SAND2012-0882C

3 Dimensional Magneto-hydrodynamic modeling of liner implosions on the Z Generator

C.A. Jennings, R.D. McBride, D.B. Sinars, J. Chittenden,
S.A. Slutz, M.E. Cuneo, M.C. Herrmann,

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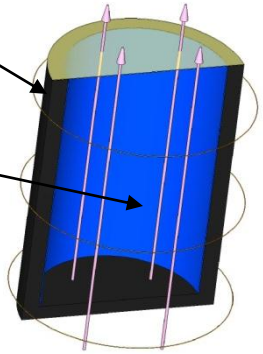
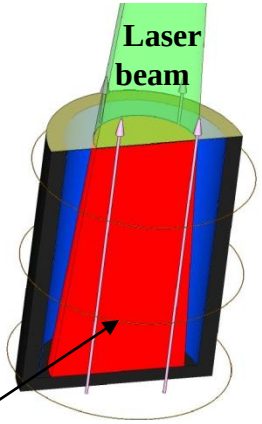
Magnetized Liner Inertial Fusion (MagLIF)* may be a promising path to high fusion yields on Z



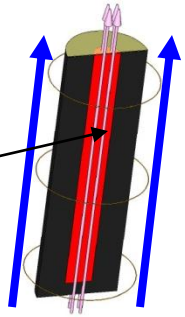
Idea: Directly drive solid liner containing fusion fuel

1. An axial magnetic field (B_z) is applied to inhibit thermal conduction and enhance alpha particle deposition



2. Z Beamlet preheats the fuel

Liner Integrity is Critical !



3. The Z accelerator efficiently drives a z-pinch implosion

*S. A. Slutz *et al*., Phys. Plasmas **17**, 056303 (2010).

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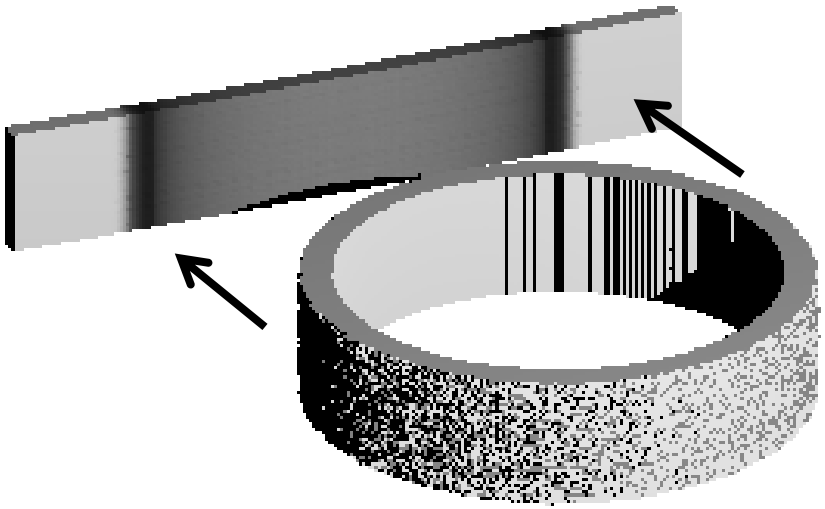
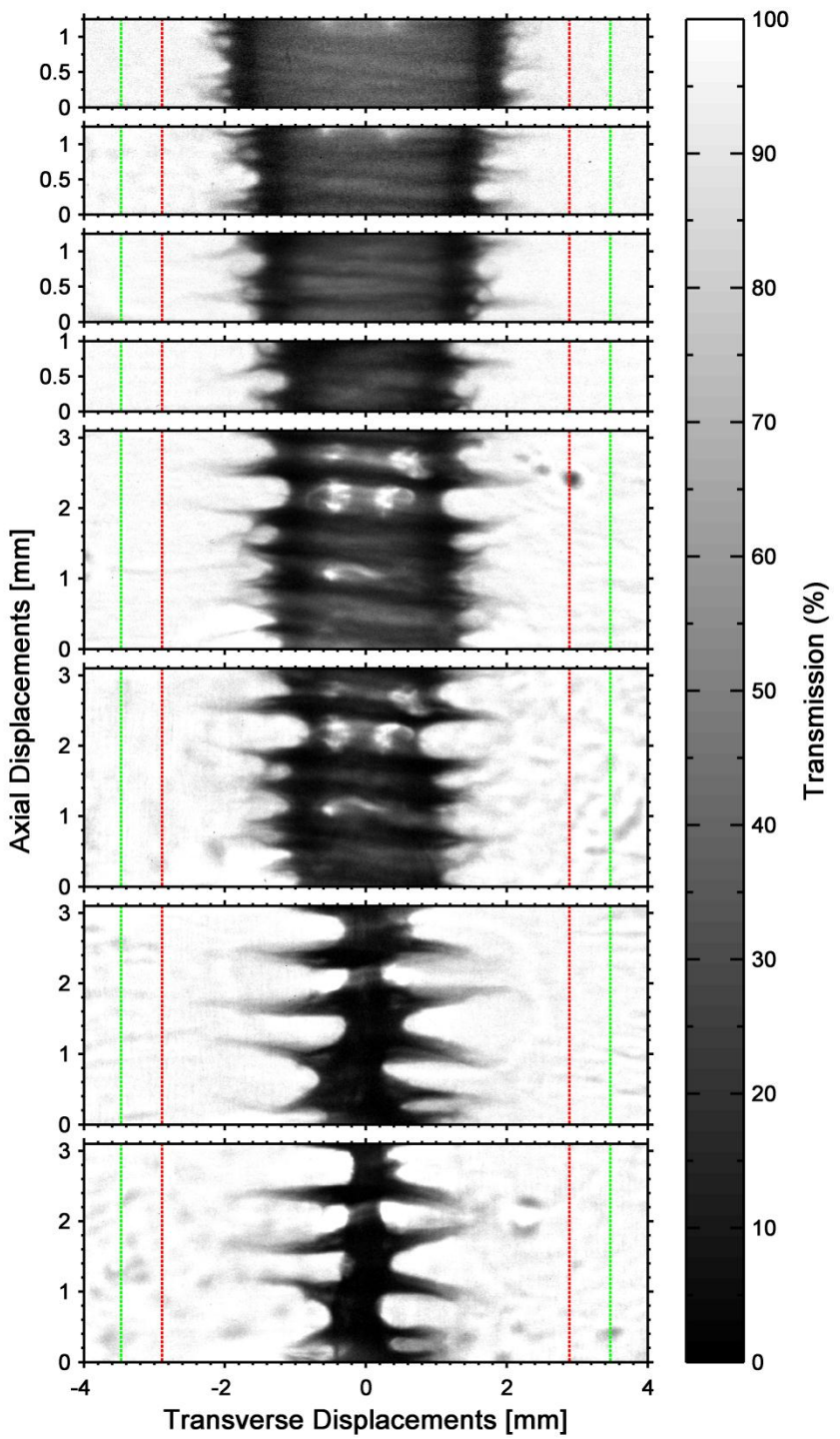
Liner Implosion

Experiments have been performed on the Z generator to study the evolution instabilities in Be liner implosions.

Ryan McBride talking Thursday

Transmission Radiographs taken of imploding liners





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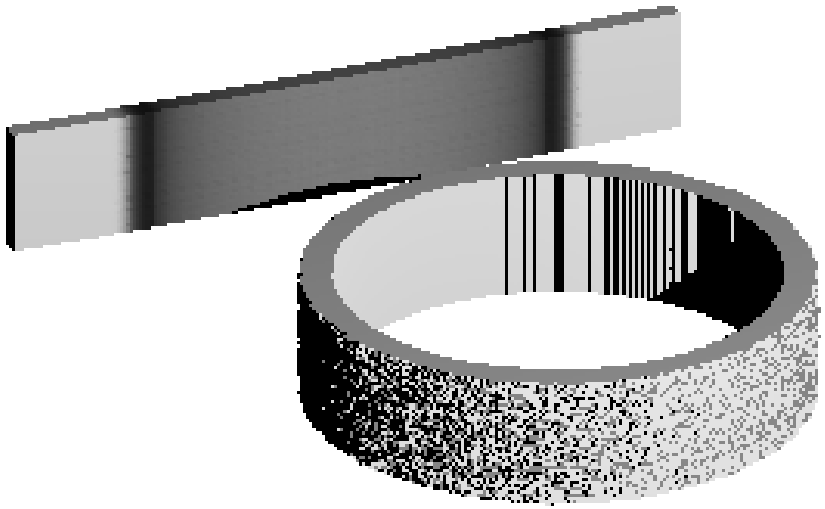

