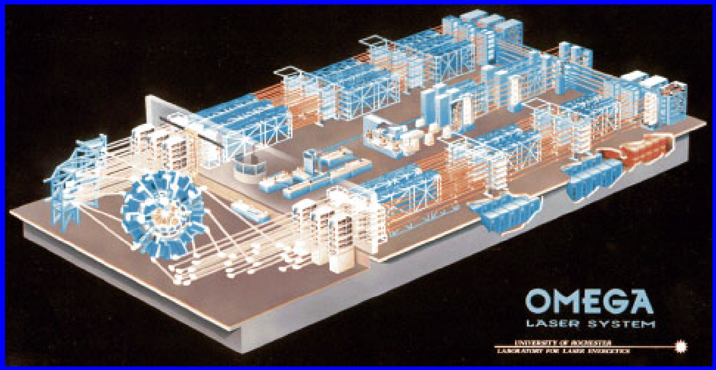
# Compressible Hydrodynamics on the Omega Laser: Motivated by Astrophysics

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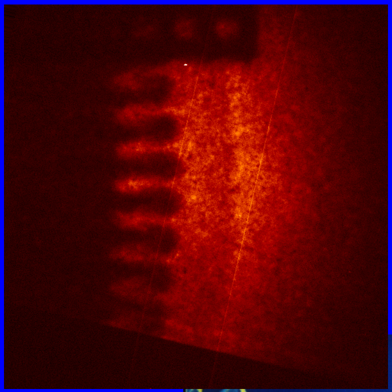

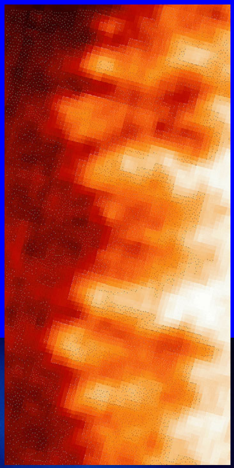

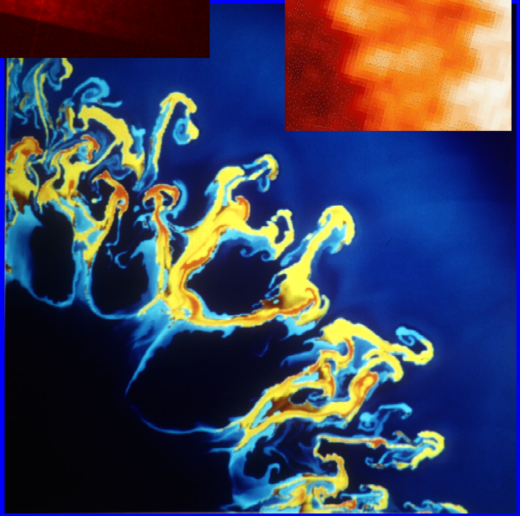

***IWPCTM, Pasadena, CA, December 2001***

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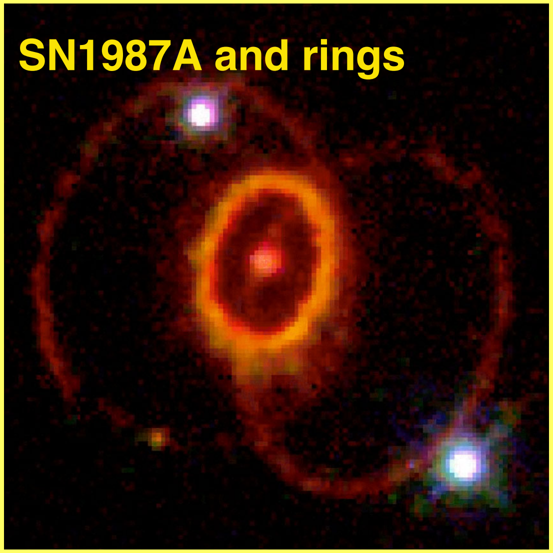
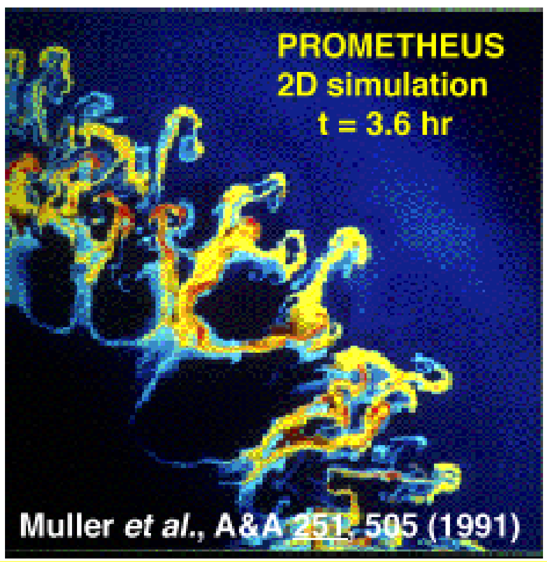
# We use the Omega laser to explore phenomena that matter for astrophysics

