Blast-wave-driven, Rayleigh-Taylor instability experiments on the Omega Laser

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I would like to acknowledge contributions by…

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J. Knauer, A. Frank, T. Boehly, LLE

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Other Collaborators:

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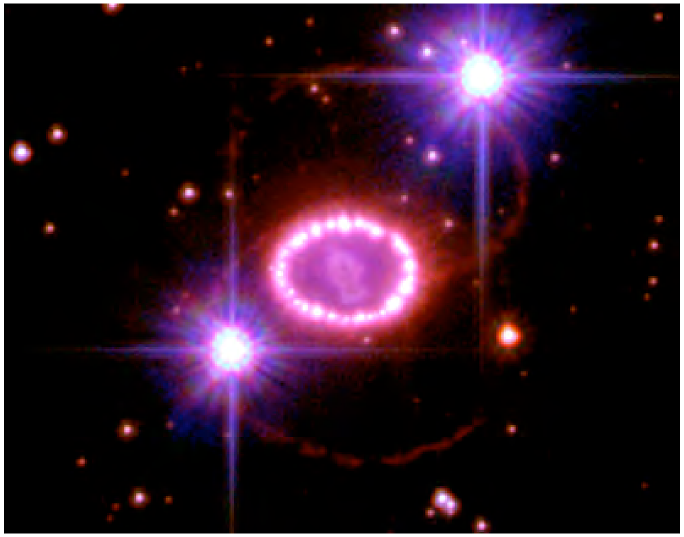
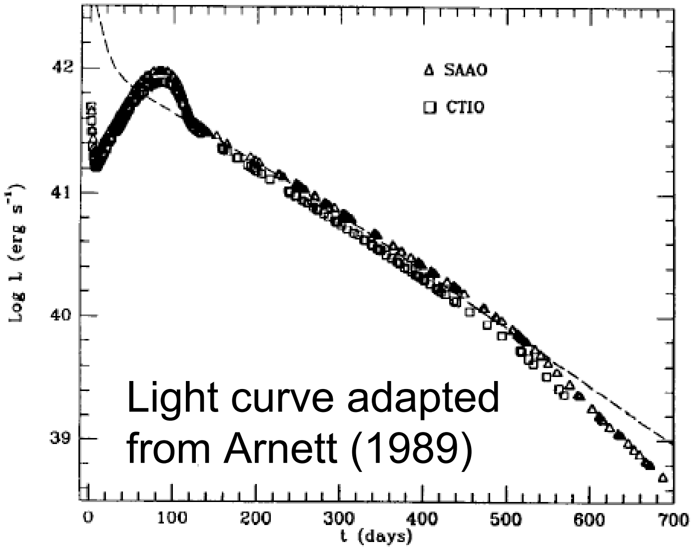
Understanding SN1987A motivates supernova hydrodynamics experiments

- Progenitor star
  - Sanduleak -69 202, blue supergiant
  - About 50 kpc (168,000 light years) away
  - 18 - 22 solar masses, ~ 43 solar radii
  - Explosion occurred in February 1987
    - Core-collapse supernova (SN)
    - Observations included modern astronomy techniques
- Observations
  - Early light curve data agreed with blue supergiant explosion models
  - Observations of ^{56}Co and ^{56}Ni were sooner than predicted
  - Thought that discrepancies could be due to large-scale hydrodynamic mixing

