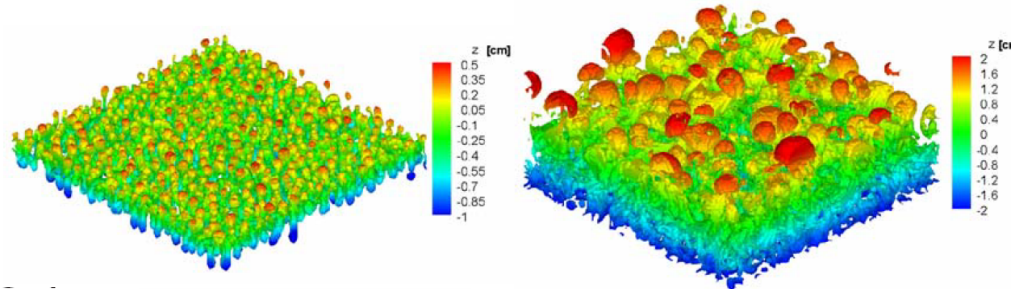
# NIF experiments to assess self-similar evolution of Rayleigh-Taylor and Richtyer-Meshkov instabilities

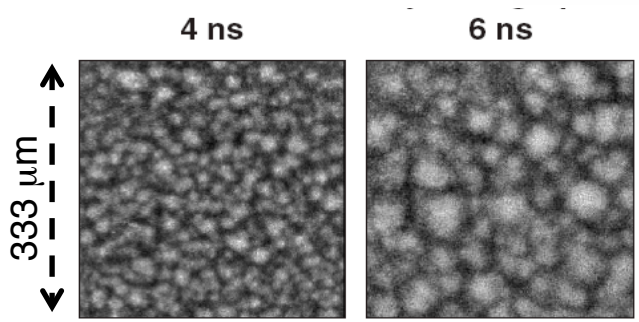
*Dov Shvarts (PI), Channing Huntington, Tammy Ma*

*Presentation to the NIF User Group*

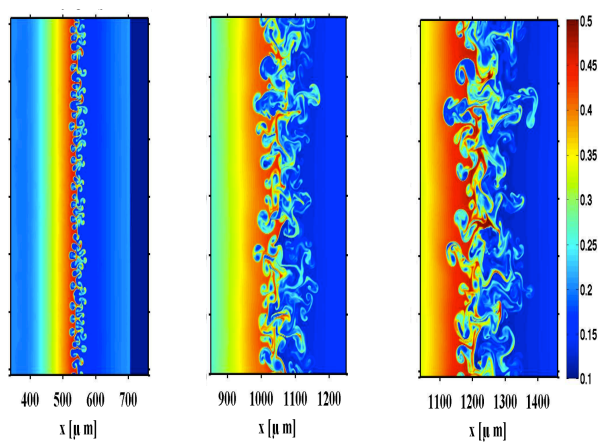
*Feb 9, 2015*

*3D RT bubble merger (N. Vigoda 2007)*




*Face-on x-ray radiography of RT bubbles (V. Smalyuk 2005)*




*2D bubble merger (G. Malamud 2014)*

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LLNL-PRES-669123

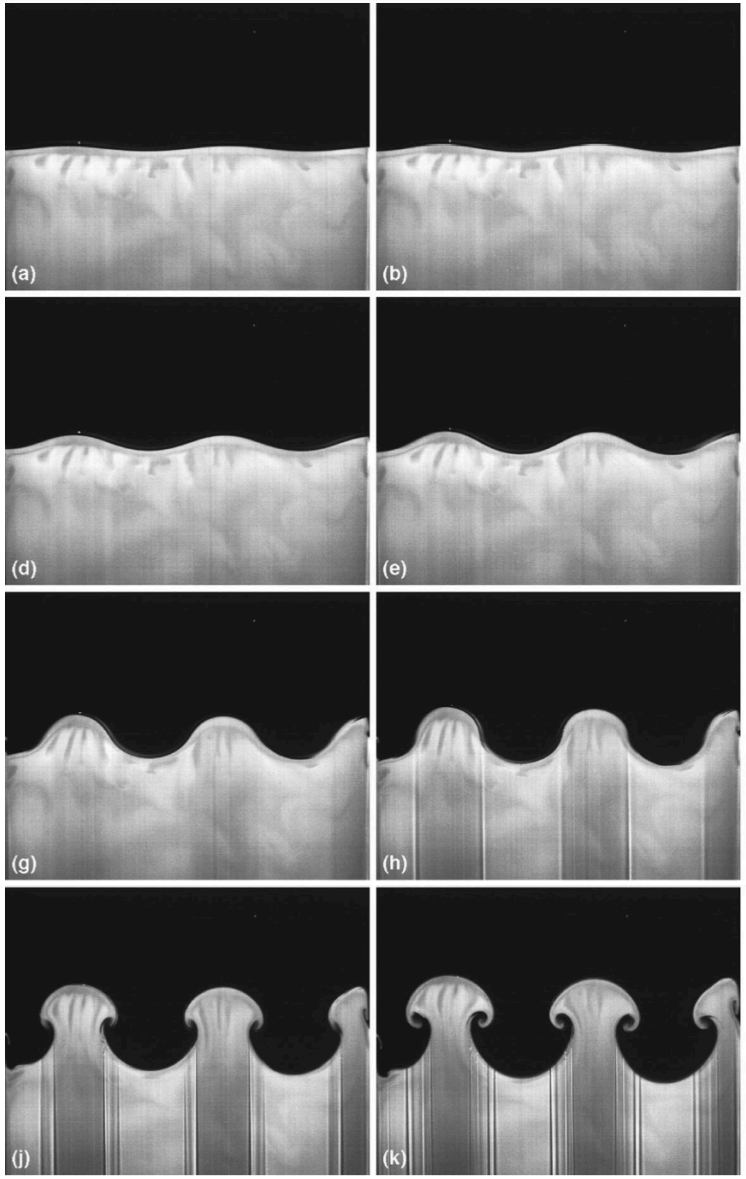
# Outline

1. Introduction to Rayleigh-Taylor

2. Aspects of RT evolution are uncertain to ~2x, more in RM

3. NIF is uniquely capable of measuring self-similar, 3D Rayleigh-Taylor in systems of interest

4. Present capabilities and new techniques will help us achieve the goals of this project




J. T. Waddell, C. E. Niederhaus, and J. W. Jacobs.
Physics of Fluids, 13(5):1263–1273, 2001.

# Introduction: Single-mode Rayleigh-Taylor fluid instability

- **RT occurs at the interface between fluids where a density gradient opposes a pressure gradient.**

