CANFSA

Center for Advanced Non-Ferrous Structural Alloys
An Industry/University Cooperative Research Center

Project 32-L: Algorithmic Analyses of X-Radiography and Computed Tomography for Multiscale Structural Investigations of Metals

Semi-annual Spring Meeting

April 2022

- Student: C. Gus Becker (Mines)
- Faculty: Drs. Amy and Kester Clarke (Mines)
- Industrial Mentor: Dr. Michelle Espy (LANL)

COLORADO SCHOOL OF MINES   NSF   IOWA STATE UNIVERSITY

Project 32-L: Algorithmic Analyses of X-Radiography and Computed Tomography for Multiscale Structural Investigations of Metals

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- Student: C. Gus Becker (Mines)
- Advisor(s): Amy Clarke (Mines)

Project Duration
PhD: Fall 2017 to Fall 2022

- Problem: Industrial processes of metals such as casting and additive manufacturing can benefit from static/dynamic radiography, but user facilities have technique and access limitations.
- Objective: Analyze existing radiography and tomography data and establish cabinet-based x-ray capabilities at Mines for further experimentation.
- Benefit: Identify technique limitations for defect detection in AM metals and studies of solidification.

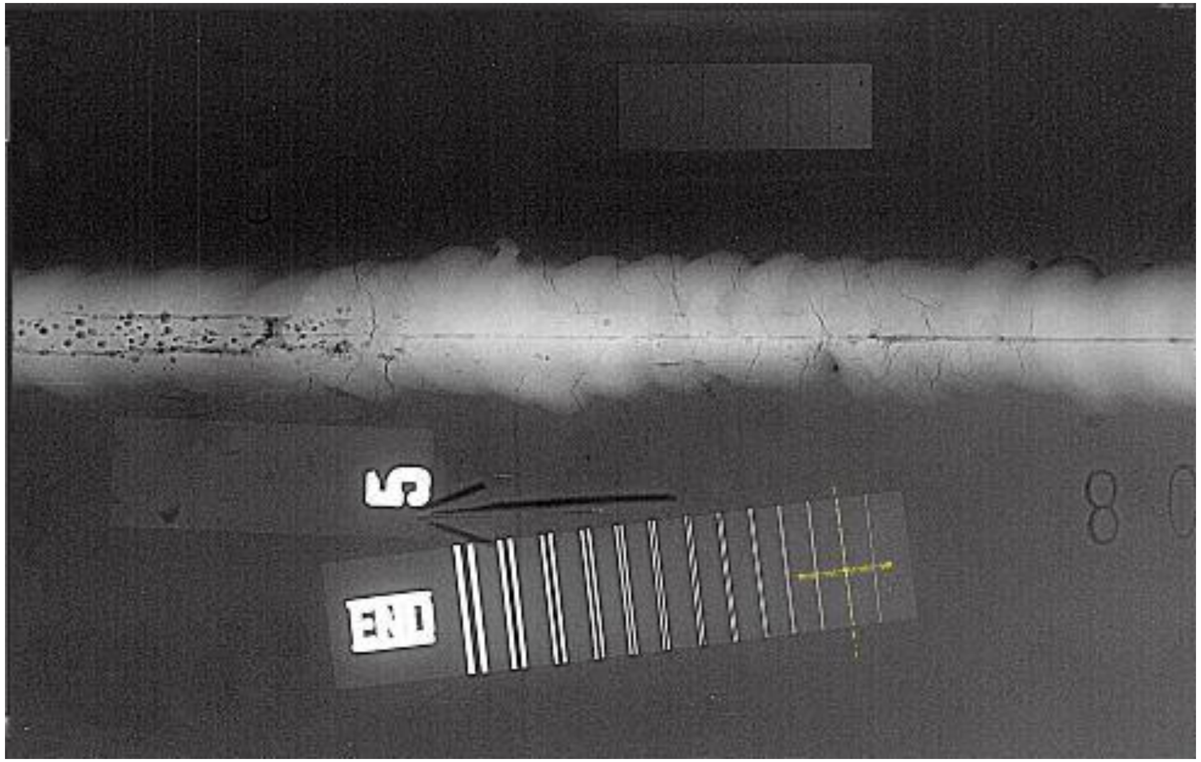
Recent Progress
- Finalized automated interface identification routine for AM simulator experiments at the APS
- Developed automated interface identification routine for DTEM solidification experiments
  - Intensity preprocessing
  - Ellipse fitting and optimization
- Finalizing manuscript for automated melt pool detection publication
- Adapted segmentation routine of mock HE
  - 2D to 3D
  - Organized into module

Metrics

Description	% Complete	Status
1. Establishment of cabinet-based high-energy microfocus x-ray capabilities at Mines	100%	●
2. Automated interface identification routine for AM simulator experimental data from the APS	100%	●
3. Automated interface identification routine for DTEM rapid solidification experimental data	100%	●
4. Segmentation of mock HE: 2D to 3D, adapt routine to Python module, exhibit workflow in Jupyter notebook	100%	●
5. Segmentation of mock HE: apply new method, quantify methodology	50%	●

Industrial Relevance

- Identify defects in additively manufactured (AM) builds by non-destructive imaging
  - Qualification and certification
  - Technique limitations
- Weld inspection
  - Safe and stable welds
  - Failure points, inclusions, porosity



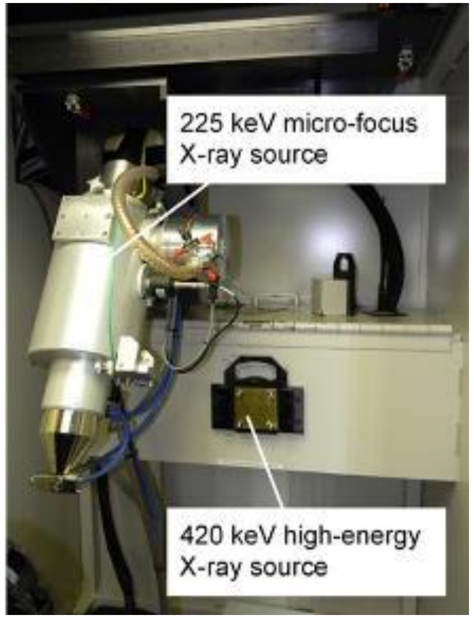
http://solutionsinimaging.com/industrial-applications/weld-inspection/

Industrial Relevance

- In situ x-ray imaging of dynamic materials processes to inform model development
  - Extracting quantitative information from images

- Establishment of x-radiography and computed tomography (CT) cabinet at Mines
  - Support ongoing projects
  - Allow for consideration of a wider range of projects from industry
  - Accommodates custom/flexible experimental platforms (solidification, deformation, etc.)

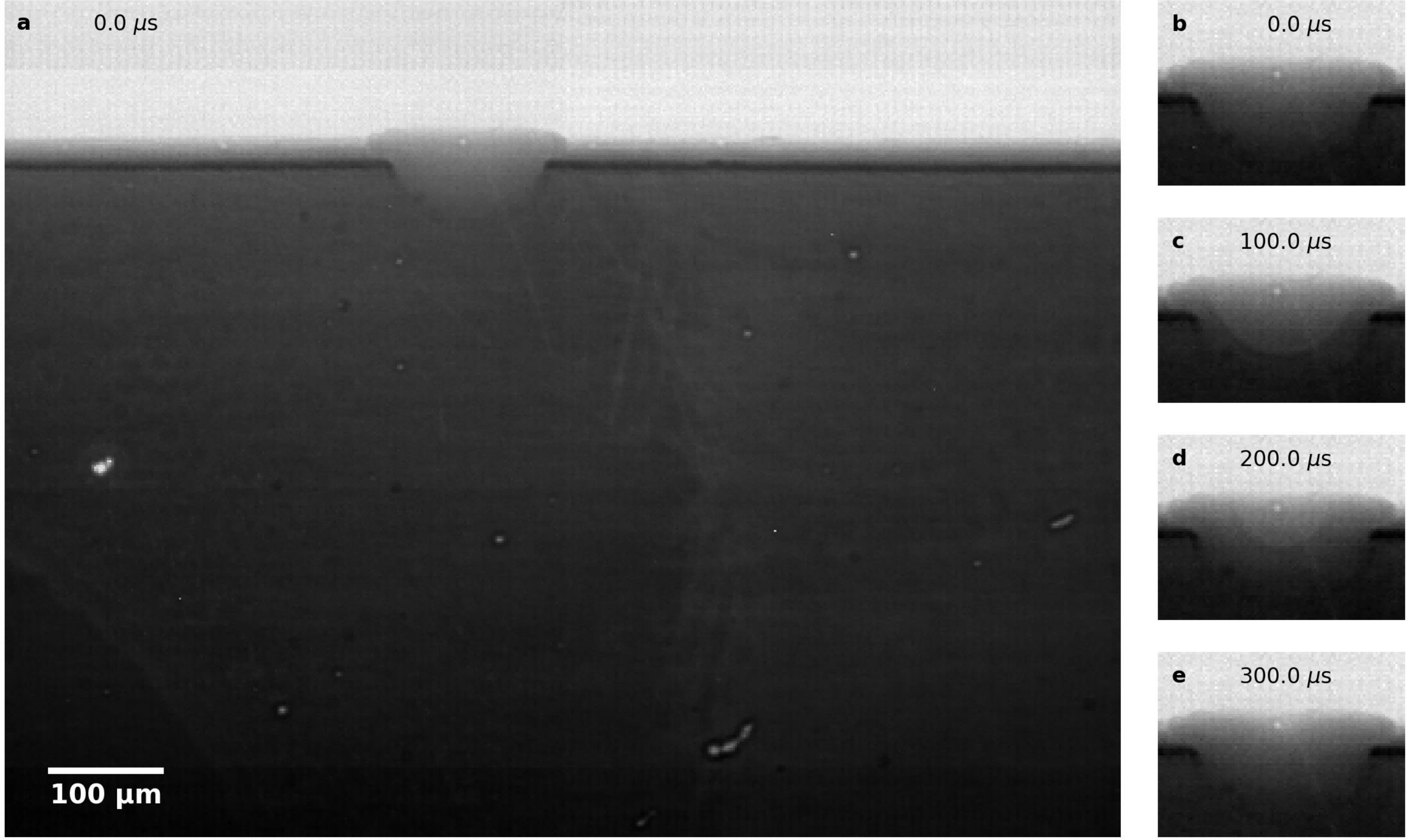
Cabinet Timeline



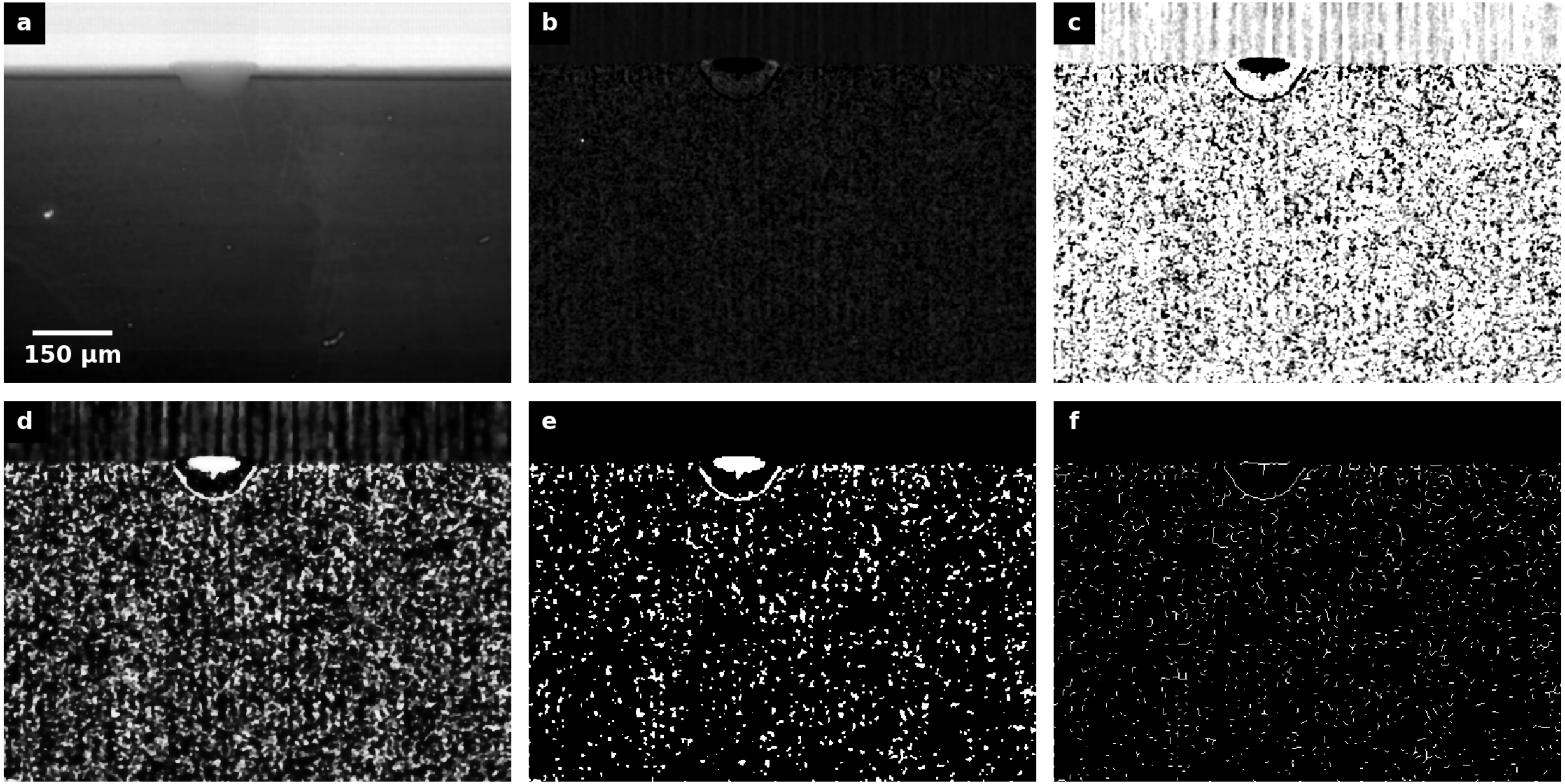
Process Donation Internally (LANL)	Ship to White Rock, NM	Ship to Santa Clara, CA for Refurbishing	Prepare Lab Space for System	Install New Microfocus System	Ship to Mines	Installation and Training
Complete	Complete	Complete	Moving Utilities	Refurbishing Complete	Complete	Complete!