SN1987A, Hubble Space Telescope

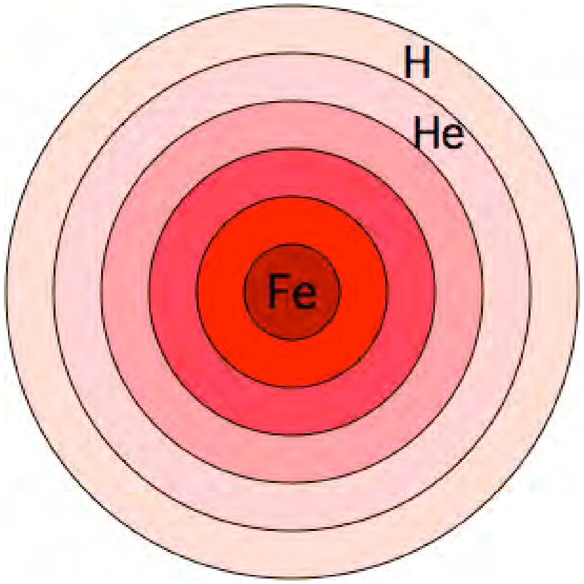




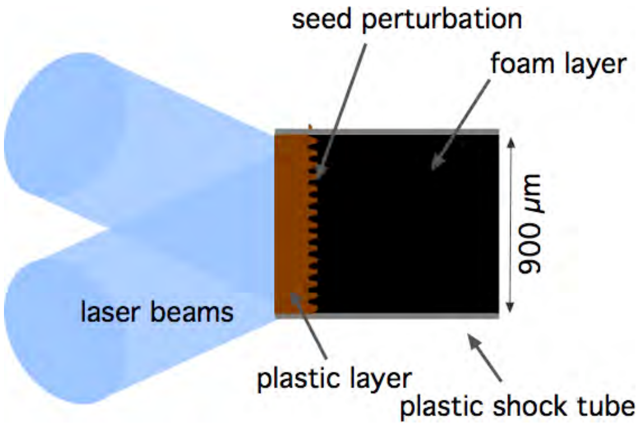
Light curve adapted from Arnett (1989)

Well-scaled targets explore hydrodynamics of supernovae

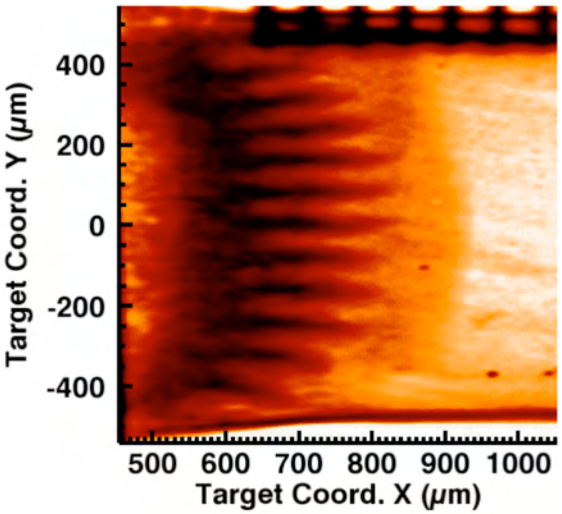
- Targets scaled to conditions of blast-wave-driven H/He interface of SN1987A
- Planar blast wave leads to decelerating interface
- Interface unstable to Rayleigh-Taylor Instability



Stellar Composition



Scaled Target

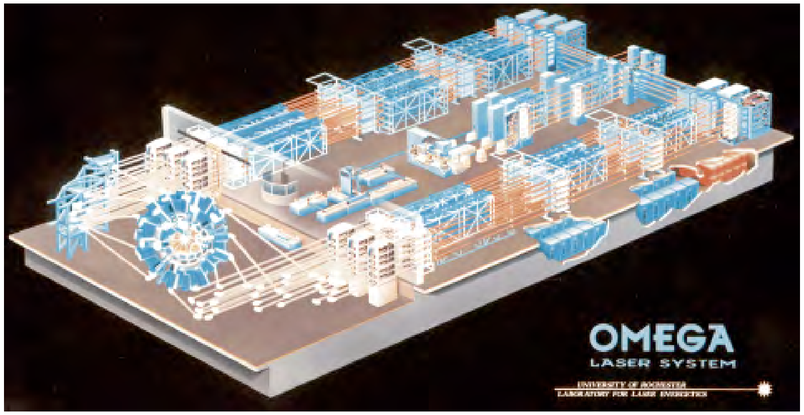


Experimental Radiograph

Experiments performed at Omega laser facility

- Ten Omega Laser beams to drive shock
  - ~450 J each, ~4.5 kJ total energy
  - 1 ns square pulse
- Produce intensity of ~9 x10^{14} W/cm^2
- Pressure of ~50 Mbars or ~50 million atmospheres

