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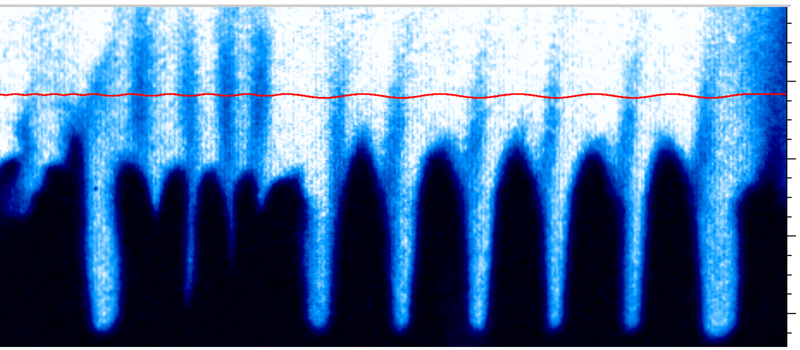

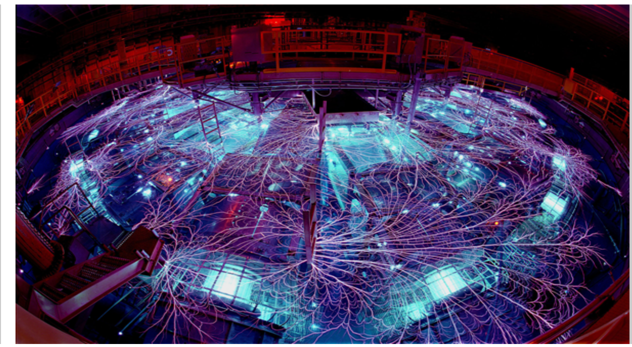

MULTI-MODE MAGNETO-RAYLEIGH-TAYLOR INSTABILITY GROWTH EXPERIMENTS IN PULSED POWER LINERS

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Abstract

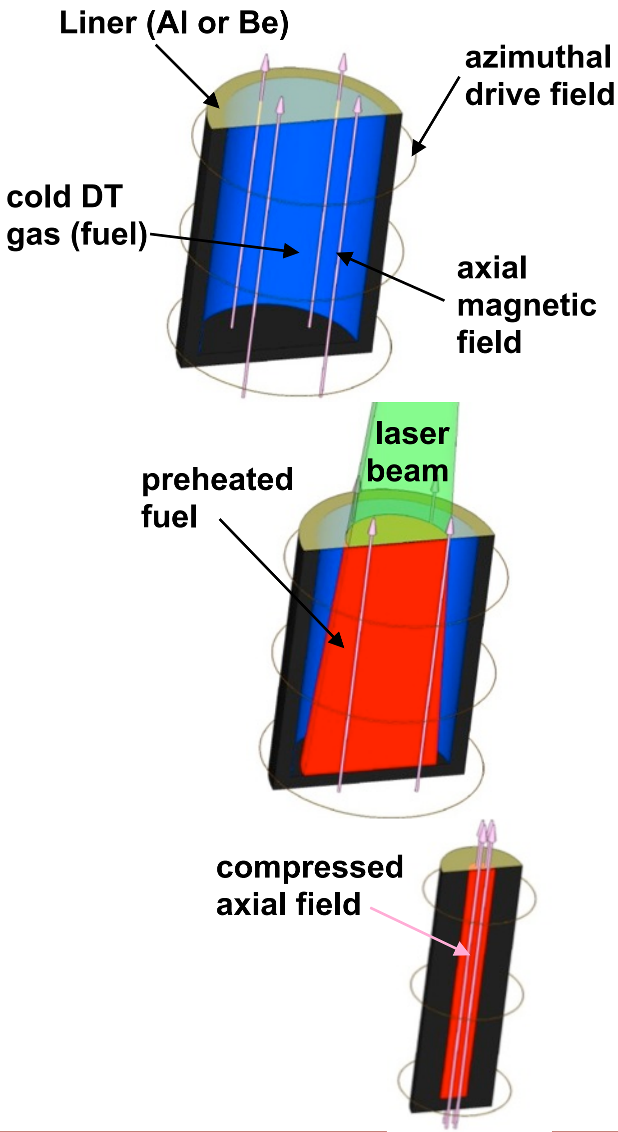
The presence of Magneto-Rayleigh-Taylor (MRT) instabilities limit the achievable controlled compression of fusion fuel in pulsed power inertial confinement fusion concepts such as MagLIF [1]. It is therefore essential to not only mitigate the growth of MRT instabilities to the extent possible, but also validate simulation tools used to evaluate and assess MRT instability growth in these types of targets.

Previously, we have shown single mode MRT experiments in solid Al liners that have proven extremely fruitful in benchmarking instability growth in several simulation codes [2]. It is also important to test our understanding and validate simulation predictions of multimode MRT growth. Computational studies of multimode perturbations have been done in the past with wire array z-pinch implosions [3]. However, heretofore no experiment has been performed to quantitatively study either linear or nonlinear multimode MRT instability growth in a controlled manner.

In this paper, we discuss new simulations and experiments designed specifically to investigate multimode MRT instability growth. These experiments utilize x-ray radiography to measure the growth of two superimposed sinusoidal perturbations (400 μm and 550 μm in wavelength with peak to valley amplitudes of 20 μm) imposed on solid Al liners 292 μm thick with an initial outer radii of 3.16 mm. These experiments are also designed to evaluate MRT growth in the quasi-linear and nonlinear regimes. As such, we will also discuss effects such as the generation of higher order mode harmonics, mode saturation, and mode coupling.

