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Z Experiments to Measure Ablative Rayleigh-Taylor Growth of Isolated Capsule Defects

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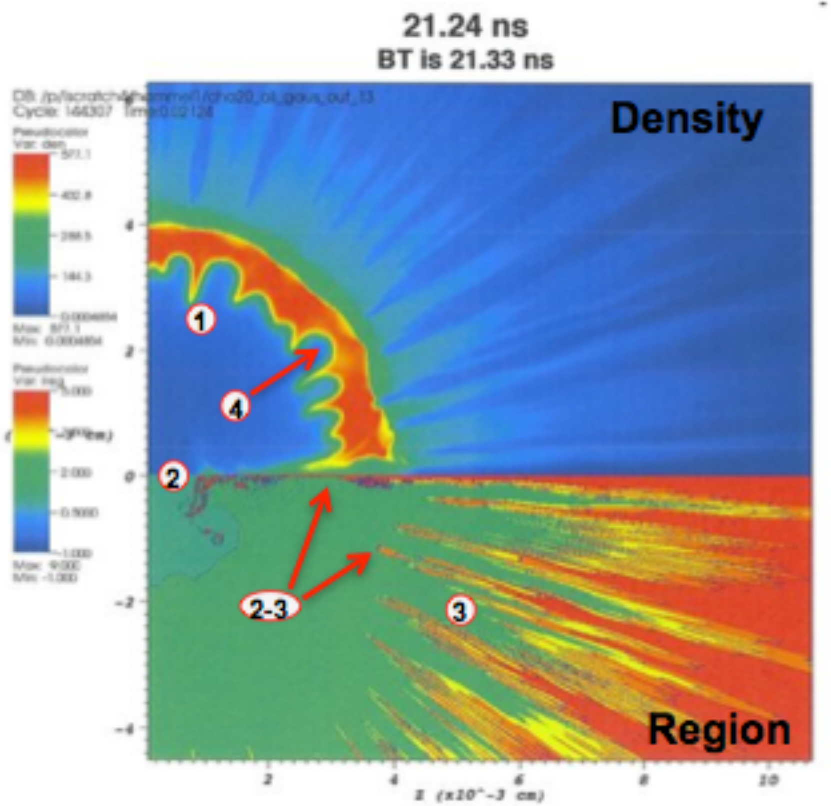
NIF convergent Rayleigh-Taylor studies have recently focused on ablator-fuel mix

2D simulation by Bruce Hammel of nominal perturbations on Rev5 implosion, plus divot



initial bump: ~ - 300 nm amp (a divot)
15 μm FWHM

Four risks to ignition due to hydro instability growth

1. **Spikes of cold DT reduce size of hot spot.**
2. **Jets of ablator material get into the hot spot from fill tube or ablator surface defects (bumps/divots). Biggest potential impact as conditions go off-normal.**
3. **High-mode growth at DT/CH interface; closest effect to conventional mix. Outlier bubbles could penetrate to hot spot (3 becomes 2).**
4. **Thin regions can blow out.**

Engineered divots/bumps are much larger than this !

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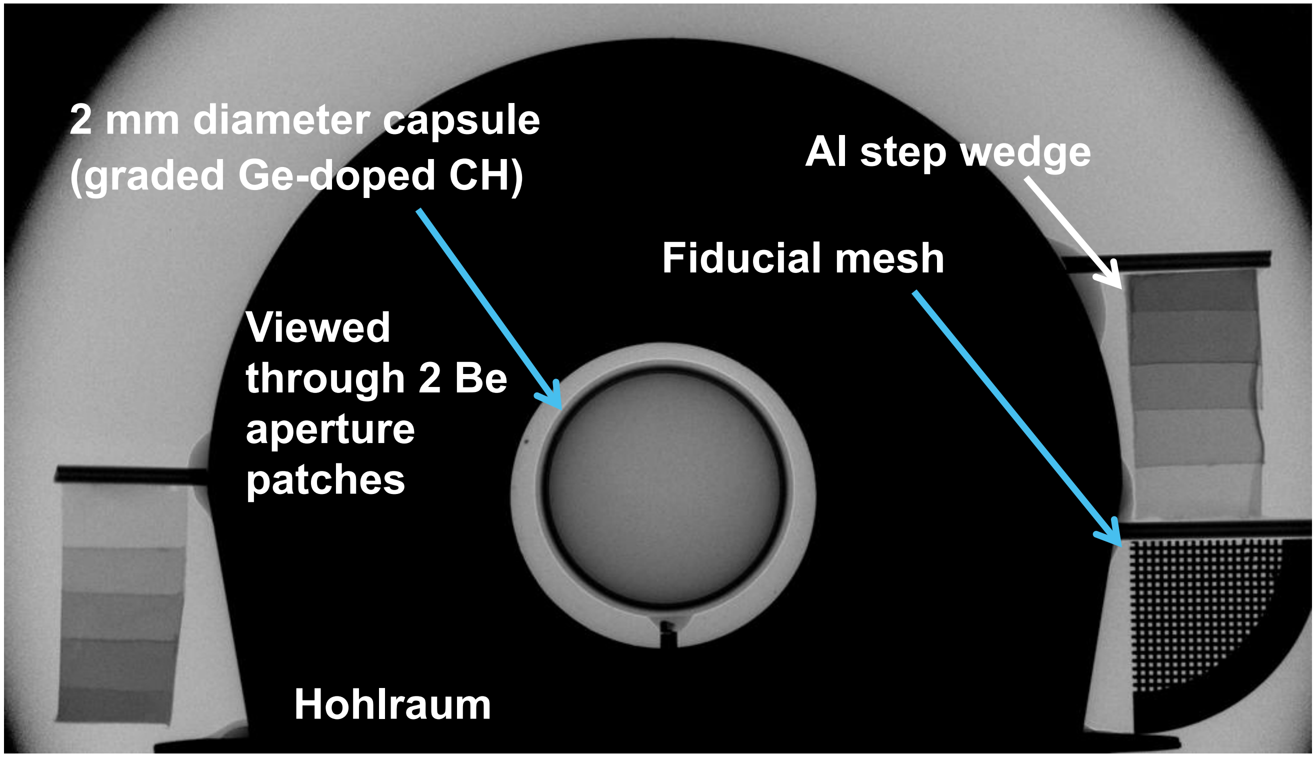
The goal of these Z experiments is to measure the RT growth of engineered defects on the capsule ablator surface

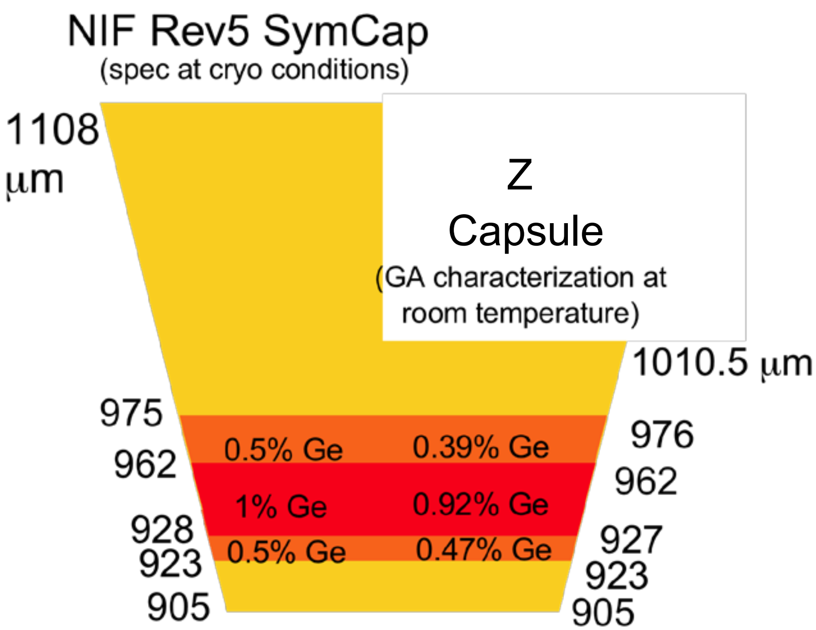
Static 45 keV radiograph of capsule and hohlraum assembly



Radiographs of the assembled targets were produced by Korbie Killebrew and Diana Schroen

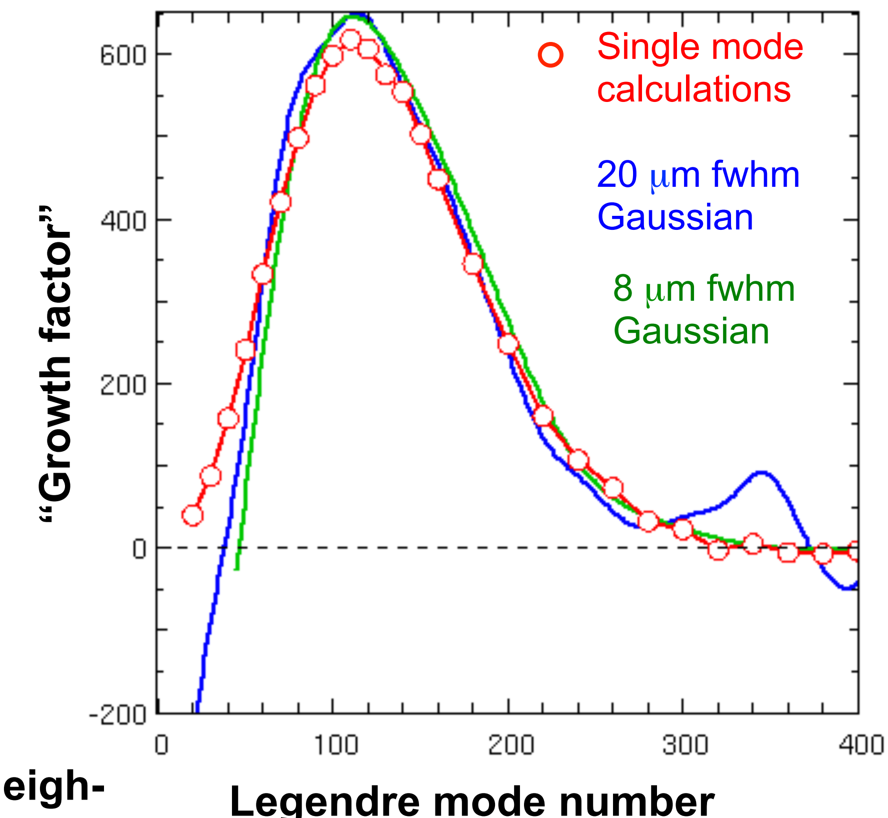
Z capsule design was chosen to give calculated RT growth factors similar to the NIF Rev 5 capsule

