Project 32-L: Development of Cabinet-Based X-Ray Computed Tomography Methods for Studies of Microstructures and Defects in Metals

Fall 2019 Semi-Annual Meeting
Colorado School of Mines, Golden, CO
October 9 - 11, 2019

Student: C. Gus Becker (Mines)

Faculty: Amy Clarke (Mines)

Industrial Mentors: Michelle Espy (LANL, E-6: Non-Destructive Testing)

Project 32-L: Development of Cabinet-Based X-Ray Computed Tomography Methods for Studies of Microstructures and Defects in Metals

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

Project Duration
PhD: August 2017 to May 2021

- 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 data and establish cabinet-based x-ray radiography capabilities at Mines for further experimentation.
- Benefit: Identify technique limitations for defect detection in AM metals and studies of solidification.

Recent Progress

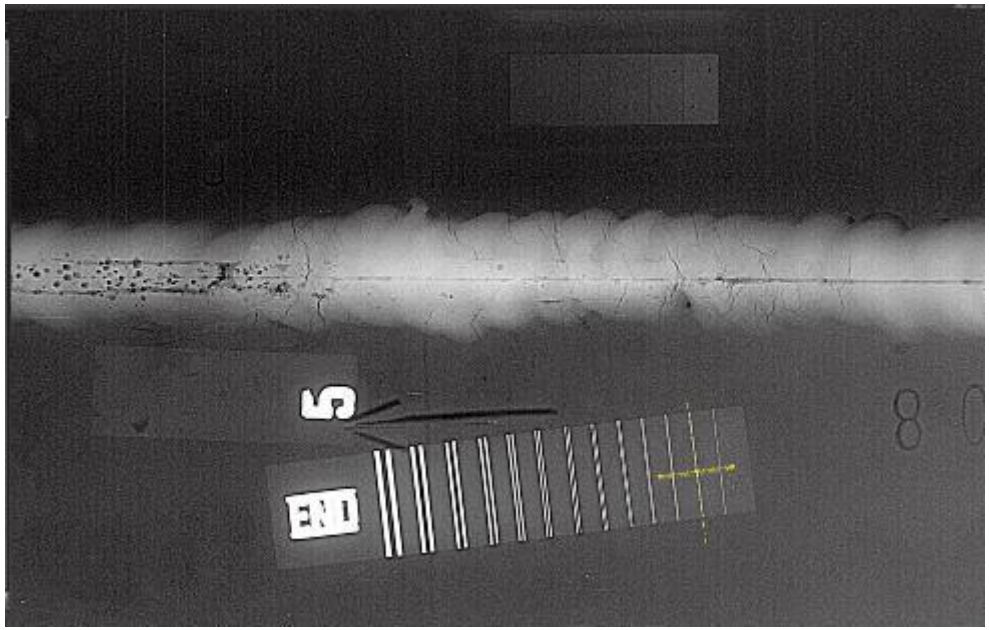
- Sharpened Python skills for more advanced and efficient image processing
- Processing of Dynamic Transmission Electron Microscopy (DTEM) data
- Continue to support other projects by building ImageJ macros (AM simulator)

Metrics		
Description	**% Complete**	**Status**
1. Development of modular image processing method using ImageJ macros	100%	●
2. Investigation of Python as alternative image processing platform	100%	●
3. Image processing and analysis of datasets from E-6, APS, and pRad	80%	●
4. Begin processing electron radiography (eRad) data and compare to micro-focus data	0%	●
5. Material investigation with micro-focus XCT (AM lattice experiments, solidification, etc.)	0%	●

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 (e.g. casting) to inform model development

- Establishment of x-ray radiography and computed tomography (CT) cabinet at Mines
  - Characterization of materials for thesis
  - Support current projects
  - Consideration of future projects from industry
  - Accommodates custom/flexible experimental platforms (solidification: casting, welding, AM, etc.; deformation: tension, compression, etc.)

