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Title: RAGE Simulations of Single-mode Richtmyer-Meshkov Growth in a Convergent Geometry

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Los Alamos
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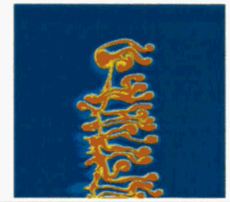

RAGE Simulations of Single-mode Richtmyer-Meshkov Growth in a Convergent Geometry

John M. Scott, Matt Balkey, Steven H. Batha,
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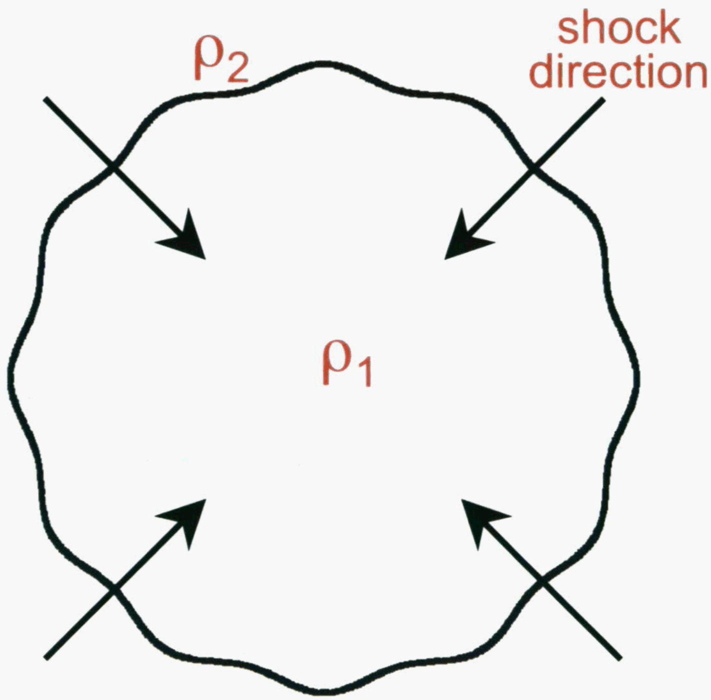
Abstract

- The Richtmyer-Meshkov (RM) instability is initiated by a shock accelerating an interface between two materials. Small perturbations of the interface grow into bubble and spike structures causing mixing of the materials that lie on either side of the interface. Recent Los Alamos National Laboratory experiments have focused on RM initiated mix in a compressible, miscible, convergent geometry. Motivated by the lack of a generally accepted model for this physical regime, cylindrical implosion experiments of single-mode, nonlinear RM growth and saturation are underway at the OMEGA laser facility. Initial targets consist of an m=28 perturbation with an initial amplitude of 2.5 microns machined onto an aluminum marker layer embedded 55 um from the target surface. Initial perturbations of varying amplitudes and wavelengths are being studied using the RAGE code.

The Richtmyer-Meshkov Instability



Instability exists for any density difference at an interface

- If $\rho_2 > \rho_1$ then the perturbations will experience an inversion after shock passage.
- If $\rho_1 > \rho_2$ then there will be no inversion.
- For this experiment, $\rho_1 > \rho_2$
- Linear theory* for planar geometry predicts growth to follow:

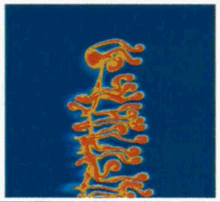
$$a'(t)_{RM}^{linear} = a'_0(1 + kuA't)$$

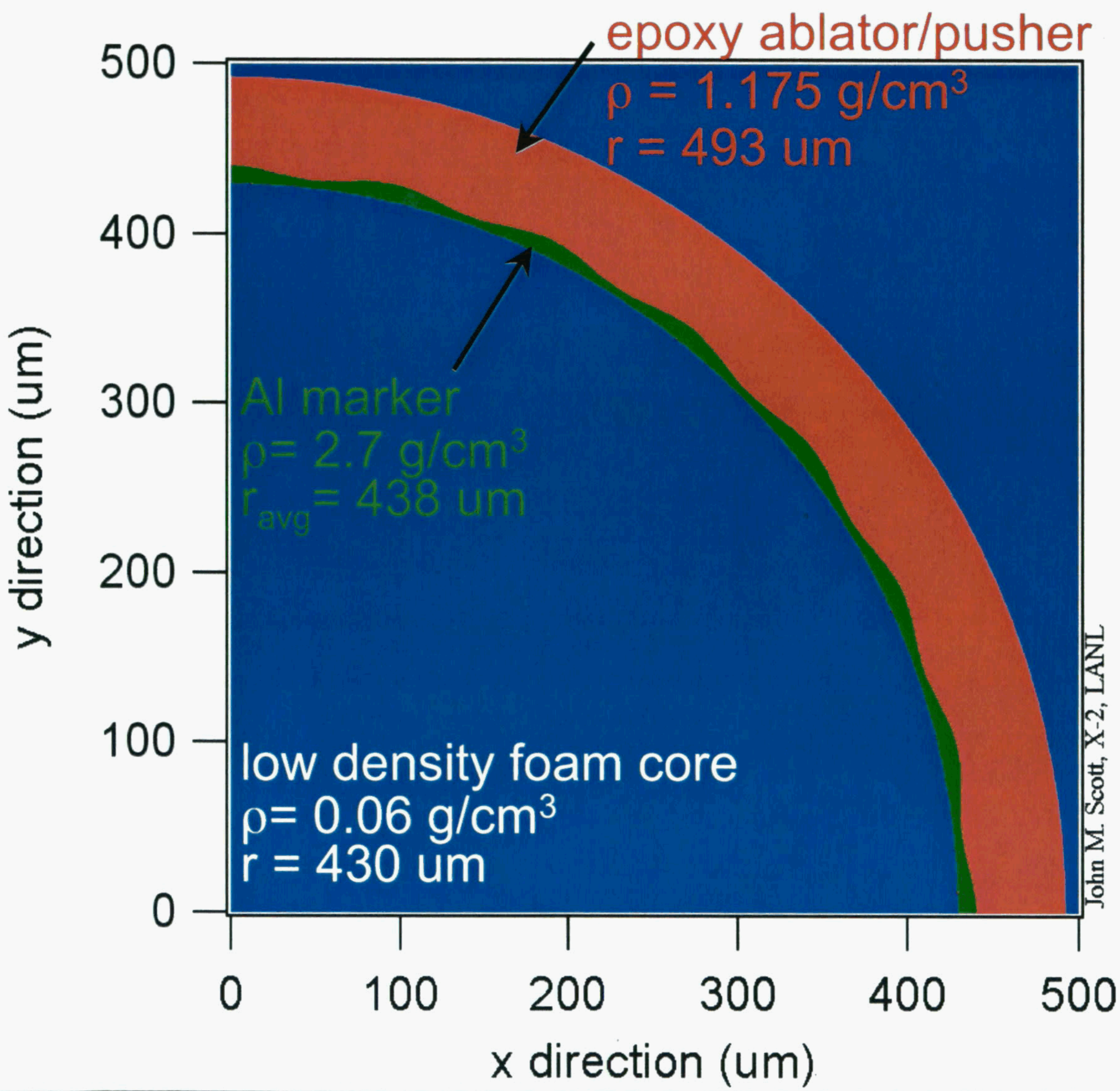
where a' = post-shock amplitude
k = wave number of perturbation
u = interface velocity
A' = post-shock Atwood number

- **Cylindrical convergence should enhance growth by a factor of ~R_0/R above the planar case**

*R. D. Richtmyer, Commun. Pure Appl. Math, **13**, 297 (1960)

Target Geometry





- Al is electroplated onto mandrel material and perturbations are machined to specified mode number and amplitude.
- Al is over coated with epoxy and machined to appropriate radius
- Mandrel is leached and the center is stuffed with low density foam

The work focuses around a validation effort of RAGE to predict hydro instabilities in a convergent geometry.