Capsule radial build comparison



Z capsule growth factors at peak velocity

(surrogate fuel interface δr)/(initial ablator δr)



Goal: Radiographically measure the Rayleigh-Taylor growth of well-characterized engineered defects to compare with simulations

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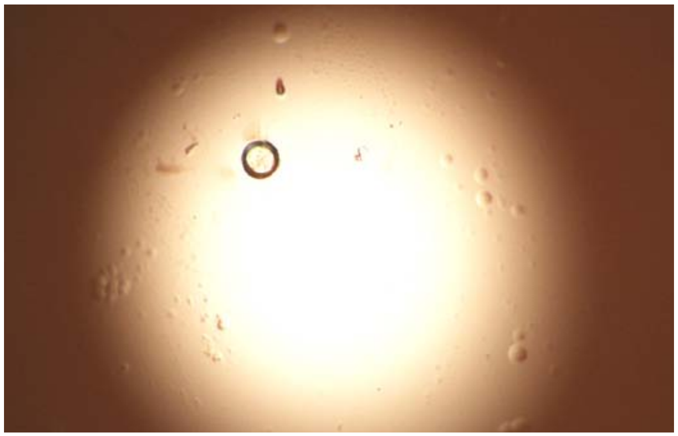
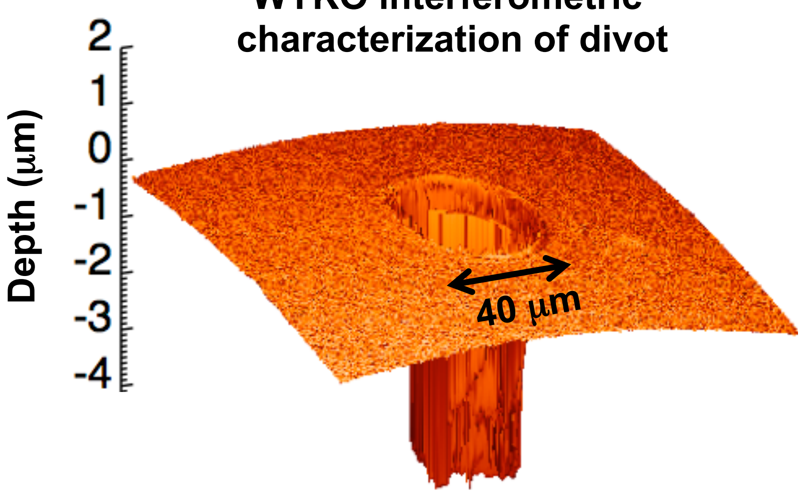
General Atomics produced and characterized capsules with divots and bumps on the ablator surface

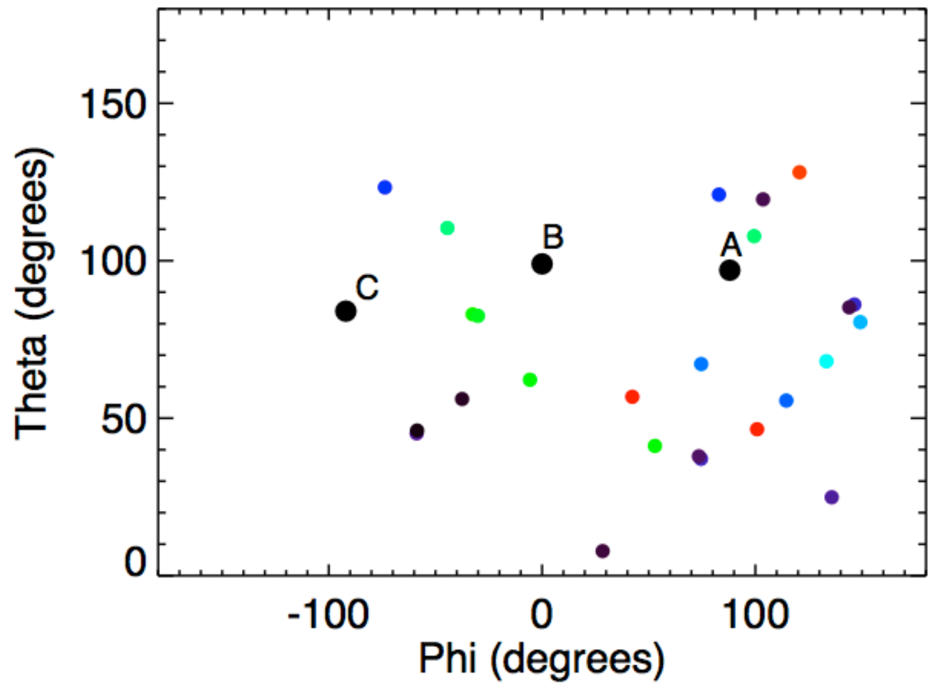
10x visible light close-up photo of divot



WYKO interferometric characterization of divot



PSDI (θ,ϕ) map of divots (A,B,C) + top 25 inherent bumps



Laser-formed divots are 4 µm deep x 40 µm wide
Inherent bumps range from 240 to 470 nm in height

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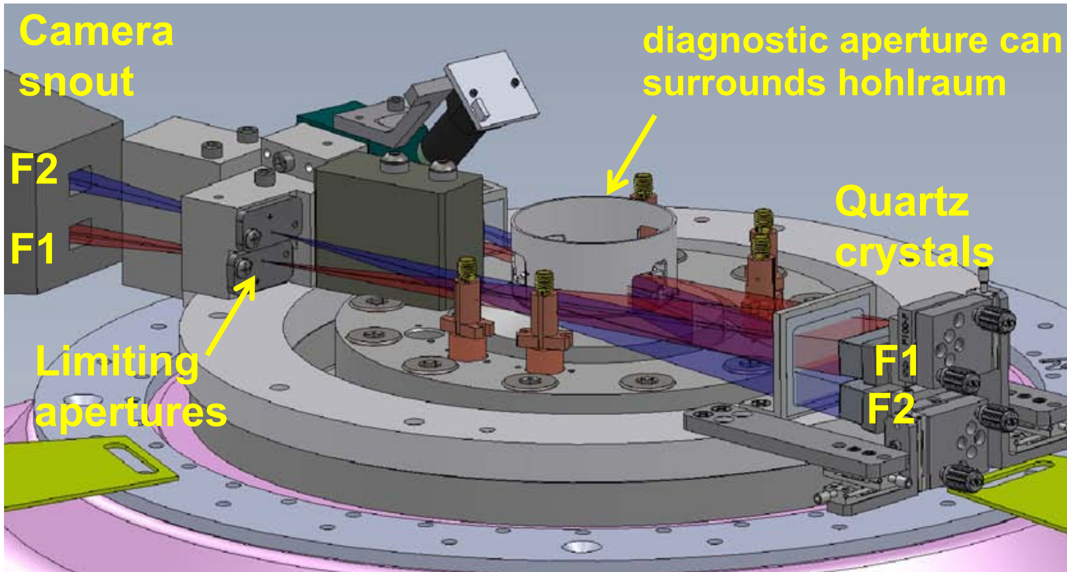
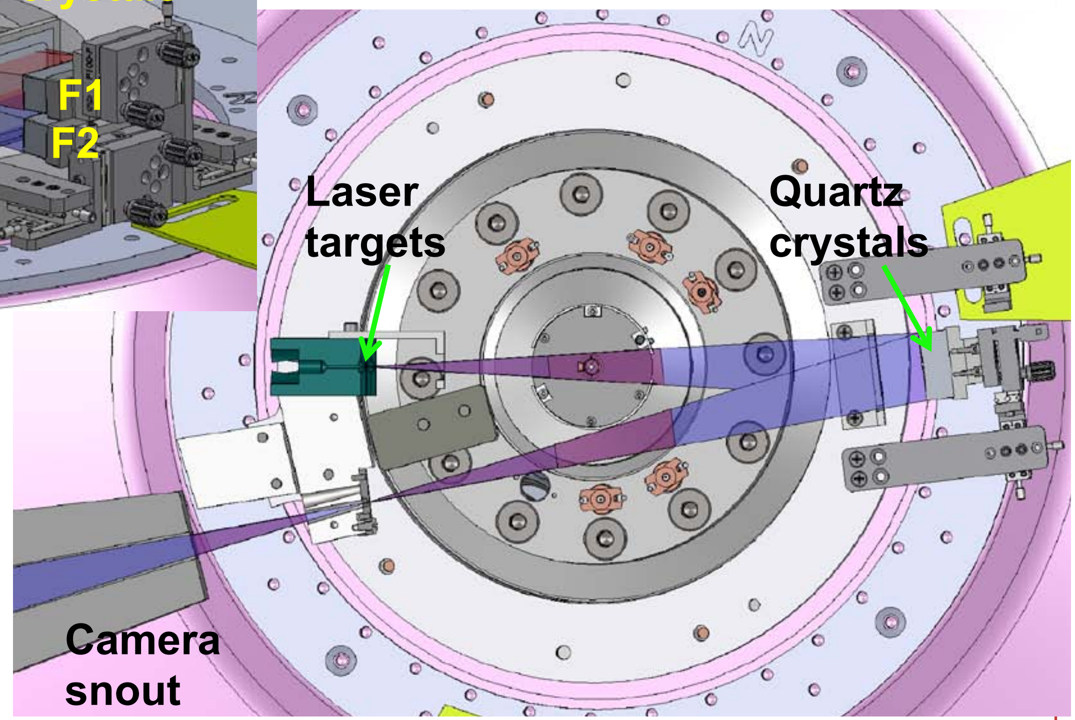
The primary diagnostic for this experiment is 2-frame radiography using bent-crystal imaging[1] at 6.151 keV