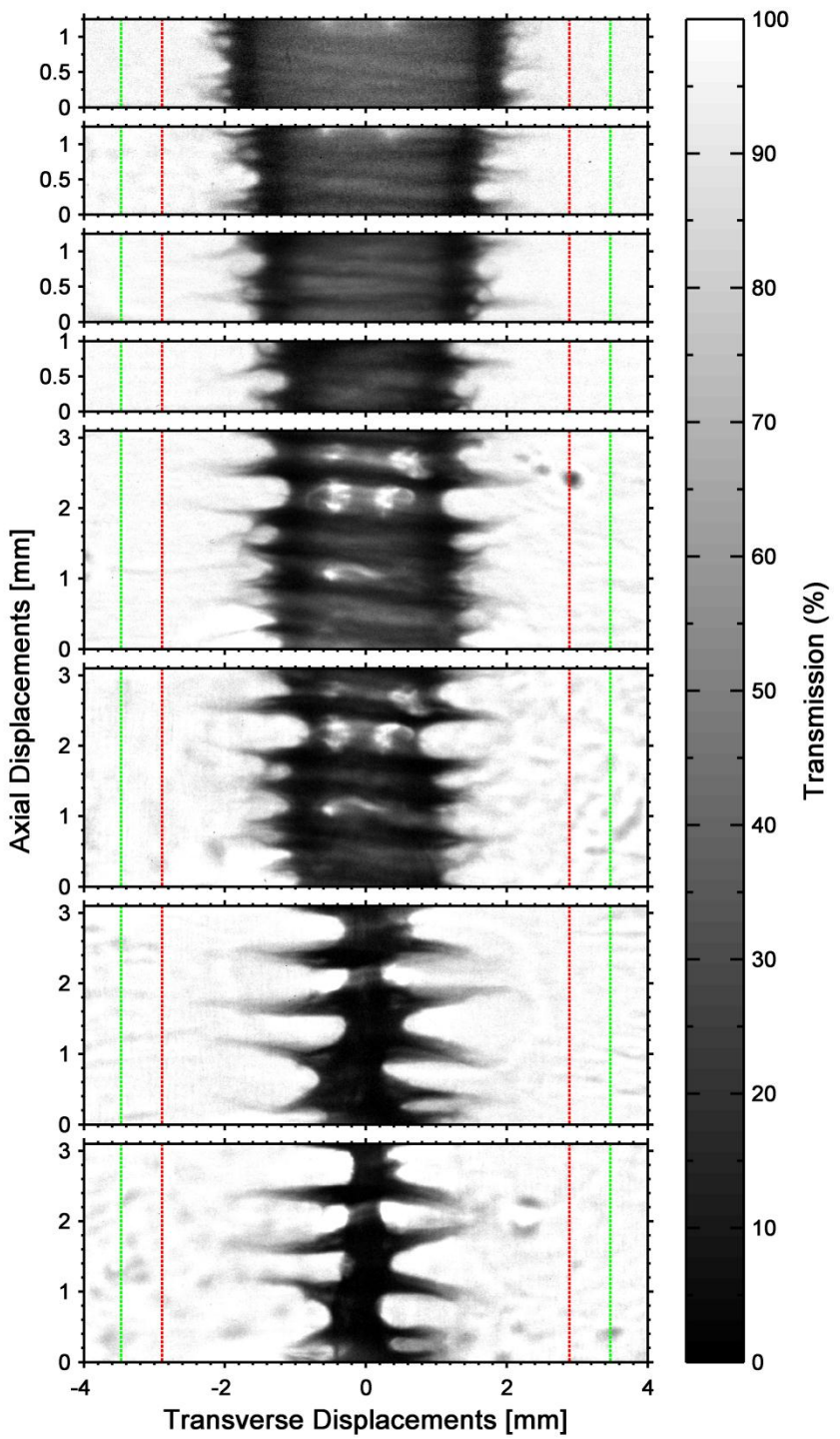

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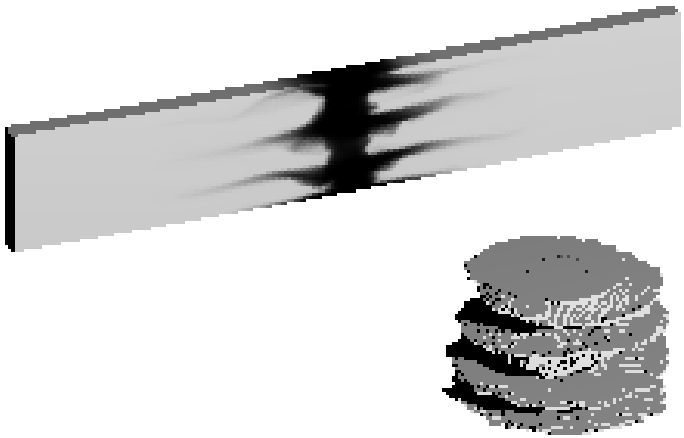
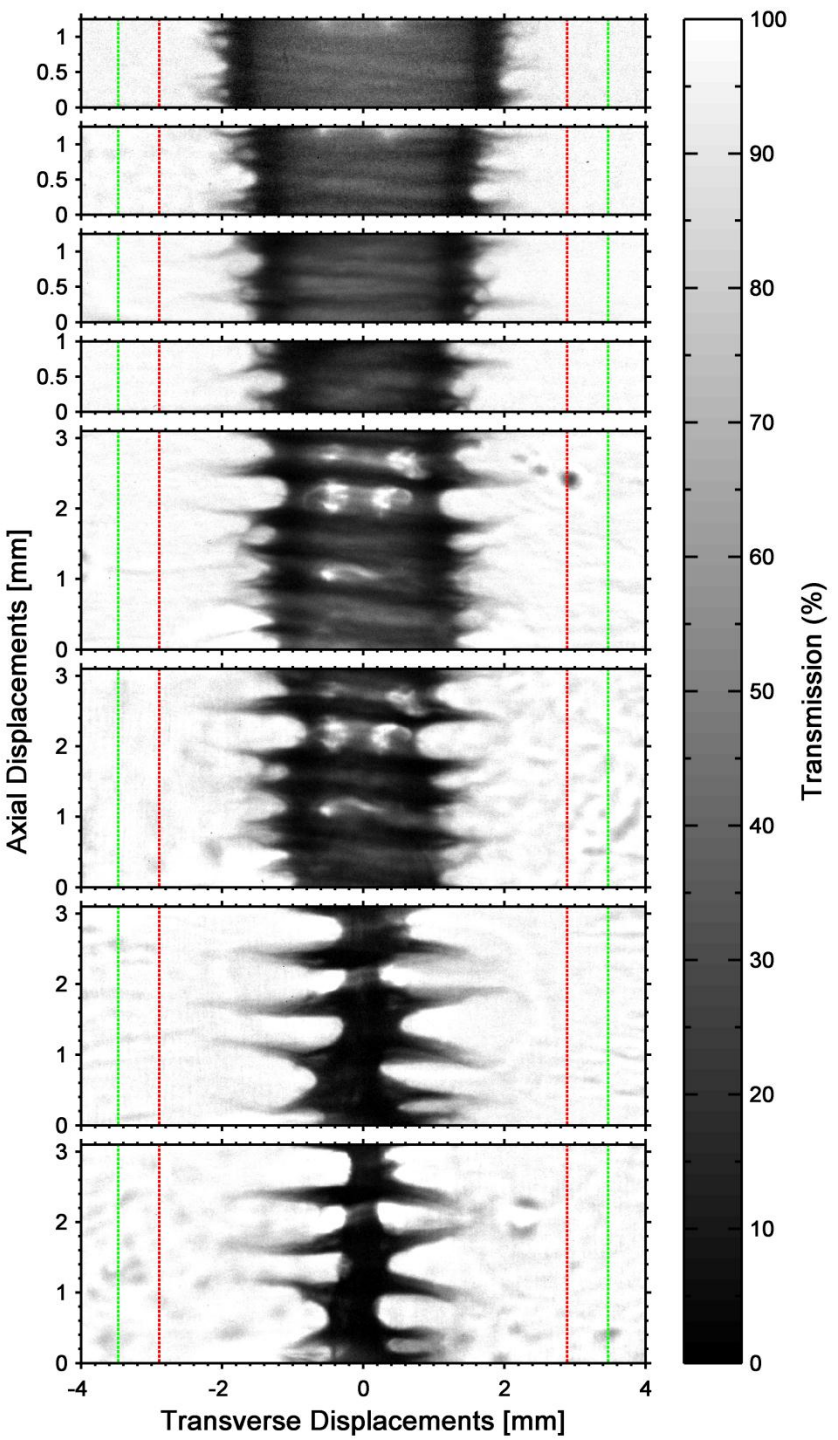




GORGON 3D resistive MHD code used to study the development of implosion instabilities

<u>GORGON – 3D Resistive MHD</u>

Fixed square grid finite volume hydrodynamics

Single fluid – separate electron and ion temperatures

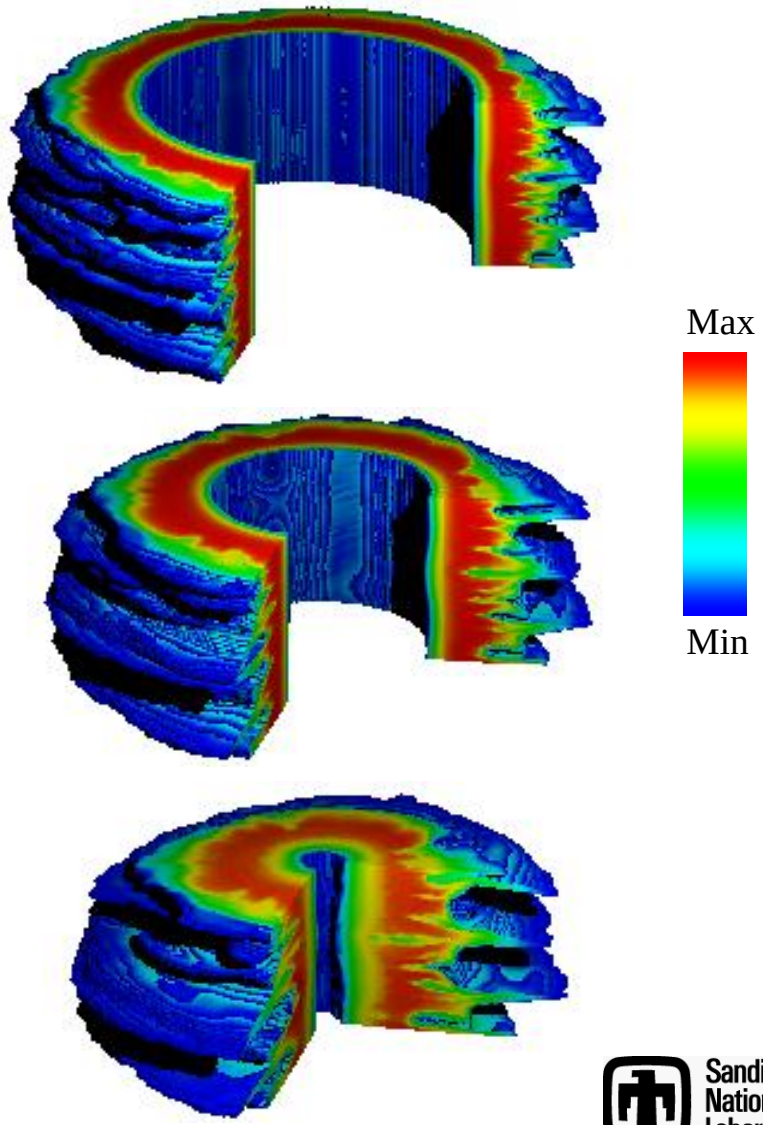
Explicit electro-magnetic field solution (wave equation in vacuum / diffusion equation in plasma)

Van Leer Advection

Driven from measured generator current

Density used to construct synthetic radiographs for direct comparison with experimental measurements

Log Density



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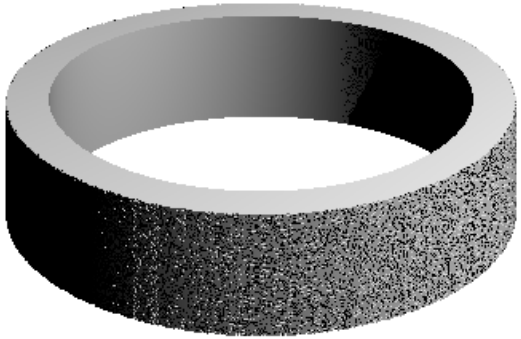
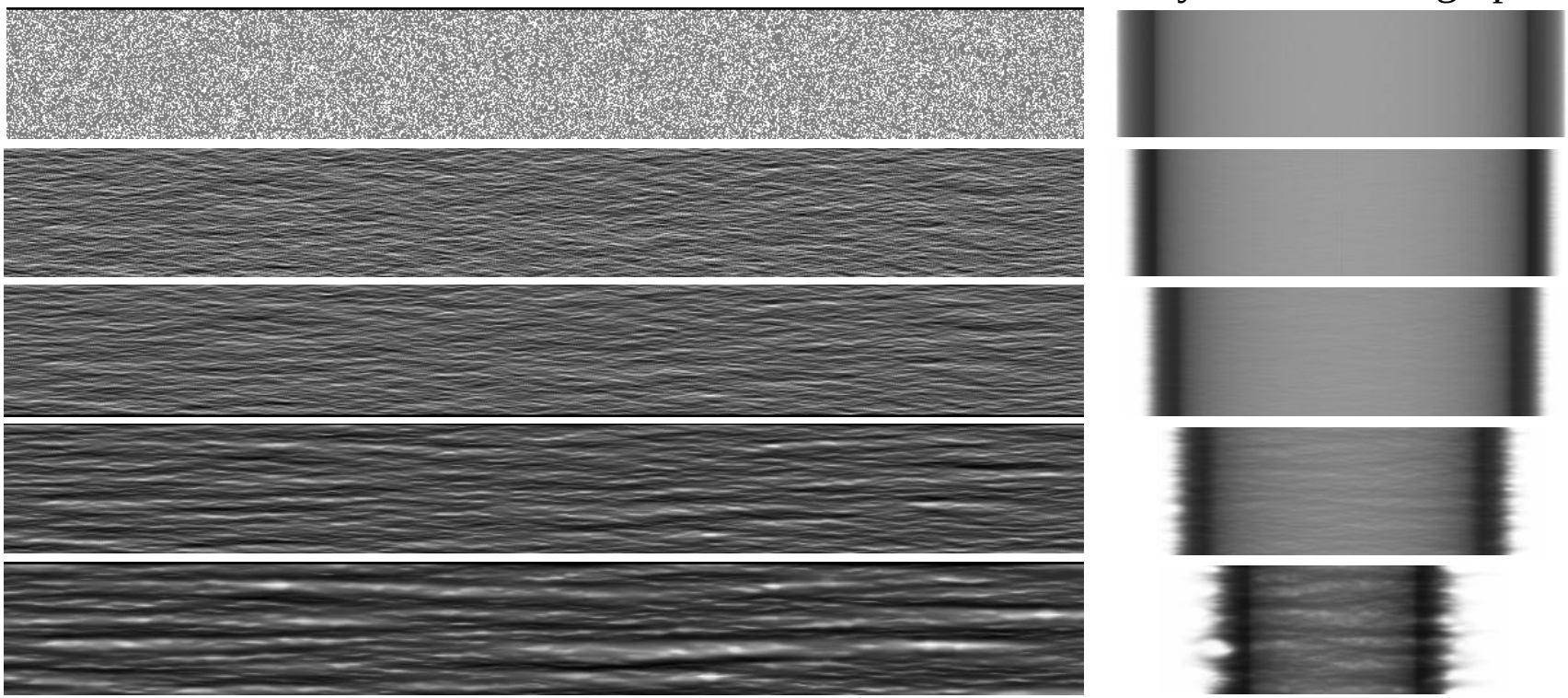
Calculations are initialized with a randomized 20 micron surface roughness