1. S.A. Slutz *et al.*, Phys. Plasmas 17, 056303 (2010).
2. D.B. Sinars *et al.*, Phys. Plasmas 18, 056301 (2011).
3. M.R. Douglas and C. Deeney and N. F. Roderick. Phys. Plasmas 5, 4183 (1998)

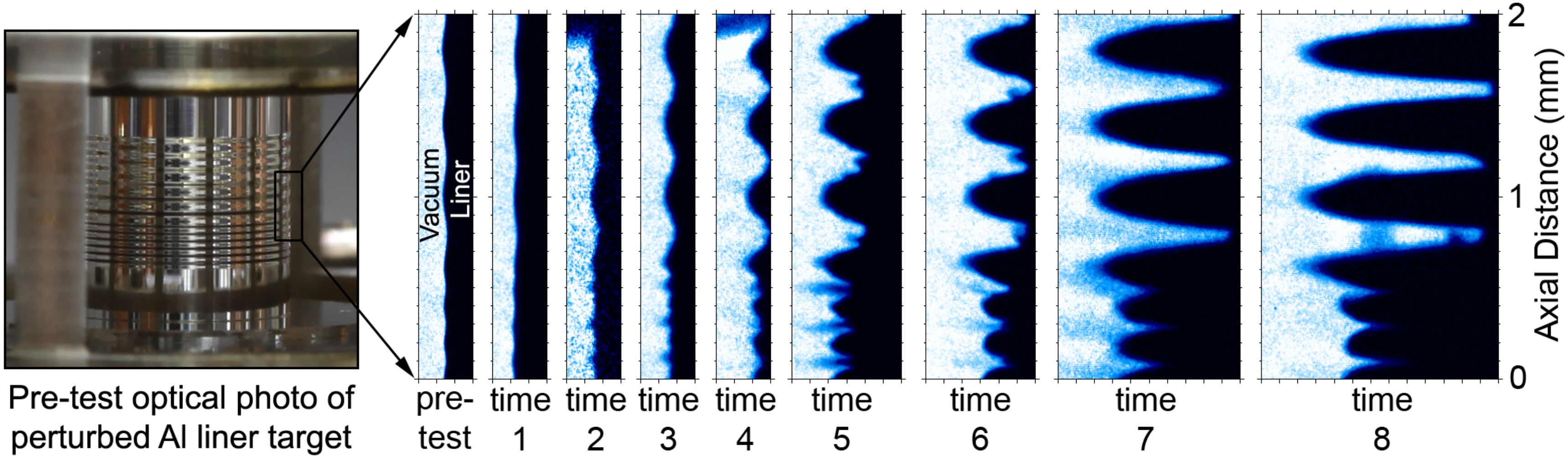
We are working toward the evaluation of a new Magnetized Liner Inertial Fusion (MagLIF)* concept



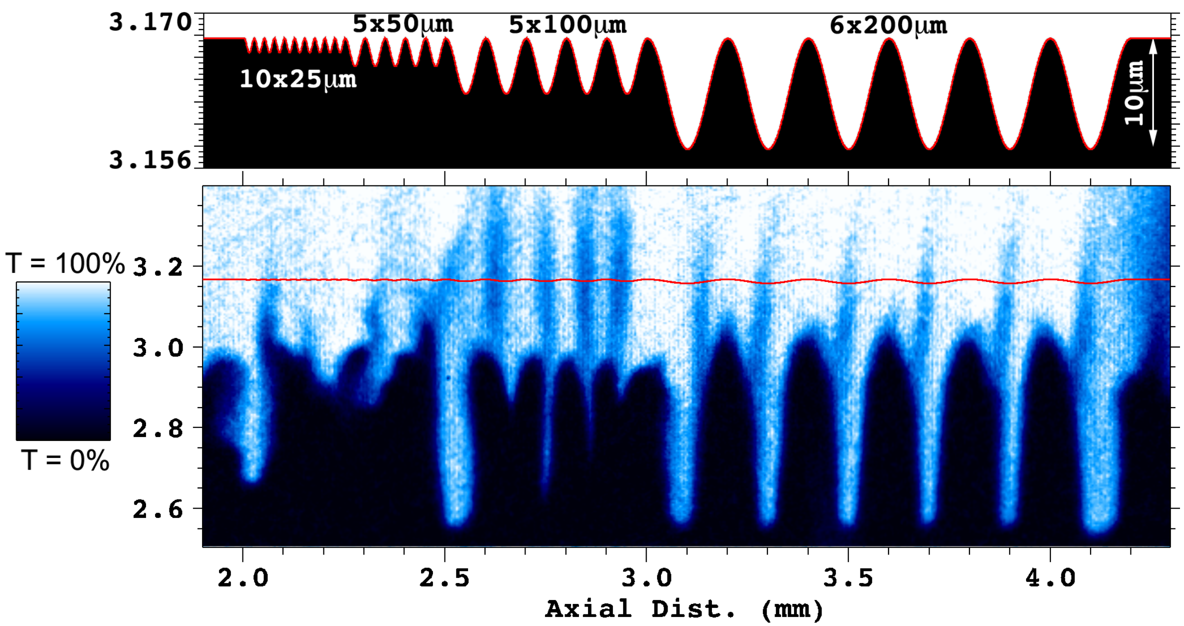
- An initial ~10 T axial magnetic field is applied
  - Inhibits thermal conduction losses
  - Enhances alpha particle energy deposition
  - May help stabilize implosion at late times
- During implosion, the fuel is heated using the Z-Beamlet laser (<10 kJ needed)
  - Preheating reduces the compression needed to obtain ignition temperatures to 20-30 on Z
  - Preheating reduces the implosion velocity needed to "only" 100 km/s (slow for ICF)
  - Stagnation pressure required is few Gbar, not a few hundred Gbar
- Scientific breakeven may be possible on Z (fusion yield = energy into fusion fuel)

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

Prior experiments (Lincoln 1,2) have studied the growth of single-mode perturbations with time



