# IFE-Related Hydrodynamic Instabilities in a Spherical Gas Bubble Accelerated by a Planar Shock Wave

**Devesh Ranjan, John Niederhaus, Mark Anderson, Jason Oakley, Riccardo Bonazza, Jeff Greenough***

**University of Wisconsin-Madison, Department of Engineering Physics**

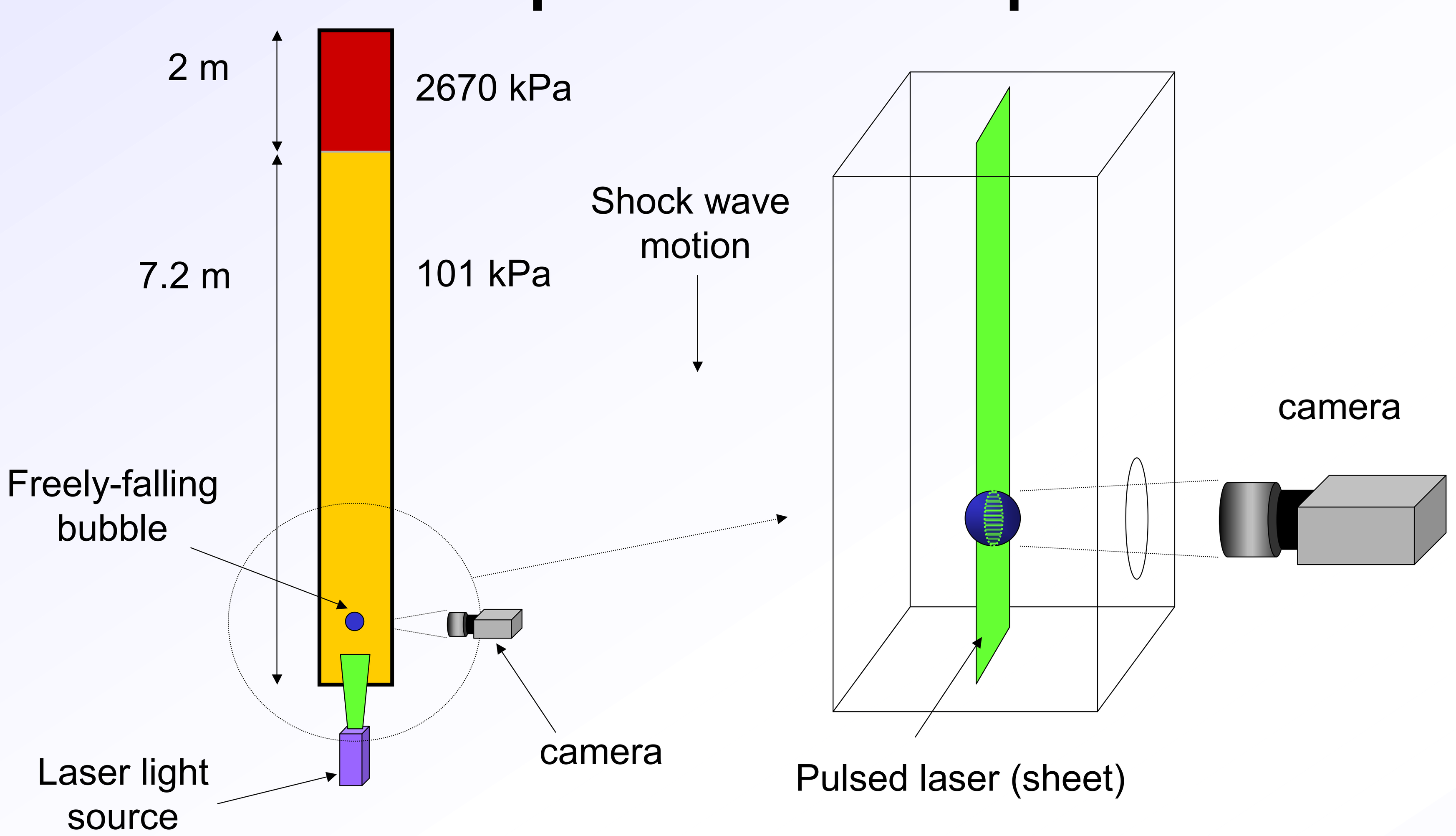
***Lawrence Livermore National Laboratory**

## Introduction:

In laser, heavy-ion, or z-pinch-driven ICF ignition, compression of the target is accompanied by fluid instability growth. This instability is key to the understanding of the ignition and yield from the target. The surface of the DT target becomes unstable due to Richtmyer-Meshkov and Rayleigh-Taylor growth. Vorticity is generated baroclinically at the interface, causing the interface to deform and allowing the materials to mix after the shock has passed. This turbulent mixing between the DT and the ablator surface and the asymmetry associated with the compression can alter the yield from the target.