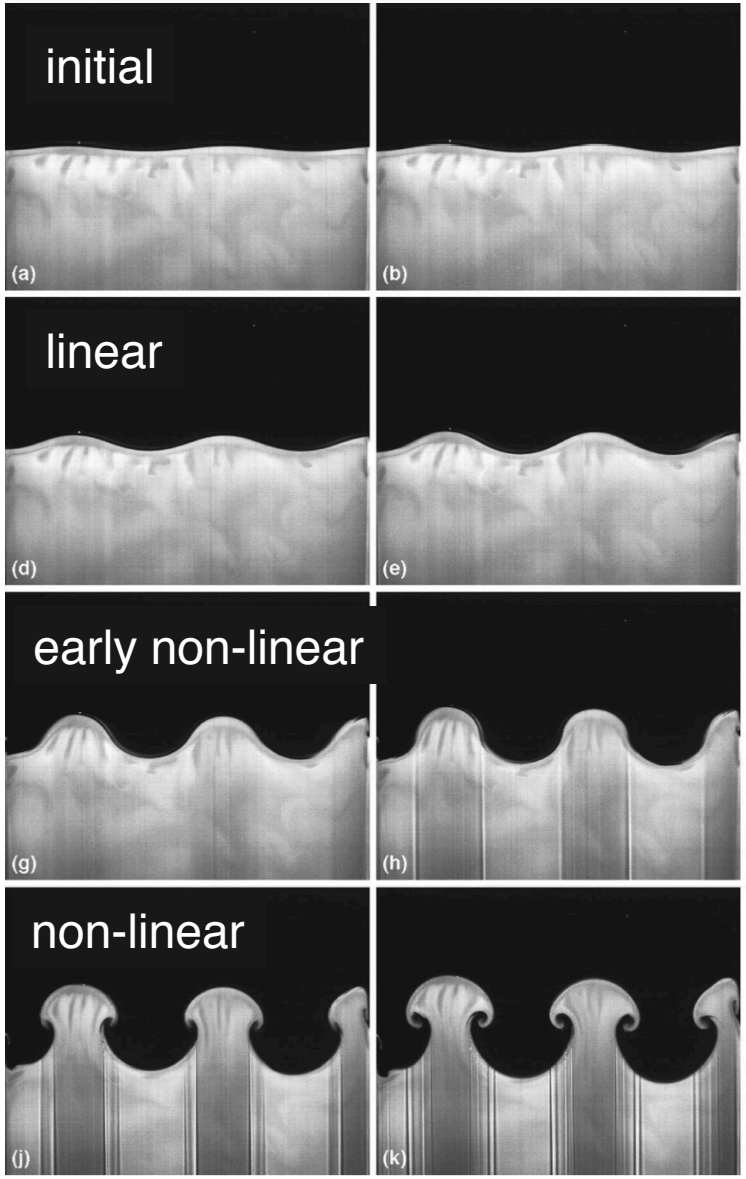
- **Initially small perturbations (h < λ/2π) grow according to:**

$$h = h_o e^{\gamma t}$$

**where** $\gamma = \sqrt{Akg}$

**and** $A = \dfrac{\rho_2 - \rho_1}{\rho_2 + \rho_1}$

- **This theory has been extended to include effects of:**
  - **Viscosity**
  - **Ablative stabilization**
  - **Surface tension**
  - **other effects…**



# The single-mode Rayleigh-Taylor system divided into spikes and bubbles

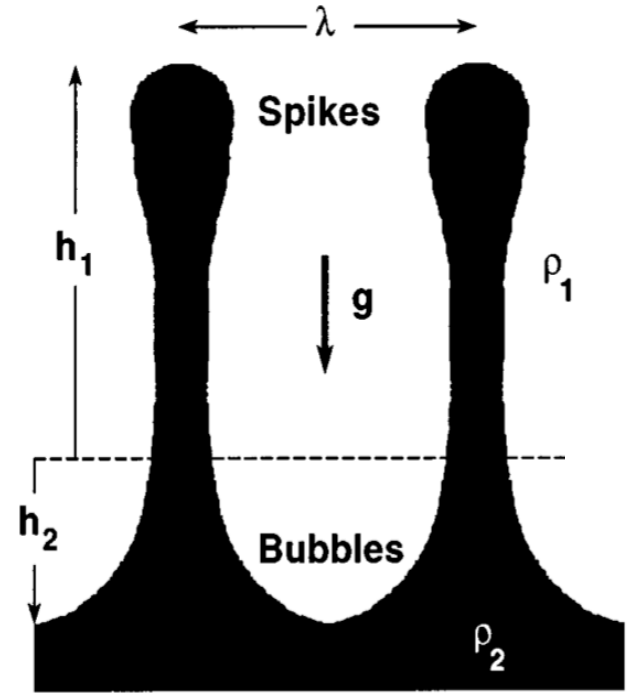
- **Bubble and spike asymptotic behavior is described by the buoyancy drag model:**

$$(\rho_1 + C_a\rho_2)\frac{du}{dt} = (\rho_2 - \rho_1)g(t) - \frac{C_d}{L(t)}\rho_2 u^2$$

- **This yields constant velocity asymptotes for the bubble and spike velocities**

- **The interface between the "falling" spike and "rising" bubble is Kelvin-Helmholtz unstable, and is deformed into the familiar mushroom shapes**