Cabinet Timeline

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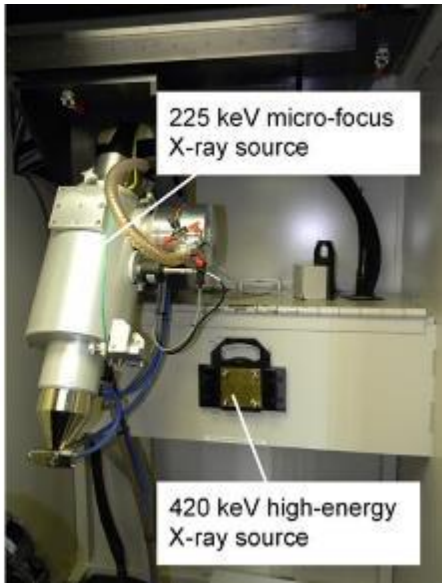
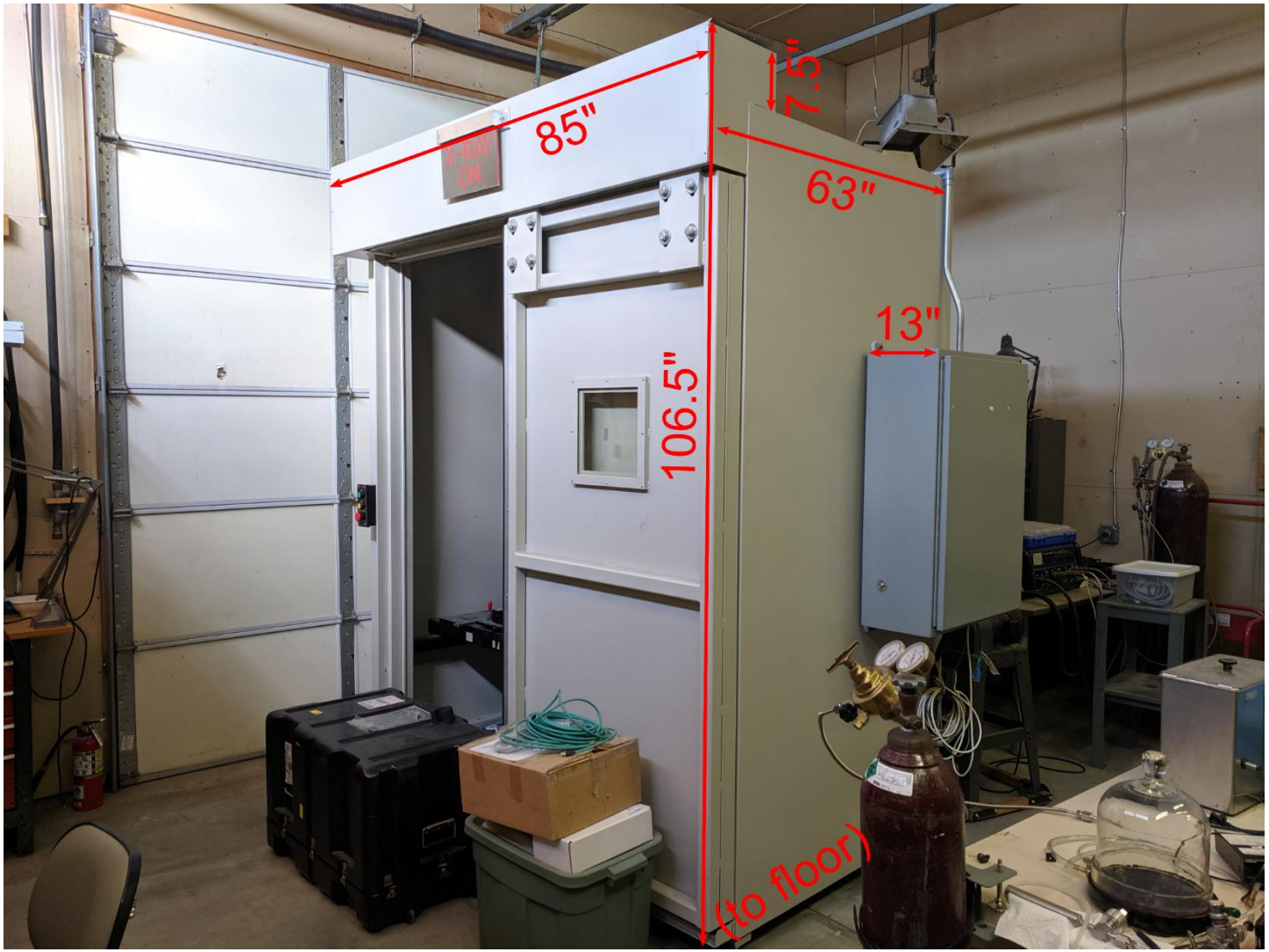


