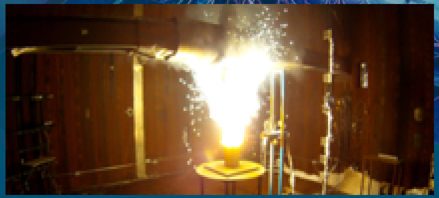
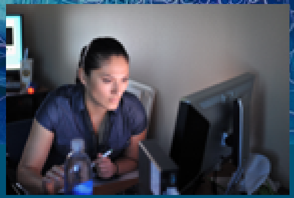
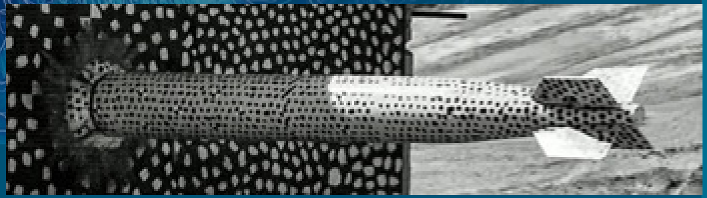
SAND2021-9674PE

Long Timescale Hydrodynamics Platform on Z for Turbulence Studies







PRESENTED BY

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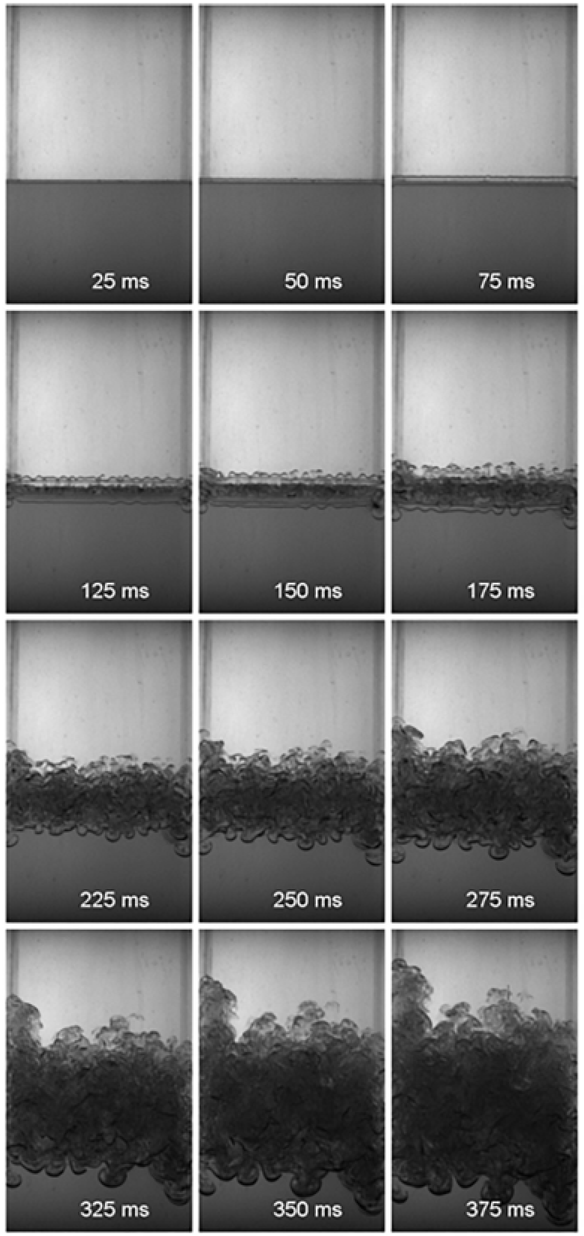
August 12, 2021

What are the open questions in HEDP instability research?



How and under what conditions does turbulence develop in an HED flow?

Once developed, how does HED turbulence evolve, dissipate energy, and mix materials

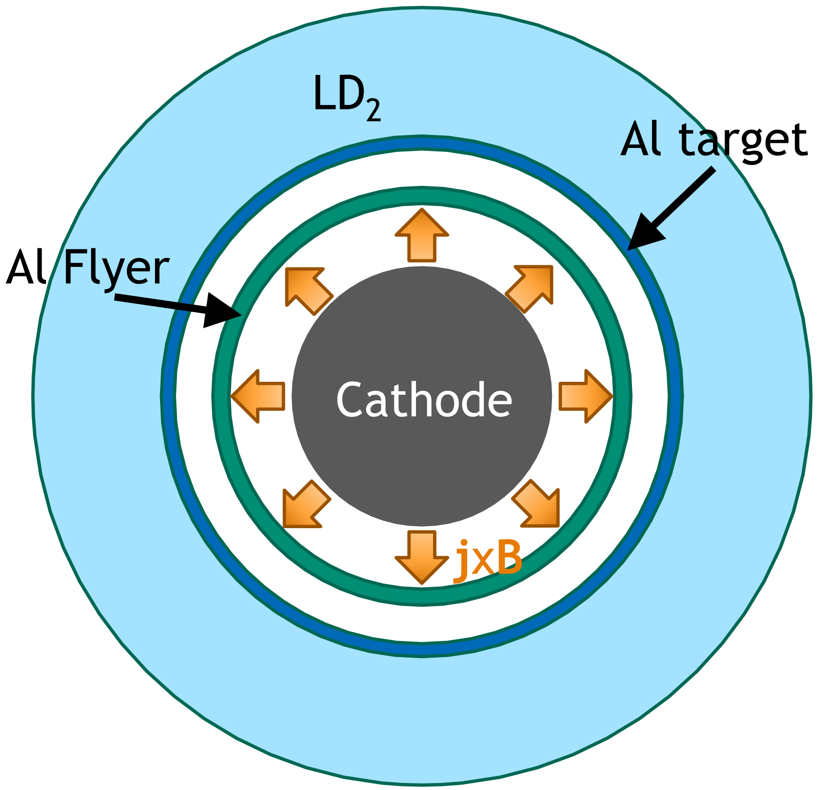
- The answers to these questions depend on interface conditions, Mach numbers, Atwood numbers, etc., but ialso on constituent properties like *viscosity, ionization state, etc.* which are often poorly understood in HED
- Turbulence has proven notoriously difficult to achieve in HED systems due to limits on driver energy and duration