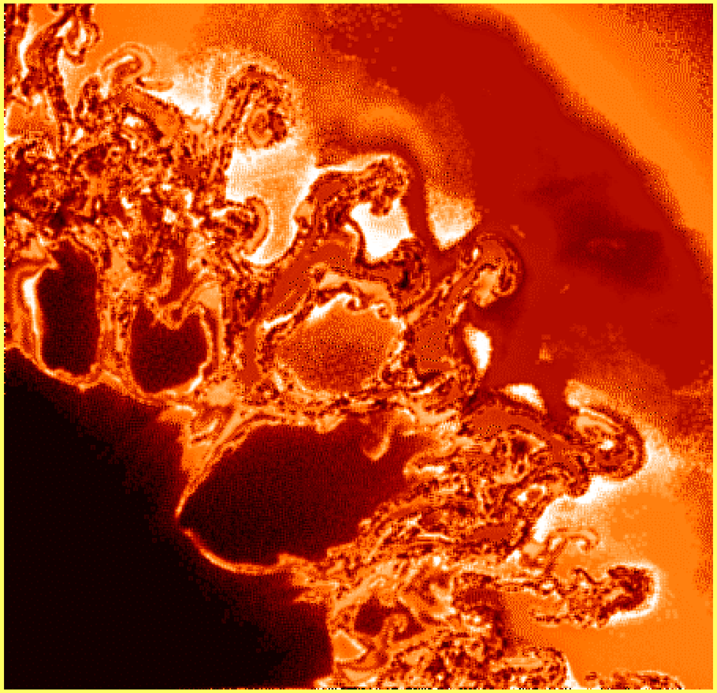
- **Our goal is to experimentally ground the understanding of important mechanisms**
  - Theory or simulation suggests explanations for astrophysical data
  - The important mechanisms have often never been observed anywhere
  - We produce and observe these mechanisms in scaled experiments
  - This tests the theory and simulations




# Astrophysical systems provide strong motivations for hydrodynamic studies

**2D Simulation of SN 1987A**



**Muller, Fryxell, and Arnett (1991)**

**The velocities of the heavy element remain larger than predicted.**

**SN 1987A provided compelling evidence that hydrodynamic instabilities are essential to supernovae**
- **Light curve**
- **Spectra**

**Compressible turbulent mixing is also present in other astrophysical systems**
- **Supernova Remnants**
- **Jets**
- **Shocks into clouds**

**Well-scaled experiments are feasible: *D.D. Ryutov, et al.***
***ApJ 518, 821 (1999)***
***ApJ Suppl. 127, 465 (2000)***
***Phys. Plasmas 8, 1804 (2001)***

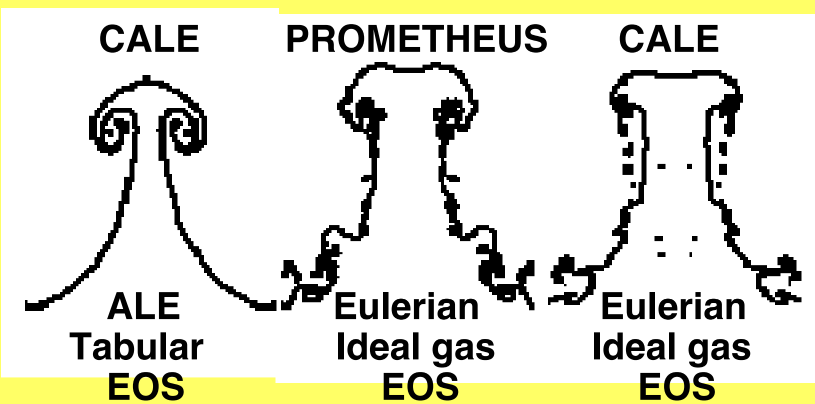
# We often must explain to astrophysicists that we don't understand hydrodynamics

- We understand the *EQUATIONS* of hydrodynamics
- But NOT numerical simulations
  - They are like series solutions to differential equations without the ability to quantify errors
  - Vanishing metrics add complications
  - No stochastic backscatter in current simulations (Leith '90, Piomelli '91)
  - Also no full turbulence

Codes disagree about asymptotic growth rates [*Glimm et al. 2001*]

| Simulation | RT growth factor, $\alpha$ |
|---|---|
| '91 Youngs | 0.04-0.05 |
| '91 Youngs | 0.03 |
| '99 S.Y. Chen | 0.043 |
| '99 Dimits et al. | 0.016 |
| '99 Cheng et al. | 0.08 |
| '99 Glimm et al. | 0.07 |
| '99 Oparin | 0.075 |

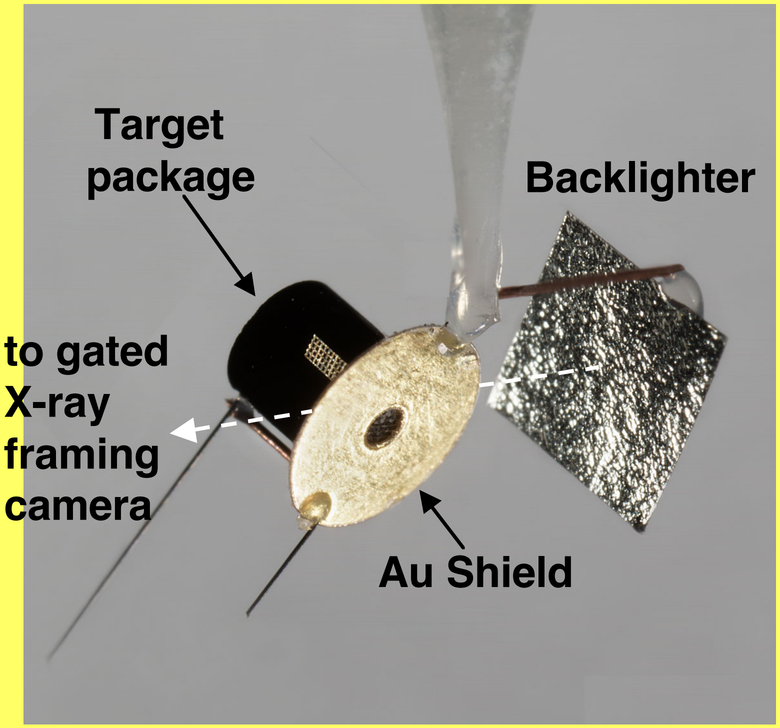
Codes disagree about structure




- This can matter for astrophysics
- Examples:
  - Size of mix layers is uncertain
  - Small details affect production of "hydrodynamic bullets" or other important structures