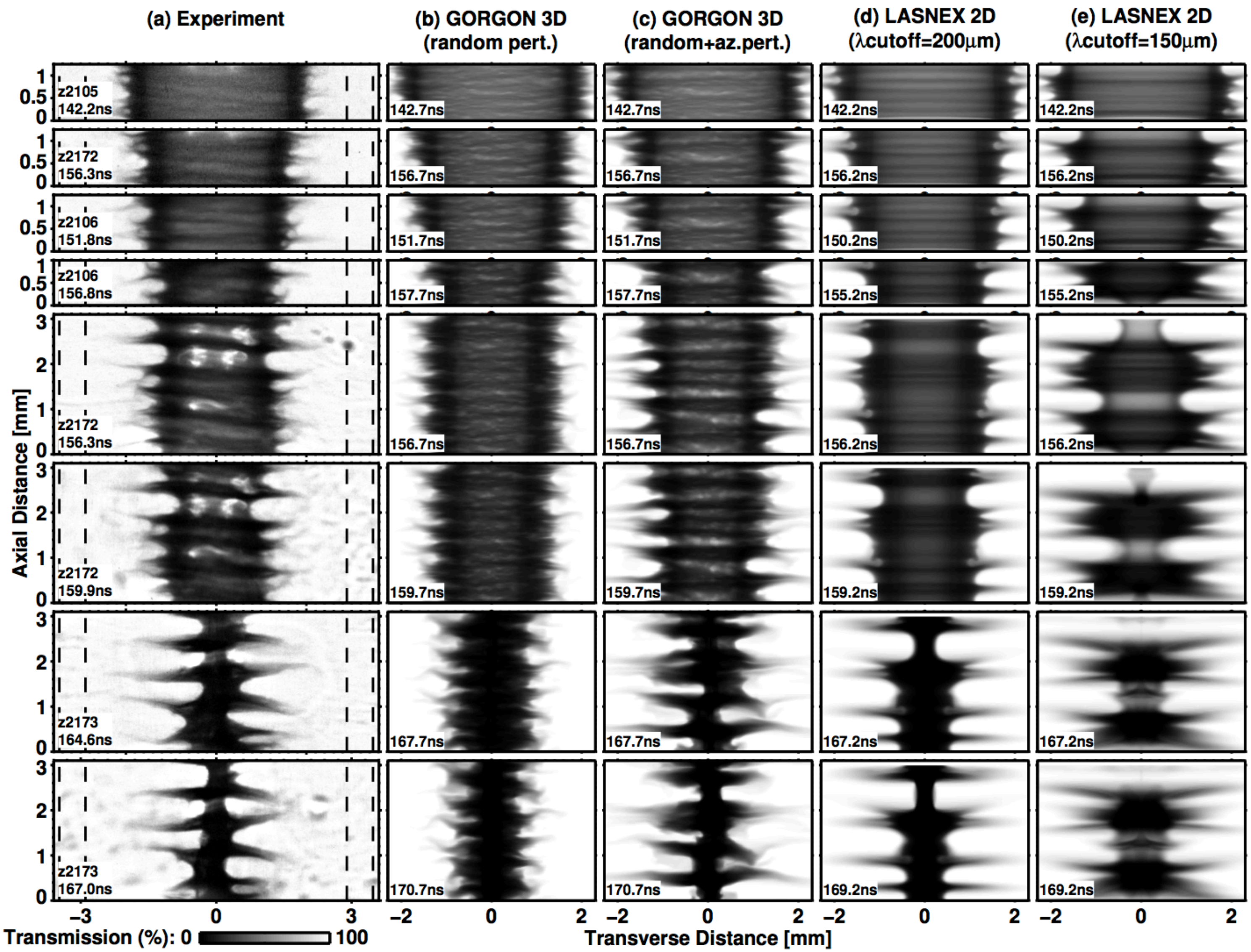
Pre-test optical photo of perturbed Al liner target



- Experiments tracked λ=400, 200, 100, 50, and 25 μm perturbations
- Tracking the details of 25-100 μm features requires a 0-degree backlighting view
- LASNEX did a good job at λ=400, 200, 100 μm, but less so at smaller wavelengths (lots of blending and end effects)

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

Previous experiments have also studied multi-mode MRT growth in Beryllium liners with initially flat contours



R.D. McBride *et al.*, Phys. Rev. Lett. 109, 135004 (2012).

We are also investigating the initial seed of multimode MRT instability growth

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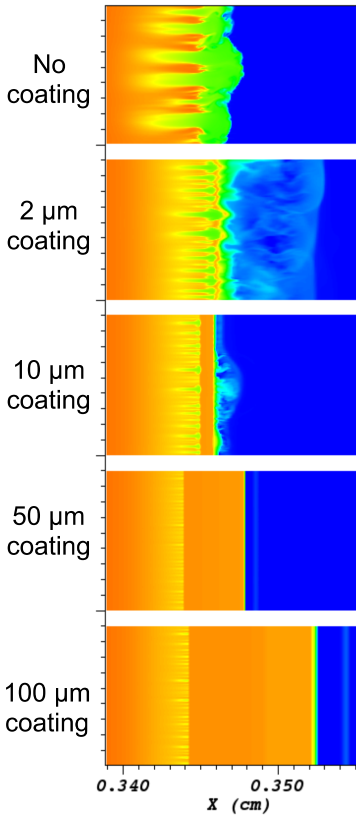
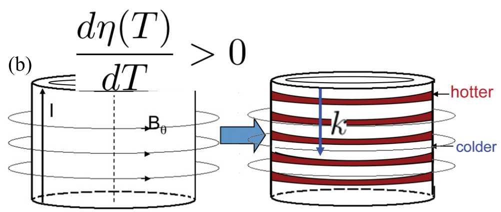
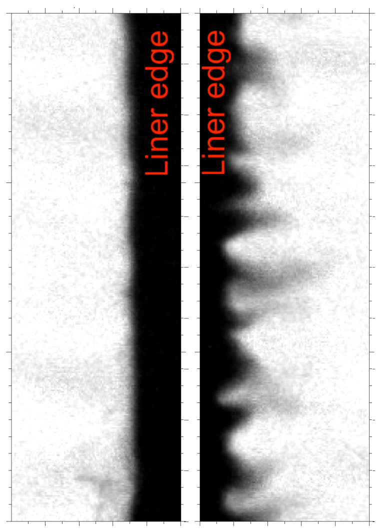
Suppression of electrothermal instabilities