AM Simulator at the APS

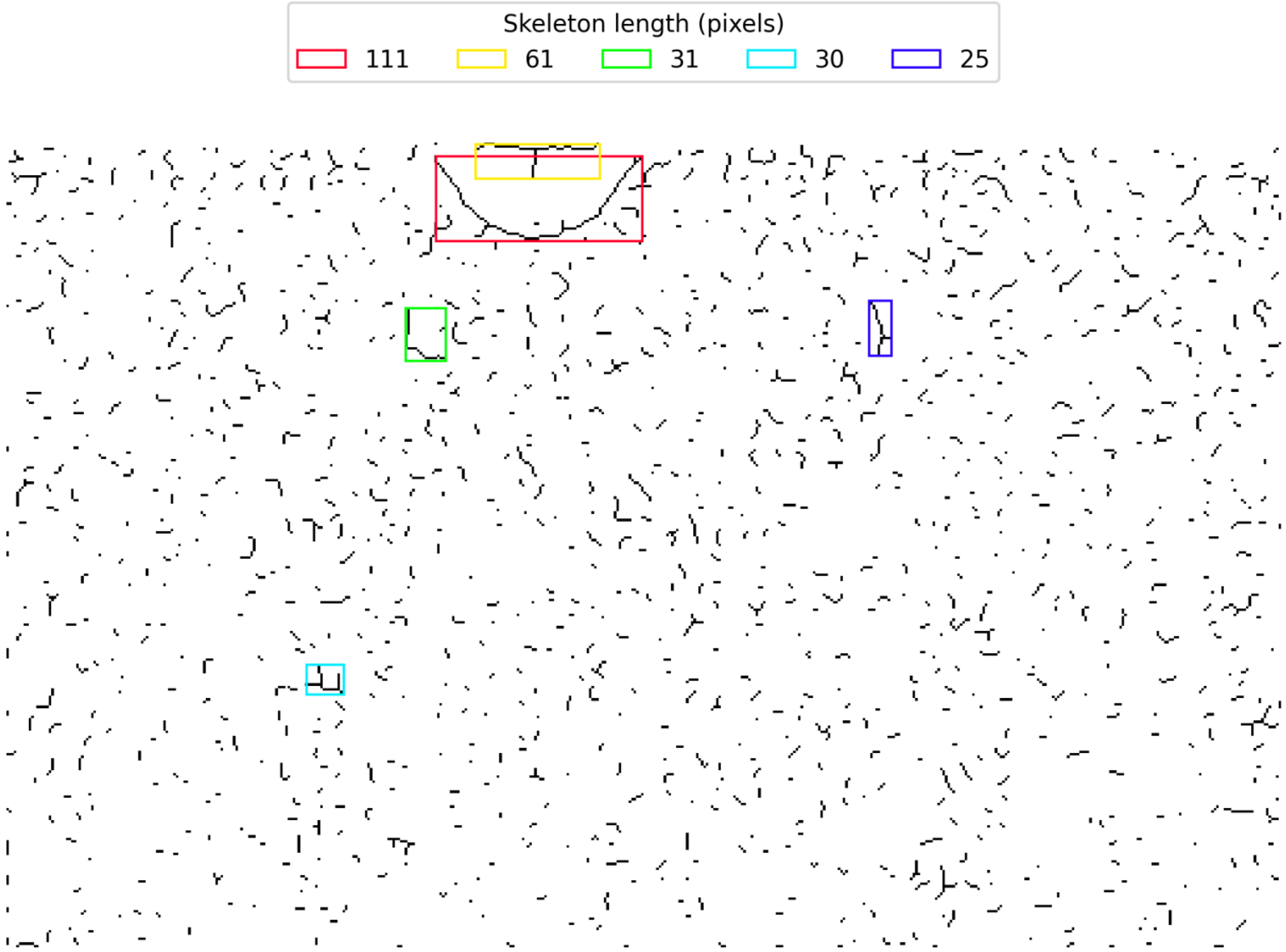
- Laser impinging on metal surface to simulate AM processing
  - Spots and rasters
  - 80,000 fps (12.5 µs)
- Directly measure solidification velocity
- Enables comparisons to solidification modeling and theory



Automated Interface ID: Full Routine



Automated Interface ID: Skeletonized Regions



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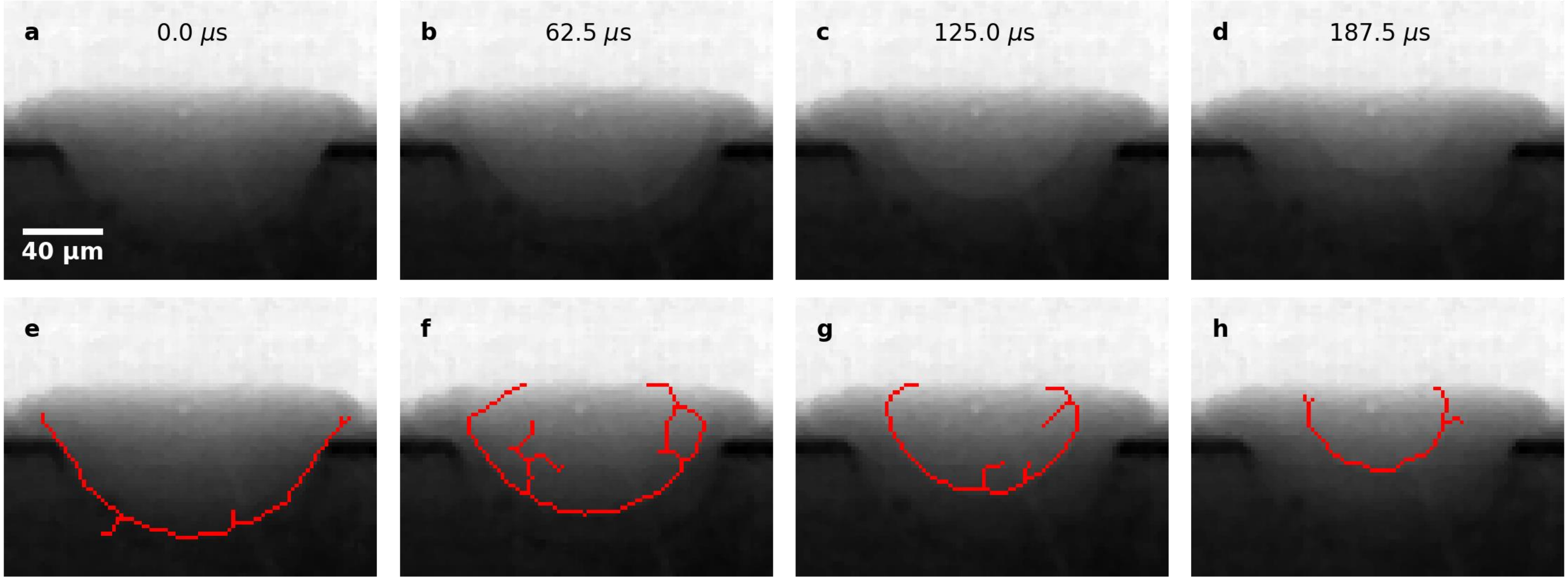
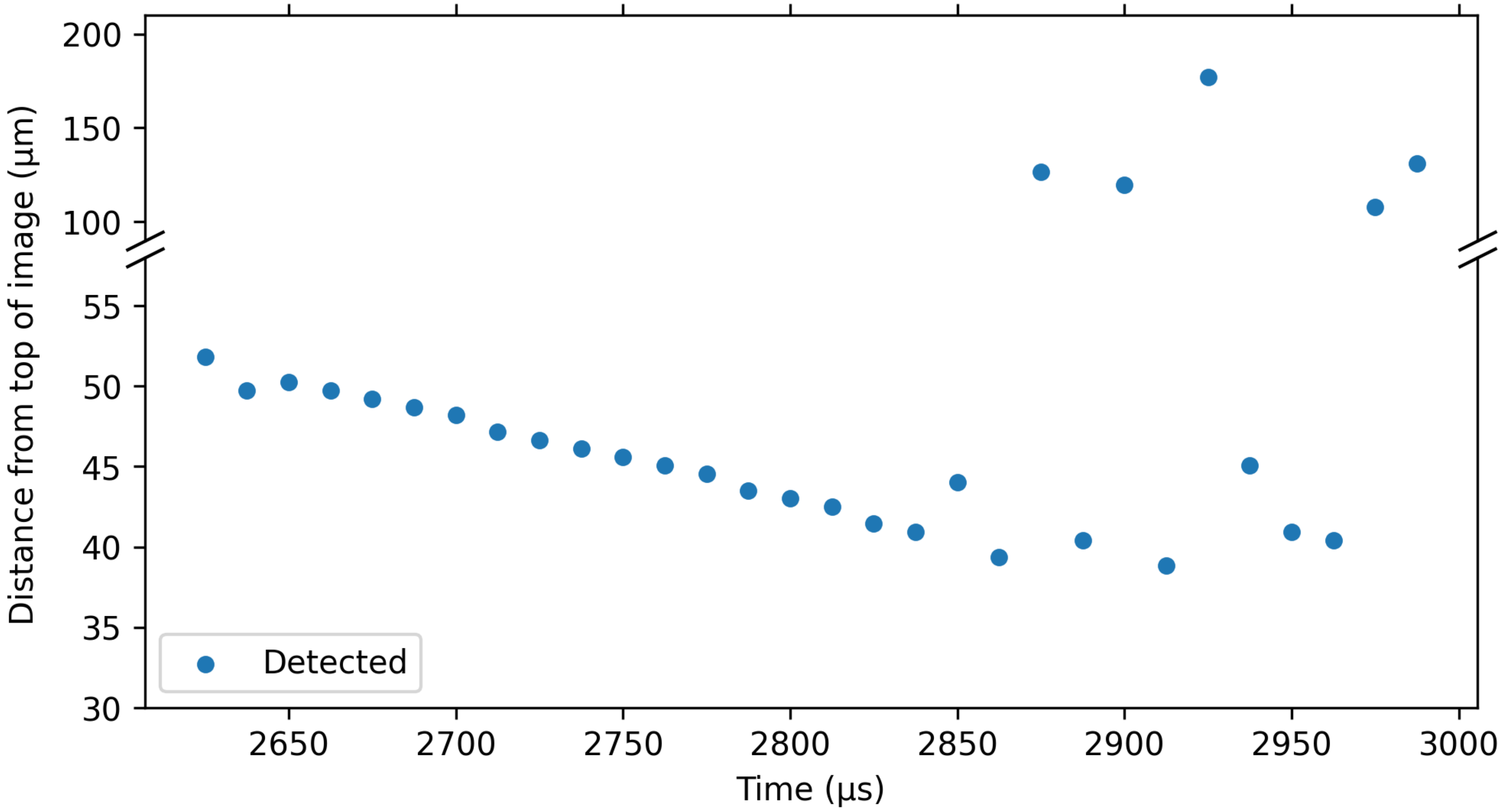
Automated Interface ID: Largest Skeletonized Regions