Inside the Omega target chamber

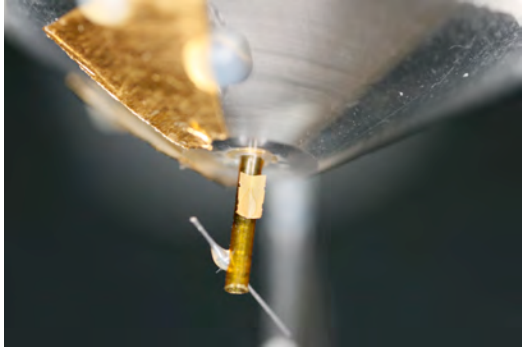


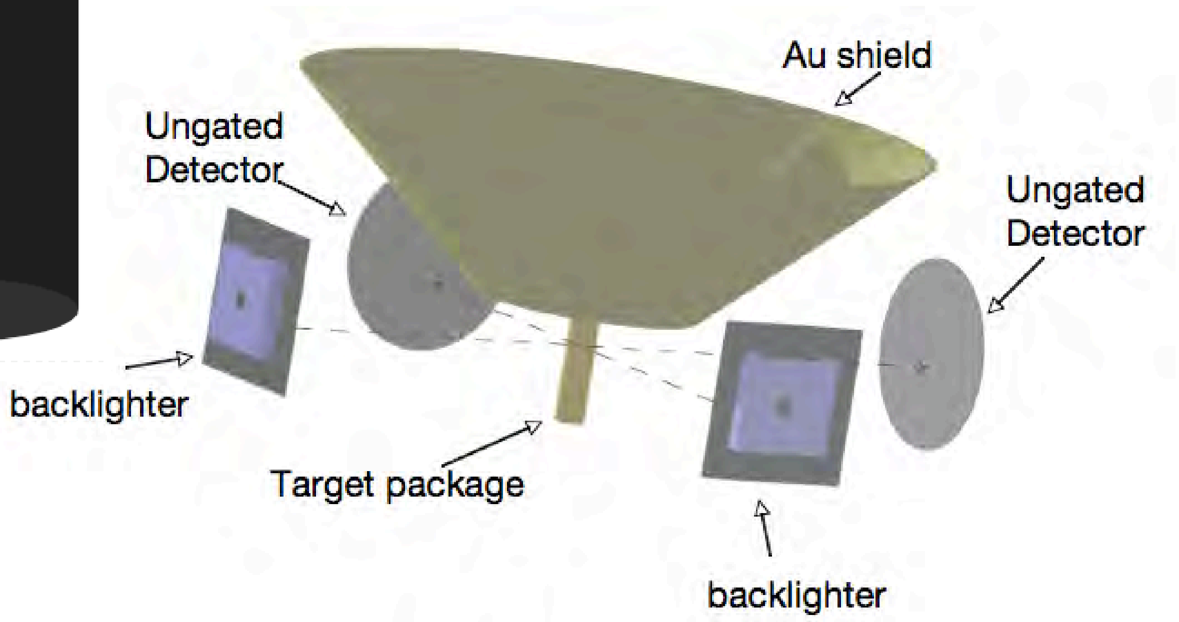
The Omega Laser System

Key components of target

- 150 µm plastic (1.41 g/cc)
  - Tracer strip material: $C_{500}H_{457}Br_{43}$ (1.42 g/cc)
  - Entire surface machined with seed perturbation
- 2-3 mm Carbonized Resorcinol Formaldehyde (CRF) foam (50 mg/cc)