Liner radiograph unwrapped to study growth of surface structures



This initialization is not intended to study how different surface structures develop, and does not attempt to reproduce initial liner surface

Synthetic Radiographs



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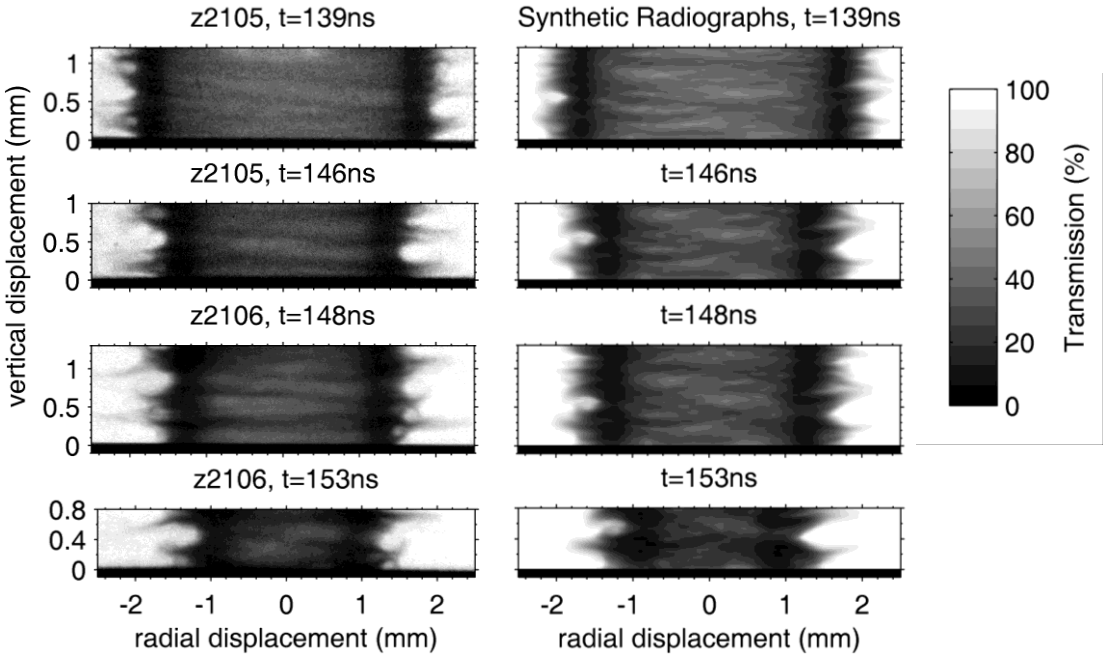
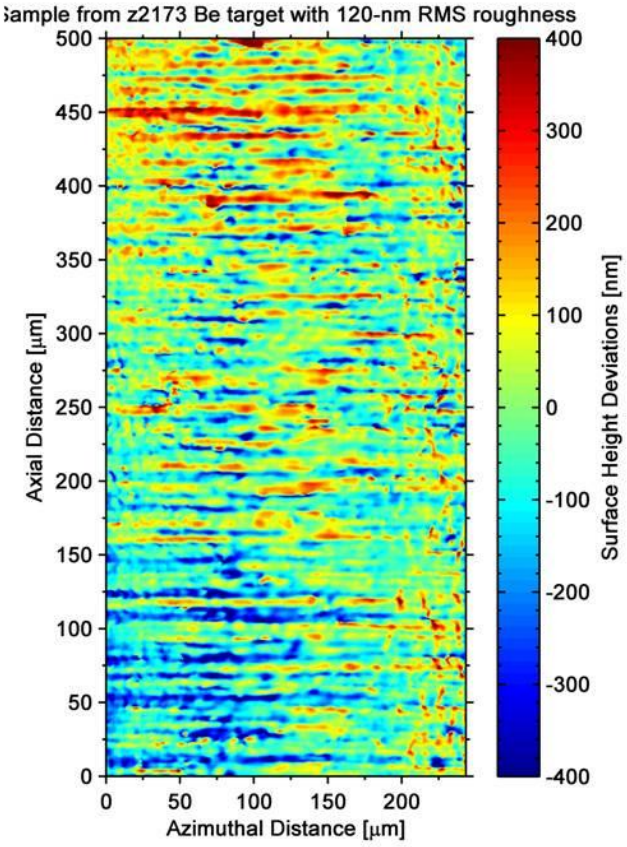
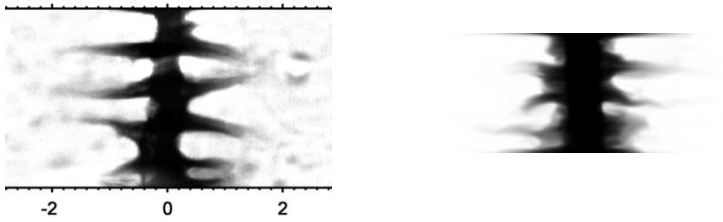
Reasonable early time agreement with measured radiographs, but late time discrepancies



Measured surface roughness is not random, but has some azimuthal correlation



Level of disruption different at late times



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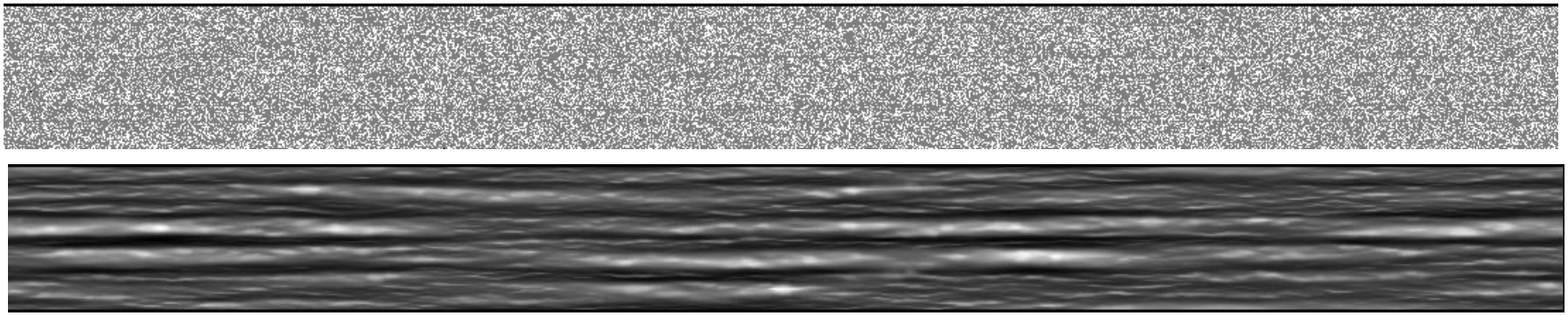
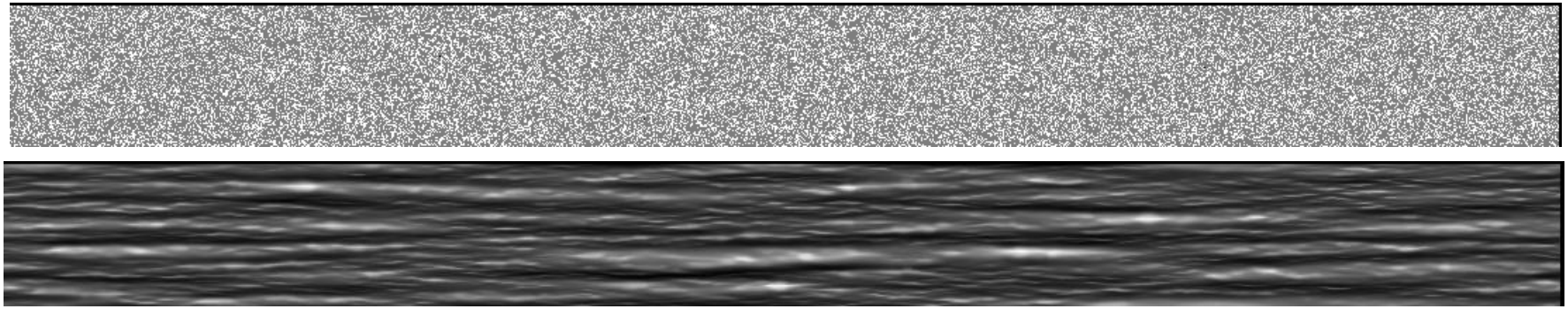
A small degree of azimuthal correlation is able to persist late in time

