Image processing methods for characterizing cryogenic target quality during fuel layer formation at the National Ignition Facility (NIF)

Presentation to

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SPIE Photonics West

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Overview

Motivation

- Cryogenic targets for NIF ignition experiments are required to have uniform thickness, spherical shape, and be largely free of isolated defects

Current Methods

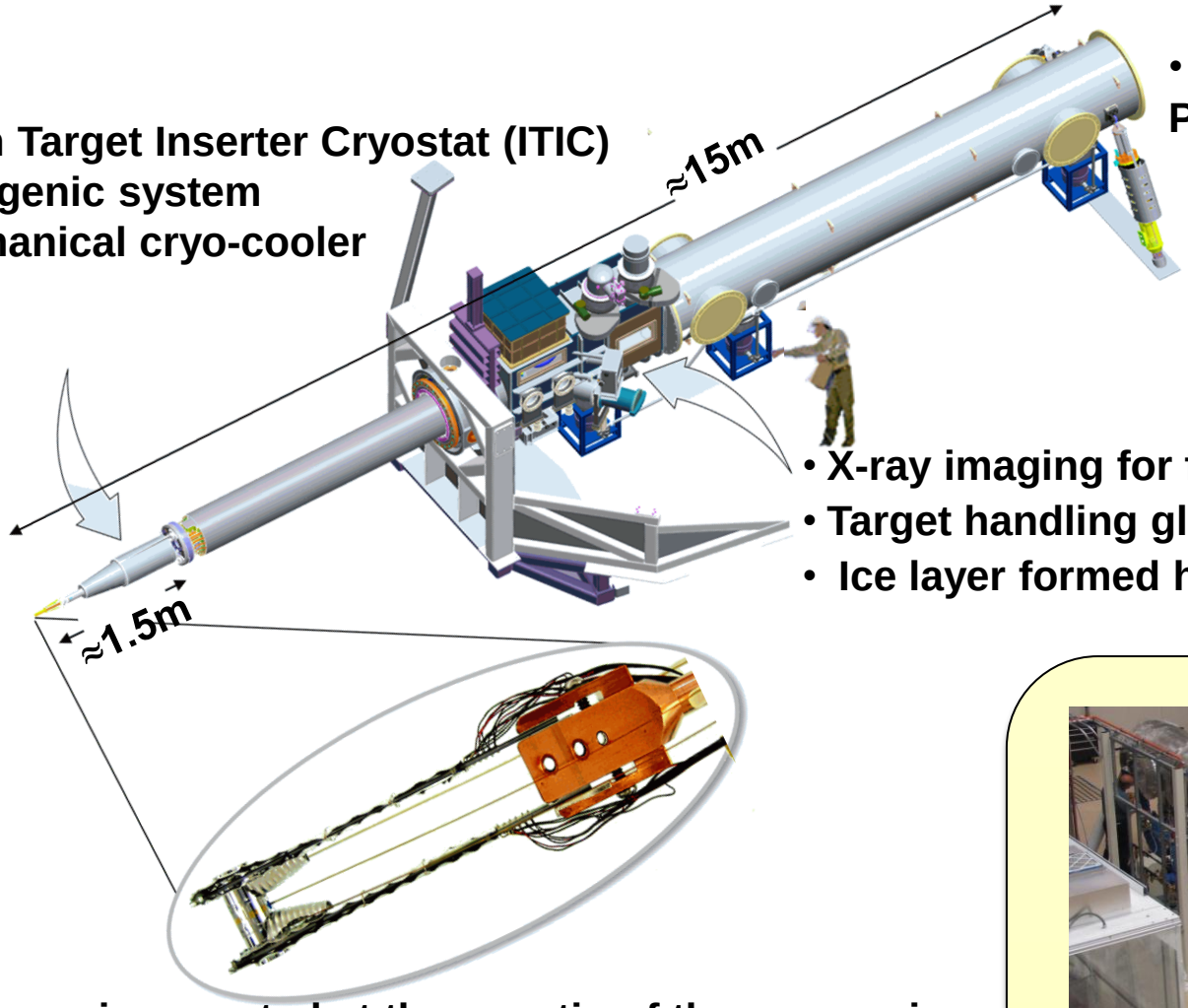
- Single target takes up to 18 hours to form
- X-ray camera images have limited resolution and sparse coverage of fuel layer

Image Processing for Symmetry Analysis of Layer Growth

- Differential trend analysis
- Image texture metrics
- Symmetry with respect to layer quality

NIF Cryogenic Target System

- Ignition Target Inserter Cryostat (ITIC)
  - Cryogenic system
  - Mechanical cryo-cooler



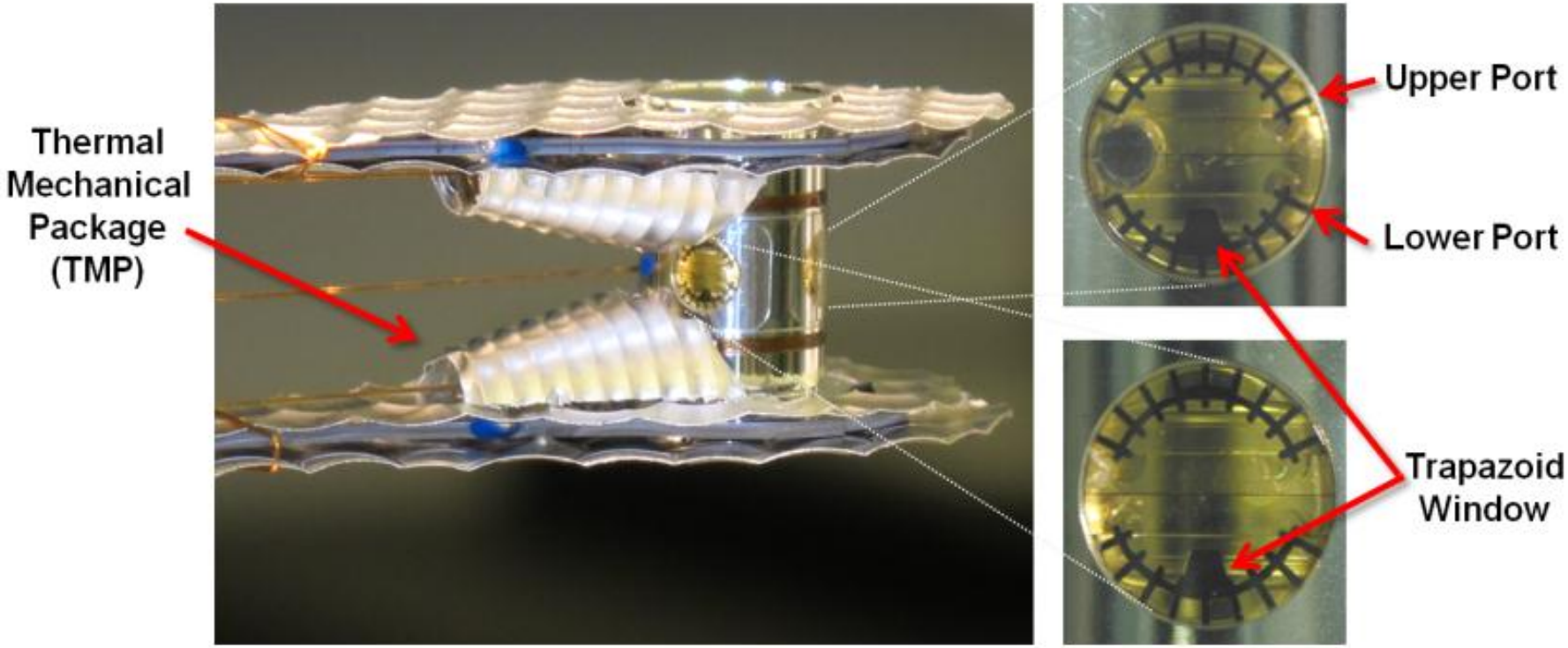
- Target Positioner
- X-ray imaging for fuel ice layer characterization
- Target handling glove box
- Ice layer formed here

- Hohlraum is mounted at the very tip of the cryogenic target system
- Spherical 2mm target fusion capsule is filled with deuterium and tritium (DT) gas