- We will be exploring a range of mode numbers (8-28) and amplitudes
  - Diagnostic resolution and target metrology restricts us from going to very high mode numbers.
  - Initial amplitudes > 3 um are difficult because of manufacture and target metrology issues.

- This is a <u>challenging</u> problem for RAGE.
  - We use a Cartesian grid to simulate a cylindrically symmetric system.
  - Therefore, the shock is propagating at every angle to the mesh.
  - *There will be grid imprint at the unstable interface.*

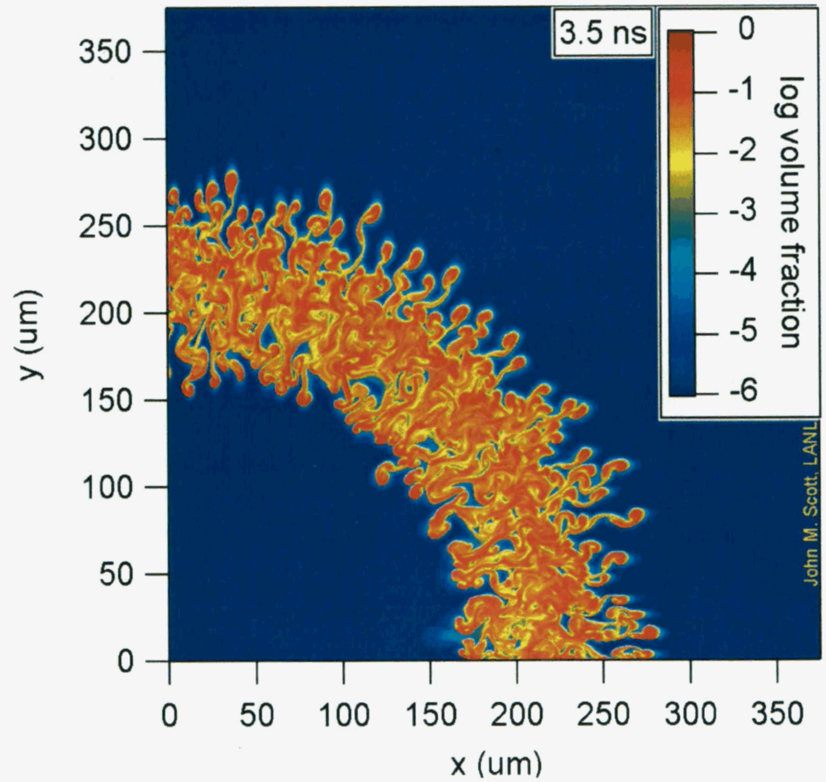
Methodology of RAGE simulations for these RM instability calculations

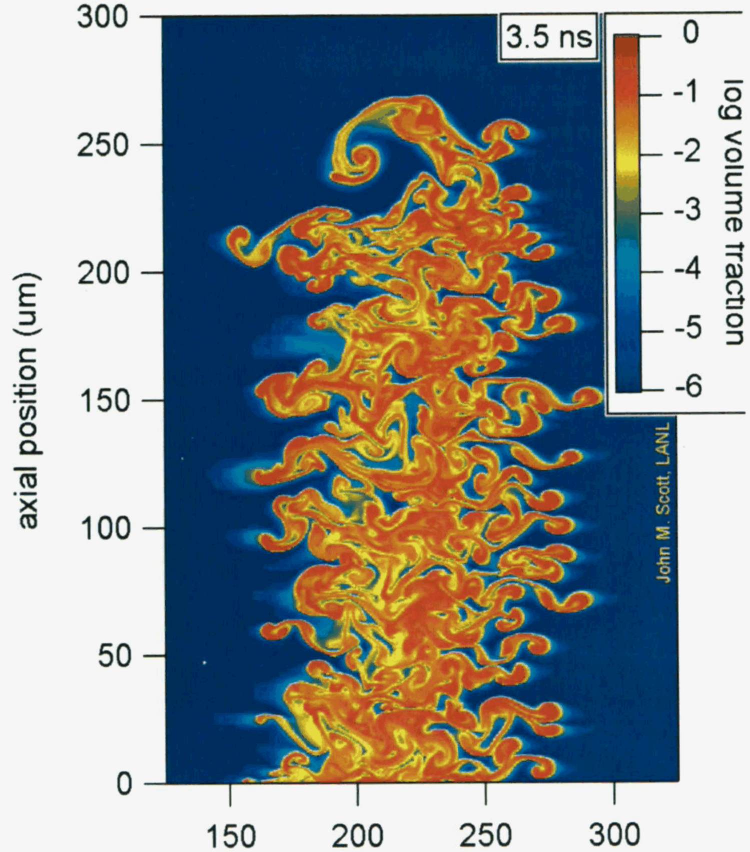
- RAGE is an Eulerian, radiation-hydrodynamics code with continuous adaptive mesh refinement.

- RAGE does not currently have a laser ray trace package for general use.
  - Laser energy is deposited some depth into cylinder surface as an internal energy source.
  - Simulations with another code that does laser energy deposition supplies RAGE with the deposition depth and energy
  - This technique has been used previously in the LANL-DDCYLMIX campaign and does an adequate job of reproducing the zero order hydrodynamics seen in experiment.

- Radiation transport has been turned off in order to produce a calculation that runs in a reasonable amount of time.
  - A 2-D simulation with radiation transport on produces similar results as with radiation transport off. Fine scale structure is different.
  - Thermal conduction is an important effect.

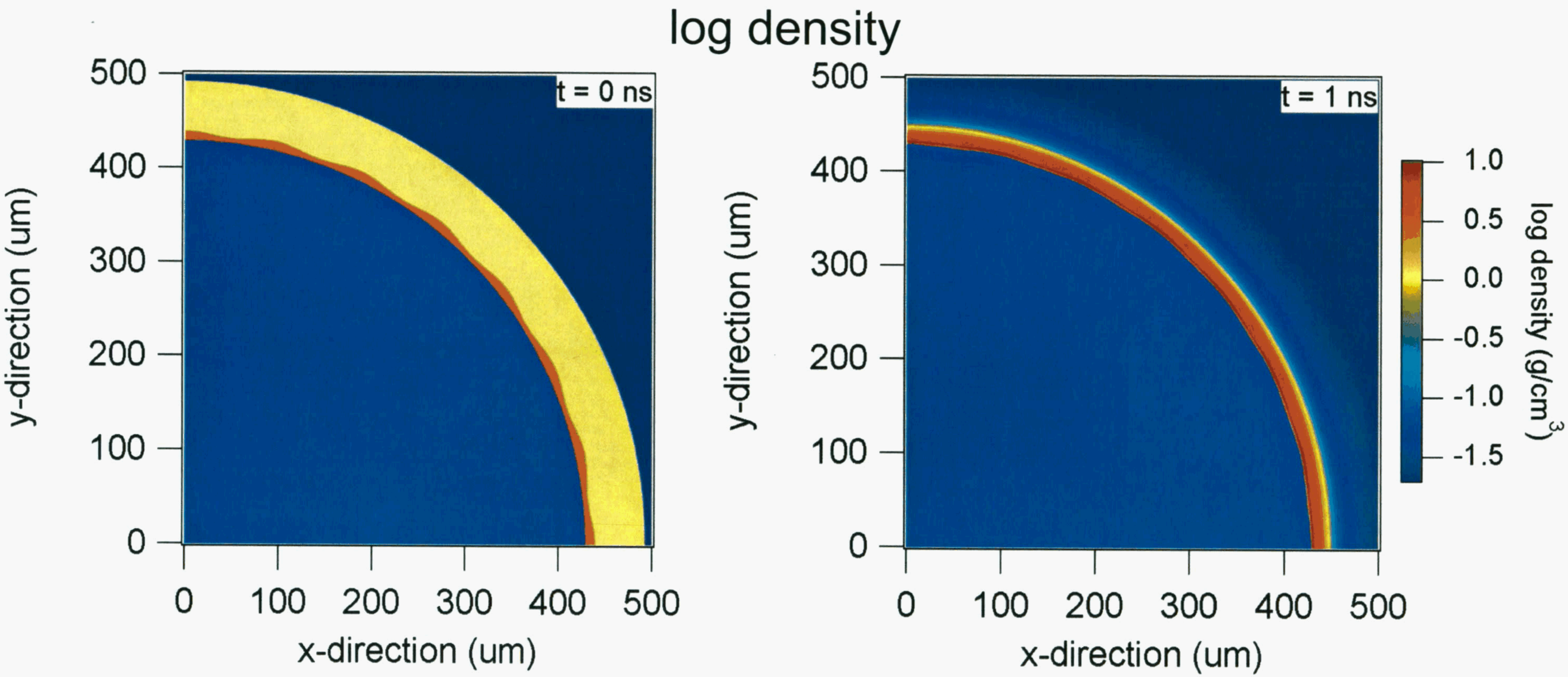
RAGE has been used previously to look at the interaction of a multimode surface perturbation.