20 % random number generator bias correlation at 6 random heights

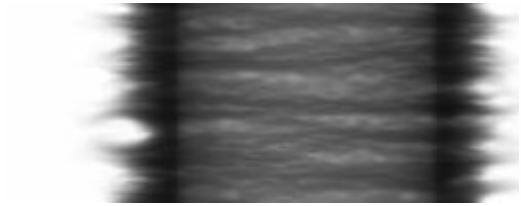


3110ns

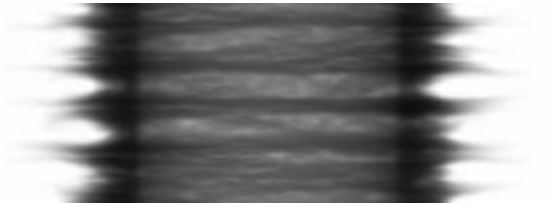
No Correlation



No correlation

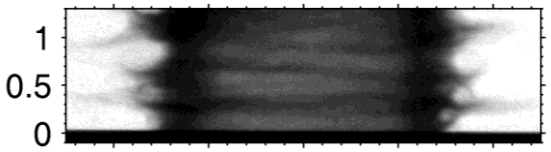


Correlation



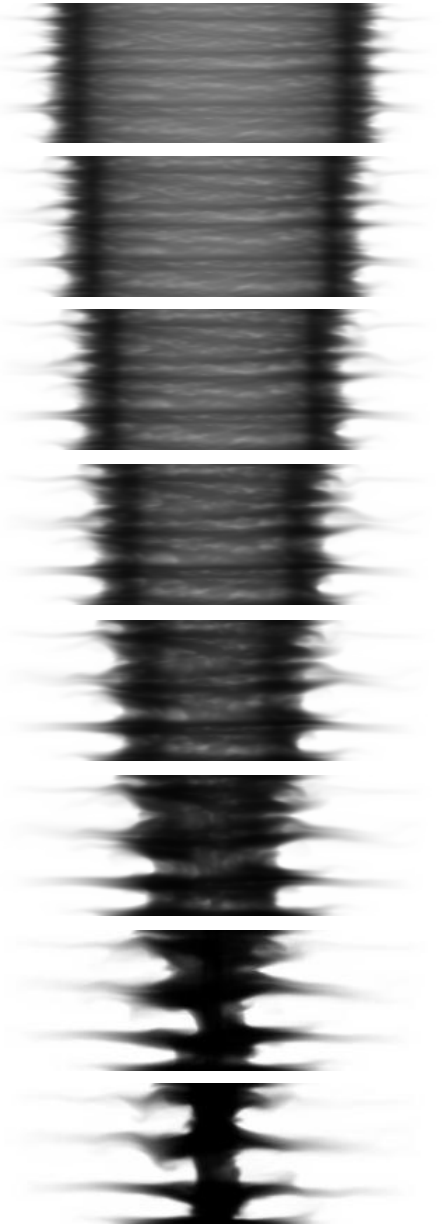
Experiment

z2106, t=148ns

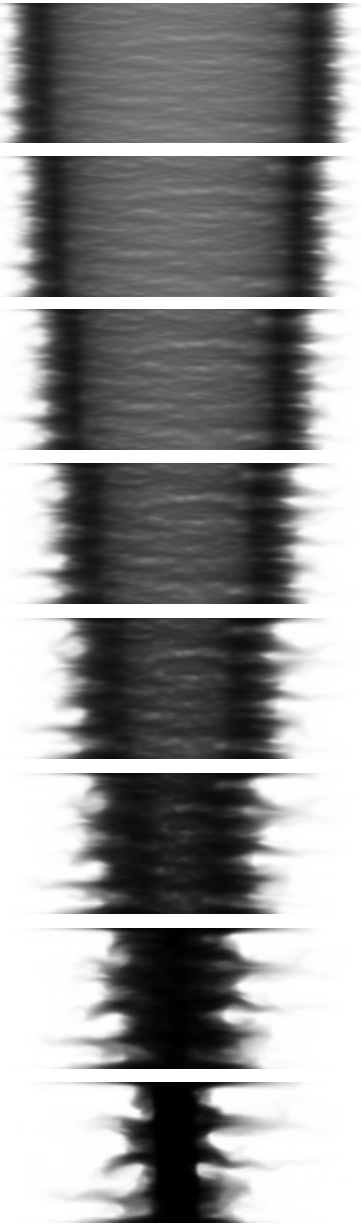


Effect of correlation more evident later in time

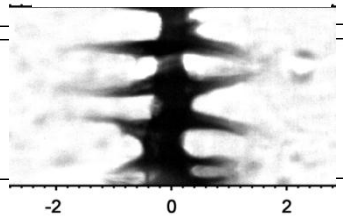
Azimuthal Correlate pert.



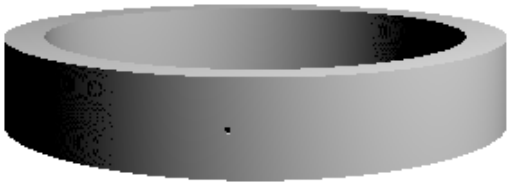
random pert.



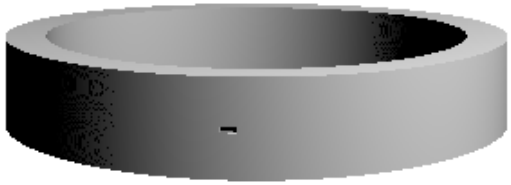
Experiment



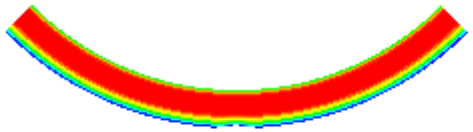
The degree of azimuthal correlation of an instability affects how much it can penetrate and disrupt an imploding shell

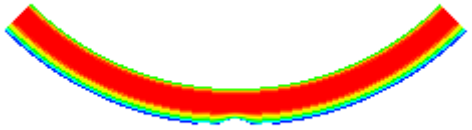


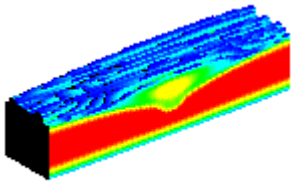
60 micron long

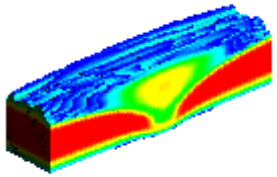


180 micron long









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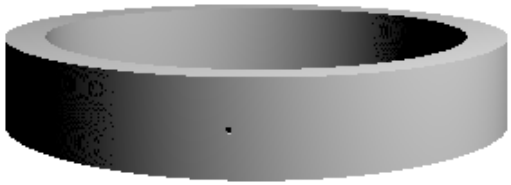

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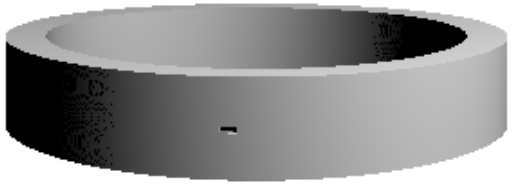

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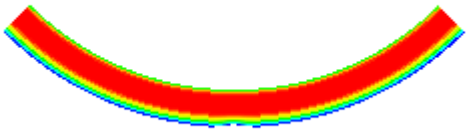

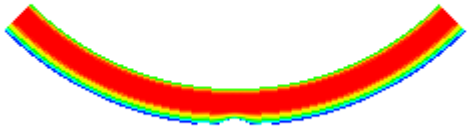

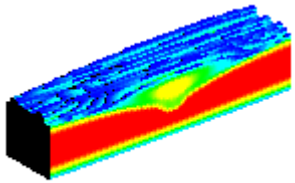

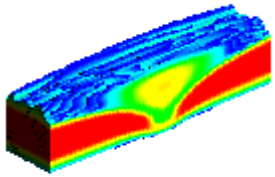

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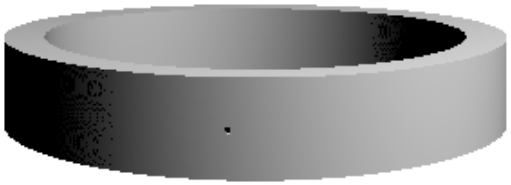

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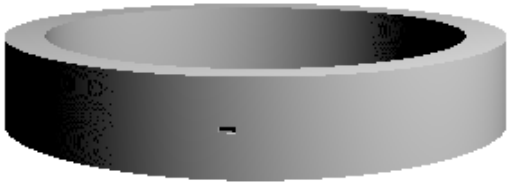

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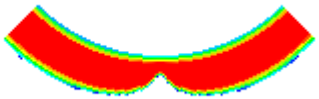

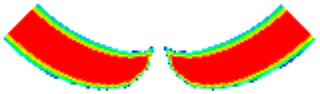

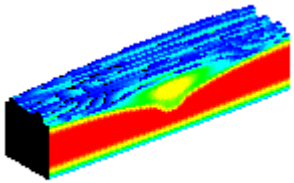

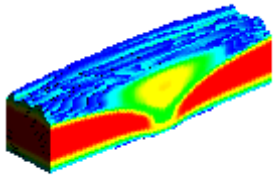

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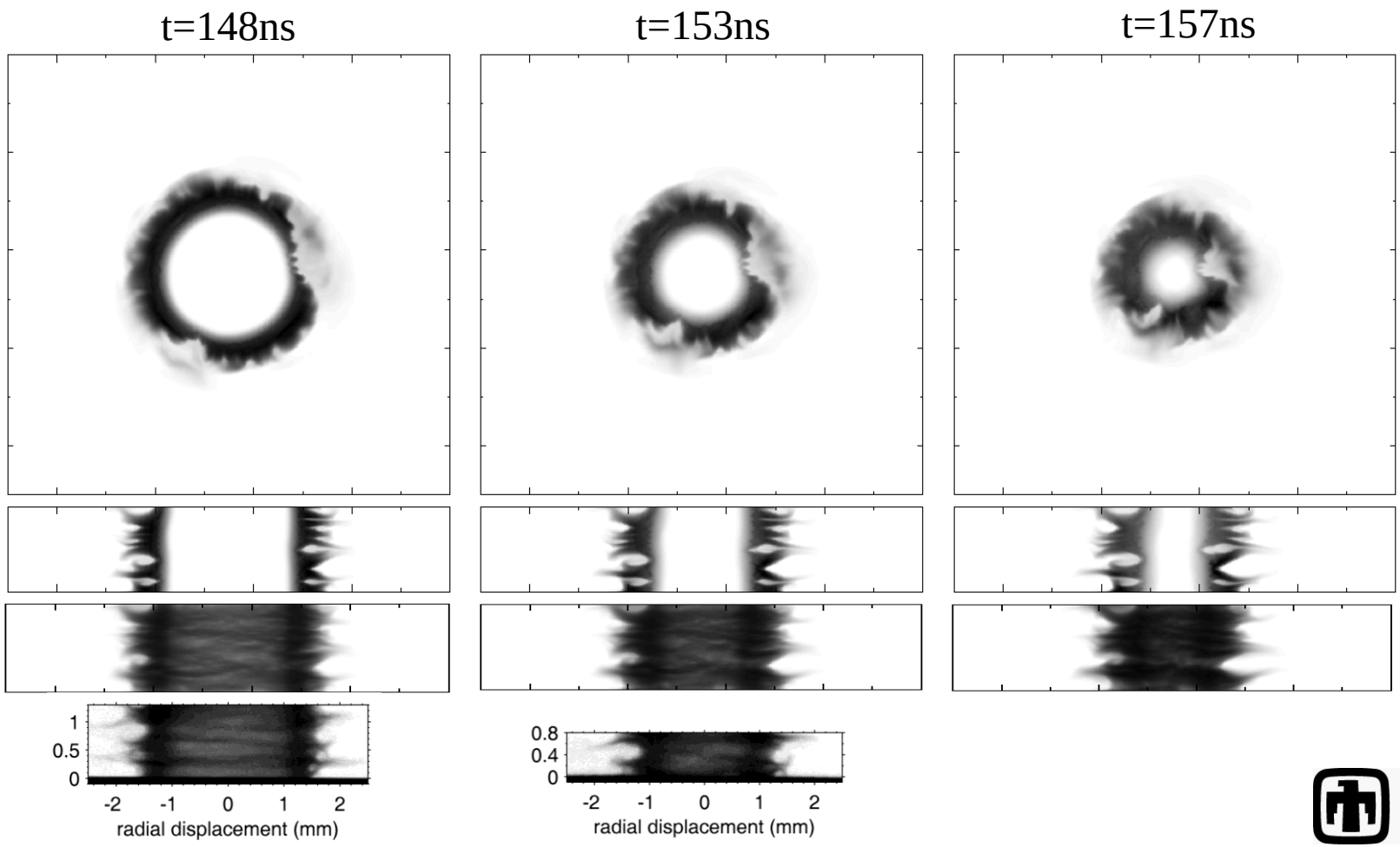
Linear density slices. Range 0 - ~6g/cc



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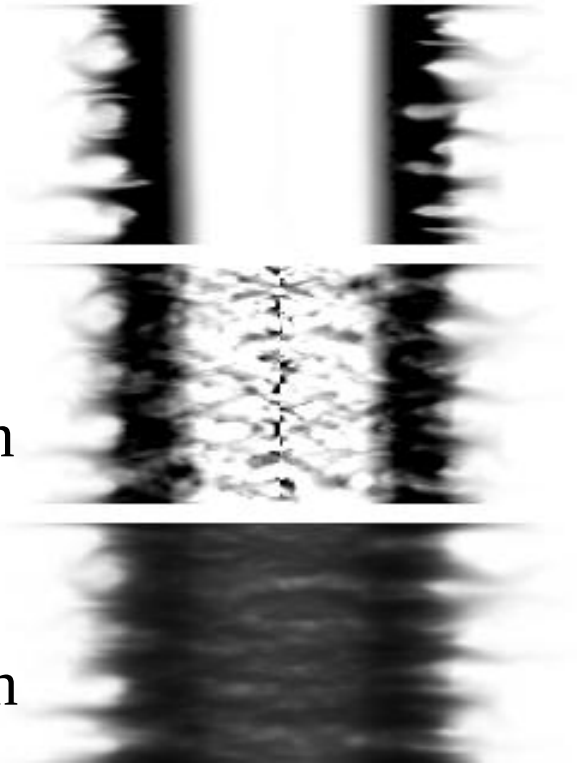
Assessing integrity of inside surface is complicated from side on radiography (R. McBride)