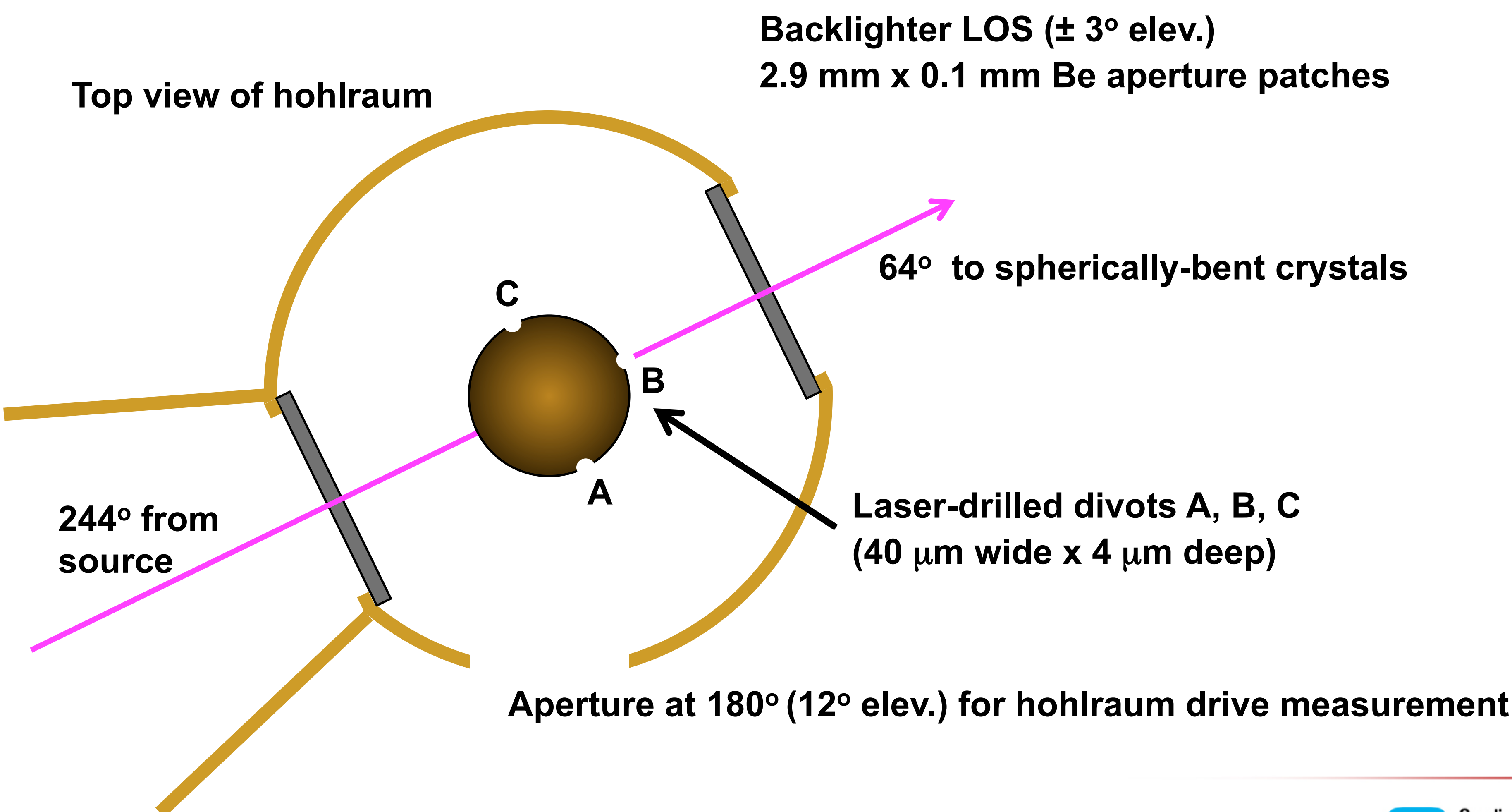
Goal: capture face-on radiographs of capsule defect development



- **ZBL laser[2] provides 2 pulses (~1 kJ, 1 ns each) of 2ω onto Mn targets**
- **Bragg angle (83.15°) selects 6.151 keV x-rays for quartz_2243 spacing**
- **2 crystals, 2 image plates provide images at ± 3° from radial**
- **System spatial resolution ~ 14 μm**

[1]D. B. Sinars *et al.*, Rev. Sci. Instr. **75**, 3672 (2004); G. R. Bennett *et al.*, Rev. Sci. Instr. **79**, 10E914 (2008).
[2]P. K. Rambo *et al.*, Appl. Opt. **44**, 2421 (2005)

First experiments fielded a capsule with 3 divots, backlit face-on using 6.151 keV bent crystal imaging



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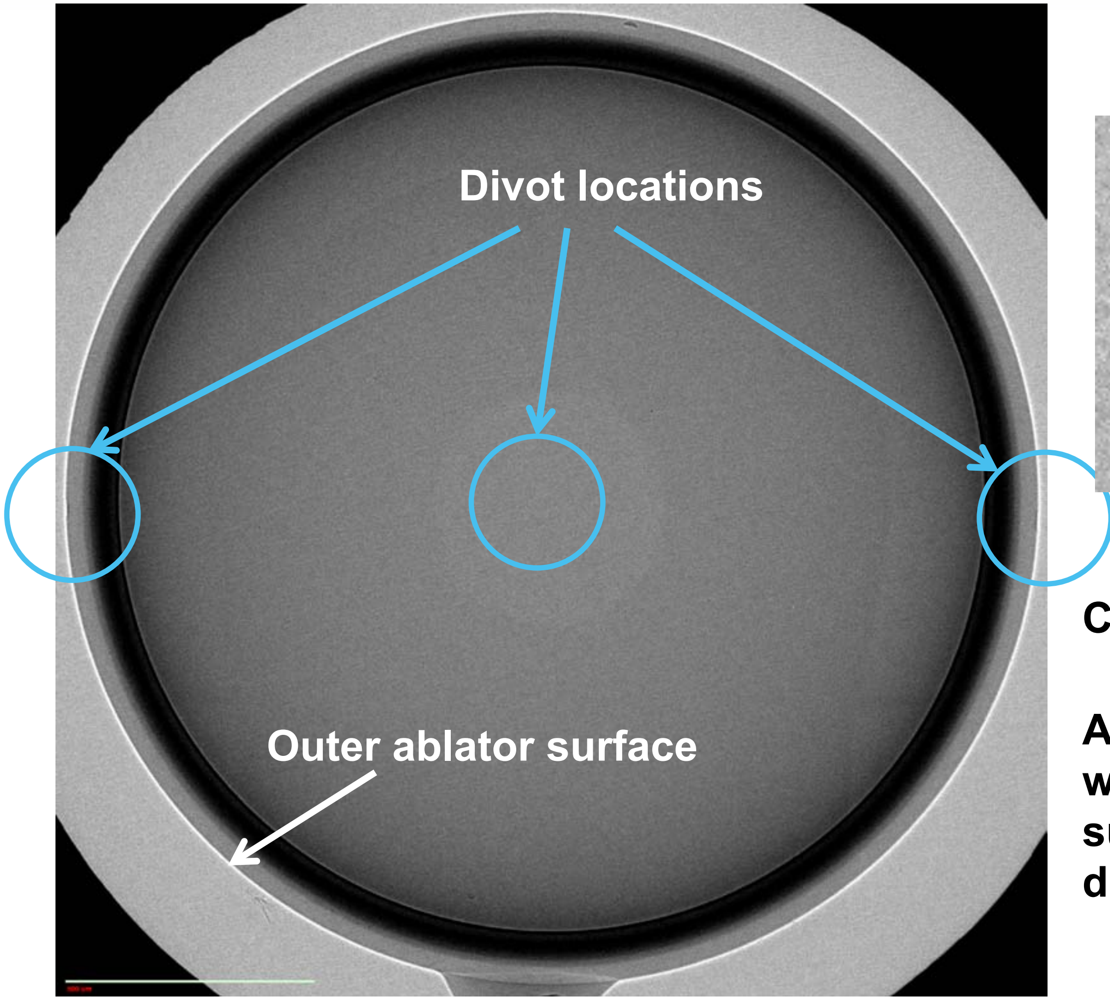
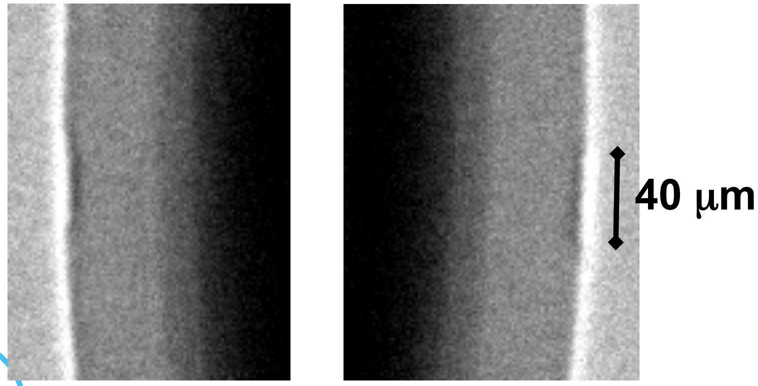
Static 45 keV radiograph of assembled capsule and hohlraum shows the divot locations



