Spike morphology in supernova-relevant hydrodynamics experiments

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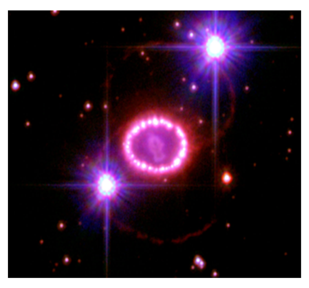
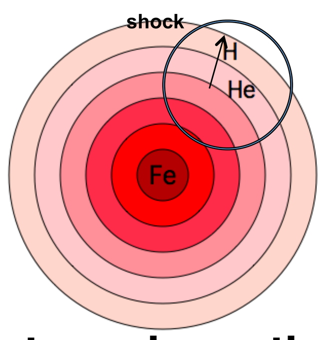
Introduction

The experiment is motivated by the behavior of supernova SN1987a, the closest core-collapse supernova to occur since modern observational techniques have been available. Light-curve data indicates the heaviest nuclides formed in the stellar fusion process, are observed much sooner than predicted by standard explosion models in which the heaviest elements are at the star's core. This could be explained by large-scale hydrodynamic mixing due to Rayleigh-Taylor unstable behavior prior to breakout of the supernova blast-wave. Our experiment focuses on the H/He interface, as shown.



SN 1987a



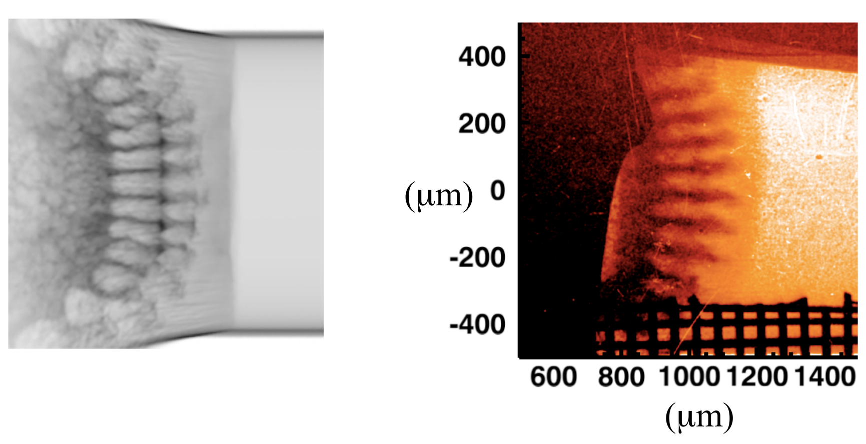
star schematic

Motivation

An experiment hydrodynamically scaled to the supernova shows clear development of Rayleigh-Taylor structure at a perturbed interface. However, there are anomalies:

1. No Kelvin-Helmoltz at spike tips
2. uniform axial spike profile
3. similar spike/bubble sizes

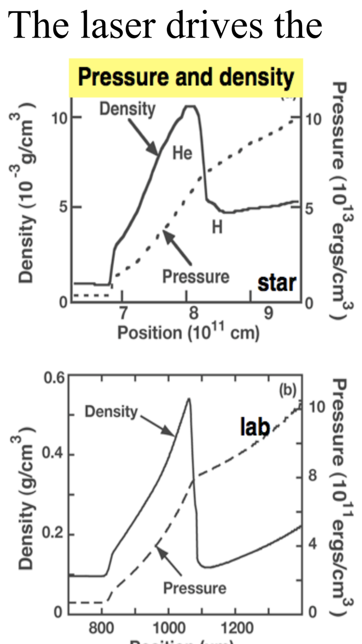
Simulation (left) shows spike structure not seen in experimental radiograph (right)



Scaling

High-energy-density facilities such as the Omega laser at the University of Rochester allow access to astrophysical conditions via hydrodynamic scaling. The laser drives the blast wave in the experiment.

If the system properties are chosen carefully, the core-collapse (top) and laser-driven (bottom) blast waves result in similar physics.



In more detail, if the ionized gases in both the experiment and the supernova can be described by the Euler fluid equations, the fundamental properties of density, pressure, size, and time evolution for each system can be scaled relative to each other.

