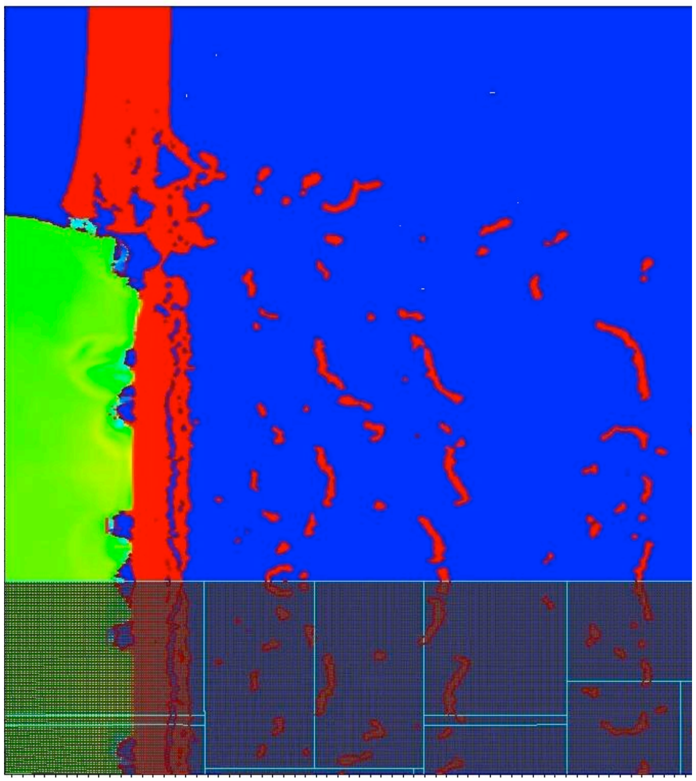
Advanced Target Effects Modeling for Ion Accelerators and other High-Energy-Density Experiments



A. Koniges[1], W. Lui[1], S. Lidia[1],
T. Schenkel[1], J. Barnard[2],
A. Friedman[2], D. Eder[2],
A. Fisher[2], and N. Masters[2]

[1]Lawrence Berkeley National Laboratory
[2]Lawrence Livermore National Laboratory

8th International Conference on Inertial Fusion Sciences and Applications

Nara, Japan
September 10, 2013

National Energy Research Scientific Computing Center

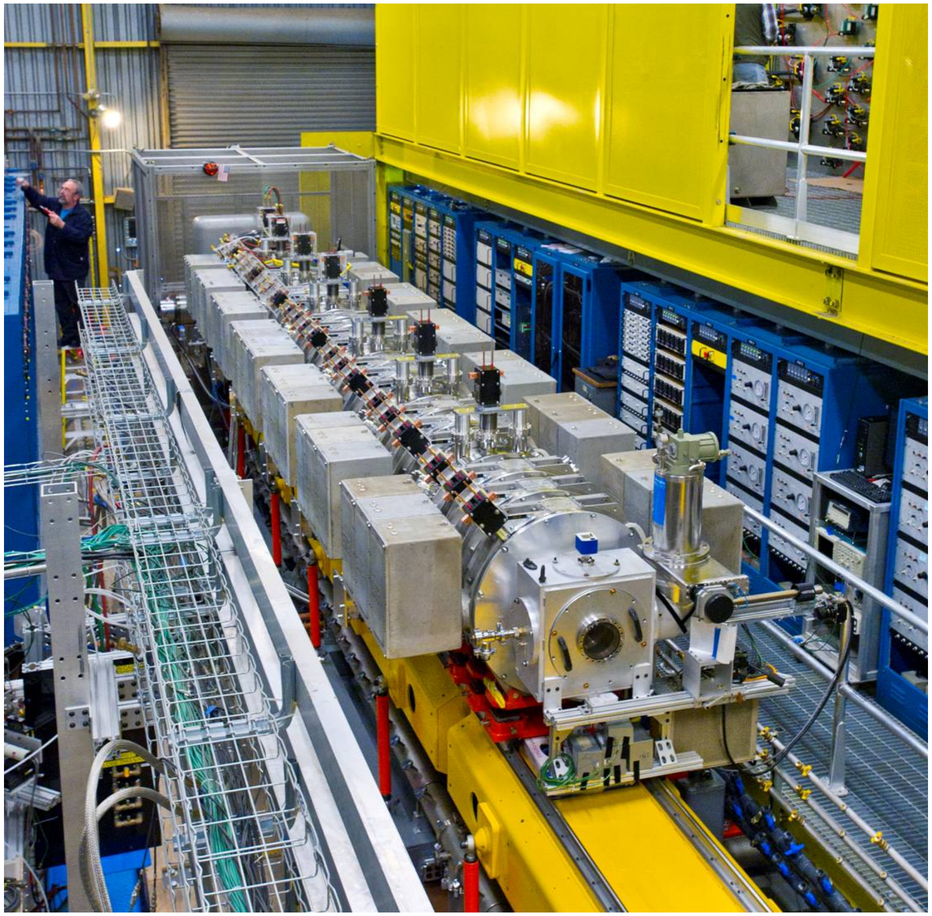
U.S. DEPARTMENT OF ENERGY | Office of Science

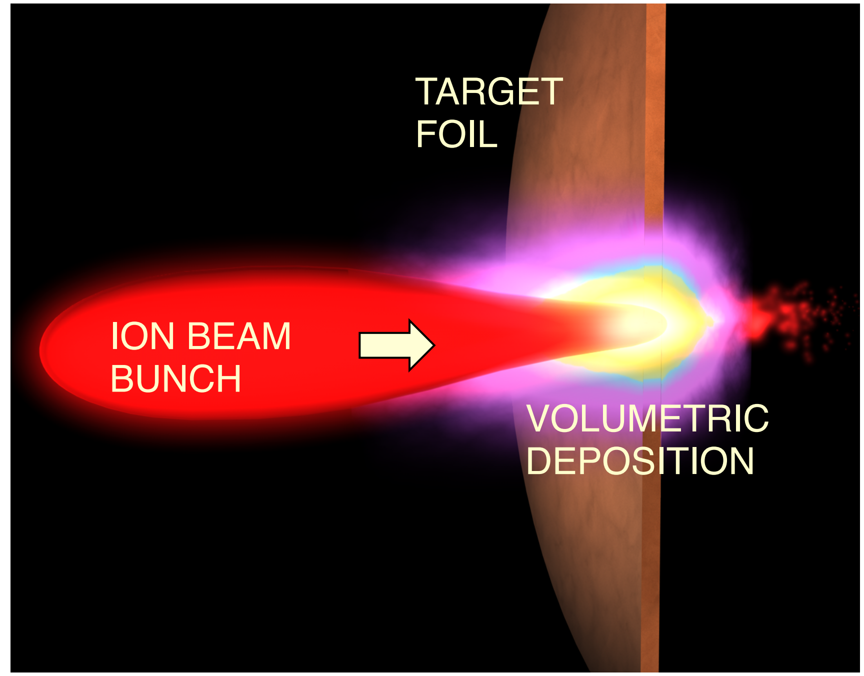
BERKELEY LAB Lawrence Berkeley National Laboratory

Outline

- Operational status of Neutralized Drift Compression Experiment-II (NDCX-II)
- Defect dynamics experiments on NDCX-II
- Proposed experiments with solid and foam targets
- Modeling developments using the ALE-AMR code
  - New surface tension model
- Additional applications for ALE-AMR

NDCX-II user facility at LBNL accelerates Li ions supplying a source for warm dense matter experiments





A user facility for studies of:

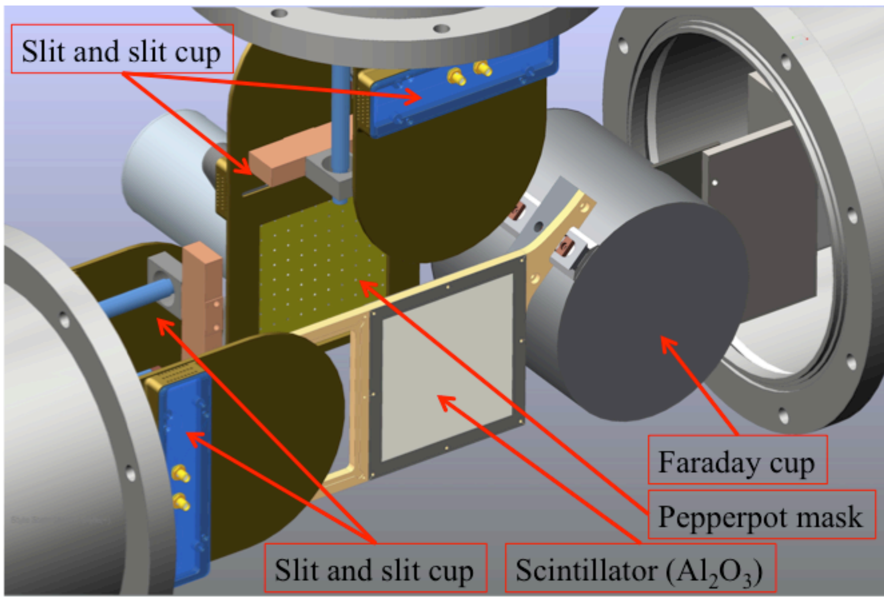
- **physics of ion-heated matter**
- **heavy-ion-driven ICF target physics**
- **space-charge-dominated beams**

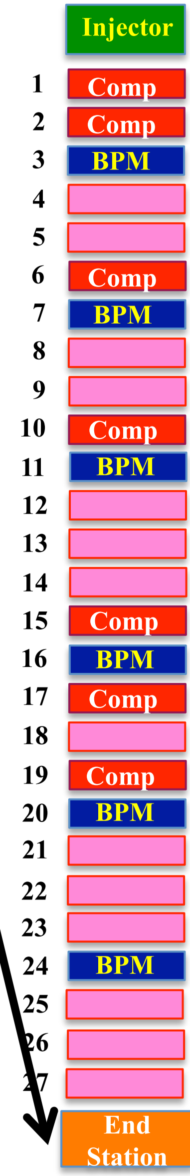
Optimized for volumetric heating of micron-thick samples to eV temperatures within hydrodynamic expansion times

Can also be used at lower energies to study defect dynamics

NDCX-II consists of 27 induction, diagnostic, and drift cells for acceleration and pulse shaping

End station



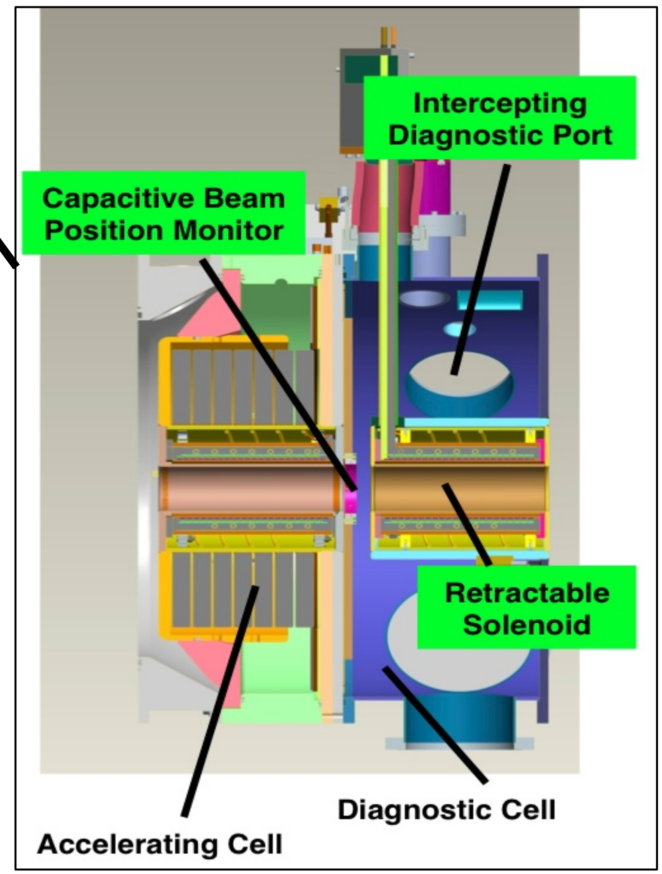


Active induction cell ('compression')