Divots viewed in limb are most easily seen

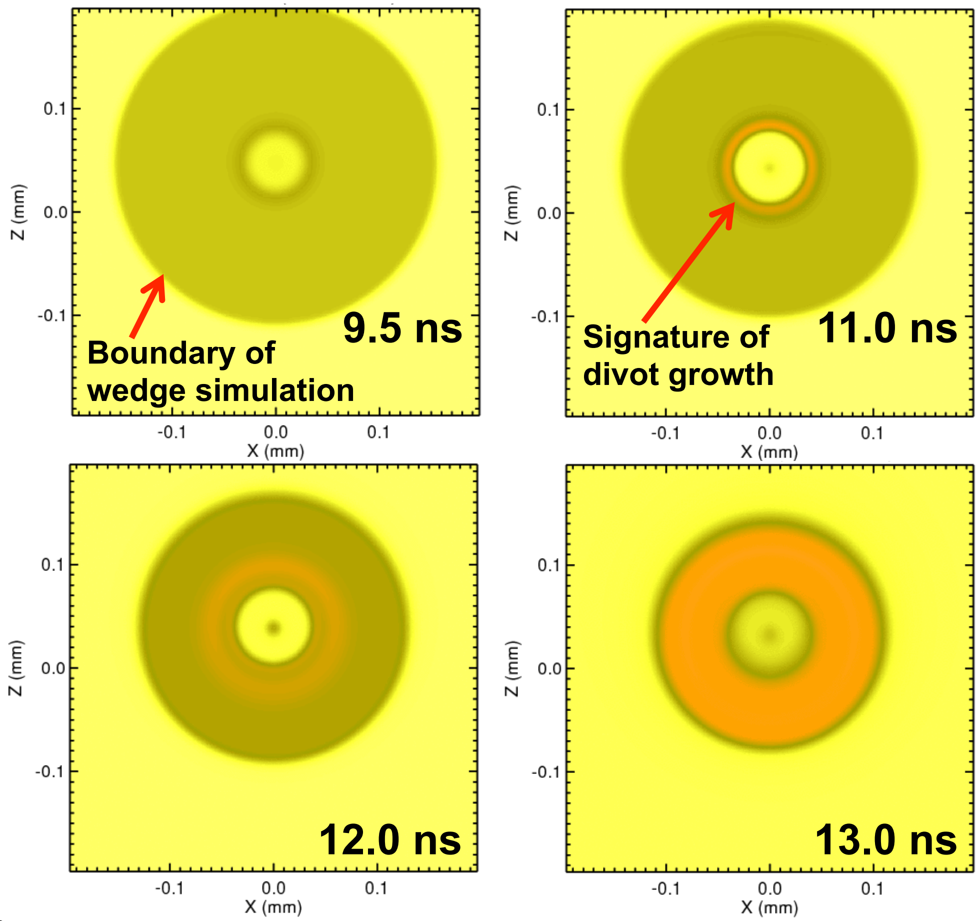


Center divot cannot be seen directly

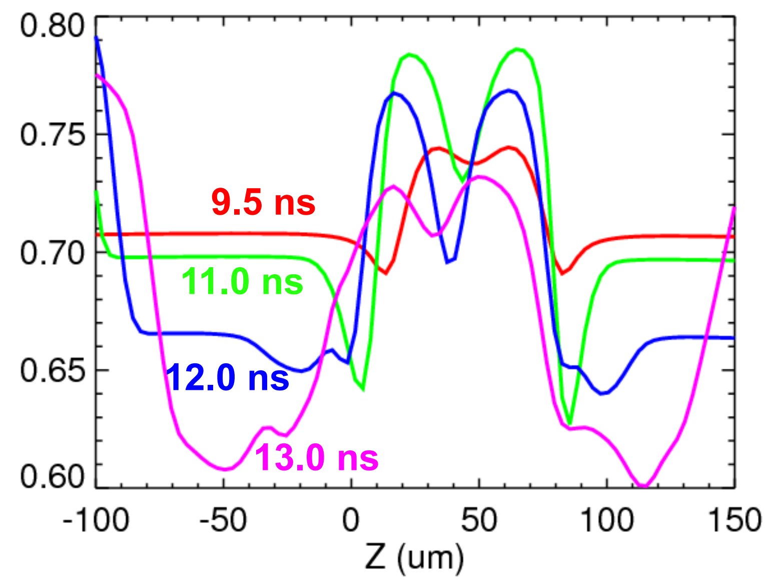
Alignment information combined with the PSDI map of the capsule surface confirms centering of the divot to be radiographed face-on

Pre-shot LASNEX simulations predict the RT growth of the divot produces a significant transmission modulation

Synthetic 6.151 keV face-on radiographs (1 ns gate, 12 μm spatial resolution)



Transmission profiles evolve as capsule implodes and divot grows



Peak drive Tr occurs at 12.5 ns

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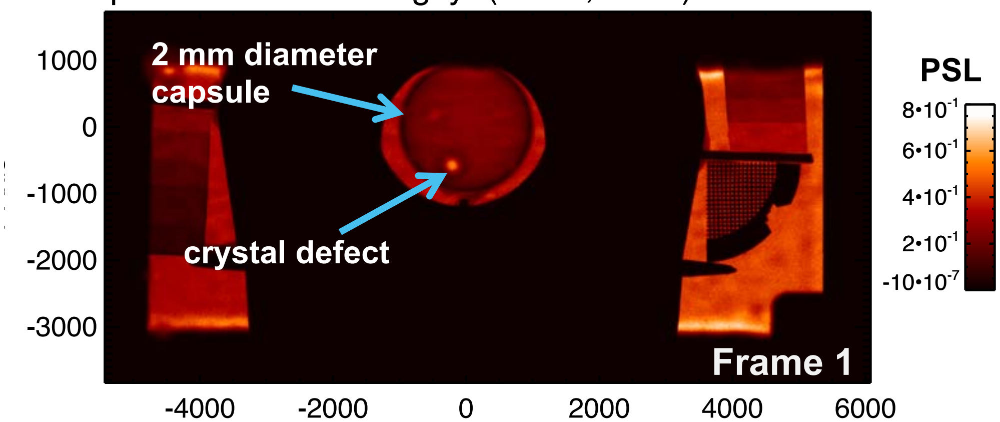
Pre-shot radiograph prior to z2149 produced 2 frames useful for registering the initial capsule center

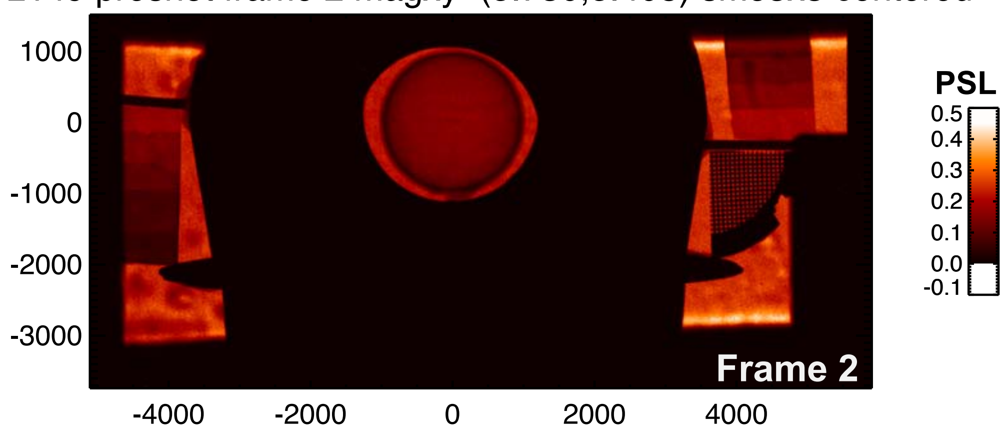
z2149 preshot frame 1 magxy=(5.702,5.382) smo3x3 centered



Prominent crystal defect near center of capsule

Backlighter = 0.33 - 0.45 PSL (low due to protective filters)

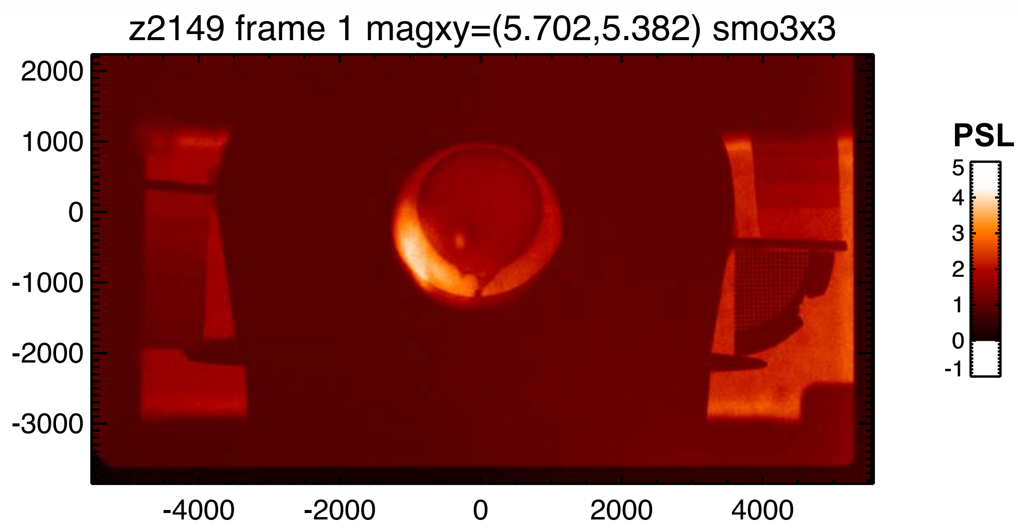
2149 preshot frame 2 magxy=(5.730,5.408) smo3x3 centered