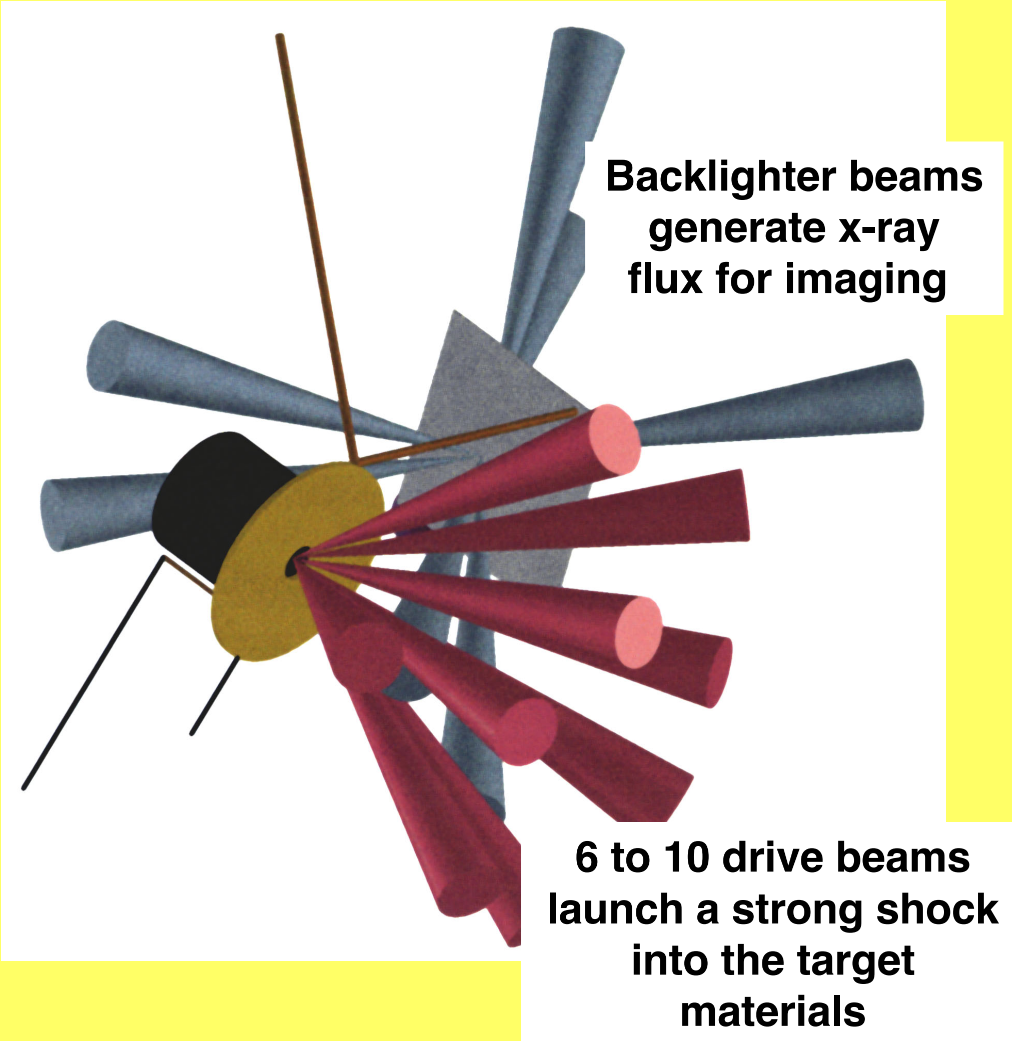
# Our hydrodynamic experiments all use similar target packages

**Photograph of target**




1 mm

**CAD drawing of target & beams**

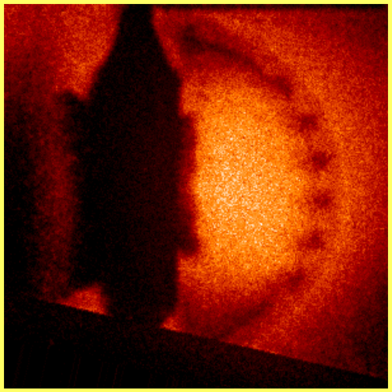


# Our experiments have been aimed at addressing the obvious first question:

- **THE FIRST QUESTION: Can the codes follow the evolution of such hydrodynamics deep into the nonlinear regime?**

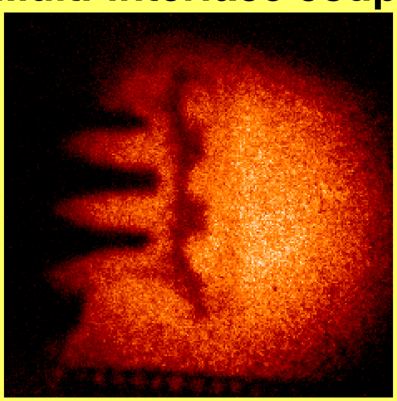
# Our experiments at Omega have addressed this question while probing several mechanisms present in supernova explosions