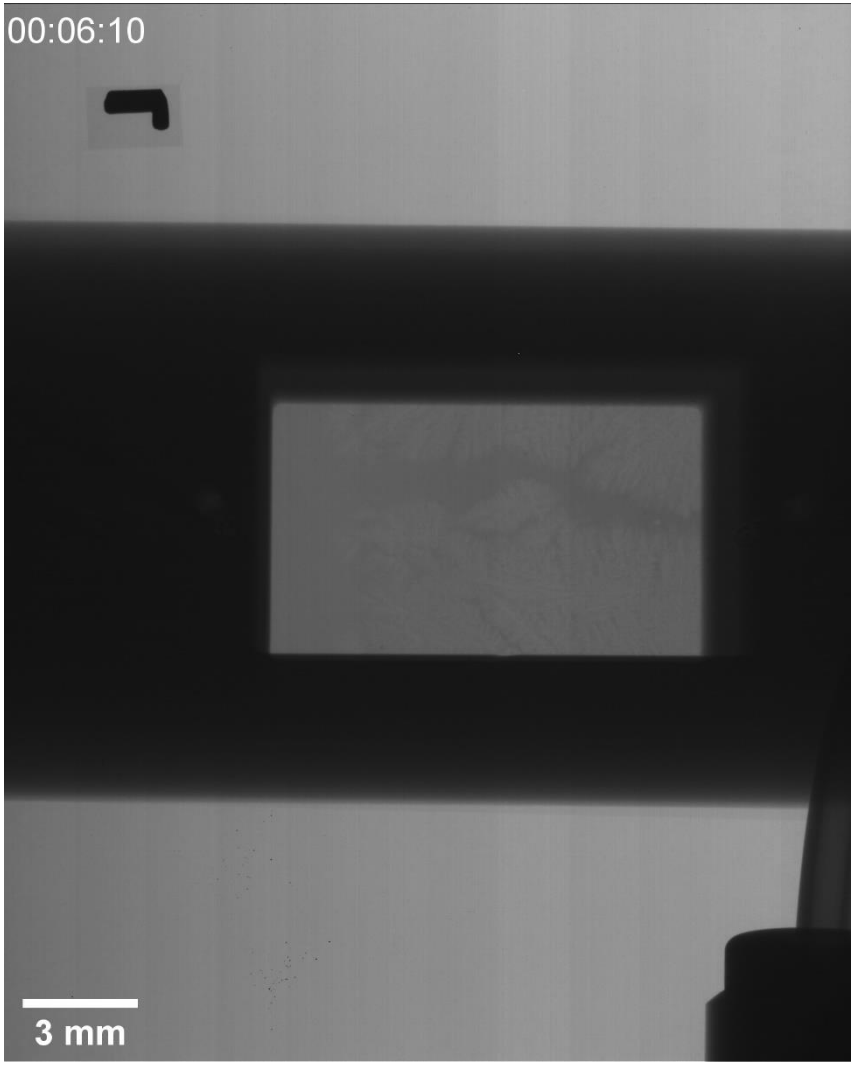
Process Donation Internally (LANL)	Ship to White Rock, NM	Ship to Santa Clara, CA for Refurbishing	Prepare Lab Space for System	Install New Micro-Focus System	Ship to Mines and Install
Complete	Complete	Complete	In Progress	In Progress	TBD