High quality crystal, especially in capsule region

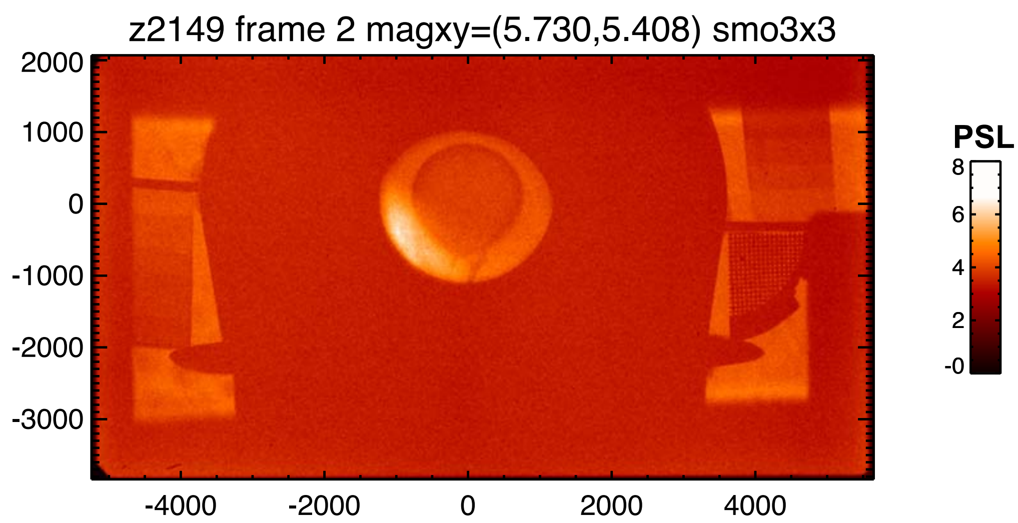
2 frames are acquired at ± 3° from equator of capsule

First Z shot (z2149, 1/6/11) produced 2 frames of 6.151 keV radiography early in the capsule implosion



Background = 0.9 - 1.0 PSL
Backlighter ~ 1.0 PSL

Image captured early due to long rise time of Tr(t) in hohlraum



Background = 3.4 - 3.5 PSL
Backlighter ~ 0.9 PSL

Timing with respect to capsule implosion phase is closer to what we wanted for frame 1

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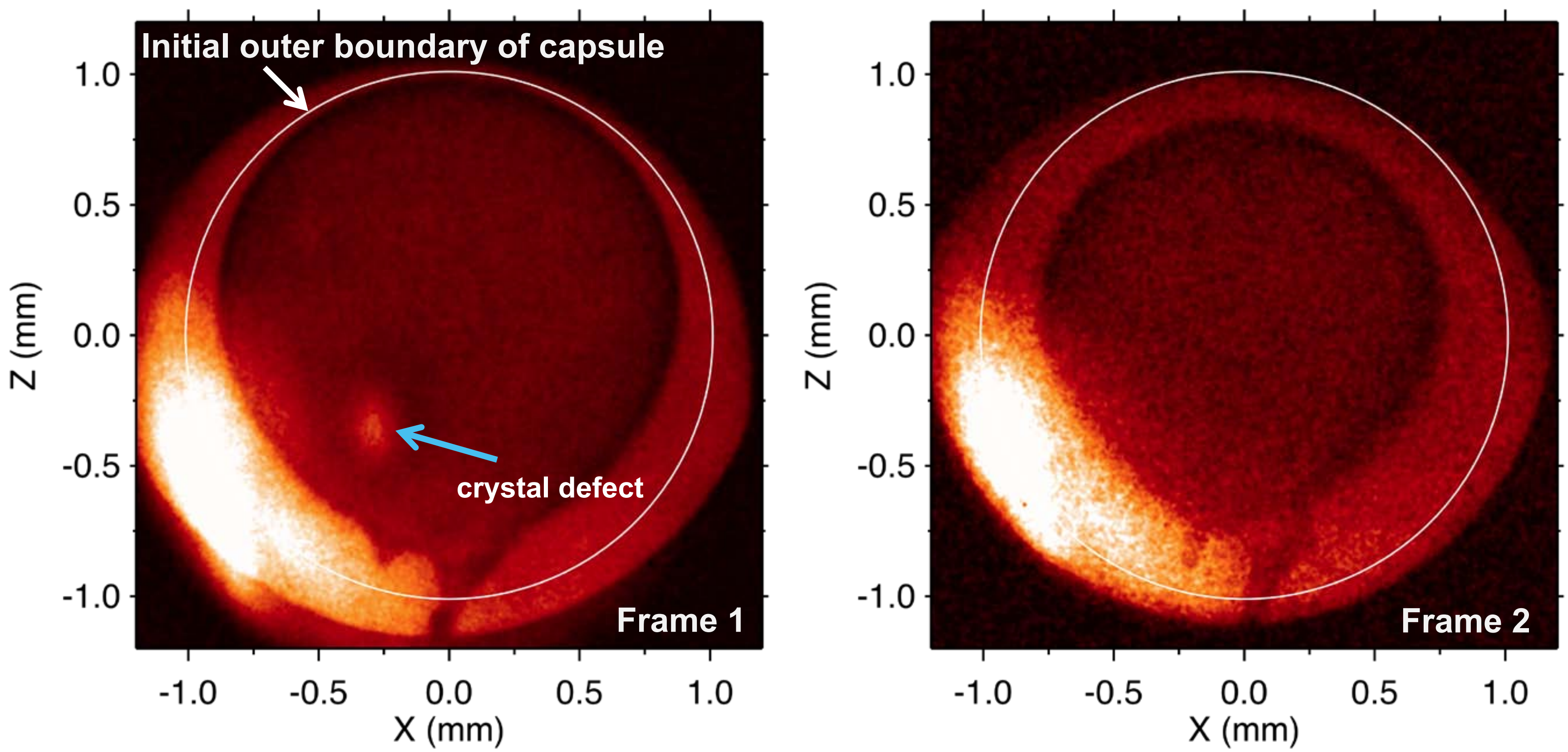
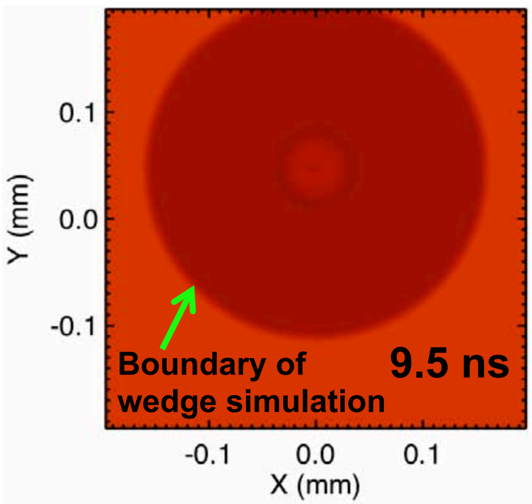
After background subtraction, capsule limb shape is measurable but no clear sign of face-on divot growth



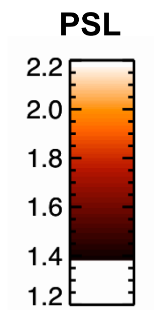
- Image centers (0,0) registered using the pre-shot radiographs
- Follow-on experiment attempted to image capsule later in the acceleration phase
- As it turned out, z2149 had the lowest background of the 3 Z shots to date

Synthetic radiographs including image plate noise* model predict faint signature of divot growth at observed backlighter and background levels