CryoTarpos System

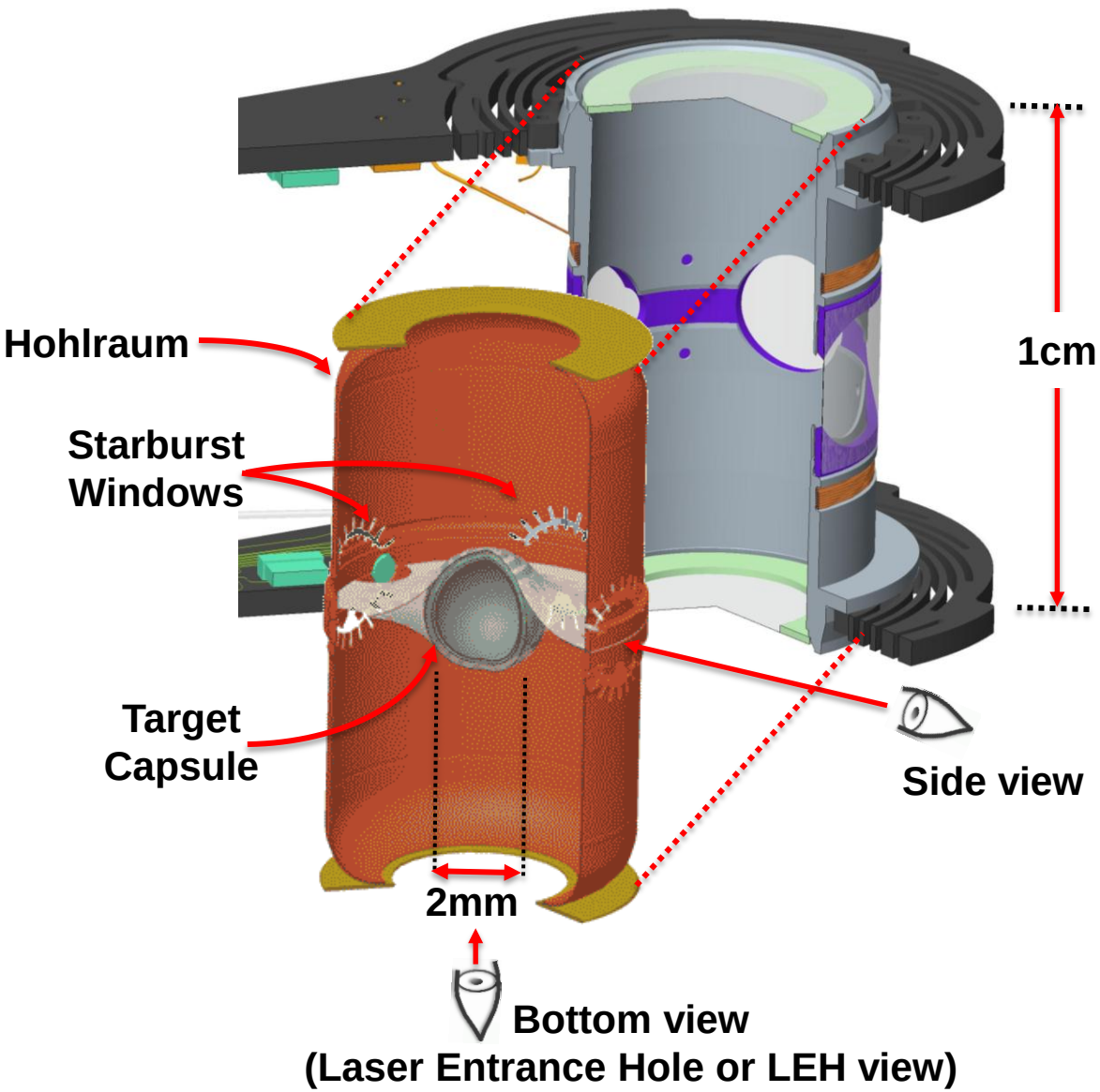
3 orthogonal x-ray views

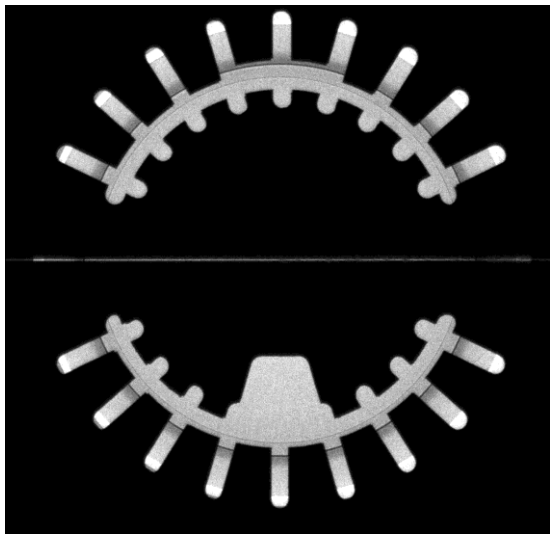
View of NIF thermal mechanical package



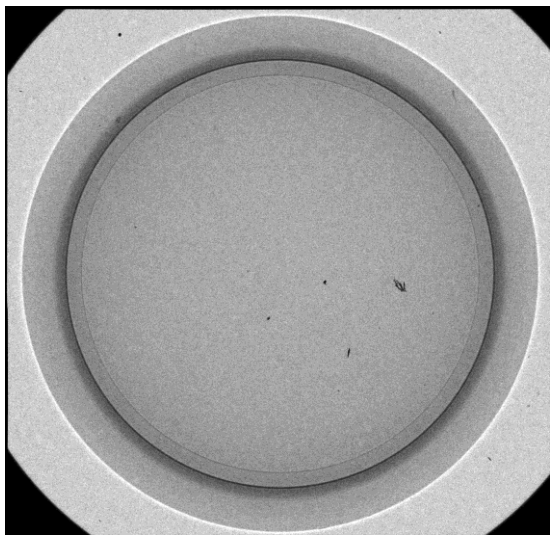
During cooling, precise control of the heat transfer between the hohlraum and the capsule inside determines its geometric shape

