# The four stages of a jet induced by the collapse of a gas bubble 

Guillaume T. Bokman ${ }^{1,2}$, Steven R. Brill${ }^{2}$, Outi Supponen ${ }^{1}$ and Britton J. Olson ${ }^{2}$

${ }^{1}$ ETH Zürich, Zürich, 8092, Switzerland ${ }^{2}$ Lawrence Livermore National Laboratory, Livermore, CA 94550, USA

The interaction of microbubbles with shock waves could play a major role in biomedical applications such as lithotripsy, or targeted drug delivery. Here, experimental x-ray phase contrast recordings of such interactions are complemented by numerical simulations, using the open-source code Pyranda, the Miranda miniapp.

## Introduction:

High speed liquid jets resulting from the interaction of shock waves with microbubbles could be leveraged in biomedical applications such as targeted drug delivery, or micro-injections.
Little is known about the physics leading to the formation of such jets and, therefore, an accurate control of this process as yet to be achieved.

The goal of the current project is twofold:

1) Validate a new multi material scheme with experiments.
2) Complement the parameter range experimentally accessible with numerical simulations.

## Methods:



(a) Schematic of the experimental chamber. (b) Schematic of the experimental x-ray imaging system. (c) Selection of initial conditions to use in the numerical simulations, using the stiffened (SEOS) and Livermore (LEOS) equation of state to match the experimental pressure impulse at the bubble and hydrophone location.

## Results:


(a) Image sequence of the four stages of a shock-induced liquid jet. Image width is 1.5 mm and time is in $\mu \mathrm{s}$. Temporal evolution of the bubble jet's (b) position and (c) speed.


First stages of a numerical simulation corresponding to the image sequence shown above, and showing the bubble in green and pressure field as a dark colormap. The time is in $\mu \mathrm{s}$ and pressure in Bar.