The Exploding Cylinder platform is designed to try to solve these problems enabling the detailed study of the onset and evolution of HED turbulence

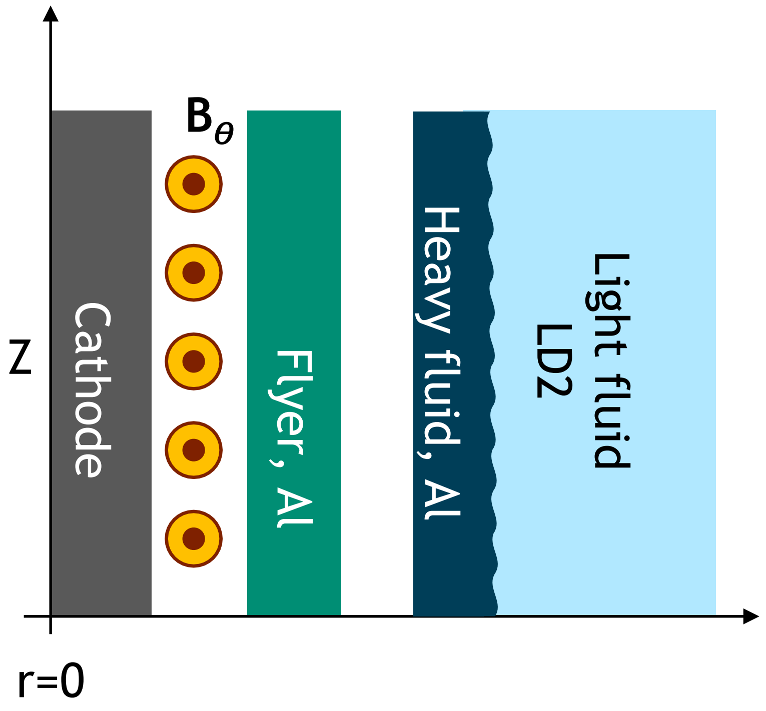
Roberts and Jacobs, J. Fluid Mech. 787, 50 (2016)

The exploding cylinder is an analog of the planar shock tube experiments which exploits cylindrical symmetry to eliminate limiting edge waves

Top View



Cross Section



Laser driven planar RM/RT experiments employ a high opacity tracer layer that isolates the dynamics to a region of interest

This has several disadvantages

- It complicates fab and limits material options
- Matching density and EOS between the tracer and bulk is difficult
- Once edge waves reach the tracer layer the experiment is over

Additionally, drive duration and available energy are small, further limiting the size and duration of the experiment

Cylindrical symmetry eliminates transverse edge waves and allows for Abel inversion to get quantitative densities. Given Z's long drive duration and energy, the practical limits to the experiment are the height and the radial size of the target