**Spherical divergence**



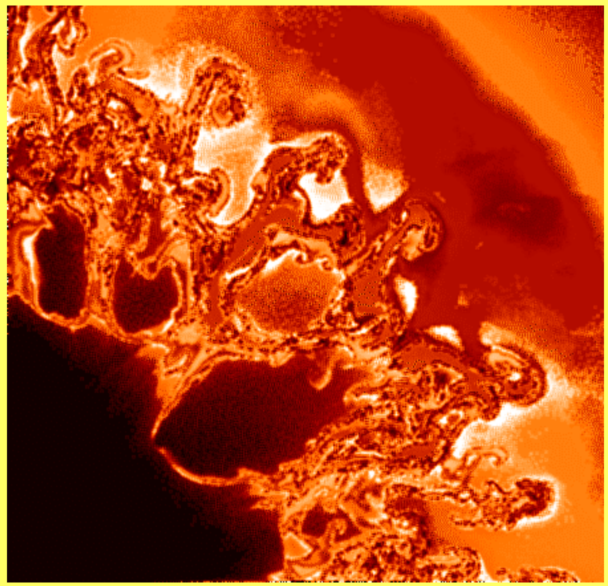
***Drake et al., ApJ Jan. '02***

**Multi-interface coupling**

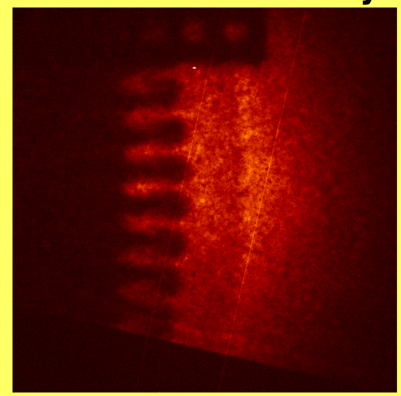


***Kane et al., PRE 63, 55401 (2001)***

**2D simulation of SN1987A**
**Muller, Fryxell, and Arnett (1991)**

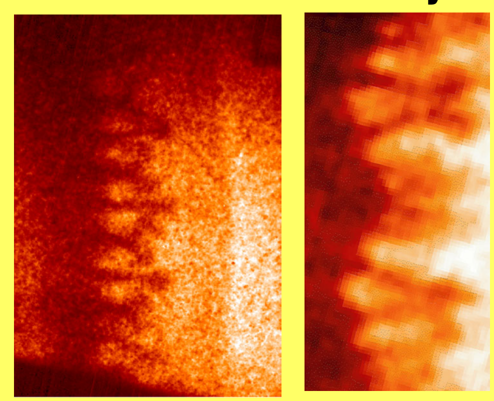


**2D vs. 3D instability**



**Finished in September**

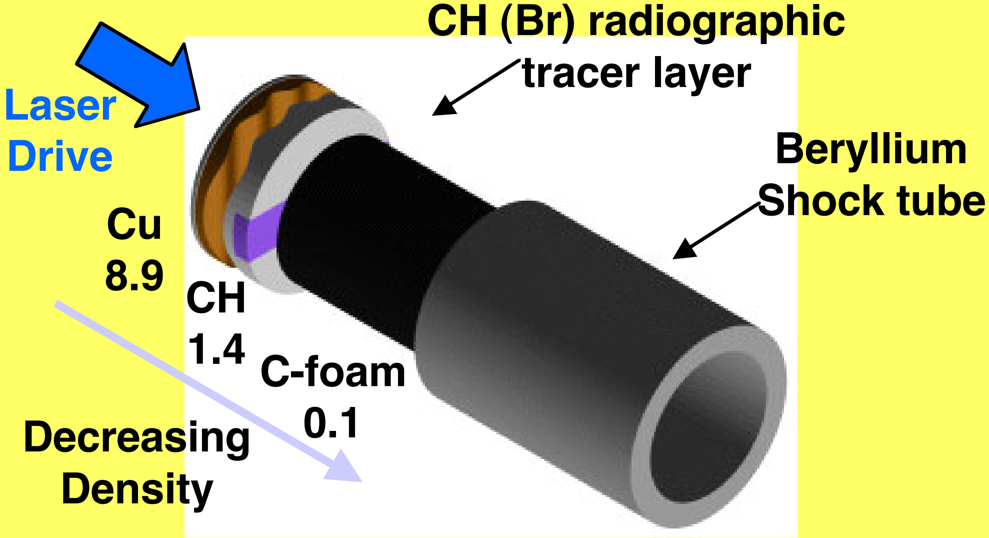
**Multi-mode instability**

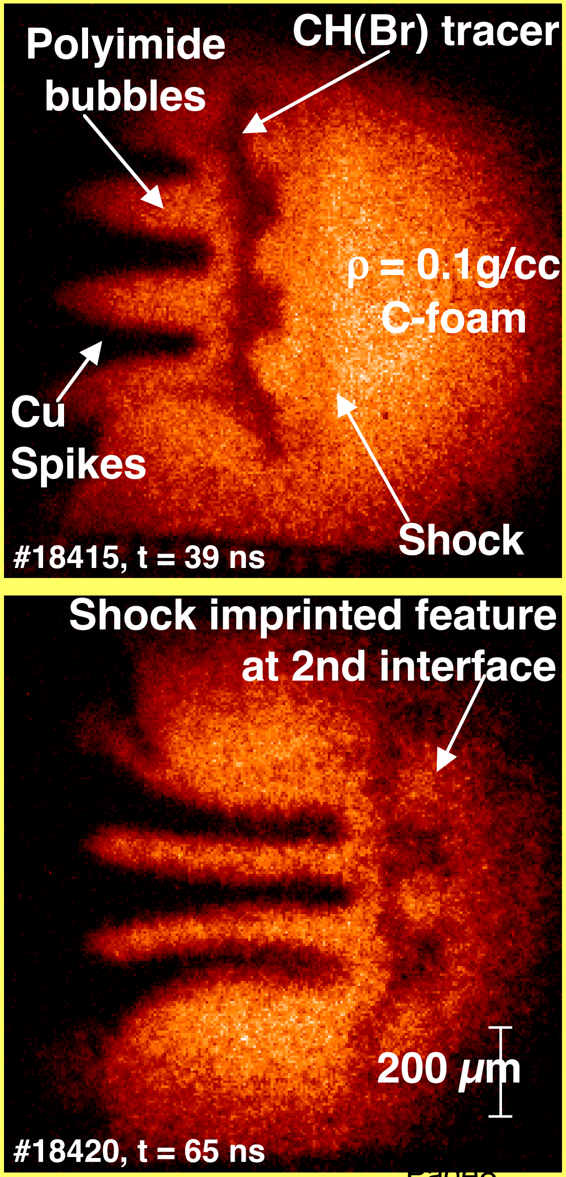


**Ongoing experiments**

# Coupling between spatially separated interfaces in a SN is studied with a multi-layer target

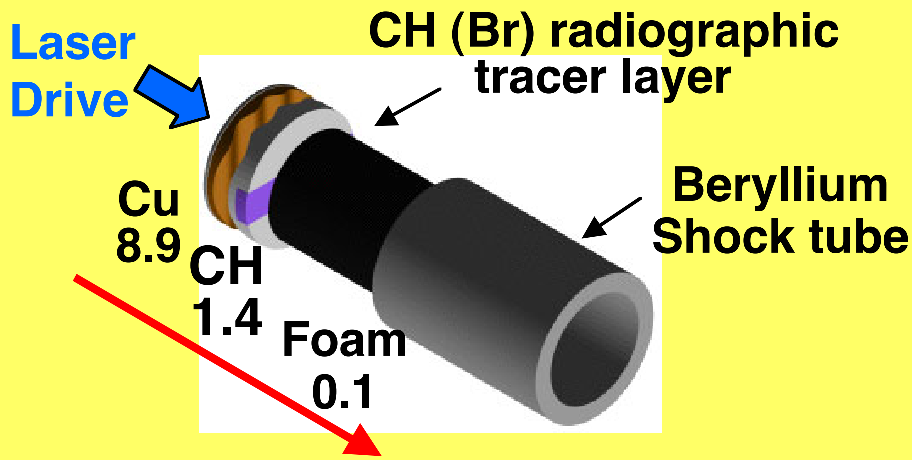
