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Implosion and Stagnation Dynamics of Liquid Deuterium Filled Liners

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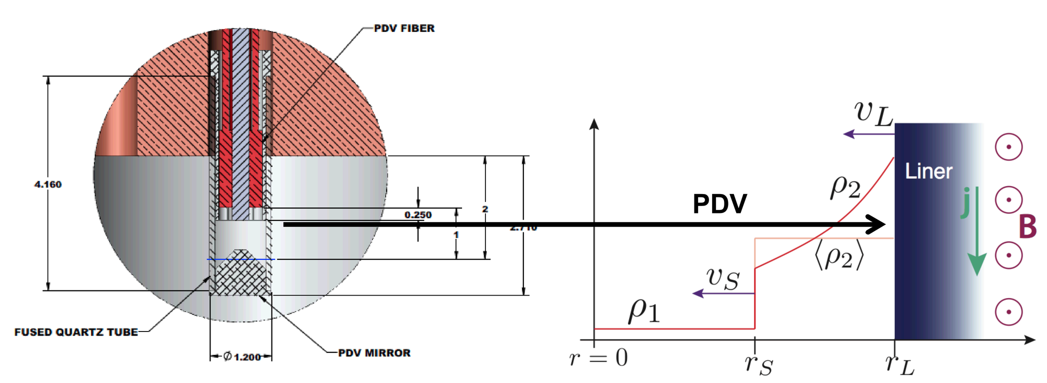
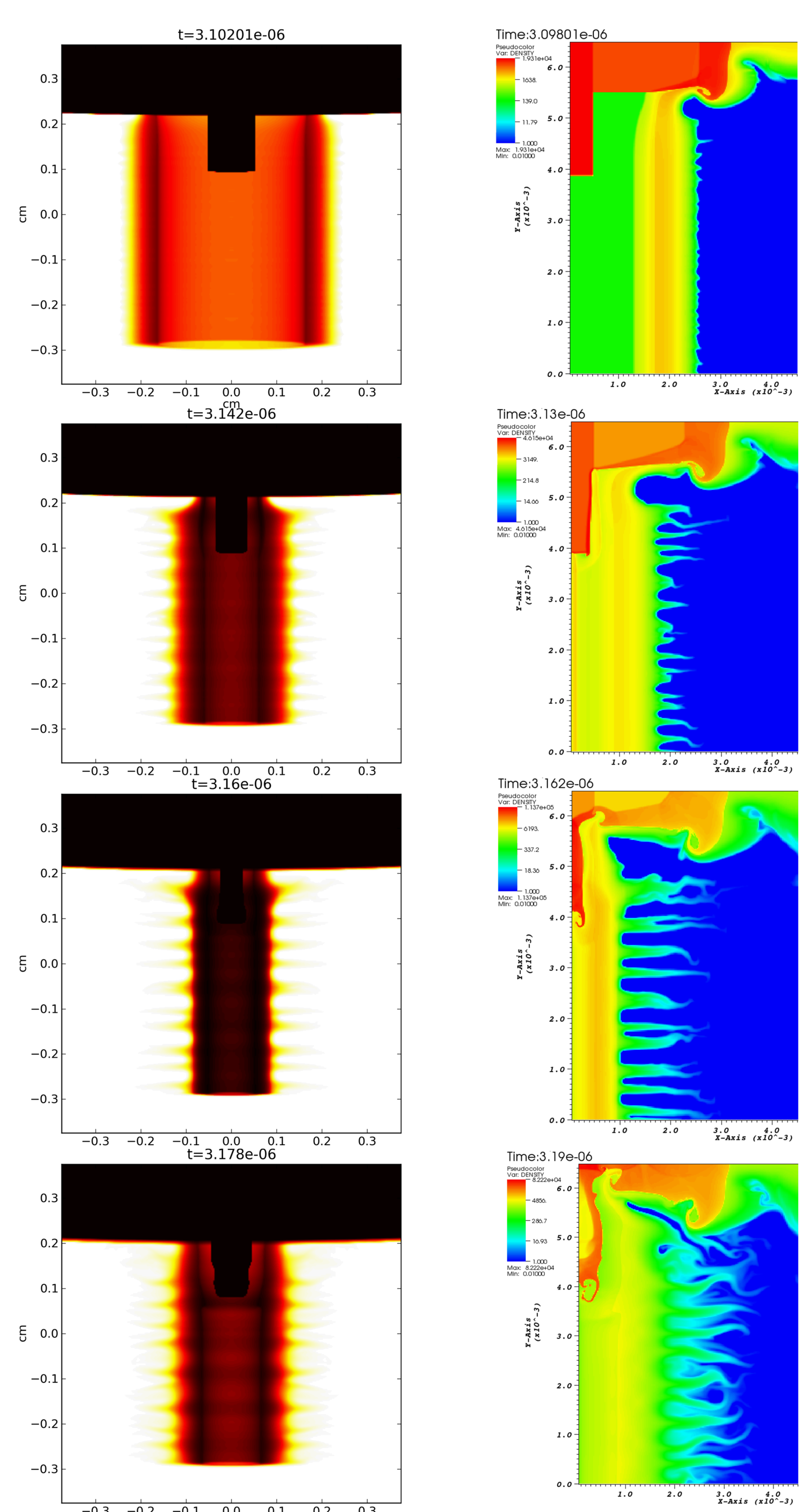
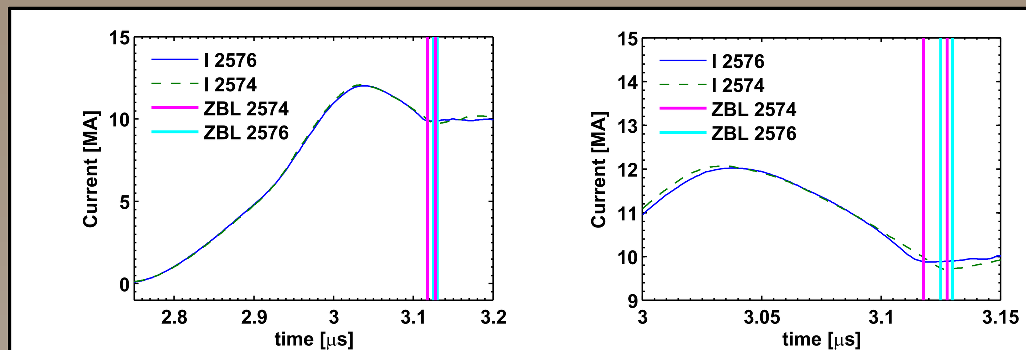
- The Eddy series utilizes cylindrical compression of initially liquid deuterium to achieve high energy density states at low temperatures (<10eV)
- These experiments demonstrated many 'firsts' on ZR
  - Obtained images of a liner at stagnation (CR=8.5) and measured inner radius and density (> 20g/cc)
  - Compressed deuterium to high density (~11 g/cc) and ρr (0.47 g/cm^2)
  - Demonstrated proof-of-principle PDV in liquid measurements (shock velocities > 30 km/s)
- The success of these experiments marks a path towards ultra-high pressure experiments impacting:
  - Planetary science equation of state experiments
  - ICF and other stockpile stewardship applications