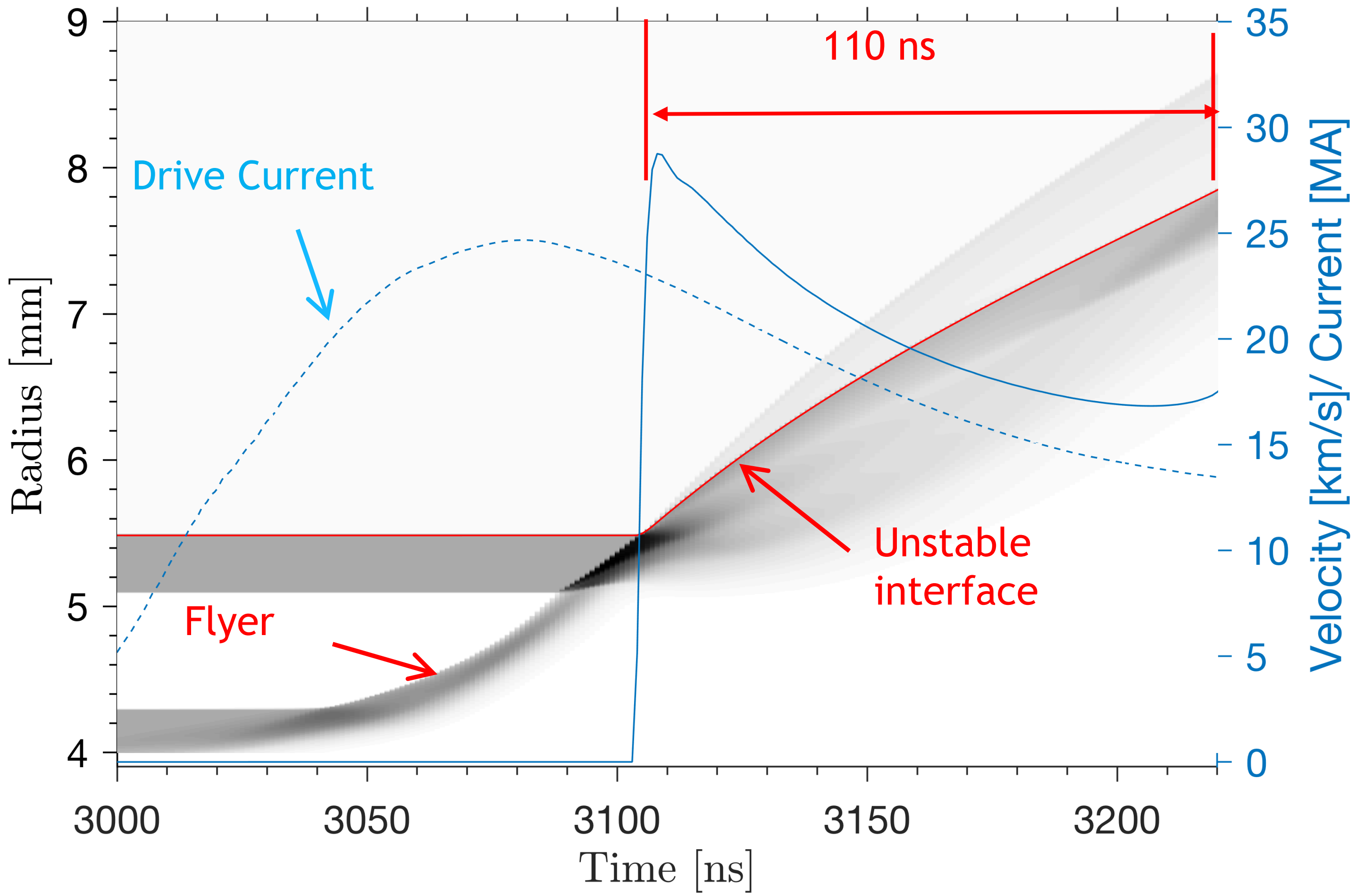
1D scoping designs using ALEGRA show that Z can drive an unstable interface for >100 ns

The flyer accelerates to peak velocity near peak current and impacts the target

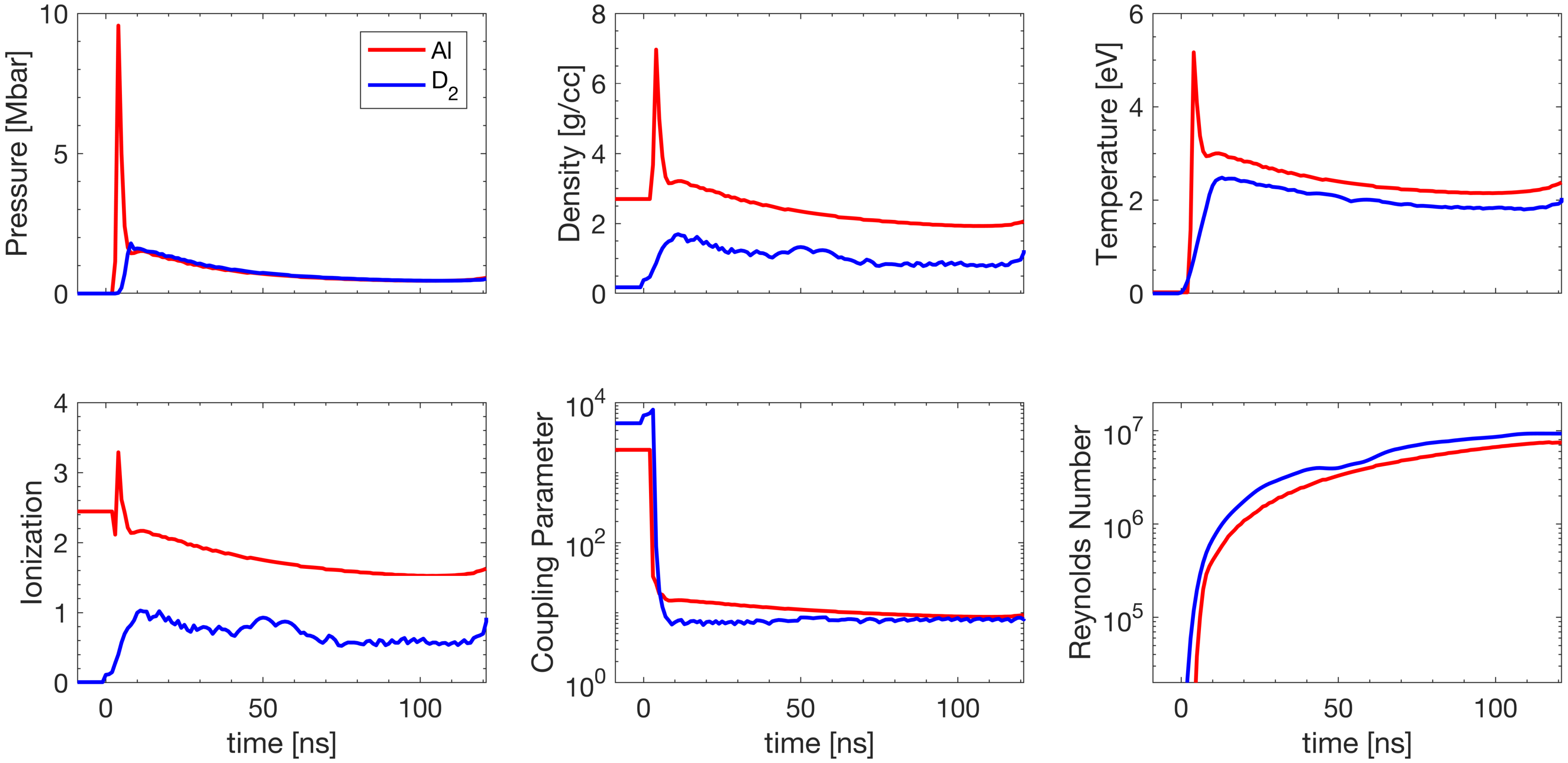
The interface exhibits an impulsive acceleration followed by an RT unstable phase with a gradual deceleration