## Exploded view of multi-layer target

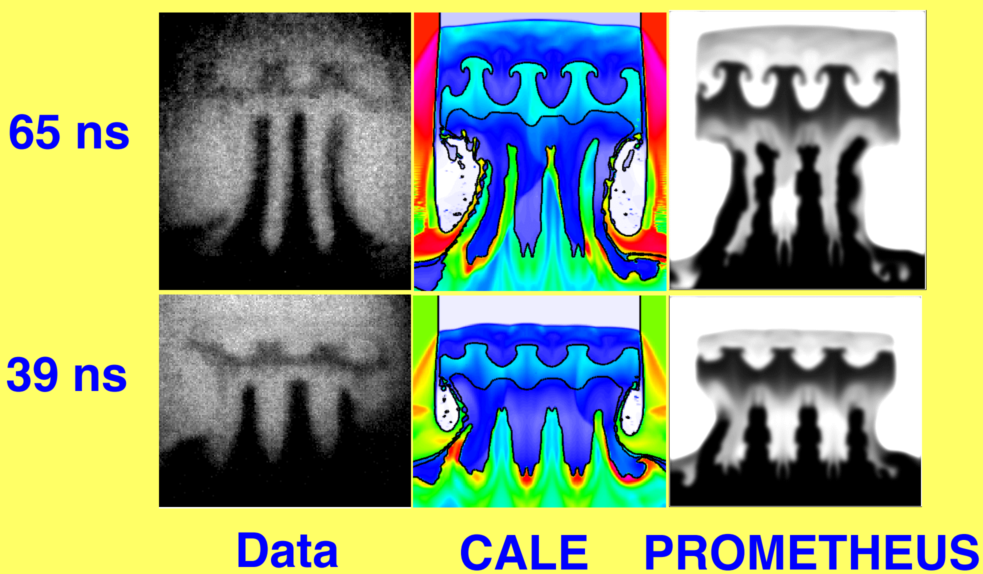



**Simulation of this experiment by the ASCI code FLASH at Chicago**

# The interface coupling experiments are typical of what we have found



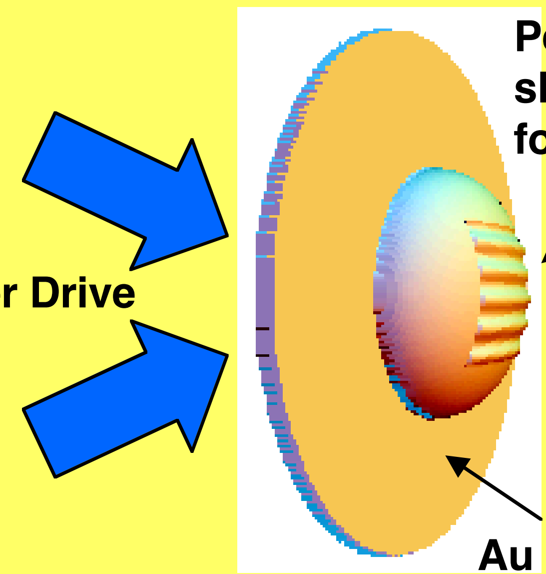



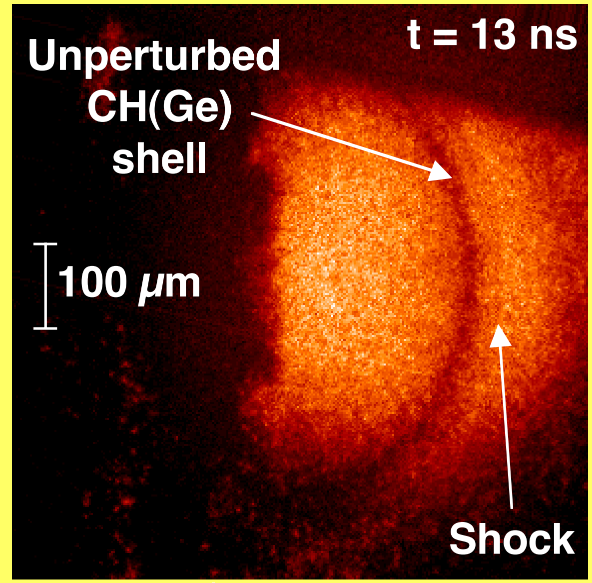

**THE FIRST QUESTION: Can the codes follow the evolution of such hydrodynamics deep into the nonlinear regime?**

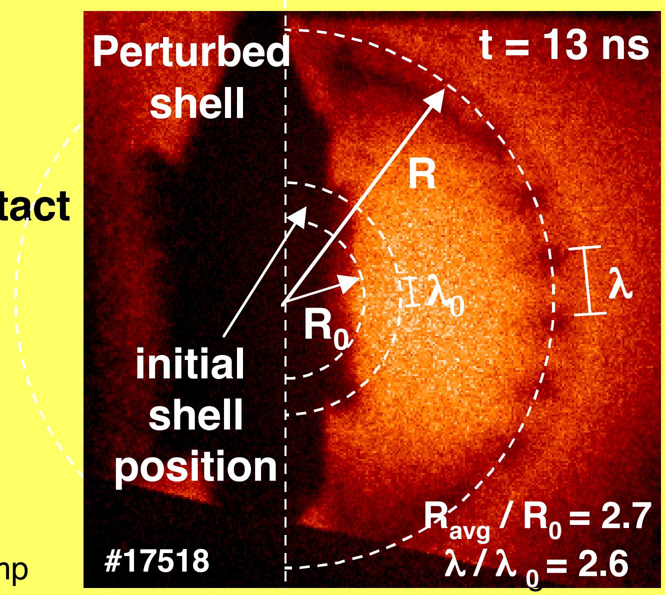
