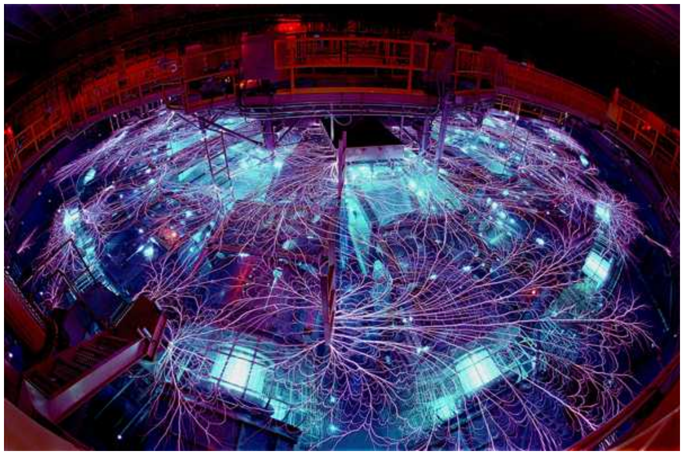
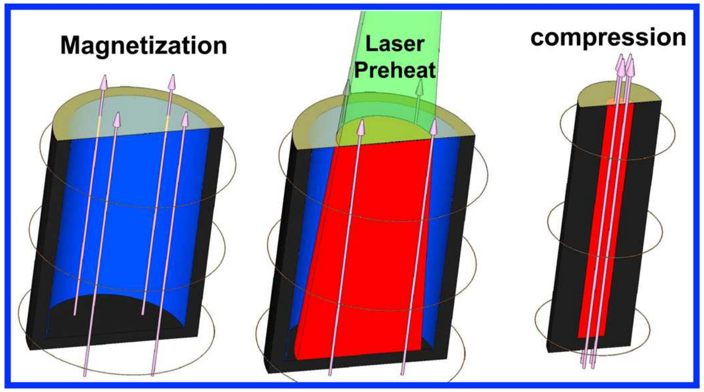
SAND2013-9676C

Exceptional service in the national interest

Sandia National Laboratories



Fundamental Magneto-Rayleigh-Taylor Instability Growth Experiments on Z



Daniel B. Sinars[1], K.J. Peterson[1], R.A. Vesey[1], C. Jennings[1], M.C. Herrmann[1], R.D. McBride[1], M.R. Martin[1], S.A. Slutz[1], E.P. Yu[1], B.E. Blue[2], K. Tomlinson[2]

[1] *Sandia National Laboratories, Albuquerque, NM*

[2] *General Atomics, San Diego, CA*

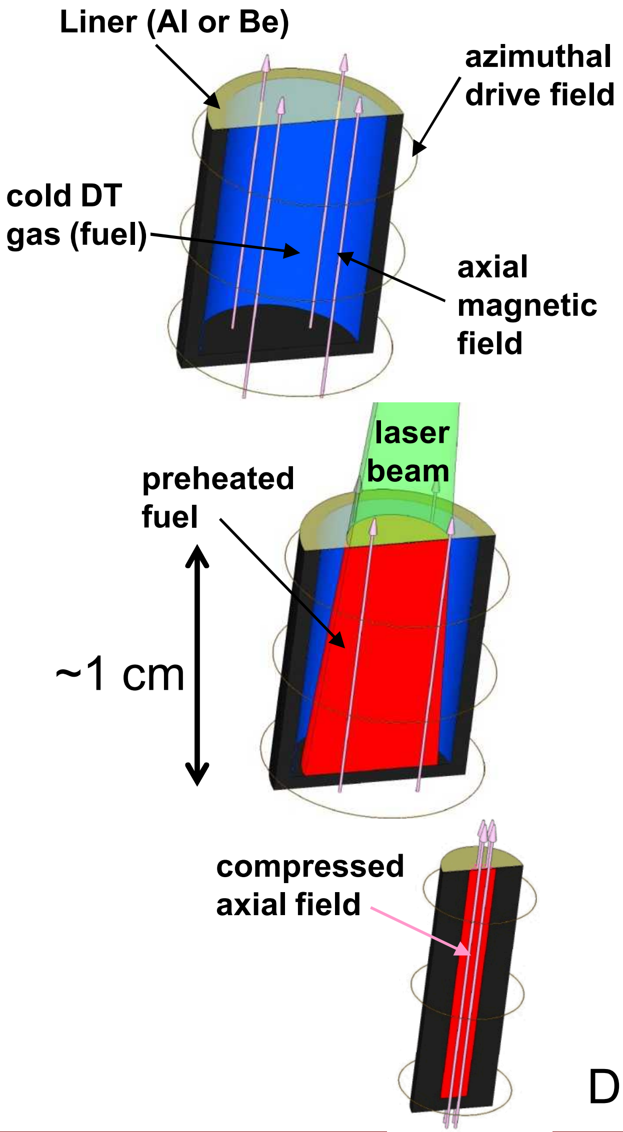
55th Annual APS-DPP Meeting, Denver, CO, Nov. 11-15, 2013

Poster BP8.00120

U.S. DEPARTMENT OF ENERGY NNSA National Nuclear Security Administration

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

We are working toward the evaluation of a new Magnetized Liner Inertial Fusion (MagLIF)* concept

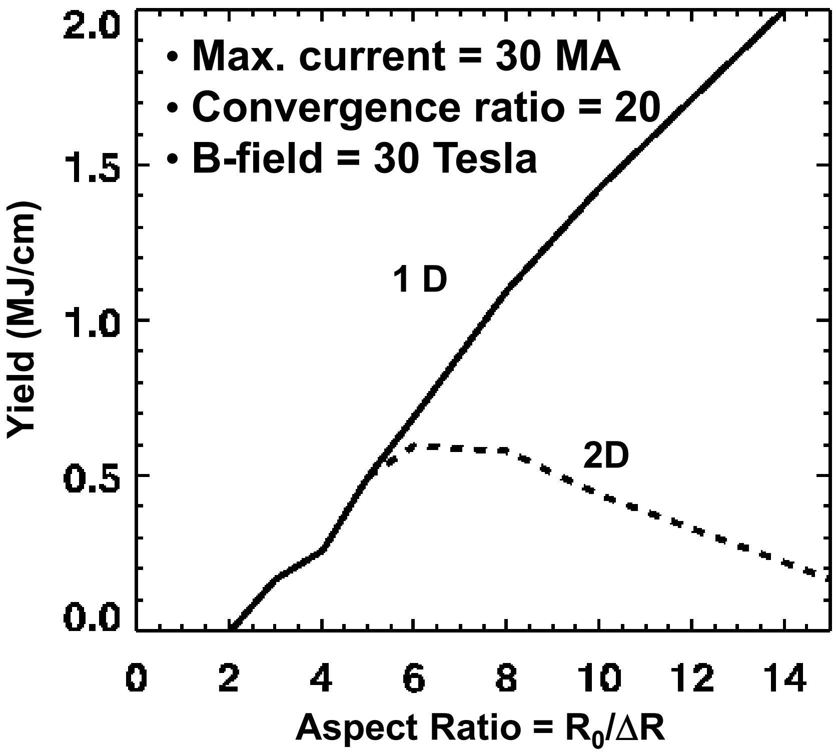


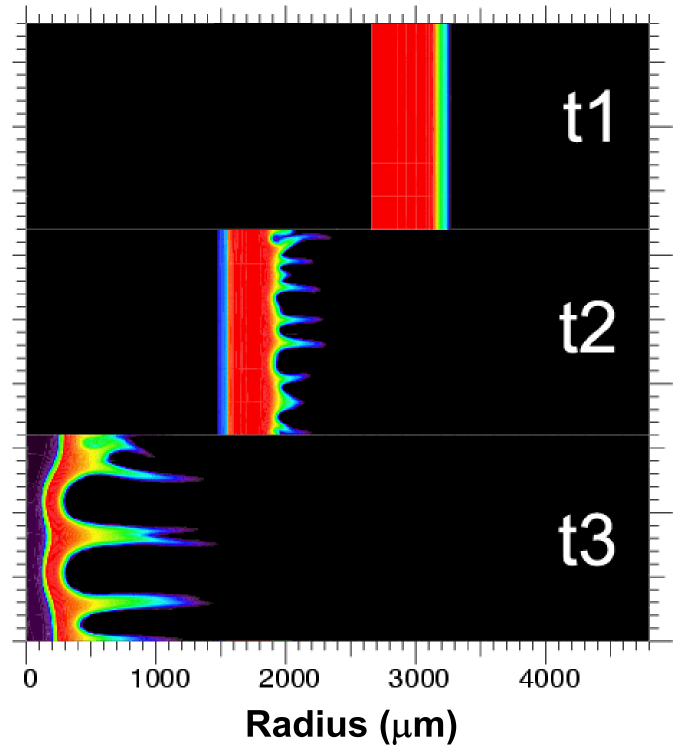
- An initial 30 T axial magnetic field is applied
  - Inhibits thermal conduction losses
  - May help stabilize implosion at late times
- During the ~100 ns implosion, the fuel is heated using the Z-Beamlet laser (about 6 kJ in designs)
  - Preheating to ~300 eV reduces the compression needed to obtain fusion temperatures to 23 on Z
  - Preheating reduces the implosion velocity needed to ~100 km/s, allowing us to use thick liners that are more robust against instabilities
- ~50-250 kJ energy in fuel; 0.2-1.4% of capacitor bank
- Stagnation pressure required is ~5 Gbar
- 100 kJ yield be possible on Z using DT
  Early experiments would use DD fuel

Designs discussed by A. Sefkow CI2.00001 Mon. afternoon!

*S.A. Slutz *et al.*, Phys. Plasmas 17, 056303 (2010). S.A. Slutz and R.A. Vesey, Phys. Rev. Lett. (2012).

Instabilities are a key concern for the MagLIF concept—we are testing the validity of our liner stability calculations





- The Magneto-Rayleigh-Taylor instability degrades the yield as the aspect ratio is increased (due to decreased liner ρr)

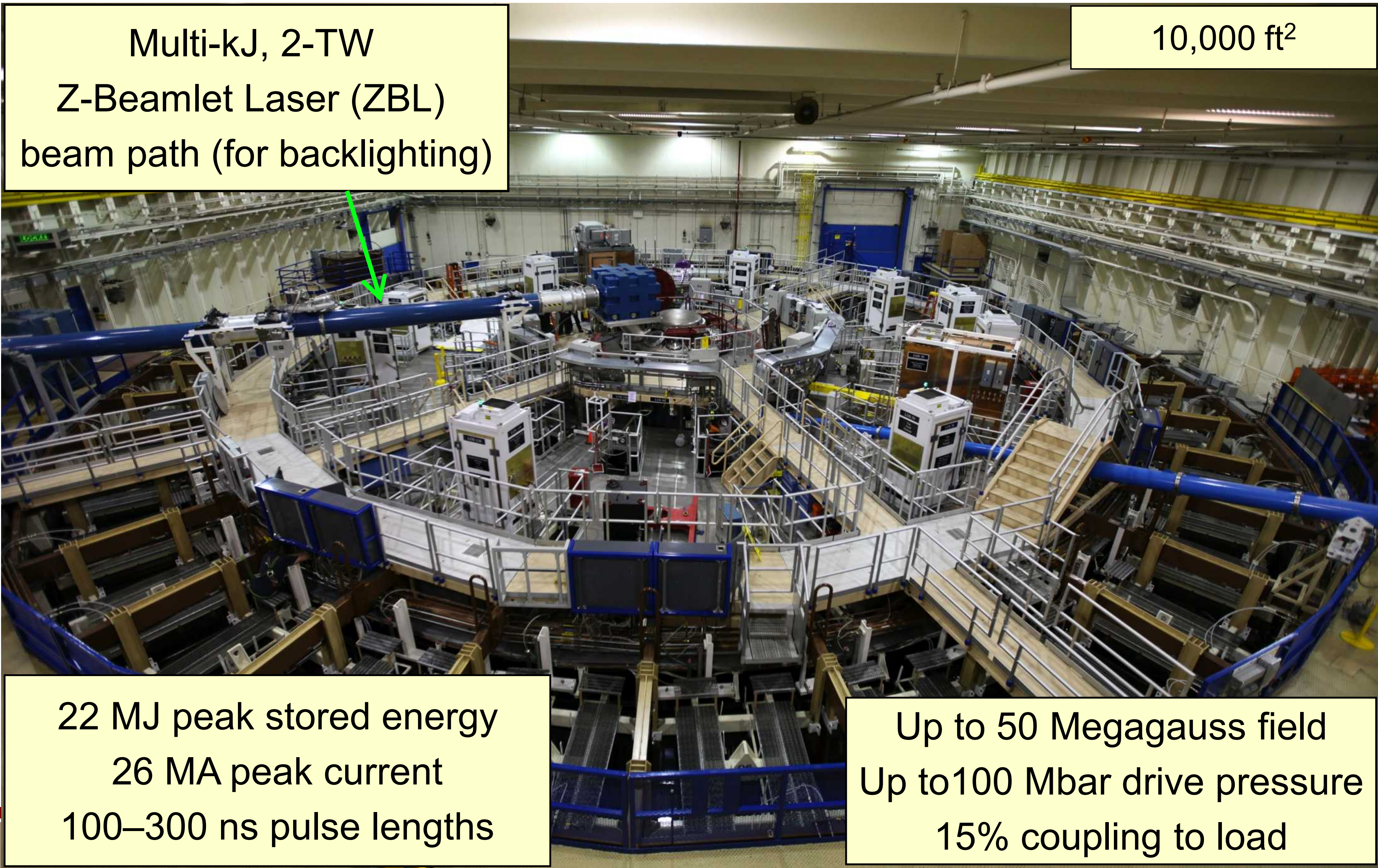
- Simulations of AR=6 Be liner
- Include ~60 nm surface roughness and resolve waves down to ~80 μm
- Simulations suggest wavelengths of 200-400 μm dominate near stagnation