The 110 ns drive time was limited by the simulation crashing (and my lack of ability to fix it), not anything inherent to the design

Density Evolution



Summary of Parameters at unstable interface

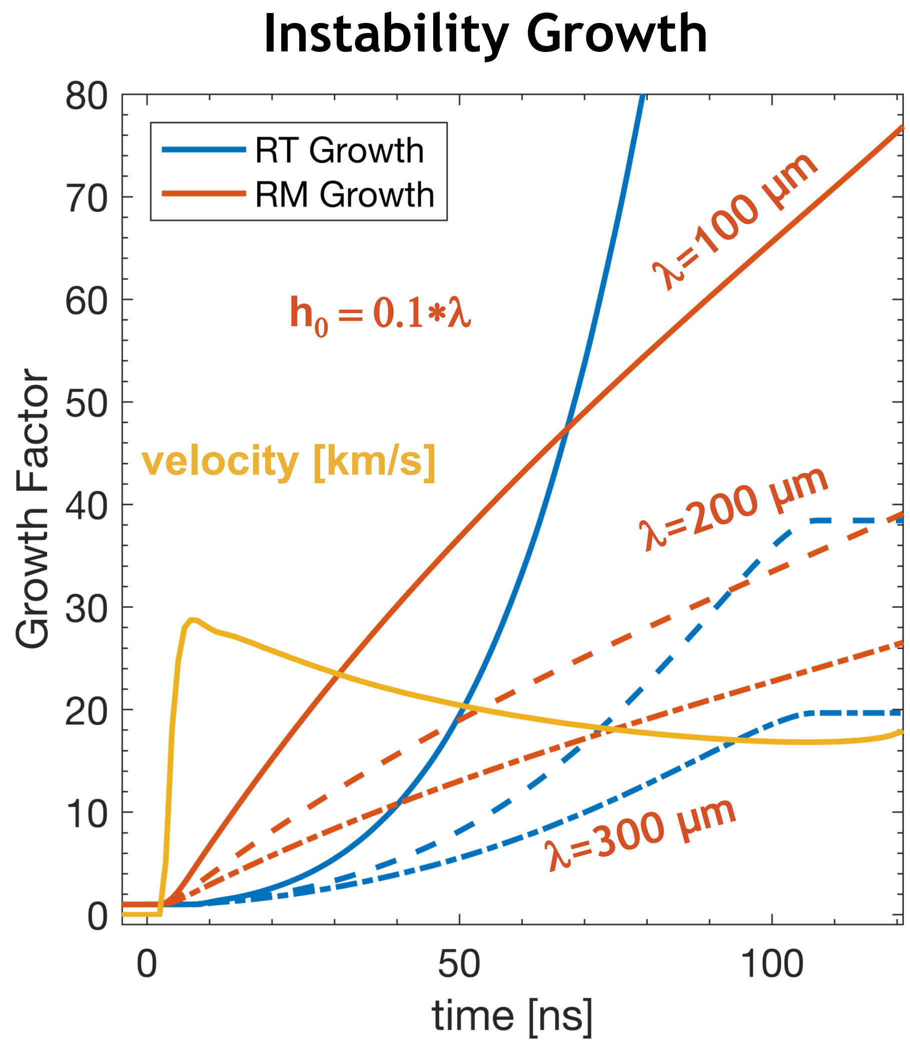


It would be worthwhile to calculate other dimensionless numbers

Quantities of interest are thermal conductivity, and diffusivity in order to calculate the **Peclet** (convection/conduction), **Prandtl**(momentum diff./particle diff.), and **Schmidt** (momentum diff./particle diff.) numbers

Other quantities of interest?

Post-processing the acceleration history shows RM and RT growth are comparable and exhibit very large (linear) growth factors



$$G_{\mathrm{RT}}(t) = \exp\left(\int_0^t \gamma_{\mathrm{RT}}(t')dt'\right) \quad \gamma_{\mathrm{RT}} \approx \sqrt{-k_z A_{\mathrm{N}} \frac{dv_i}{dt'}}$$

$$G_{\mathrm{RM}} = \frac{1}{h_0}\int_0^t \frac{h_0}{R_0} v_i(t')\left(1 + \frac{k_z A_{\mathrm{N}}}{f(n, k_z)}\right)dt'$$

Radiography and velocimetry will be used to compare against simulations

If successful, this platform offers a very attractive means to study fully developed HED turbulence