Diagnostic (BPM) and pumping cell

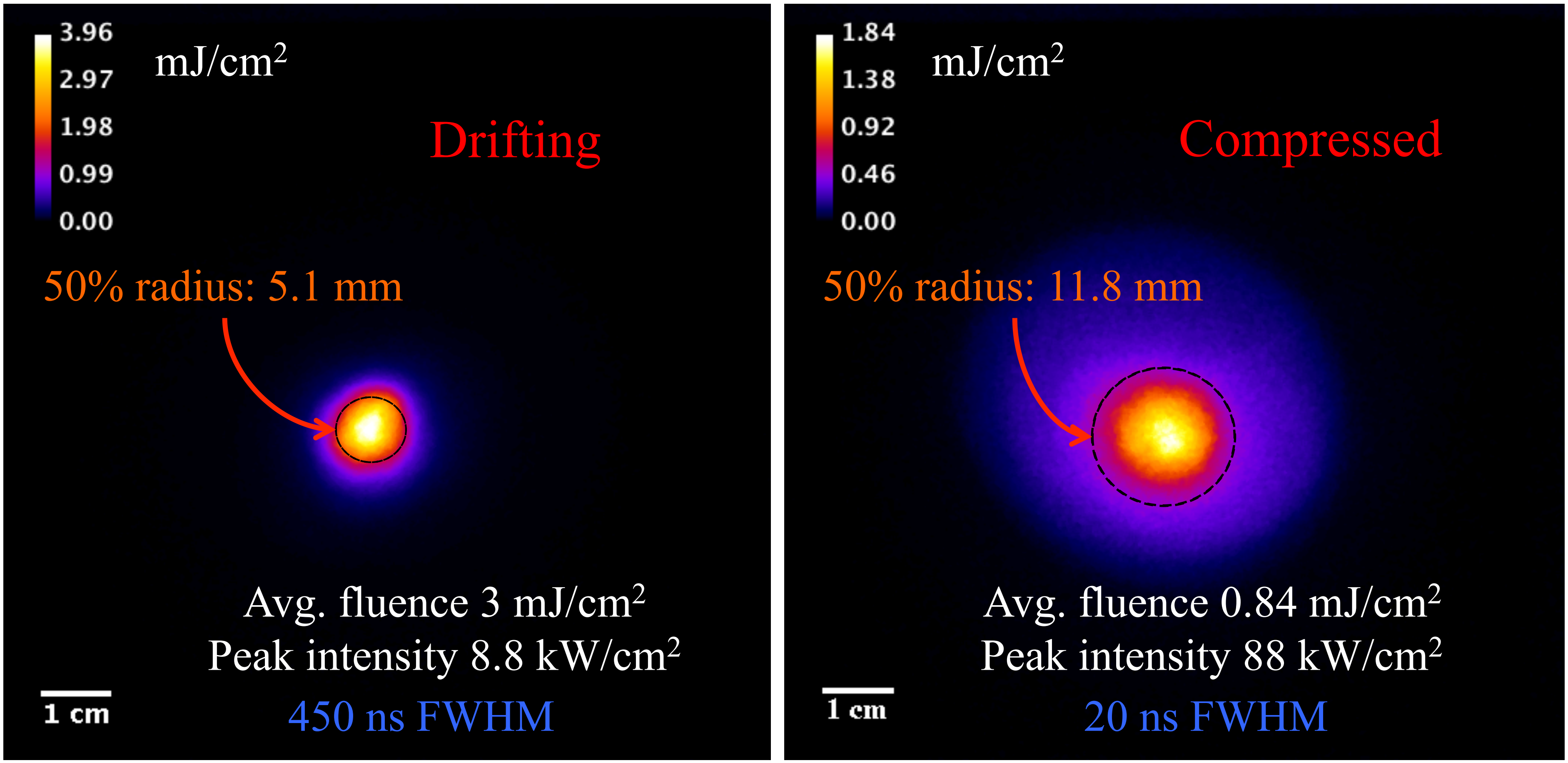
Inactive (drift) cell

Induction cell



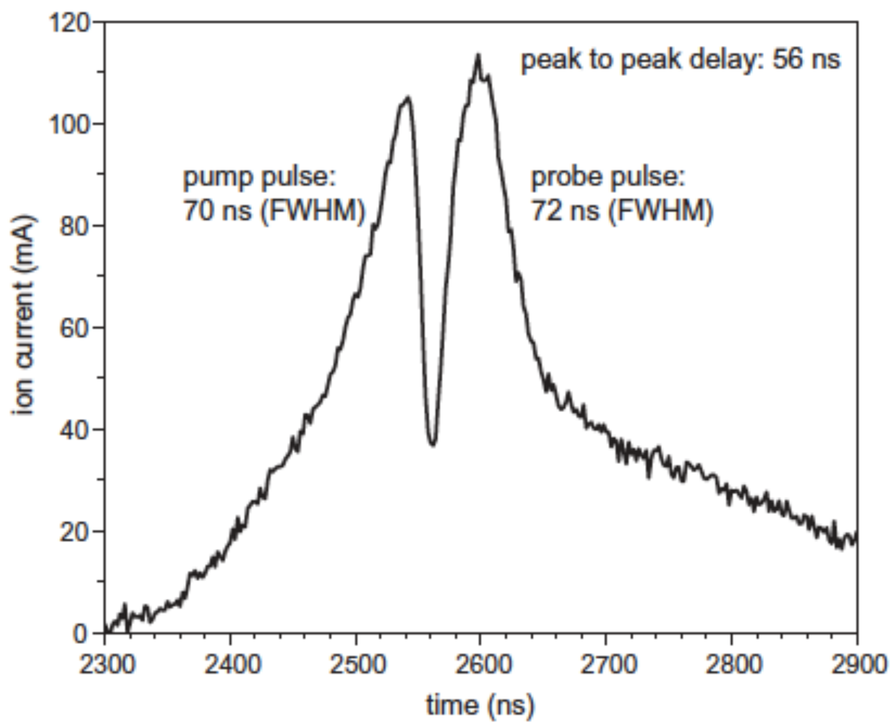
Neutralizing plasma drift section for final compression and final focus solenoid not yet in place

The drifting pulse has longer duration but has a smaller radial extent than the compressed pulse

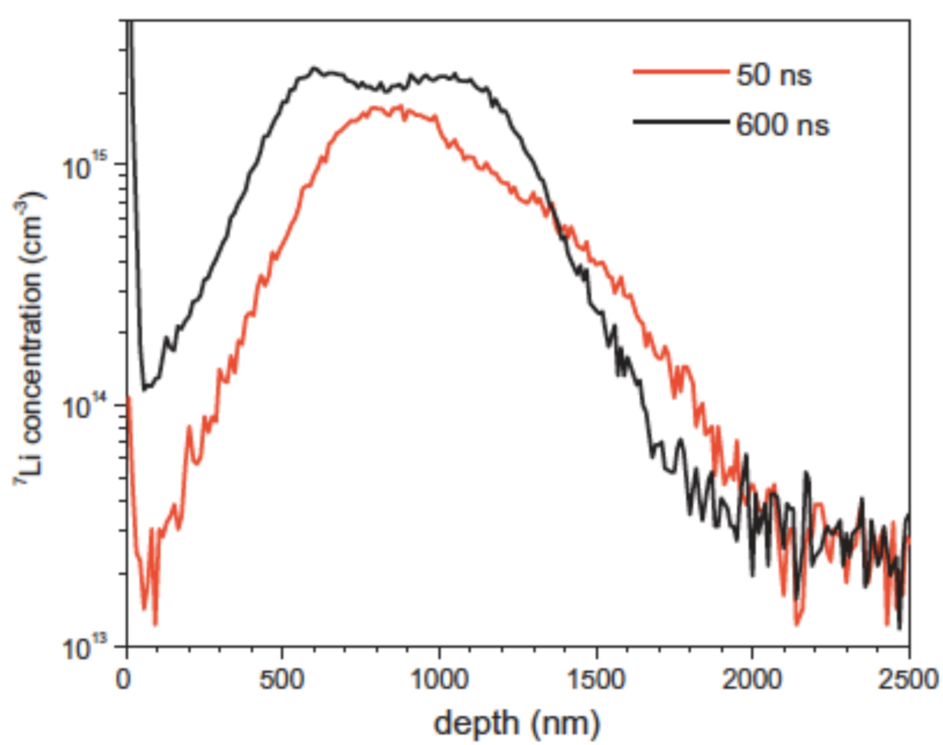


NDCX II is being used for pump-probe experiments of defect dynamics

Nearly two separated ion pulses from a single generated pulse



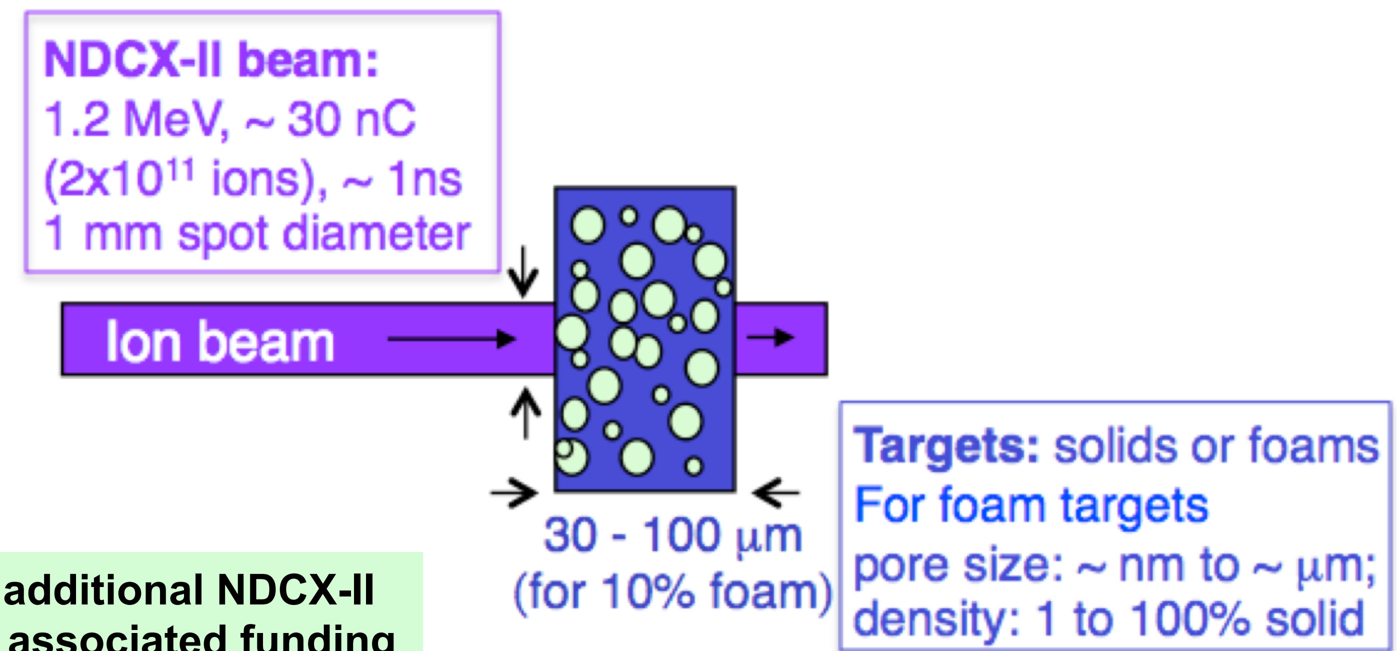
Implantation of Li ions into Si using single pulses