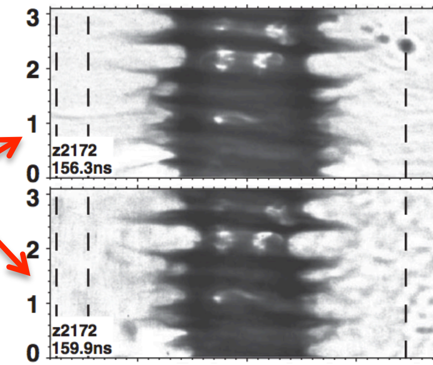


Coated Uncoated

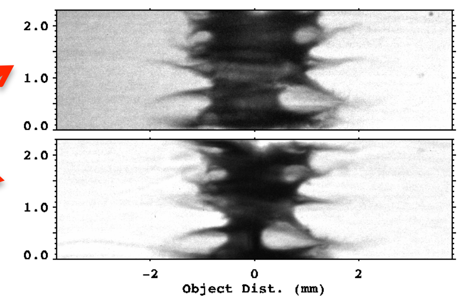
Relatively thick insulating coatings suppress liner instabilities that are seeded by the electro-thermal instability*

Modification of liner surface characteristics

Normal azimuthally-correlated finish from previous experiments*



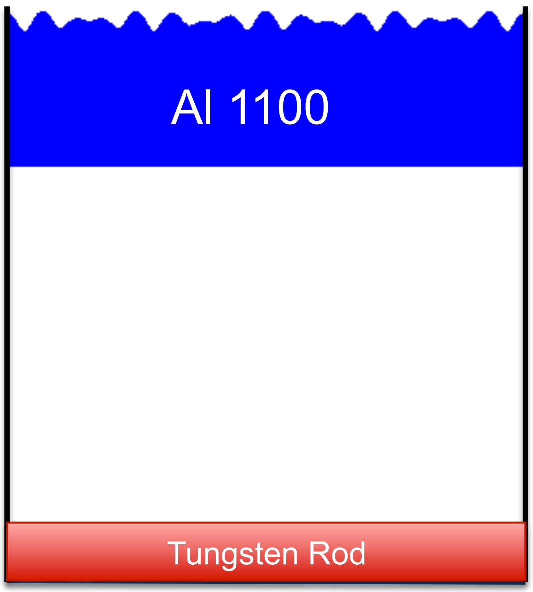
Axially-polished data from Lincoln 6 experiments



Late-time results from z2356 may show an effect of removing azimuthal correlation

*K.J Peterson et al., Phys Plasmas 19, 092701 (2012) and Phys Plasmas 20, 056305 (2013)

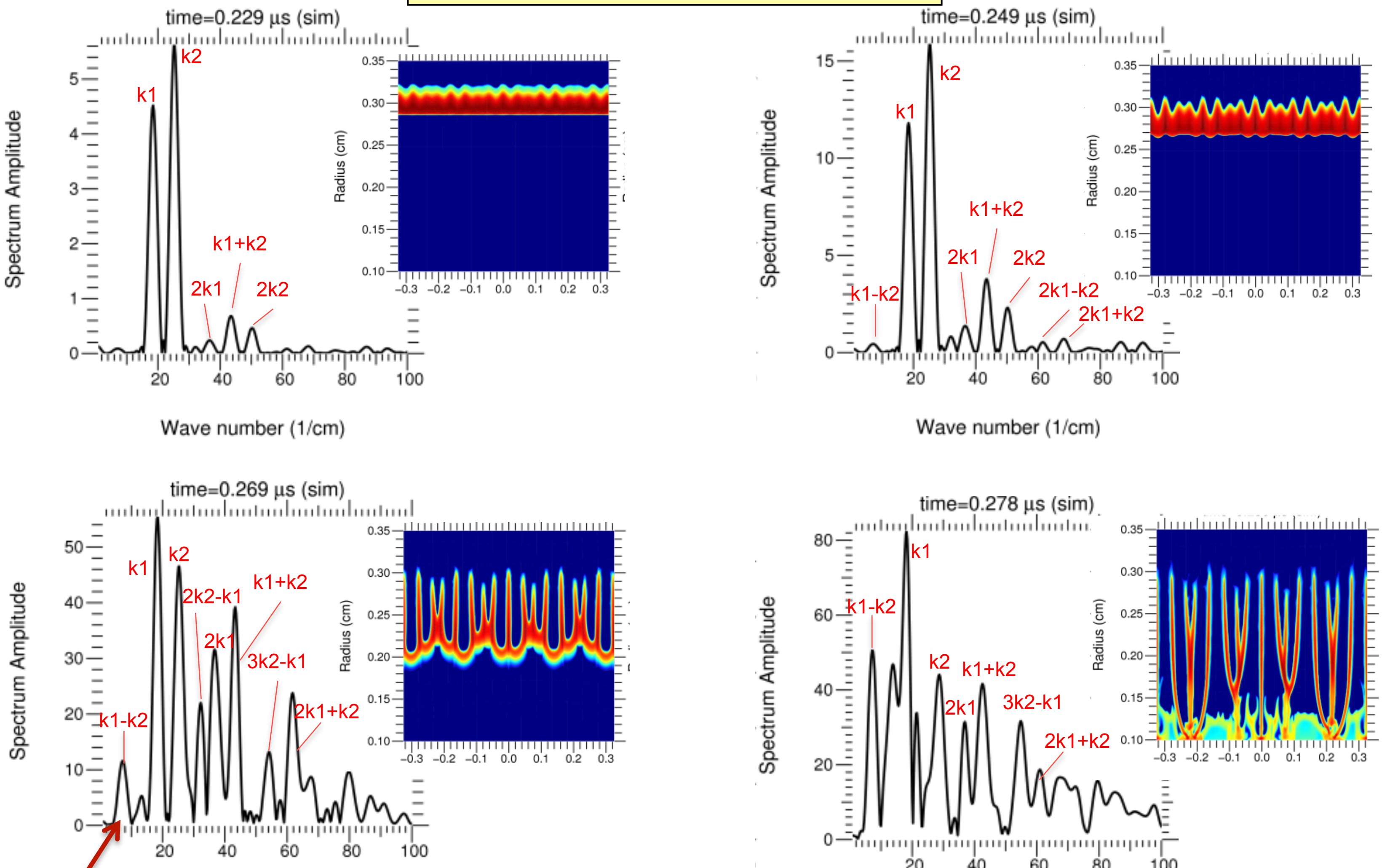
Experiments have been designed to test our understanding of multimode MRT instability growth in a controlled manner