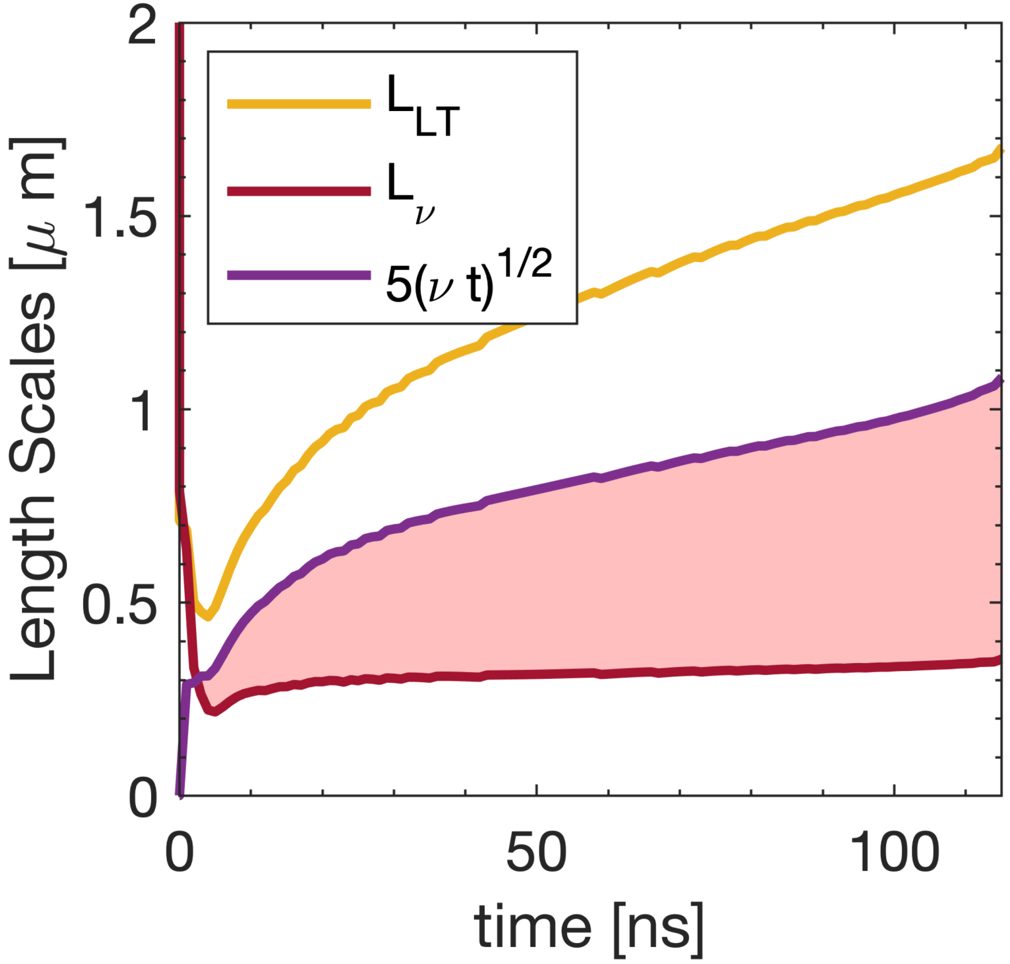
Analytic models suggest more than enough time for separation of scales to form, resulting in a well defined inertial subrange

The Liepman-Taylor L_{LT} scale represents the scale of a laminar diffusion layer surrounding the perturbations

The inner viscous scale L_{ν} is well above the Kolmogorov scale

Purple line indicates the temporal evolution of a diffusive layer

~5 ns into the experiment a separation exists between these scales, indicating the potential for a turbulent cascade where the energy injection scale is fully decoupled from the viscous dissipation scale (assuming I understood this properly)



Robey et al., Phys. Plasmas, Vol. 10, No. 3, March 2003

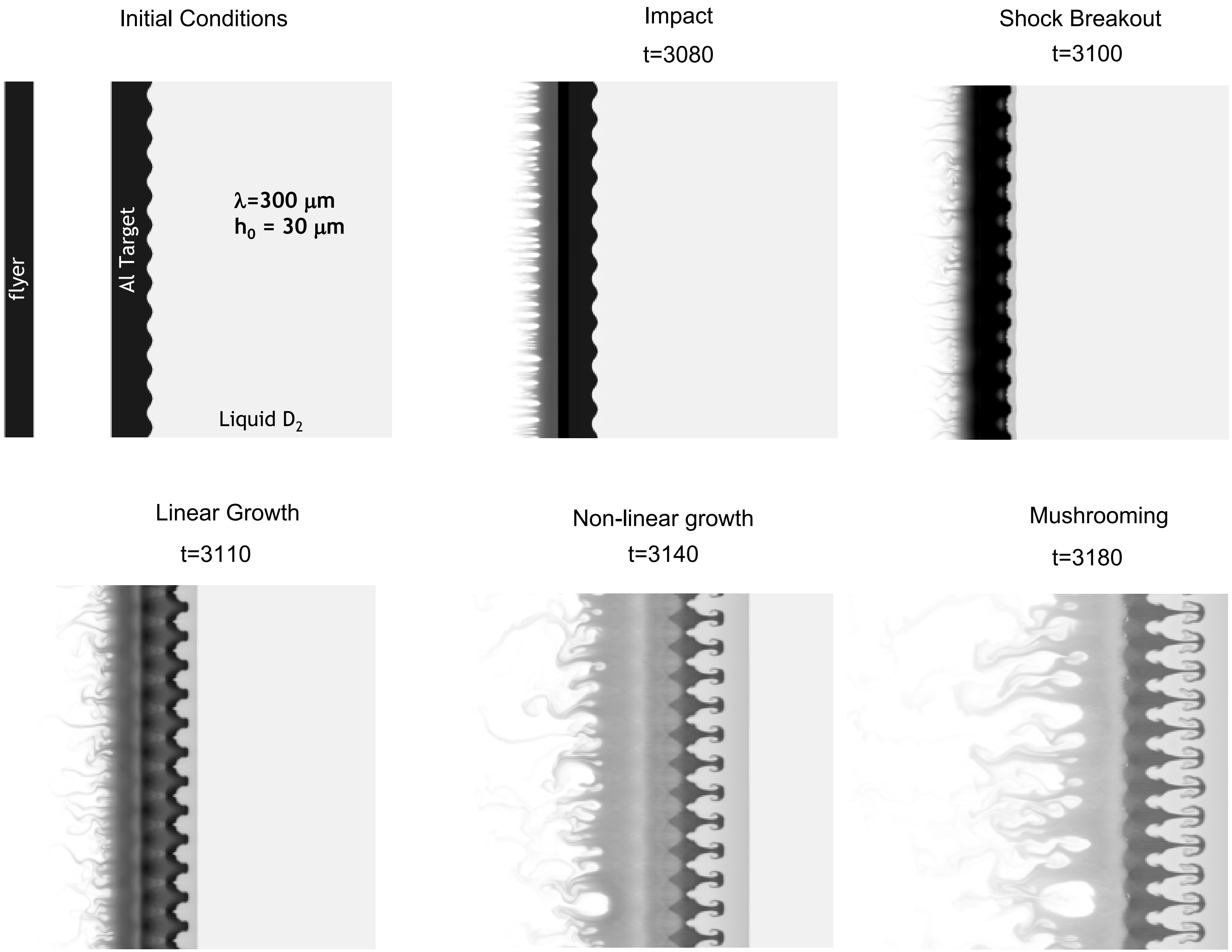
This design was simulated using 2D GORGON to model MRT development and the perturbation evolution