We are trying to address several key liner dynamics questions for magnetically driven implosions through detailed comparisons between modeling & experiments

- Do we have a predictive simulation capability for modeling cylindrical liner implosions?
  - Can we model growth of single-wavelength perturbations?
  - Can we model coupling between multi-mode perturbations?
  - Can we model growth of unseeded perturbations?
  - Can we model fundamentally 3D perturbations (e.g., helical)?
  - How far can we push our models? (e.g., down to what convergence?)
- What is the dominant seed for the instabilities we see?
  - Electro-thermal instability?
  - Surface roughness?
- Today's poster is focused on the growth of acceleration-driven instabilities on the outside liner surface. Sandia will also begin to look at deceleration-driven instabilities on the inner liner surface in 2014

We are using the Z pulsed-power facility to develop MagLIF and conduct fundamental liner dynamics experiments

Sandia National Laboratories



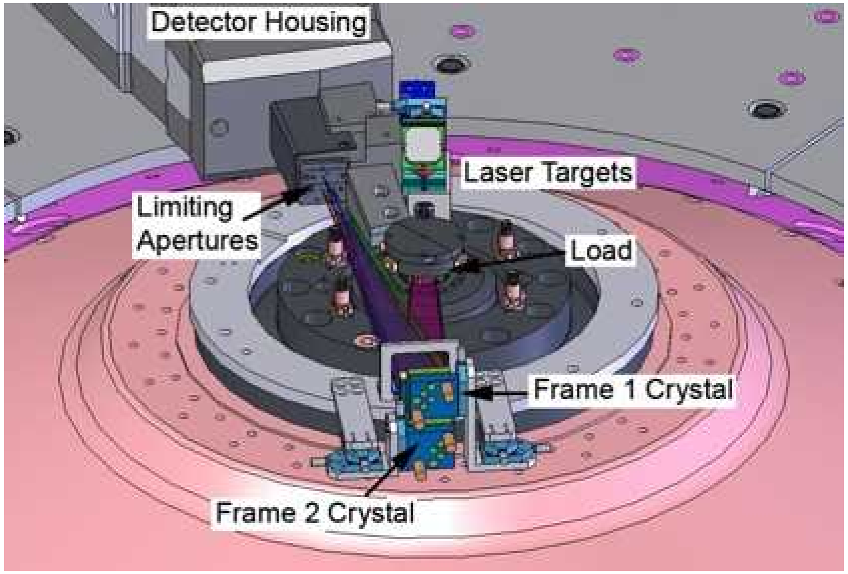
Multi-kJ, 2-TW
Z-Beamlet Laser (ZBL)
beam path (for backlighting)

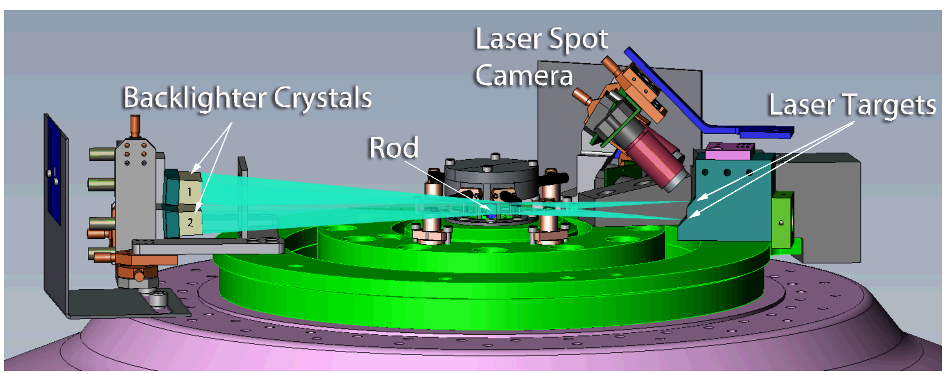
10,000 ft^2

22 MJ peak stored energy
26 MA peak current
100–300 ns pulse lengths

Up to 50 Megagauss field
Up to100 Mbar drive pressure
15% coupling to load

2-frame monochromatic crystal backlighting is being used to image instability growth





Radiograph lines of sight ±3° from horizontal

2-frame keV Crystal Imaging

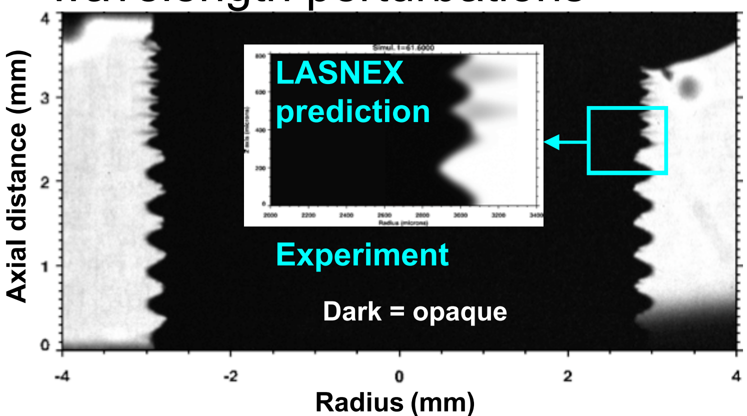
- **Monochromatic (~0.5 eV bandpass)**
- **6.151 keV (Mn)**
- **15 micron resolution**
- **Large Field of View (4 mm x 10 mm)**
- **Debris mitigation**

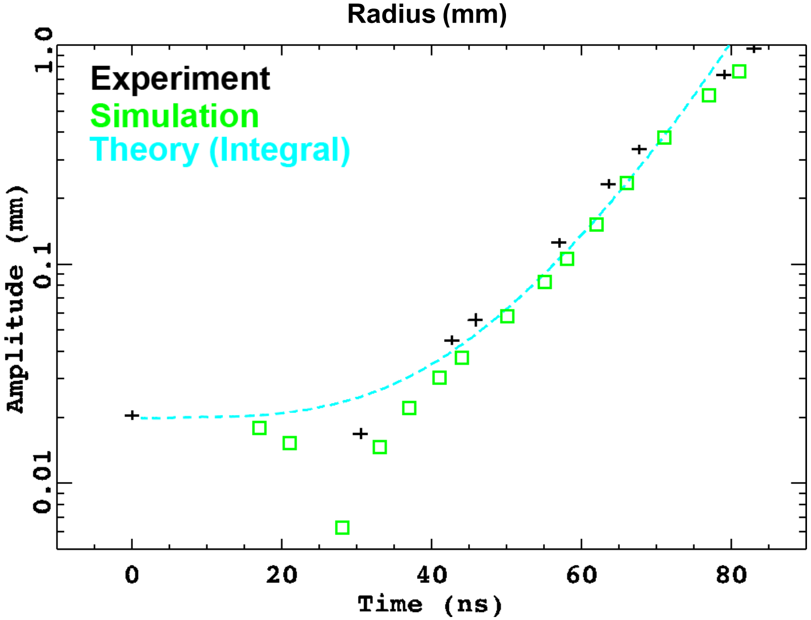
- **Original concept**
  - S. A. Pikuz *et al*., RSI (1997)
- **1.865 keV backlighter at NRL**
  - Y. Aglitskiy *et al*., RSI (1999)
- **Single-frame 1.865 keV and 6.151 keV implemented on Z facility**
  - D.B. Sinars *et al*., RSI (2004)
- **Two-frame 6.151 keV on Z facility**
  - G.R. Bennett *et al*., RSI (2008)

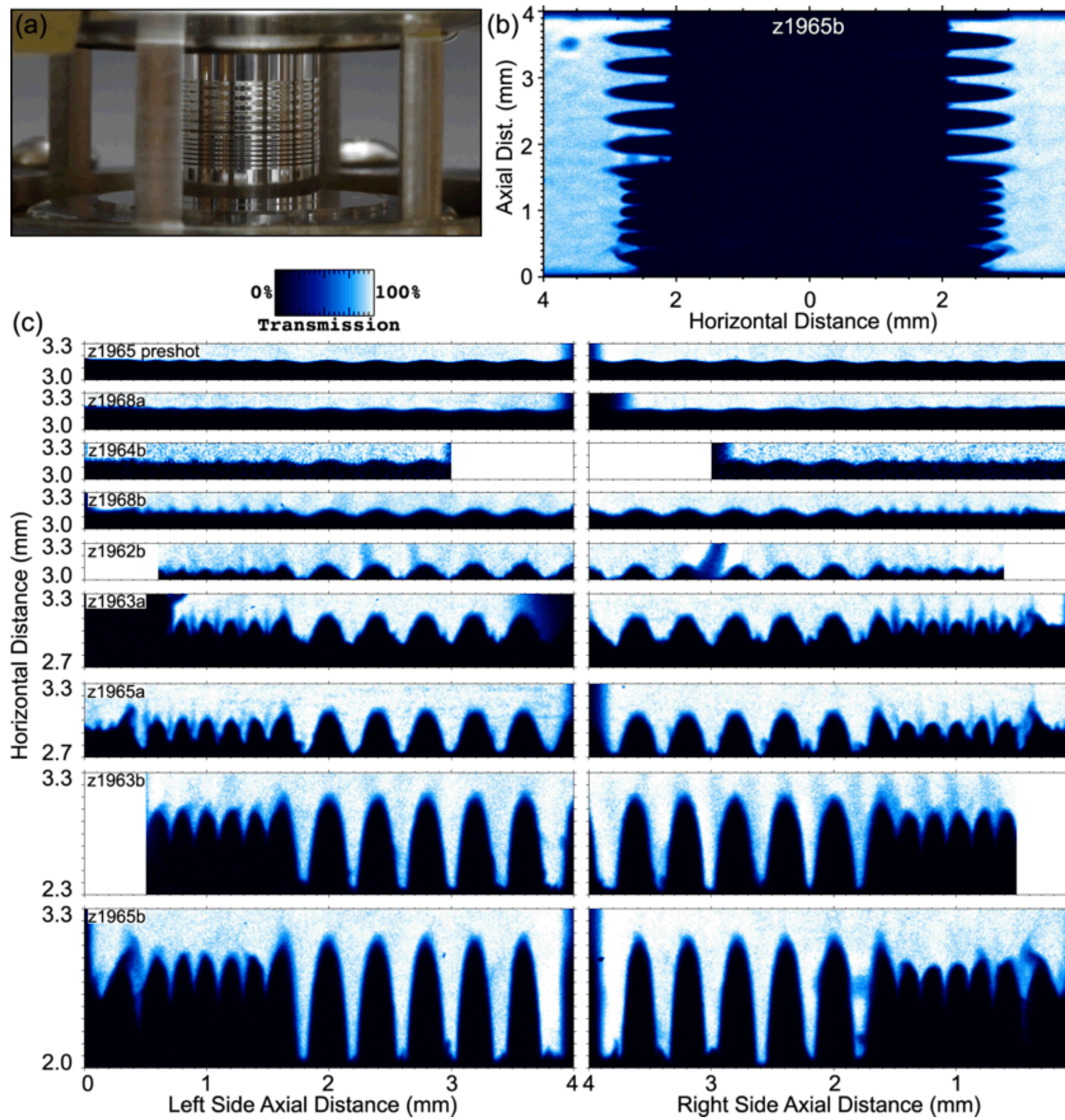
We did controlled experiments as the first critical test of our understanding of the Magneto-Rayleigh Taylor instability

Sandia National Laboratories

Radiographs captured growth of intentionally-seeded 200, 400-μm wavelength perturbations

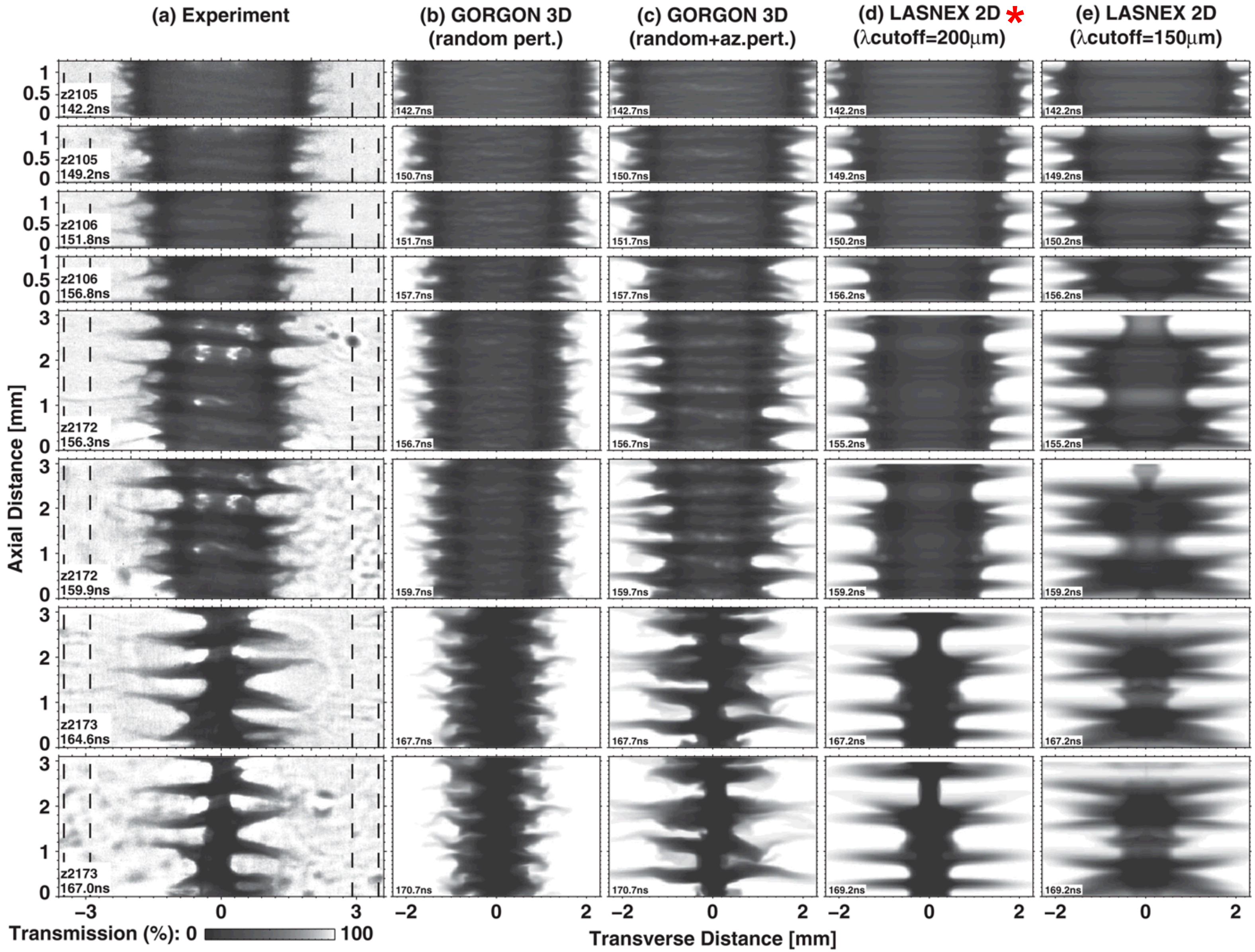






D.B. Sinars *et al.*, Phys. Rev. Lett. (2010); D.B. Sinars *et al.*, Phys. Plasmas (2011).