Acknowledgements

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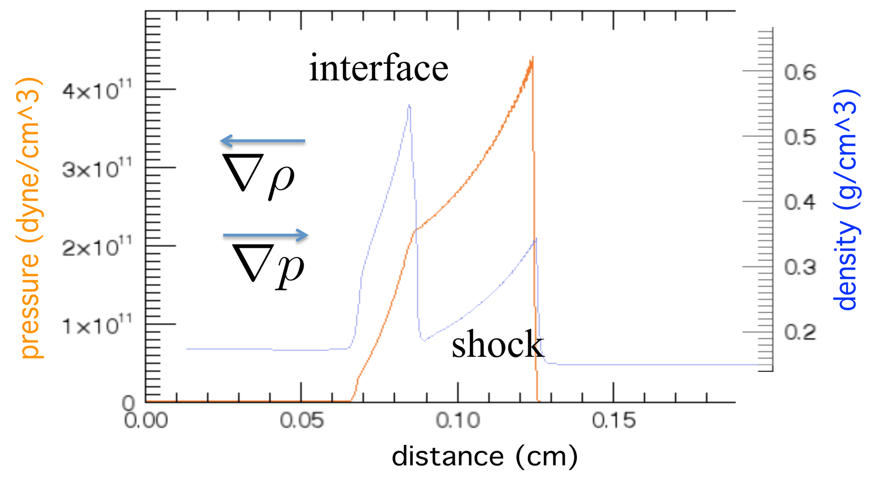
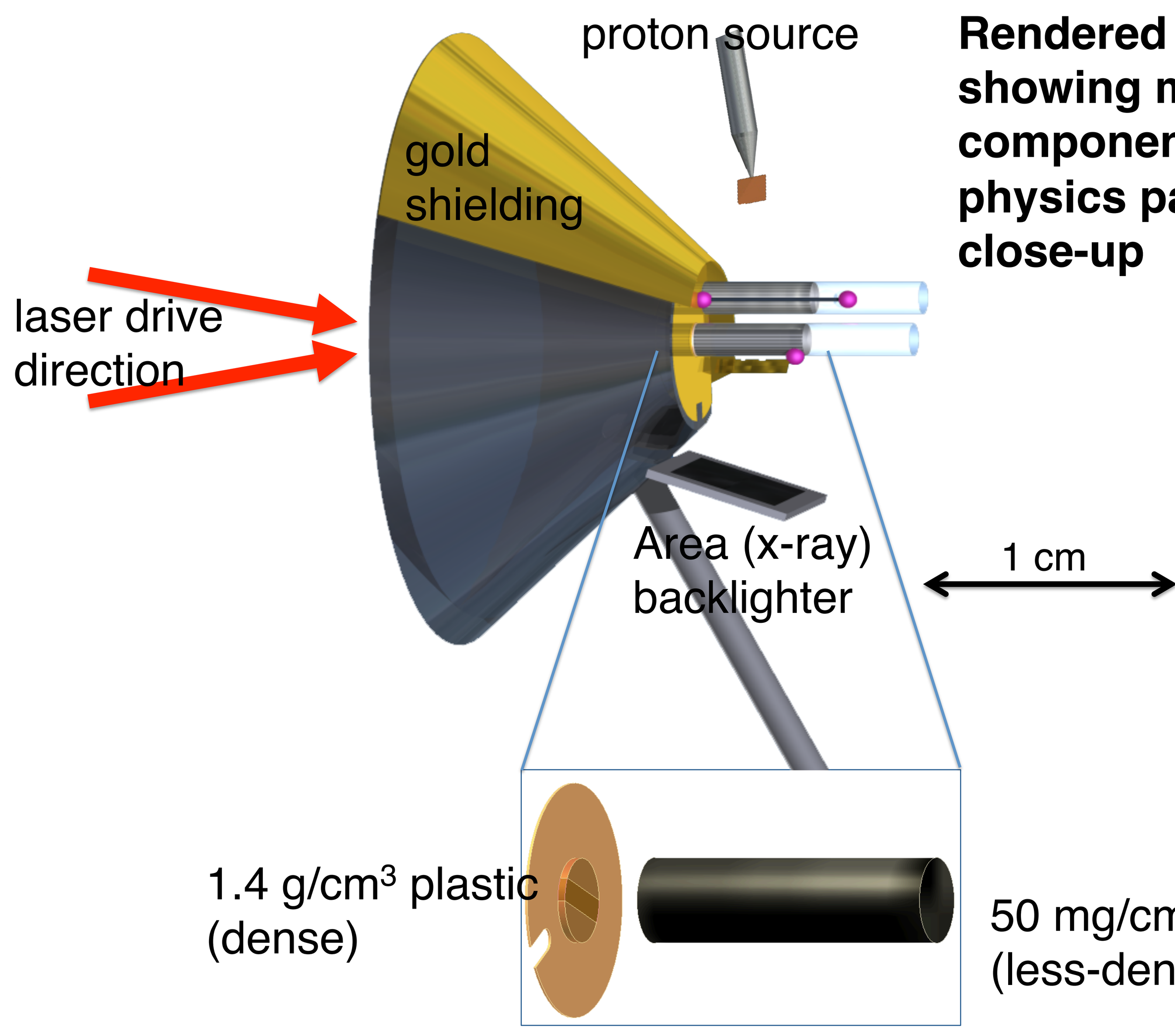
Experimental Design