Shock tube experiments are currently underway at the University of Wisconsin-Madison in an effort to characterize the growth of these instabilities, for the special case of a dense spherical bubble. The high structural capacity of the shock tube facilitates experiments at Mach numbers exceeding those achieved in previous hydrodynamic shock-induced-mixing experiments. Richtmyer-Meshkov and Kelvin-Helmholtz instabilities on the bubble surface lead to the formation of large vortical structures in the post-shock flow, which are analyzed here and can be used in testing the hydrodynamics in radiation hydrodynamics codes.

## Experimental Setup:




**Wisconsin Shock Tube Laboratory**
**Madison, WI**

**Shock tube:**
- Vertical, modular
- 20 MPa impulsive load capability
- 25.4 cm square cross section
- Planar laser imaging ports
- Retractable bubble dropper

**Imaging:**
- Nd:YAG pulsed laser sheet
- CCD cameras
- Mie scattering or PLIF
- Dual exposure

## Abstract:

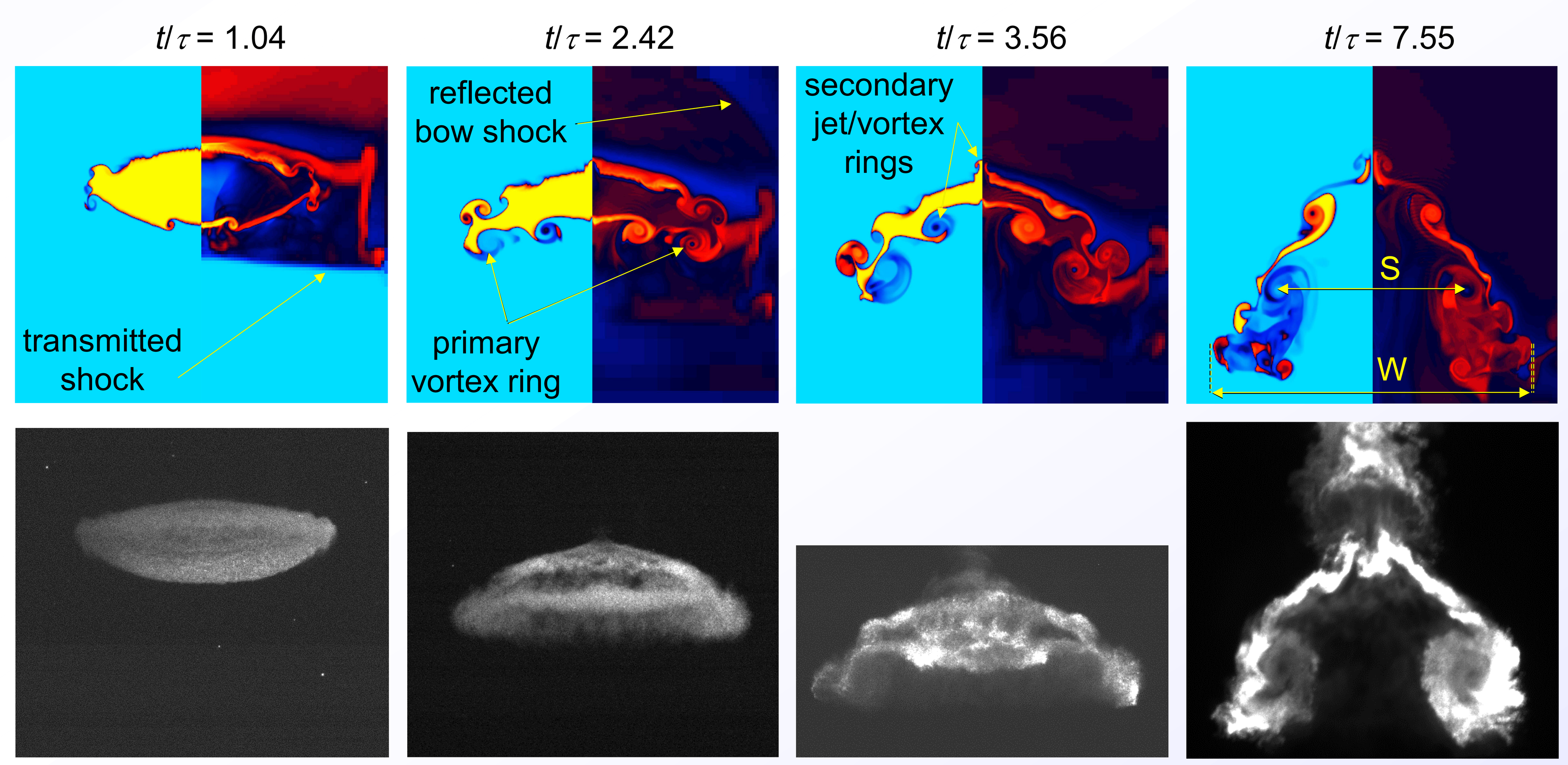
Experiments studying the unstable growth of a dense spherical bubble in a gaseous medium, subjected to a strong planar shock wave (2.8 < M < 3.4), are performed in a vertical shock tube. The test gas is contained in a freely-falling spherical soap-film bubble, and the shocked bubble is imaged using planar laser diagnostics. Concurrently, simulations are carried out using a 3-D compressible hydrodynamics code.