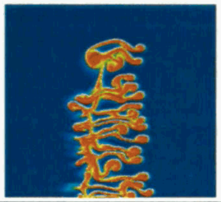
- **These multimode experiments will be discussed at Nick Lanier's talk on Thursday morning, November 14 in the Junior Ballroom.**

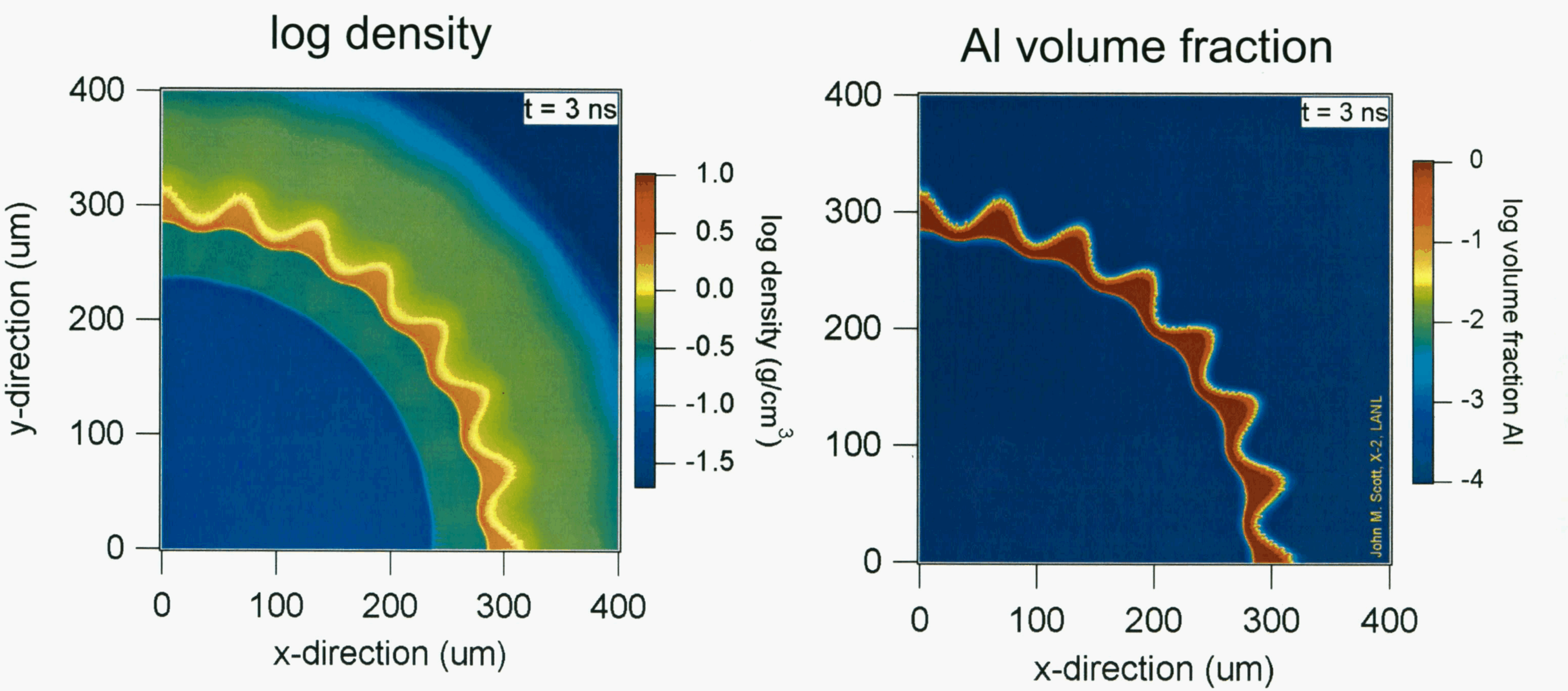
Simulation time snaps from a mode 28, 2.5 um initial amplitude target (1)



- The target is driven by 15.75 kj of energy deposited as a 1-ns square pulse. The shock mach number is > 5.
- The energy is distributed in a 3-um layer on the outside of the target.

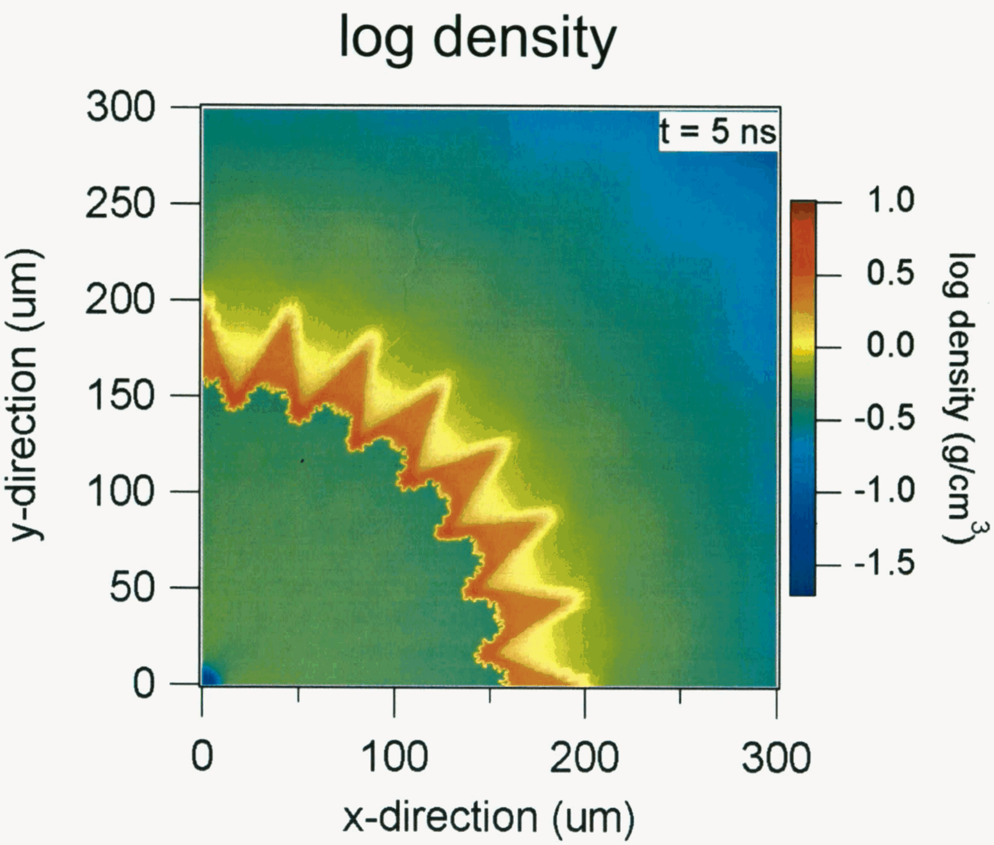
Simulation time snaps from a mode 28, 2.5 um initial amplitude target (2)