- Target parameters chosen to complement and compare to existing single mode Lincoln series experiments
- Initial wavelength (400, 550 µm) and amplitude (20 µm peak to valley) chosen to be large enough to be resolved with backlighter at t=0, dominate over electrothermal instabilities, and enter nonlinear regime quickly
- Non-integer wavenumbers chosen to remove ambiguity of mode coupling with higher mode harmonics
- Tungsten rod suppresses time integrated self emission in radiographs

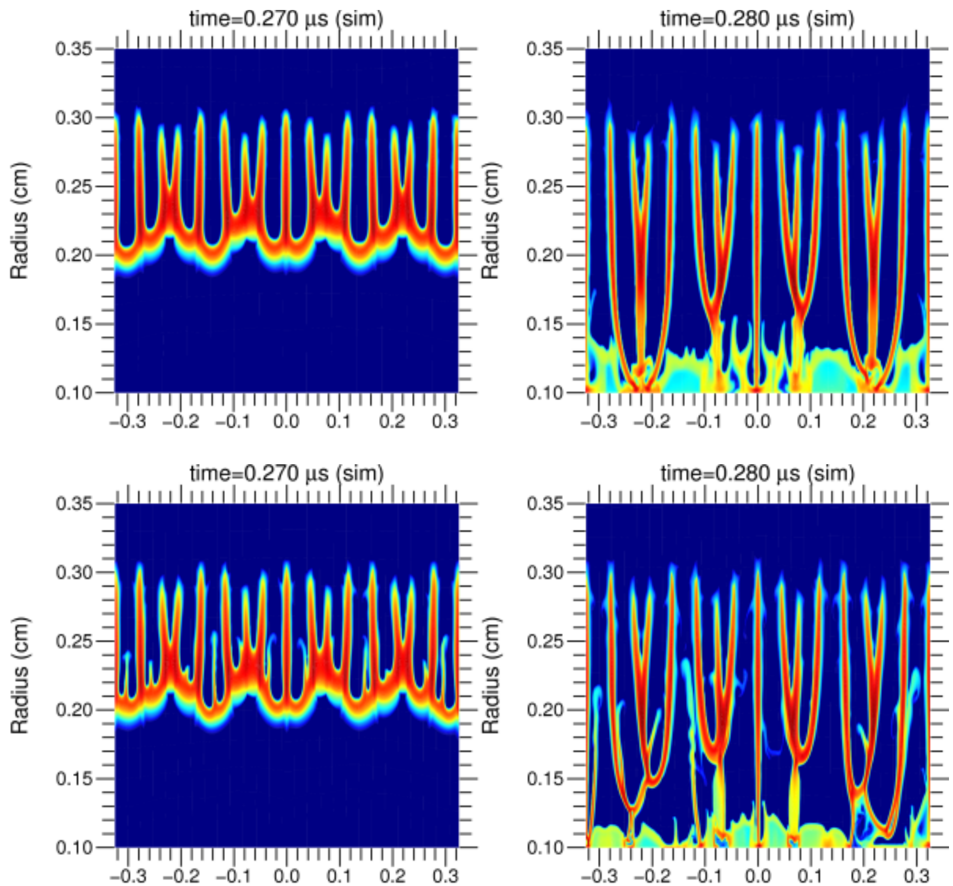
Lincoln multimode experiments will test our simulation codes prediction of MRT instability growth in the nonlinear regime

areal density FFT at each axial position



Inverse cascade process

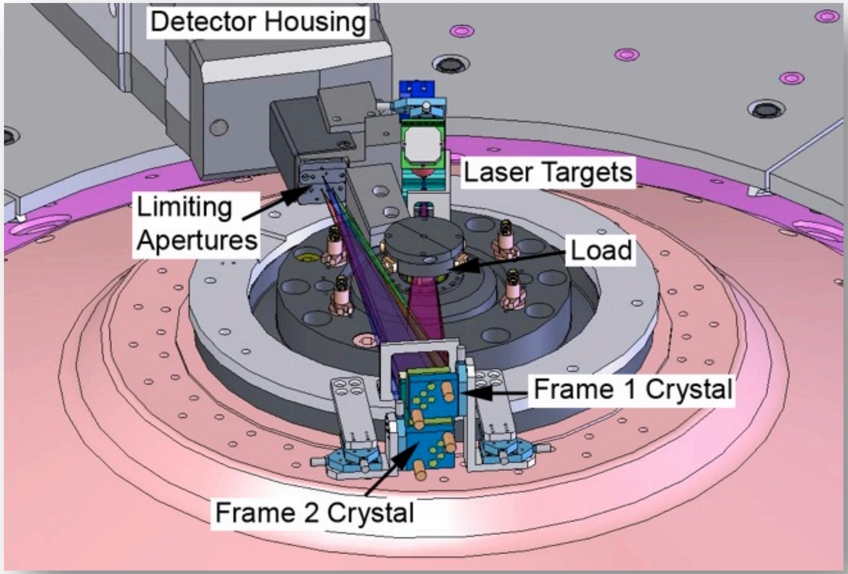
Development of well resolved long wavelengths can affected by higher grid resolutions through nonlinear mode coupling