X-ray image views of target from hohlraum side and bottom



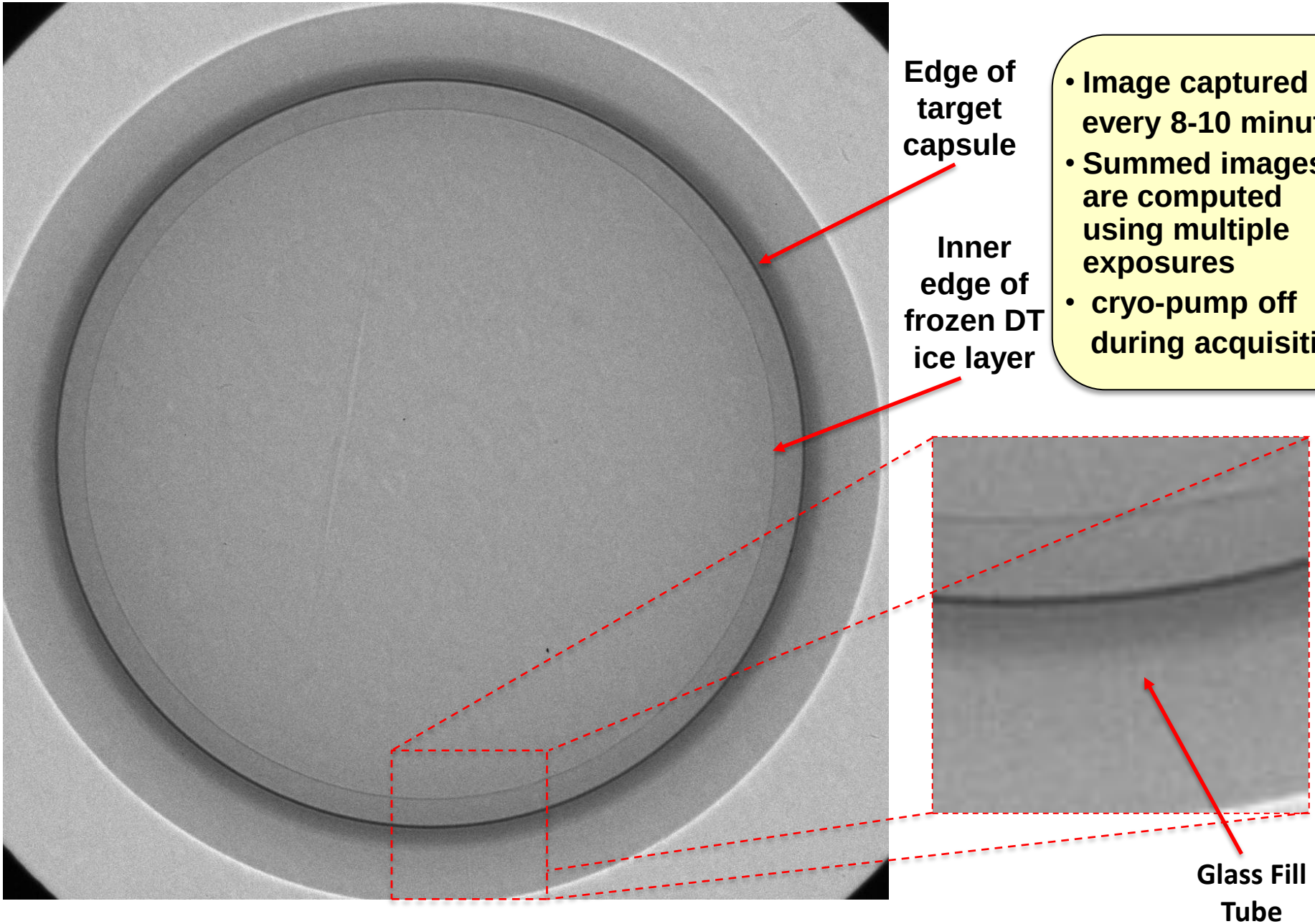


Side view



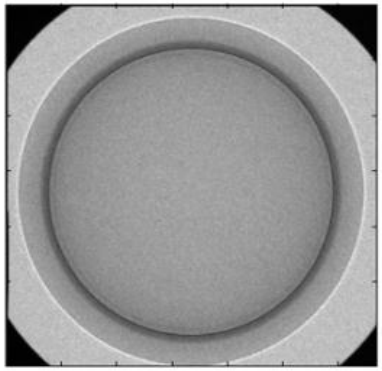
LEH view

X-ray image. DT ice layer is 68 μm-thick at the end of the liquid to frozen cooling cycle (19.7 to 18.3K)

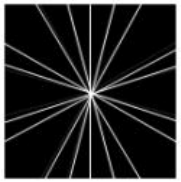


- Image captured every 8-10 minutes
- Summed images are computed using multiple exposures
- cryo-pump off during acquisition

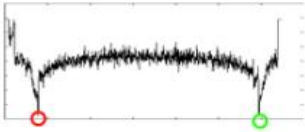
Images are registered and normalized using pixels within the capsule area



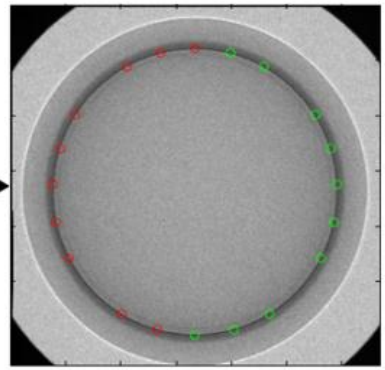
Create indices of radial line-outs through image center



lineout Vector angle
0
15
30
45
60
75
.
.
.



detect capsule edges



$$d_1 = \sqrt{(x_{b1} - x_{e1})^2 + (y_{b1} - y_{e1})^2}$$

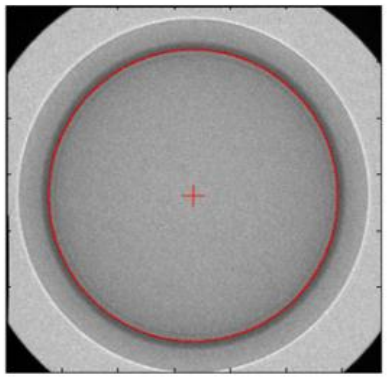
Calculate distances
$\bar{d} = [d_1, d_2, d_3 \ldots]$

Cull using median of distances

$$\frac{\bar{d} - med(\bar{d})}{med(\bar{d})}$$

Circle Fit (Taubin, G. ,1991)

x_c
y_c
$radius$



$$image = \frac{image - \min(image_{ROI})}{\max(image_{ROI}) - \min(image_{ROI})}$$

Physical changes during the cooling cycle such as capsule drift can introduce artifacts and positional shifts within the images

Subtracting consecutive images yields a difference image and highlights changes in the forming ice layer

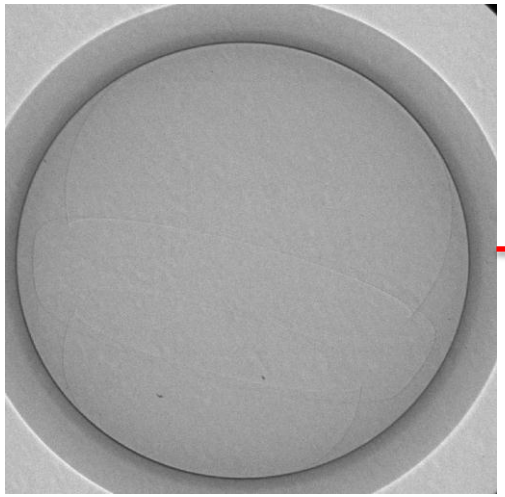
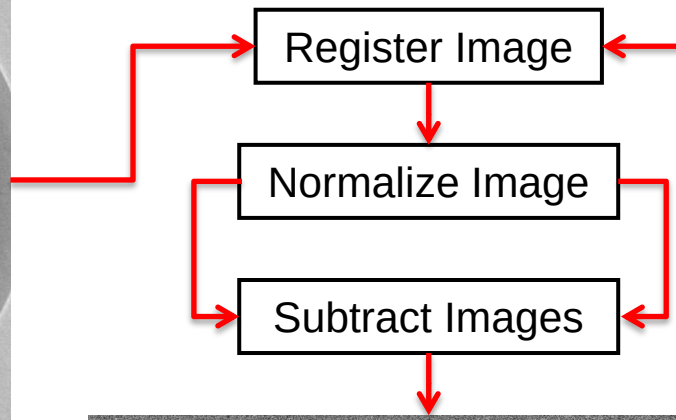