Target Fabrication:
M. Grosskopf, D. Marion

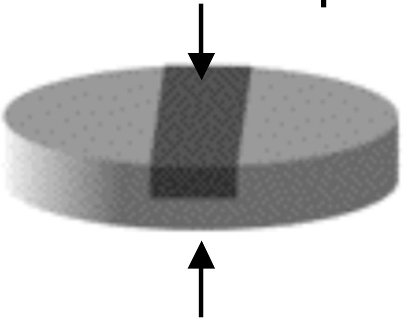




3D single mode Rayleigh-Taylor seed perturbations

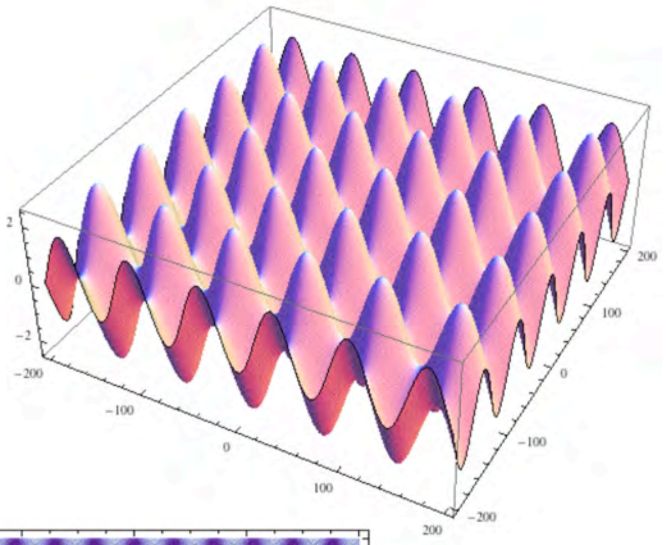
Image stretched to show structure

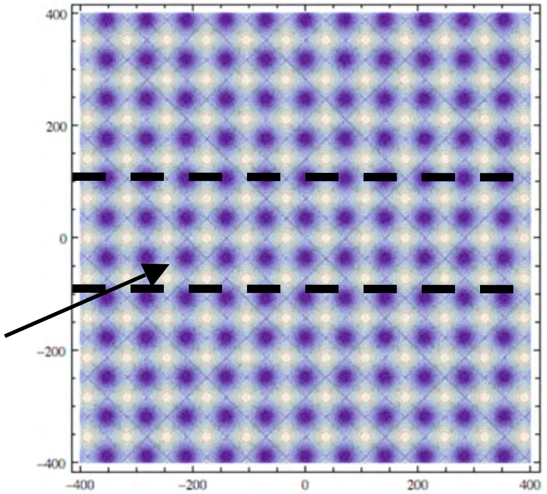
- Two sine waves in orthogonal directions creates “egg crate” pattern
- Single mode: a_o = 2.5 μm and $k_x = k_y = 2\pi/(71\ \mu m)$