T. Schenkel, et al., Towards pump–probe experiments of defect dynamics with short ion beam pulses, in press Nucl. Instr. Meth. B (2013)

Proposed experiments on NDCX II can study a wide range of warm dense matter regimes

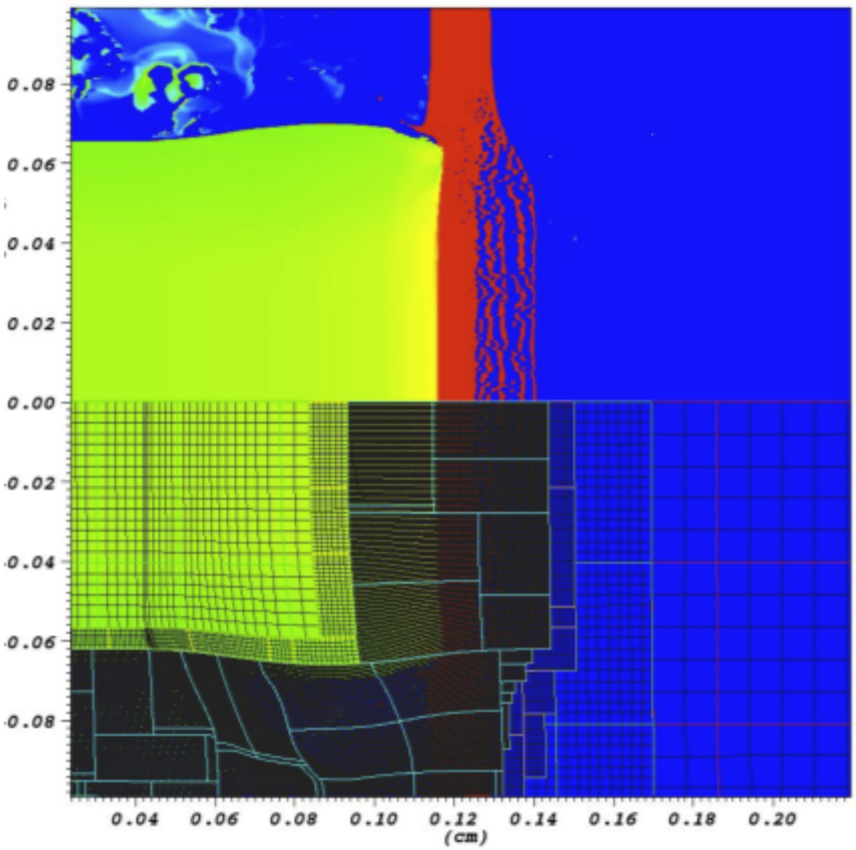
- **Diagnostics could measure properties of hot expanding matter including droplet size, droplet rate formation, homogeneity of temperature, hydrodynamics instabilities growth rate, etc.**
- **New modeling techniques will allow the design and analysis of these experiments, which can include both solid and foam targets**



These require additional NDCX-II capability and associated funding

Complex hydrodynamics requires comprehensive modeling provided by the ALE-AMR code

Thin foil target hit from LHS



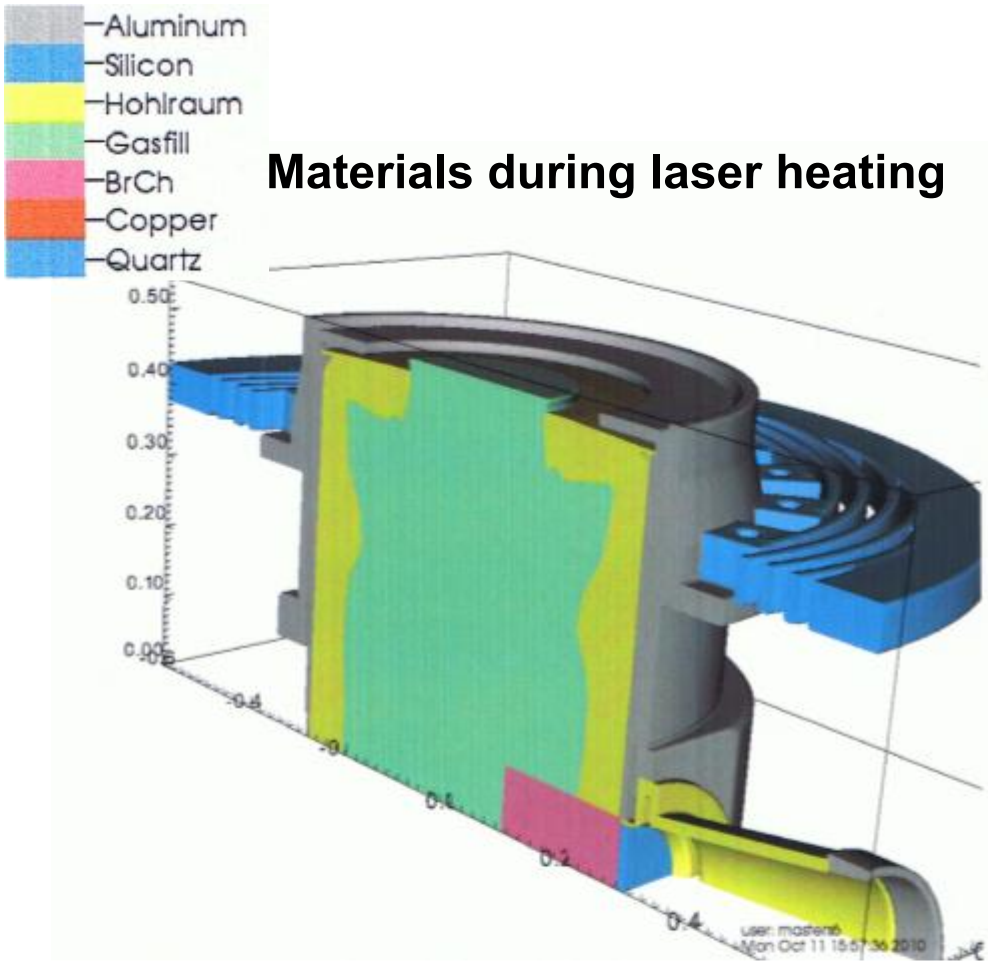
- 3D ALE hydrodynamics
- AMR (use 3X refinement)
  - With 6 levels, vol ratio 10^7 to 1
- Material interface reconstruction
- Anisotropic stress tensor
- Material failure with history
- Ion/laser deposition
- Thermal conduction
- Radiation diffusion
- Surface tension