"Unseeded" Be experiments show surprisingly correlated instability growth at late times that implies a highly-correlated initial seed



R.D. McBride *et al.*, Phys. Rev. Lett. (2012); R.D. McBride *et al.,* Phys. Plasmas 20, 056309 (2013).

Previous simulations* have attempted to quantify how instabilities interact to form additional wavelengths, but experimental validation of such models has been lacking

At t=0 only two modes were seeded (2.5 and 1.67 mm)

k=1/wavelength

As the implosion evolves new modes appear

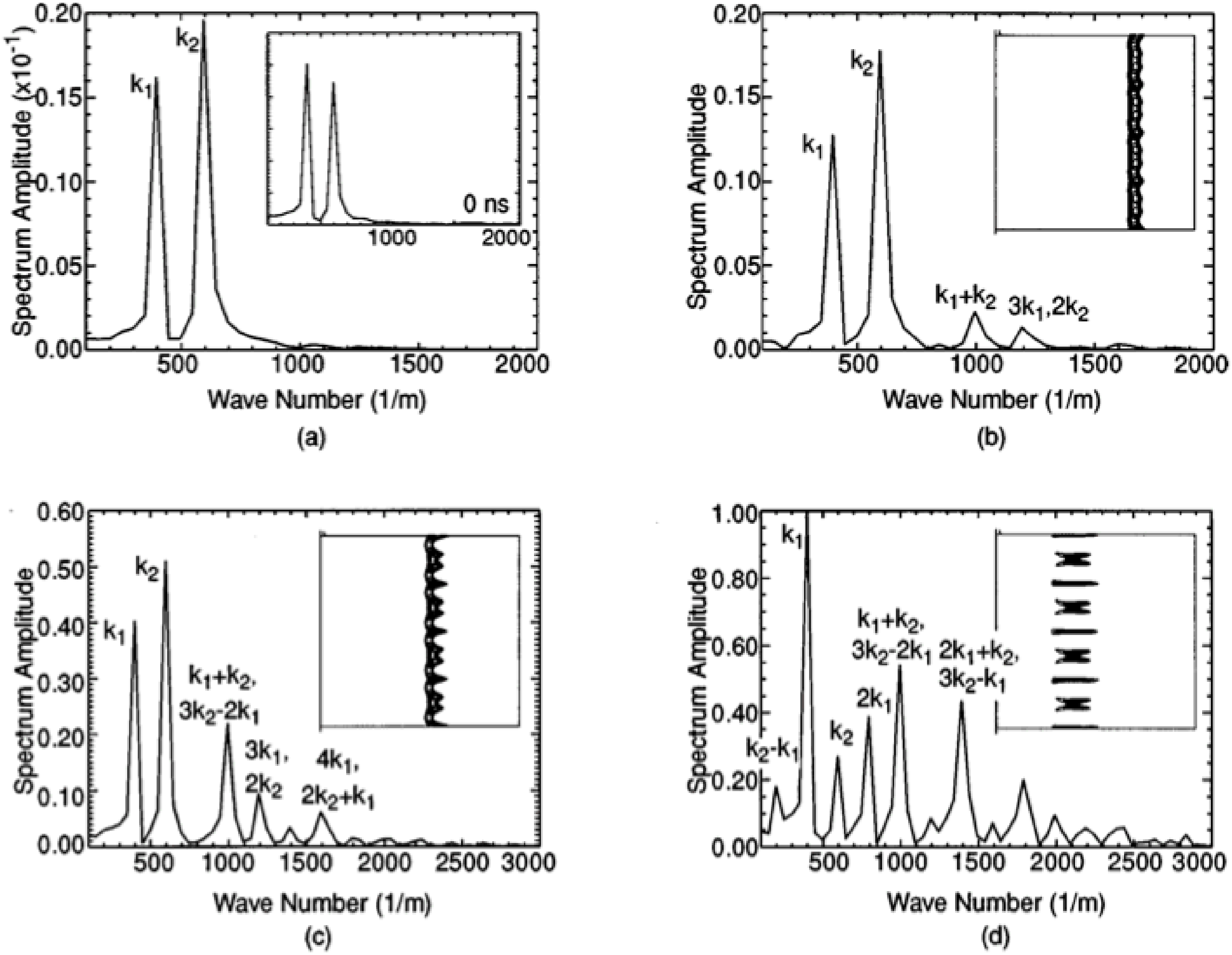
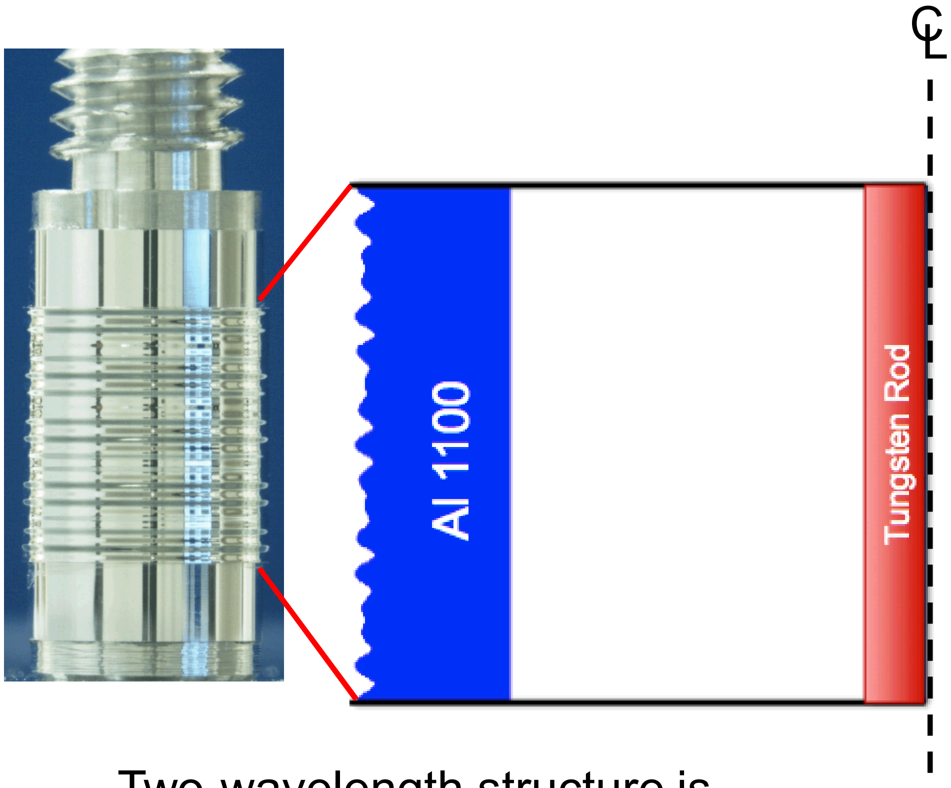


FIG. 12. Two mode evolution of 2.5 mm and 1.67 mm modes at (a) 170 ns, (b) 190 ns, (c) 200 ns and (d) 210 ns.

*Example calculations from M.R. Douglas, C. Deeney, and N.F. Roderick, Physics of Plasmas (1998).

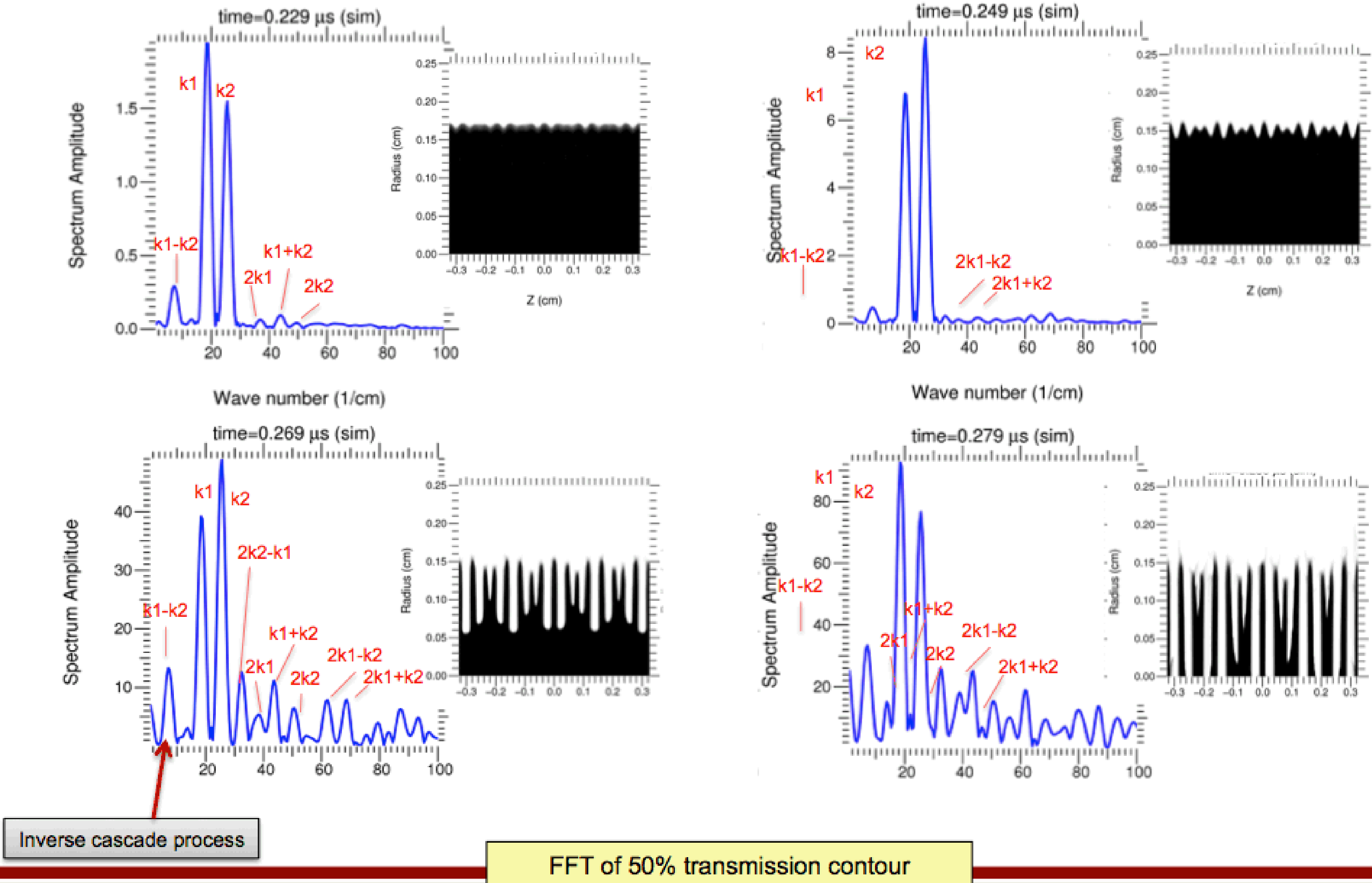
We began studying mode coupling in multi-mode seeded perturbation experiments to test our understanding of multimode MRT instability growth



Two-wavelength structure is machined on outer surface of a cylindrical Al 1100 liner

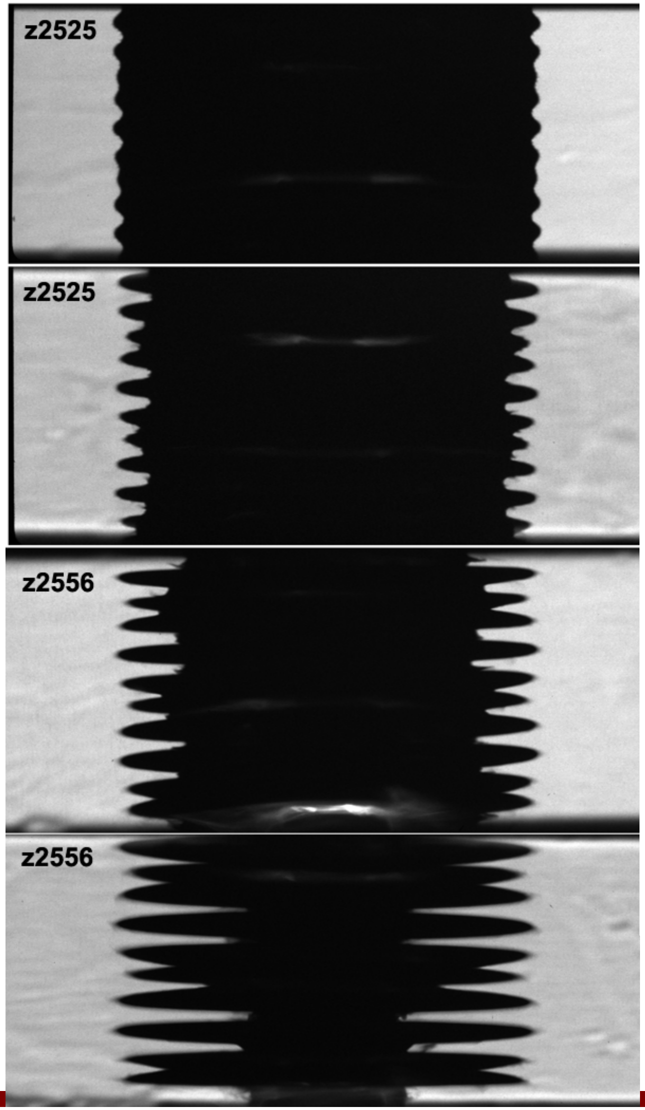
- Target parameters were chosen to complement and compare to previous single-mode experiments
- Initial wavelength (400, 550 microns) and amplitude (20 microns) chosen to be large enough to be resolved by radiography at t=0, dominate over electro-thermal instabilities, and enter the nonlinear regime quickly.
- Non-integer wavelengths chosen to remove ambiguity of mode coupling with higher-mode harmonics
- On-axis tungsten rod suppresses time integrated self-emission in radiographs