MRT apparently does not impact the interface evolution

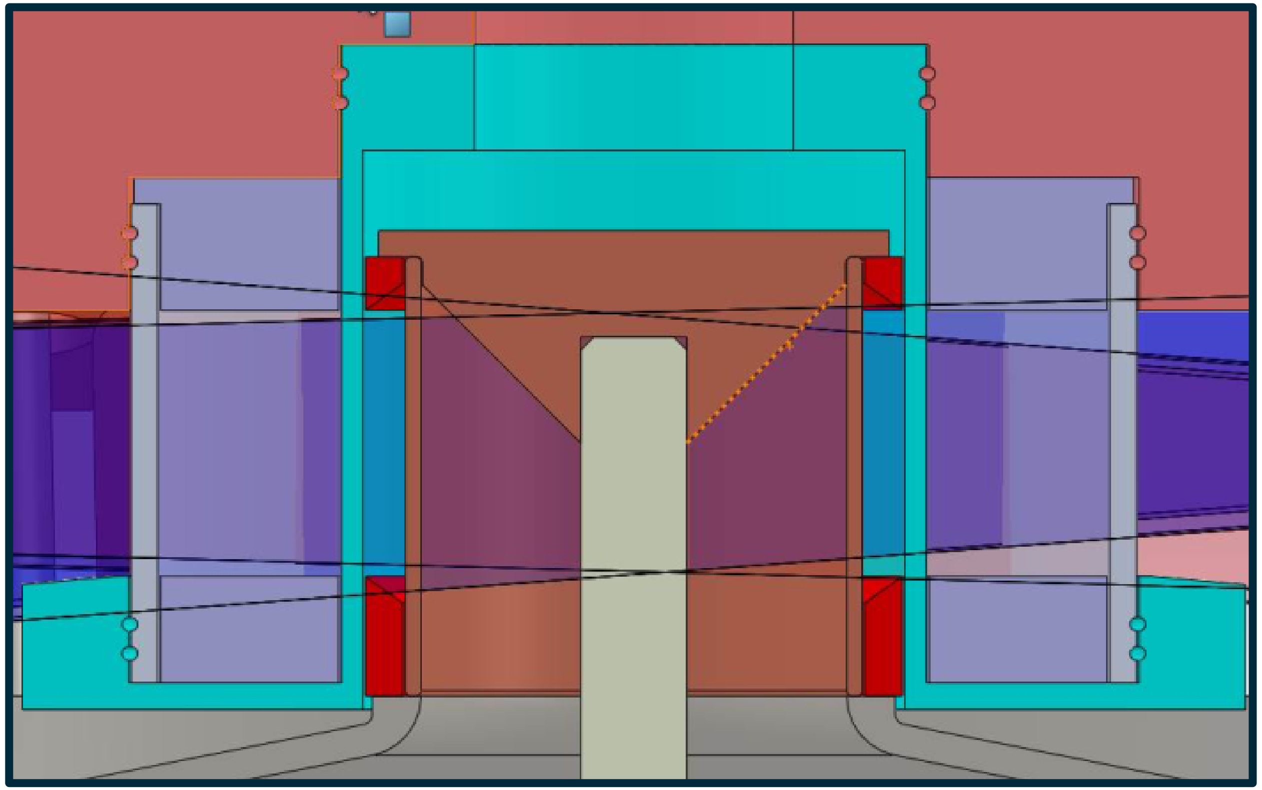
The perturbation becomes highly nonlinear and develops secondary instabilities

Electrodes were not modeled, so we will need to take care to properly design the target