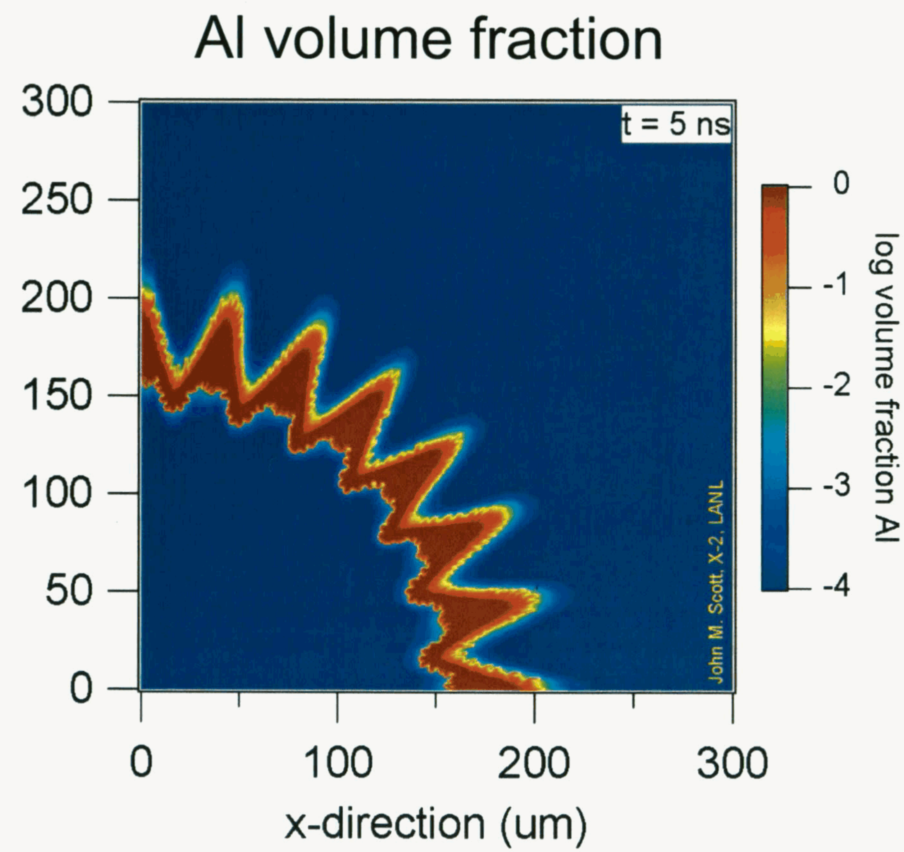




- The effect of grid imprint can be seen on the outer layer of the marker.

Simulation time snaps from a mode 28, 2.5 um initial amplitude (3)





- As the inner core foam begins to decelerate the Al shell, perturbations from grid imprint appear on the inner marker interface.

What does linear theory say about the expected growth?

- For the case of a shock traveling from a light to heavy fluid and an initially small amplitude sinusoidal perturbation Richtmyer* gives: $a'(t)_{RM}^{linear} = a'_0(1 + kuA't)$

- Accounting for convergence one can multiply this growth rate by a factor of R_0/R yielding:

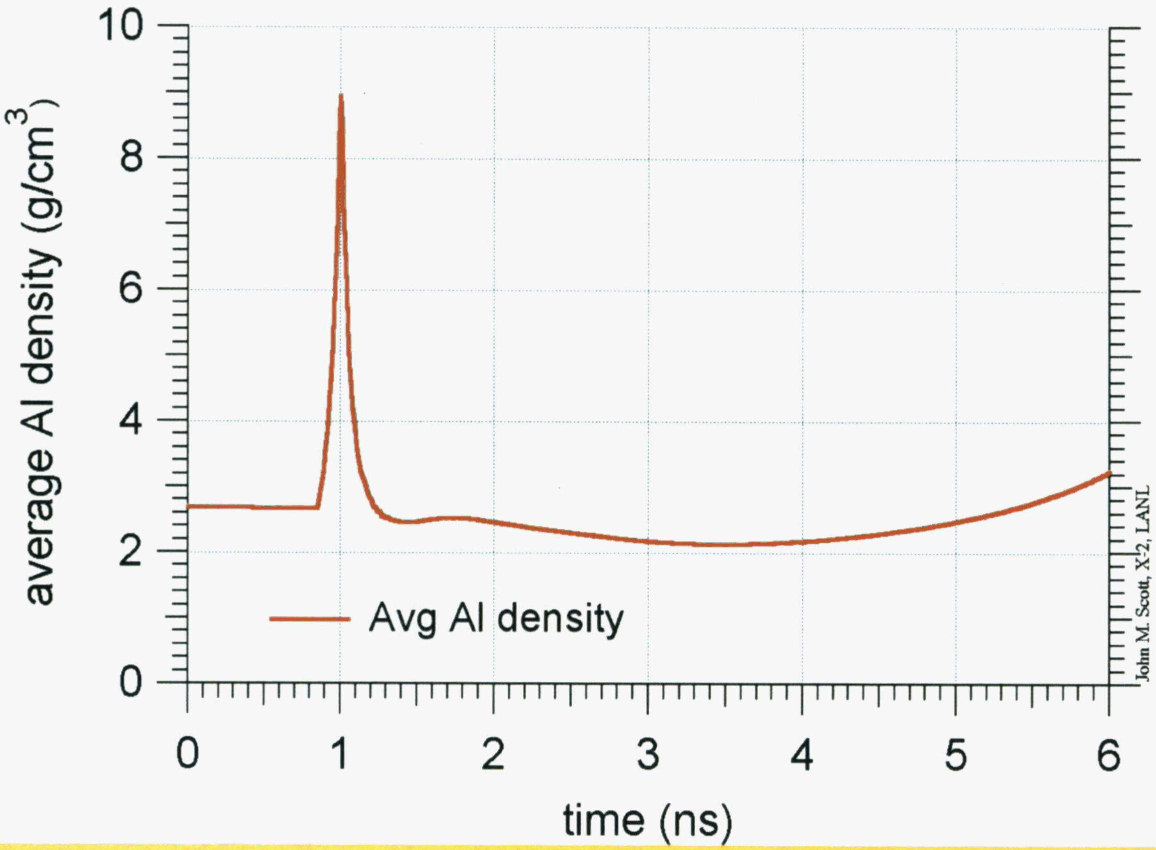
$$a'(t)_{RM}^{linear} = \frac{R_0}{R} a'_0(1 + kuA't)$$

← A more detailed derivation can show this.

- The above assumes accelerationless movement of the interface.
  - Simulations show a weak deceleration at later times that will lend a Rayleigh-Taylor component to the growth.

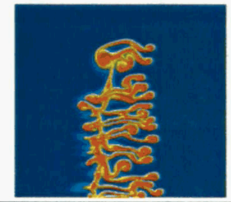
*R. D. Richtmyer, Commun. Pure Appl. Math, **13**, 297 (1960)