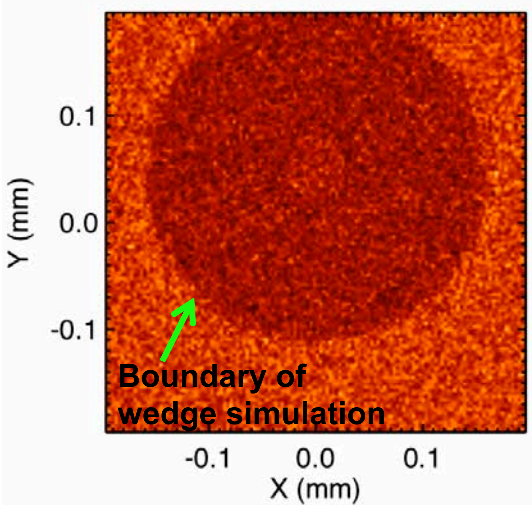
Frame 1



No noise
background = 1.0 PSL
backlighter = 1.0 PSL

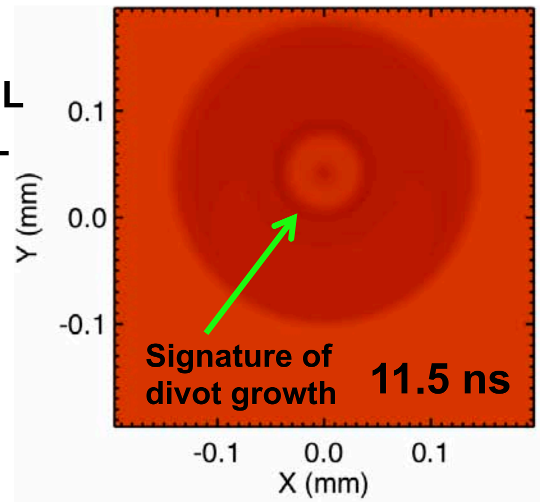


Noise model

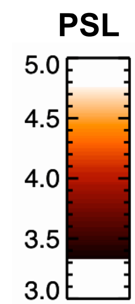


Divot growth hard to distinguish at this early time

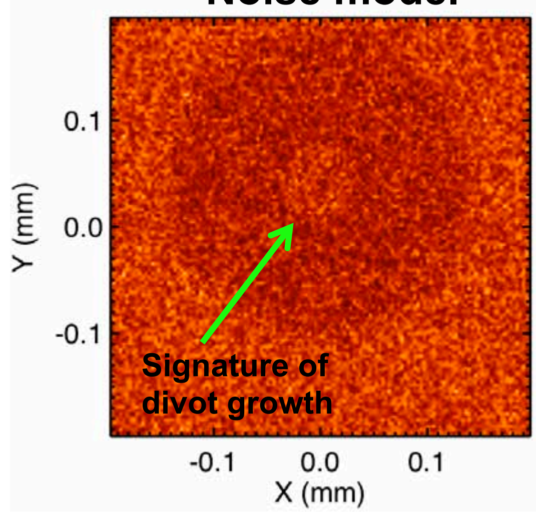
Frame 2



No noise
background = 3.4 PSL
backlighter = 0.9 PSL



Noise model

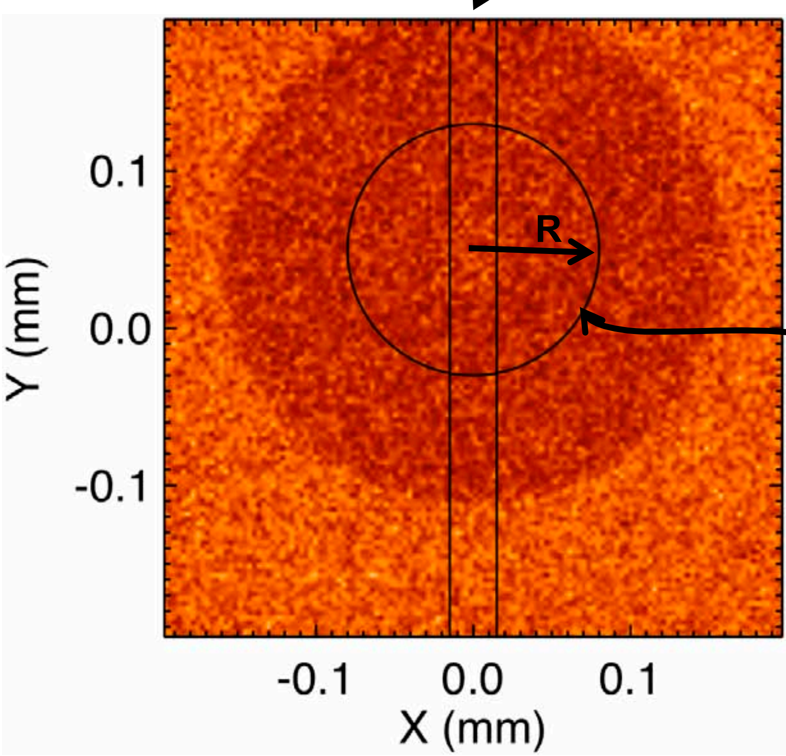


Divot visible to the eye even at this level of background…

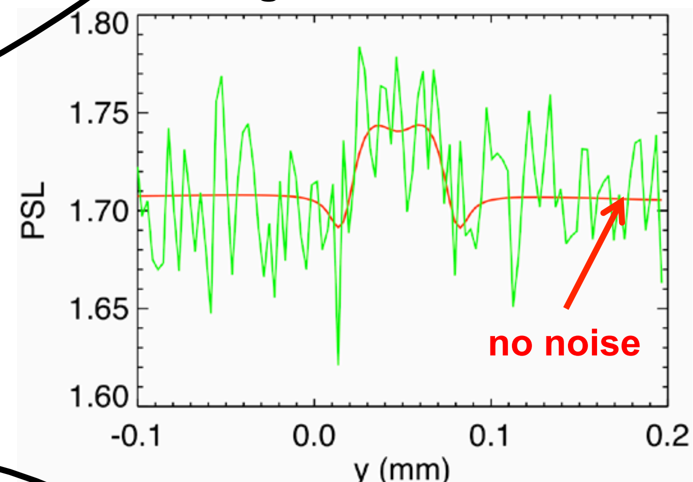
*** includes photon statistics + IP scanner noise**

Angle-averaged lineouts can identify divot feature in noisy synthetic radiographs more clearly than straight lineouts

Frame 1 synthetic radiograph with noise (another realization)

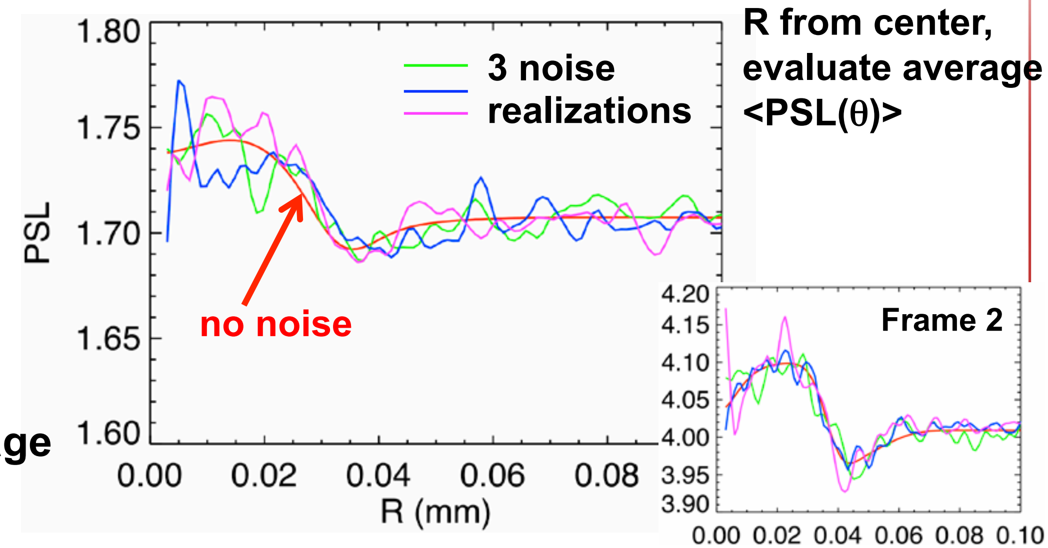


Straight vertical lineout



Average over 30 μm wide lineout through divot center

Angle-averaged lineouts



For each radius R from center, evaluate average <PSL(θ)>

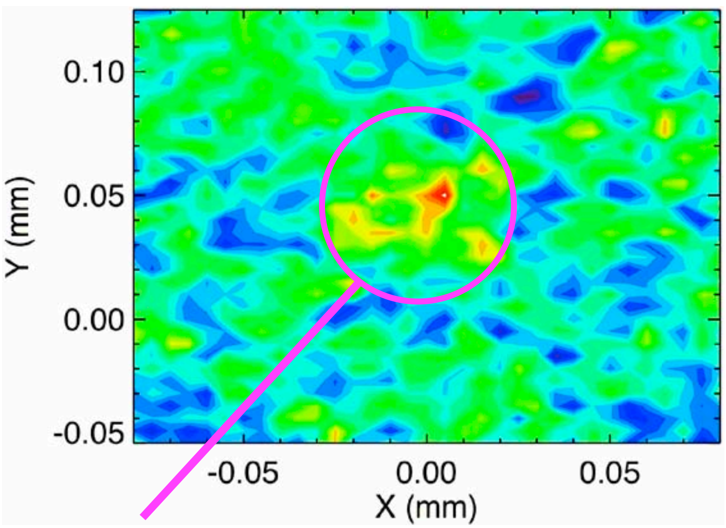
In this case we know *a priori* where the center of the divot should be in the image

Without precise knowledge of the divot center, angle-averaged lineouts *may* allow identification of divot in noisy synthetic image

- Scan (x_o,z_o) within a 160x175 μm box around (known) divot location
- For each center point (x_o,z_o) form a radial (angle-averaged) lineout of PSL(R)
- Define F(x,z) as PSL(R=3 μm) – PSL(R=60 μm) for radial lineout
- Expect F(x,z)>0 for divot profile

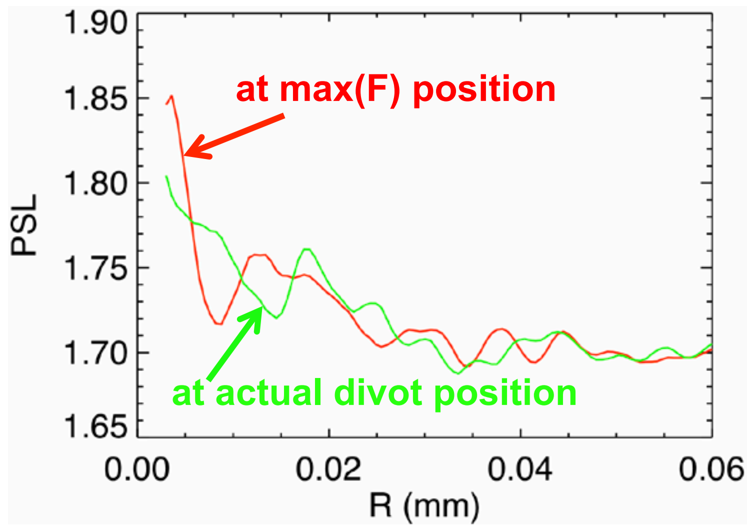
Result for noisy synthetic Frame 1 image from previous slide:

F(x,z)



Grouping of higher F values near actual divot location (0.,0.05)