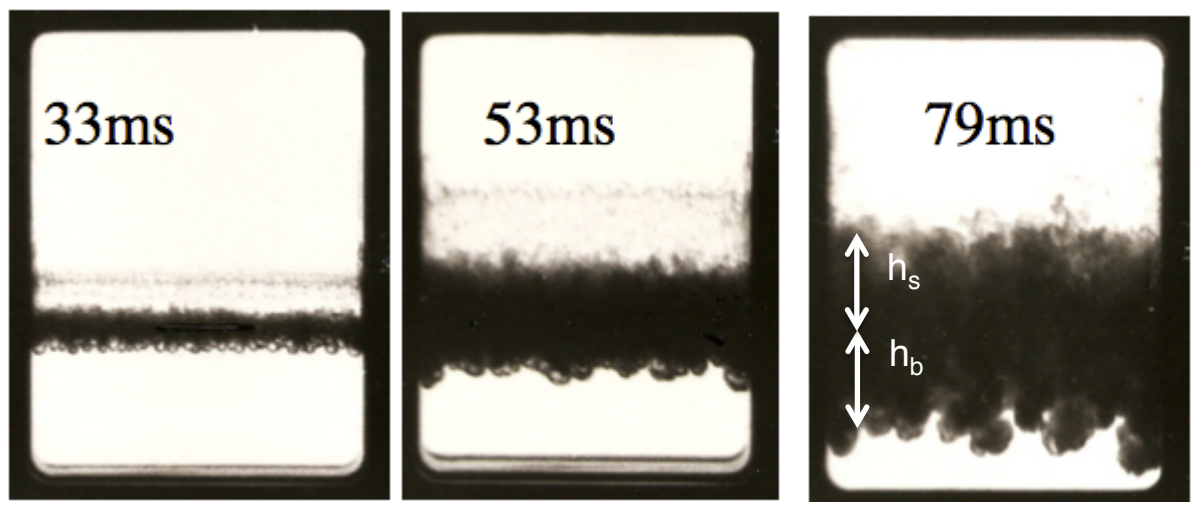
*J. P. Wilkinson and J. W. Jacobs. Experimental study of the single-mode three-dimensional Rayleigh-Taylor instability. Physics of Fluids, 19(12), 2007.*




*G. Dimonte and M. Schneider. Physics of Fluids, 12(2):304–321, 2000.*

# Multi-mode RT evolves via bubble competition

- **Asymptotic RT mix has been studied through theory, simulation, and experiments for decades**
- **The bubble and spike are described by** $h_{b/s} = \alpha_{b/s} A g t^2$
- **Models of the system must be multi-dimensional (2D / 3D), and these approximate models must be tested against experimental data**
- **The exact values of $\alpha_b$ and $\alpha_s$ are open questions, and from simulations depend on :**
  - **Dimensionality**
  - **Numerical resolution**
  - **Fluid miscibility**

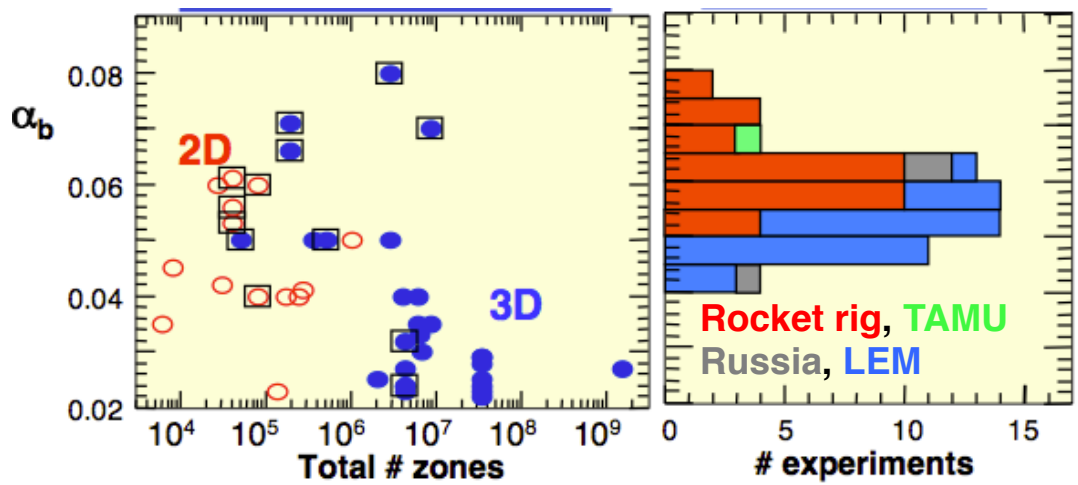



*Bubble competition and merger in immiscible fluid experiments*

*K. Read. Physica D: Nonlinear Phenomena, 12(1–3):45 – 58, 1984.*

# The bubble/spike a constant is uncertain to a factor of ~2

- **The uncertainty in $\alpha_b$ exists in both simulations and experiment**




*Simulations (left) and experiments (right) illustrate the variation in $\alpha_b$.*
*G. Dimonte. Phys. Rev. E, 69:056305, May 2004.*

- **Simulations in 3D suggests $\alpha_b$ *effective* may be reduced from ~0.05 to ~0.025 by entrainment in 3D miscible fluids** $(A \rightarrow A/2)$

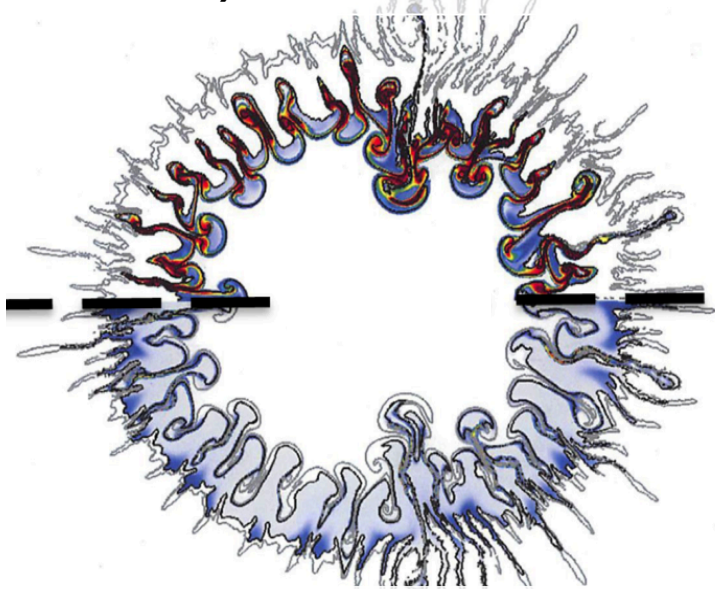
We aim to measure $\alpha_b$ in turbulent RT experiments on the NIF