**ANSWER: Yes, eventually, based on work to date.**

**But not in the first run in every version.**

# Another example: effect of spherical divergence is studied by laser illumination of a perturbed hemispherical shell

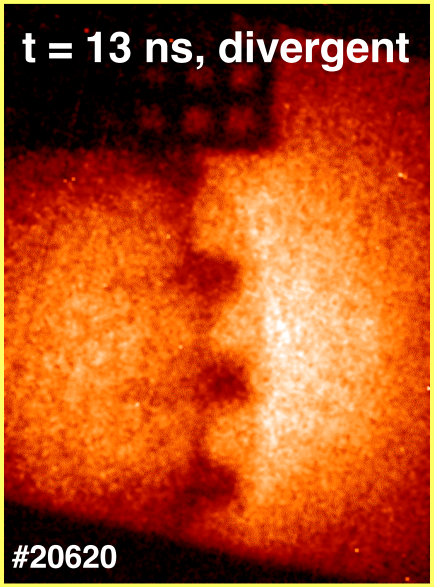


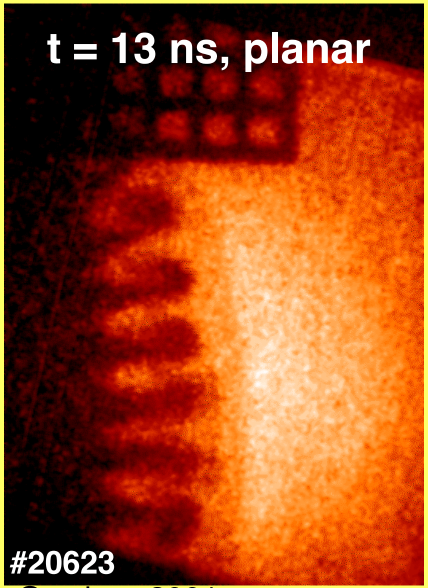




- The unperturbed hemispherical shell remains intact indicating no significant perturbation from the laser drive
- The perturbed shell ($\lambda$=70μm, $a_{P-V}$=10μm) breaks up due to R-T and R-M instability

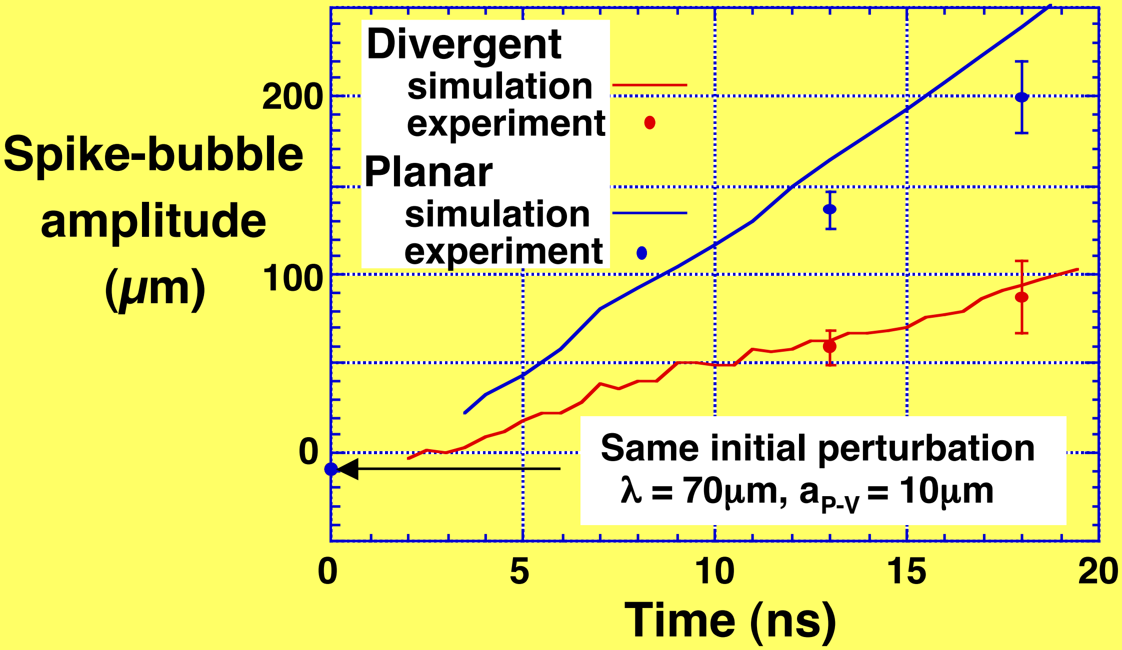
# Perturbation growth in spherical geometry is observed to be significantly smaller than in planar geometry