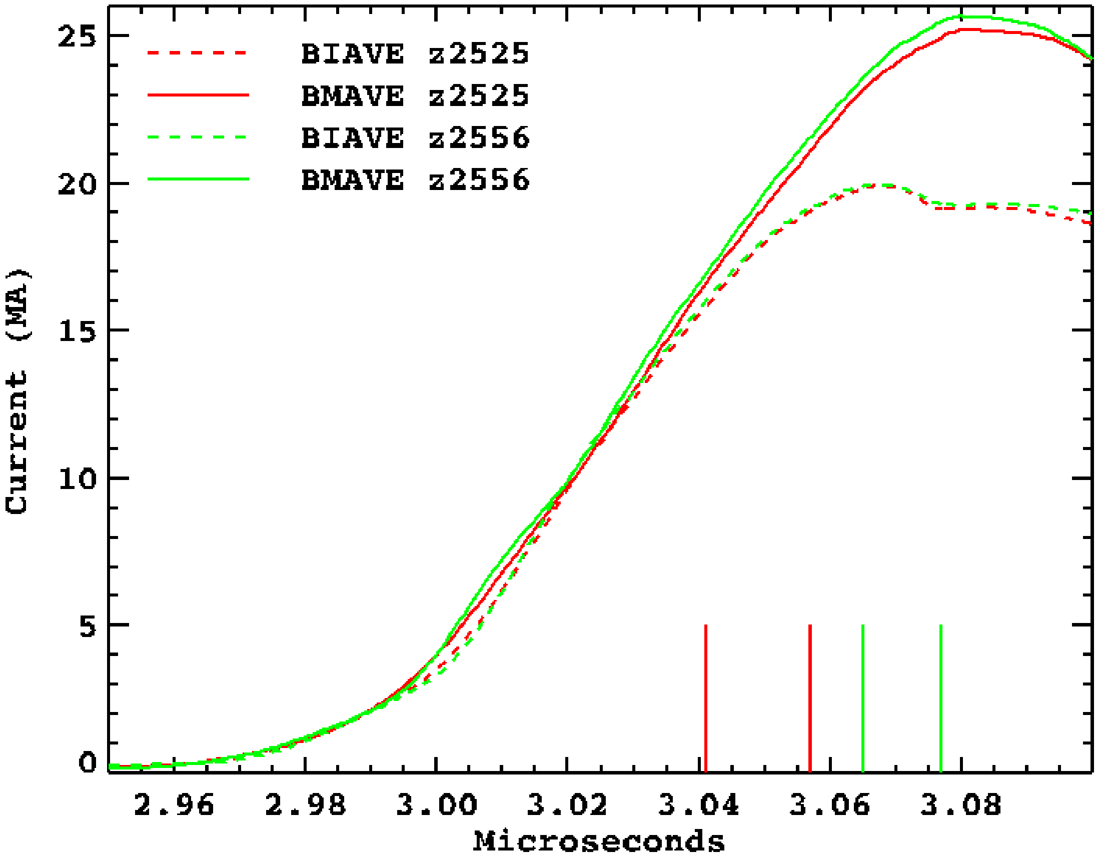
Example simulated radiographs from HYDRA calculations clearly show the appearance of additional modes as the implosion progresses



Experimental radiographs showing the growth of a two-mode perturbation during a magnetically driven Al liner implosion have been obtained

Sandia National Laboratories

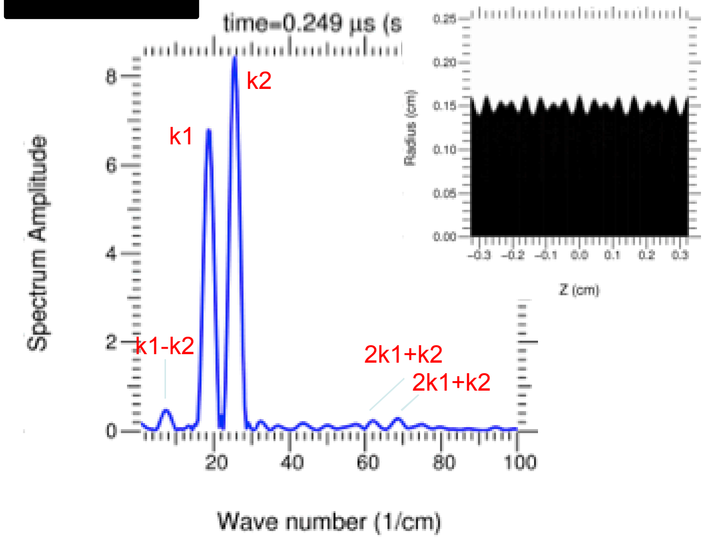


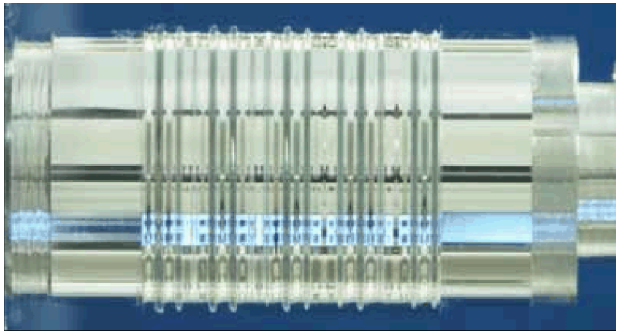


Images at 3041 ns, +16, +24, and +36

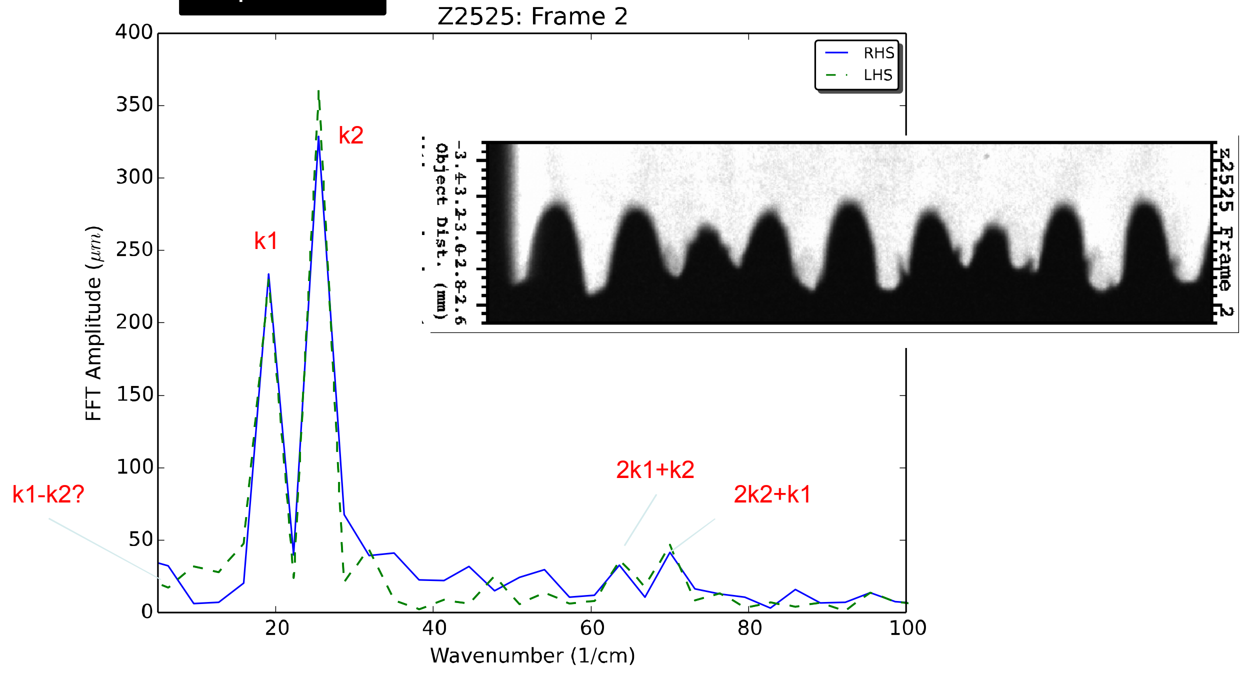
Initial results indicate that we are doing a reasonable job of modeling multimode MRT instability growth

Simulation





Experiment

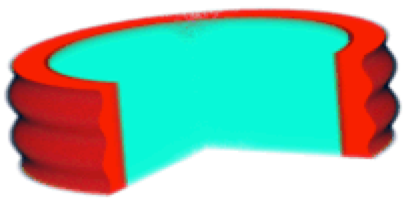


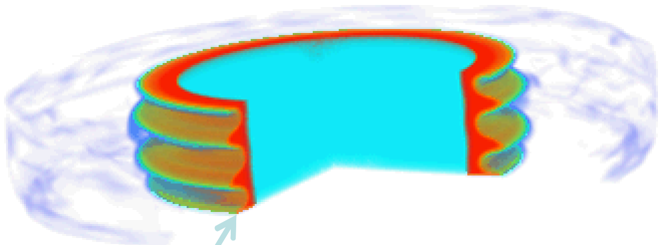
Experimental data does show additional short wavelength features not present in simulations

Helical perturbations are also being investigated as a means to mitigate instabilities and as a 3D test problem

$$\lambda_{kp} = 4\pi\Delta\cos^2\theta$$

Lincoln single-mode MRT
λ=400 μm test target

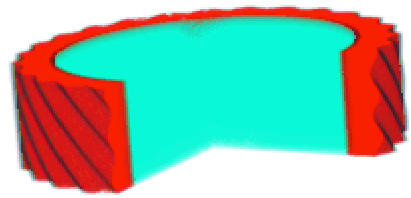




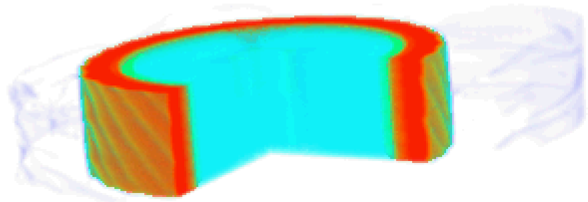
Fundamental mode grows like $\Gamma^2 = kg$

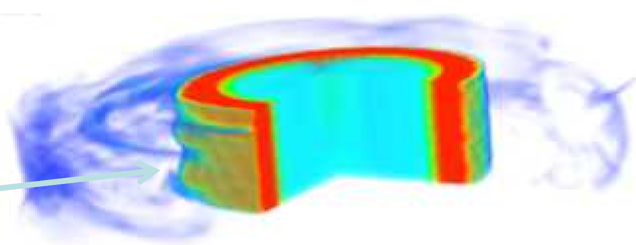
~Zero growth in Fundamental mode

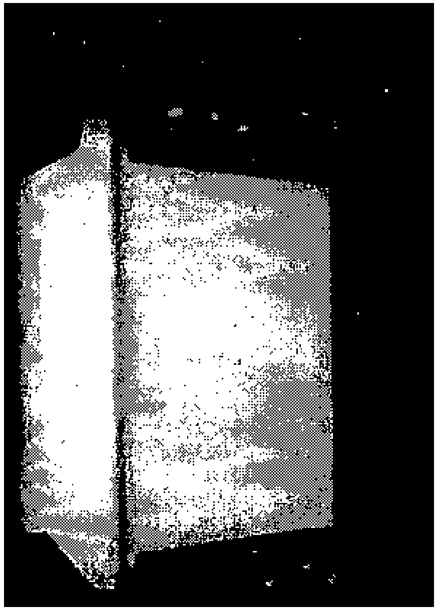
Single-mode MRT
λ=400 μm, 45° pitch target



$\lambda_{kp} = 4\pi\Delta\cos^2\theta$







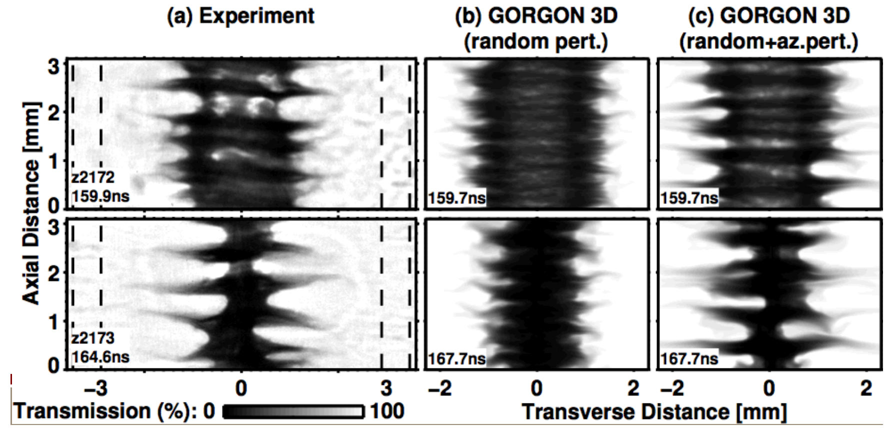
Joint LANL/VNIIEF helical liner Experiment on PEGASUS*

*B. G. Anderson *et al.*, Pulsed Power Plasma Science (2001).