Cabinet Timeline



Dynamic X-Ray Radiography

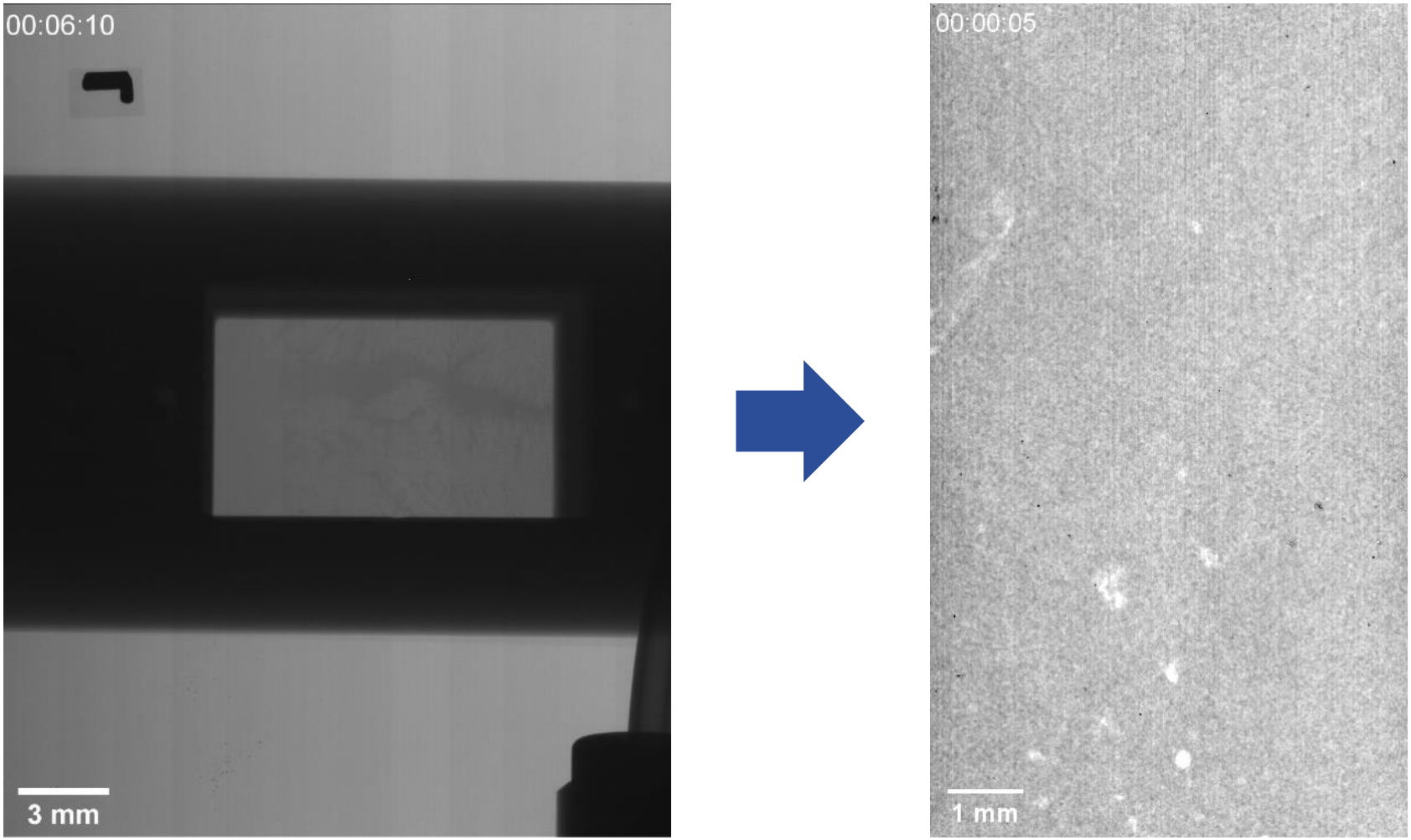
- High-energy micro-focus radiography
- APS setup
  - 15 mm steel bar
  - 7 x 12 mm window
- Al-30wt.%Ag
- Controlled directional solidification
- Through image processing:
  - Solidification velocity
  - Solute segregation



Modular Image Processing Method

- Split image processing routine into separate “modules”
- Each module takes an image directory, performs an image processing step, and outputs the edited images
- Chain modules together by using output images from one as the input images for another
- Creates ordered file hierarchy with each module

Modular Image Processing Method



Switch to Python Image Processing with scikit-image

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- Why Python?
  - Control
  - Flexibility
  - Ease of use
  - Community

scikit-image
image processing in python

Dynamic Transmission Electron Microscope (DTEM)