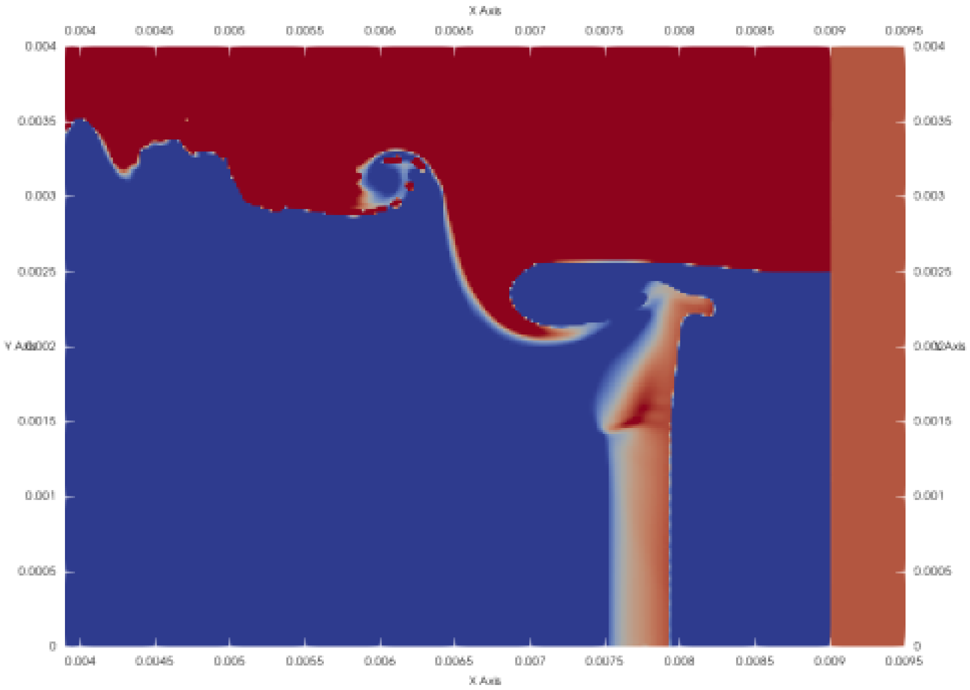
No strength models were used



An initial design was fabricated, but has yet to be executed on Z



Glide planes were designed to minimize the impact of the wall instability

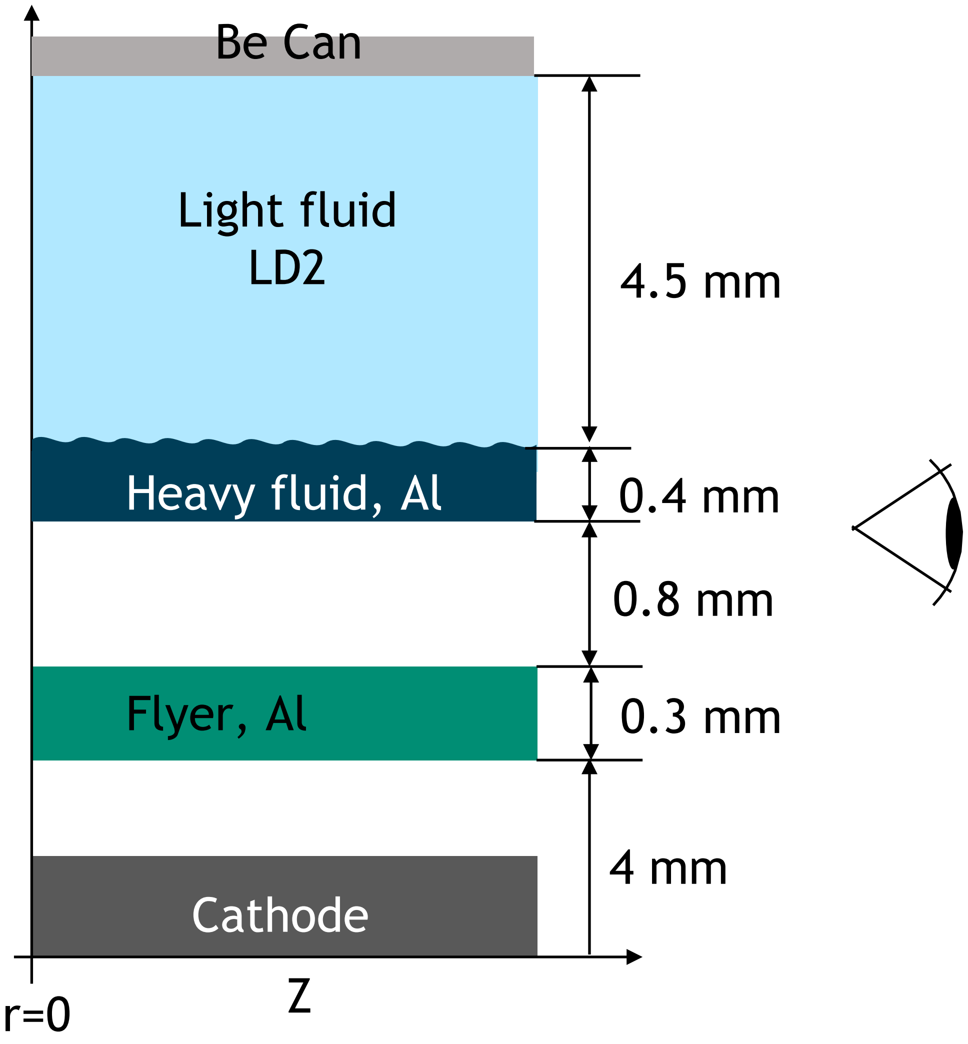


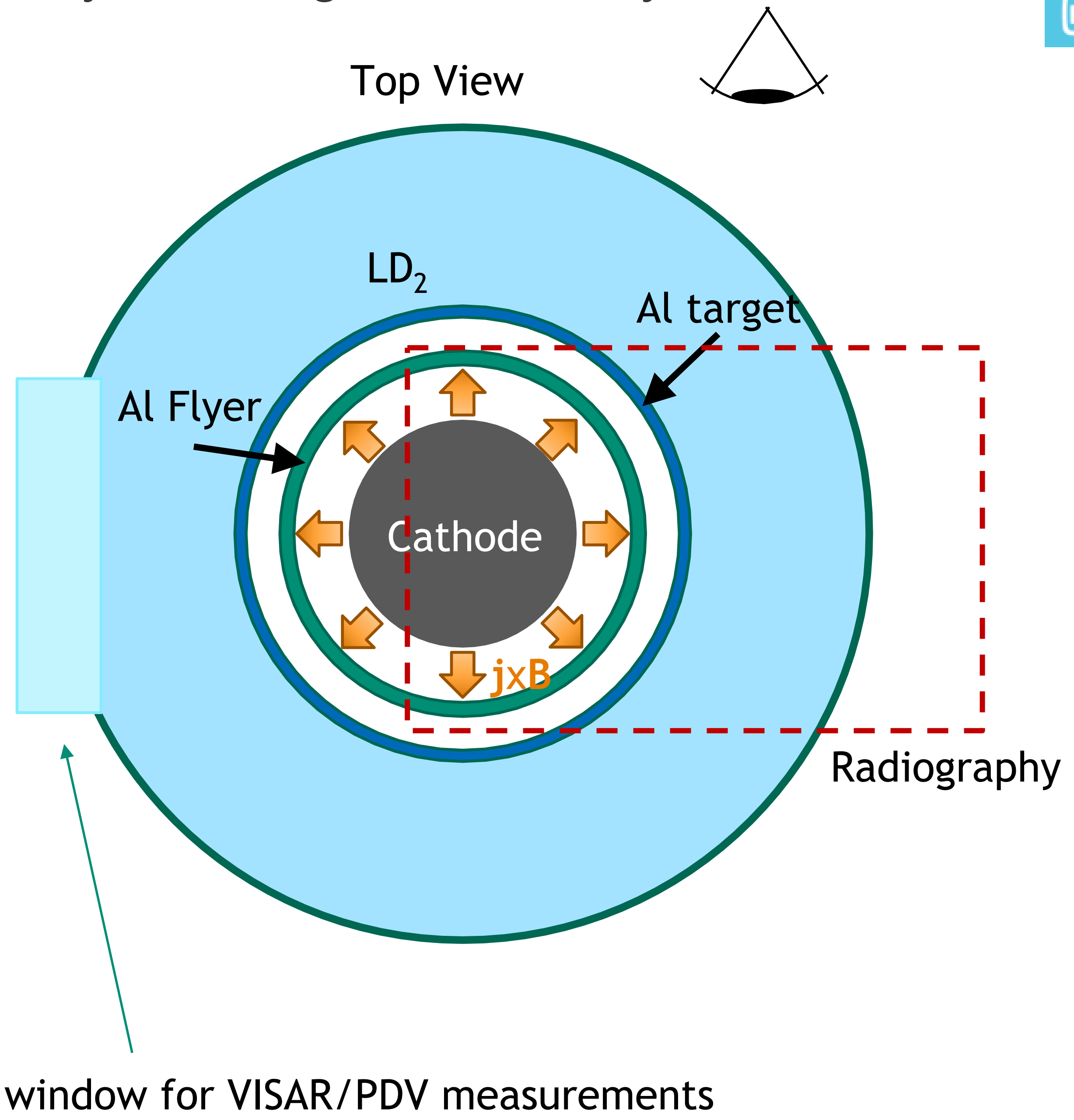
The geometry has a relatively high inductance, and the need for multiple cryo gas seals was a challenge

New fabrication methods could reduce the height of the target by brazing the seals instead of gluing them

The primary objectives of this design is to validate wall instability mitigation and MRT feed through, and to assess powerflow

Target symmetry allows the possibility of using velocimetry and radiography simultaneously





Be Can: Inner Radius 9 mm
thickness ~300-500 microns

In order to make maximum use of this platform we will need significant diagnostic improvements

Our existing radiographic capability is limited:

- 12 um Spatial resolution & 1 ns temporal integration
- This is sufficient to measure instability growth into the non-linear regime, but not sufficient to distinguish “messy” from *turbulent*
- In order to confirm a separation of scales we will need to measure features down to a ~few microns or better
  - Zone plates, aspherical crystals, much faster integration times to minimize motion blur

Are there other approaches?

- Techniques in the Fourier domain (e.g. x-ray scattering) remove the spatial resolution requirement, but usually require coherent beams
- Cross-correlation of images obtained close in time can be used to extract velocity and density fluctuations
- X-ray induced fluorescence imaging could be used to track mixing of species
- Can we adjust the platform to use a gas as the light fluid so optical techniques could be used?
  - This would enable spectroscopic measurement of density, temperature, species location, interferometry, etc.
  - At low temperatures perhaps optical emission from compounds formed at high pressure could be used to identify mixing (I have to credit Bruce Remington for sticking this idea in my head)