We fielded axially-polished liners to assess the importance of the initial surface roughness on the observed MRT growth in beryllium liner implosions

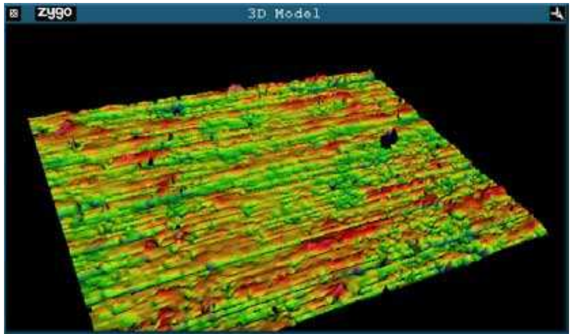
Sandia National Laboratories

- **Azimuthal correlation**
  - **Necessary in 3D simulations**
  - **Single-mode MRT growth studies**



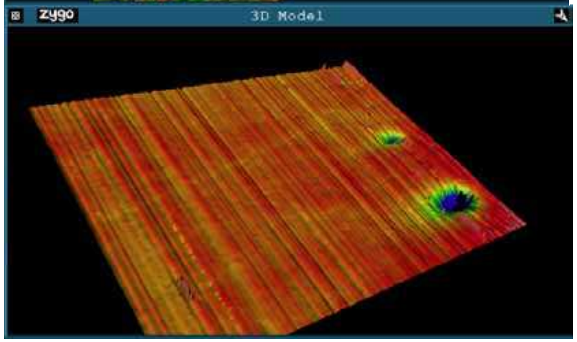
- **Liners are generally diamond-turned**
  - **Smooth (10-50 nm RMS surface)**
  - **Azimuthally-correlated tool groove**
  - **Could seed MRT**

Standard Process (50 nm RMS)



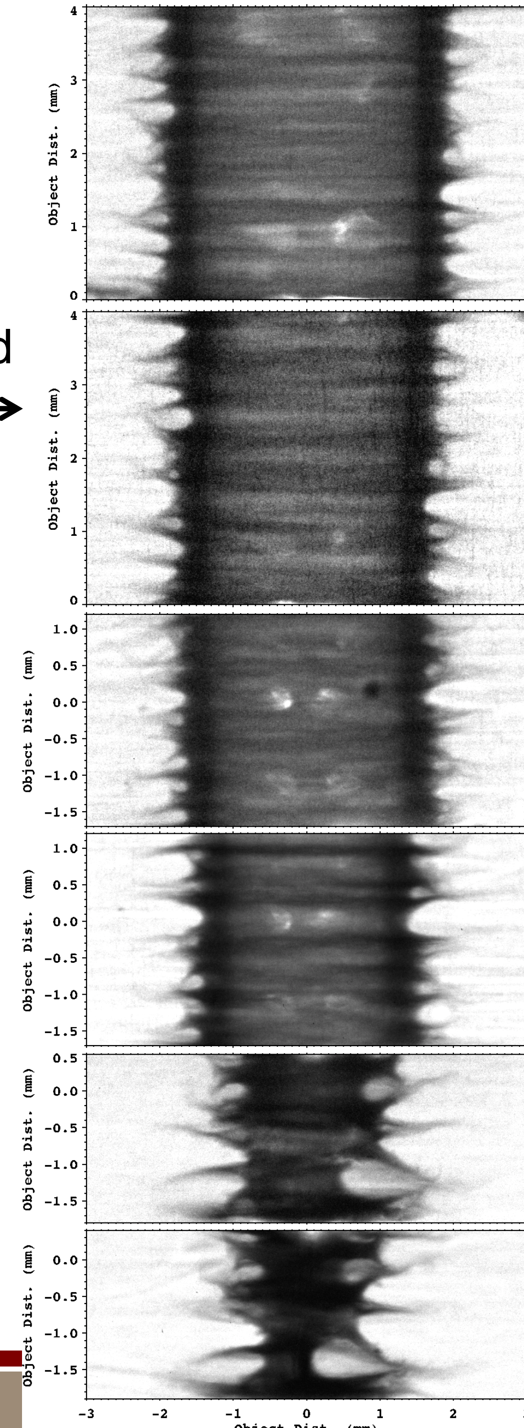
- **Axially-polished liners were developed to test effects of correlation and importance of surface roughness**

After axial polishing (50 nm RMS)

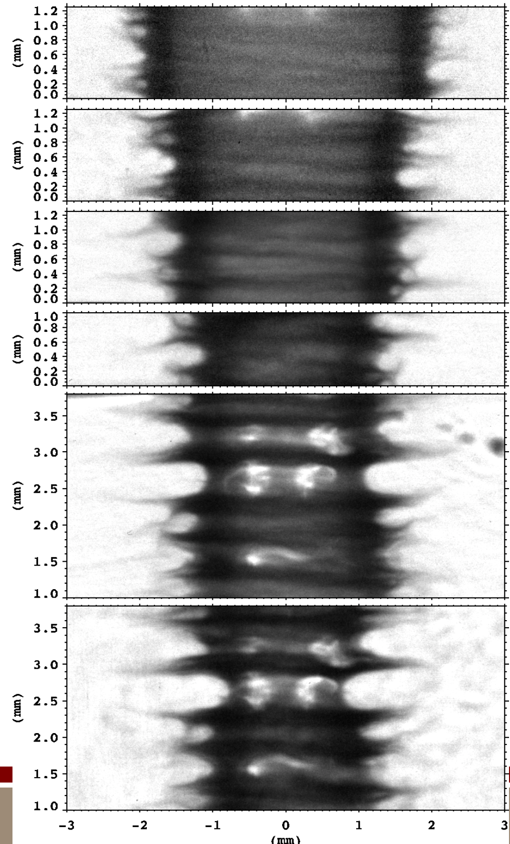


Are the axially-polished liners behaving in a significantly different fashion?

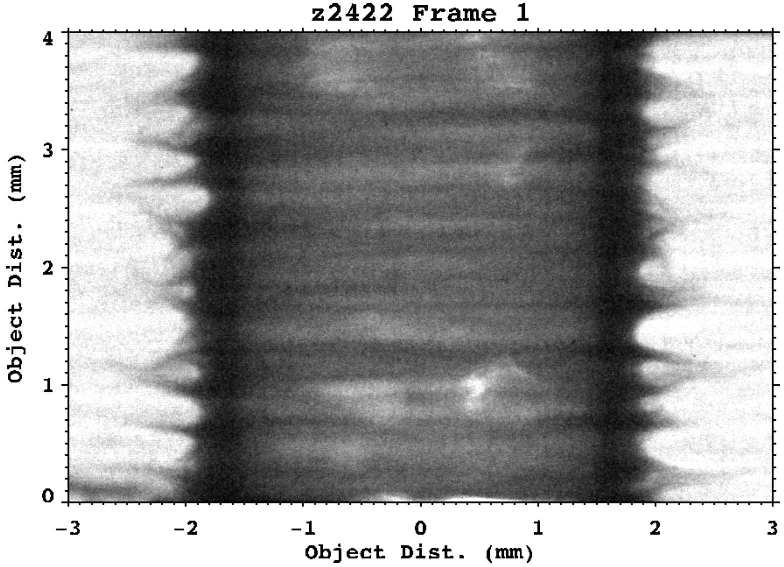
New axially-polished data →

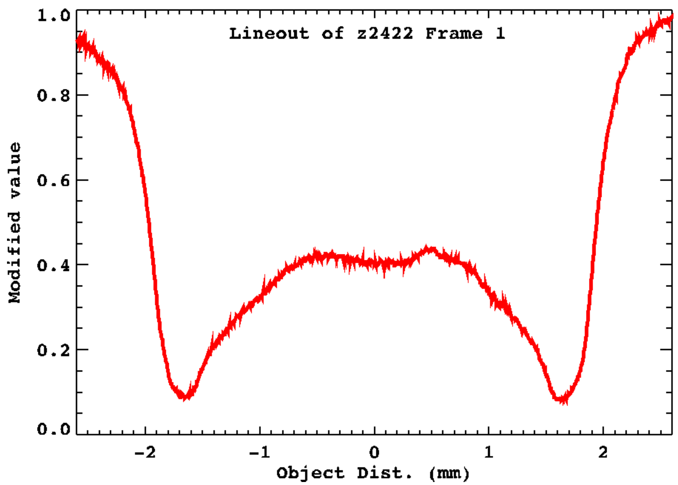


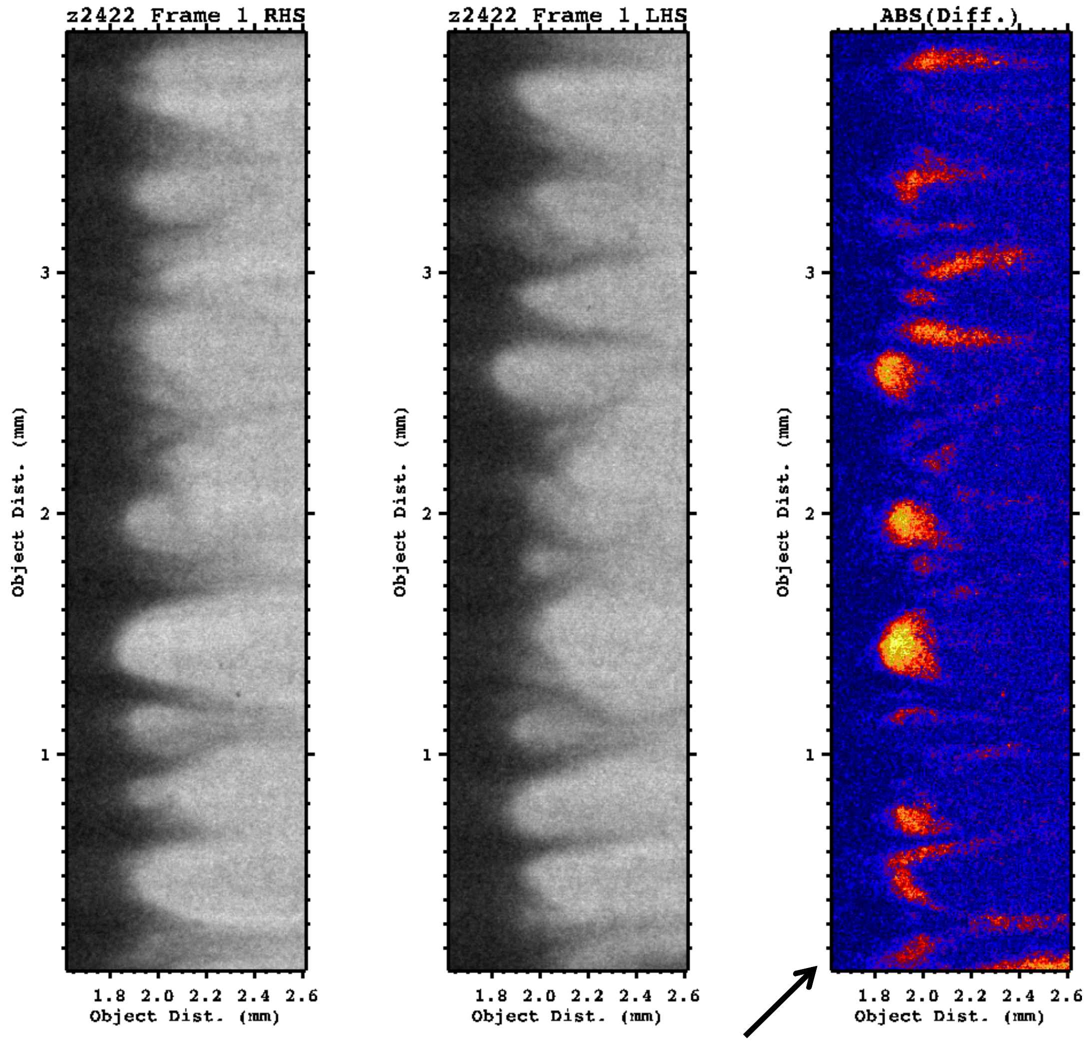
McBride PRL data



To address this question (and avoid time-integrated self-emission) we focus our analysis on the edge structure and try to quantify the symmetry