**CALE vs. data**

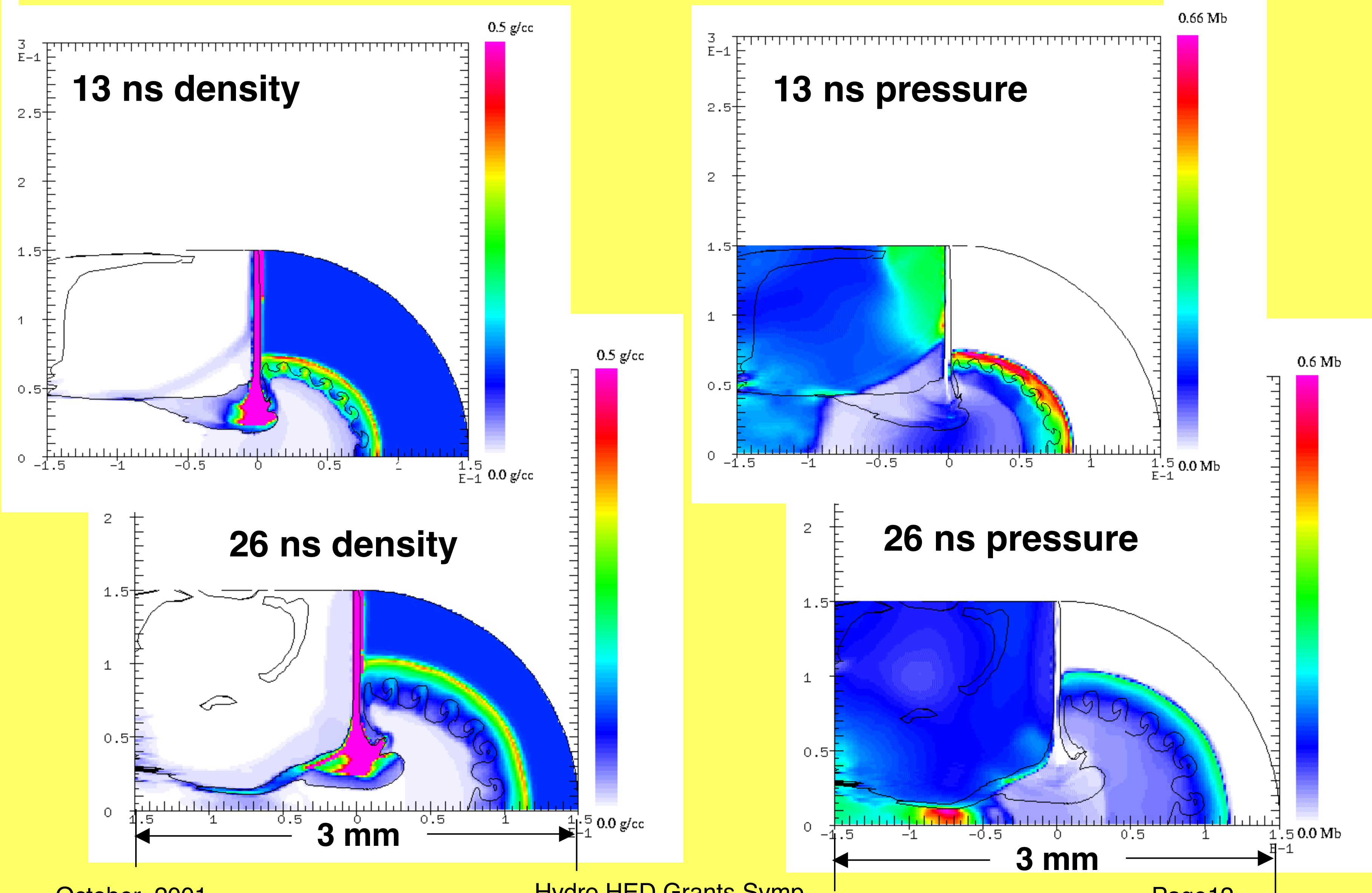
**Comparison of spherical vs. planar**




**Growth in spherical geometry is reduced due to :**

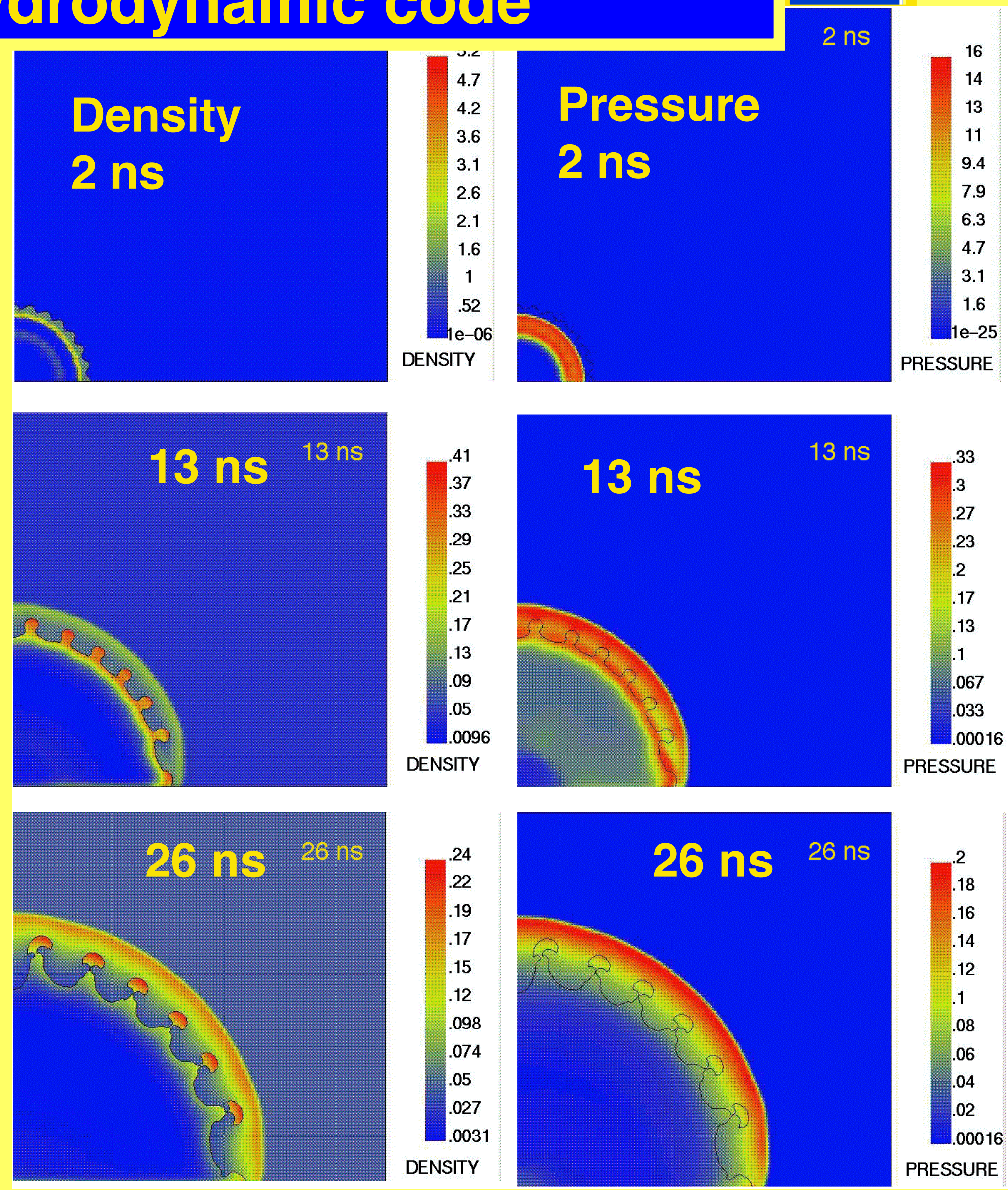
- **Wavelength increase due to divergence**
- **Possible effect of shock proximity**