Tracer strip

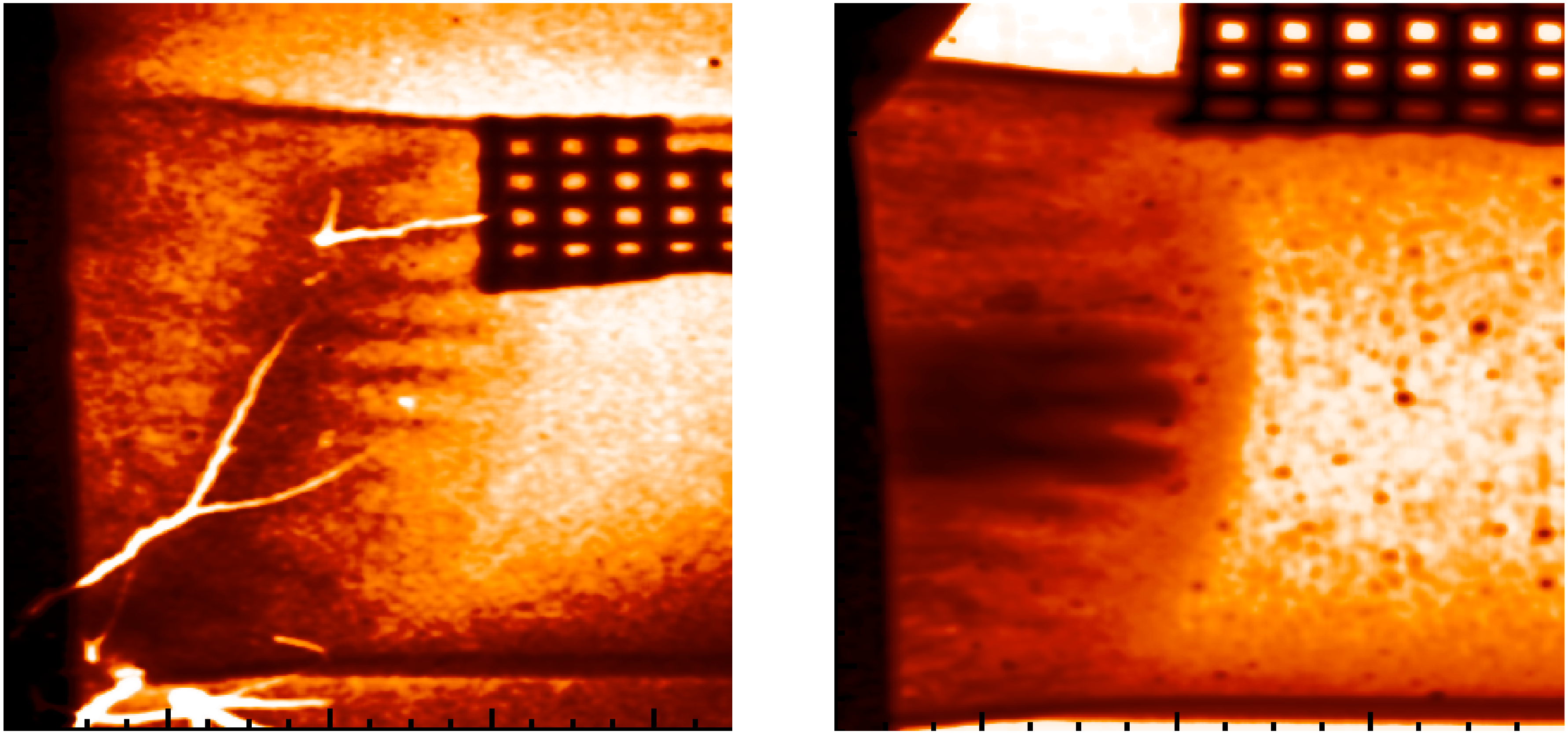
Driven surface





Tracer strip

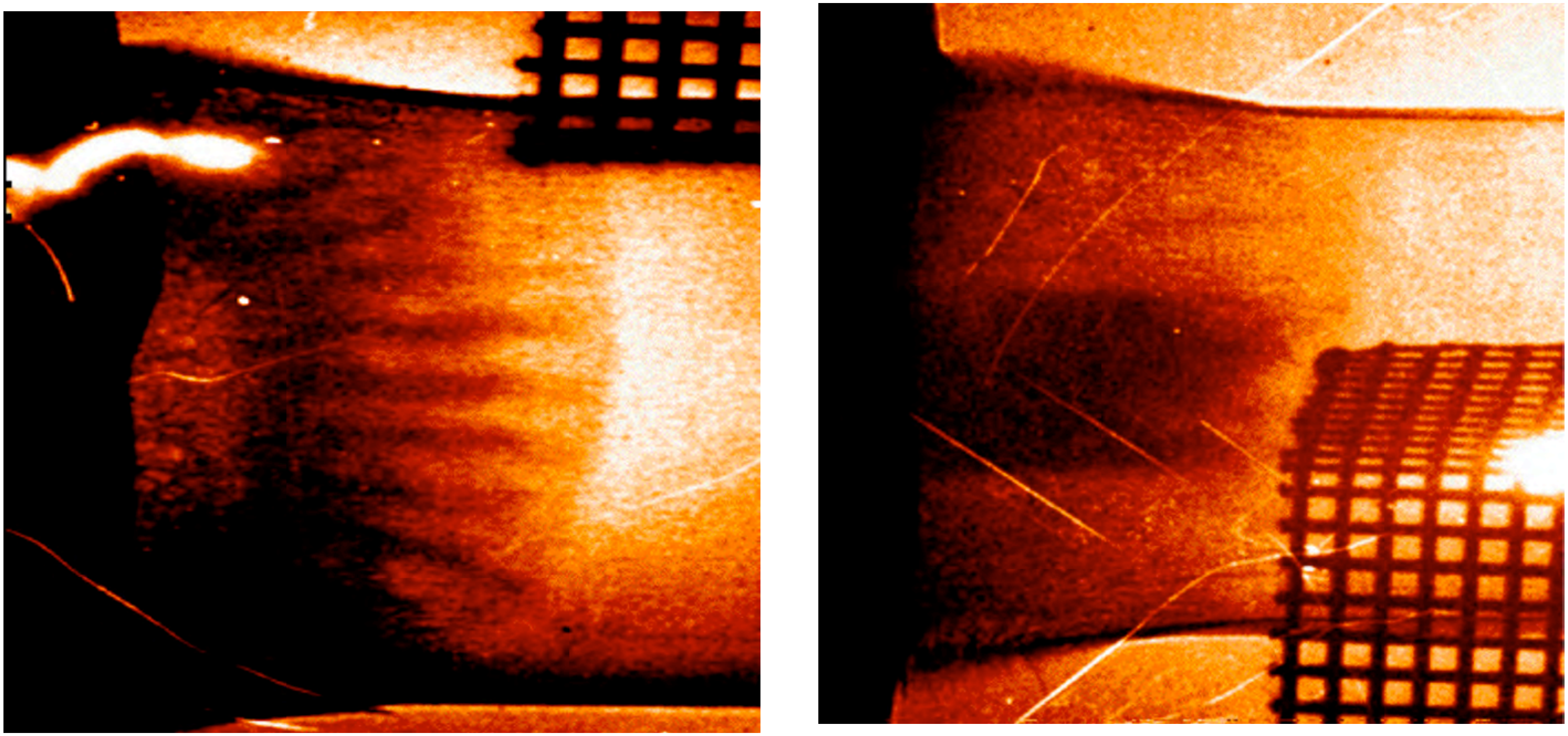
Aug 05: First Physics Data From Dual, Orthogonal, Simultaneous Radiography!