# The NIF is a unique facility to perform these experiments

**Research questions for the initial Discover Science experiments:**

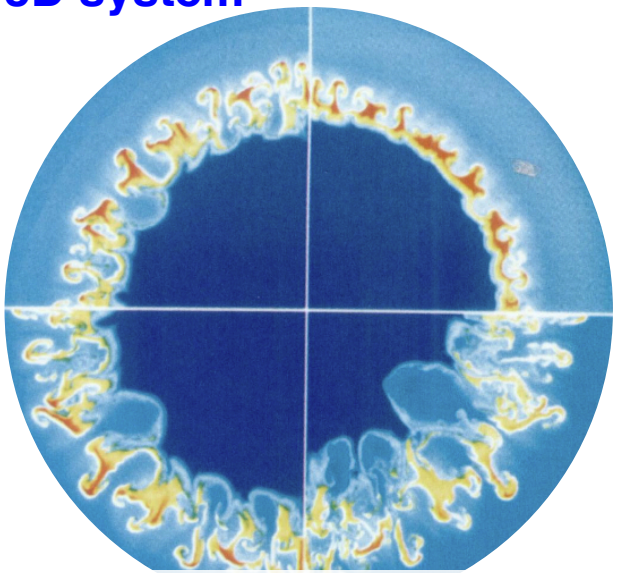
1. ***Is significant entrainment in 3D causing $A_{effective} \sim A/2$, or $\alpha_{b\ (effective)} \sim \alpha_b/2$***
2. ***Does the bubble distribution reach the self-similar condition, $h/\langle\lambda\rangle \sim 1$***

**NIF allows us to investigate several generations of turbulent mixing (10's of ns) between miscible fluids in a fully 3D system**



*RT-induced mix in an ICF capsule*

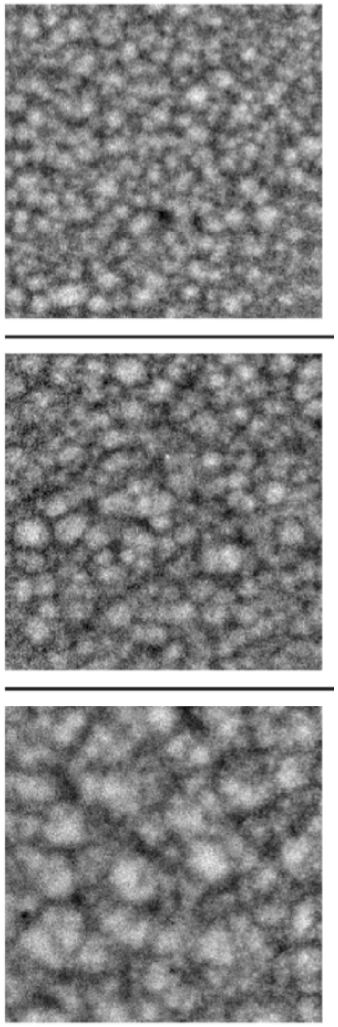
*V. A. Smalyuk et al. Phys. Rev. Lett., 112:025002, Jan 2014.*



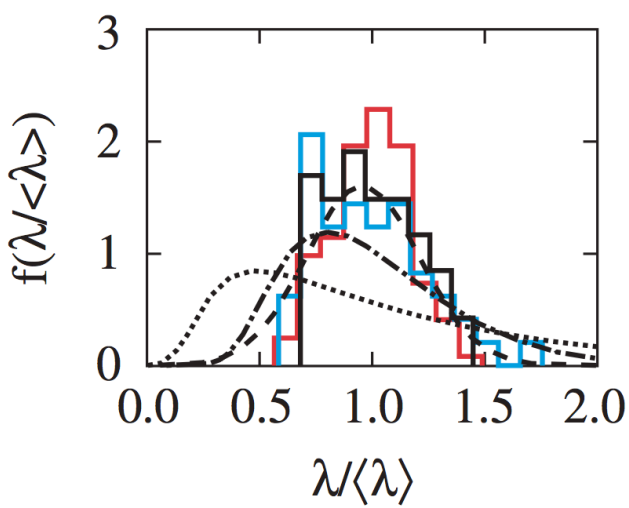
*RT instability between He and H interfaces during SN1987A*

*E. Mueller, and B. Fryxell and D. Arnett. Astronomy and Astrophysics, 251, 505-514, 1991.*

# Initial research plan focuses on Rayleigh-Taylor x-ray radiography



- **To differentiate $\alpha_b$ ($h_b$) and $\alpha_s$ ($h_s$), we must be able to identify the unperturbed interface**
- **Fabricating targets with small, well-characterized initial spectrum will be important to reach 2 – 3 generations of bubble merger**
- **Dual axis backlighting provides separate measures of bubble length (h) and size ($\lambda$)**
- **Taking data at multiple times will confirm cascade to longer wavelengths**

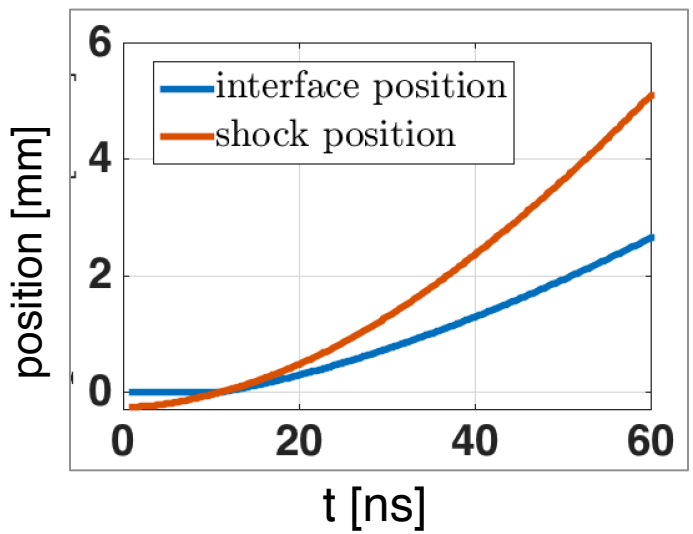



*Face on images of RT growth confirm a normalized $\lambda/\langle\lambda\rangle$ is nearly constant, indicating self-similar evolution*