# CALE results show spike development



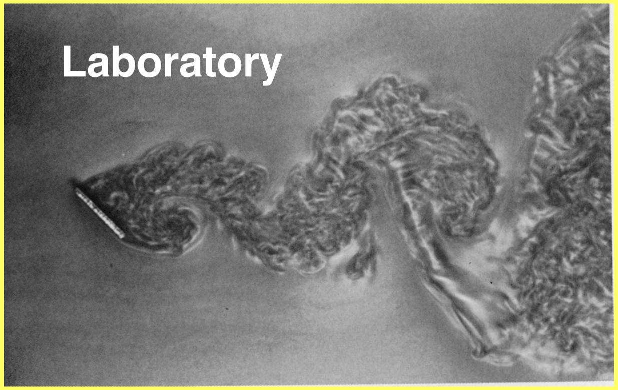
# We used FronTier to demonstrate mapping to a purely hydrodynamic code

- **FronTier**
  - Front tracking by independent updating on the two sides of the discontinuity: there is never finite differencing across the front
  - The common MUSCL (Monotonic Upstream-centered Scheme for Conservation Laws) approach is used to advance the hydro normal to the front and elsewhere
  - For this problem, outgoing boundary conditions are used within the capsule and at the outer boundaries; the remainder of the axis of symmetry is a reflecting boundary
  - Results shown on 1.5 mm x 1.5 mm scale

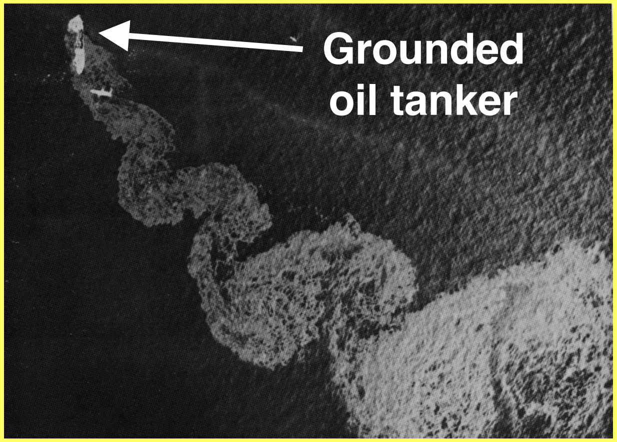


# Our hydrodynamic experiments are ready to ask the second question

- **THE SECOND QUESTION: Does this medium (plasma) exhibit a transition to turbulence like that seen in fluids?**
- **A: In ongoing experiments, we are working to find out.**
  - **If so, this will be a much bigger challenge for simulations.**
  - **It will probably also mean that much published astrophysical hydrodynamics is wrong.**




**Re = 4300** **Cantwell,** ***Ann. Rev. Fluid Mech.*****, 13, 457 (1981)**

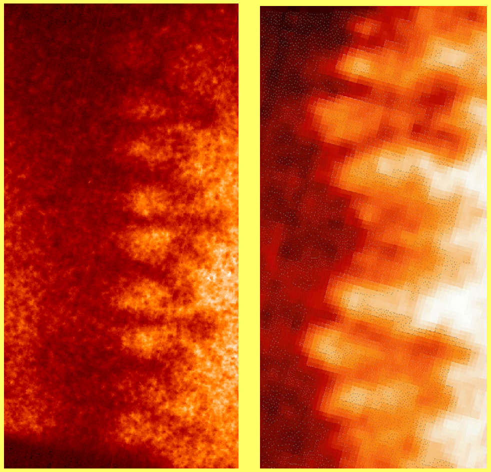



**Re = $10^7$** **Van Dyke, "An Album of Fluid Motion", Parabolic Press, p.100 (1982)**

# We are excited about our progress and look forward to forthcoming experiments

- **We've made demanding tests of deep nonlinear hydrodynamics at high energy density**

- **Next: Push high energy density systems into the "fully turbulent" regime**



- **Join us the February 23-25, 2002 for the**
- ***4th International Conference on High Energy Density Laboratory Astrophysics***
- **At the University of Michigan in Ann Arbor**