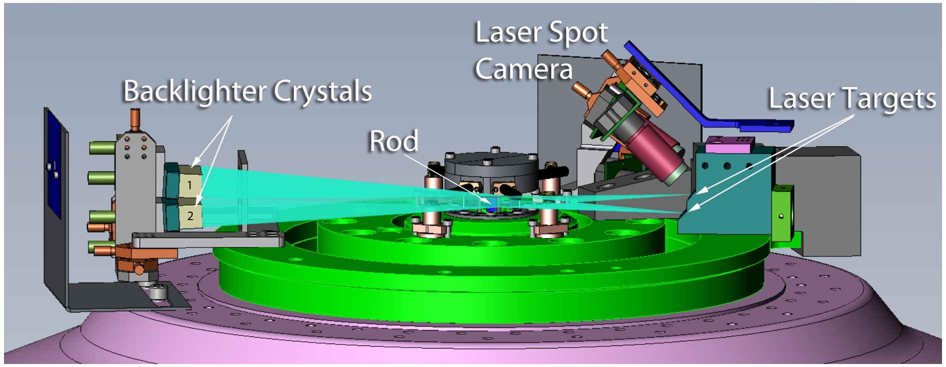
16 micron axial resolution
Wavelengths > 160µm resolved

8 micron axial resolution
Wavelengths > 80µm resolved

2-frame monochromatic crystal backlighting will be used to image instability growth



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)

Radiograph lines of sight ±3° from horizontal

Quantitative comparisons must account for opacity affects in the observed perturbation spectrum

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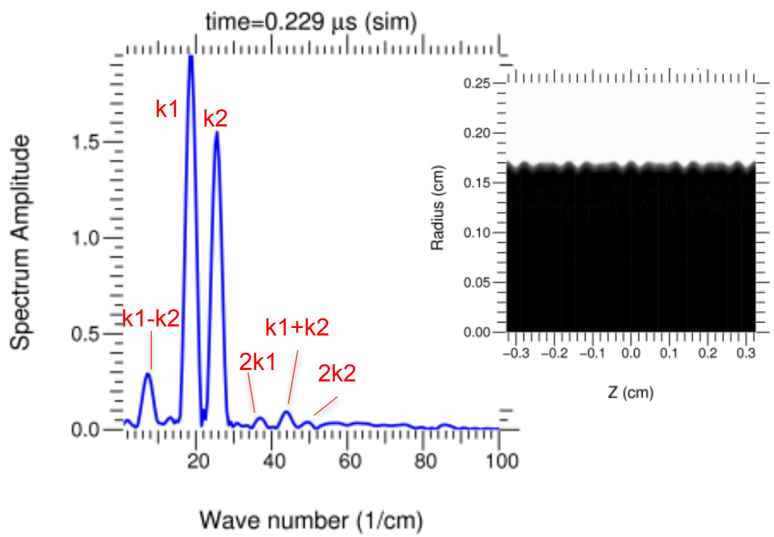
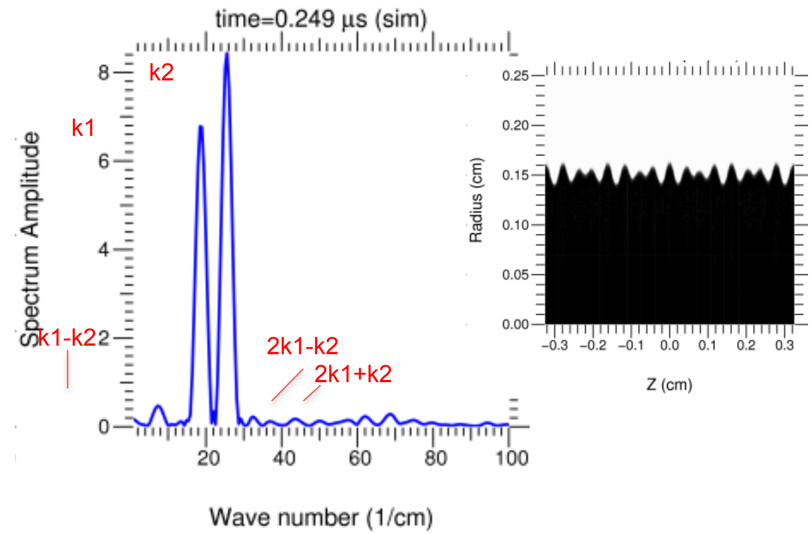
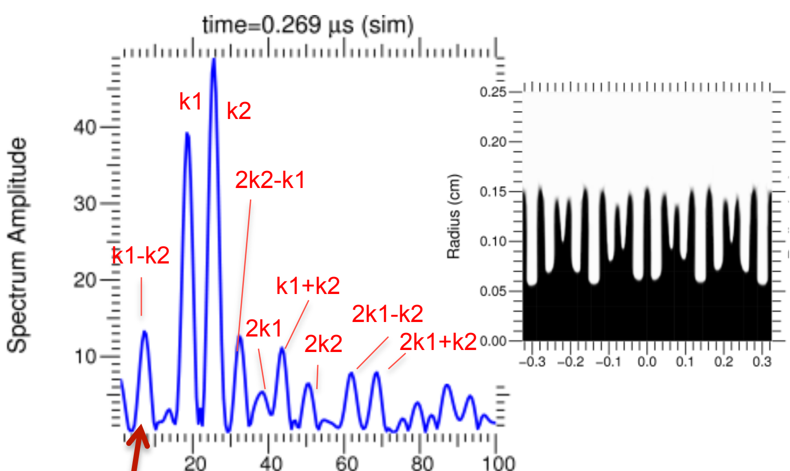
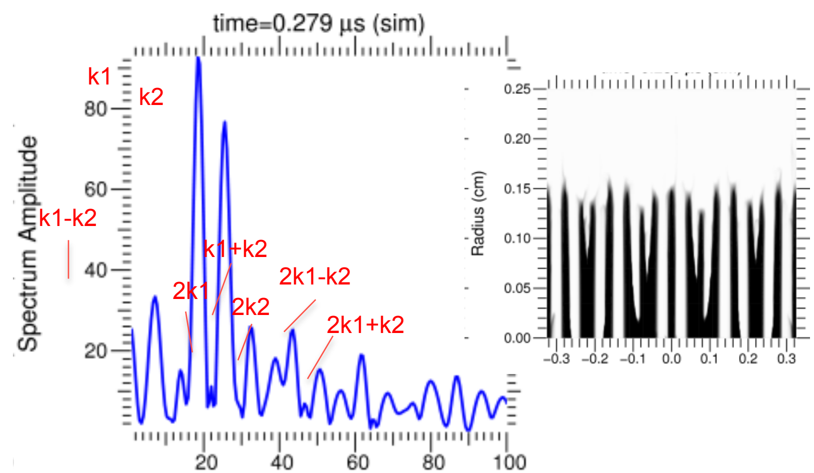