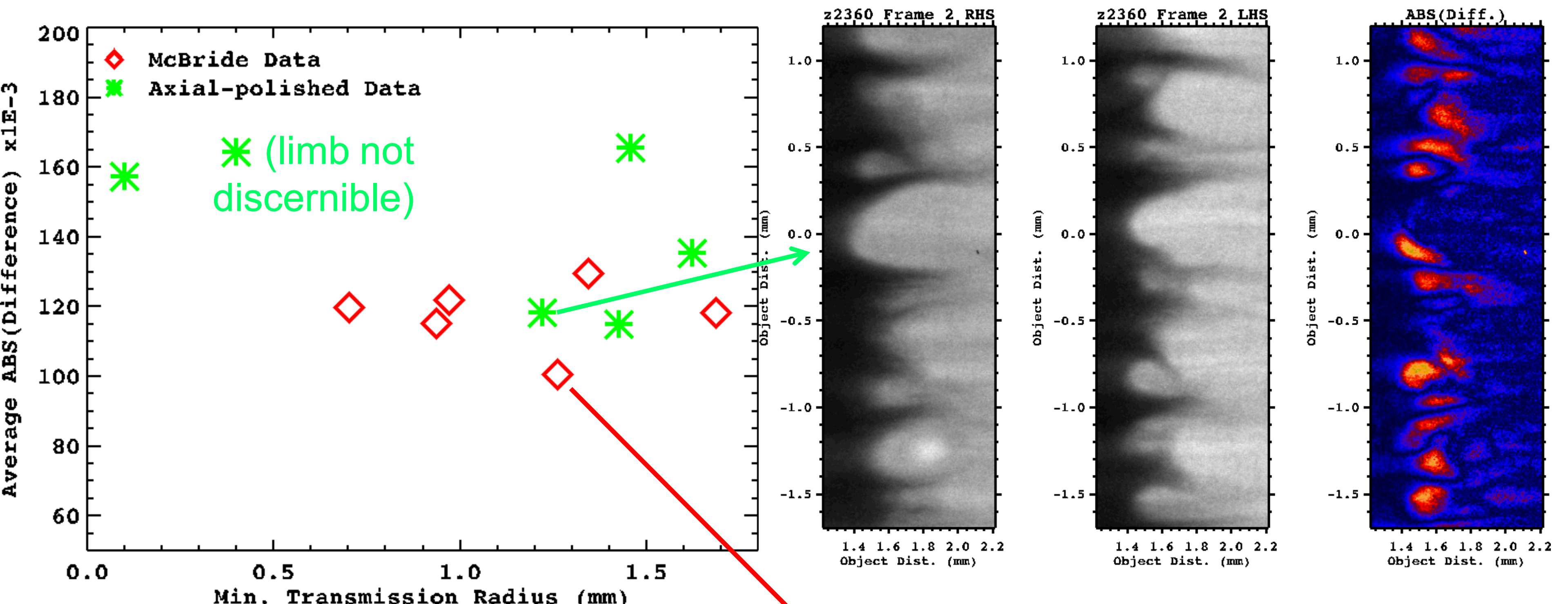


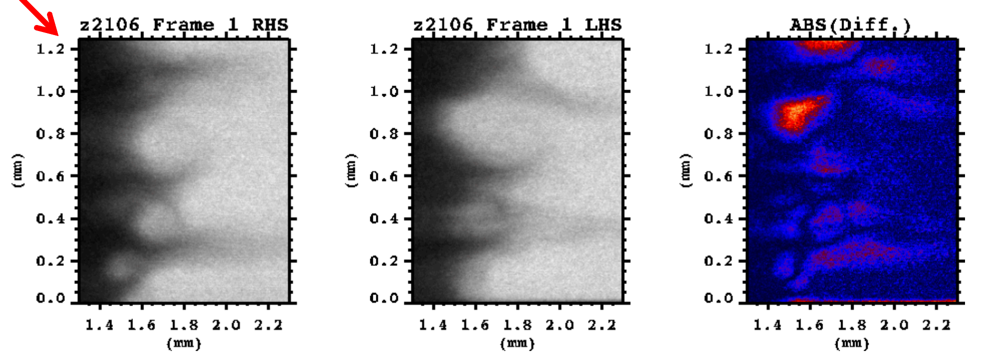




Map of difference in transmission

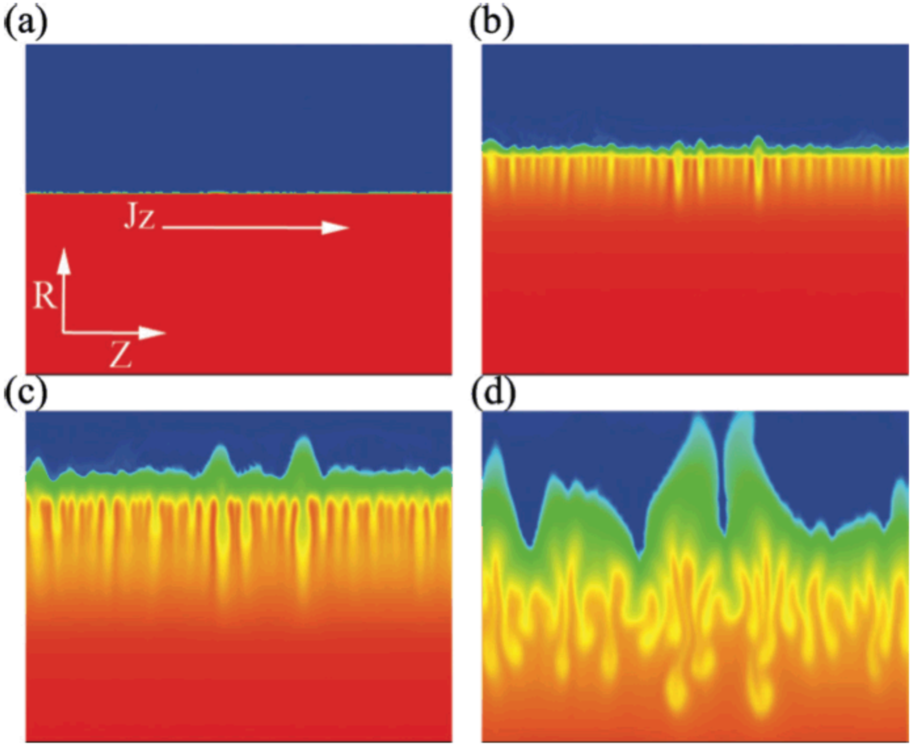
The data do not suggest a significant implosion symmetry difference for the two different initial surfaces

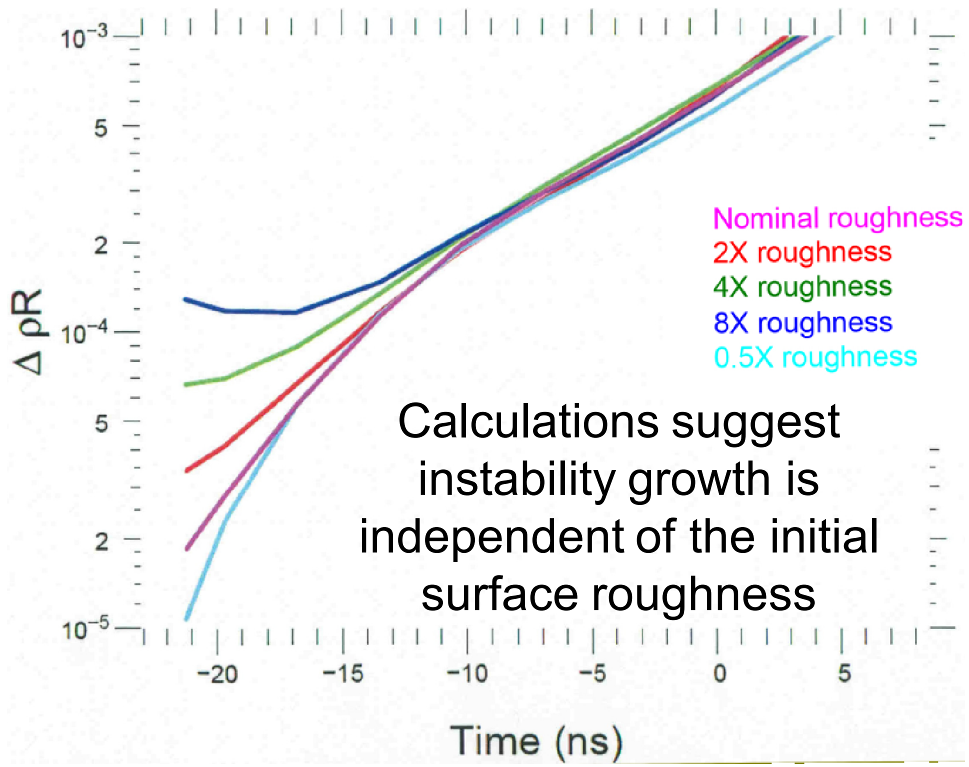




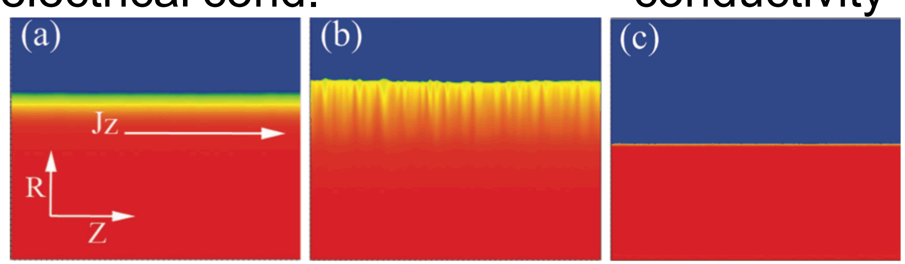
Above plot is average image differences in transmission—areal density would be more meaningful. However, the low transmission of limb + image noise puts emphasis on features in limb instead of edge structures in some of the shots

The electro-thermal instability is an alternative mechanism that could seed MRT growth*





Constant electrical cond. | Nominal | 10x thermal conductivity



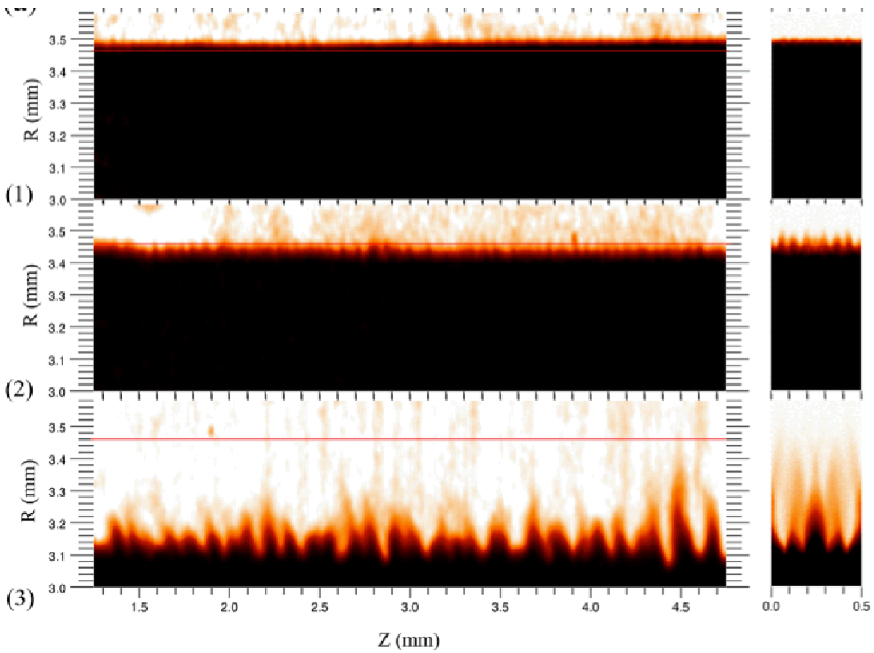
Temperature perturbations give rise to pressure variations which eventually redistribute mass

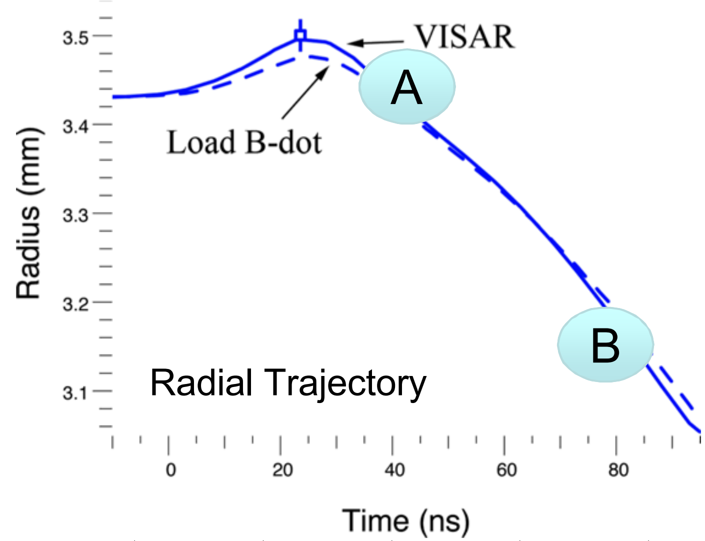
* c.f., K. Peterson YO4.00004 on Friday

K.J. Peterson *et al.*, Phys. Plasmas (2012); K.J. Peterson *et al.*, Phys. Plasmas 20, 056305 (2013).