ALE - Arbitrary Lagrangian Eulerian
AMR - Adaptive Mesh Refinement

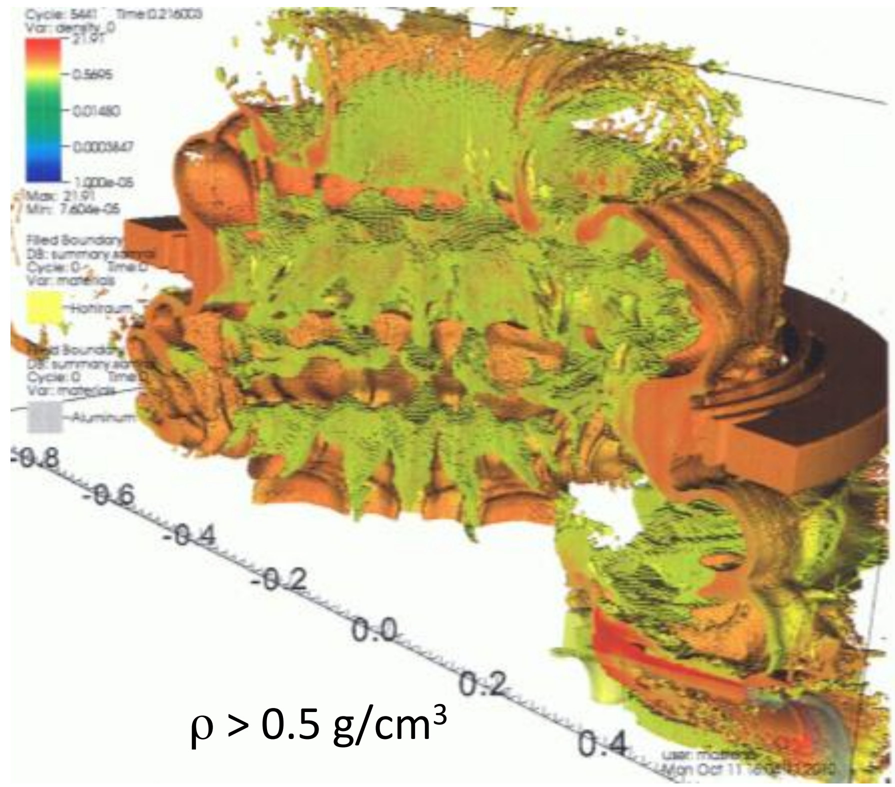
ALE-AMR is an open science code that runs at various computing centers including NERSC and has no export control restrictions

ALE-AMR was developed initially for late-time whole-target (not just hohlraum) NIF simulations

Materials during laser heating



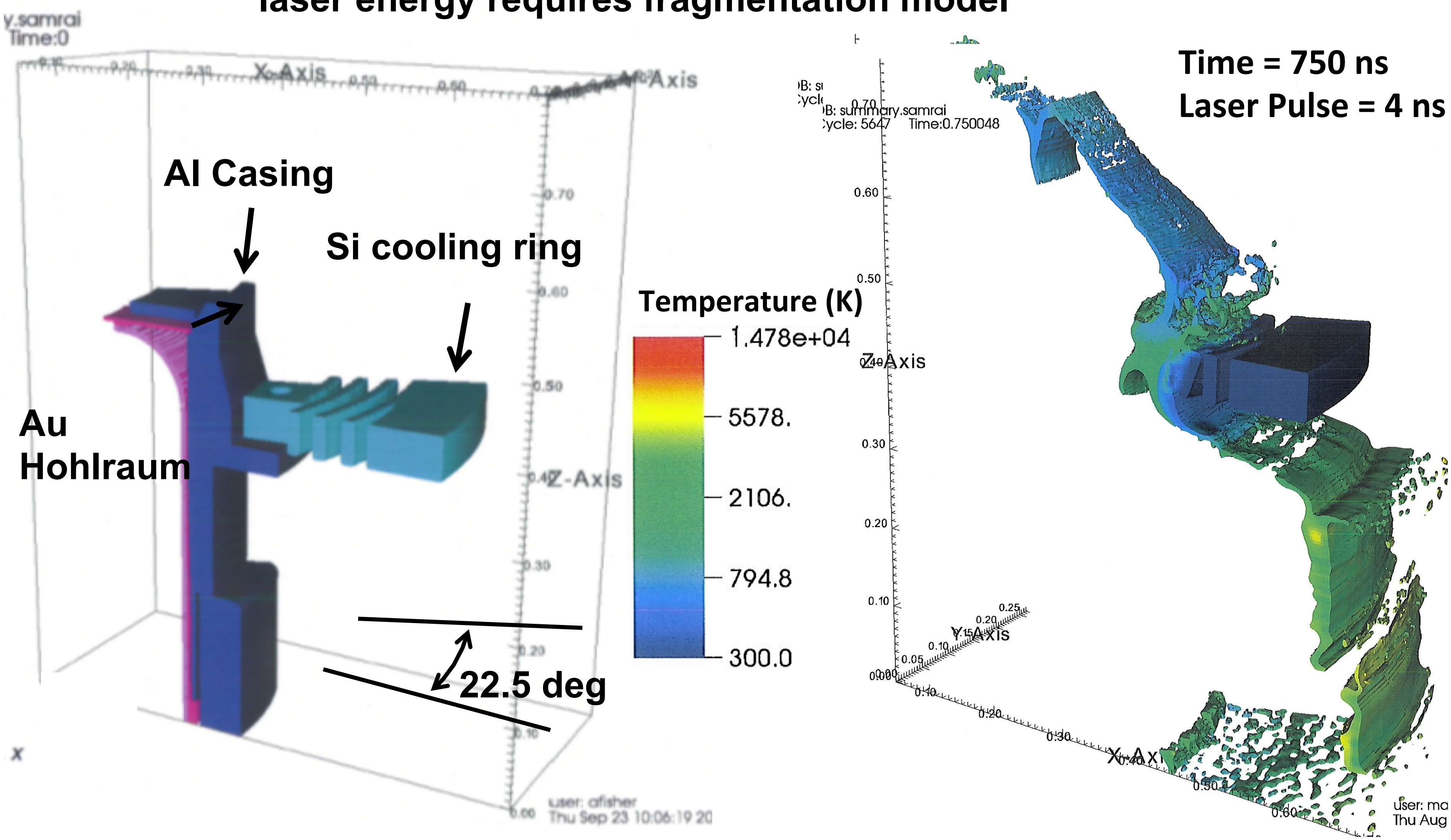
Threshold density at 220 ns



D. C. Eder, A. C. Fisher, A. E. Koniges, and N. D. Masters, "Modeling Debris and Shrapnel Generation in ICF Experiments," to appear in Nuclear Fusion (2013)

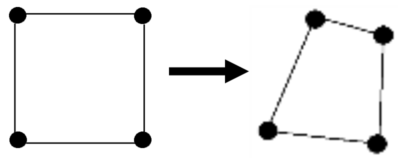
Fragmentation and failure modeling is adopted for warm dense matter regime and NDCX targets

Simulation of NIF experiment using 1% of full laser energy requires fragmentation model