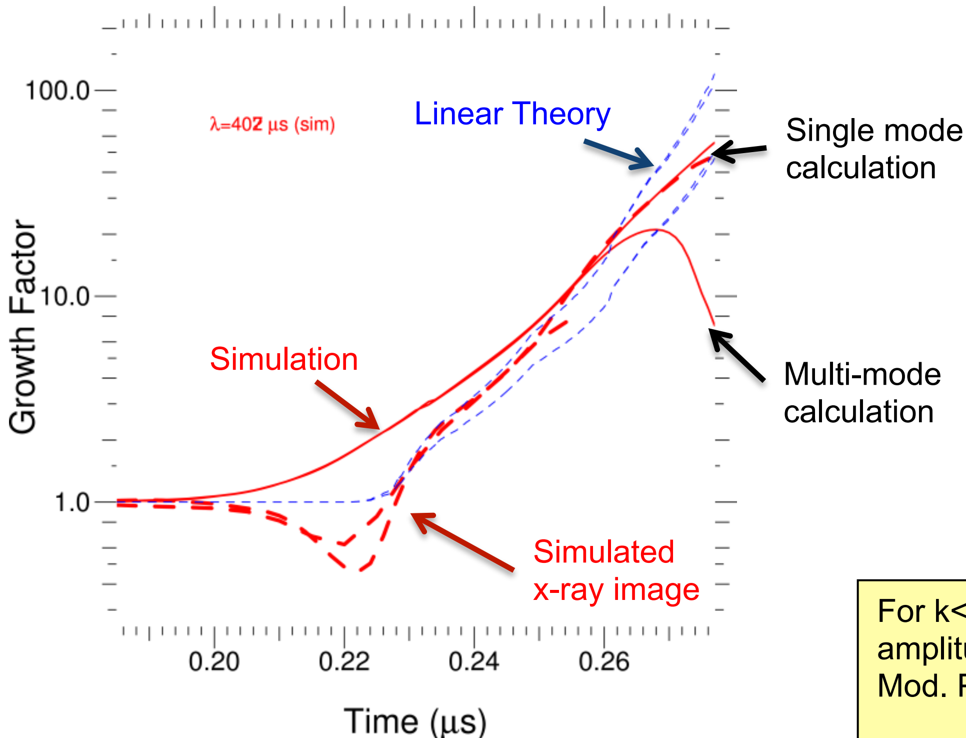




Inverse cascade process

FFT of 50% transmission contour

Both single mode and multi-mode calculations fit linear MRT theoretical growth predictions well after amplitude becomes comparable to wavelength



Growth rate
from linear theory

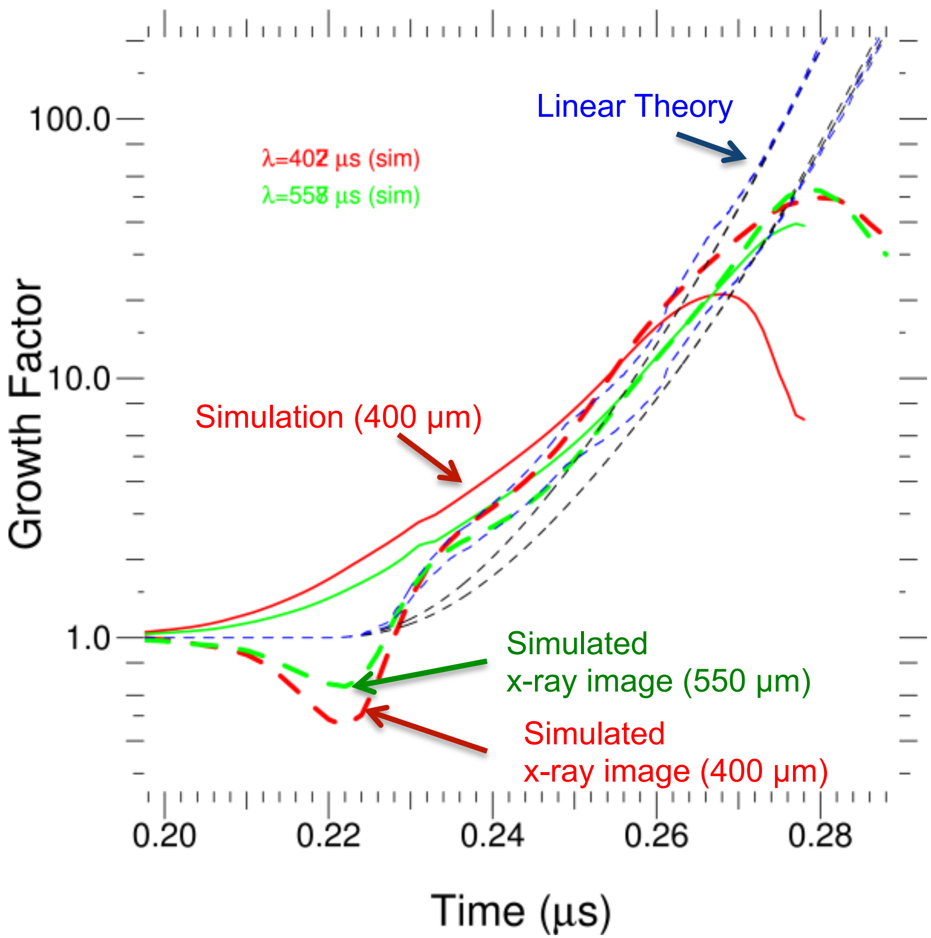
$$\Gamma^2 = kg$$

Calculate *g* using I(t)