Single Mode Perturbation at 17 ns

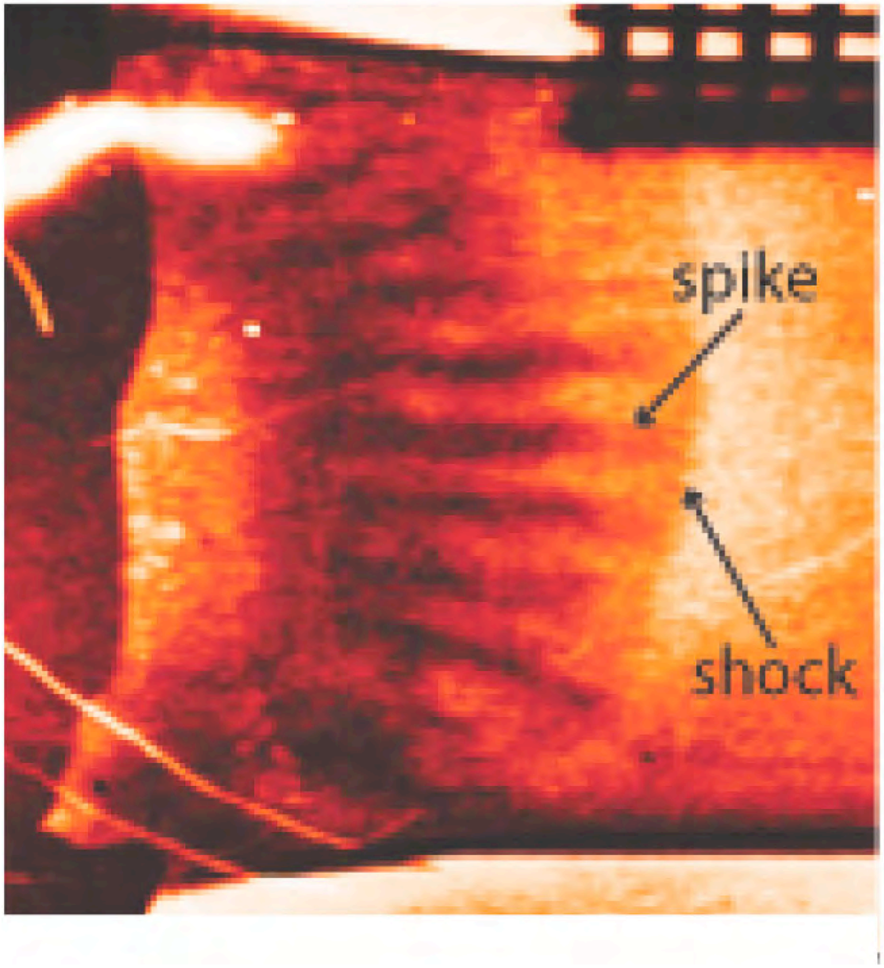
50 μm to 20 μm stepped pinhole and DEF film