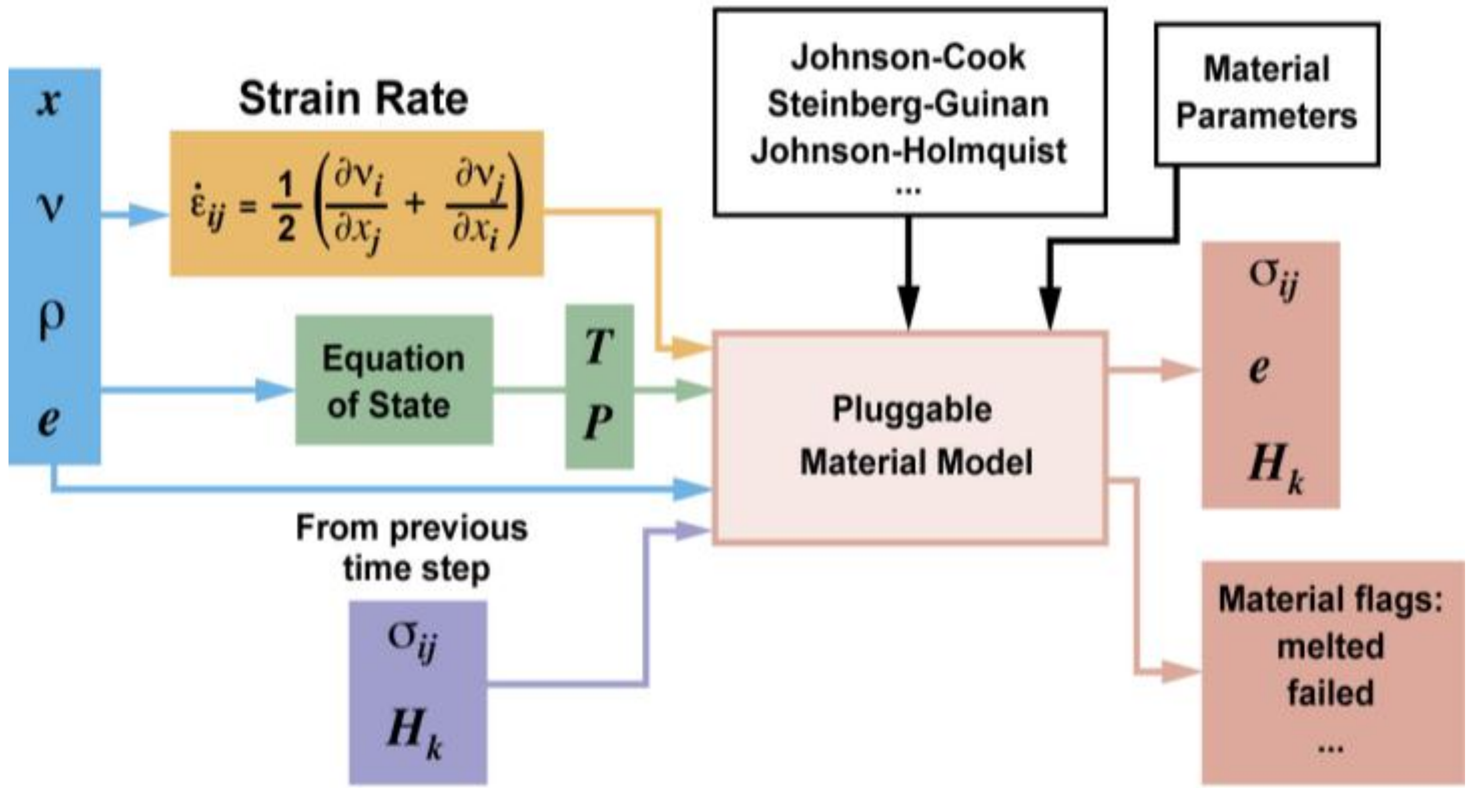
Code has a flexible framework with a new surface tension model active during the Lagrange step

Lagrange Step



Calculate surface curvature using volume fractions giving additional term in stress tensor

Post-Lagrange Material Update



Relax/Remap Split Physics

Details of surface tension model under continuing development for accuracy, stability, and benchmarking

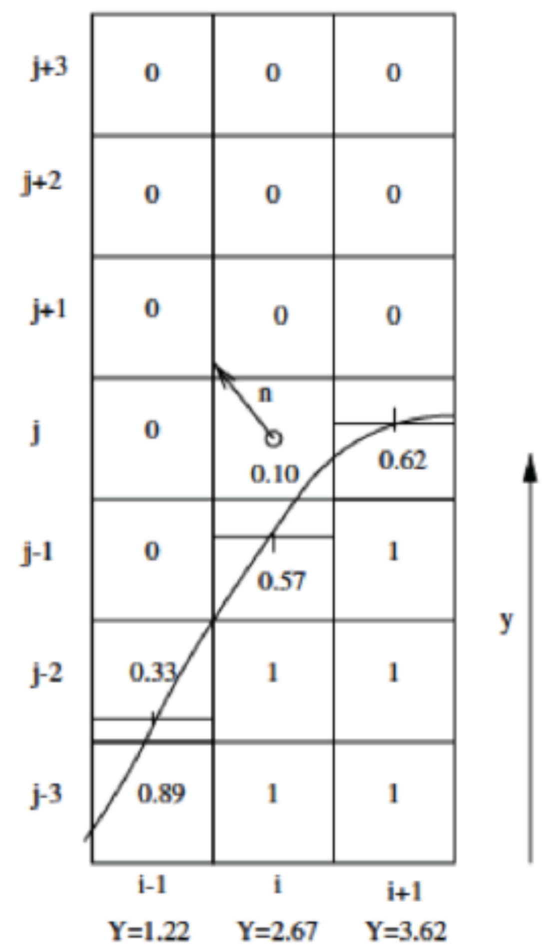
Surface tension calculation is adopted from the height function method using volume fractions

Force f = $\gamma \kappa \vec{n}$, where γ is the surface tension coefficient, κ is the curvature, and $\vec{n}$ is normal

Calculate volume fraction of liquid in each zone and then calculate resulting height function

In 2D, we do a quadratic fit using 3 points
$y = h_1x^2 + h^2x + h_3$ and $\kappa = 2h_1 (1 + h_2^2)^{-1.5}$

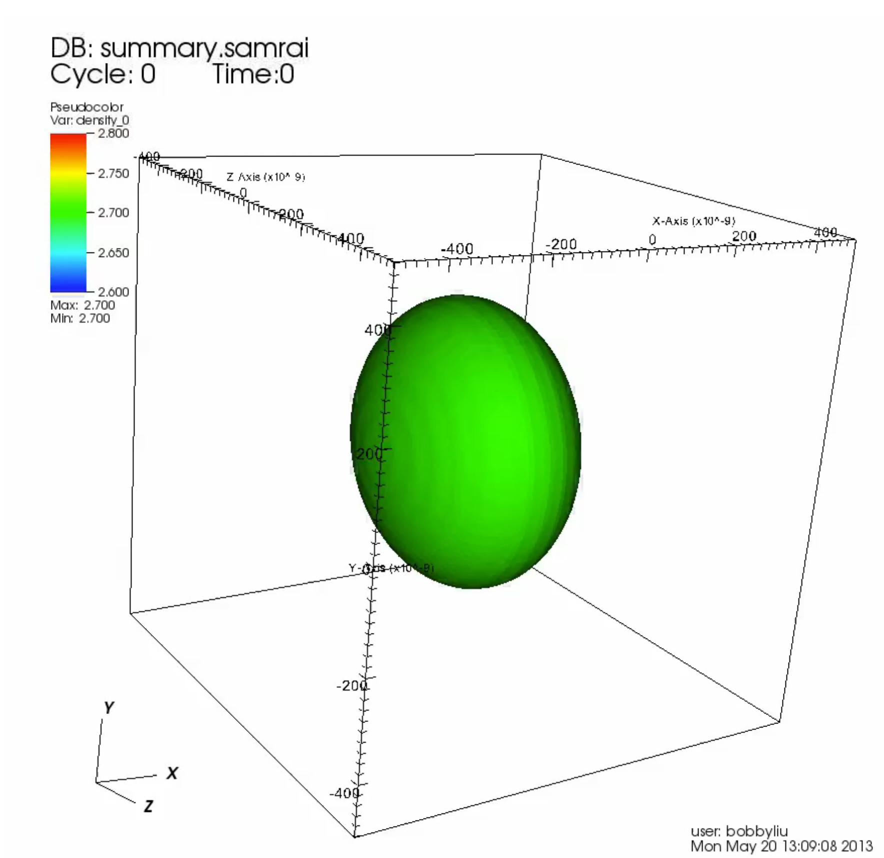
The curvature and normal are calculated in cells but the force like velocity are nodal so cell curvature is averaged to get node value