Image taken 3 hours after melt-back



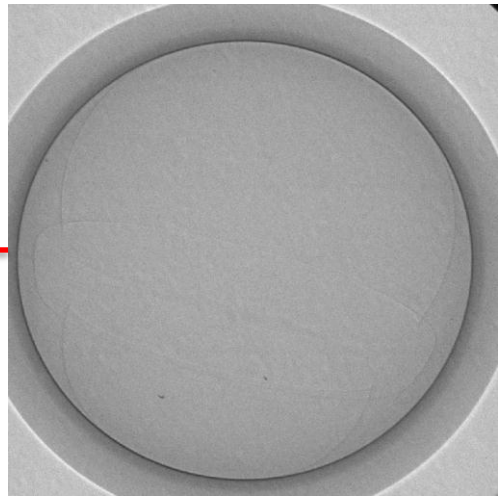
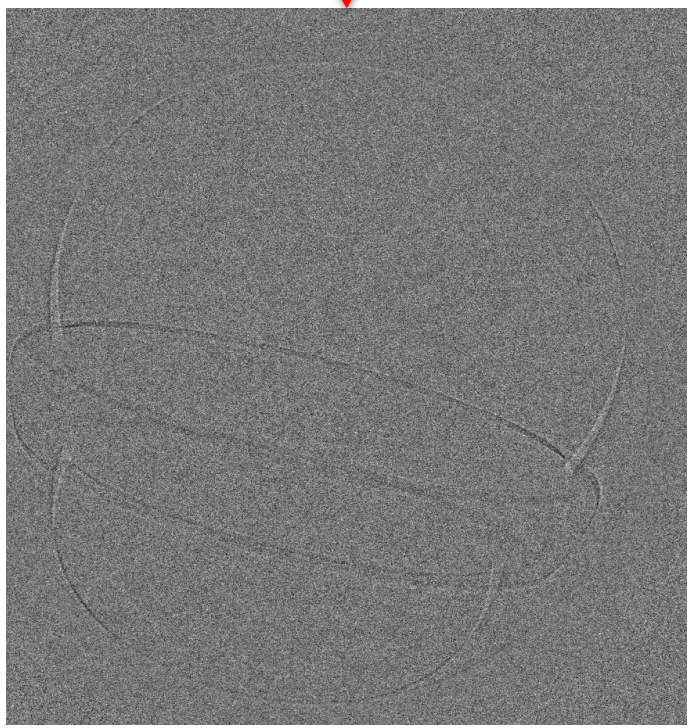
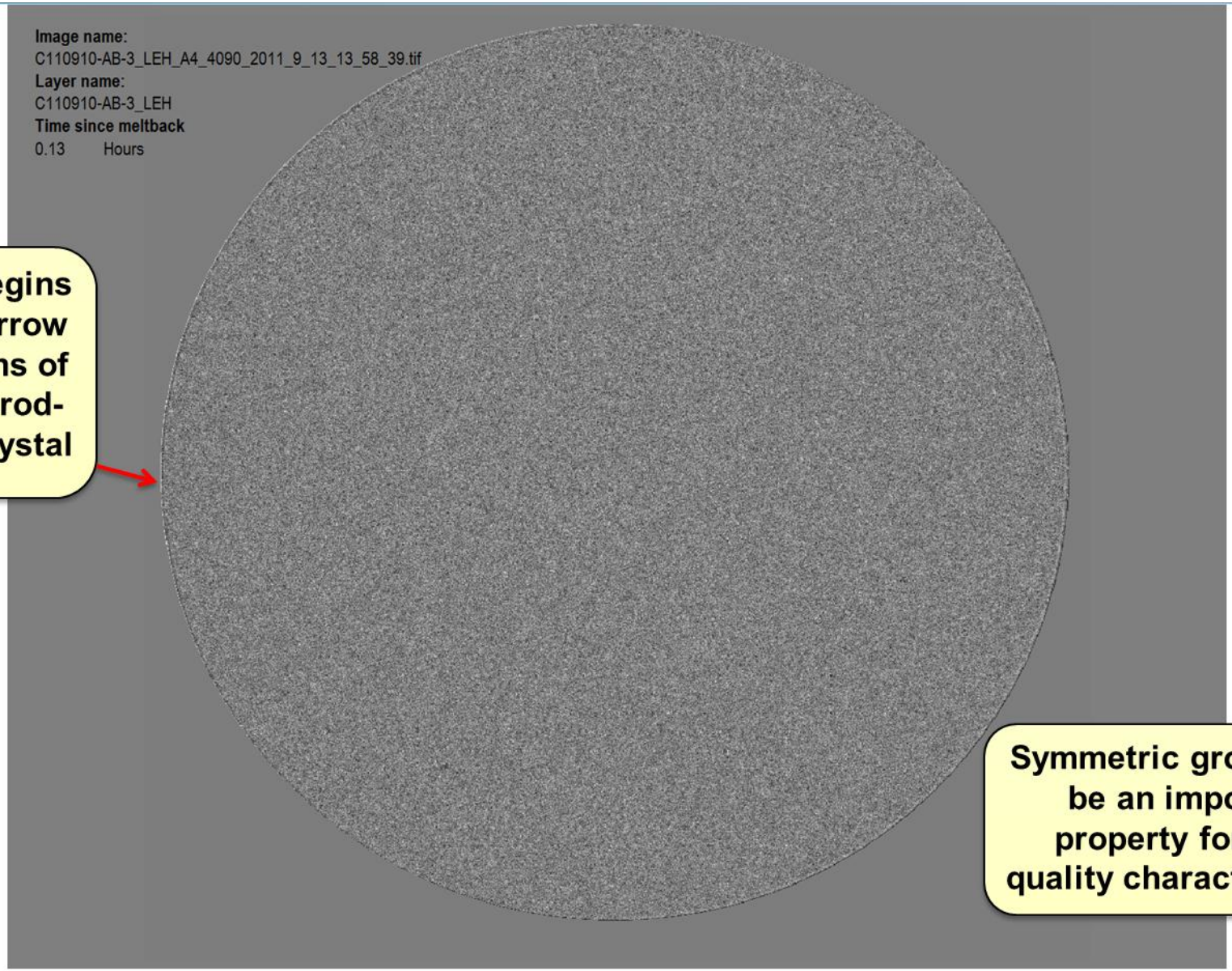


Image taken 8 minutes later in cooling cycle



Difference image

Ice forms along a major axis forming a closed belt which expands, covering the entire inner surface of the capsule



Growth begins from a narrow single (tens of microns) rod-shaped crystal

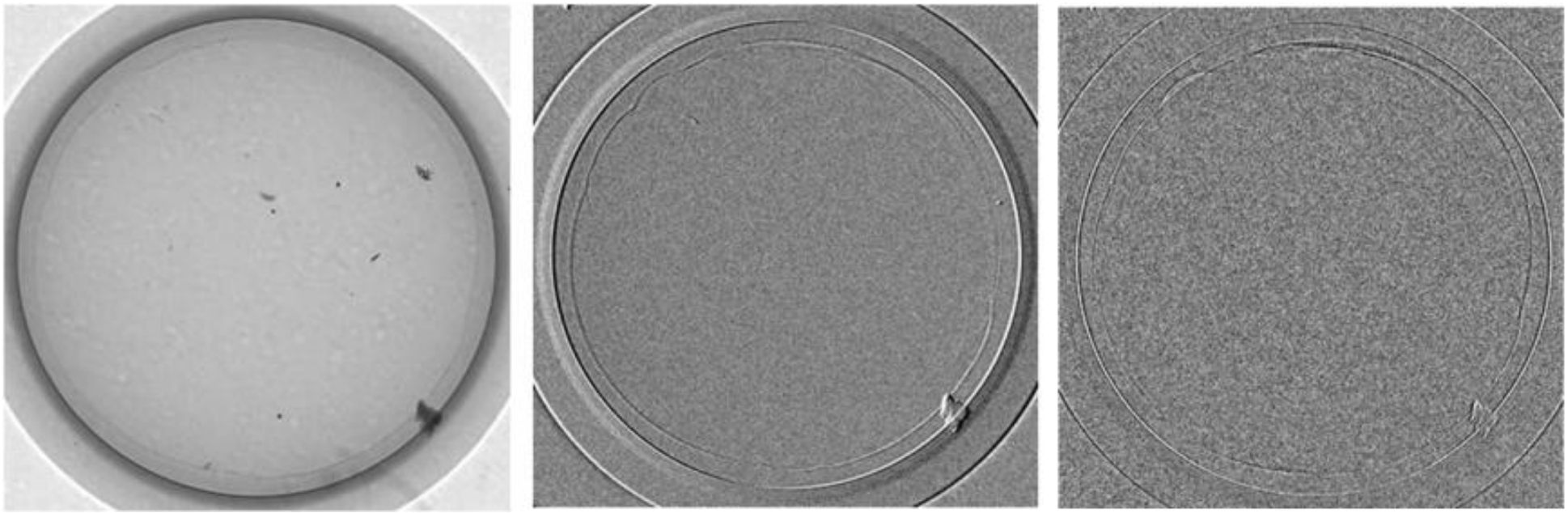
Symmetric growth may be an important property for layer quality characterization

Image enhancements and various metrics are being tested to enhance the faint edges in the x-ray images