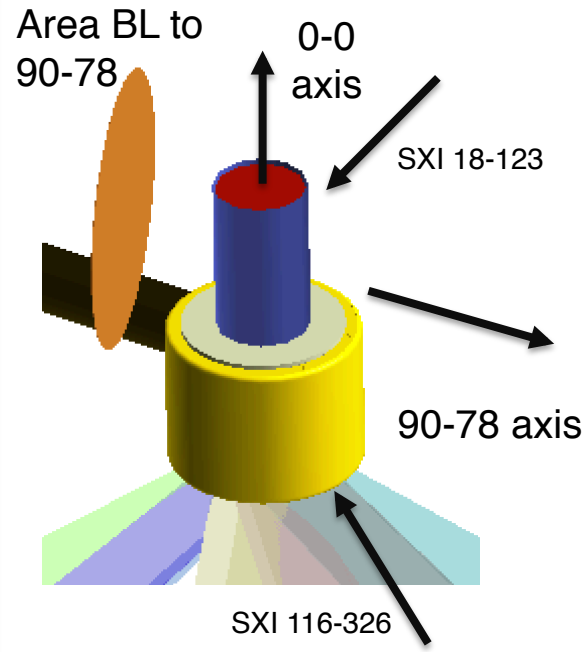
*O. Sadot, V. A. Smalyuk, et al. Phys. Rev. Lett., 95:265001, Dec 2005.*

# Experimental approach is based on current NIF experiments

- **Drive is generated by halfraum designed and fielded by the LANL Shear platform**
- **X-ray radiography is the primary diagnostic (DIM 90 – 78 for side on, 0 – 0 for face-on)**
- **Backlighter quads will use existing fibers for long-delay (45 – 75 ns) imaging**
- **Face-on measurements may require a gas-filled hohlraum**



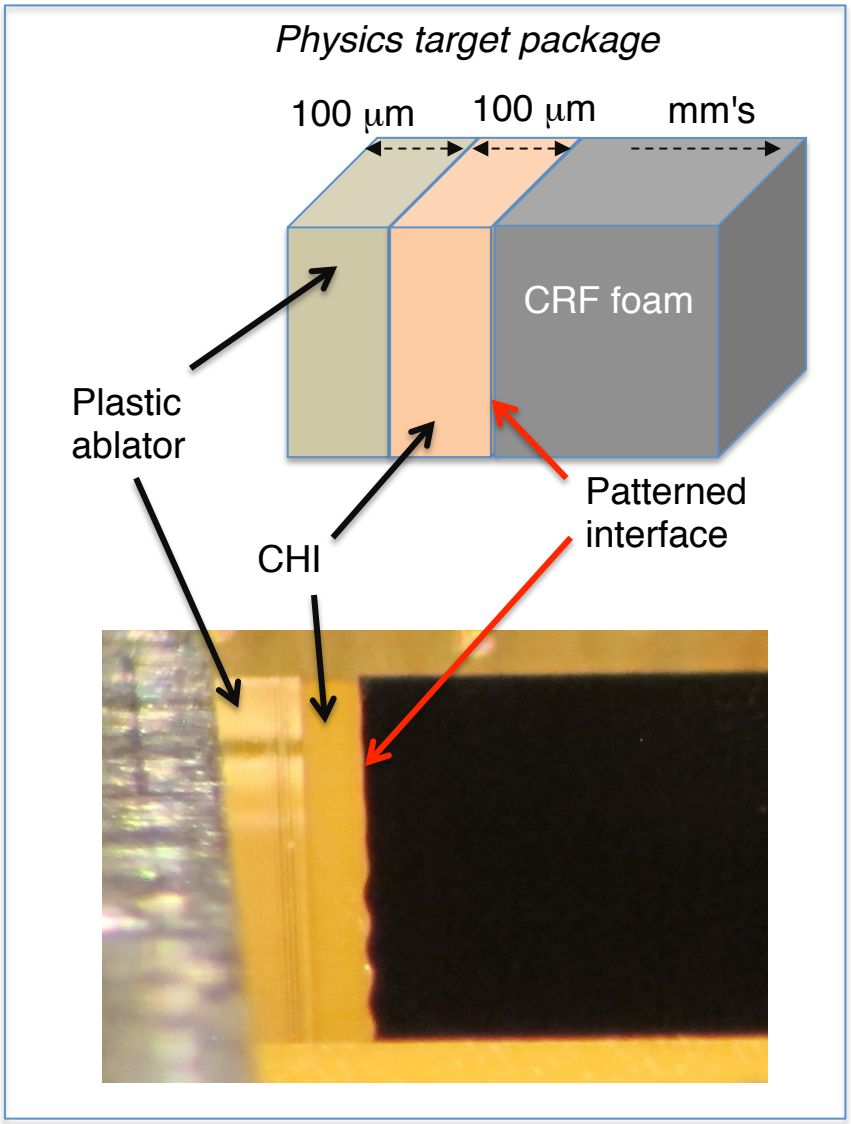

*Shock and interface position for demonstrated NIF drive profiles*




*The experimental geometry is based on existing platforms and is informed by on-going efforts.*

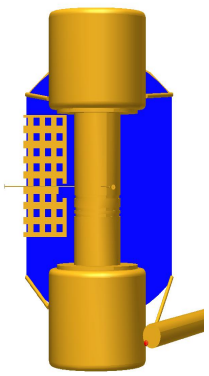
## Interior target components are based on existing designs, but require small-scale instability seed features

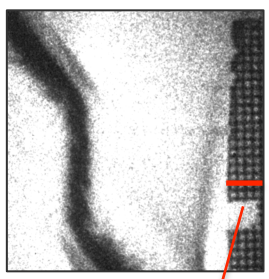
- **Backlighters are standard transition metals**
- **Embedded interface between plastic and foam is a common RT target geometry**
- **Single-mode seed perturbations can be diamond turned (10 - 30 μm)**
- **Creation of small scale features for multi-mode targets (λ ~ 5-15 μm, η ~1 μm) are under development**
- **Characterization of the initial structure is essential in this work**