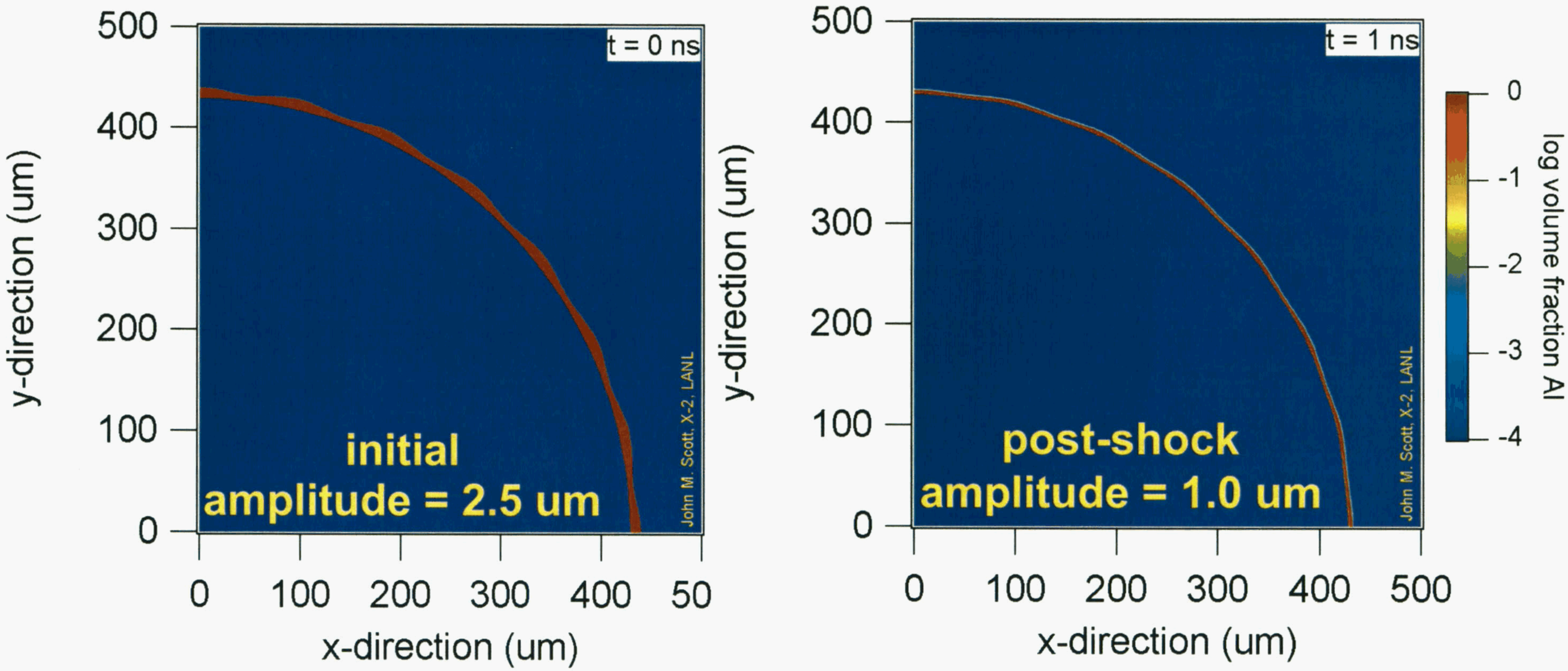
Some calculational results that demonstrate marker layer behavior.



- An average density plot of the Al marker layers shows it compressing and then relaxing to a value near its original value after shock passage.

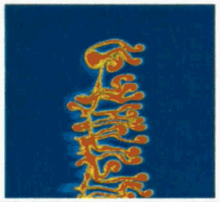
Initial perturbations are reduced by 60% with passage of the shock through the marker.

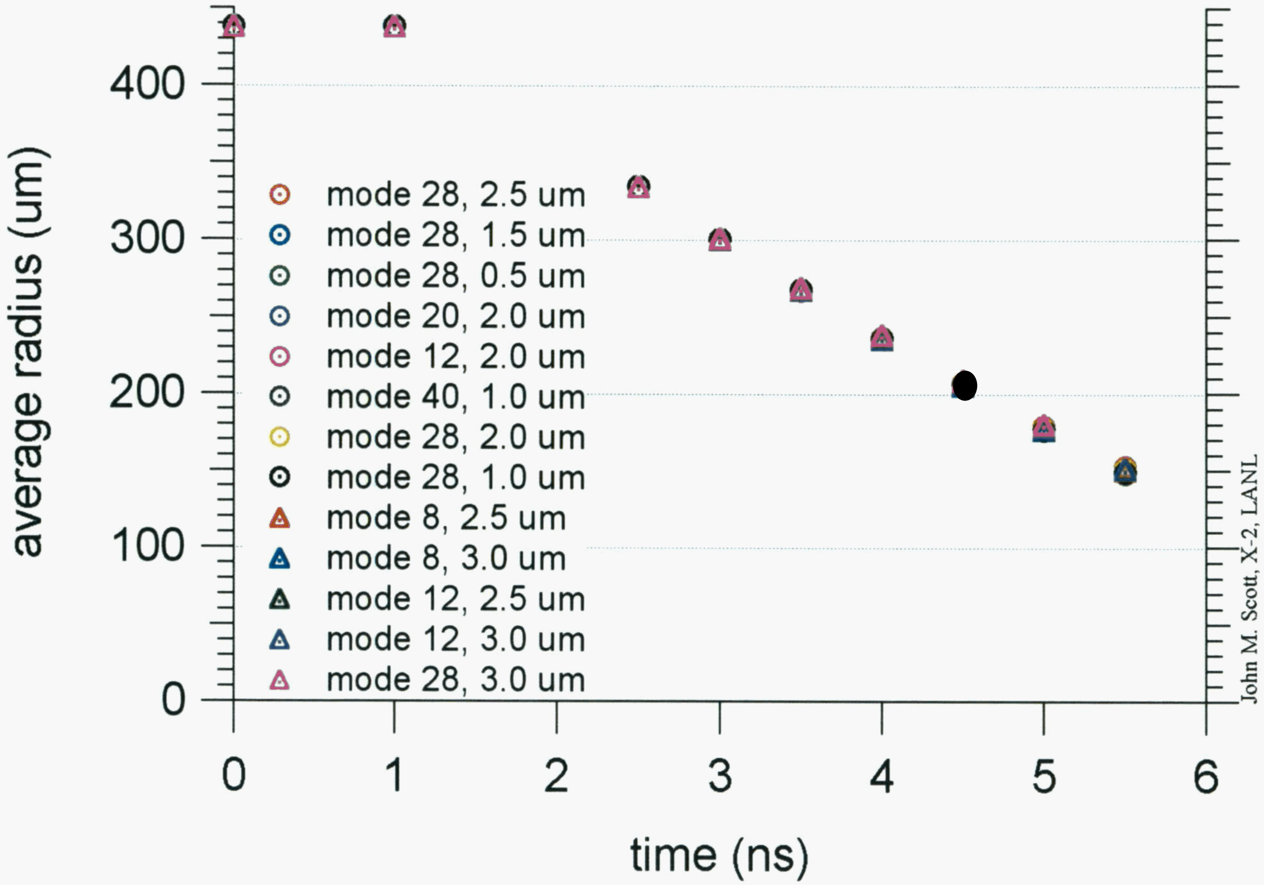




- 60% is a consistent value across mode number and amplitude with targets driven by same energy.