Experiments and computations show consistent results, indicating the formation of characteristic vortical structures in the post-shock flow. The results emphasize the significance of 3-D effects, and of small non-uniformities in the initial bubble geometry. Further, the time-behavior of flow features is analyzed, showing that, under some conditions, the development of the unstable interface can be parameterized for variable shock strength.

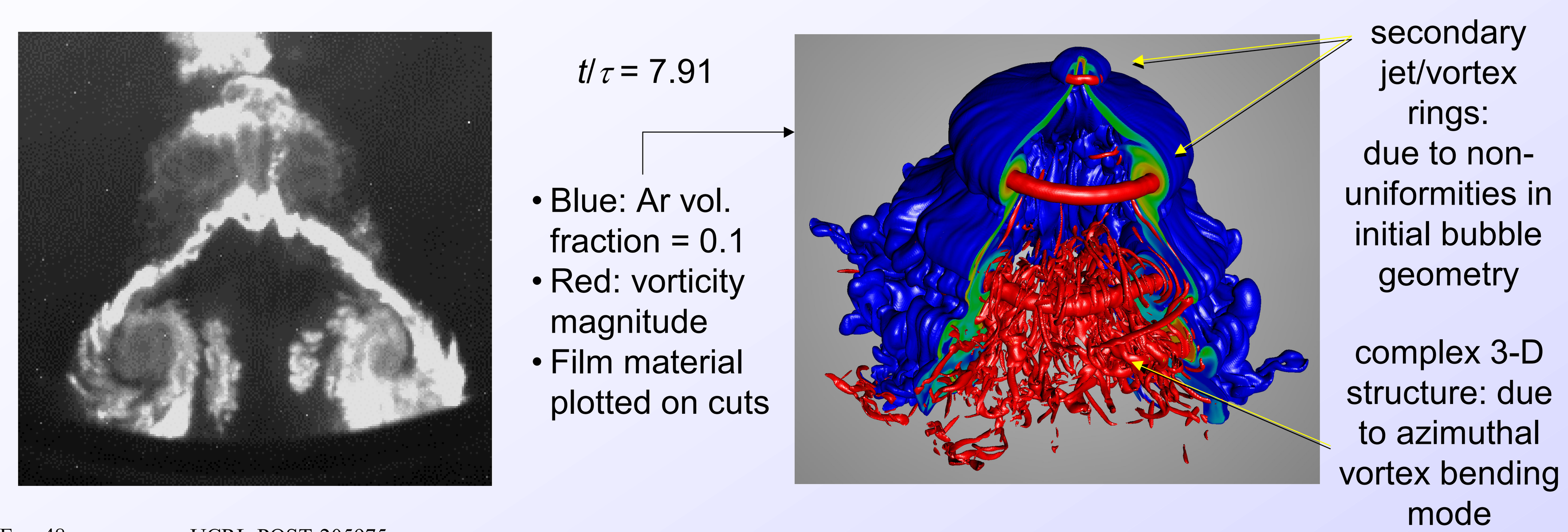
## Bubble Development:

$t$ = time since initial shock/bubble contact

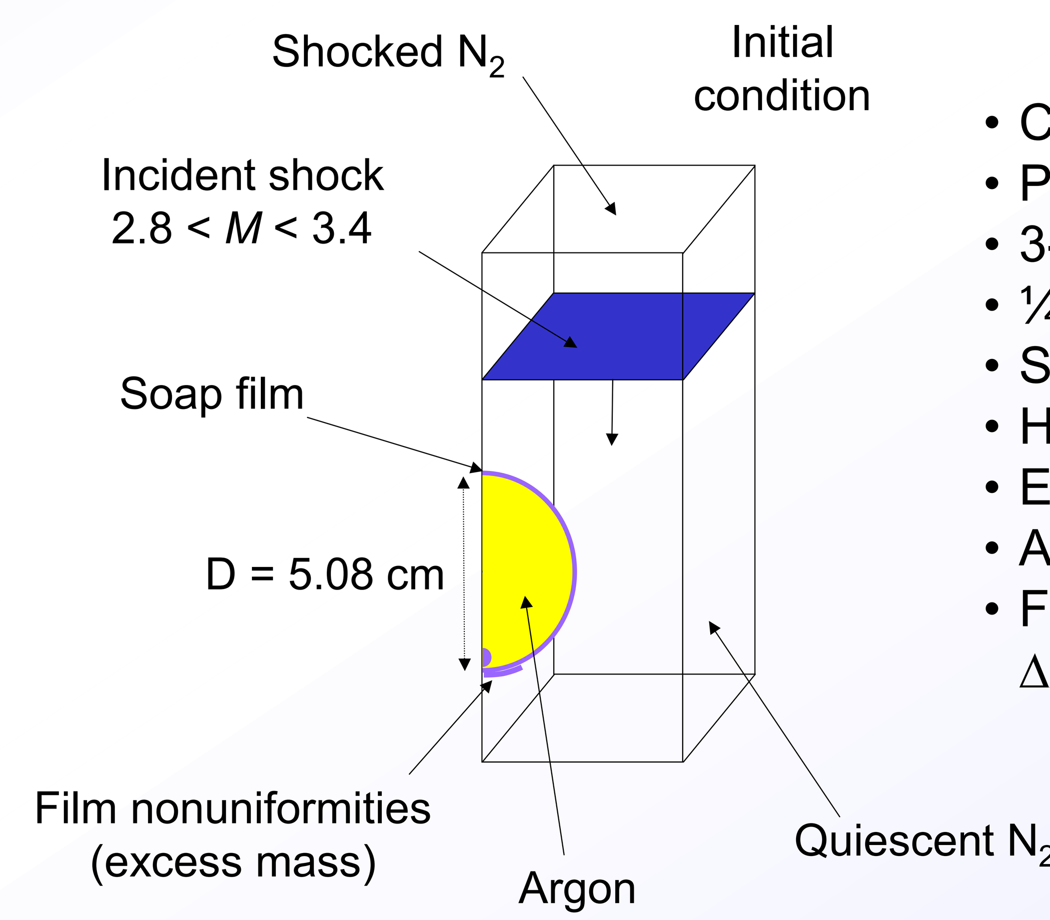
$\tau$ = characteristic time, defined as $D/u_p$, where $D$ is the initial bubble diameter, and $u_p$ is the shocked particle speed ($M = 2.88 \rightarrow \tau = 68.2\ \mu s$)




Top: Numerical results; Ar volume fraction (left) and total density (right) plots at midplane, for $M = 2.88$.
Bottom: Experimental shock tube images obtained using laser light scattered at bubble midplane.
Below: Late-time image and 3-D rendered plot showing multiple vortex rings and complex 3-D structure.