Automated Interface ID: Detected Location



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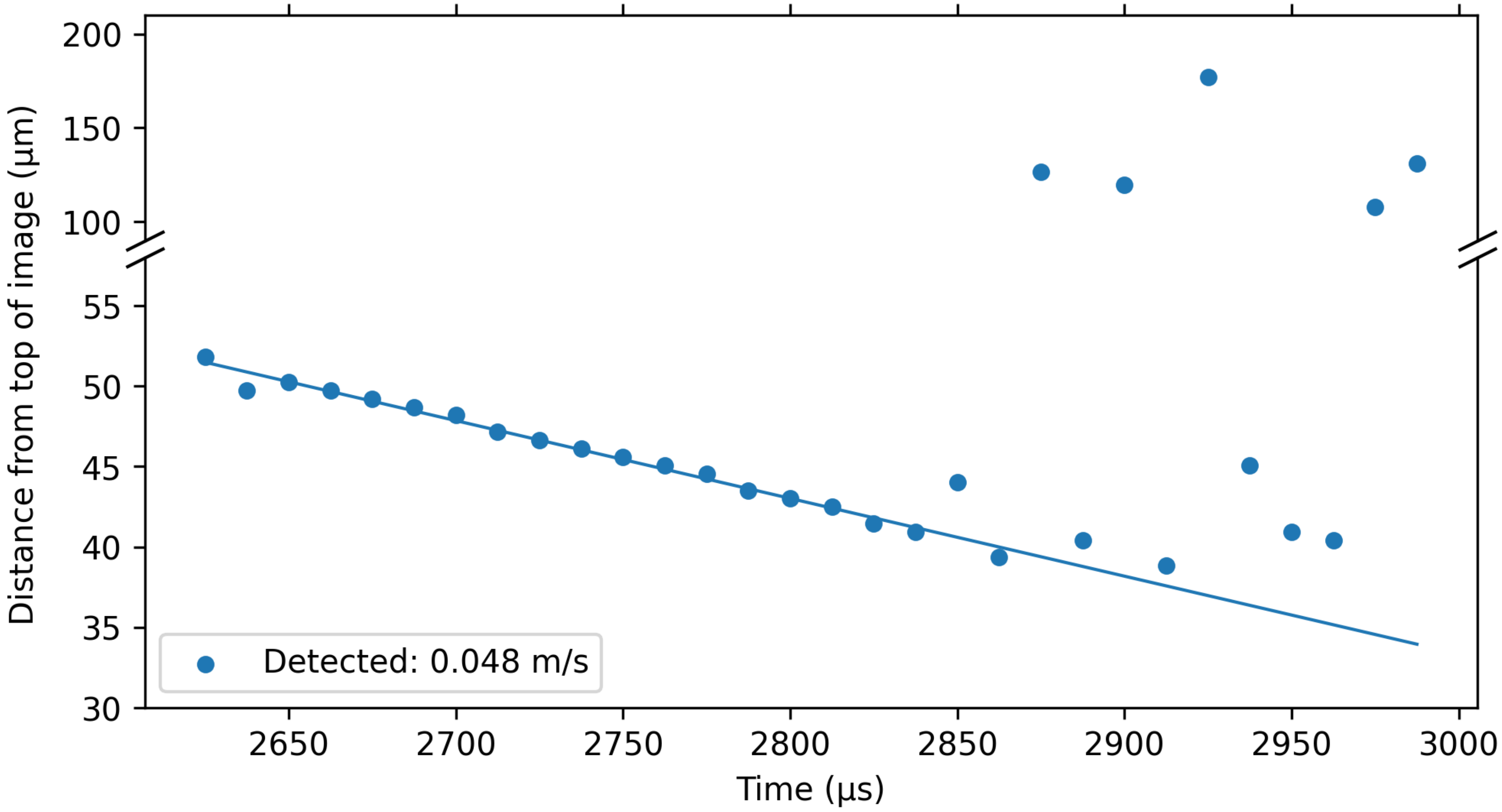
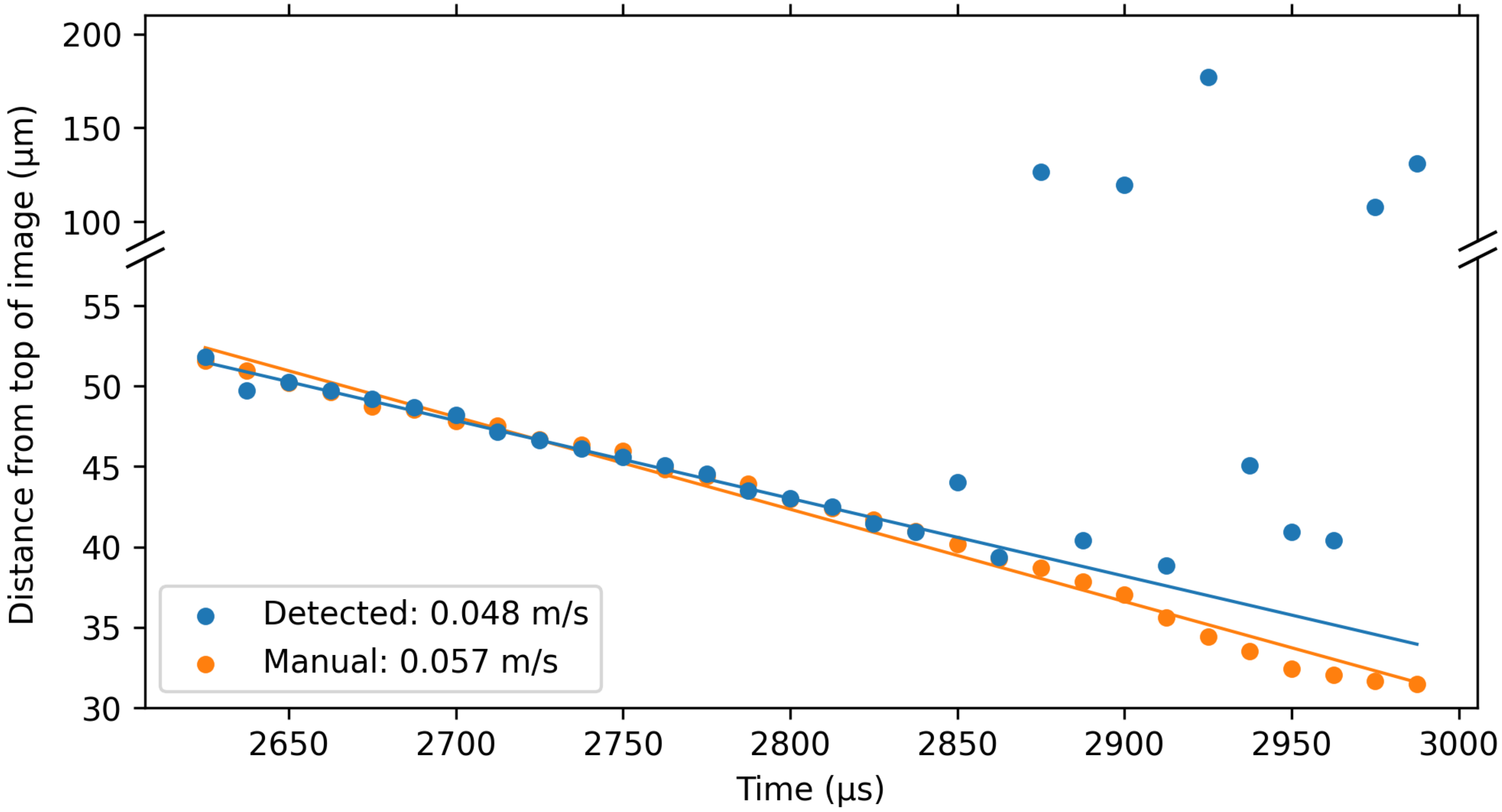
Automated Interface ID: Detected Location