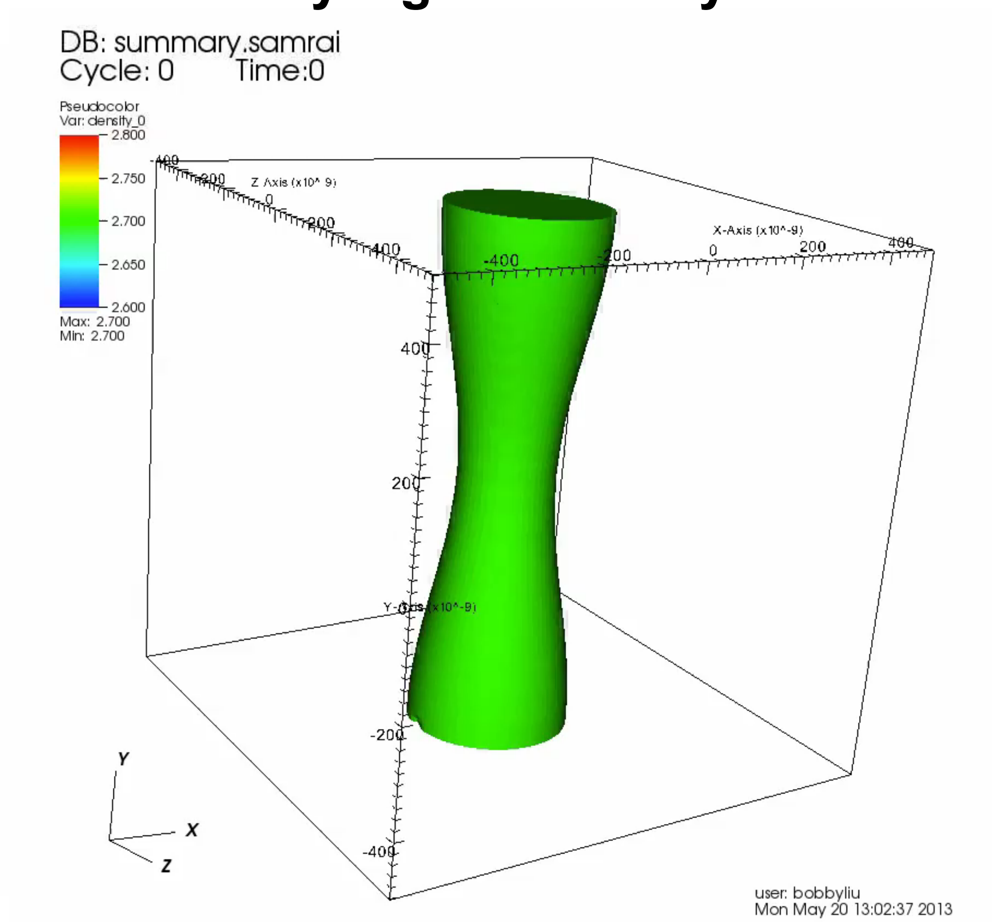
“Estimating curvature from volume fractions,” S. J. Cummins, M. M. Francois, and D. B. Kothe, Computers and Structures **83**, 425 (2005)

We have validated the surface tension model using different test cases with analytic solutions

Ellipsoid oscillation

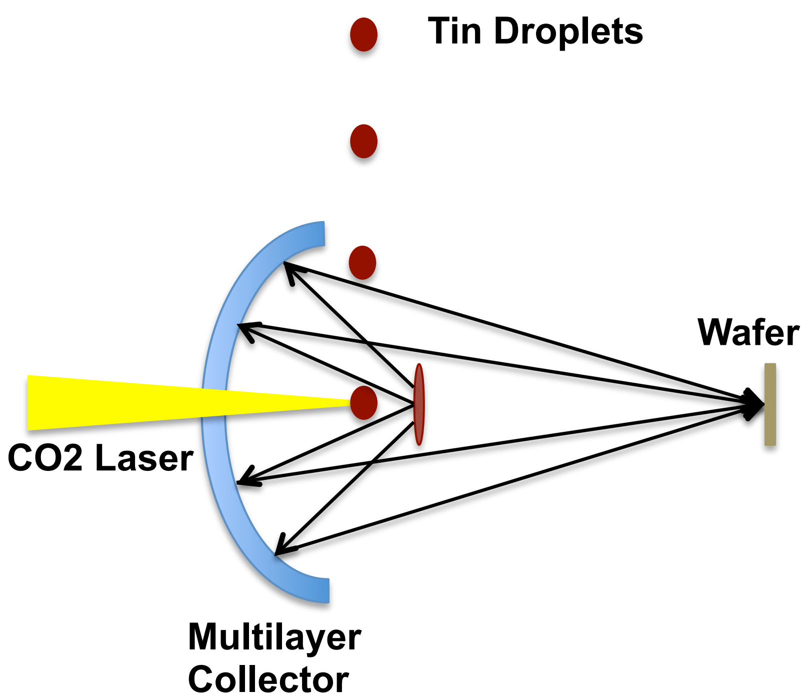


Rayleigh instability



Level of damping depends on the surrounding material

The role of surface tension is also being explored in an extreme UV lithography application using metal droplets