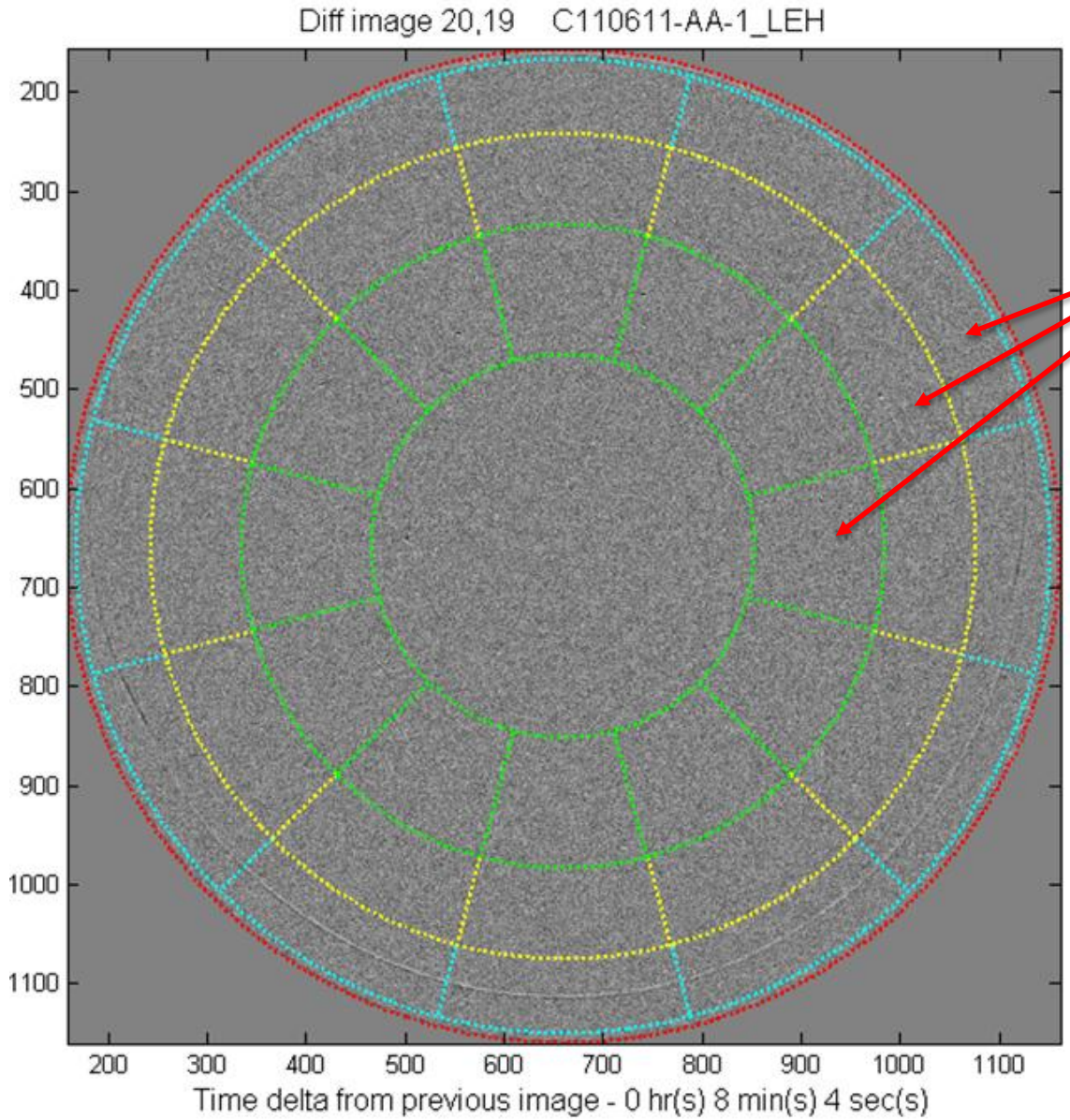
- Image or sub-image standard deviation
- Image or sub-image entropy
- Image or sub-image mean

Eigenimage Transform:

First, second, and third eigenimages of a set of 8 images. In the second and third eigenimages, edges and other high frequency features seen in a single layer image are preserved, implying that they are good candidates. The remaining eigenimages mostly consist of noise, and may not suitable for analysis.



Measuring symmetry requires each image be subdivided into equal-area segments from which a texture measurement is taken



Equal area annular concentric rings segmented every 30 degrees

Calculated for each segment

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}}$$

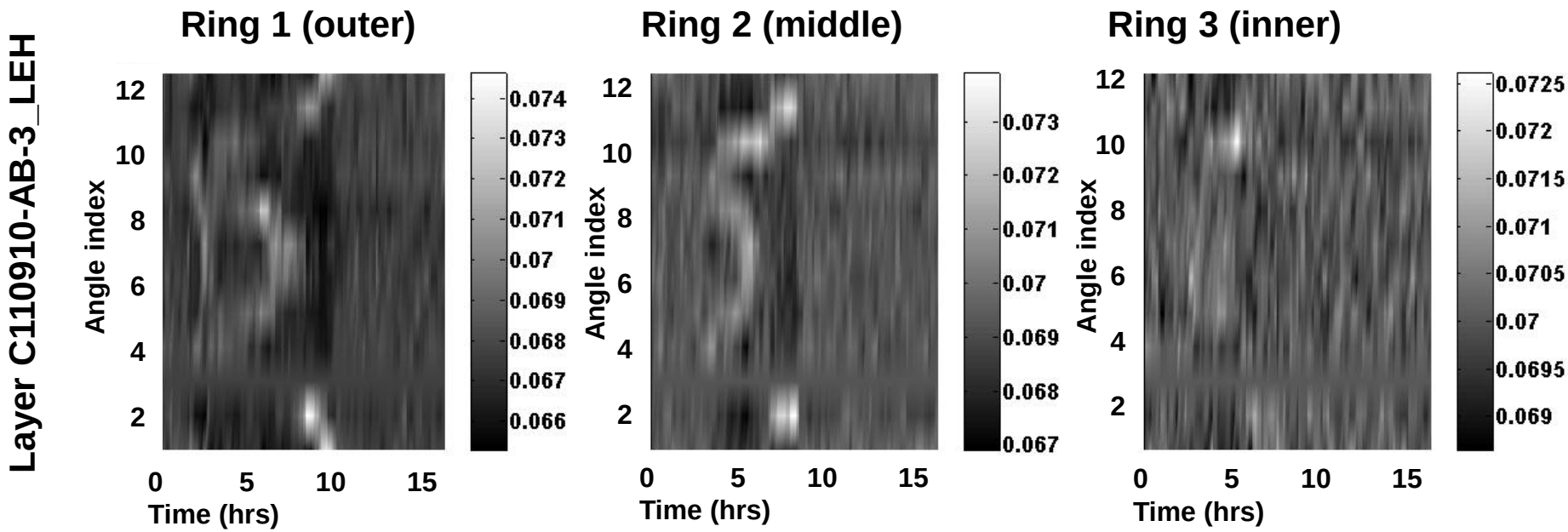
$\sigma = standard\ deviation$

$x_i = gray\ scale\ intensity$

$\bar{x} = mean\ of\ sample\ values$

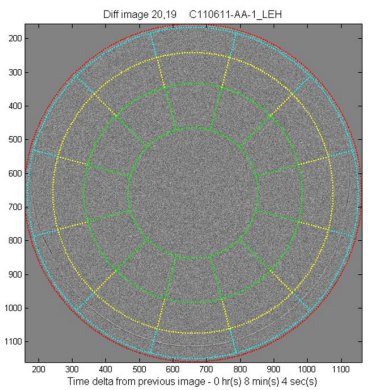
$n = number\ of\ samples$

Resulting matrices or trend images for each layer using the σ values for all angles (y) vs cooling cycle time (x)

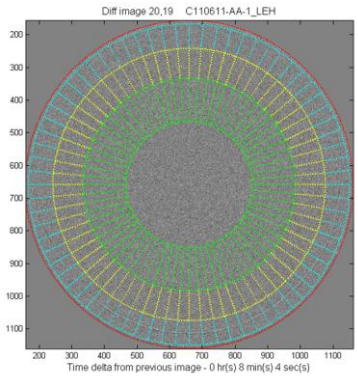


- σ of the differenced images for 12 radial segments per column
- cooling continued for 15 hours
- white curves indicate changes in the fuel layer

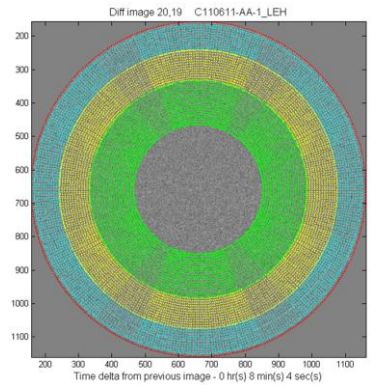
Segmentation using angular resolution of 30, 5, and 1 degrees. Focus improves with finer sampling