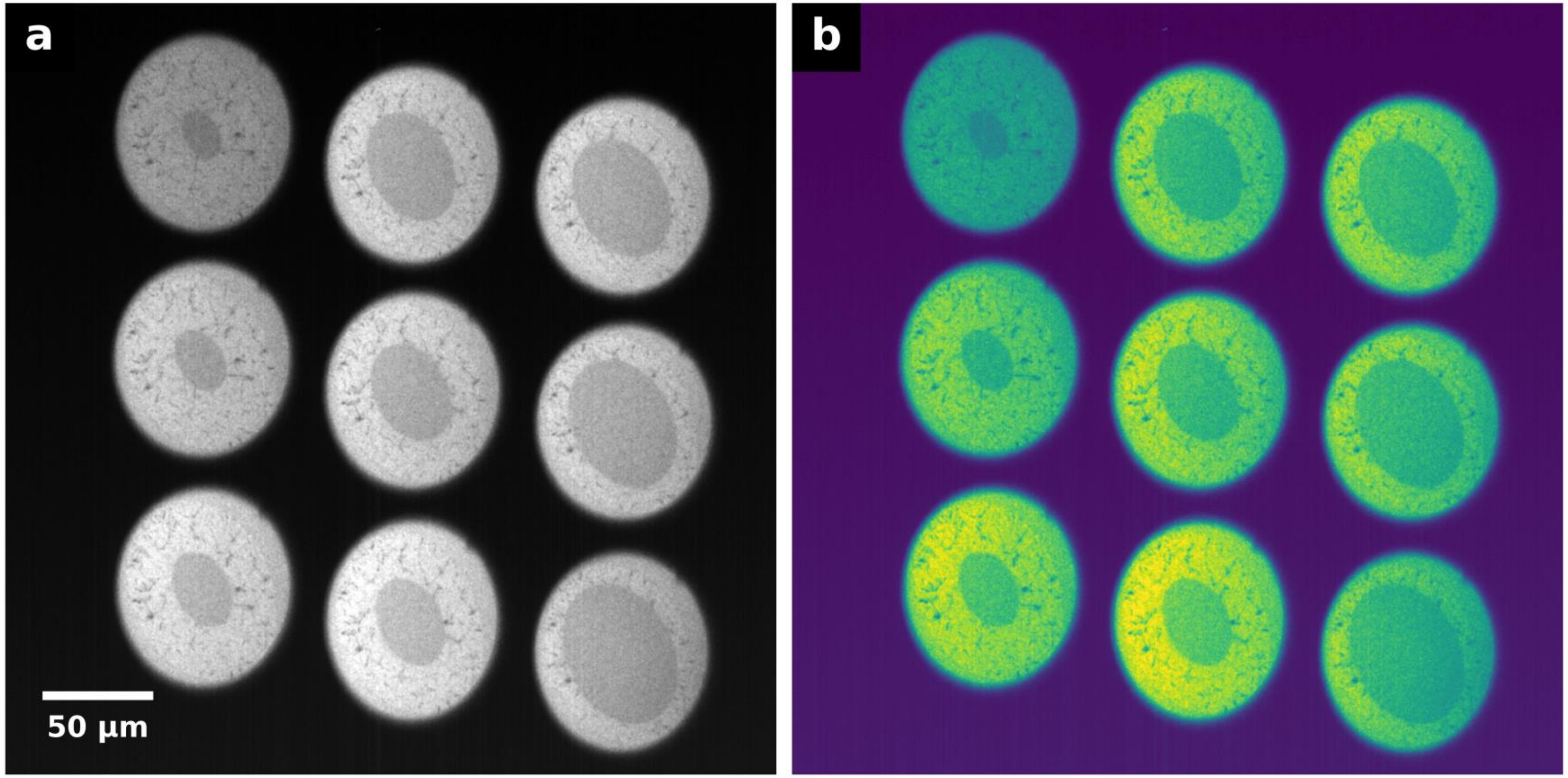


Automated Interface ID: Manually Measured vs Detected Location

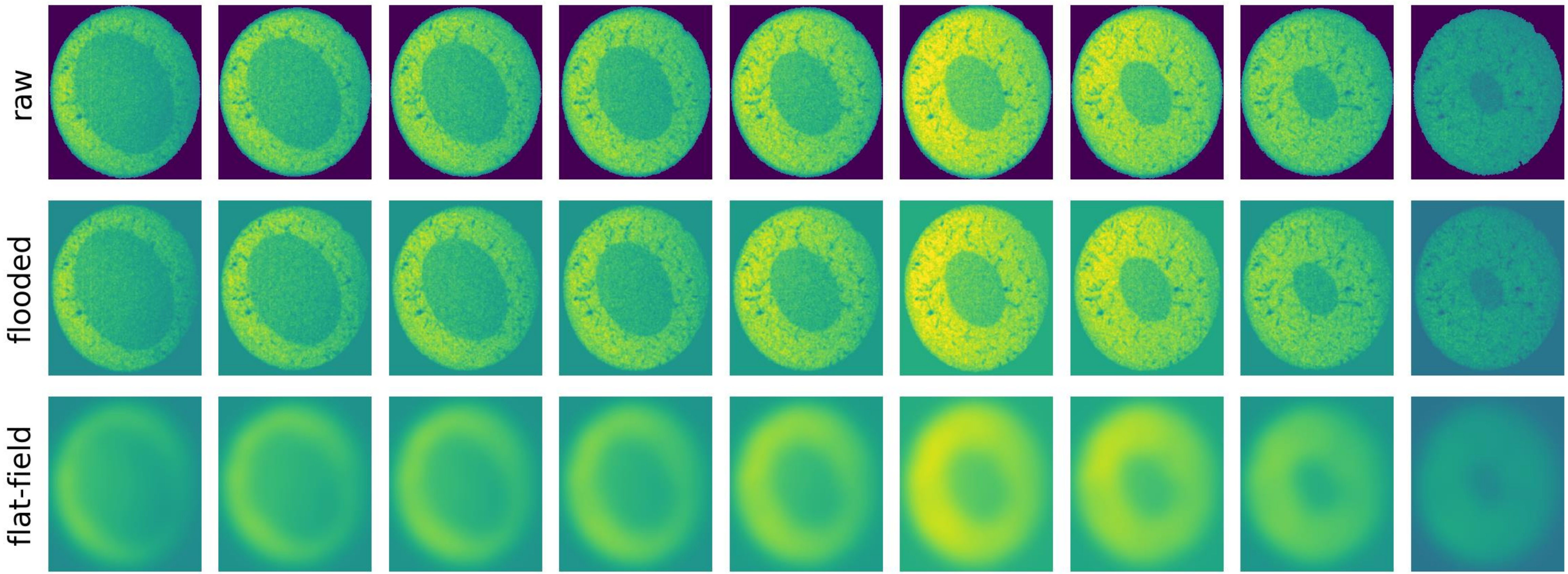


DTEM Rapid Solidification: Al-Si

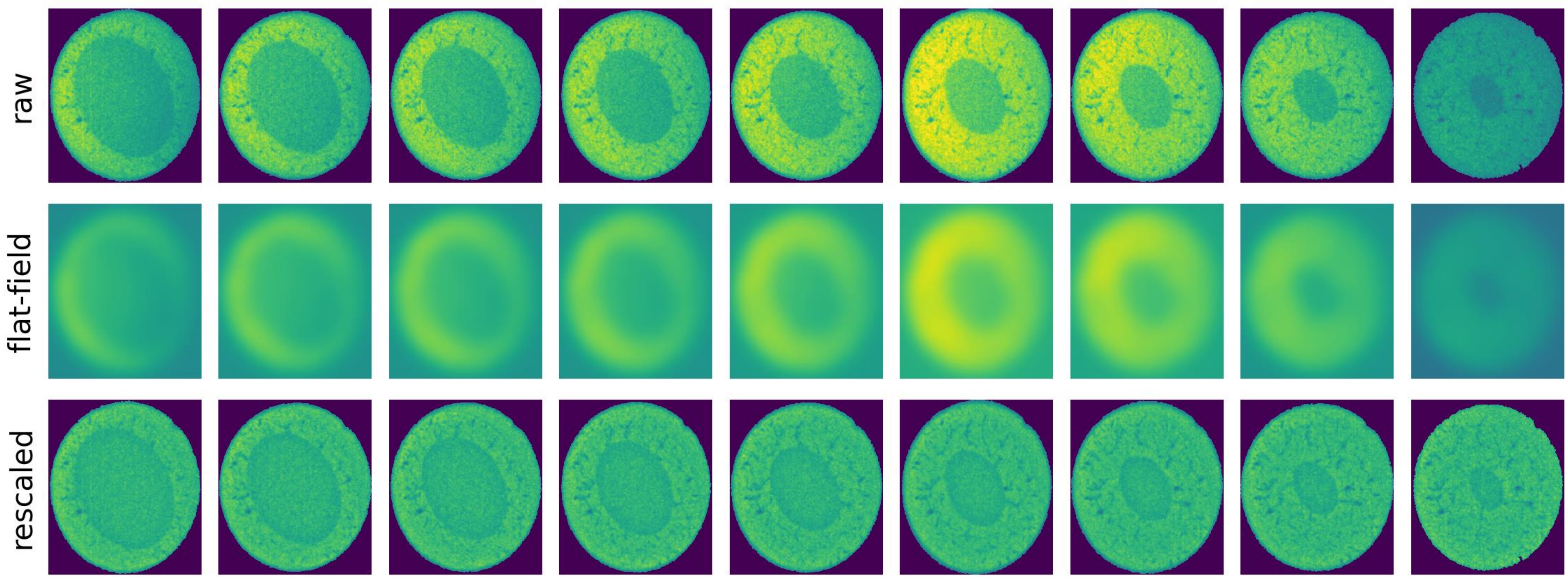
- Novel method at LLNL
- Probe unique time and length scales
  - 400,000 fps (2.5 µs)
- Enables study of rapid solidification



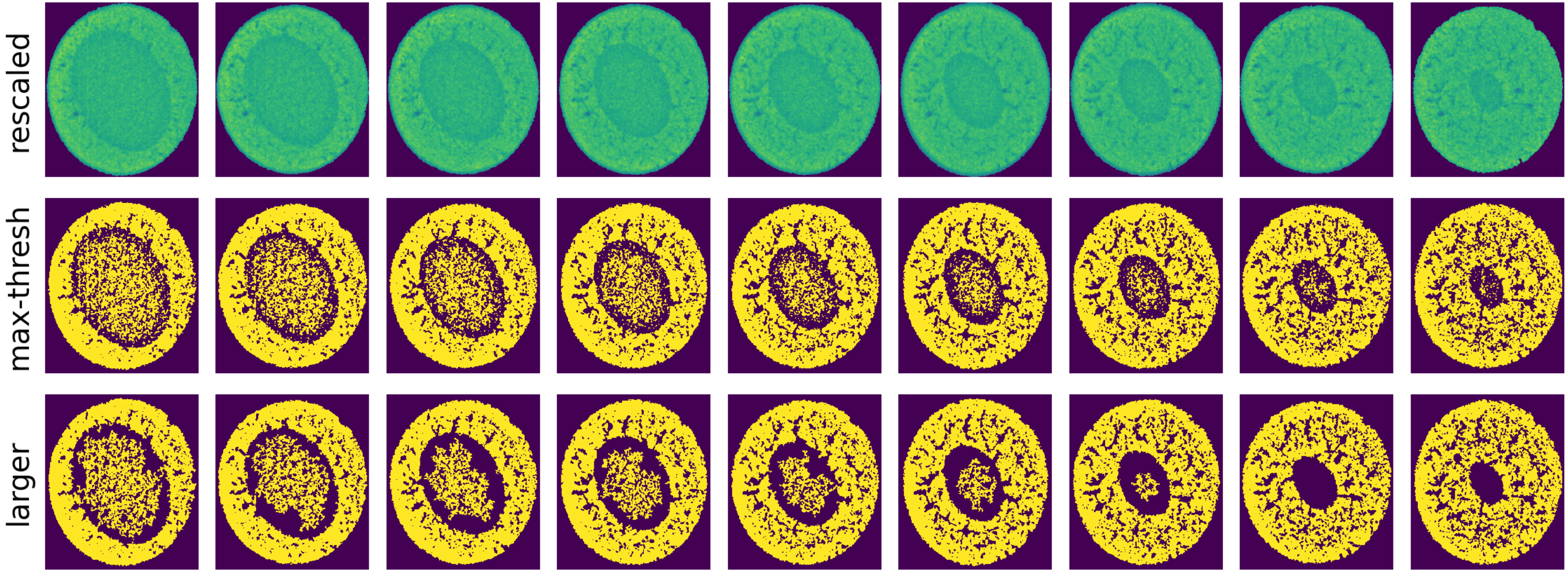
DTEM Rapid Solidification: Pseudo Flat-Field Correction



DTEM Rapid Solidification: Pseudo Flat-Field Correction



DTEM Rapid Solidification: Morphological Operations



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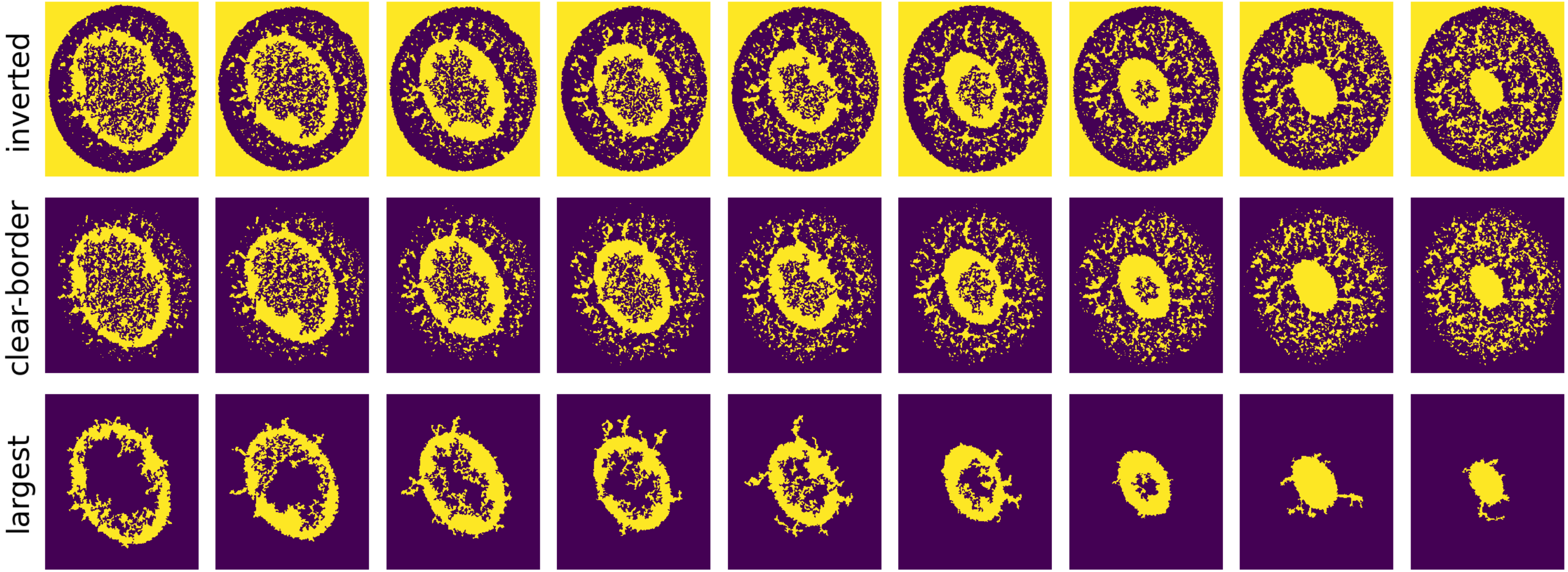
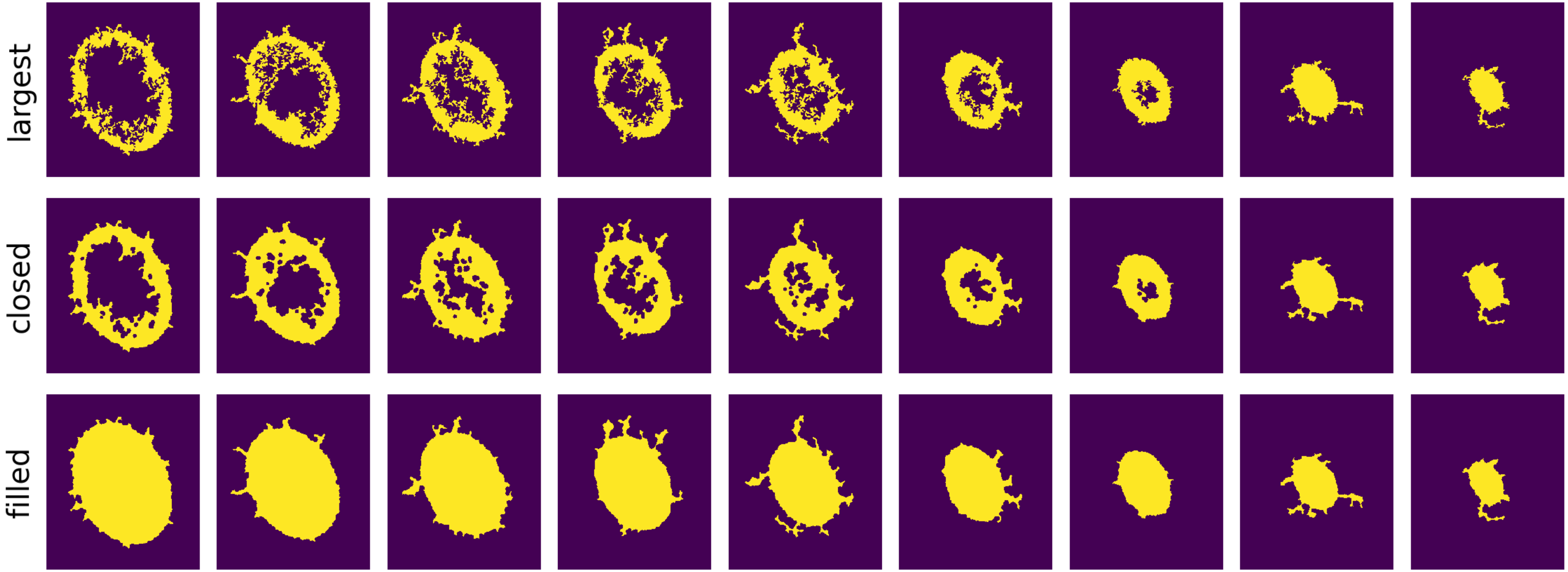
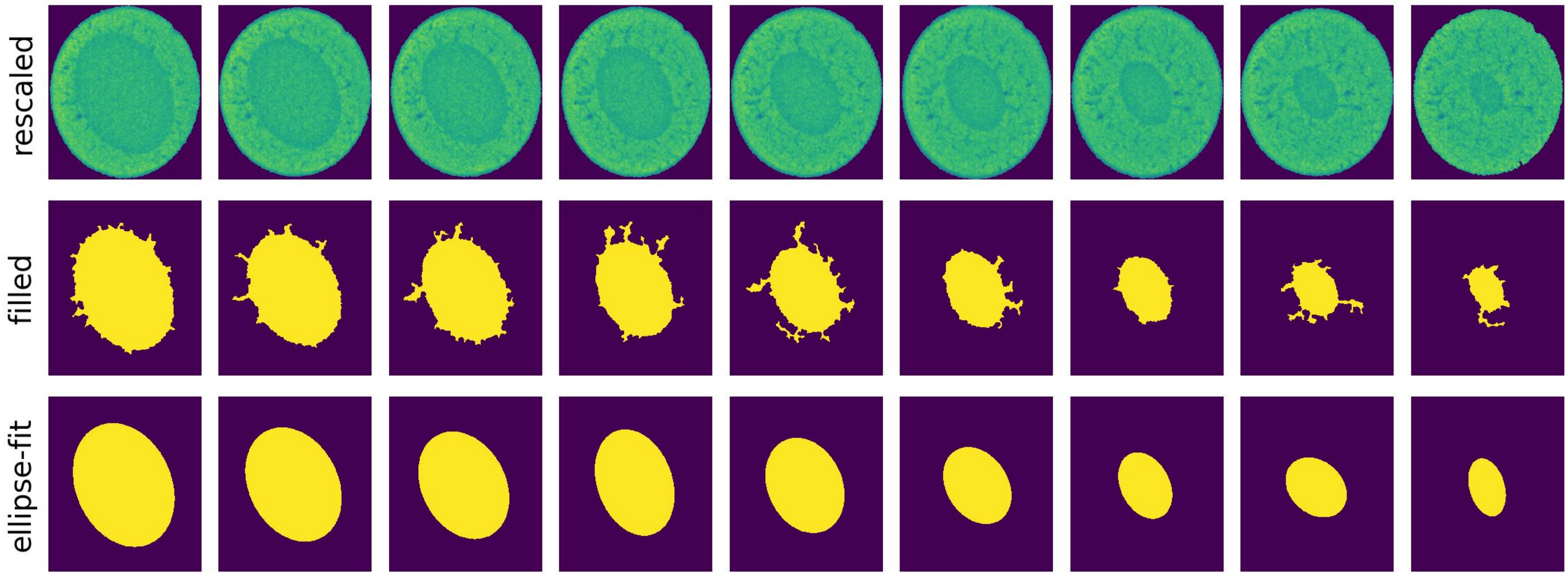