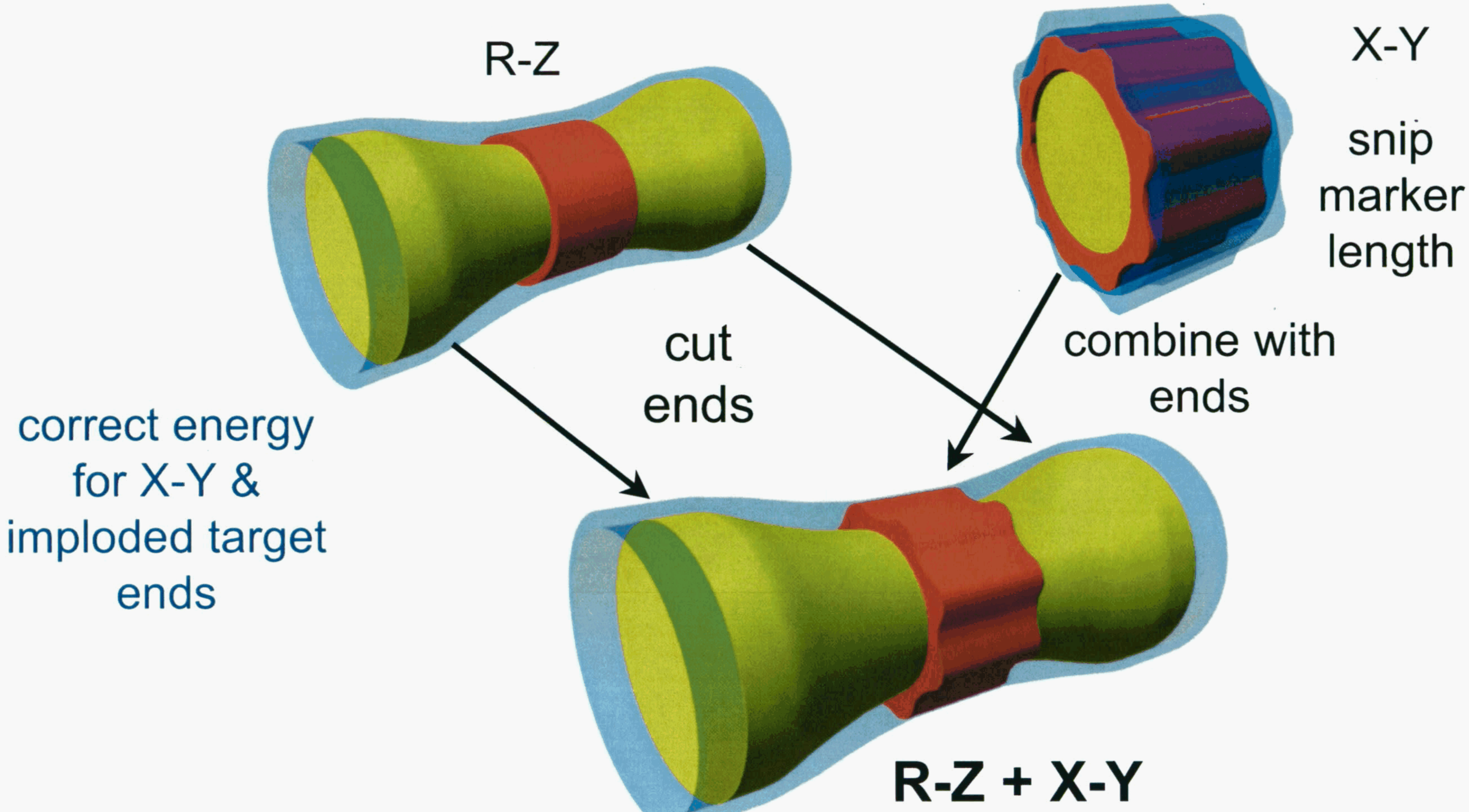
The marker layer has a nearly constant velocity during the implosion.





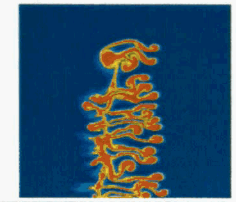
- A weak deceleration appears at later times.
- Zero order hydro nearly independent of mode number or initial amplitude.

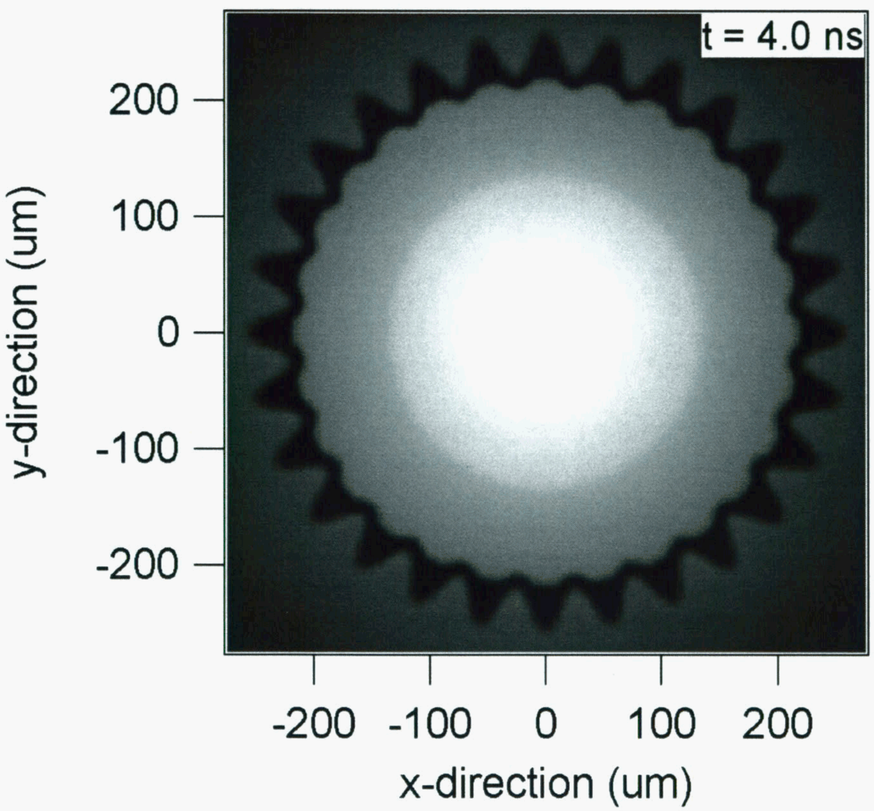
The simulated radiograph of a perturbed target comes from two geometries.

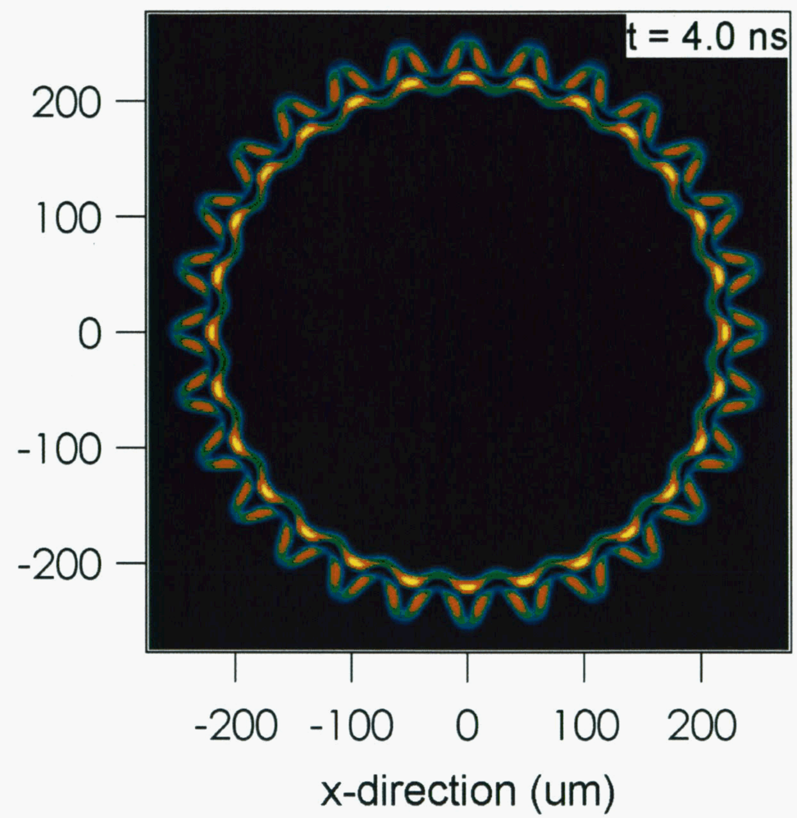


- R-Z and X-Y simulations are combined to construct a model of the experiment.

Simulated images are analyzed to yield perturbation growth information.