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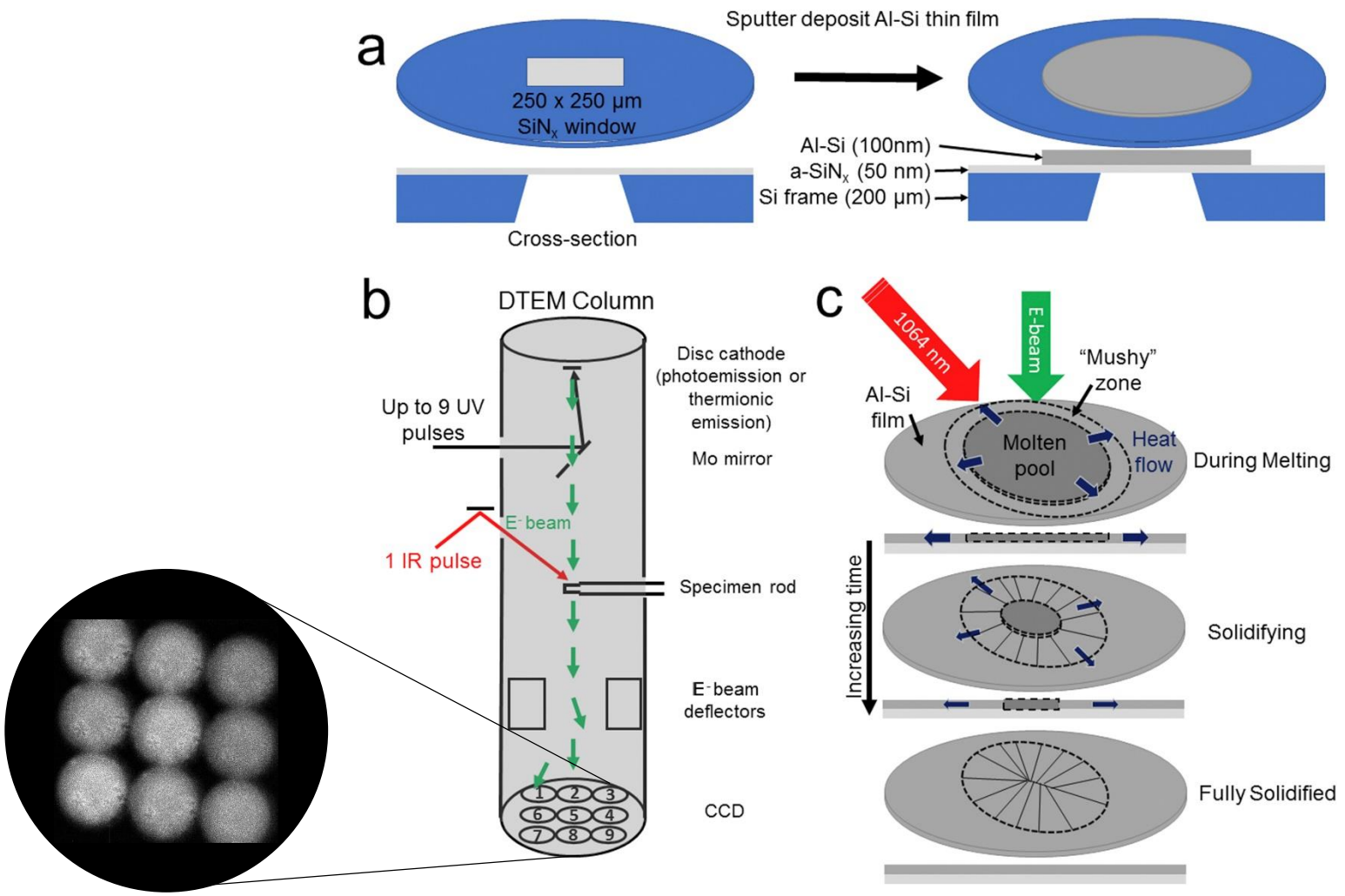

Roehling J, Coughlin D, Gibbs J, Baldwin J, Mertens J, et. al. Acta Mater. 2017.

Dynamic Transmission Electron Microscope (DTEM)