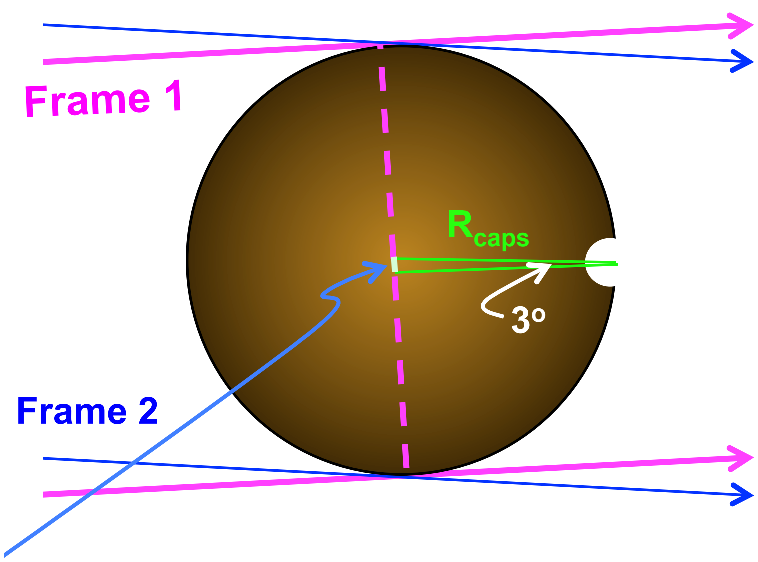
Radial (angle-avg) lineouts



Noise compromises divot growth measurement

2-frame radiography geometry determines expected separation of divot image in frame 1 vs. frame 2

2 frames on each shot acquired at ± 3° from capsule equator



Δz offset of divot in image

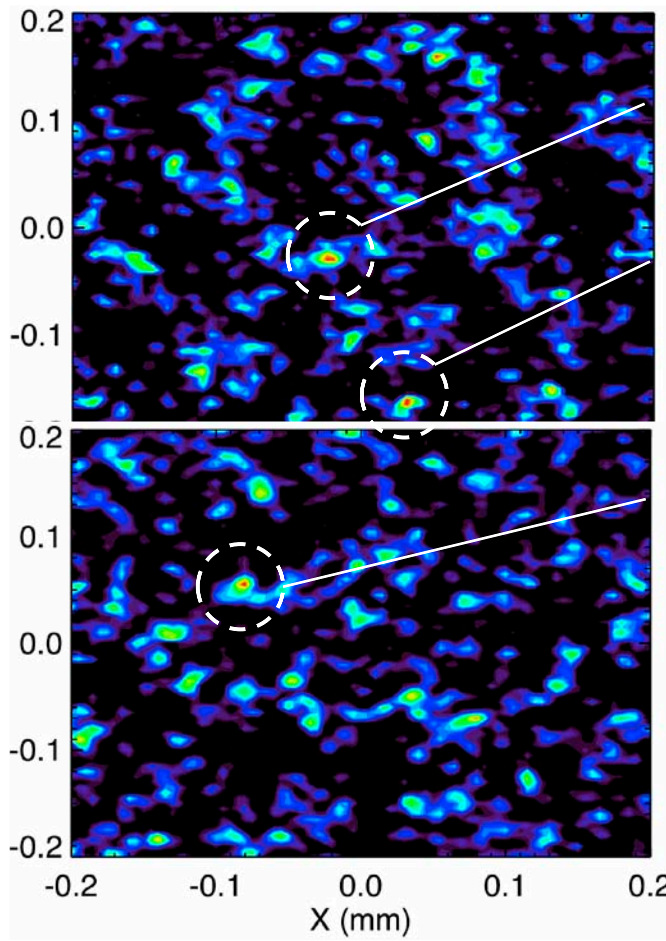
At image times acquired on shot z2149:

Frame 1 R_{caps} = 0.87 mm, Δz ≈ -46 μm

Frame 2 R_{caps} = 0.70 mm, Δz ≈ +37 μm

Divot in frame 2 should be ~ 83 μm above divot in frame 1

Contours of F(x,z)>0 in 200x200 μm window around initial capsule center



z2149 frame 1

Local F maximum (x_1,z_1)

Feature is outside divot placement window

z2149 frame 2

Peak F location (x_2,z_2)

z_2-z_1 = 85 μm consistent with divot location

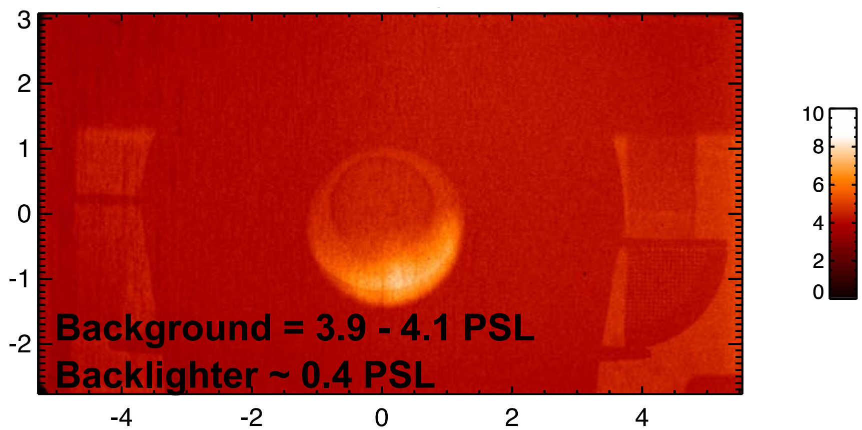
x_2-x_1 = -57 μm is inconsistent

Noise prevents unambiguous divot identification

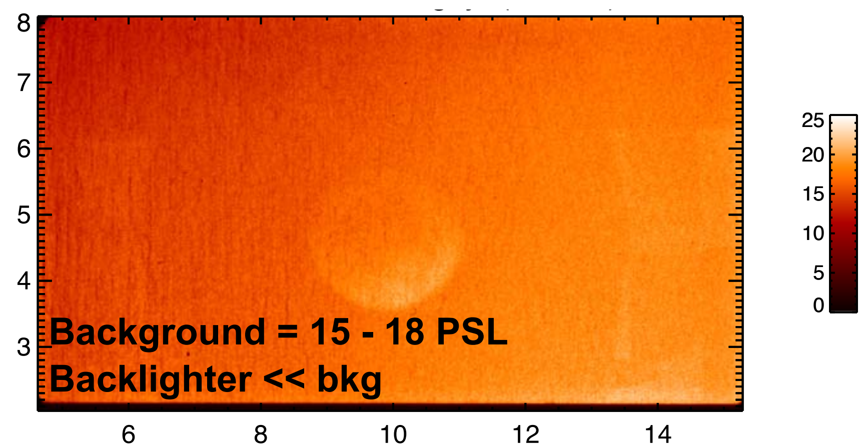
Shots z2162 and z2163 (2/9 & 2/11) were plagued by the high background levels seen in earlier series