Targets are fabricated primarily in-house, with the drive disk machined by General Atomics. The current experiment features orthogonal proton and x-ray imaging of the RT-unstable interface.

Simulation of this system shows, like in the star at left, that a blast wave crossing a density drop results in the an RT-unstable interface.





Rendered target, showing major components and physics package close-up

Magnetic fields

Plasma quasineutrality requires E&M forces arise in opposition to hydrodynamic forces in the system.

$$\nabla p_e = n_e(q\mathbf{E})$$

$$\frac{1}{c}\frac{\partial \mathbf{B}}{\partial t} = -\nabla \times \mathbf{E}$$

If the pressure gradients take the right profile, magnetic fields are induced.

$$\frac{\partial \mathbf{B}}{\partial t} = \frac{ck_B}{e}\left[\nabla T_e \times \nabla(\log n_e)\right]$$

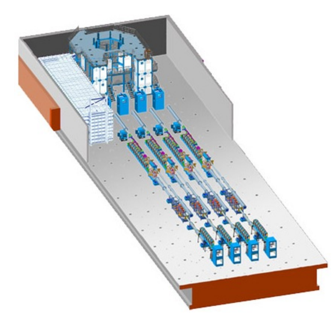
Preliminary calculations from 1-D simulations show thee field could be on the same order as fluid pressure, and influence spike behavior.[1]

Charged-particle imaging is a natural choice for probing these effects.

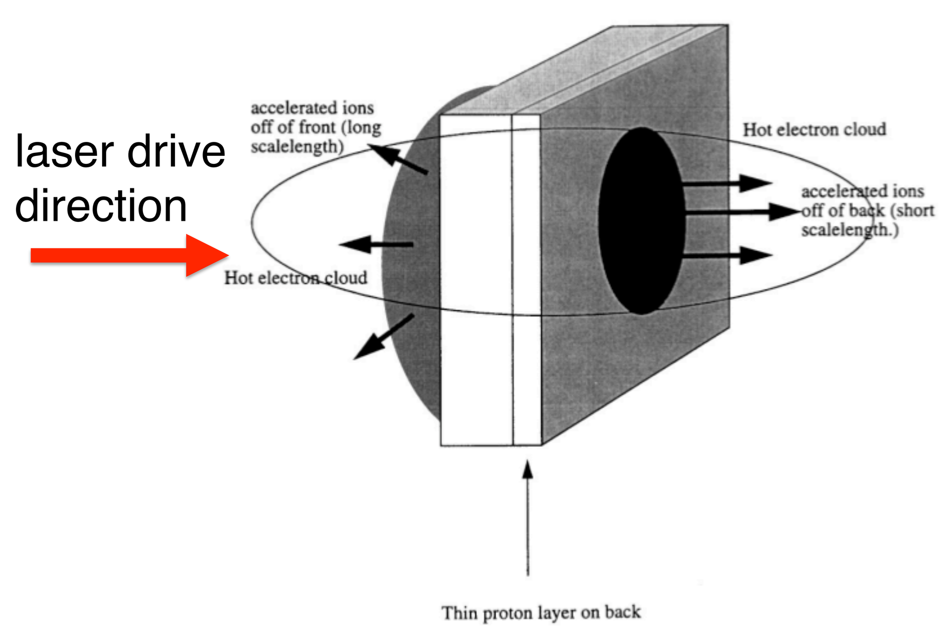
[1]CAVEAT: this simple estimate considers neither dissipative nor heating effects, which complicate the calculation.