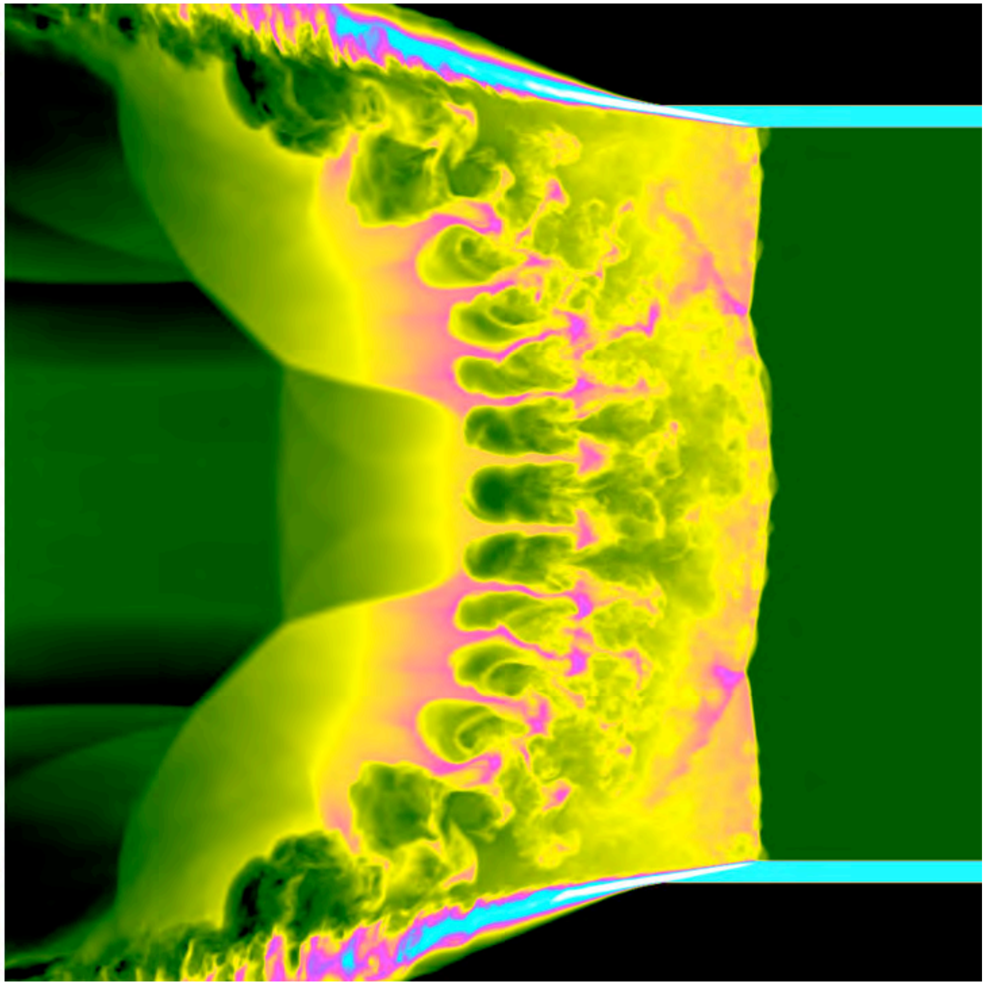
Even better data with 10 µm pinholes and D7 film



Single Mode Perturbation at 21 ns
10 µm tapered pinhole and D7 film

There are differences in morphology between the observations and simulations





3D FLASH simulation

Magnetic field may play a role in spike morphology

The magnetic-field generation mechanism that is relevant here is the Biermann battery effect.* An electric field is produced to balance the electron pressure,