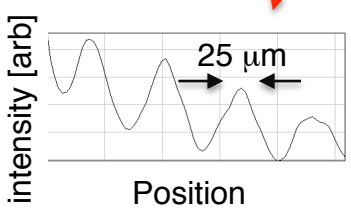


# Phase 1 RT experiments rely on existing diagnostics

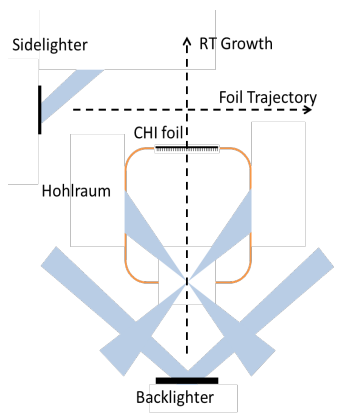
| Measurement | Diagnostic | Spatial scale | Precedent | Developmental timeline |
|---|---|---|---|---|
| Bubble and spike height | Side-on x-ray radiography, either LANL BABL or x-ray pinhole | 60 – 100 μm | Based on Shear & ReShock | • Requires imaging the shock front for calibration of initial interface position—demonstrated by ReShock<br>• Will benefit from continued GXD development |
| Bubble distribution | Face-on x-ray imaging | 10 -20+μm | Face-on has been demonstrated (Casner & Smalyuk, Budil) | • Face-on may require gas filled holhlraums |

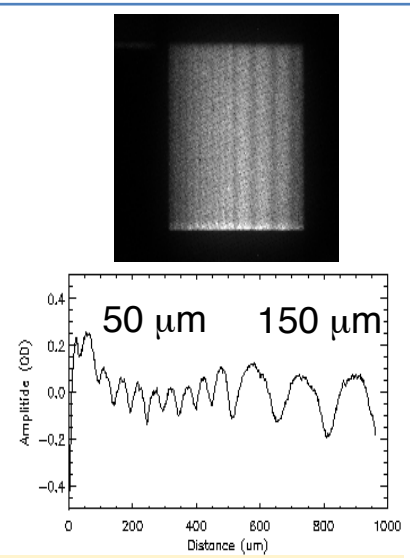




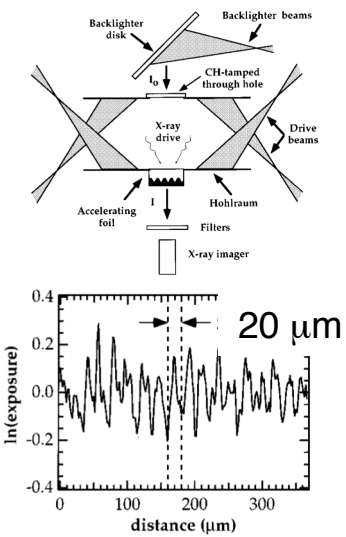



*Side-on radiography from Kline and Flippo*



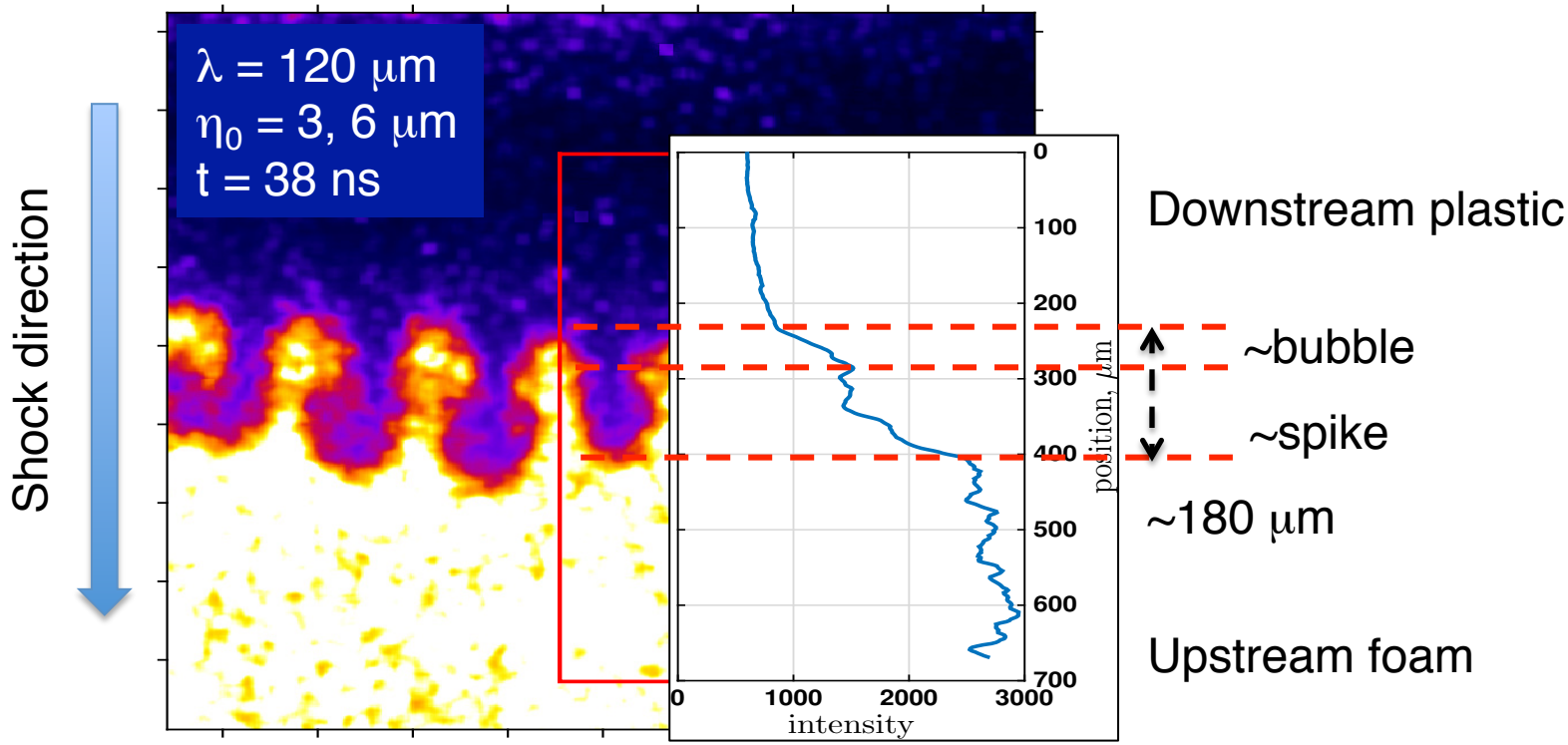

*Face-on RT from Casner, Smalyuk and Martinez ( gas –filled hohlraum)*




*Face-on data from Budil et al. ( $\lambda_0$ = 4 & 5 μm)*

# Current experiments investigating RT in the nonlinear regime provide basis for initial work

- **Ongoing experiments on NIF are paving the way in laser and diagnostic development that will benefit this (and other DS!) projects:**
  - **Fiber delay backlighters, for imaging at late time**
  - **Longer pulse networks (i.e., longer optical integration times) for framing cameras**
  - **Increased flexibility in strip orientation**