Density Slice

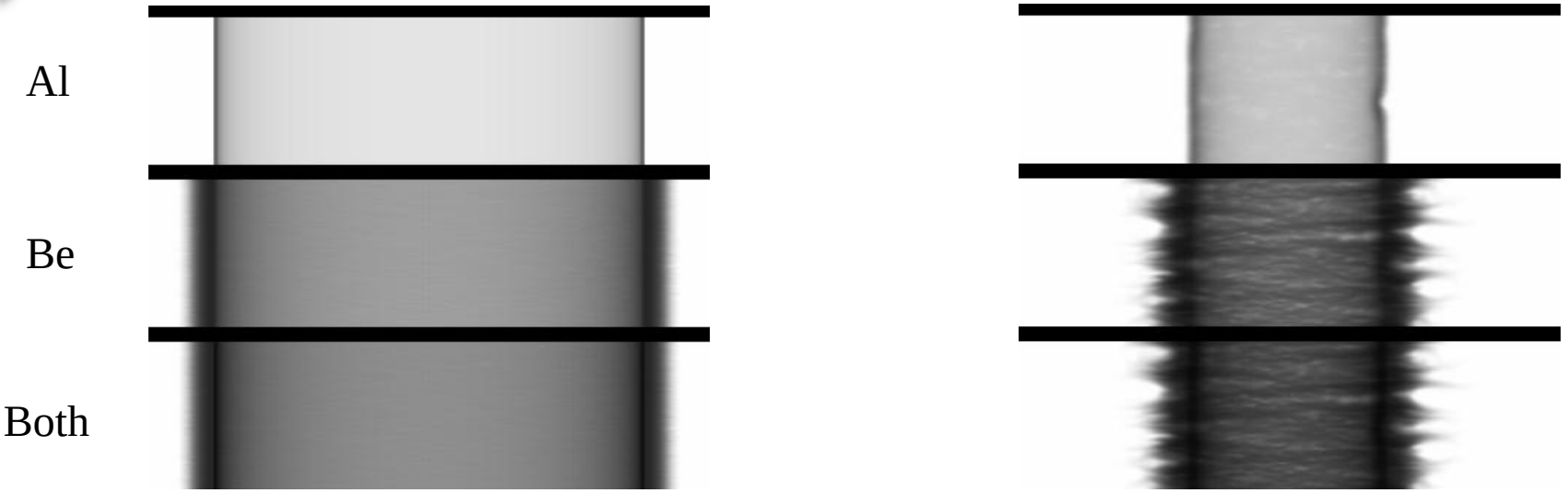
Abel Inversion

Synthetic Radiograph

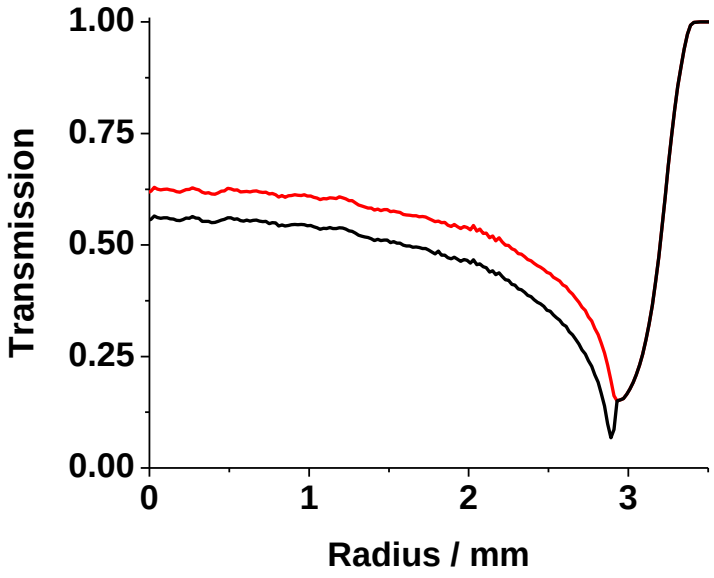


Inner surface can be better highlighted by coating inner surface (D. Ryutov)

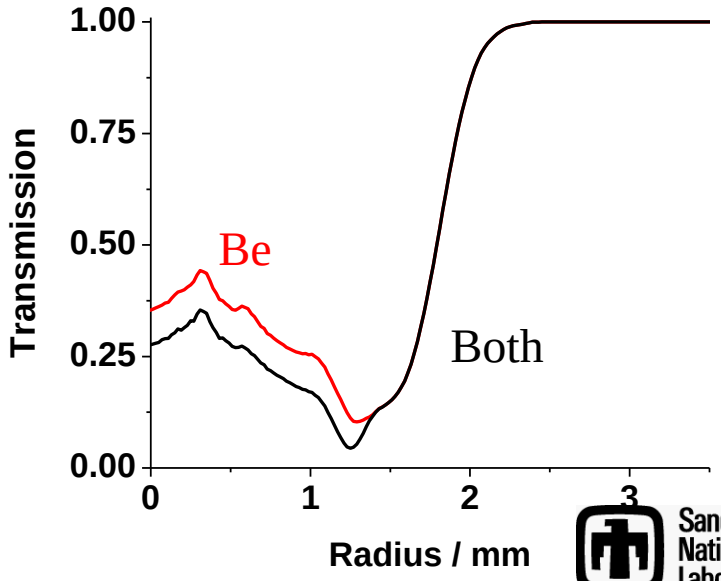
Effective 2 micron Al inner coating with Standard random cell by cell initial



3050ns



3110ns



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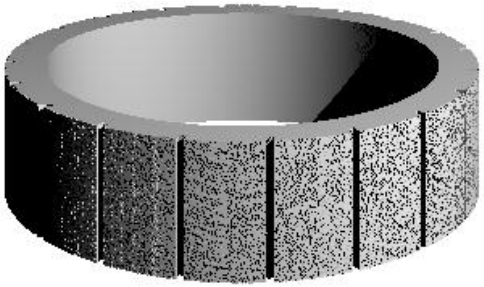
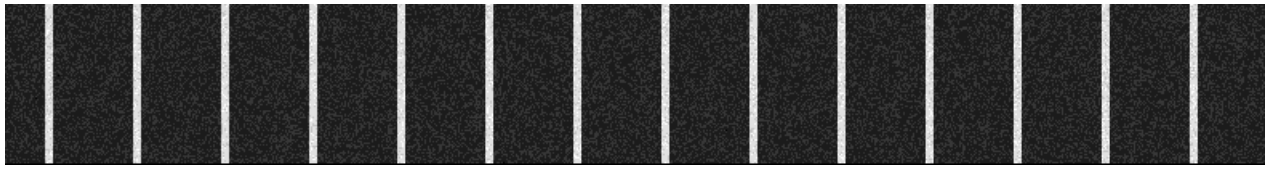
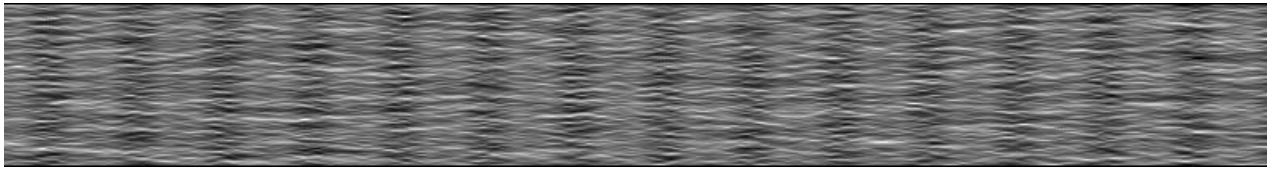
Short Wavelength Vertical features do not grow.



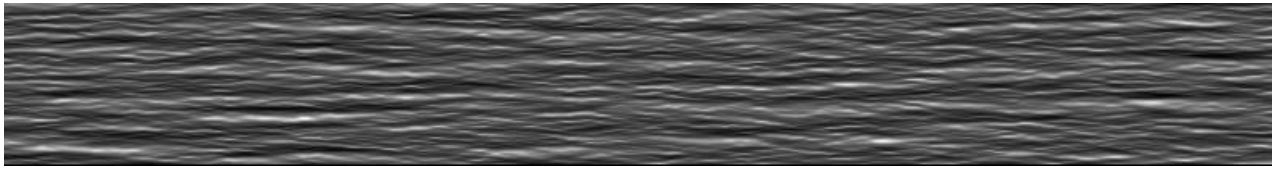
Initial



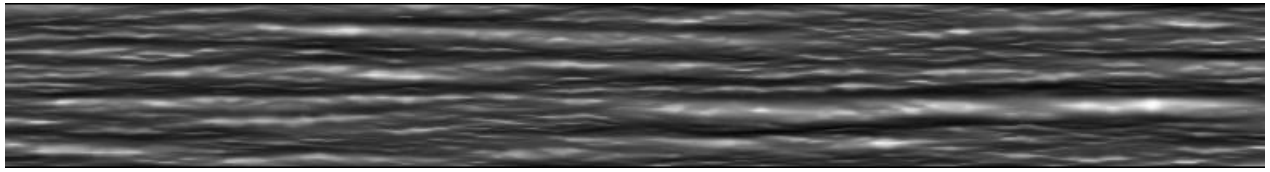
3070

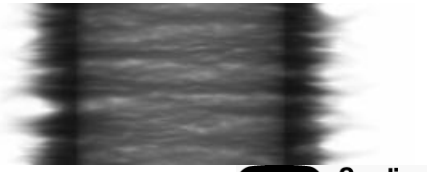


3090



3110





Initial 80 micron deep groove

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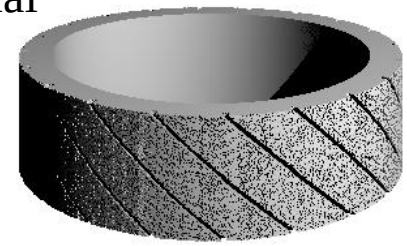
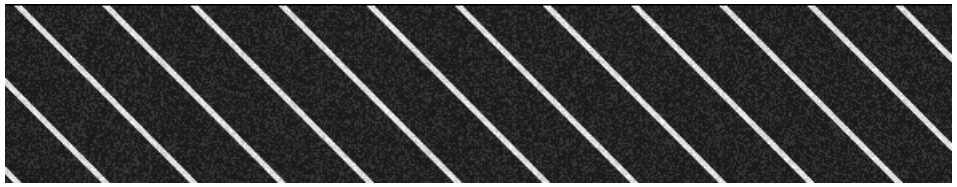
Reorientation the perturbation away from azimuthal prevents it from growing

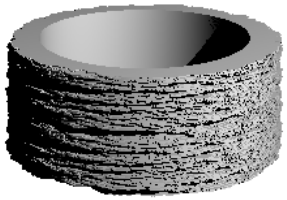
Periodic boundary conditions in Z to study helical perturbation growth