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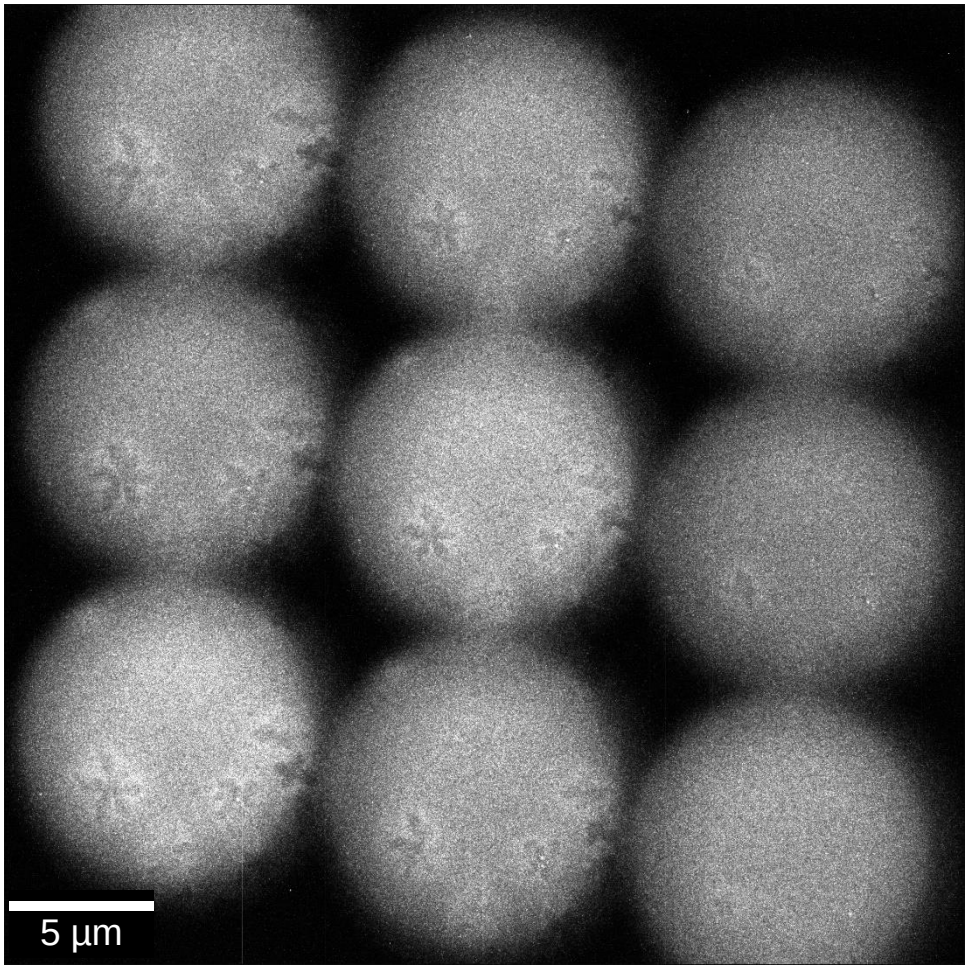
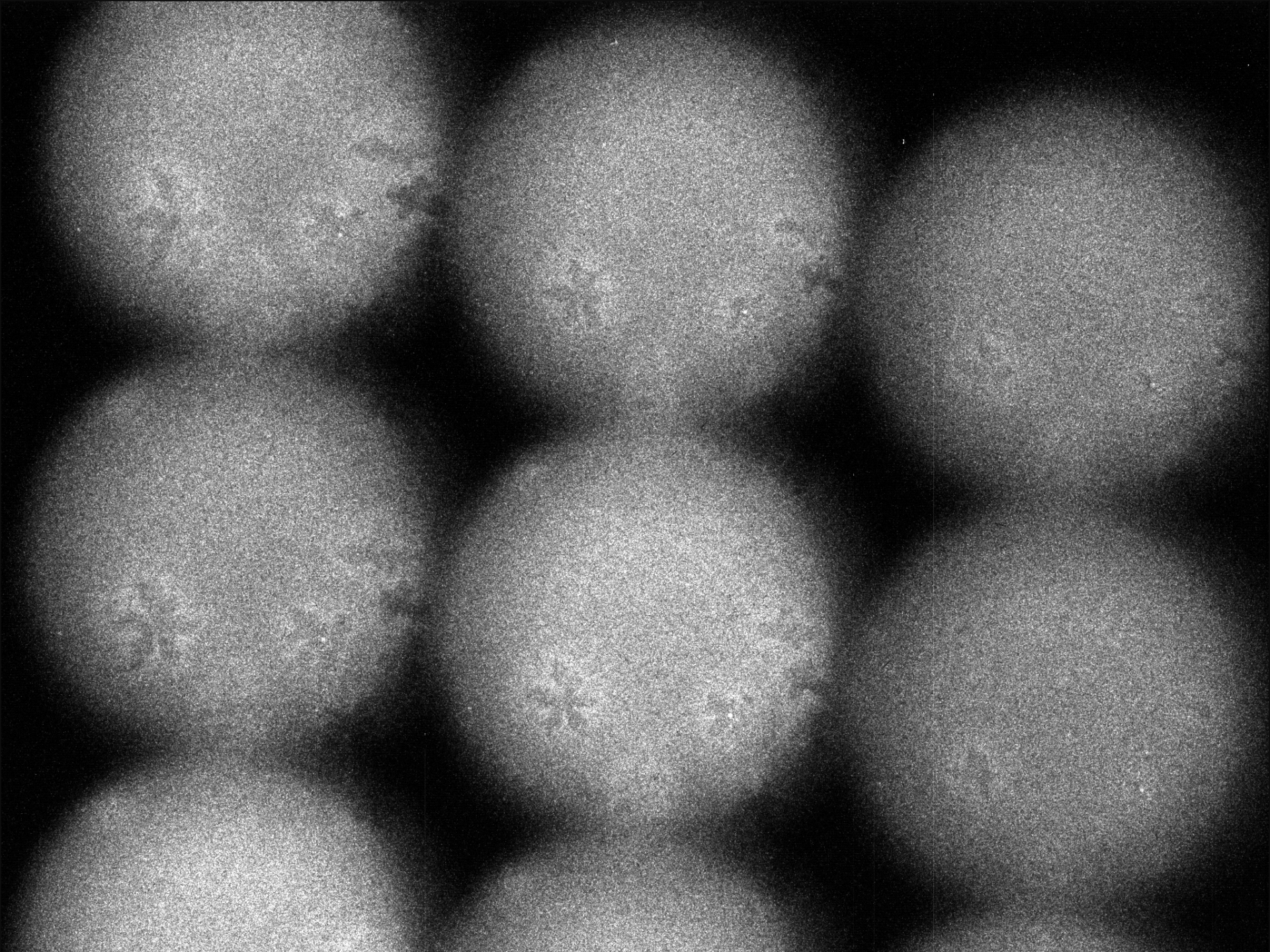