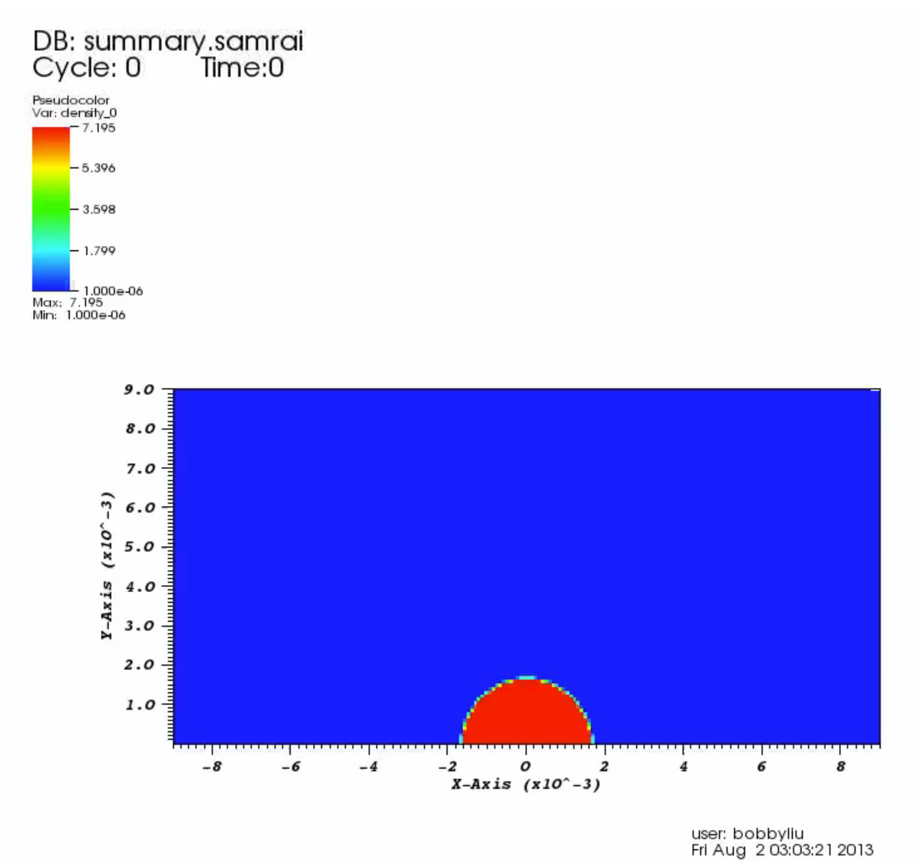


- Technique uses a prepulse to flatten droplet prior to main pulse
- At low prepulse energy droplet is observed to oscillate (surface tension effect)
- Any misalignment requires detailed 3D simulations

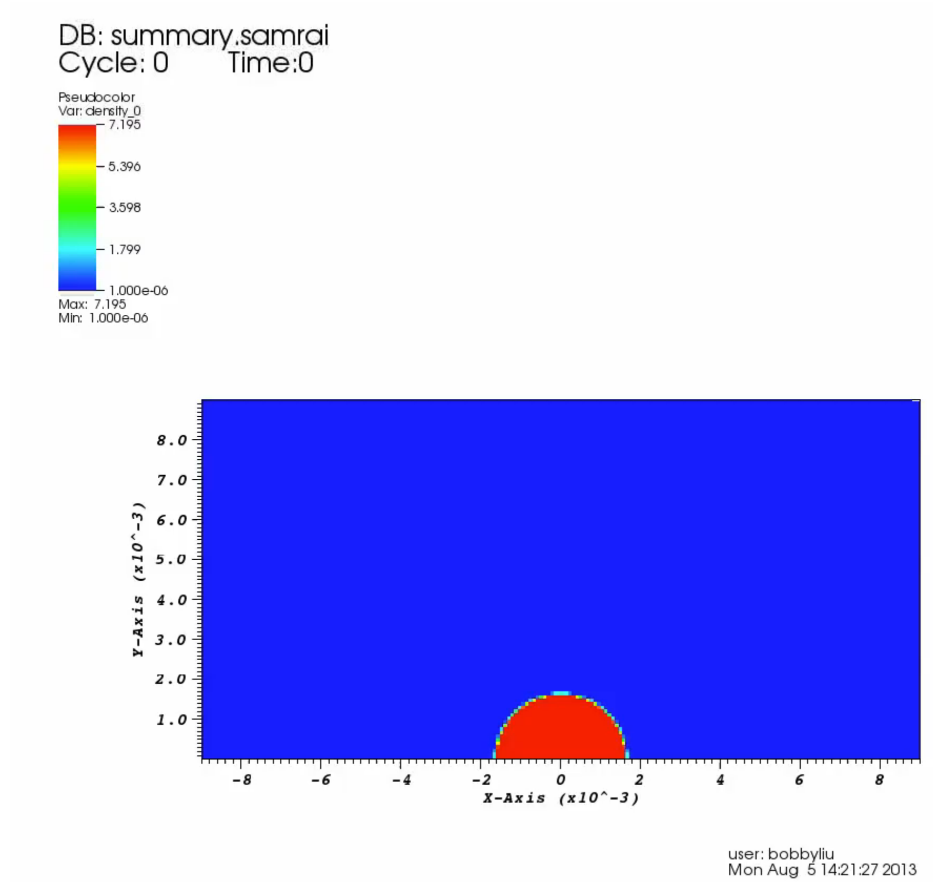
Press release: http://www.laserfocusworld.com/articles/print/volume-49/issue-03/world-news/lithography--pre-pulse-technology-scales-euv-source-power.html

We are exploring different ways to define the liquid vapor interface in the simulations

Without surface tension

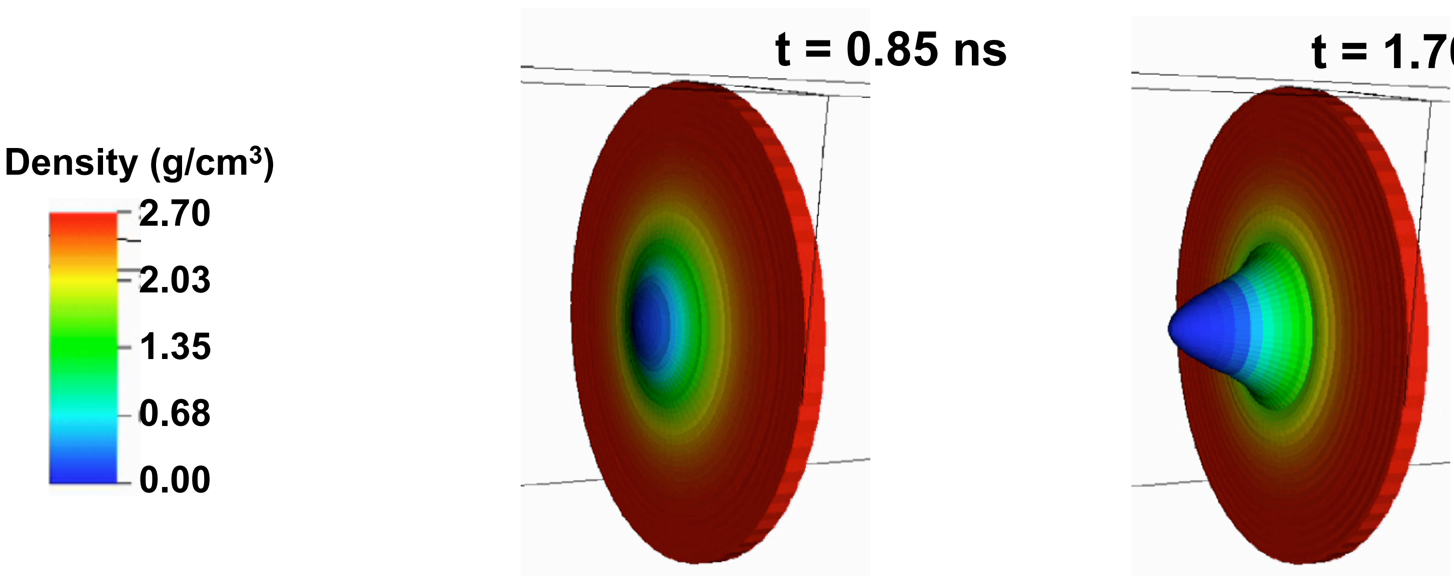


With surface tension



These simulations use a simple density criteria to define interface

ALE-AMR being used to design future NDCX II experiments with sub ns high-energy pulses



- 2D simulation of thin (1 micron) foil at end of heating pulse (left) and at 2X the pulse duration (right)
- The longitudinal scale is exaggerated relative to the transverse
- The radius of the simulated target is 1 mm
- In addition to thin foils, we are looking into low-density foam targets

Summary

- NDCX II is now operational, but full commissioning is pending
- Pump-probe techniques used in defect dynamics experiments
- New surface model added to ALE-AMR code
  - Validation, accuracy and stability of model in progress
- Exploring new application areas, e.g., EUV lithography
- Proposing new warm dense matter experiments on NDCX II