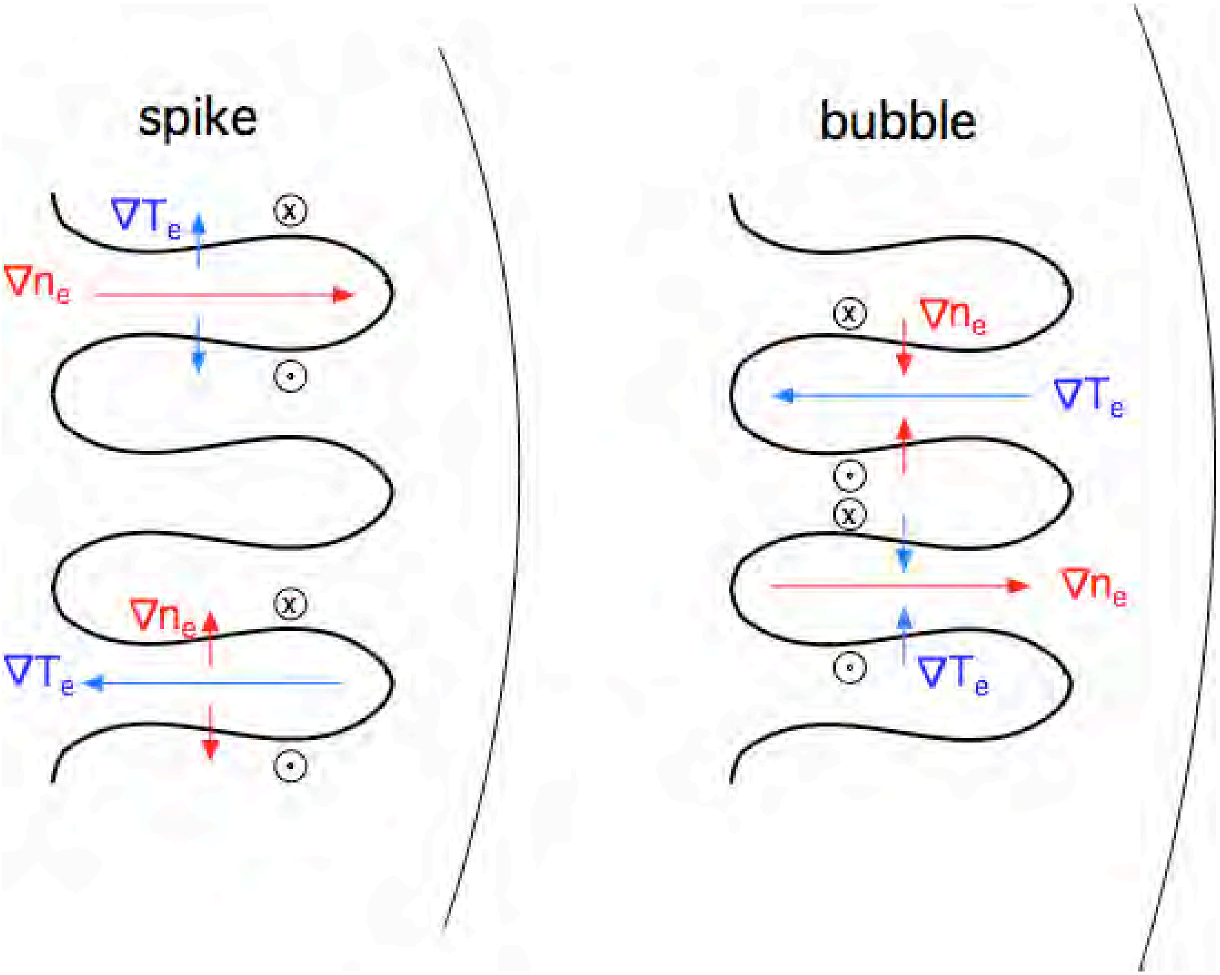
$$\mathbf{E} = -\frac{1}{en_e}\nabla p_e$$

Using Faraday's law in cgs units, $\frac{1}{c}\frac{\partial \mathbf{B}}{\partial t} = -\nabla \text{ x } \mathbf{E}$

$$\frac{\partial \mathbf{B}}{\partial t} = \frac{ck_B}{e}\left[\nabla T_e \text{ x } \nabla \ln n_e\right]$$

*Biermann (1950)

B-fields wrap around individual spikes and bubbles



An azimuthal magnetic field would have the effect of laterally confining the spike and potentially moving material to the shock

Approximated B-field from 1D Hyades is the same magnitude as the plasma pressure

Magnetic field generation rate ~ 10^{14} Gauss/s
Magnetic field after 20 ns ~ 5 MGauss
Magnetic Pressure ~ 10^{12} dynes/cm^2

Plasma Pressure ~ρu_s^2 = 10^{12} dynes/cm^2

This is not the case in the SN!!

This estimate shows that magnetic pressure might be important in the experiment. A full MHD treatment of the system, including dissipation and plasma heating, must be considered to assess this hypothesis.

Conclusions

- We have been able to study supernova-relevant hydrodynamics in laboratory experiments
- Spike morphology remains anomalous in both shape and penetration one hypothetical explanation is magnetic fields