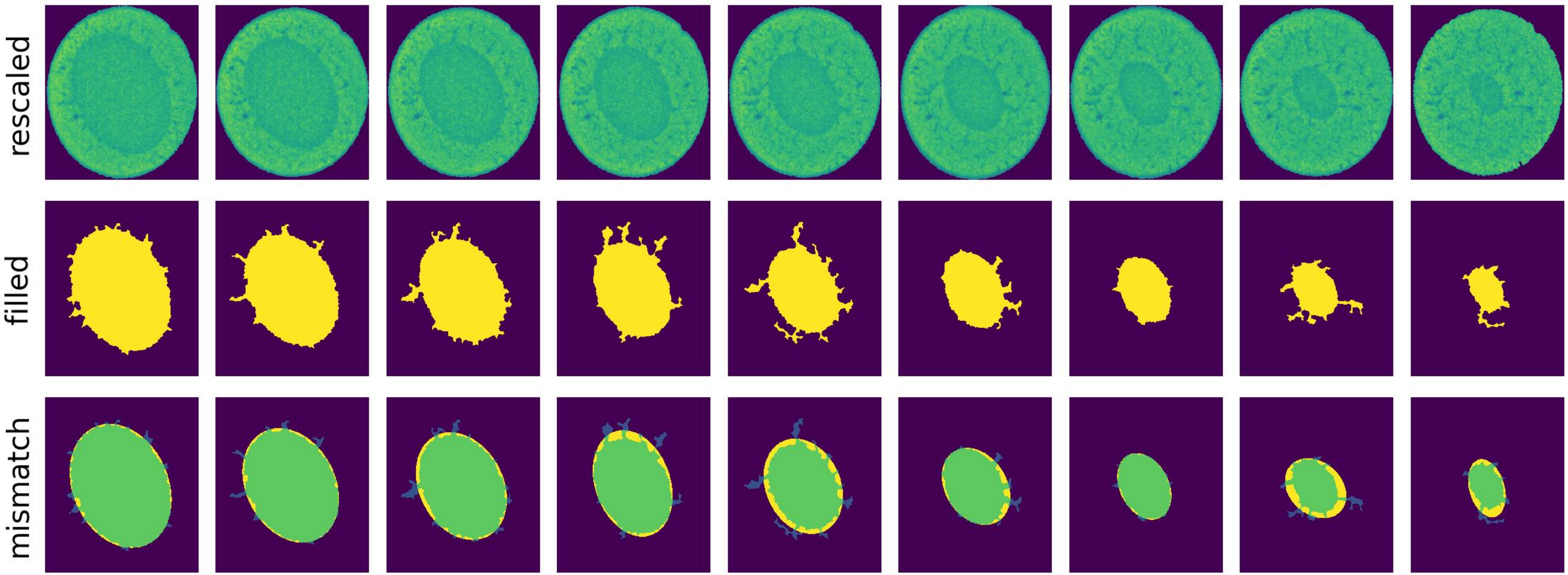
DTEM Rapid Solidification: Morphological Operations



DTEM Rapid Solidification: Ellipse Fitting



DTEM Rapid Solidification: Ellipse Fitting



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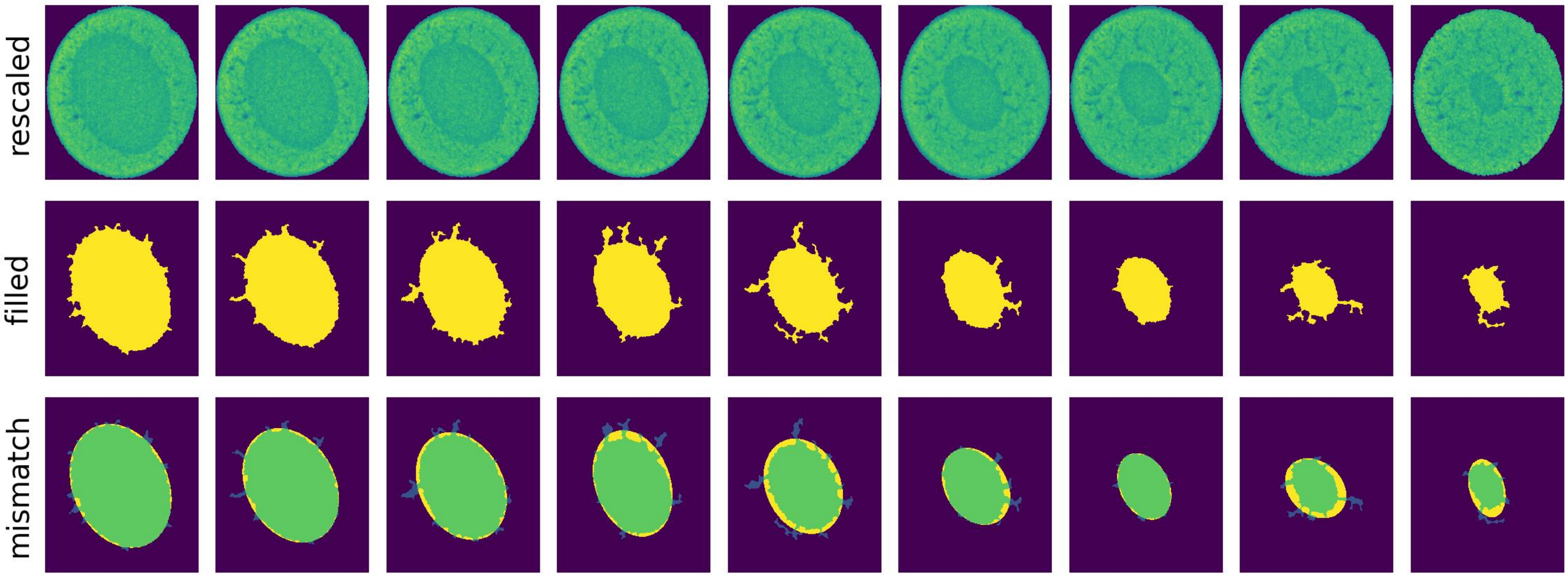
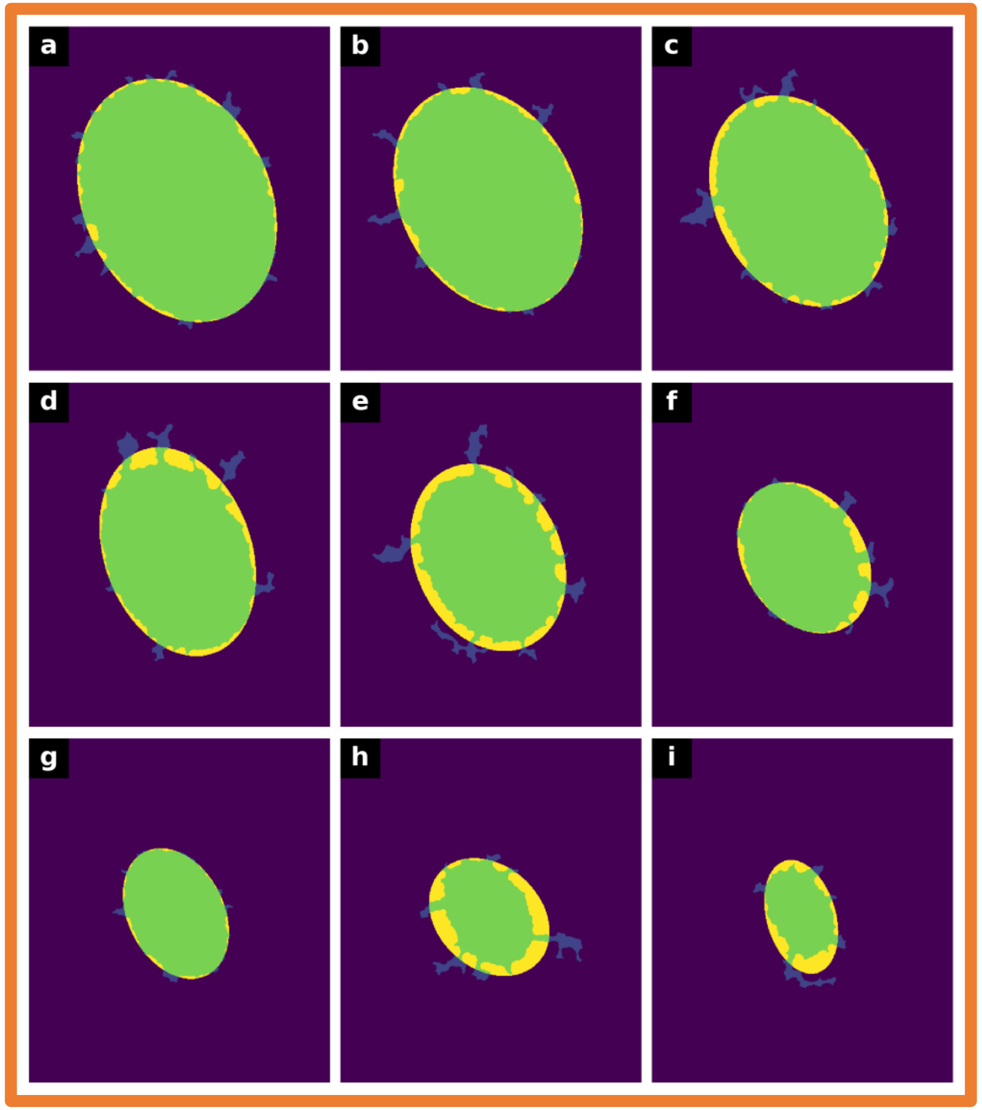