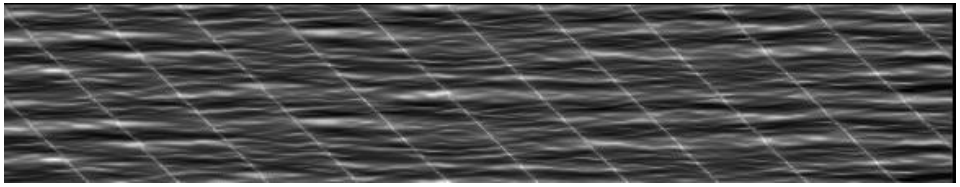
Initial



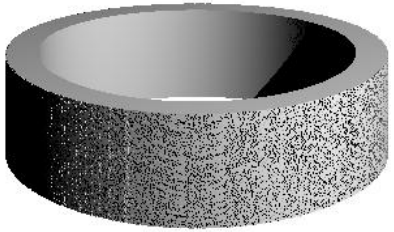


3095ns

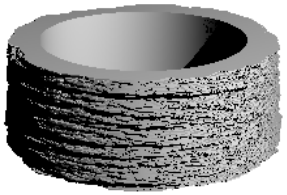


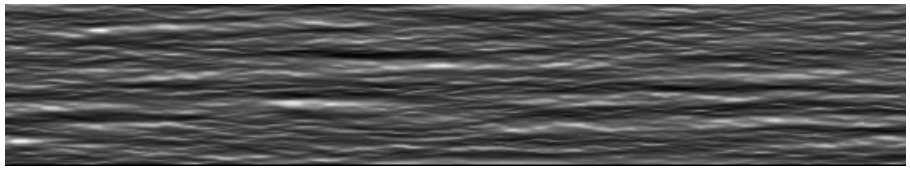


Initial

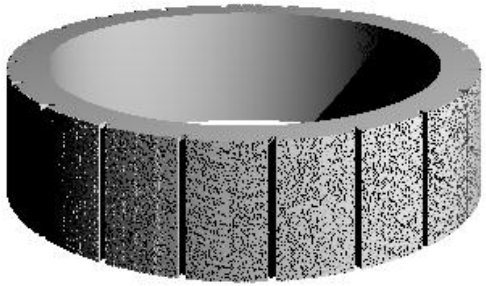


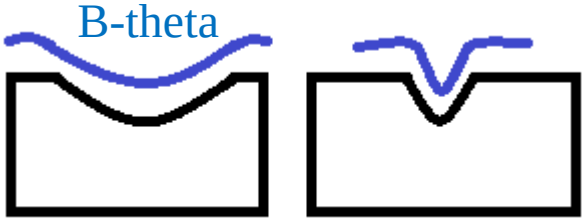
3095ns





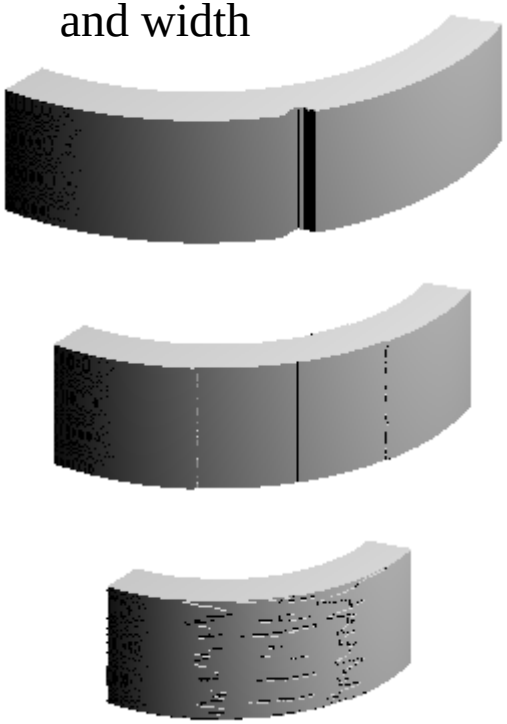
Vertically orientated perturbations do not persist as the field line tension does not allow them to grow and penetrate



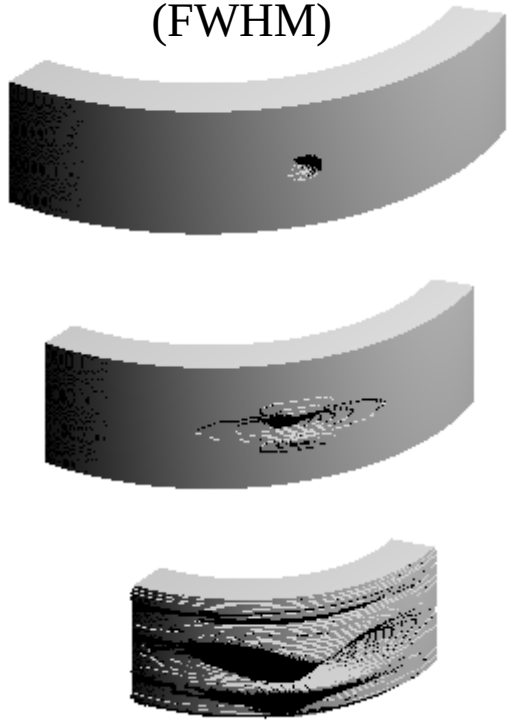


Field line tension will not allow us to simply drill a hole through the liner

Groove of same depth and width



~100 micron hole (FWHM)



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Presence of a large initial Bz field does not significantly reduce instability growth, but can change their angle

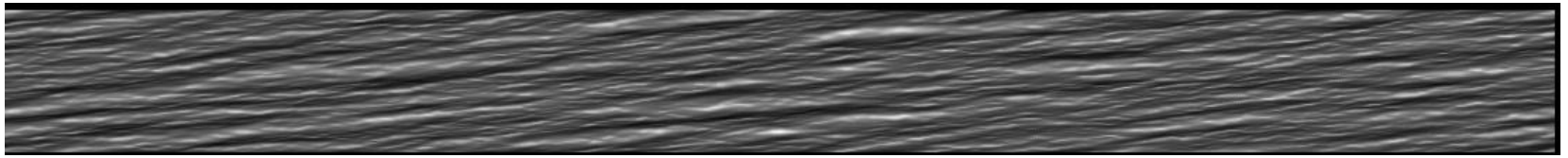
Initial Bz field can re-orintate instabilities on outer surface, but does not seem to significantly inhibit growth

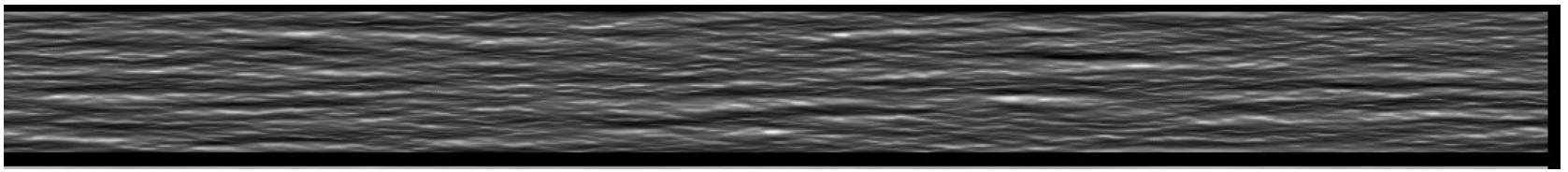
No initial Bz field

100T initial Bz field

3095ns

100T initial Bz field





No initial Bz field

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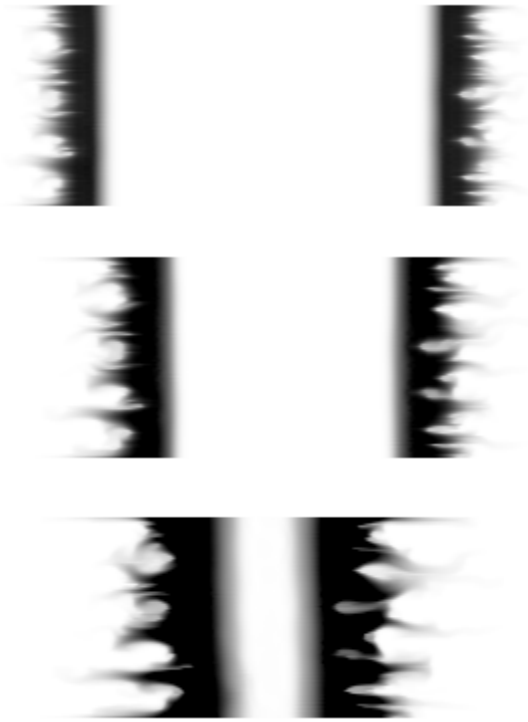
3 different resolutions, essentially run with increasing smoothness does not significantly alter the level of late time disruption

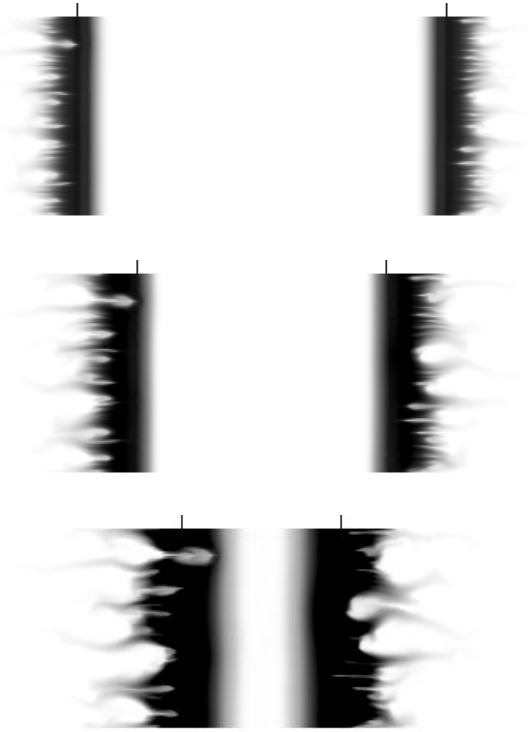
Slices

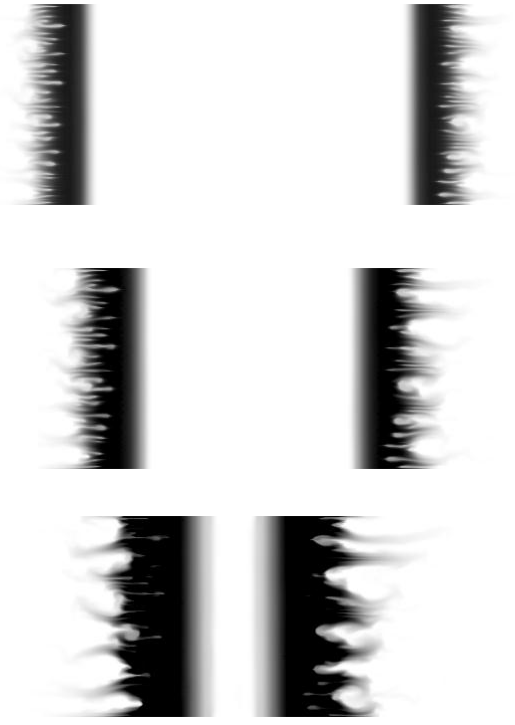
20 micron

15 micron

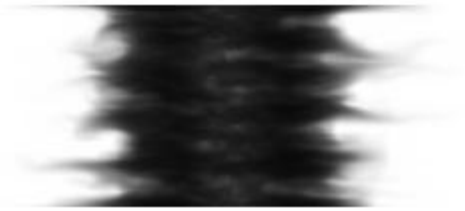
10 micron

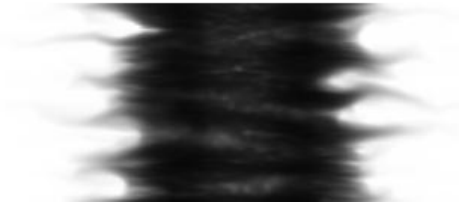


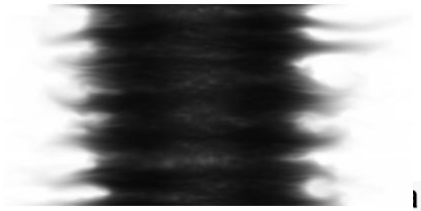




Radiograph







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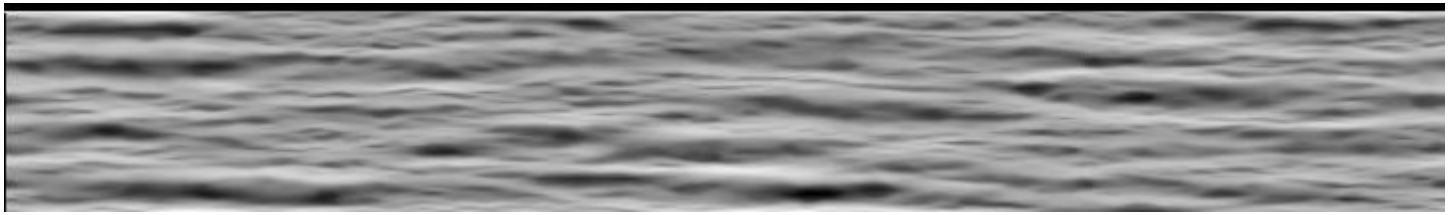
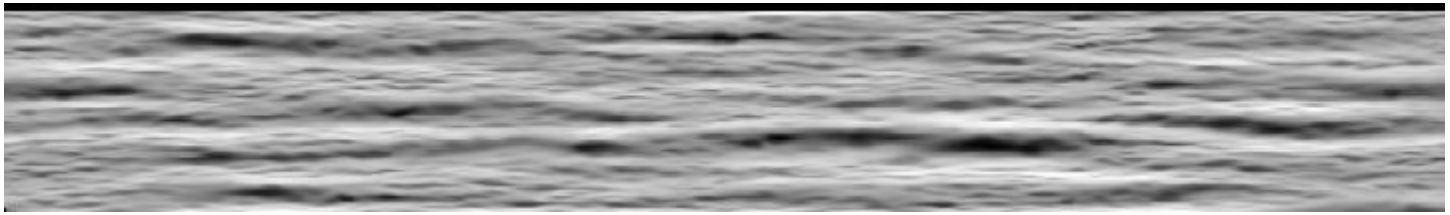
Unwrap surface to study extent to which instabilities grow at different resolutions