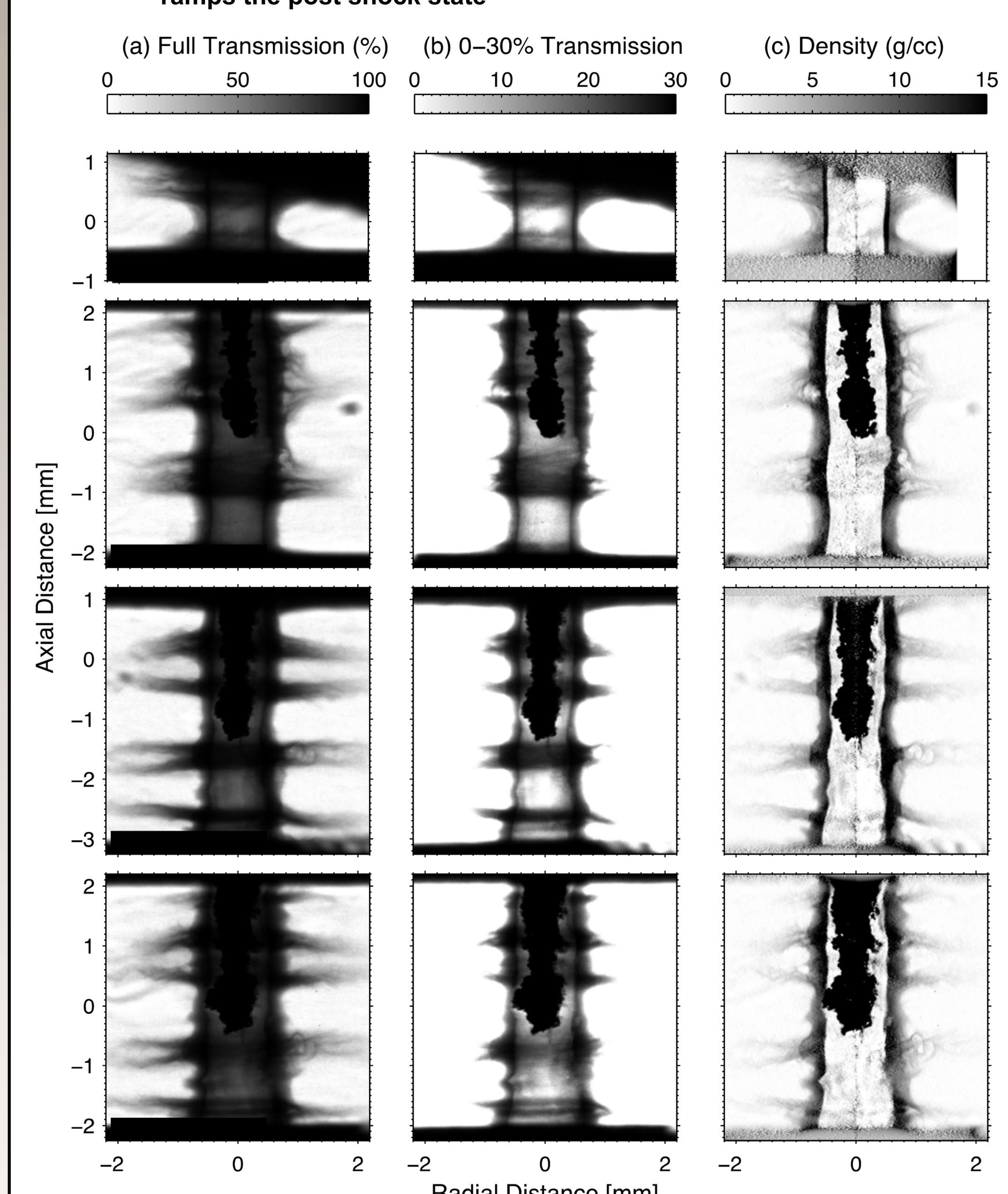






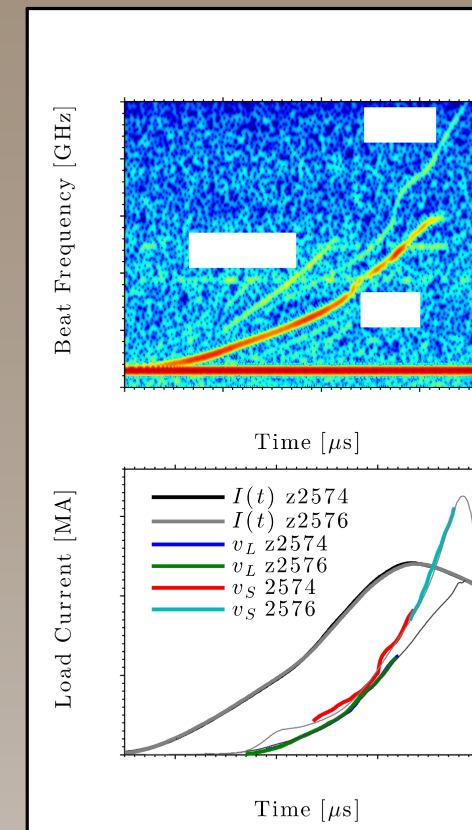
- Top: Measured load current and radiograph times
  - Demonstrated highly repeatable current pulse shape
  - Radiograph timings were set to map out the stagnation phase of the beryllium liner

