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 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.

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-Helmholtz at spike tips
2. uniform axial spike profile
3. similar spike/bubble sizes

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

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.

Magnetic fields

Plasma quasi-neutrality requires E&M forces arise in opposition to hydrodynamic forces in the system. If the pressure gradients take the right profile, magnetic fields are induced.

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

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

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

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.

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.

Conclusions

Preliminary analysis indicates that magnetic fields could be forming within our experimental system, and could potentially be strong enough to explain the 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.