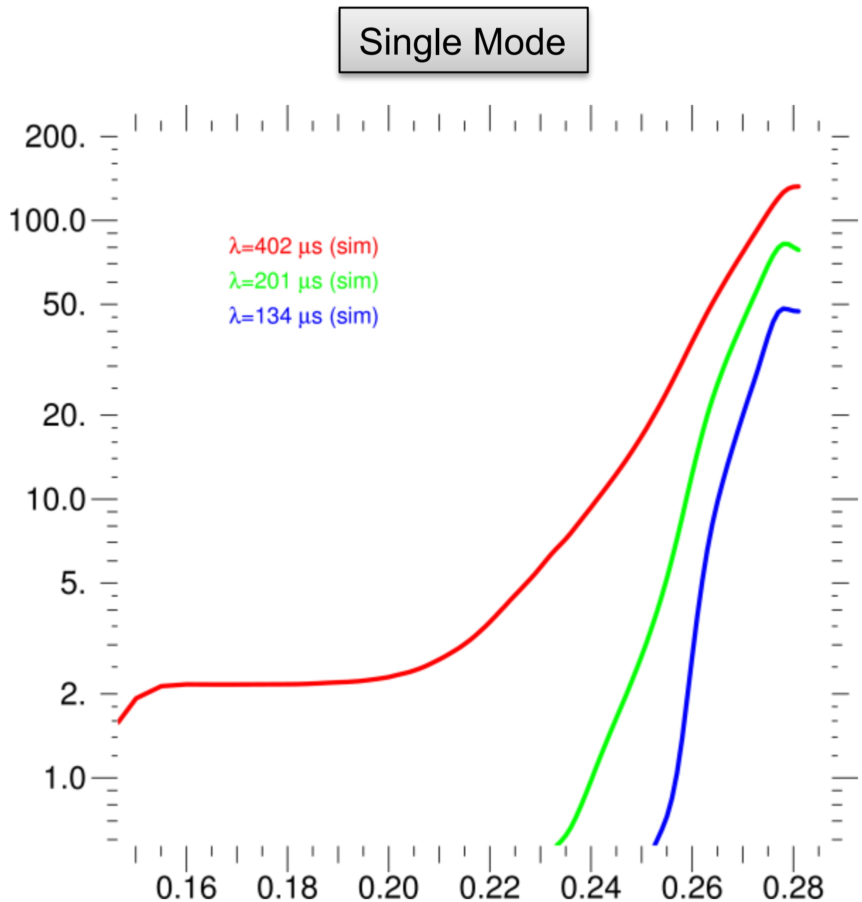
$$\Gamma^2 = k\frac{\mu_0}{8\pi^2}\frac{I^2}{R^2}\frac{1}{\rho(\Delta r)}$$

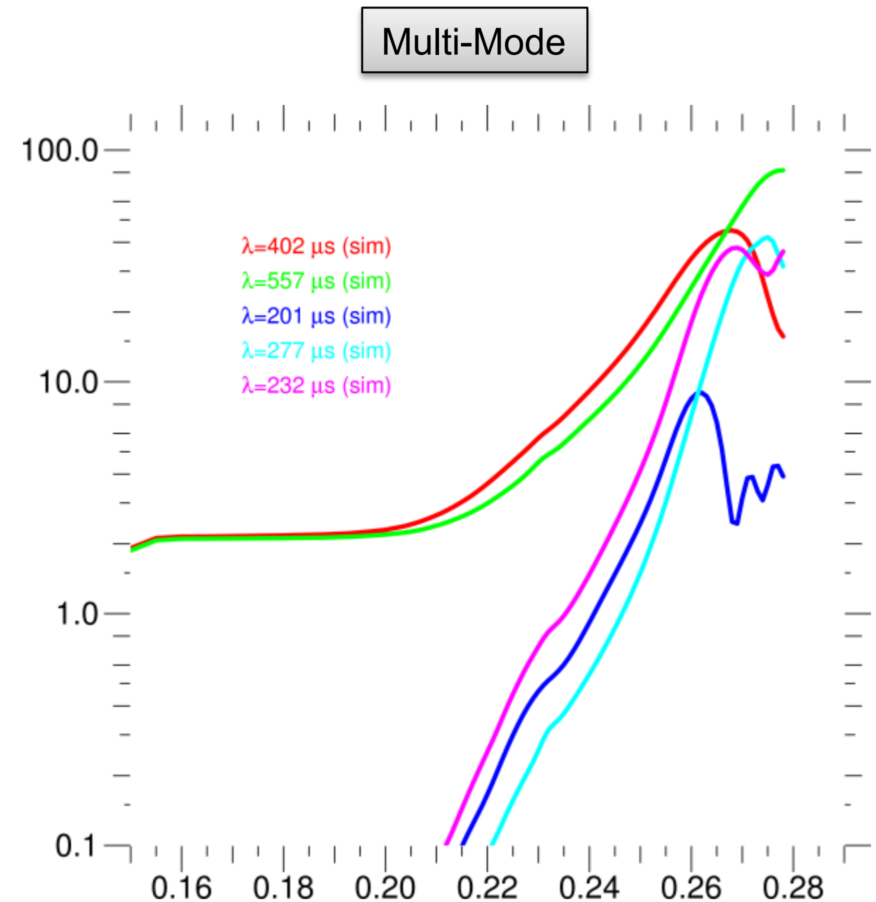
For k<(1/h), linear theory increasingly poor approximation as amplitude goes to ~1/k , Ryutov, Derzon, & Matzen, Rev. Mod. Phys. 72, 167 (2000).

Simulated radiographs match linear growth theory significantly better than direct FFTs of simulated areal density



Onset of nonlinear saturation occurs earlier in time at smaller amplitudes in the multimode case





Conclusions

- Experiments have been designed to test code predictions of multi-mode MRT instability growth in a controlled manner
- These experiments should be able to quantitatively test multi-mode coupling and the inverse cascade process in magnetically driven liners
- Interestingly, x ray images of the perturbation growth are predicted to fit linear theory much better than a direct comparison to the simulations
- At early times, both multi-mode perturbations are predicted to grow completely independently and identically to single mode calculations
- MRT multi-mode perturbations in liners exhibit exponential growth even after nonlinear effects become apparent
- Higher resolution can affect well resolved long wavelength modes via mode coupling