Proton radiography: Omega EP

Omega-EP's short-pulse capability permits generation of an energetic proton beam off a metal foil via target-normal sheath acceleration. (TNSA)

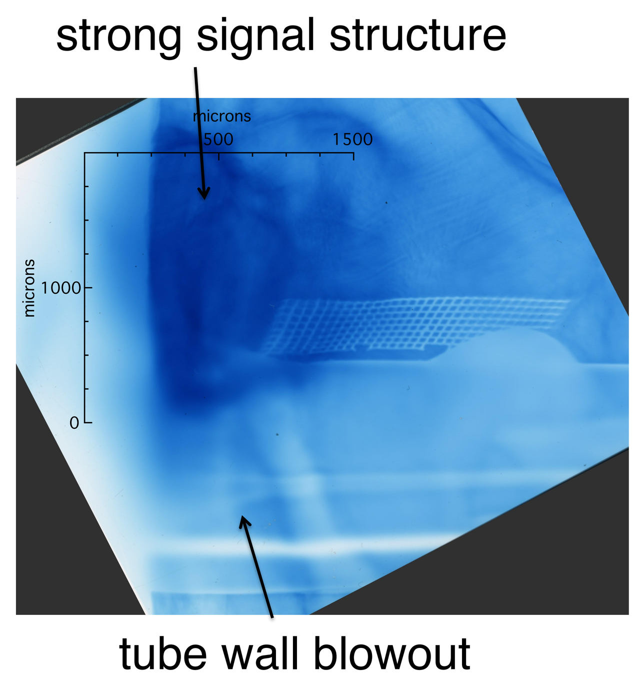


The laser generates an electron sheath near the foil, which in turn accelerate H^+ ions accumulated on the foil surface creating a proton beam.

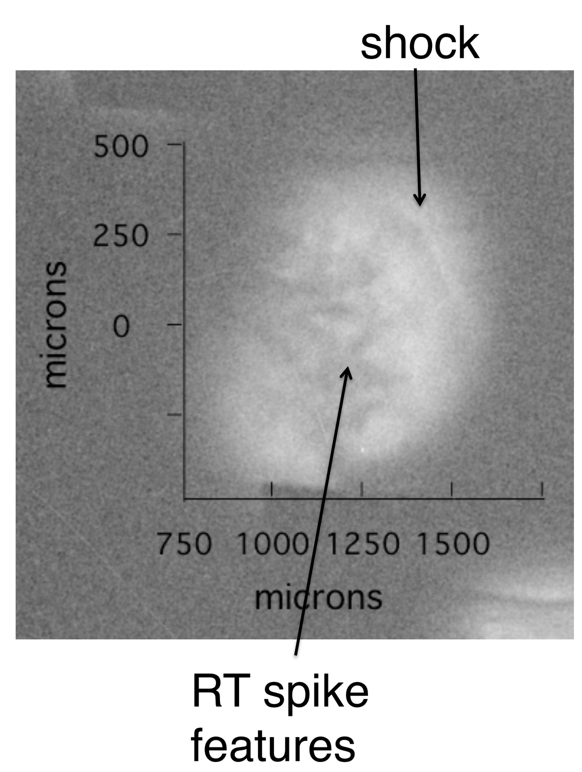


Results

Our May 2011 campaign had some success with the proton diagnostic, as well as seeing interesting behavior in the x-ray images. Radiographs are oriented as in the rendering above.



An example of a proton radiograph with target features clearly visible, but with much structure in the signal.



X-ray radiograph confirms shock propagation, and also shows turbulent breakup of RT features.

Conclusions

Preliminary analysis indicates that magnetic fields could be forming within our experimental system, and could potentially be strong enough to explain its anomalous behavior. This is an important question for scaling, because field effects are not significant during this phase of the supernova's evolution.

We were able to execute our experiment on Omega EP, and image our system with a proton beam. We expect that in future experiments, we will be able to solve issues with proton beam quality.