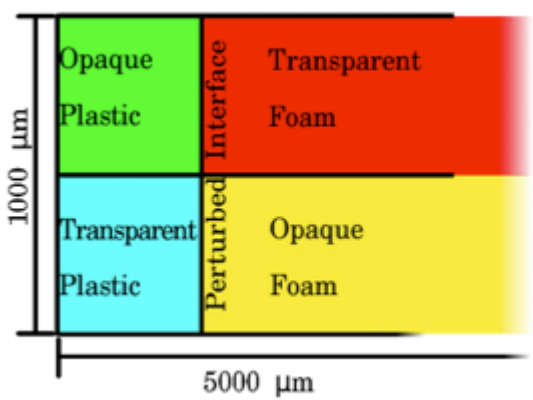
# Longer term goals are substantial, and will require new facility developments

**Near term (2015 – 2017):**

- **In order to take this system to multi-generational bubble merger, we will benefit from an extended, sustained drive (75+ ns, and increased energy)**

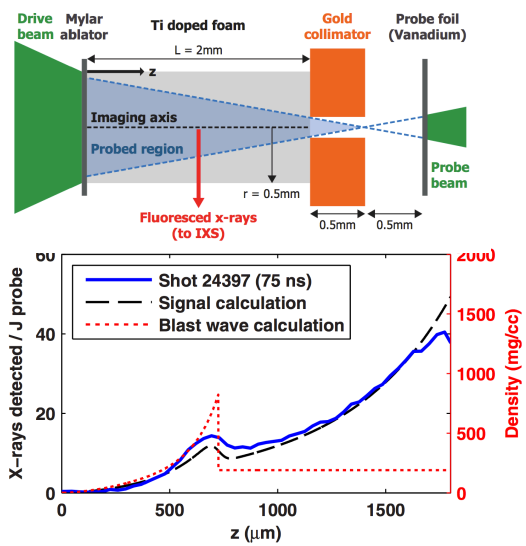
**Long term (2017+):**

- **"Phase 2" measurements aim to measure Richtmyer-Meshkov features after 3+ merger generations**
- **Imaging of internal structure will require new diagnostics: laser-induced or x-ray pumped fluorescence, and proof-of-principle experiments have been proposed:**




*Proof of principle experiments with high-contrast foams and multi-color backlighters are being developed for mix width tests*

*Image from K. Raman*




*Imaging of Fluorescent x-rays from a shocked foam target reveals inner structures*

*M. MacDonald et al., RSI 2014*

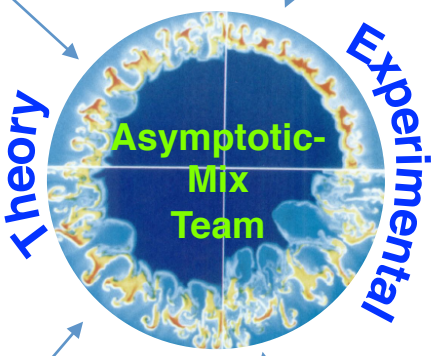
# We have assembled a team of leading experts in hydro instability studies

**<u>NRCN, Israel</u> – Y. Elbaz , G. Malamud, D. Shvarts**

***Role:*** *Theory, Conceptual designs; 3D simulations and modeling; analysis*
***Experience:*** *Pioneered theory and simulations of evolution of 2D & 3D RT and RM instabilities; development of codes LIOOR & DAFNA*

**<u>LLNL (NIF)</u> – C. M. Huntington, D. Martinez, T. Ma, H. S. Park, V. Smalyuk**

***Role:*** *Experimental implementation; data analysis*
***Experience:*** *ICF + HED experiments (including hydro instability studies) on NIF, Omega; x-ray imaging + radiography diagnostics; Leads on: NIF Ablative RT, HGR, ReShock, RadSNRT*




**<u>U. Michigan</u> – C. Kuranz, R. P. Drake**

***Role:*** *Conceptual Designs, Omega complementary experiments, Development of advanced diagnostics ("LIF-Like")*
***Experience:*** *Dual axis side-on + face-on measurements of RT*

**<u>SNRC, Israel</u> – M. Fraenkel, A. Zigler**

***Role:*** *Development of spectroscopic (LiF-Like)methods*
***Experience:*** *Determine plasma conditions using Spectroscopic methods*