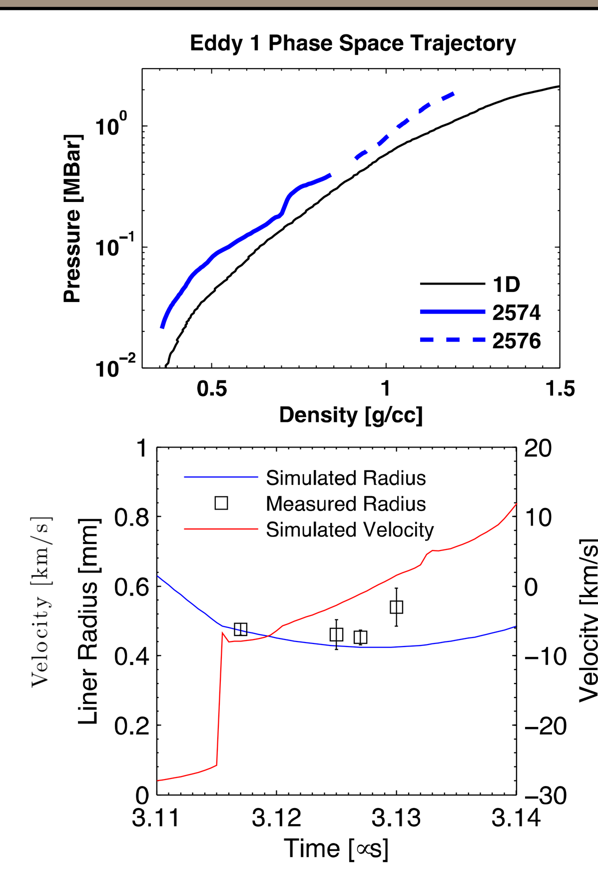
- Left: Radial PDV housing and experimental configuration
  - Radial PDV was directed at an imploding beryllium liner filled with cryogenic liquid deuterium
  - Magnetic pressure implodes the liner which shocks the deuterium then ramps the post shock state



- Top: Radiographs from monochromatic 6.151 keV imager taken during the experiment
  - Experimental data shows a stable liner wall at stagnation with perturbations increasing upon explosion of the beryllium liner
  - The PDV housing has been compressed by a factor of three and is mixing into the deuterium

- Left: ALEGRA simulation of the Eddy experiment
  - During the isobaric stagnation the deuterium reaches pressures of order 100 Mbar and temperatures of order 8 eV with an average density of 11g/cc
  - Simulations show the region free of perturbations due to reflected waves off the PDV housing can be identified through a divot in the liner density profile
  - Synthetic radiography allows for direct comparison to diagnostics and is in qualitative agreement with the data

