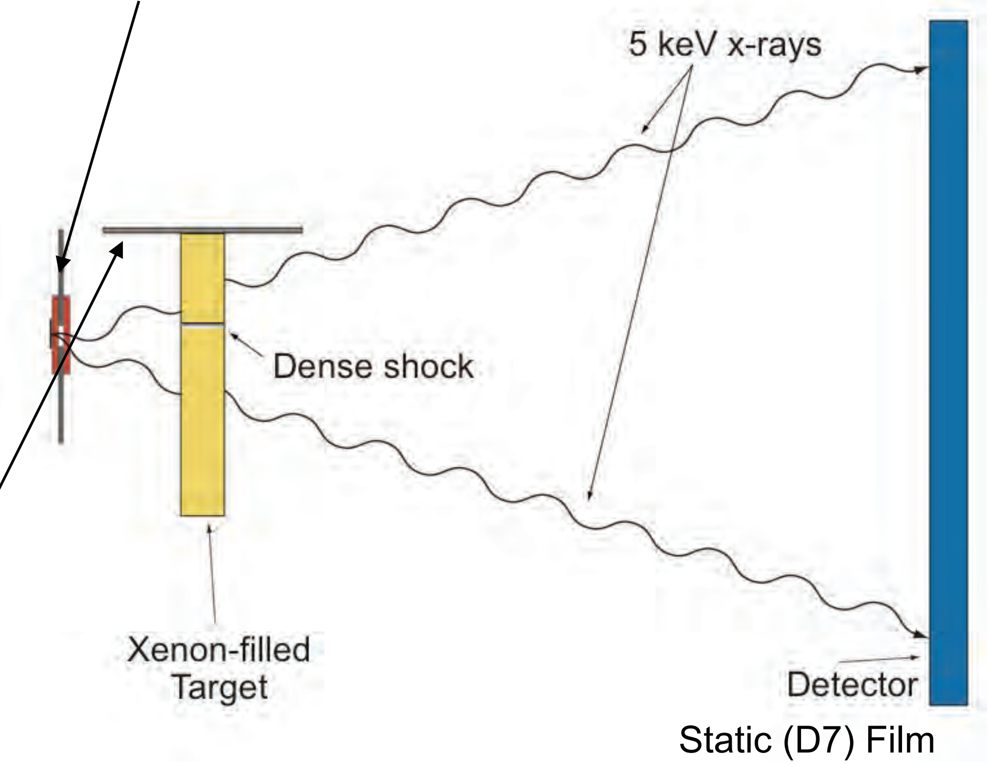
Xenon Gas Fill
Tube / Stalk

Plastic Shock Tube

Beryllium Drive Disc

Gold Section
Shielding
Diagnostics

Pinhole Apertured Backlighter



Static (D7) Film

Driven by 1 ns, 4 kJ, square pulse