Some finer structures exist at higher resolution, but gross features are comparable

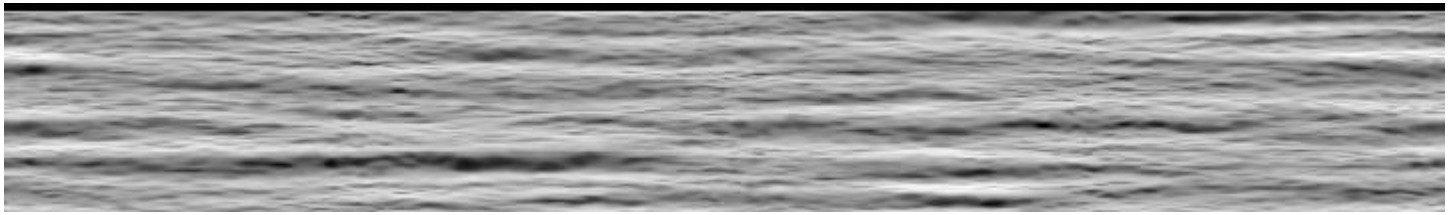
20 micron



15 micron

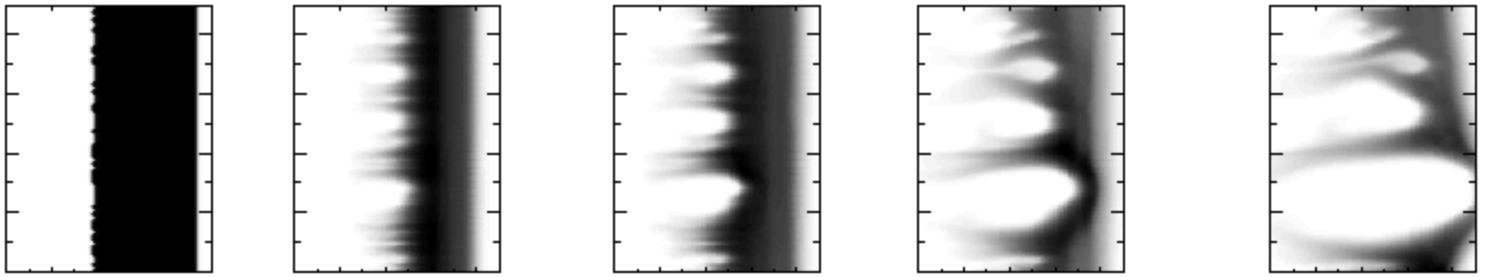


10 micron

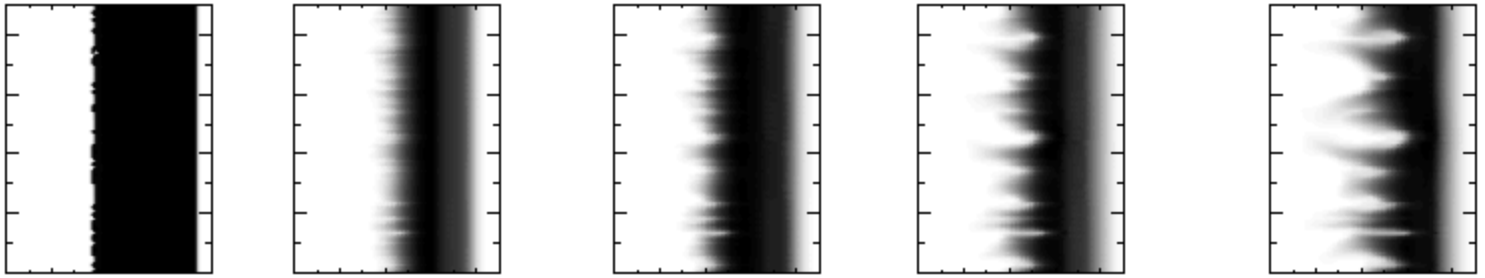


Liner R-T growth rate comparison of 3D full circumference, and 2D initialized with a slice through the 3D initial conditions. MRT perturbation growth far more aggressive in 2D from the same initial conditions. 3D initial perturbation was a random 1 cell perturbation to the outside surface over the entire surface.

2D



3D



These calculations used EXACTLY the same physics packages, hydro routines, cooling rates, thermal diffusion rates etc… They were exactly the same code, just employing a geometry change

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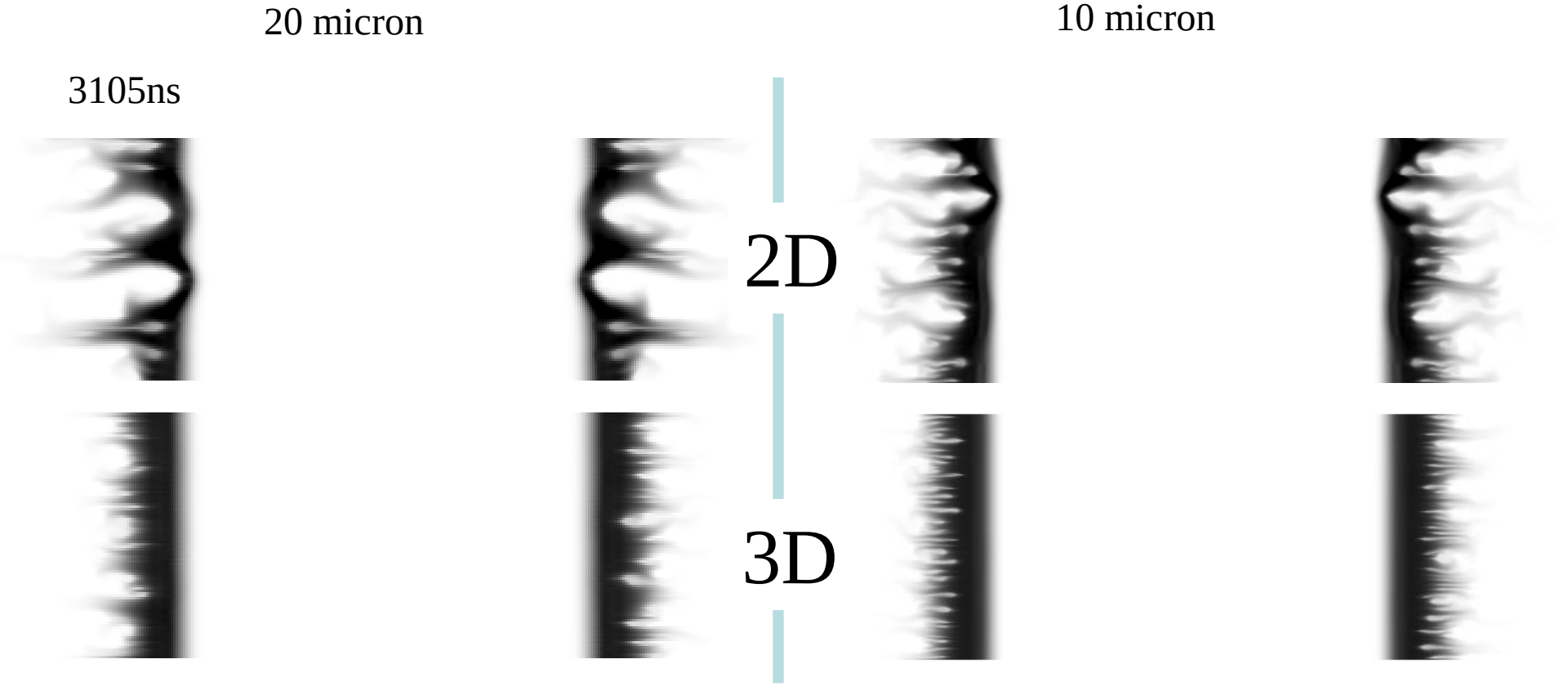
Finer resolution, and smoother initial surface in 2D, does reduce the level of disruption at later times