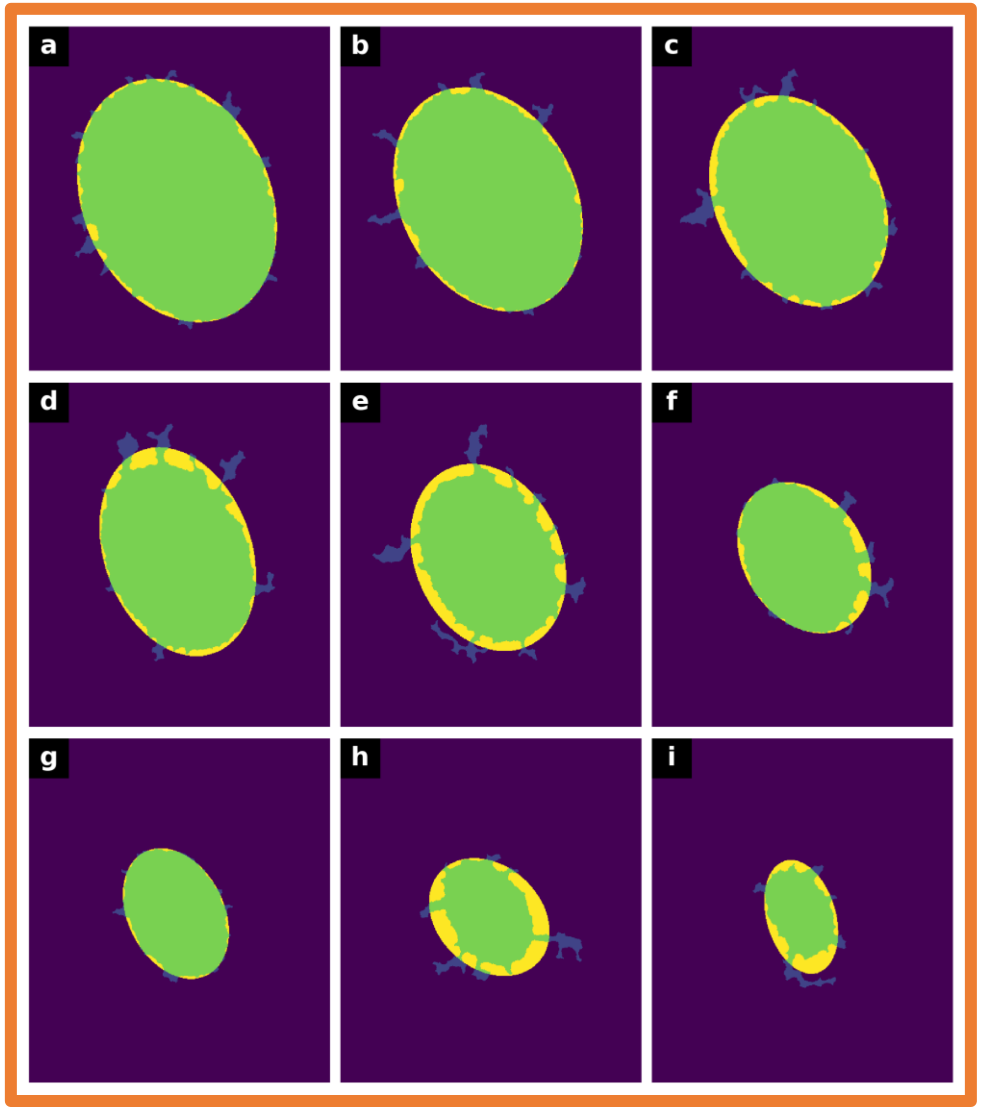
True positive False positive False negative

DTEM Rapid Solidification: Ellipse Fitting



$$Cost = \frac{-\sum true\ positive}{\sum true\ positive + \frac{1}{2}(\sum false\ positive + \sum false\ negative)}$$

DTEM Rapid Solidification: Ellipse Fitting



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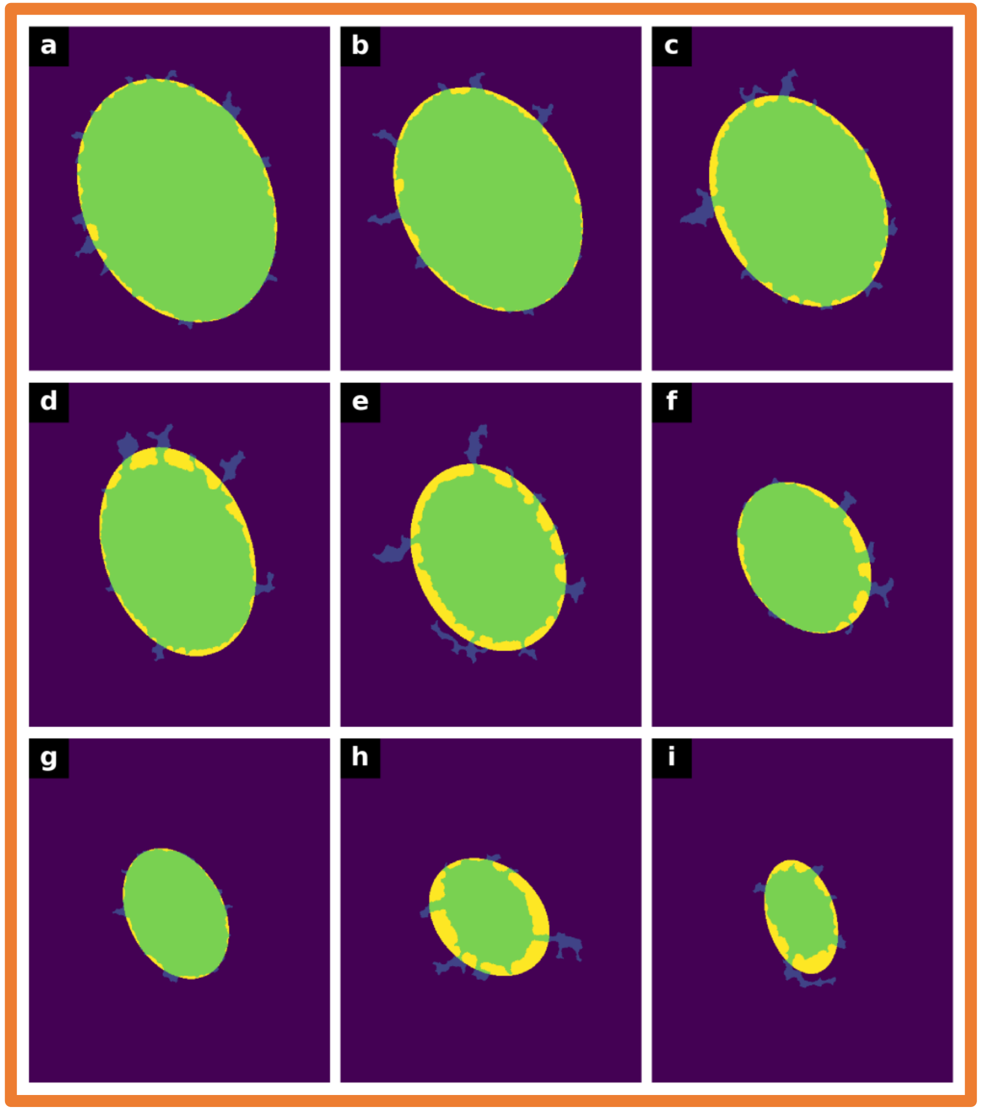