**<u>LLNL (WCI +NIF)</u> – K. Raman, D. Clark, S. MacLaren, S. Haan**

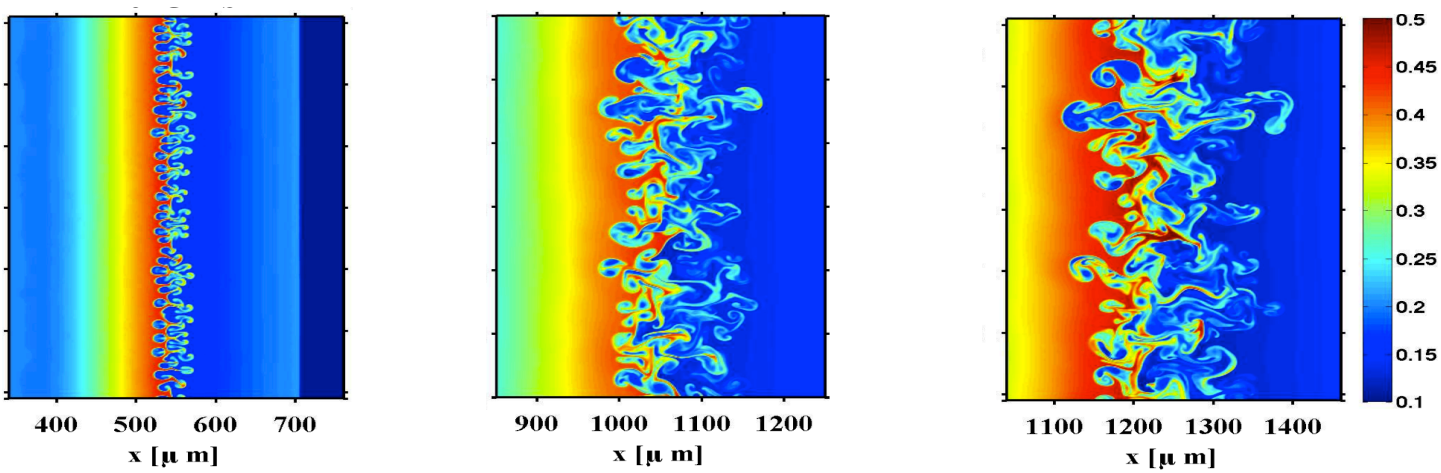
***Role:*** *Experimental design; design of the drive; 3D simulations ;*
***Experience:*** *Pioneered theory and simulations of RT growth; 3D integrated ICF + HEDP simulations*

**<u>CEA</u> – A. Casner**

***Role:*** *Experimental implementation of Face-On Radiog,*
***Experience:*** *Lead of NIF fundamental science IDD & DD Abl. RT campaign; HED experiments (including hydro instability studies) on NIF, Omega*

## Conclusions: NIF Discovery Science affords great opportunities to study RT

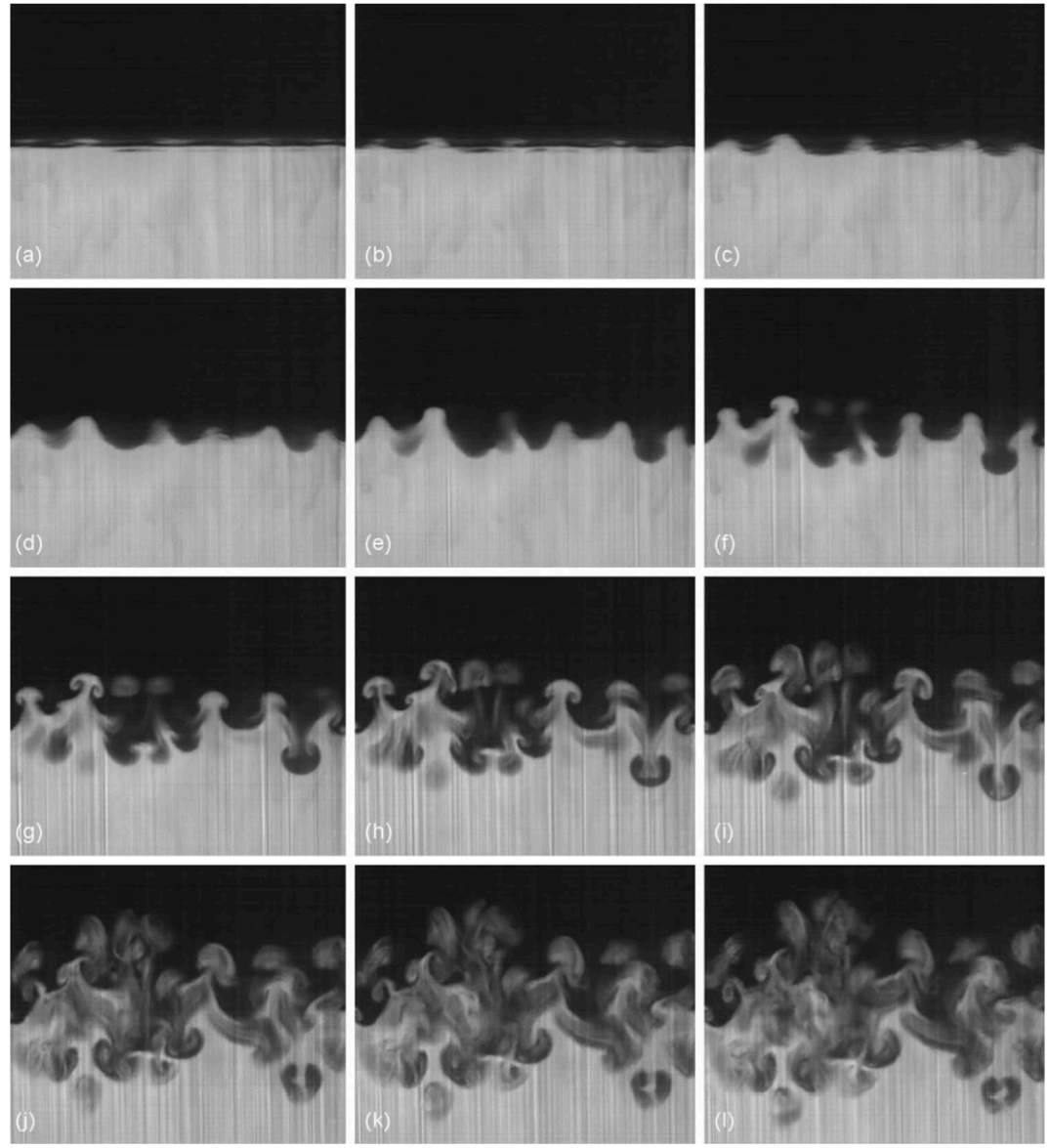
- **Outstanding fundamental questions about Rayleigh-Taylor and Richtmyer-Meshkov instabilities can be tested on the NIF**
- **Only the NIF offers a fully 3D experiment with miscible fluids which evolve into the self-similar regime over several generations**
- **Learning from ongoing efforts, as well as innovating some aspects of the experiments, will be essential to the success of this project.**




***Multimode RT growth is assessed in 2D for NIF-relevant conditions to design this experiment***

***G. Malamud, M.J. Grosskopf, and R.P. Drake et al., HEDP J. 11, 17-25, 2014.***

## Questions?




*D. H. Olson and J. W. Jacobs. Experimental study of Rayleigh–Taylor instability with a complex initial perturbation. Physics of Fluids, 21(3):–, 2009.*