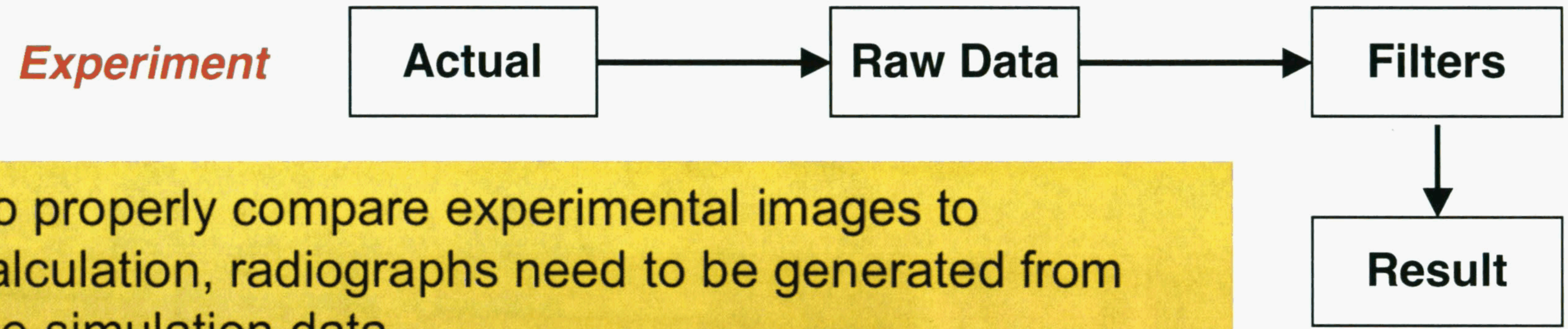




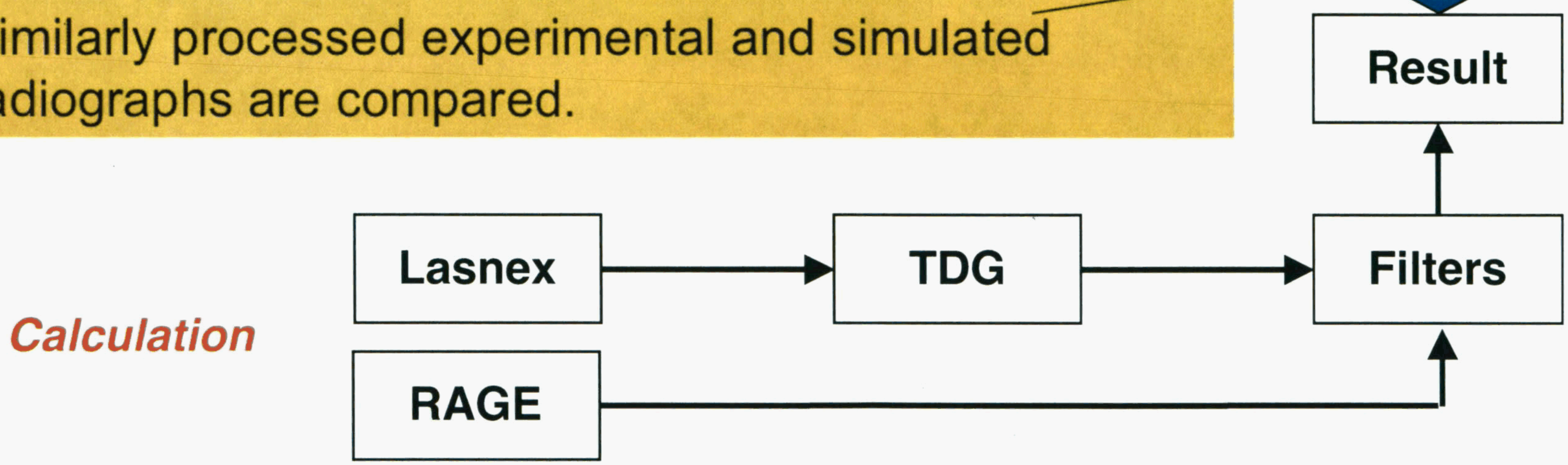


- Image post-processing yields information regarding the edges of the marker layer.

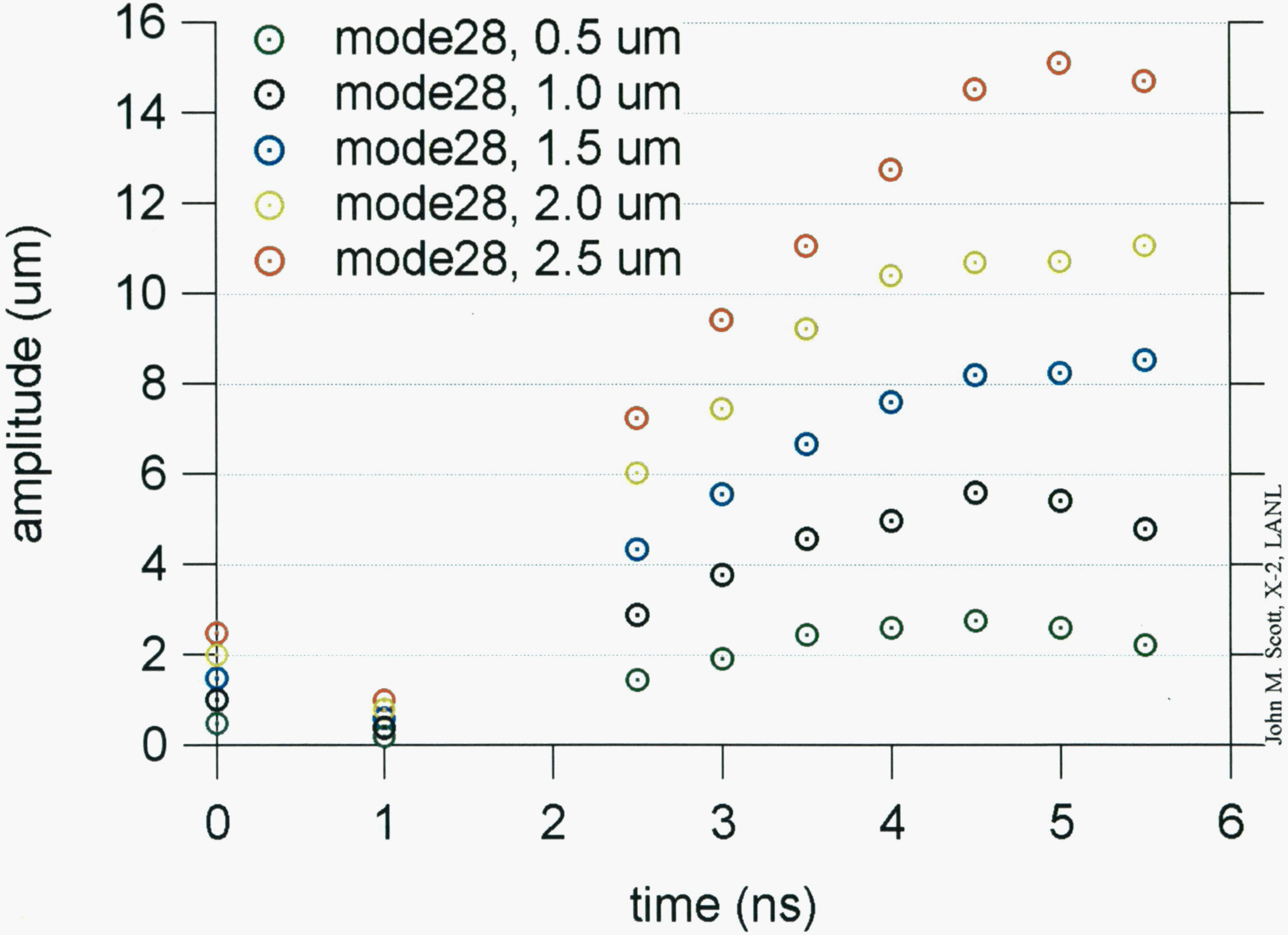
Both simulated and experimental images should be analyzed using the same methodology for a valid comparison.