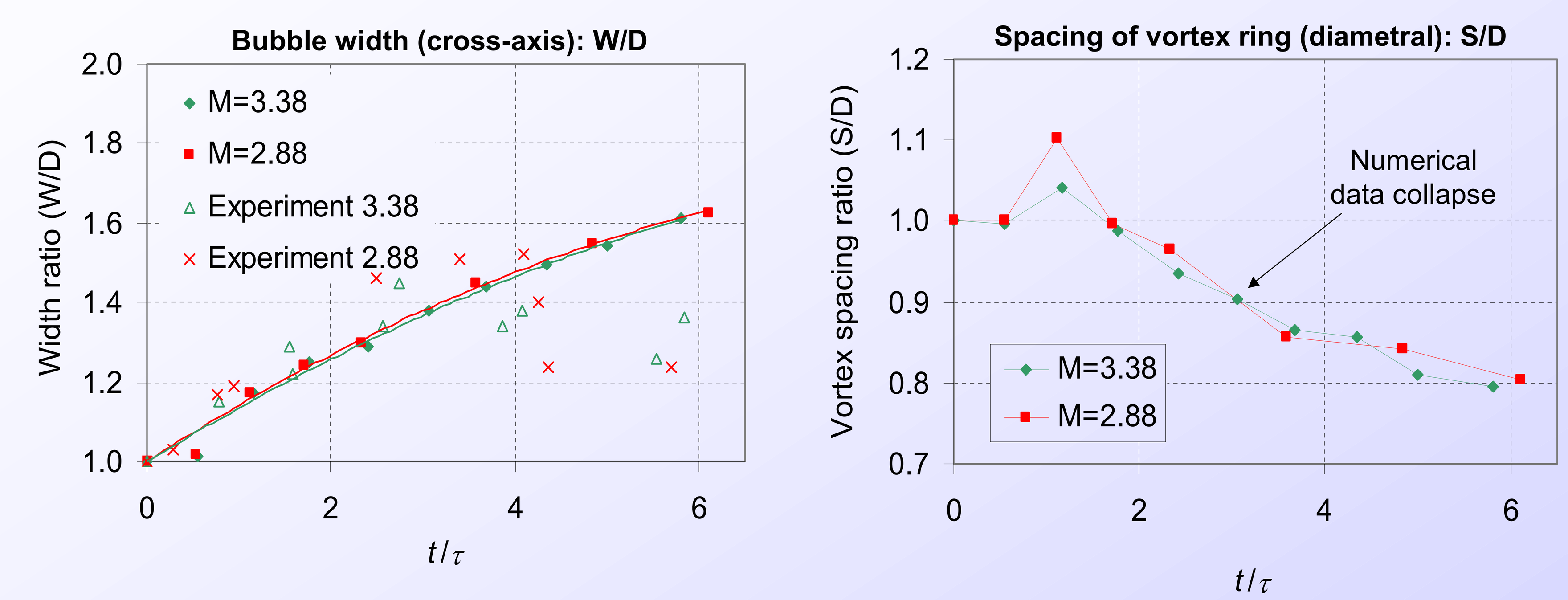



## Simulations with Raptor:




- Compressible Euler equations
- Perfect equation of state
- 3-D Cartesian grid
- ¼ symmetry
- Shock-capturing scheme
- Higher-order Godunov solver
- Eulerian framework
- Adaptive mesh refinement (AMR)
- Finest-level grid spacing: $\Delta x = 195\ \mu m$ ($R_{130}$)

## Growth Trends:




Selected flow features are tracked over time, with parameterization using the shocked particle speed $u_p$ ($\tau = D/u_p$). Flow features shown here are the maximum transverse bubble width (W) and the spacing (S), or primary diameter, of the major vortex ring (numerical only). Reasonable agreement with computations (closed data points) is found for early times ($t < 3.5$), and both experimental and computational data collapse with this scaling, for these Mach numbers. Further experiments and calculations have shown that such a collapse is not achieved at lower shock strength, where compressibility effects can come into play.

## Discussion:

- Novel experimental approach:
  - Strong shocks, free-falling bubble, planar imaging, dual exposure
- Key observed feature:
  - Heavy spherical bubble in a light gas, accelerated by a shock wave, forms a large vortex ring in the shocked flow, due to fluid instabilities.
- Other important features seen in experiment and/or computations:
  - 3-D effects, film non-uniformity effects
- Collapse of time data is possible within higher Mach number range studied here, using parameterization by shocked particle speed, $u_p$. This may allow future studies to be scaled to the regime of laser-driven experiments.

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