z2162: 3-divot capsule

Frame 1

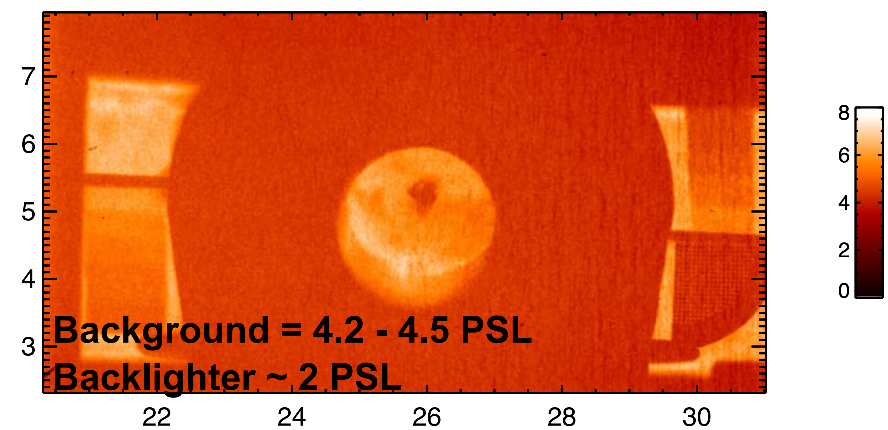


Frame 2

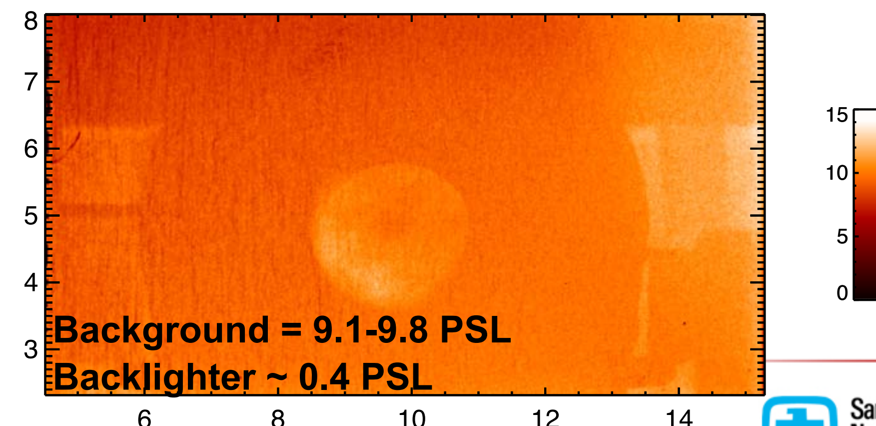


z2163: featureless capsule

Frame 1

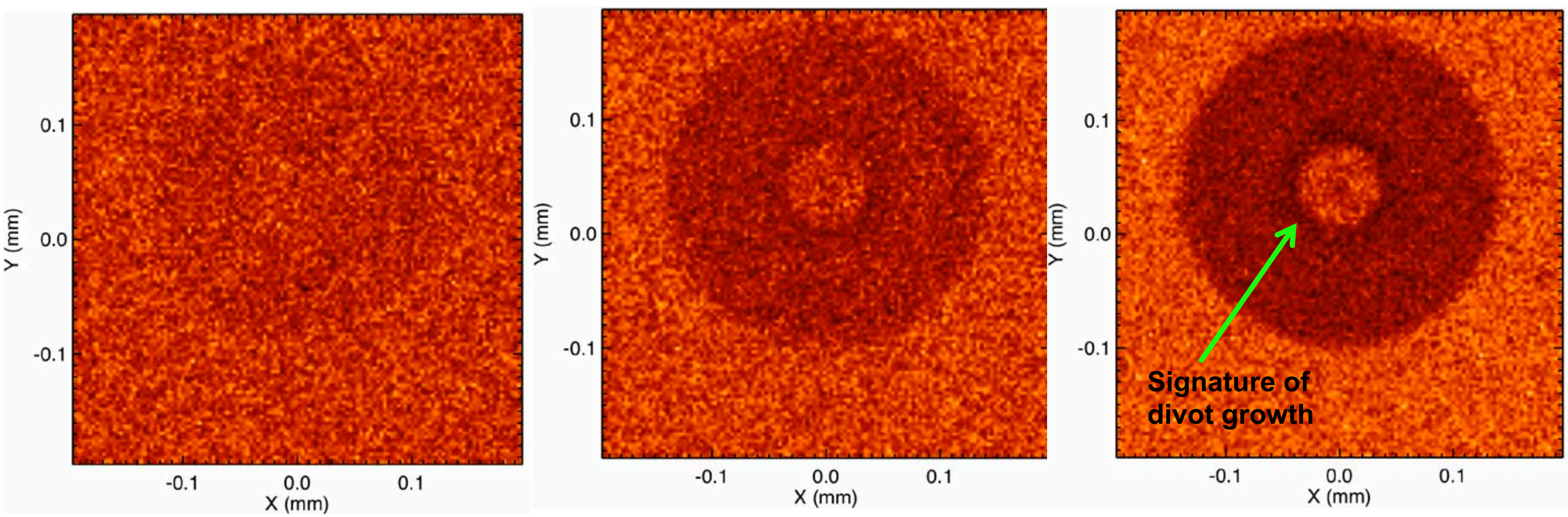


Frame 2



Noise model shows z2162 had too low S/N, while z2163 (featureless capsule) had usable S/N

z2162	z2163 levels	3-shot best levels
Bkg = 4.0, BL=0.4 PSL	Bkg = 4.3, BL=2.0 PSL	Bkg = 1.0, BL=2.0 PSL
Timing of frame 1	Timing chosen for maximum divot contrast	Timing chosen for maximum divot contrast



Low background is clearly desirable but a strong backlighter exposure can allow feature growth to be imaged even with high background levels

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Several steps have recently been taken to mitigate background and improve data return for Z shots

Mitigate

- ✓ **Change camera filter to reduce < 2 keV photon time-integrated exposure of IP**
  - ✓ Be filter non-uniformity imprint revealed low-energy background source
- ✓ **Modify diagnostic aperture can to channel / shield plasma flows**
  - ✓ Taller aperture can reduces frame 2 background to frame 1 levels
- ✓ **Provide more complete shielding of the camera snout/limiting aperture transition**
  - ✓ Larger tungsten shield eliminates high-energy background gradient

Characterize

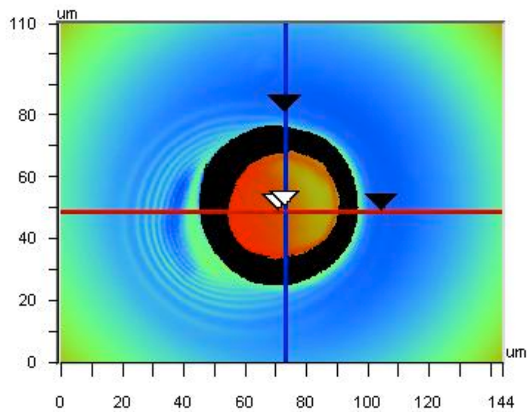
- ✓ **Second (& third) image plates behind first to characterize high-energy background**
  - ✓ Exposure on 2^{nd} & 3^{rd} plates indicates 10-30 keV contributions

Improve data quality

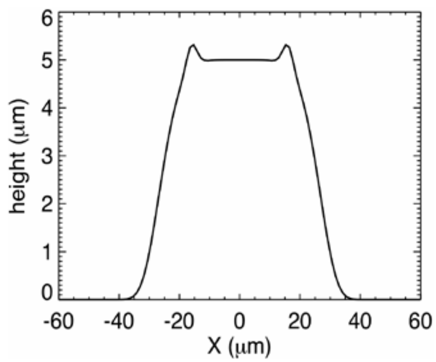
- **Reduction in background to ~ 1 PSL on recent shots effectively doubles data return by making frame 2 more reliable**

Capsules have also been fabricated with engineered bumps which should have an absorption signature

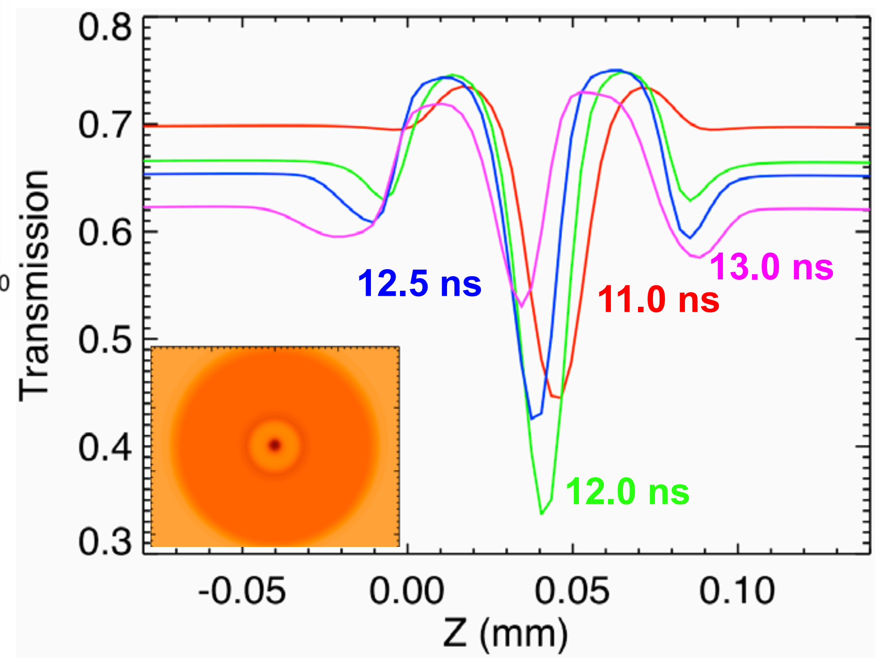
WYKO characterization of bumps (K. Moreno, GA)

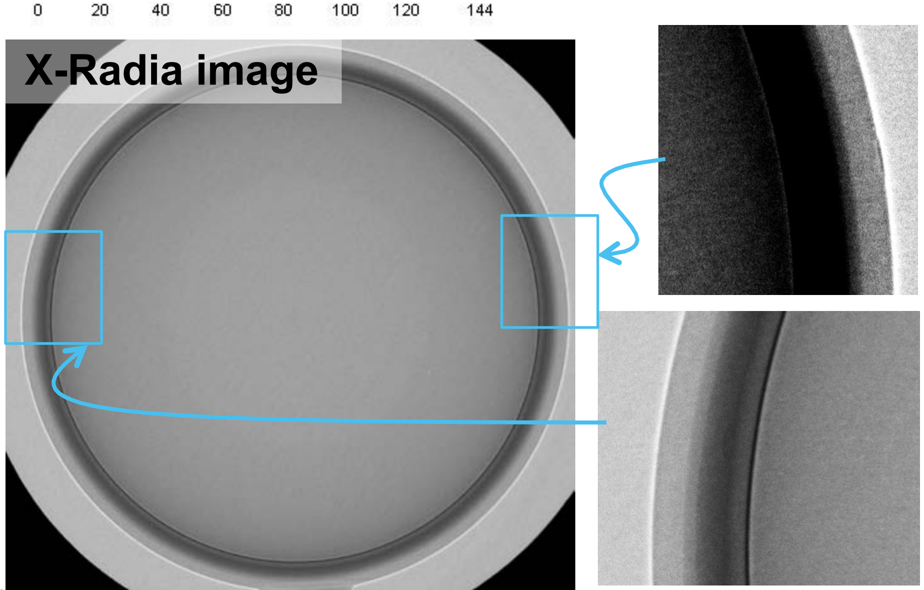


Modeled bump profile



Lineouts through synthetic 6.151 keV face-on radiographs of bump evolution (1 ns gate, 12 μm spatial resolution)





Two targets of this type have been assembled and characterized

Summary

- NIF-relevant graded-doped ablator capsule with engineered defects have been fielded for the first time in Z hohlraum experiments
- Divot capsule radiographs were too noisy (due to x-ray background) to unambiguously identify divot growth
- Image plate noise model developed that is consistent with experimental images
- Synthetic images (w/noise) from postprocessed LASNEX divot growth simulations suggest that divot growth would be just barely detectable at observed noise levels
- Improvements have been made in the meantime to decrease the overall x-ray background and improve data quality for this type of Z experiment
- Two capsules with engineered ablator bumps have been assembled and characterized for upcoming Z shots

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