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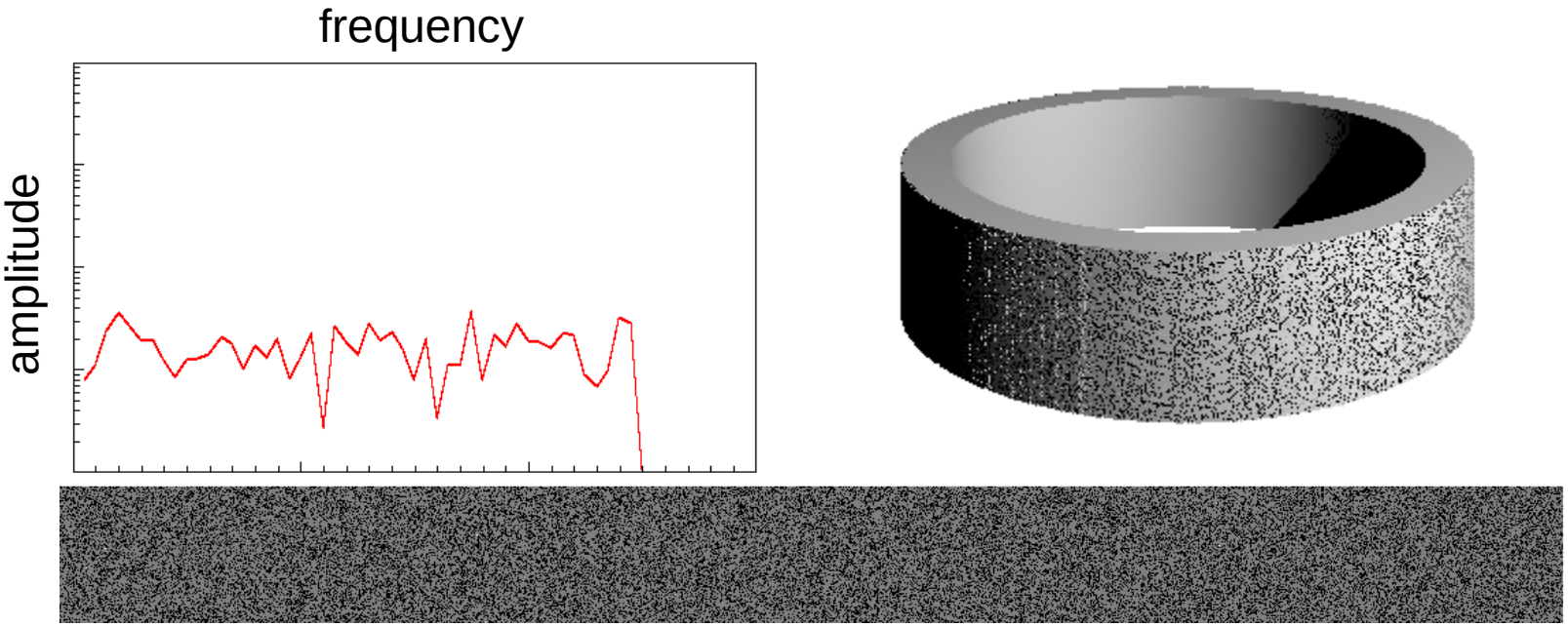
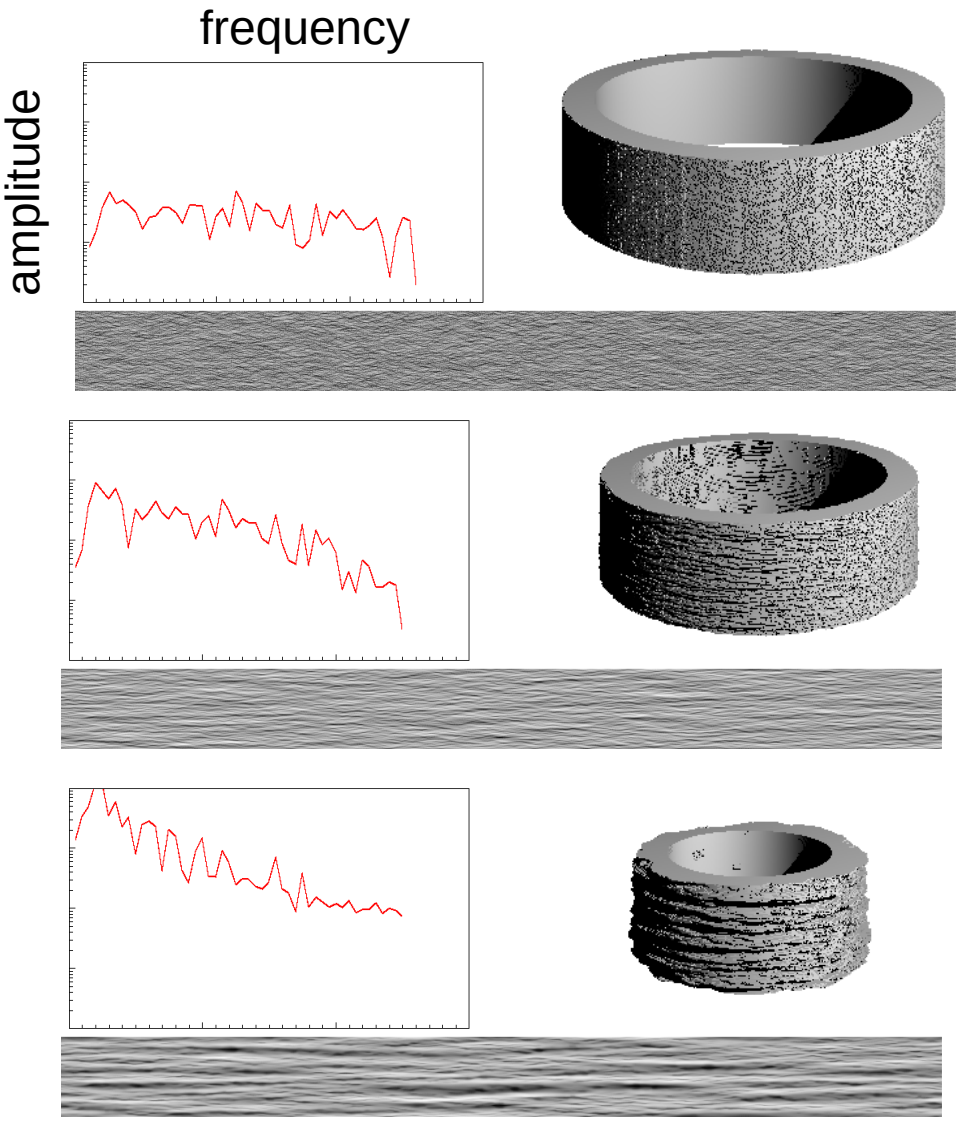
Fourier transform of initial random surface finish



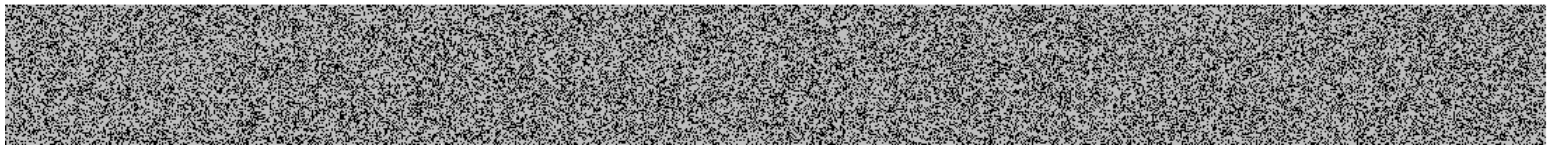
Essentially a white noise spectrum cutting off around the highest frequency supported by the grid (~20 microns)

Lower frequency modes grow faster and ultimately dominate

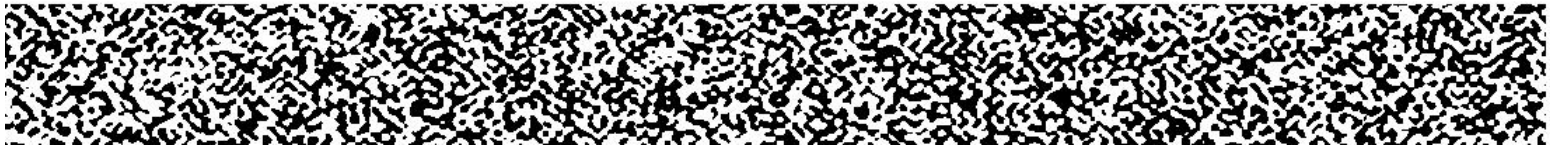


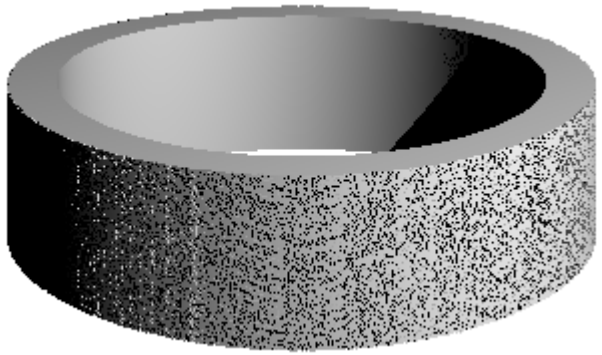
Clip off all the high frequency components and we are left with the low frequency component of the initialization

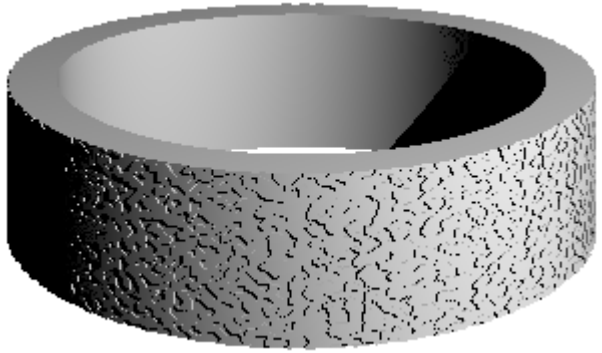
Standard white noise initialization



High frequency component of instabilities removed







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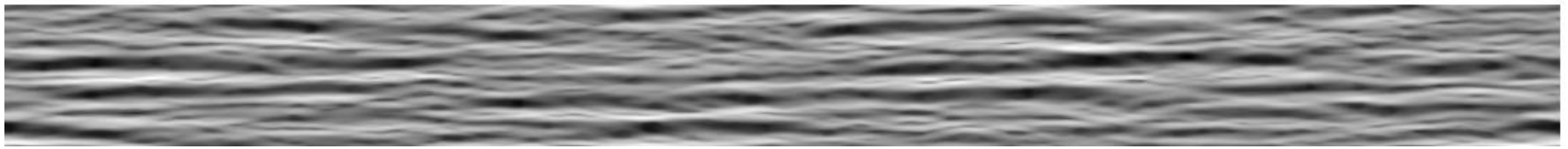
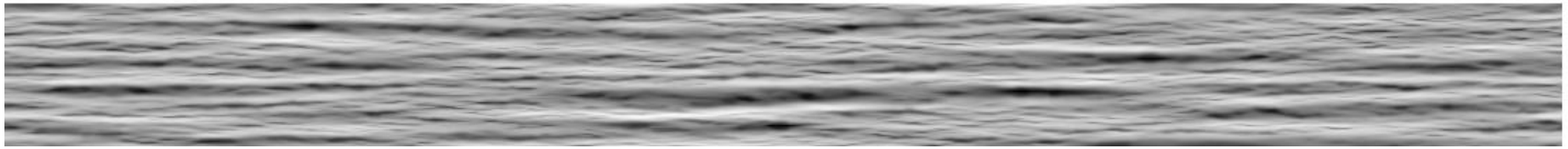
Location of late time disruption does not depend on evolution of short wavelength instabilities

High frequency component of instabilities removed (3095 ns)





Standard white noise initialization (3110ns)

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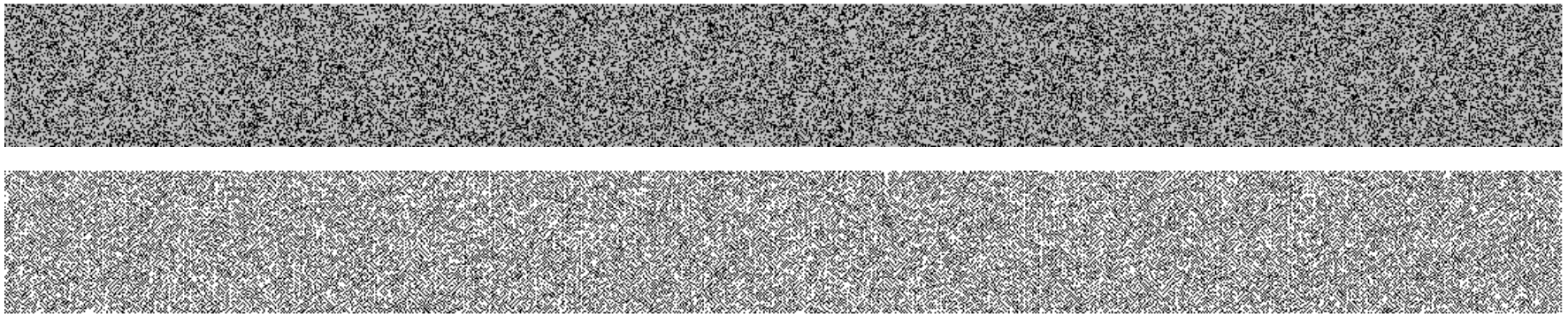
Conclusions

If surface perturbations are seeding late time instabilities then:

- To disrupt an imploding shell a perturbation needs some azimuthal extent.
- Perturbations grow and correlate quite slowly in the azimuth
- Real damage can be done if the initial seed perturbation has any azimuthal correlation
- If an infinitely smooth liner is an unrealistic ideal, then there are surface structures we can pick to leave behind that are better than others
- Local surface smoothness is potentially not as important as macroscopic longer wavelength structures that underpin the shorter wavelength instabilities.

(Backup)
Alternatively, retain the high frequency component and loose the longer wavelength



Standard white noise initialization

Standard white noise initialization

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