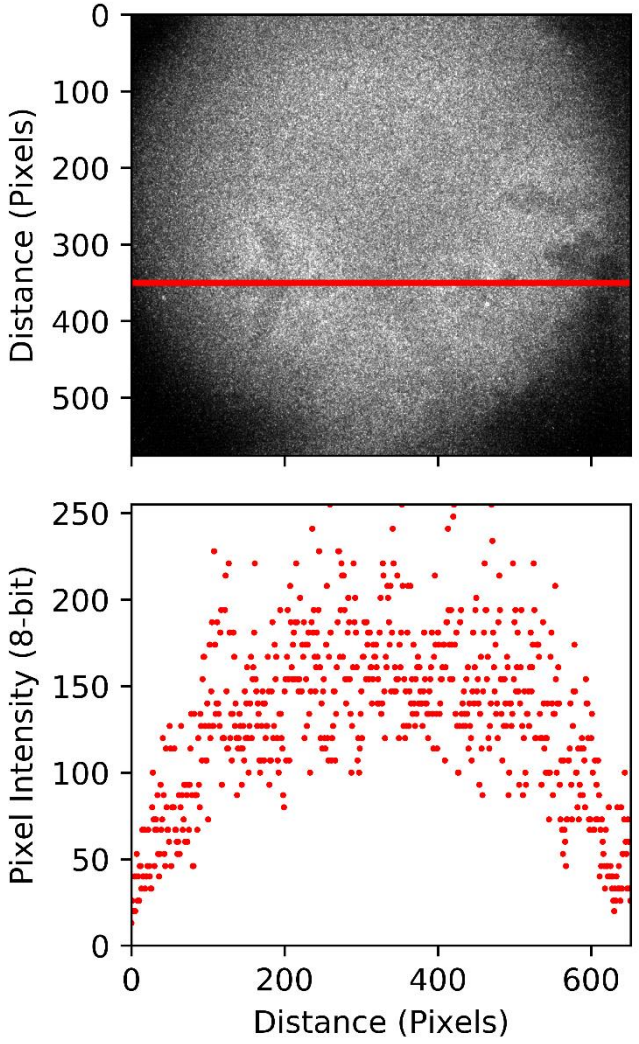
- LLNL
- Al-45wt.%Ge
- 10 µs intervals
- Through image processing:
  - Image denoising
  - Region separation
  - Animation