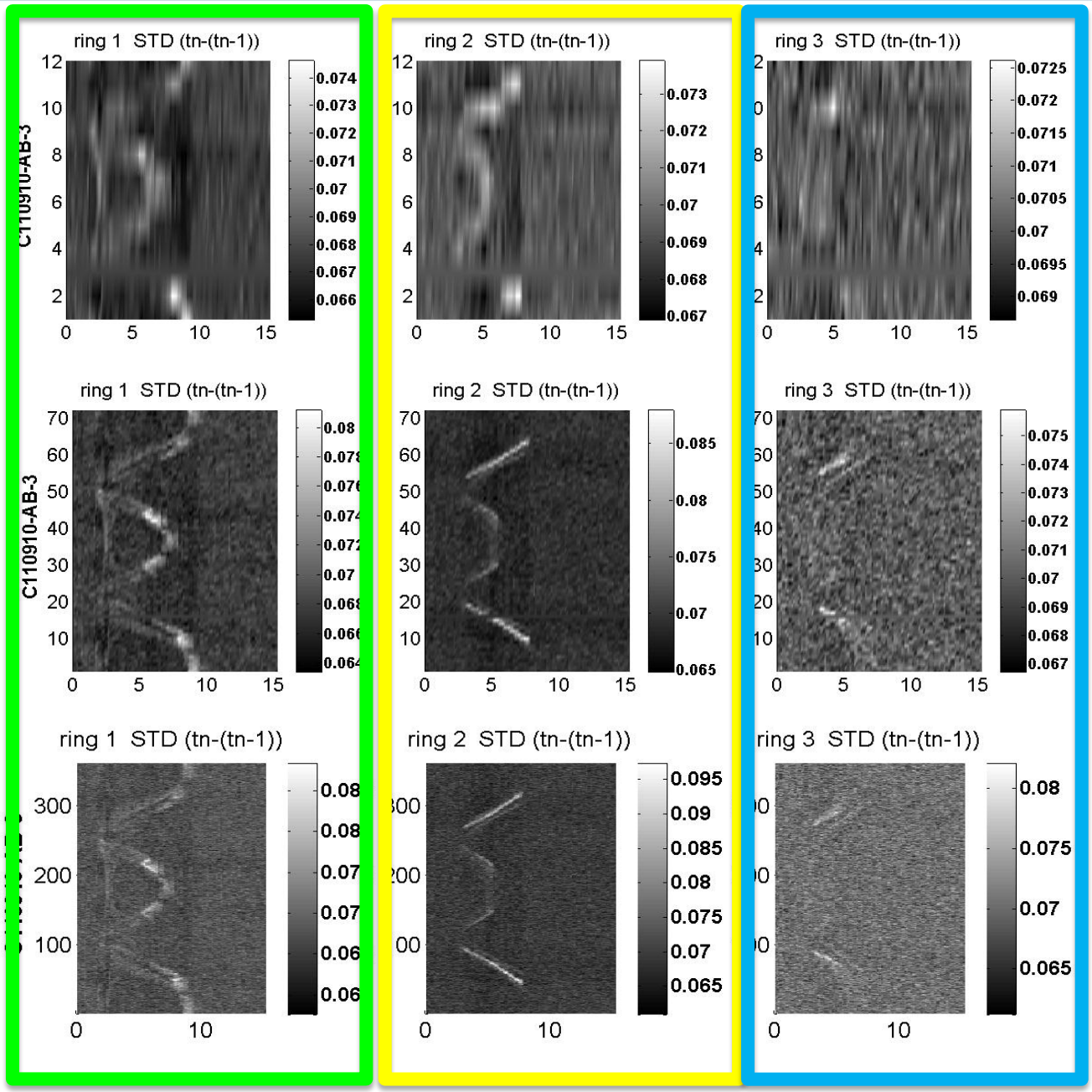
30 degrees



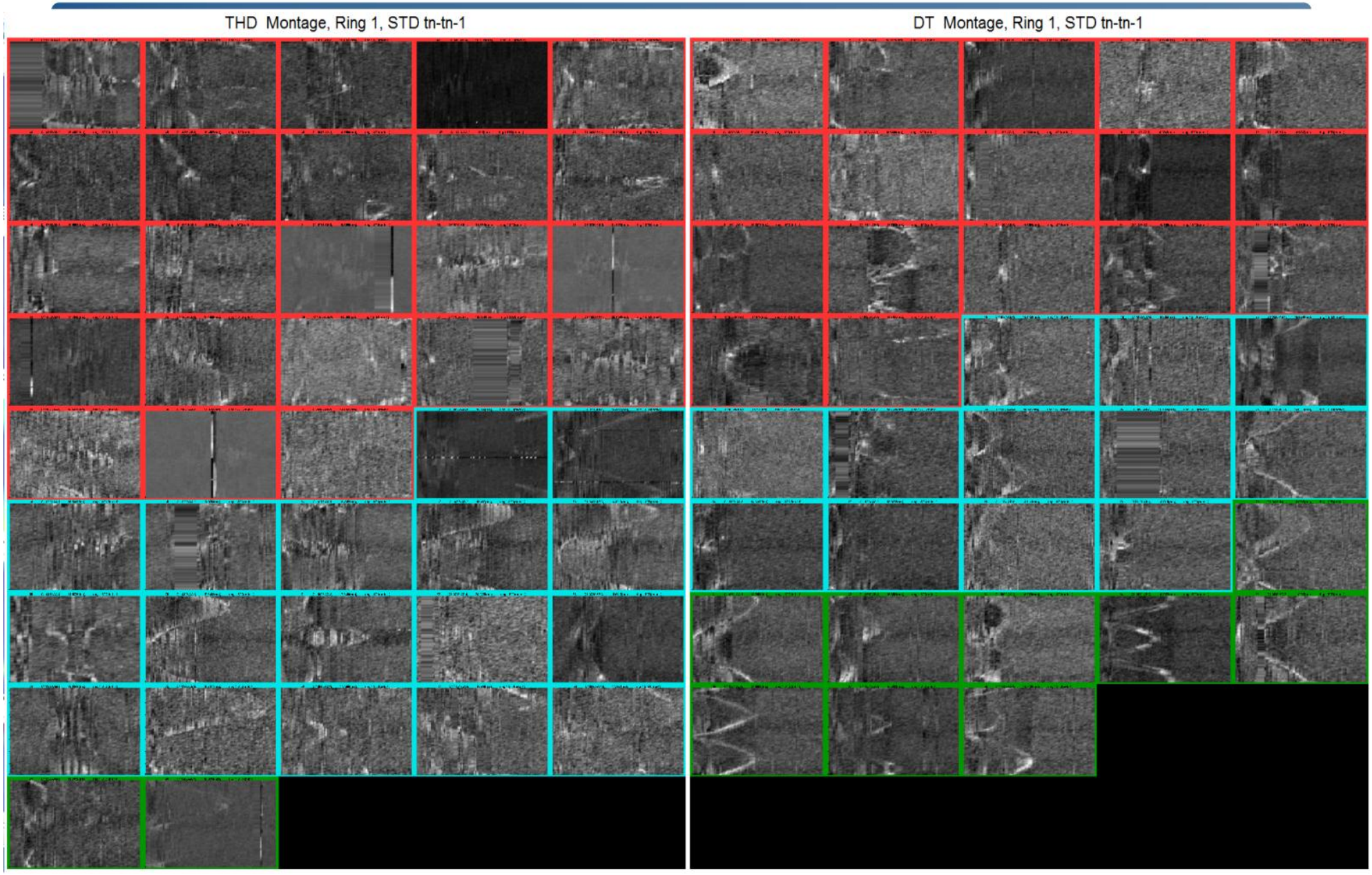
5 degrees



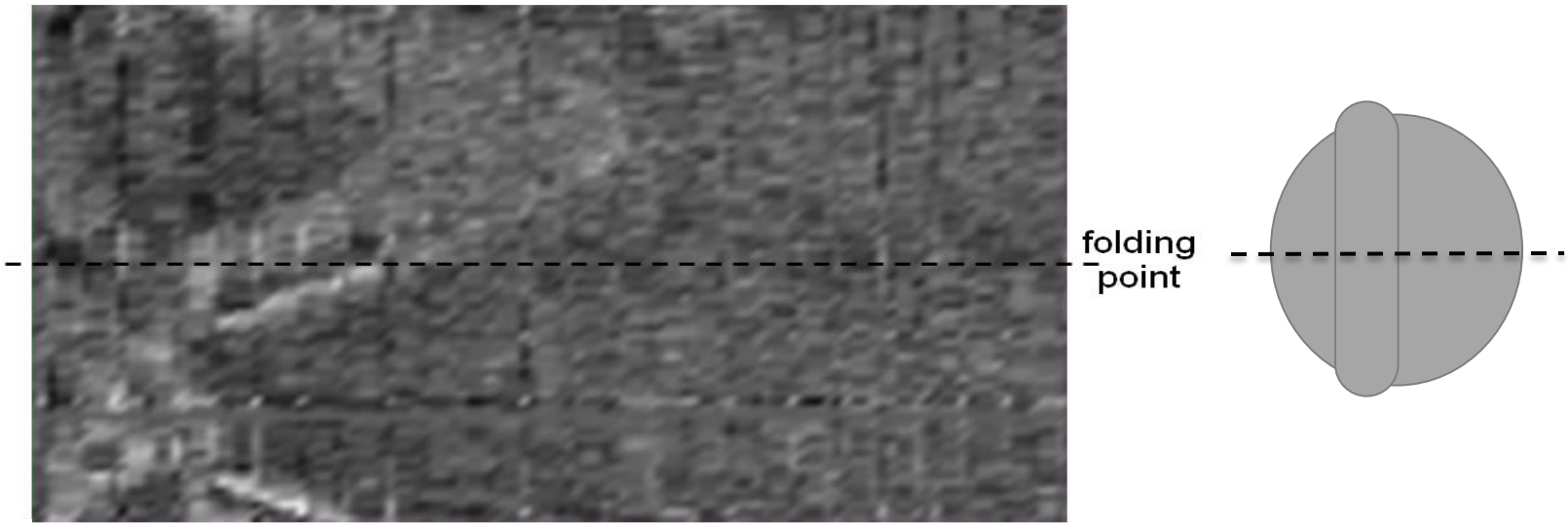
1 degree

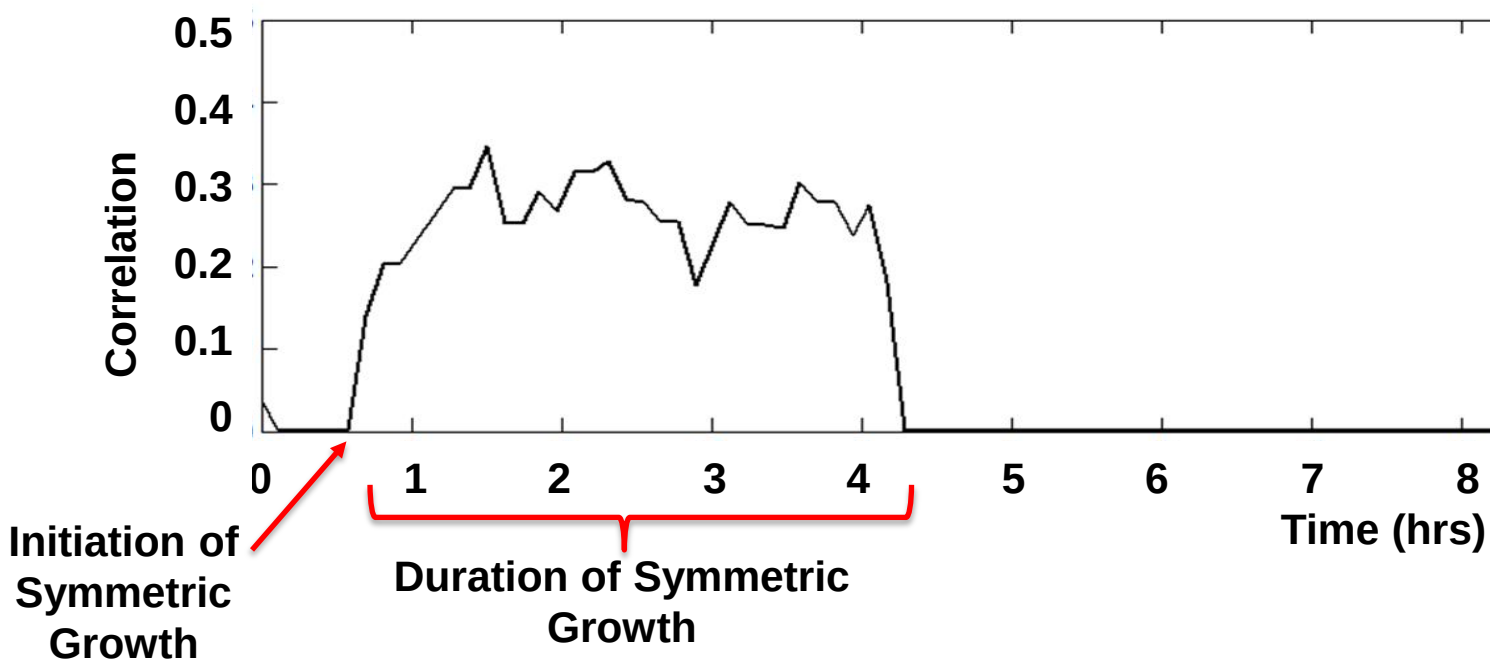


Montage of 79 layer trend images showing Ignition