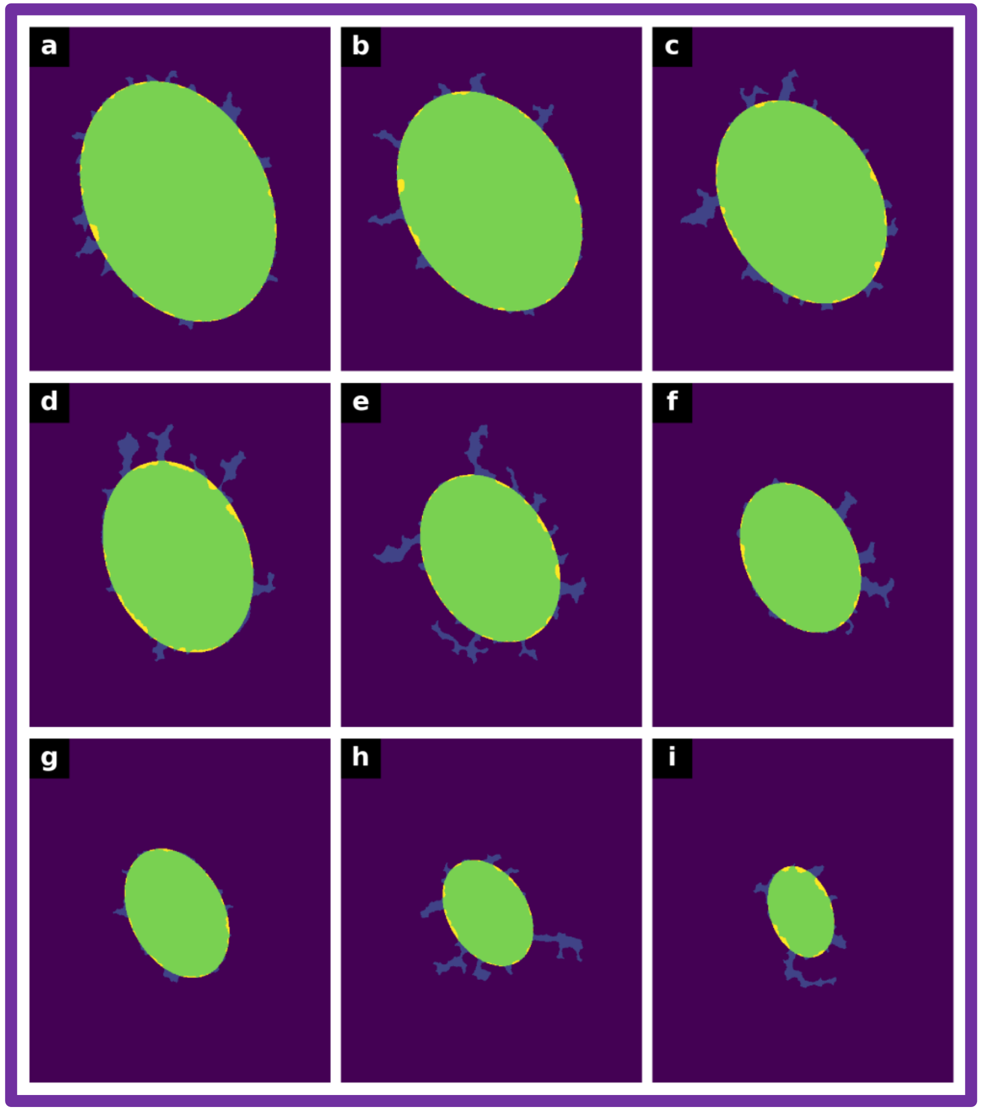

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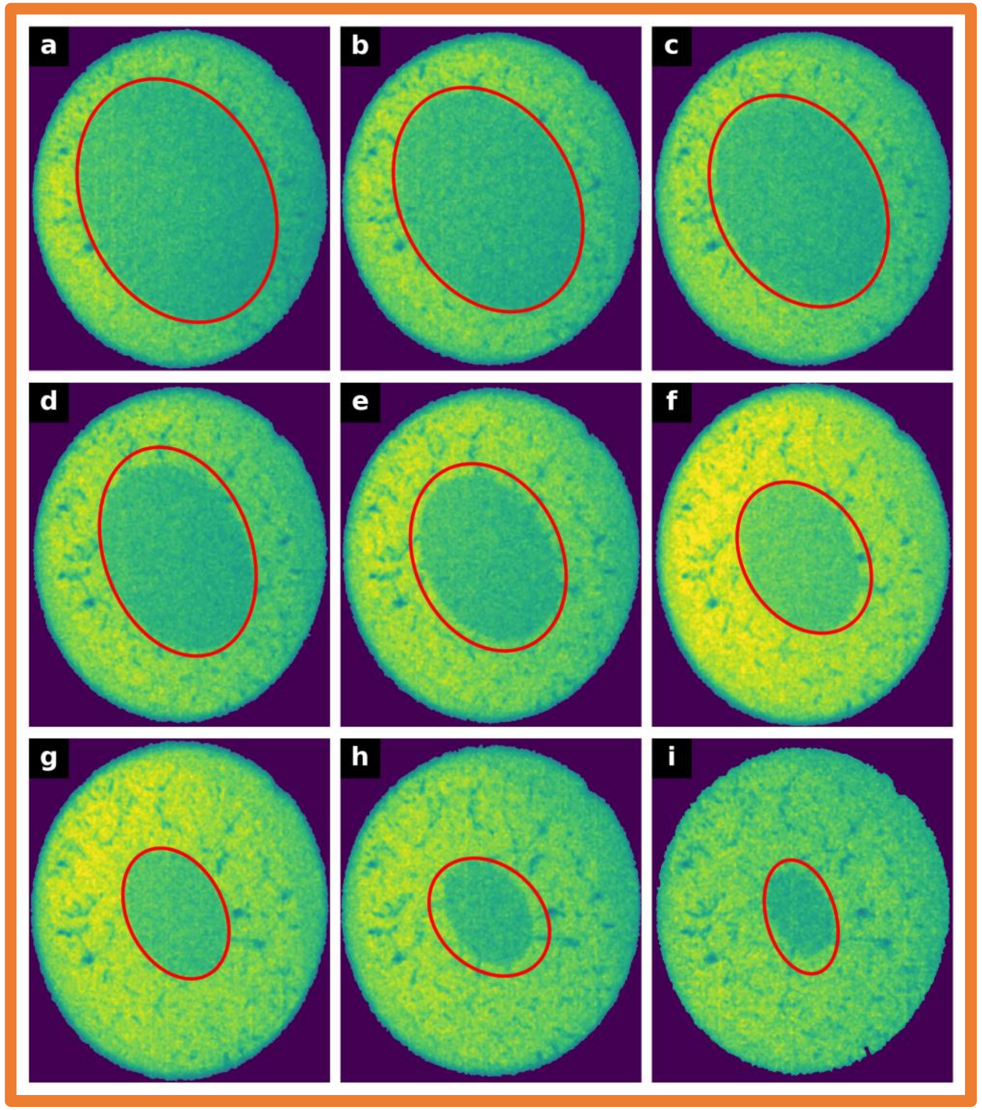
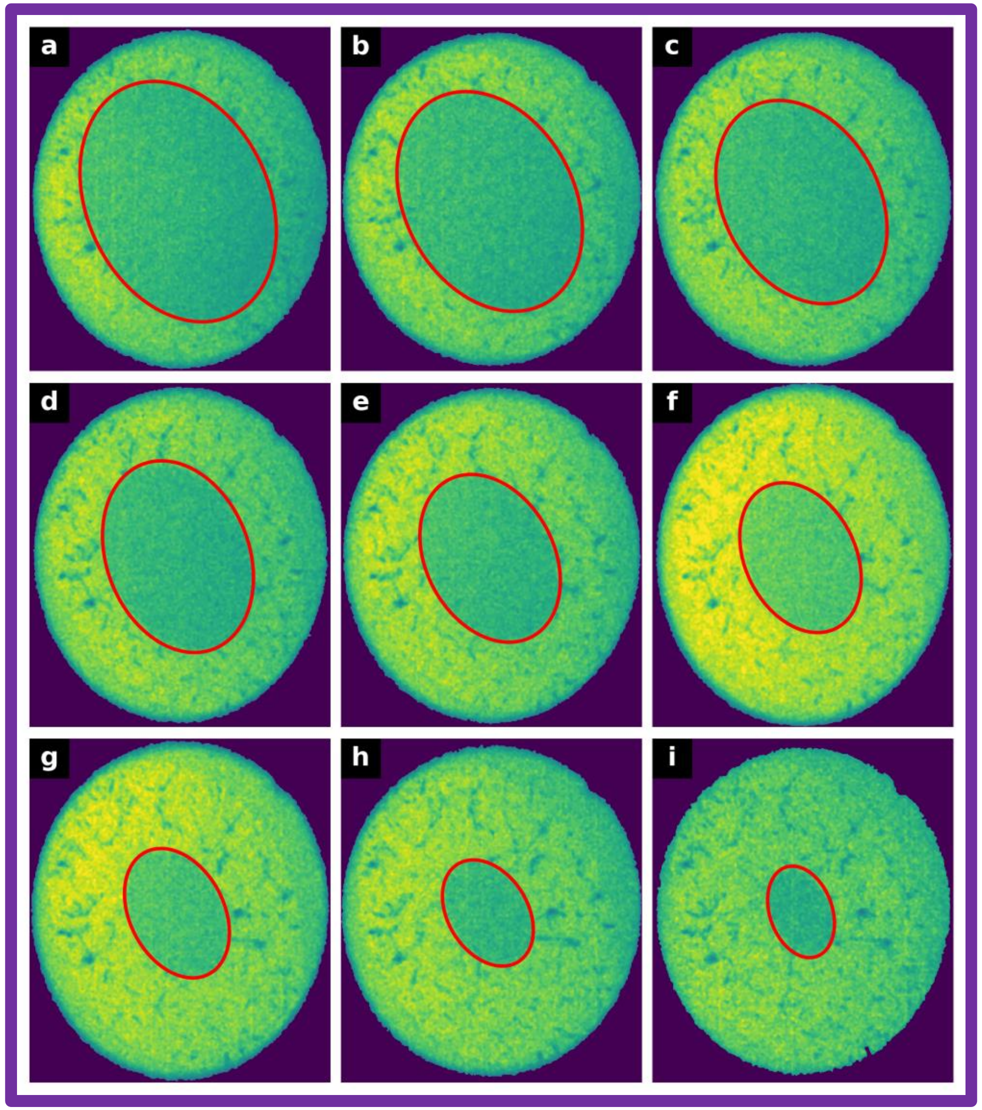
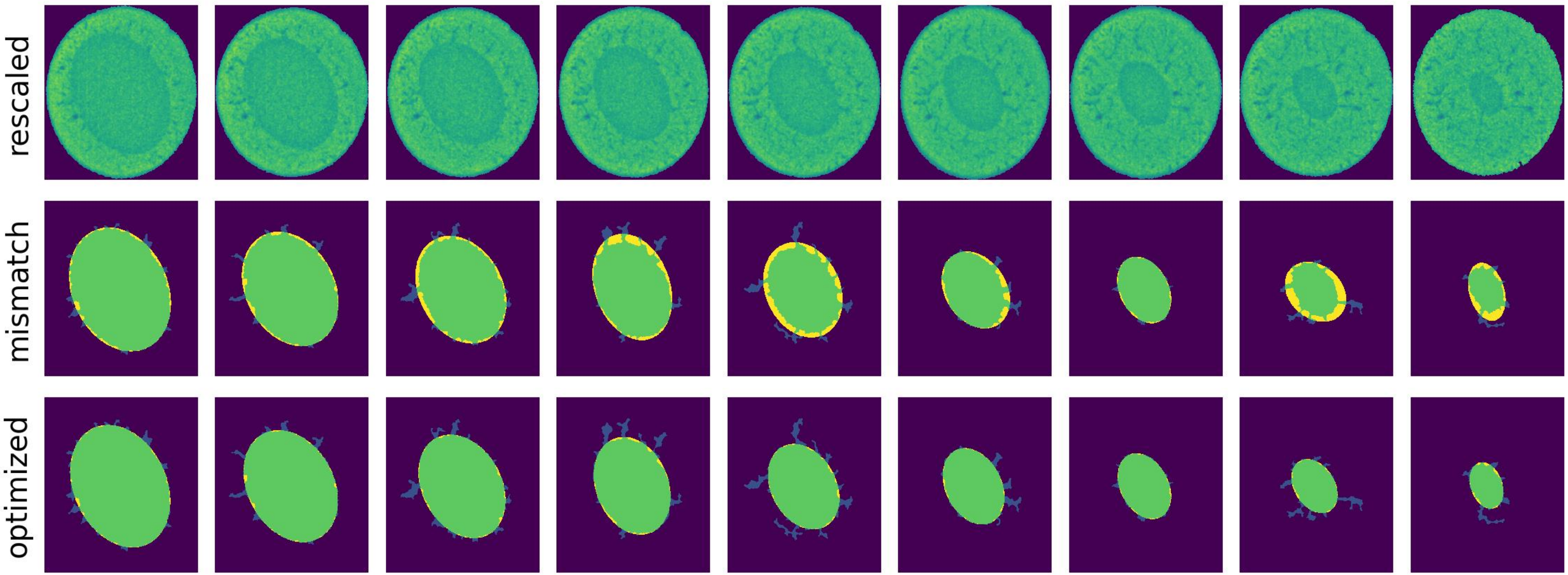
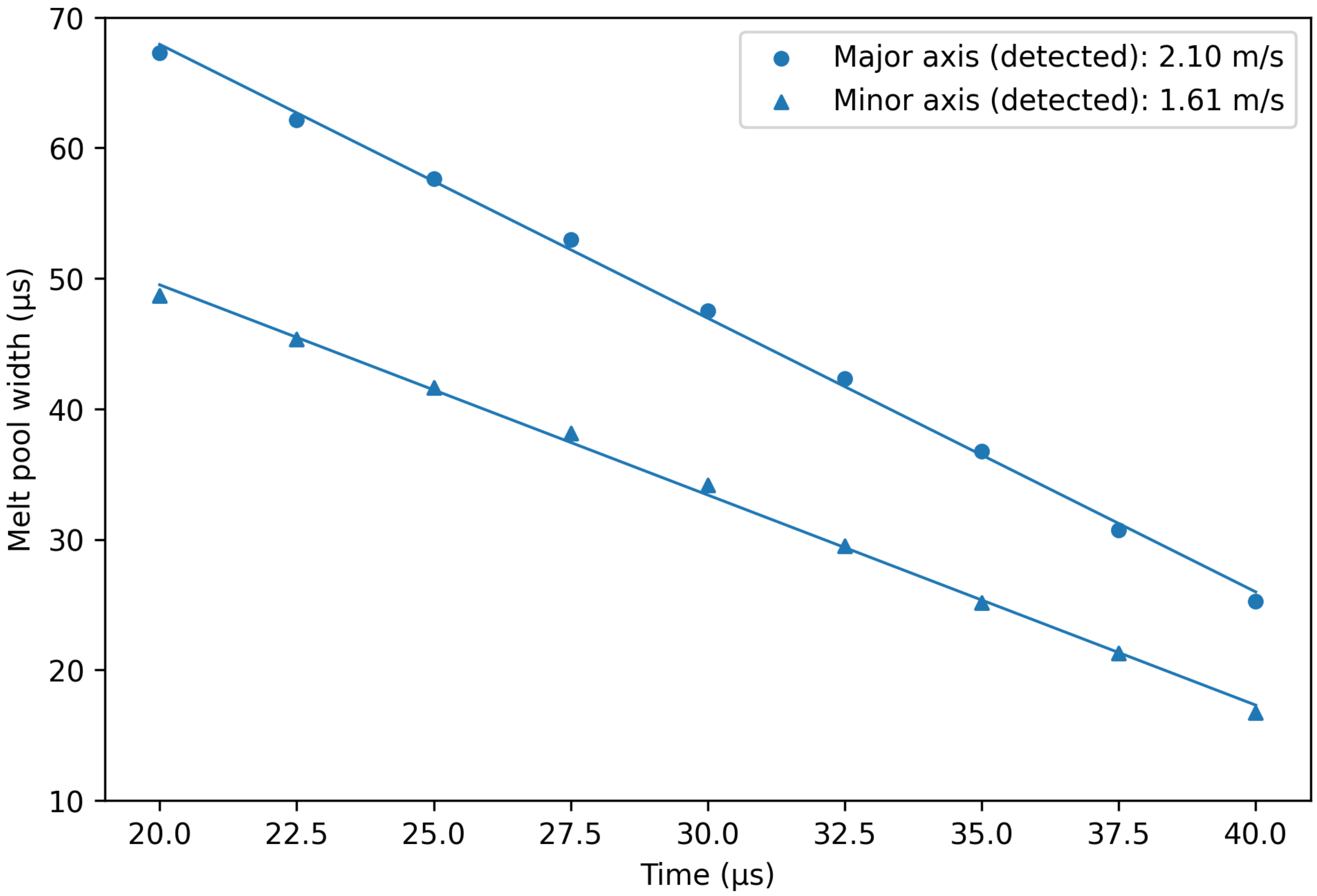