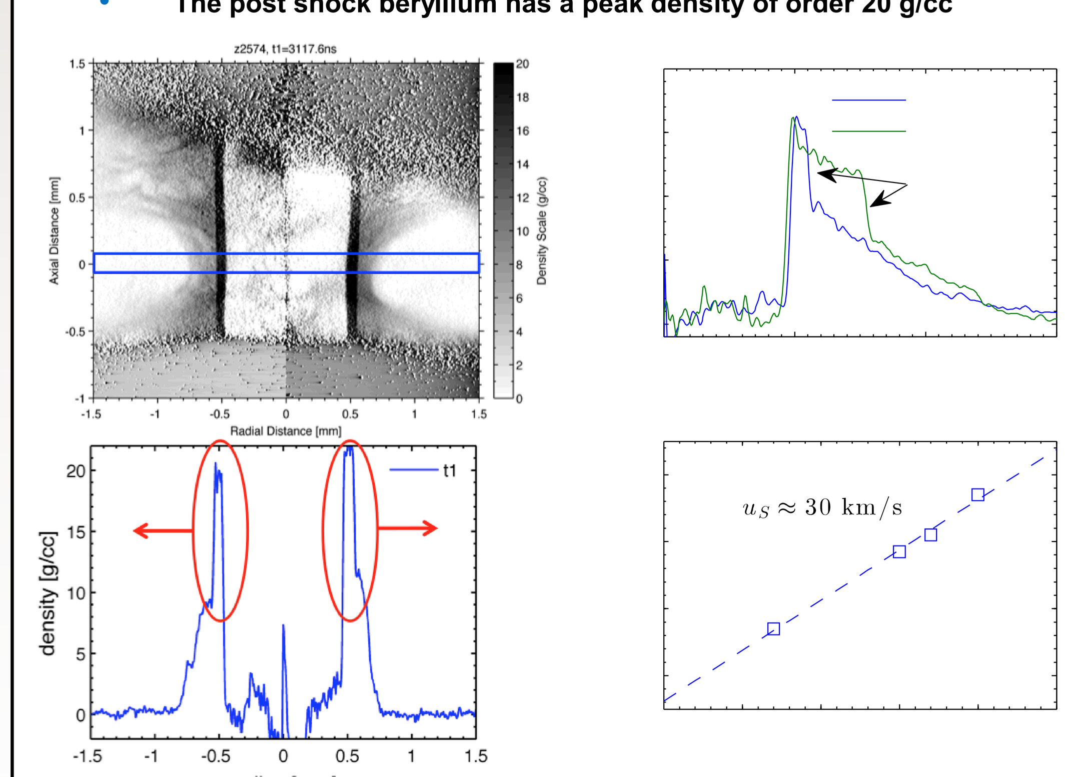


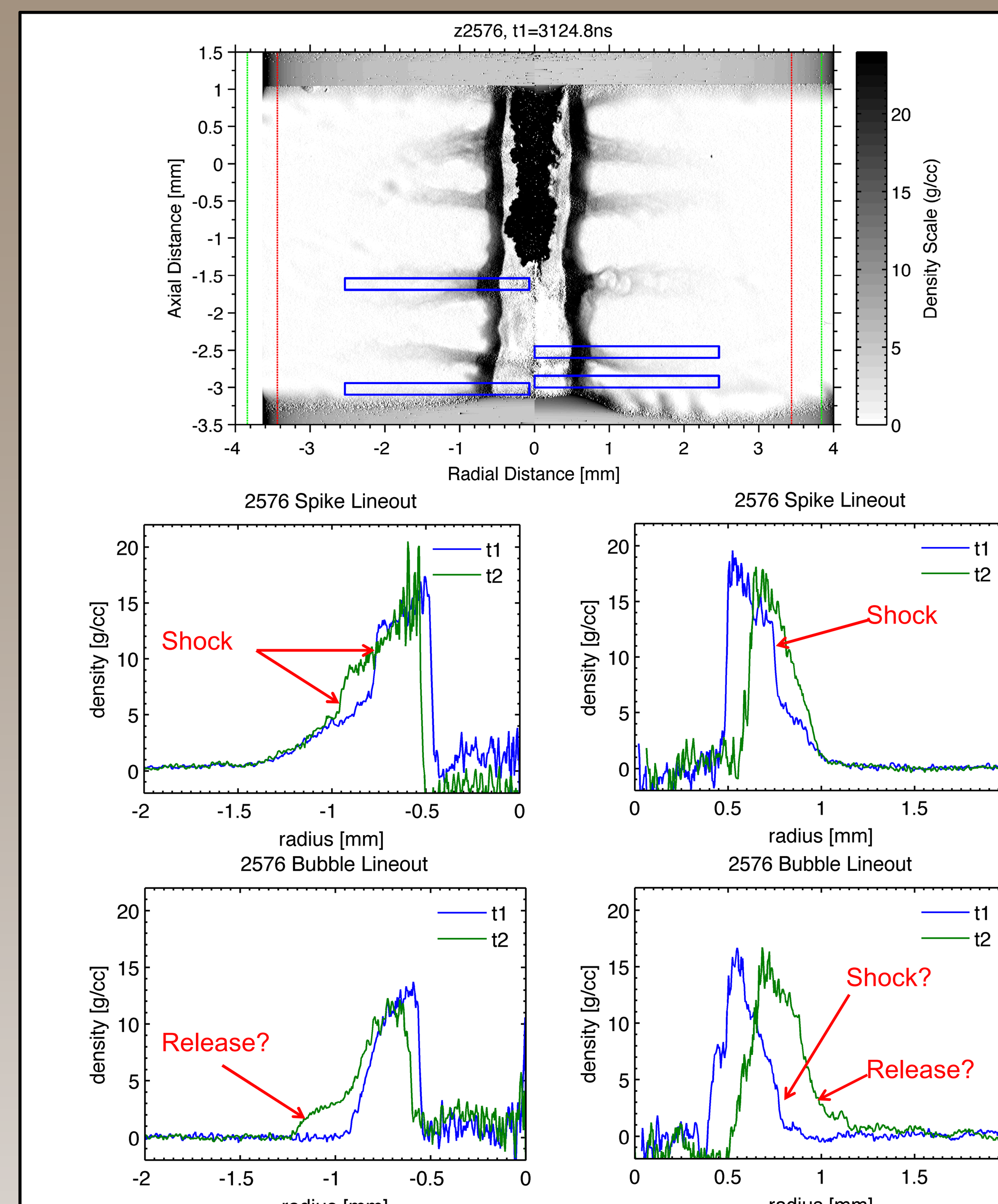


- Top: Analysis of radial PDV data
  - Radial PDV diagnostic was able to simultaneously track the motion of the liner inner surface and the motion of the shock front in the deuterium
  - At 15 km/s light reflected from the liner inner surface is lost and only the deuterium shock is tracked to 35 km/s, just before impact on the PDV housing
  - Cylindrical compression allows for shock-ramp loading of large deuterium samples to high densities without the need for shock reverberation loading