quality layer (grn border), tuning quality (cyn border) and failed layer (red border) using 5 degree sampling

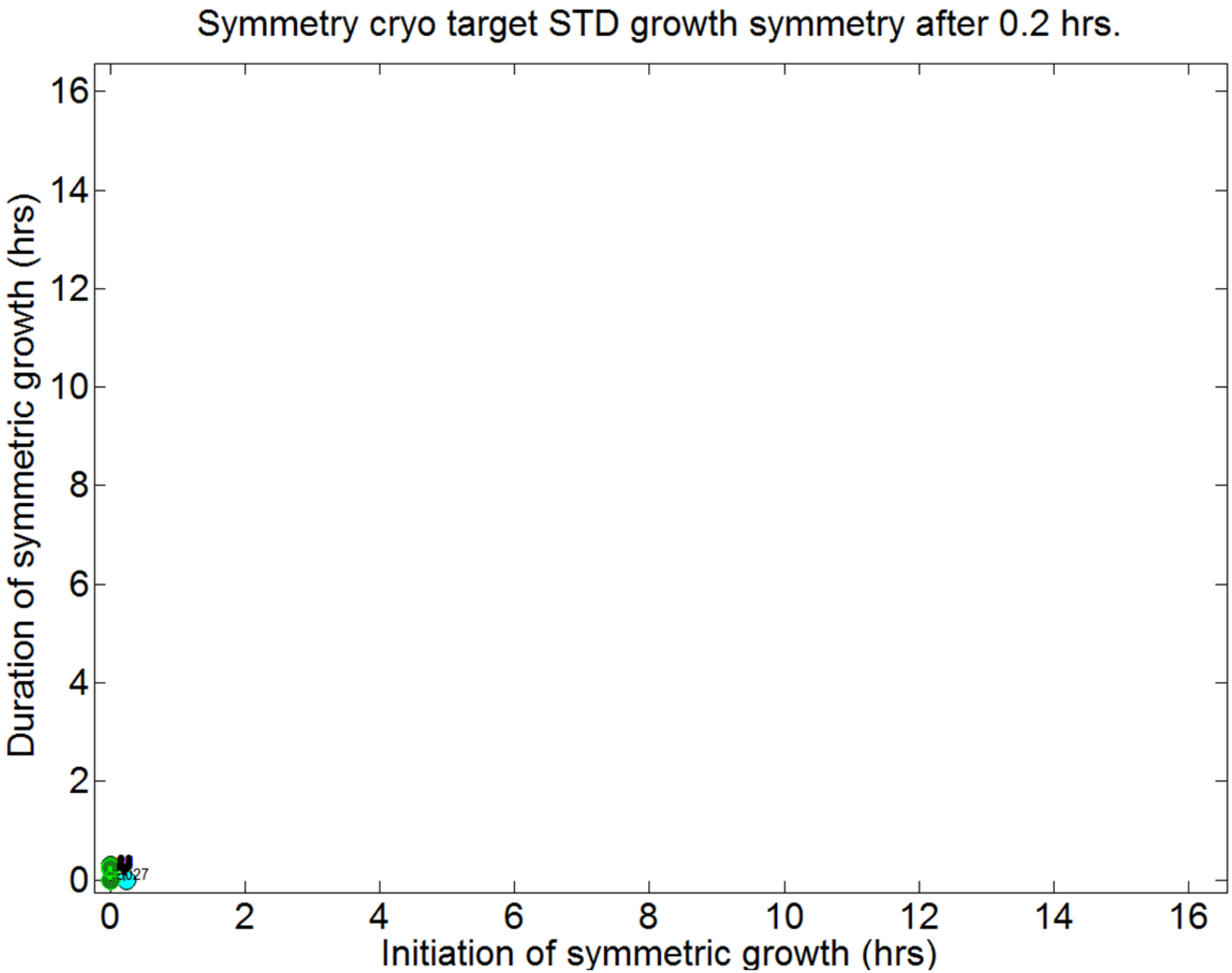


Trend images are analyzed for symmetry by correlating the two target hemispheres over time