DTEM Rapid Solidification: Ellipse Fitting



DTEM Rapid Solidification: Routine-Identified Melt Pool



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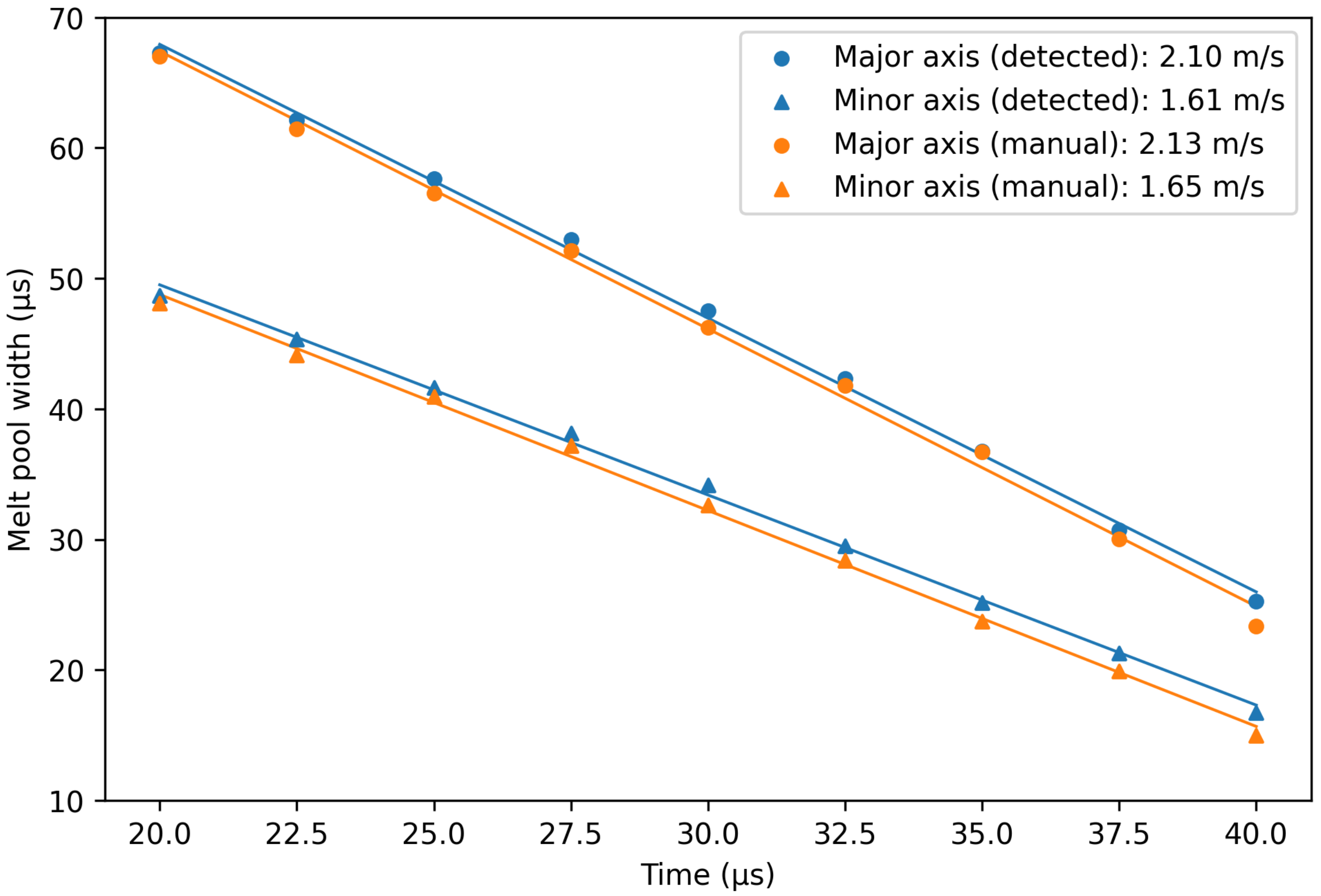
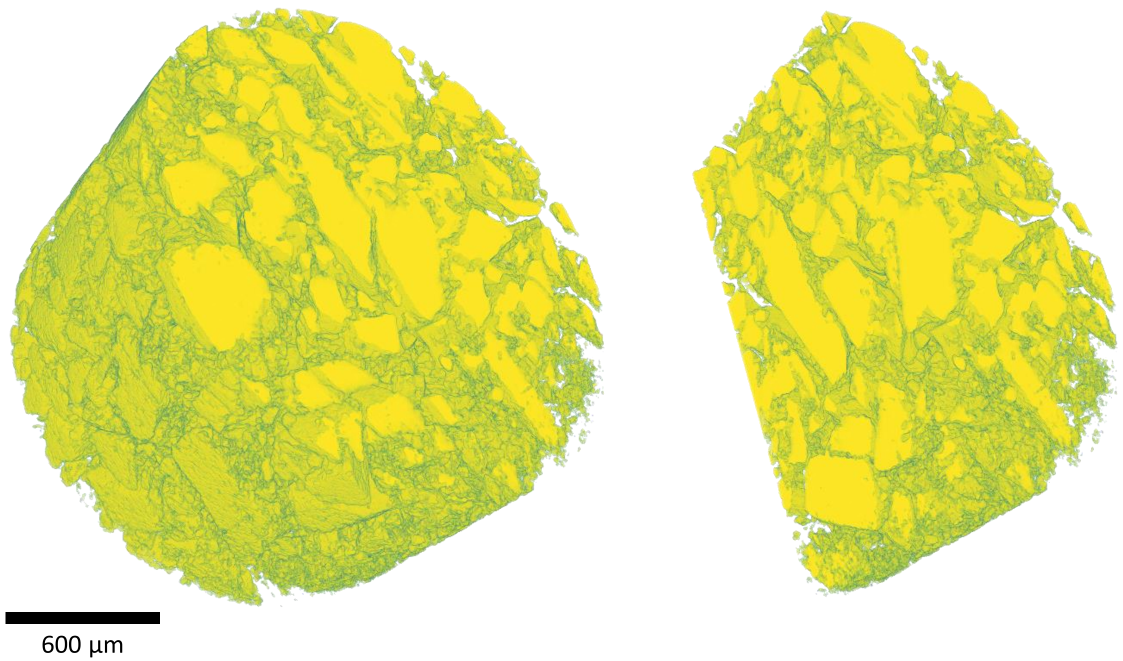
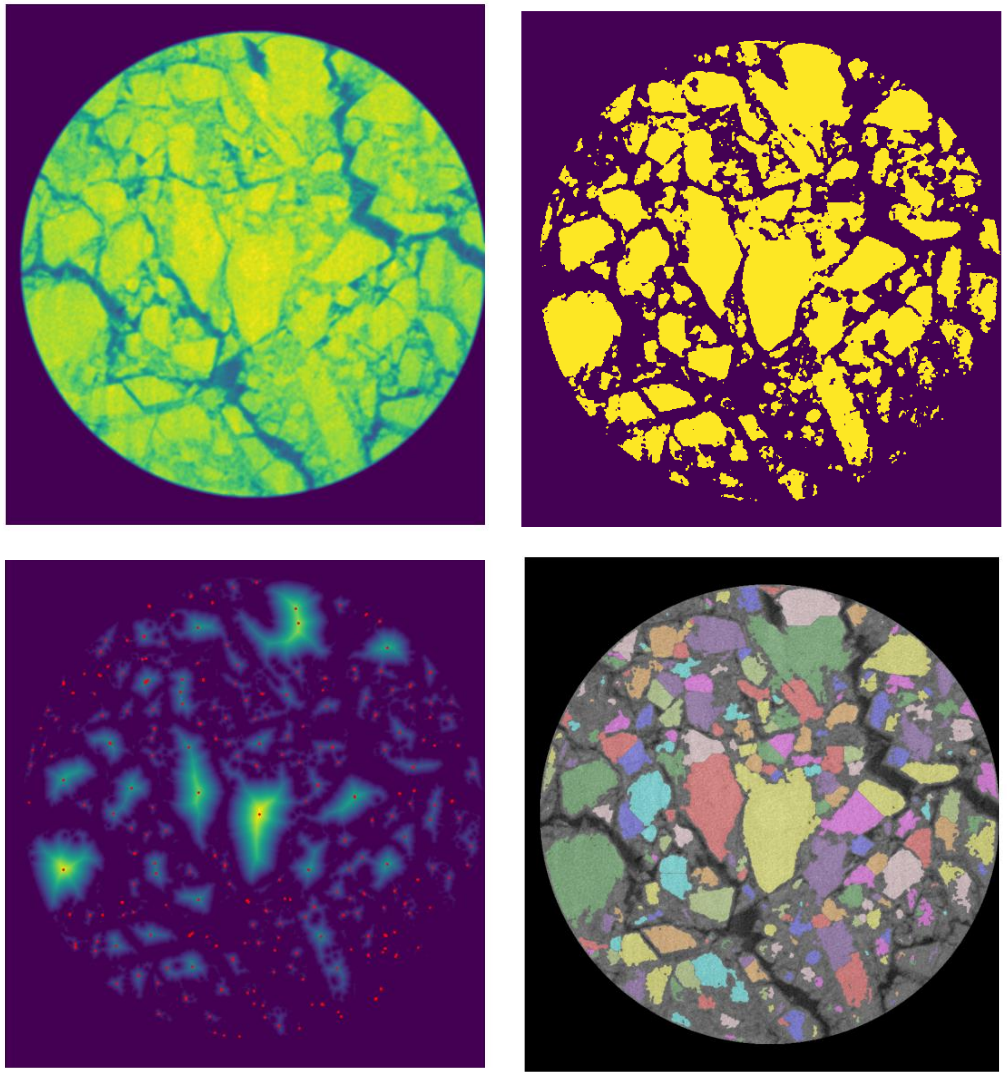
DTEM Rapid Solidification: Manually Identified Melt Pool



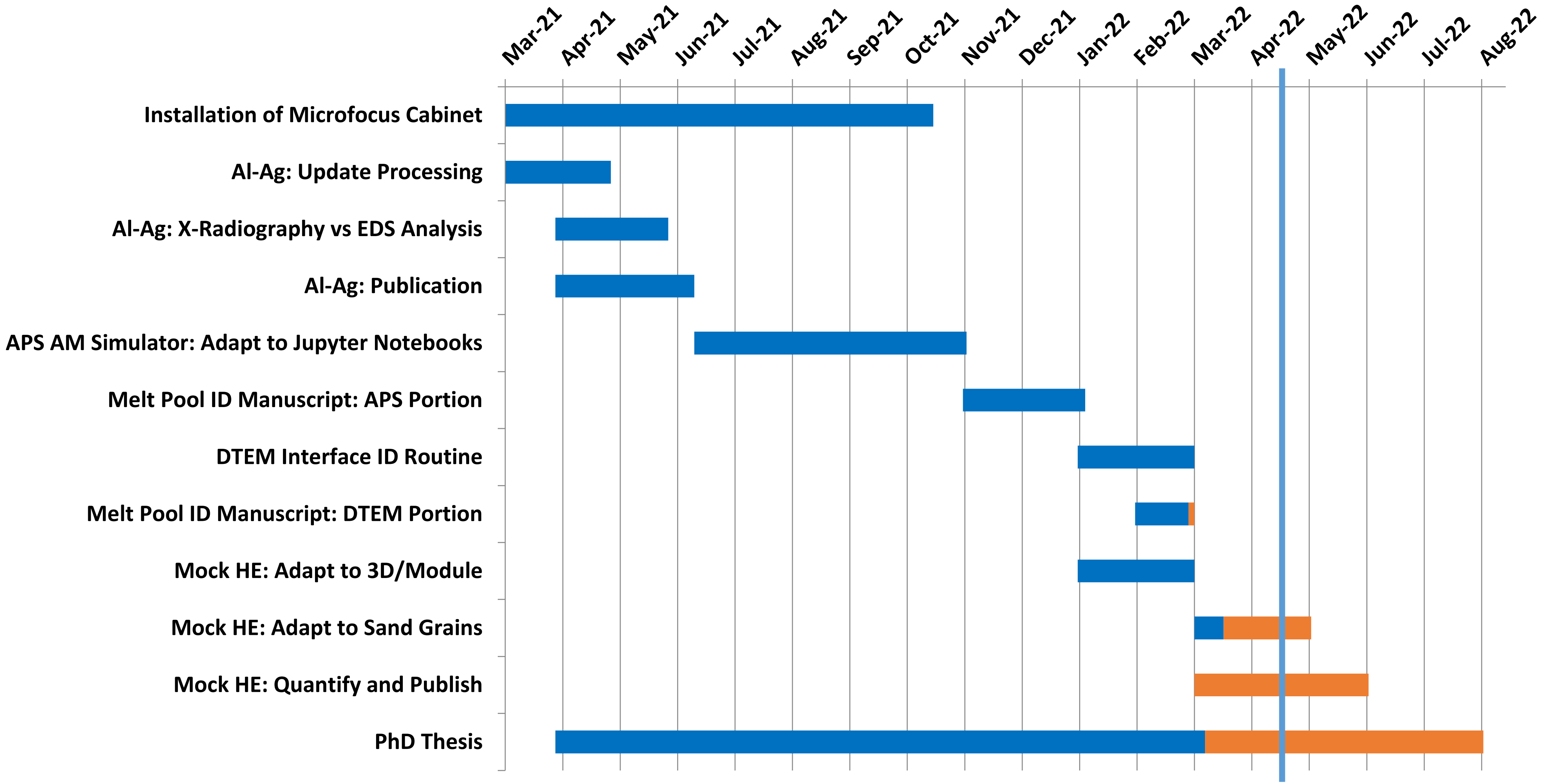
Mock HE Segmentation

- IDOX surrogate material for HE
- Material of interest to NNSA labs
- Understand behavior during processing and deformation





Progress


Mar-21
Apr-21
May-21
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Sep-21
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Nov-21
Dec-21
Jan-22
Feb-22
Mar-22
Apr-22
May-22
Jun-22
Jul-22
Aug-22
Installation of Microfocus Cabinet
Al-Ag: Update Processing
Al-Ag: X-Radiography vs EDS Analysis
Al-Ag: Publication
APS AM Simulator: Adapt to Jupyter Notebooks
Melt Pool ID Manuscript: APS Portion
DTEM Interface ID Routine
Melt Pool ID Manuscript: DTEM Portion
Mock HE: Adapt to 3D/Module
Mock HE: Adapt to Sand Grains
Mock HE: Quantify and Publish
PhD Thesis

Challenges & Opportunities

- Python and Jupyter Notebooks for data processing and analysis
  - Reproducible workflows
  - Maximize data transfer across grad student “generations”
- Quantifying segmentation results

Thank you!

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References

- [1] C. G. Becker, D. Tourret, D. Smith, B. Rodgers, S. Imhoff, J. Gibbs, J. Hunter, M. Espy, K. Clarke, A. Clarke, Integrating In Situ x-Ray Imaging, Energy Dispersive Spectroscopy, and Calculated Phase Diagram Analysis of Solute Segregation During Solidification of an Al-Ag Alloy, JOM. (2021). https://doi.org/10.1007/S11837-021-04884-8.
- [2] C. Wälhby, I.M. Sintorn, F. Erlandsson, G. Borgefors, E. Bengtsson, Combining intensity, edge and shape information for 2D and 3D segmentation of cell nuclei in tissue sections, J. Microsc. 215 (2004) 67–76. https://doi.org/10.1111/J.0022-2720.2004.01338.X.