Comparisons between our modeling and experimental instability growth in solid Al liners are promising—the perturbation growth is larger than expected from MRT alone

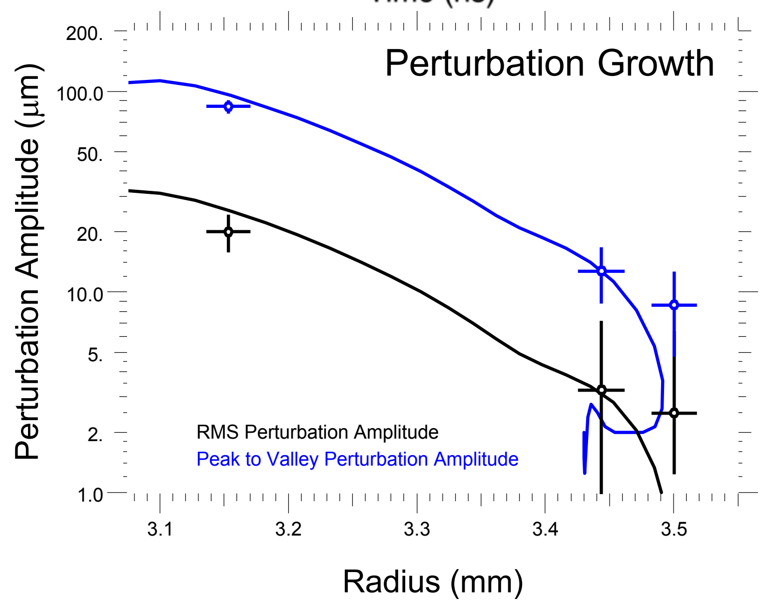
Experimental (left) & simulated (right) radiographs





Perturbation Growth Comparison

Time	Est. MRT (λ=100 μm)	$h=0.06Agt^2$	Observed
A	0.36 μm	6.2 μm	13 ± 7 μm
B	24 μm	41 μm	80 ± 7 μm

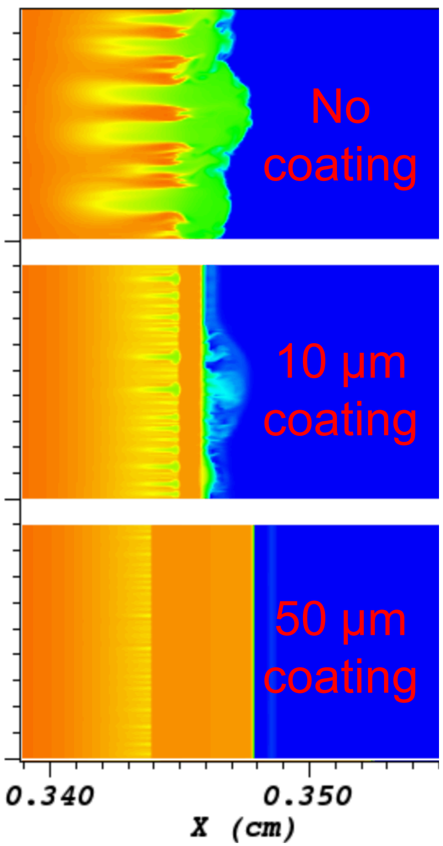


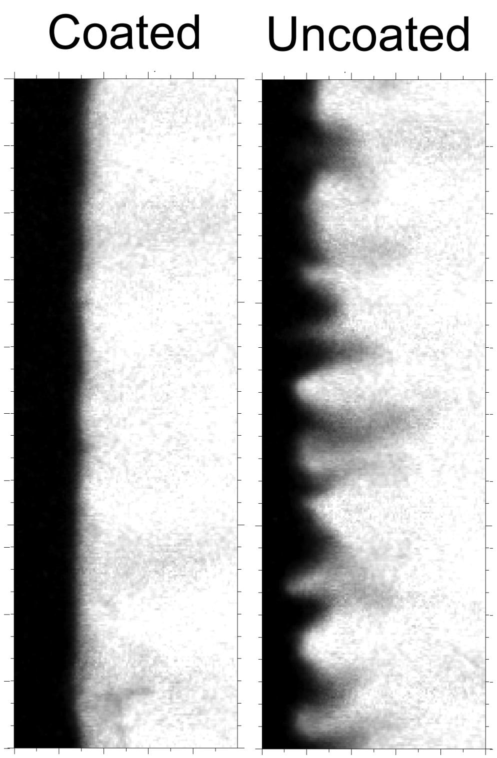
*K.J. Peterson *et al.*, Phys. Plasmas (2012); K.J. Peterson *et al.*, Phys. Plasmas 20, 056305 (2013).

Two recent results may suggest that surface topology is not the dominant origin for the correlated instabilities

Sandia National Laboratories

Dramatic reduction of instability growth is consistent with predictions of electro-thermal instability origin

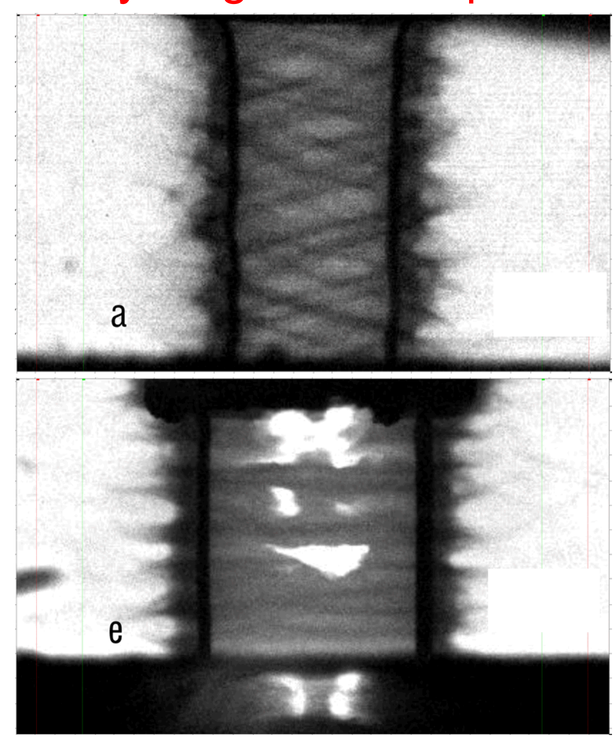




K.J. Peterson *et al.*, manuscript in preparation.

Persistent helical structure in magnetized tests suggests lathe marks do not dominate structure

Axially magnetized implosion



Same target, un-magnetized

T.J. Awe *et al.*, accepted by PRL (2013).

* c.f., K. Peterson YO4.00004 on Friday

* c.f., T.J. Awe CI2.00002 on Monday

There are several related MagLIF presentations including some in parallel with this poster session!

- Monday 10:30 Gomez Overall progress on MagLIF
- Monday 10:42 Slutz Low-convergence MagLIF
- Monday 10:54 McBride Semi-analytic MagLIF model
- Monday 11:30 Weis MRT growth simulations
- Monday 2:00 Sefkow MagLIF designs
- Monday 2:30 Awe Magnetized liner dynamics
- Thursday 9:30 Hansen Spectroscopic Bfield Meas.
- Friday 10:06 Peterson Electro-thermal instability

We have made significant progress in developing a fundamental understanding of implosion instabilities in magnetically-driven systems

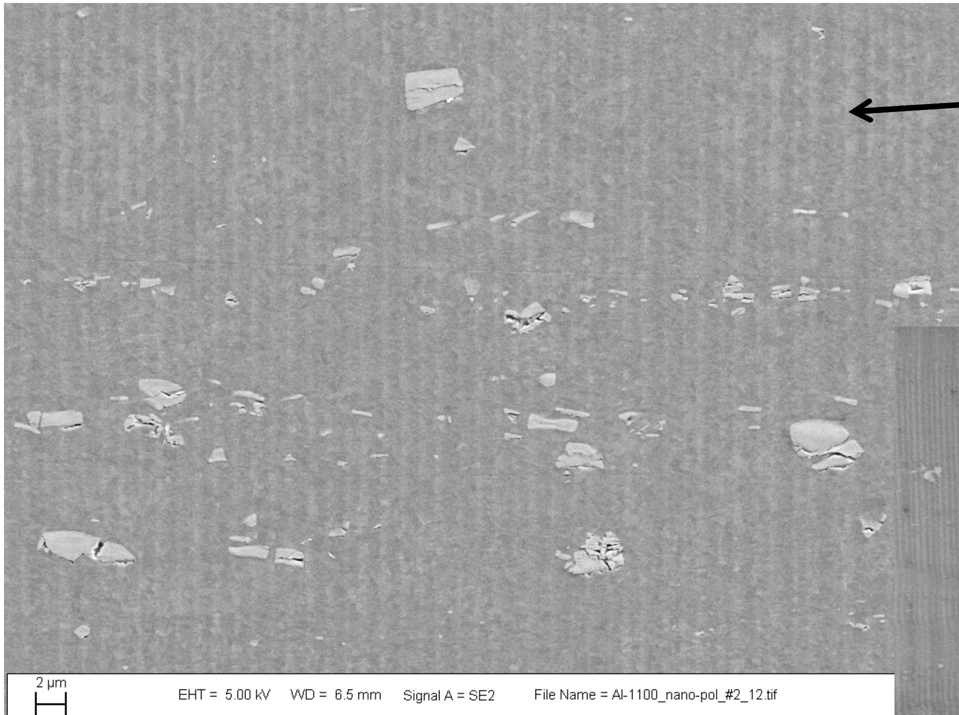
Sandia National Laboratories

- We have benchmark-quality implosion radiography data for
  - Single-wavelength seeded perturbations
  - Two-mode multiple-wavelength seeded perturbations
  - Unseeded beryllium liner implosions with standard surface finish
  - Unseeded beryllium liner implosions with altered surface finish
  - Axially-magnetized beryllium liner implosions (changes structure!)
- Detailed comparisons to simulations are underway or have been published alongside the data
- The electro-thermal instability appears to be the dominant seed for implosion instability growth
- Experiments in 2014 will collect additional radiography data
  - Helically-perturbed beryllium liner implosions
  - Deceleration instability growth in inner liner surface

Extras

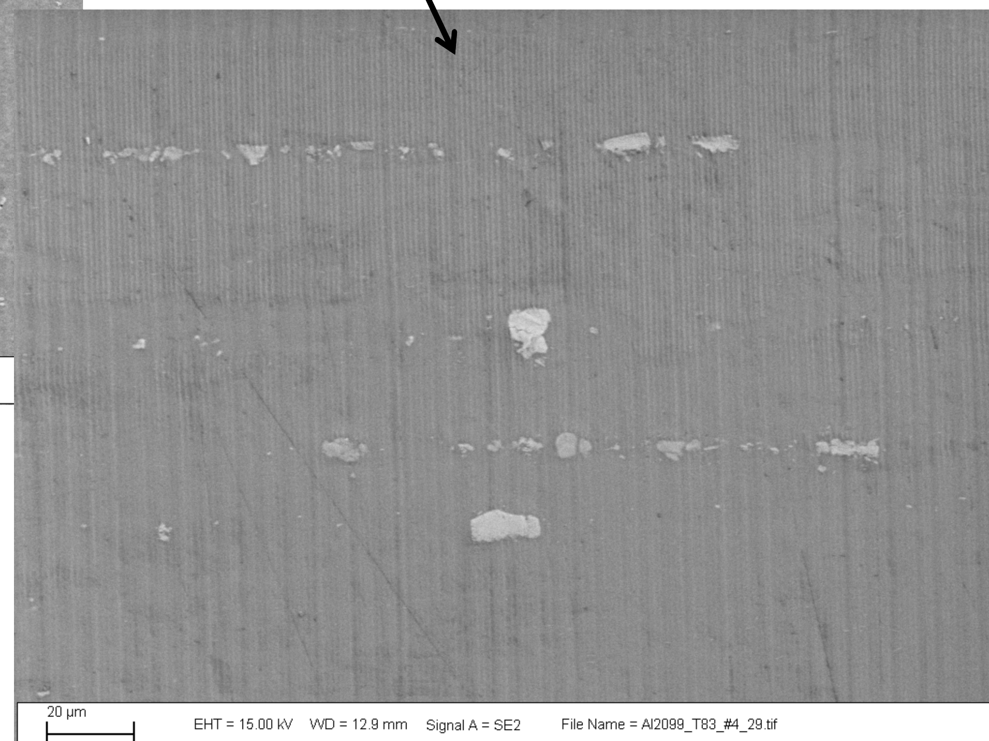
Example Al liner surface photos indicate that alloys precipitate material in axially-correlated direction when electrochemistry treatments are applied*

Sandia National Laboratories



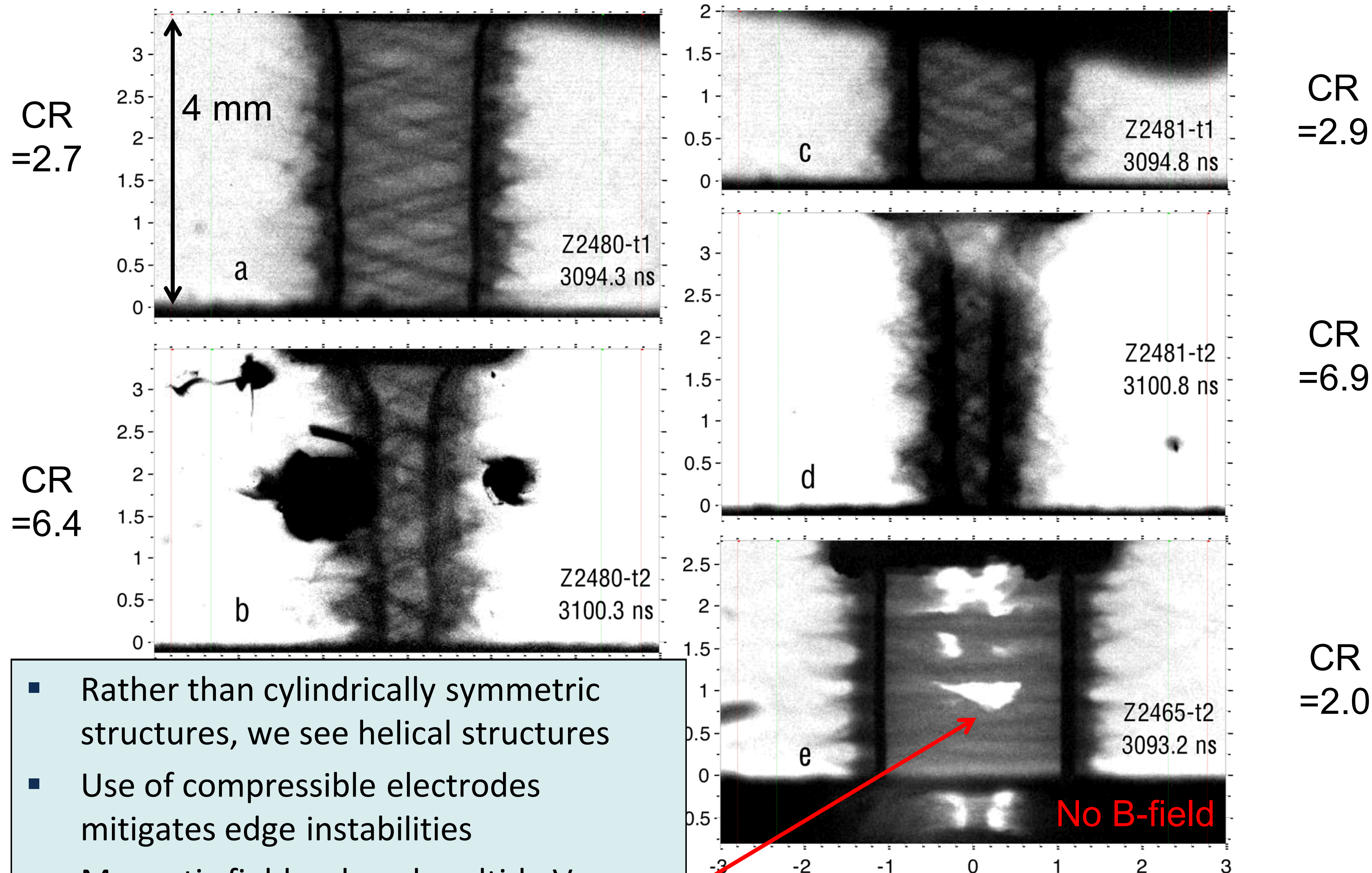
Vertical lines are machining marks along azimuthal direction