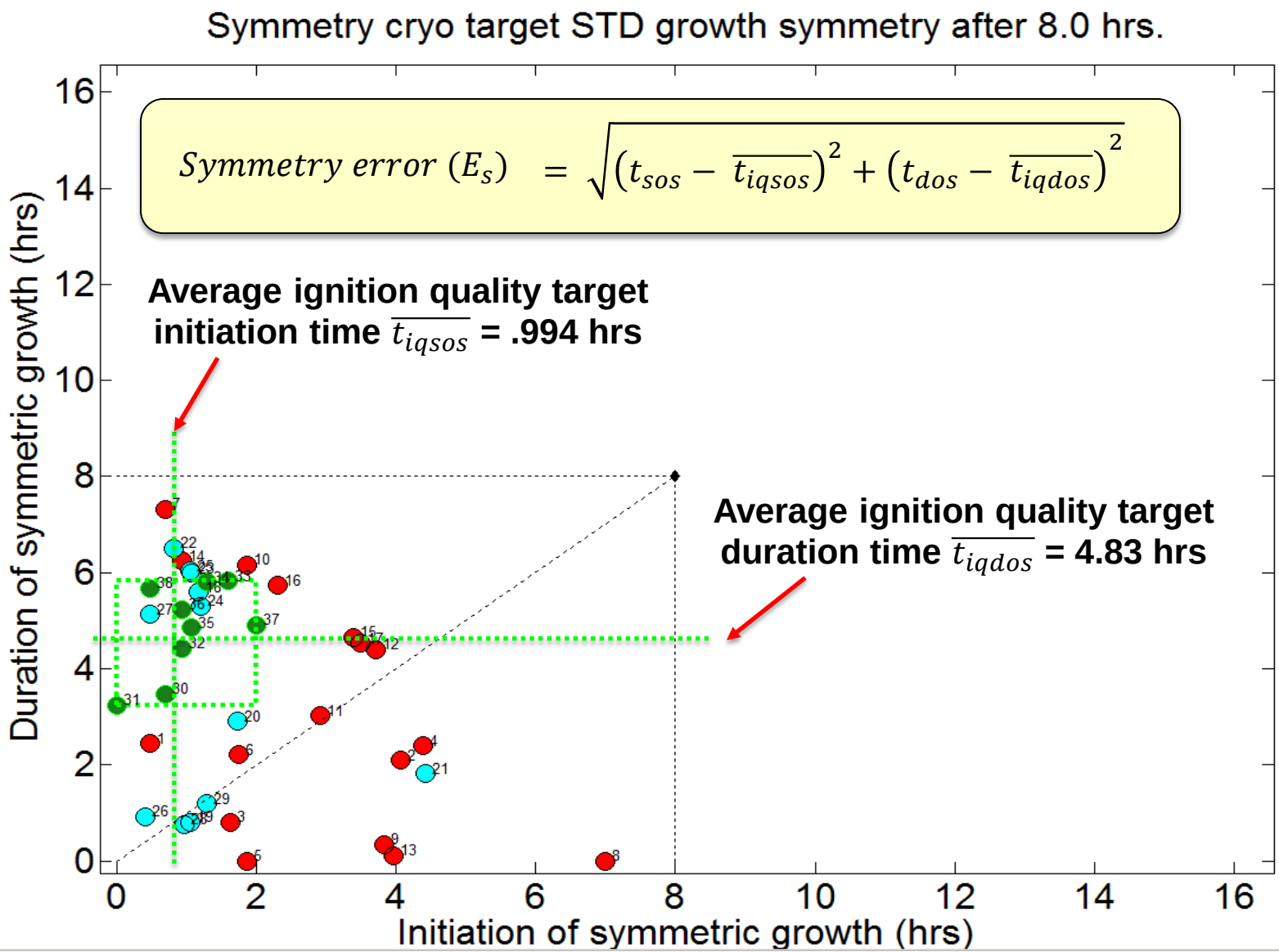




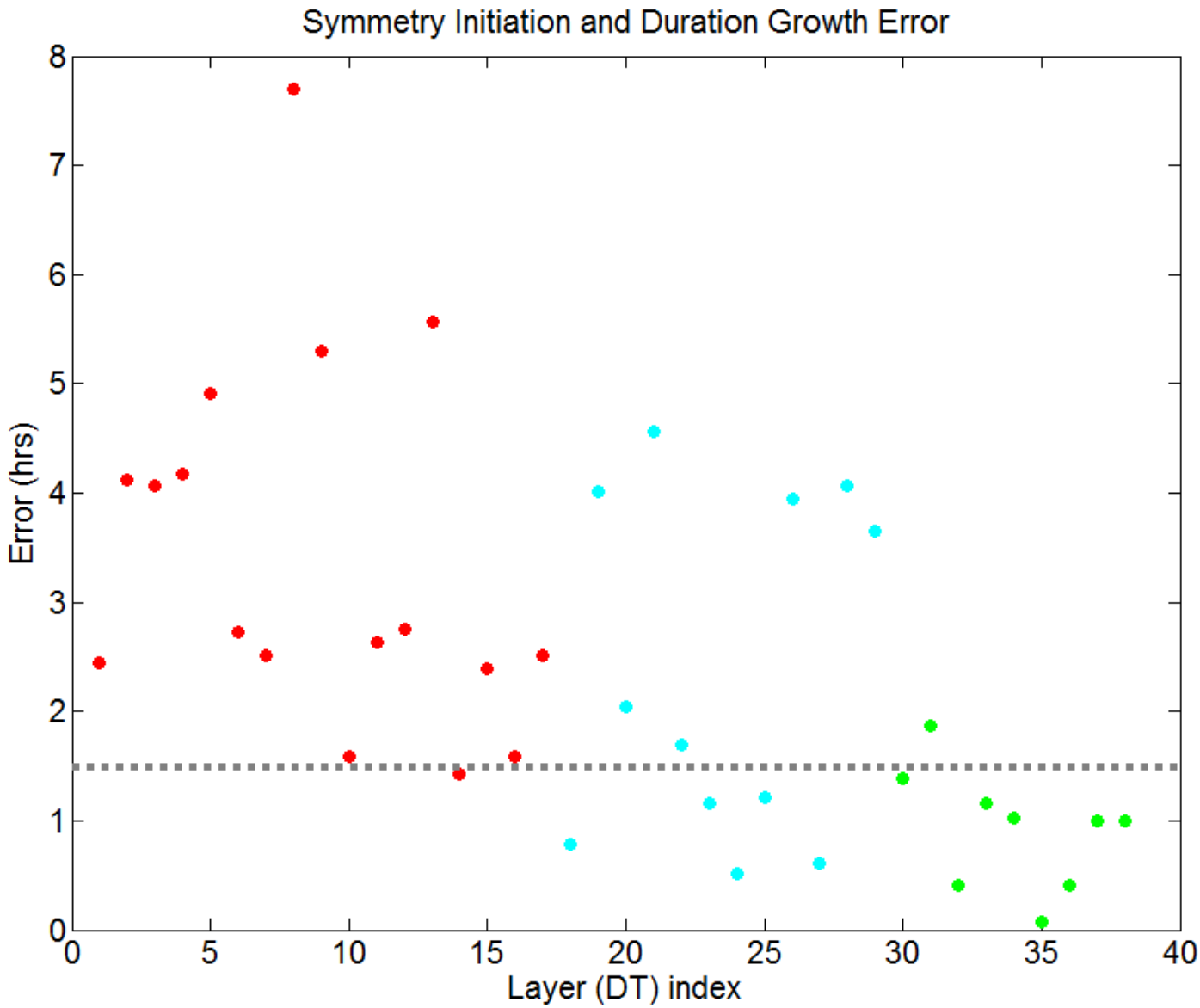
Symmetry start and duration for 39 DT layers were continuously measured using the trend images



Symmetry error was calculated after 8 hours of growth for 39 DT layers.



Symmetry error after 8 hours for 39 DT layers



Closing Topics

1.) Predominant area for layer initiation – 180 degrees (at or near the fill tube)

2.) Quality layers correlate strongly with clear and unbroken growth curves

3.) Quiet (no changes) at end of cycle is an indicator of a good layer

4.) Other metrics besides current position and texture changes should be studied

Conclusion

- Demonstrated differential trend analysis for measuring symmetry during target layer formation
- Segmentation of x-ray images will identify position of growth
- Standard deviation as well as other texture metrics can be used to measure symmetry
- Start of symmetry and duration of symmetry are indicators of layer quality

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