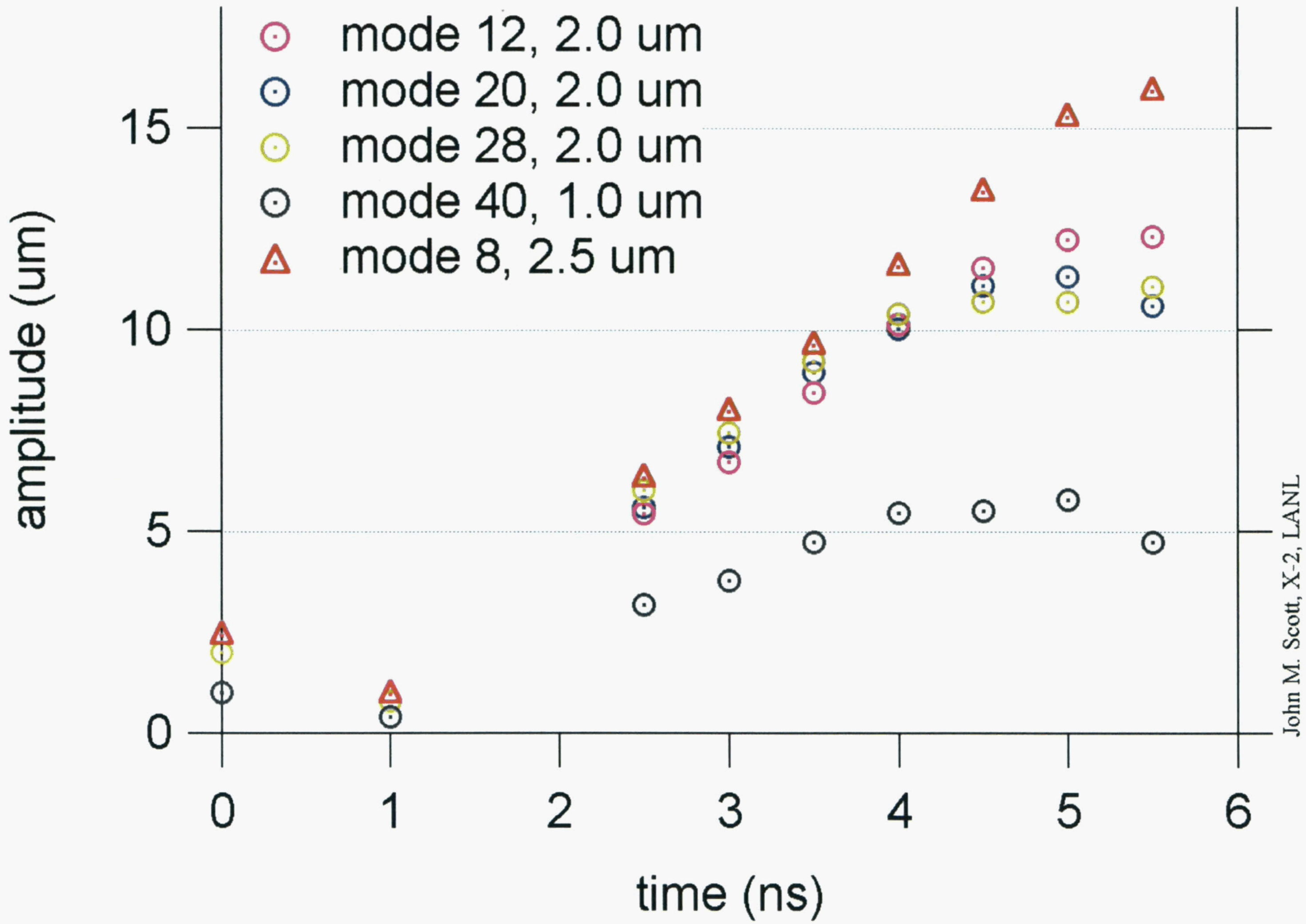
- To properly compare experimental images to calculation, radiographs need to be generated from the simulation data.
- Similarly processed experimental and simulated radiographs are compared.



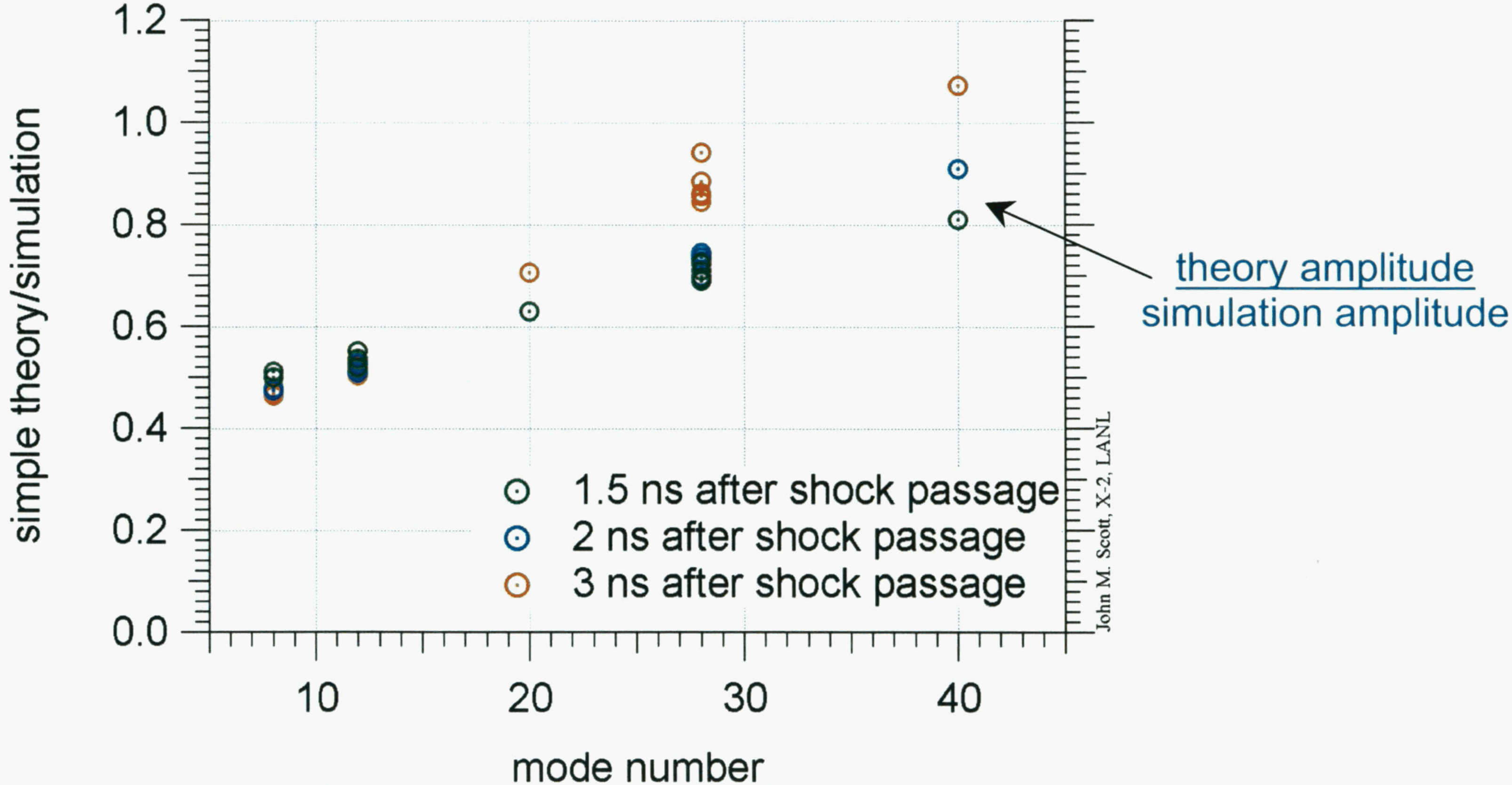
A series of mode 28 simulations demonstrates growth rate vs. initial amplitude.



The effect of varying mode numbers is being investigated as well.

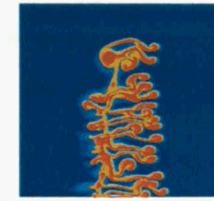


Simulations show greater growth than linear theory.



- Is the effect due to the rarefaction generated at the inner interface of the marker layer?
- How does shock proximity to the layer affect growth?

Conclusions



- Experiments will be performed in Jan 2003 at University of Rochester.
- The experiments will vary both mode number and initial amplitude.
- Investigation of simulations continues to ascertain why growth is seen to be large compared to simple theory.

- See poster #KP1.137 for experimental setup description.