Non-Al precipitates appear correlated along axial direction, believed to be due to the use of extruded metal stock



* W.G. Yelton, J.R. Pillars, A.C. Sun (Sandia Org. 1728)

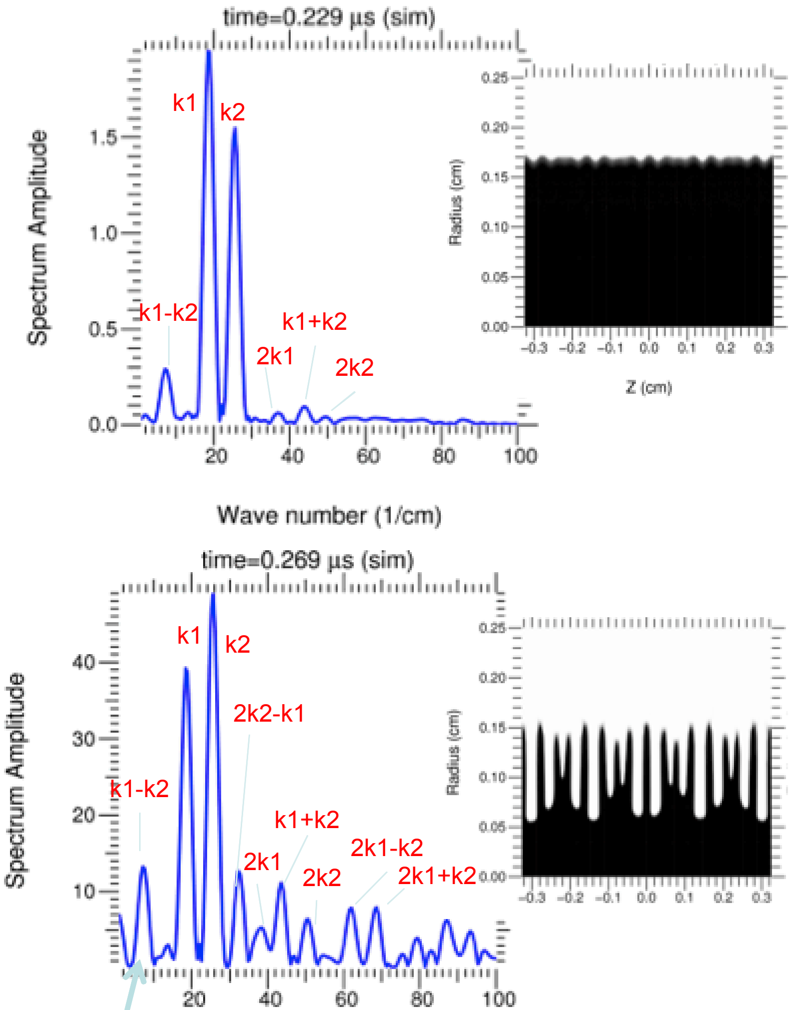
The addition of a 7-10 T axial magnetic field produces a dramatic change in the structure of the liner instabilities



- Rather than cylindrically symmetric structures, we see helical structures
- Use of compressible electrodes mitigates edge instabilities
- Magnetic field reduced multi-keV x rays associated with late-time instabilities

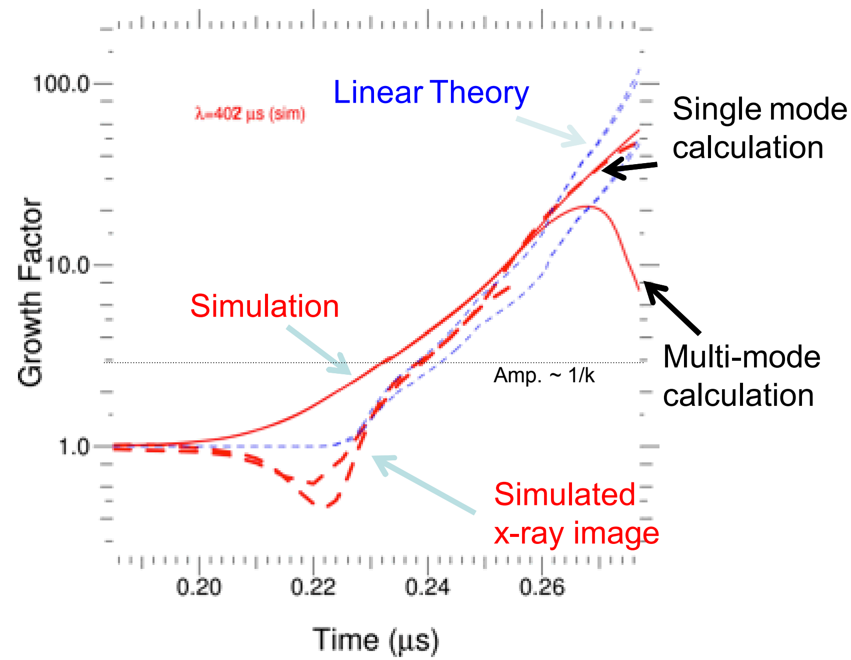
We have begun to study nonlinear MRT instabilities and mode coupling in carefully seeded multi-mode experiments

HYDRA Simulations



Inverse cascade process

$$\Gamma^2 = k\frac{\mu_0}{8\pi^2}\frac{I^2}{R^2}\frac{1}{\rho(\Delta r)}$$

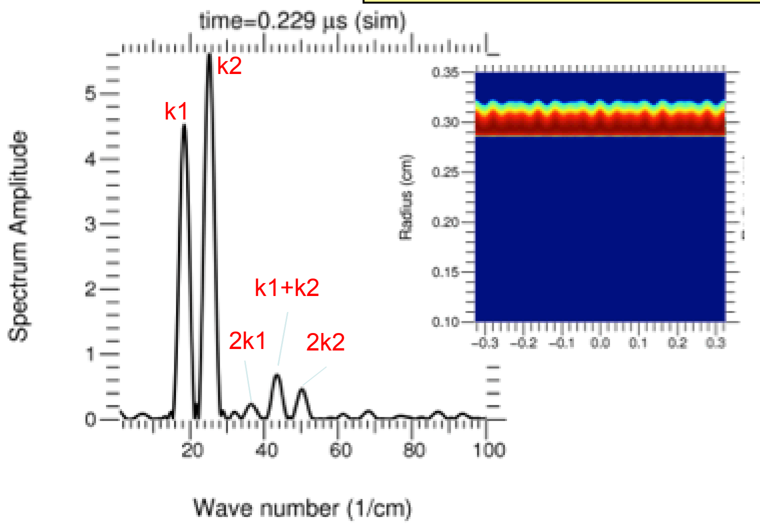


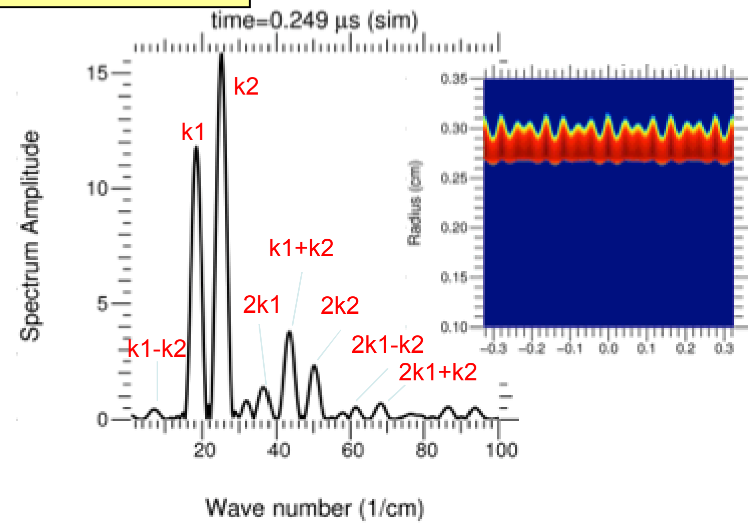
For k<(1/h), linear theory increasingly poor approximation as amplitude goes to ~1/k ,.

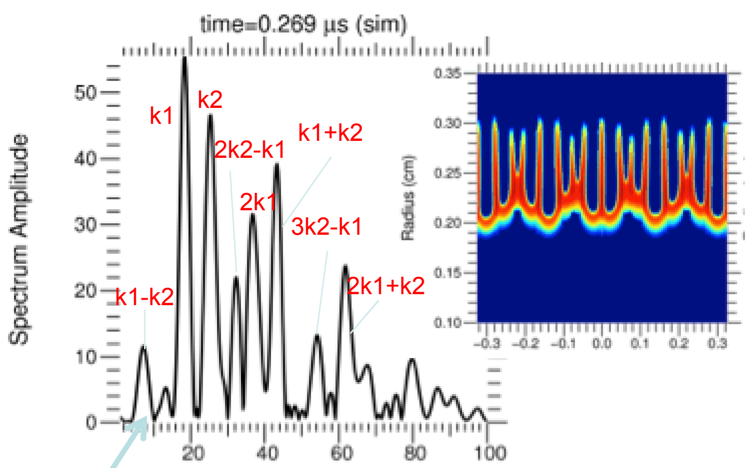
*Ryutov, Derzon, & Matzen, Rev. Mod. Phys. 72, 167 (2000)

Lincoln multi-mode experiments will test our simulation code predictions of MRT instability growth in the nonlinear regime

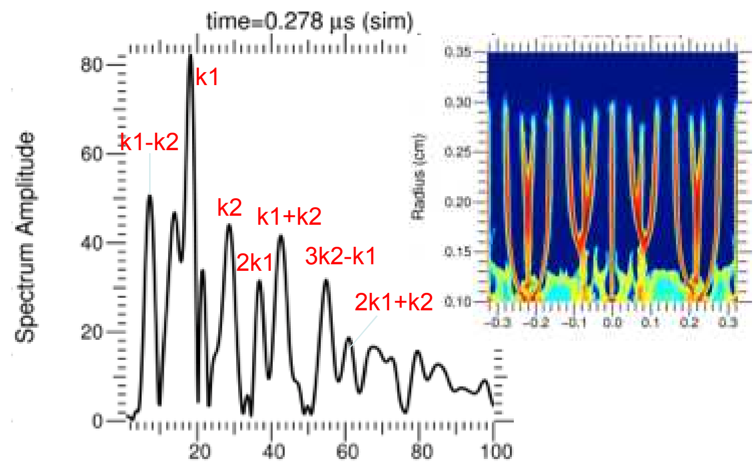
areal density FFT at each axial position



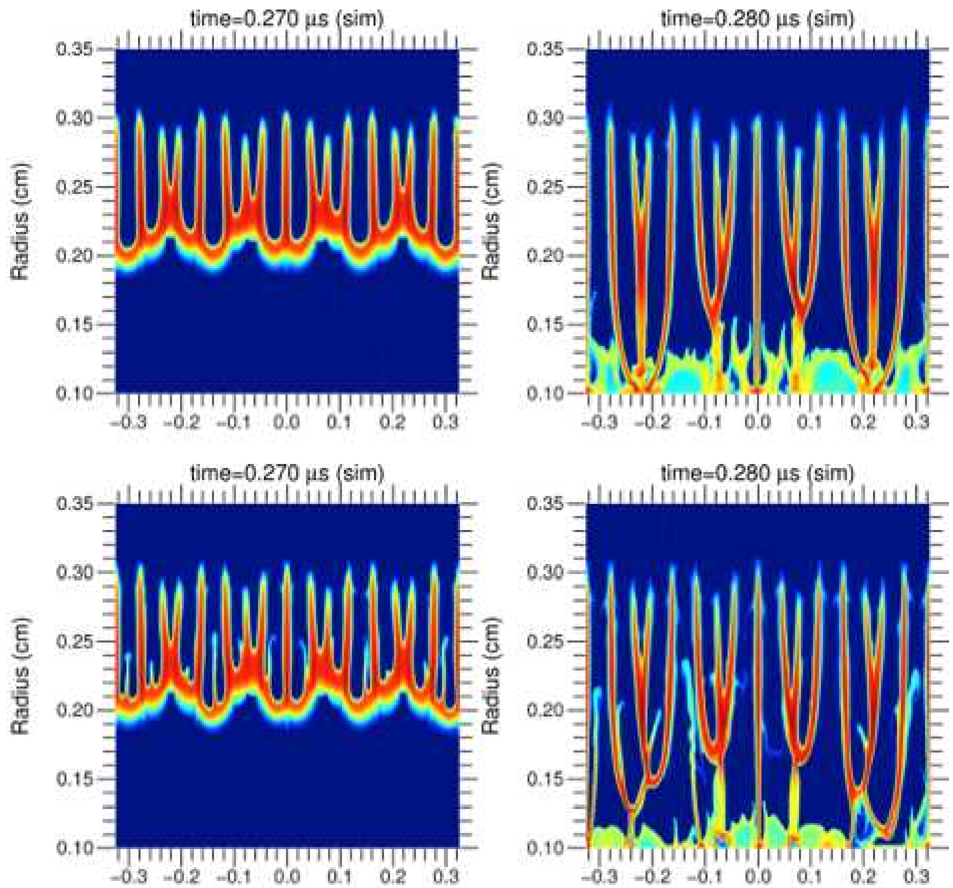




Inverse cascade process



Development of well resolved long wavelengths can be affected by higher grid resolutions through nonlinear mode coupling



16 micron axial resolution
Wavelengths > 160µm resolved

8 micron axial resolution
Wavelengths > 80µm resolved

Onset of nonlinear saturation occurs earlier in time at smaller amplitudes in the multi-mode case