- Right: Exploding liner density profile determined from Abel inversion
  - Lineouts of density profiles through magneto-Rayleigh-Taylor spikes and bubbles demonstrate the instabilities impact on the stagnation reverberation process
  - The reflected shock propagates out through the spike regions while portions of deuterium confined by a bubble region see the release state earlier

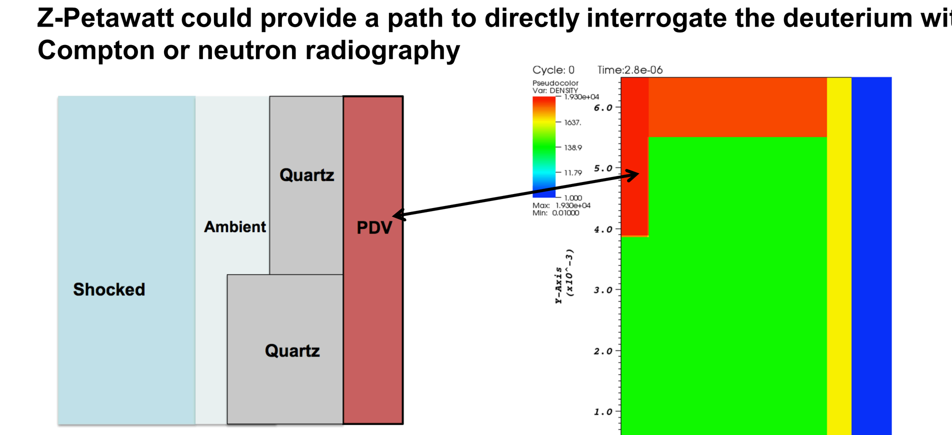
- Bottom: First shock stagnation density profile determined from Abel inversion
  - Lineouts of the density profile show the initiation of liner stagnation from an outward propagating shock
  - Tracking the shock position through different radiographs gives an estimated shock velocity of 30 km/s
  - The post shock beryllium has a peak density of order 20 g/cc



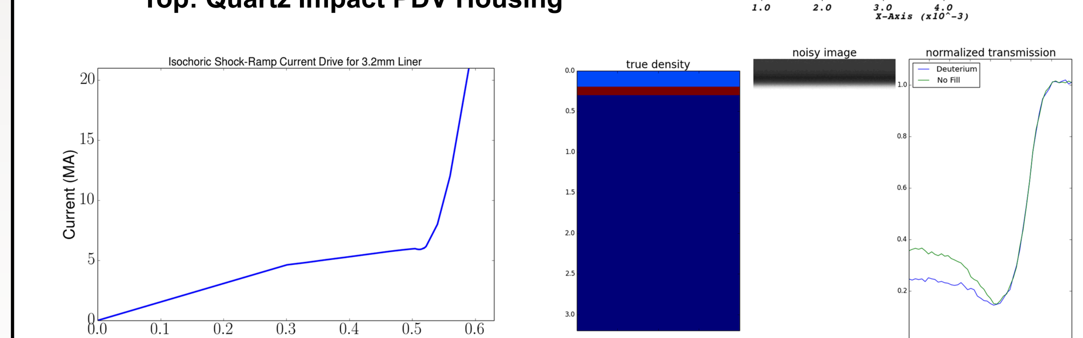


Future Work

- The next set of experiments will explore isochoric stagnation states and direct radiography of ultra dense deuterium (~30 g/cc)
- Custom made quartz tubes for the PDV housing will allow us to use impedance matching when the shock strikes the tube for ultra-high pressure measurements
- Higher photon energy backlighting could allow us to increase the convergence ratio and therefore diagnosable stagnation ρr
- Z-Petawatt could provide a path to directly interrogate the deuterium with Compton or neutron radiography



Top: Quartz Impact PDV Housing



Top: Current pulse shaping and simulated limb transmission for an isochoric stagnation of an initially liquid deuterium filled beryllium cylinder. The expected stagnation state of the deuterium is a constant 30 g/cc over a 200 micron radius with temperature less than 3eV.