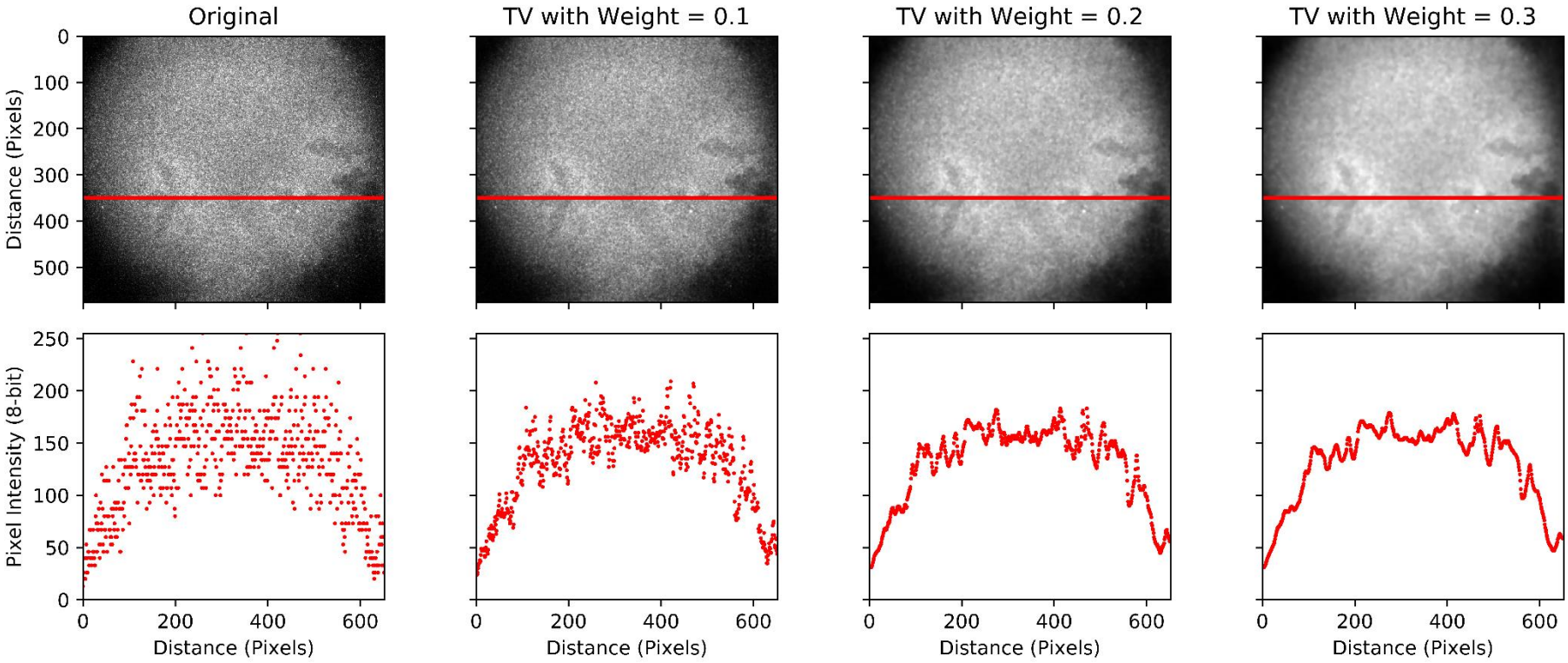


Noise Reduction in DTEM Images

- Total variation (TV) denoising
- Edge preserving
- TV Chambolle algorithm from scikit-image



Noise Reduction in DTEM Images



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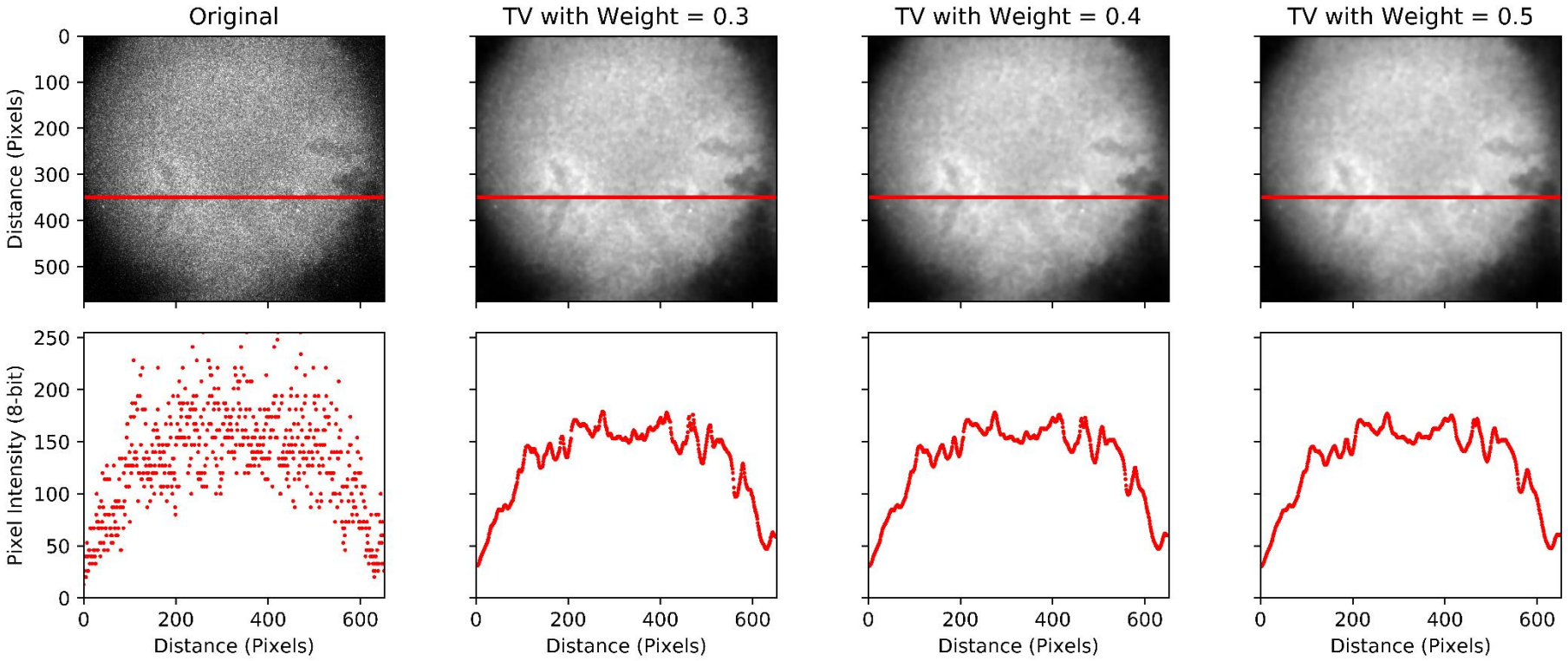
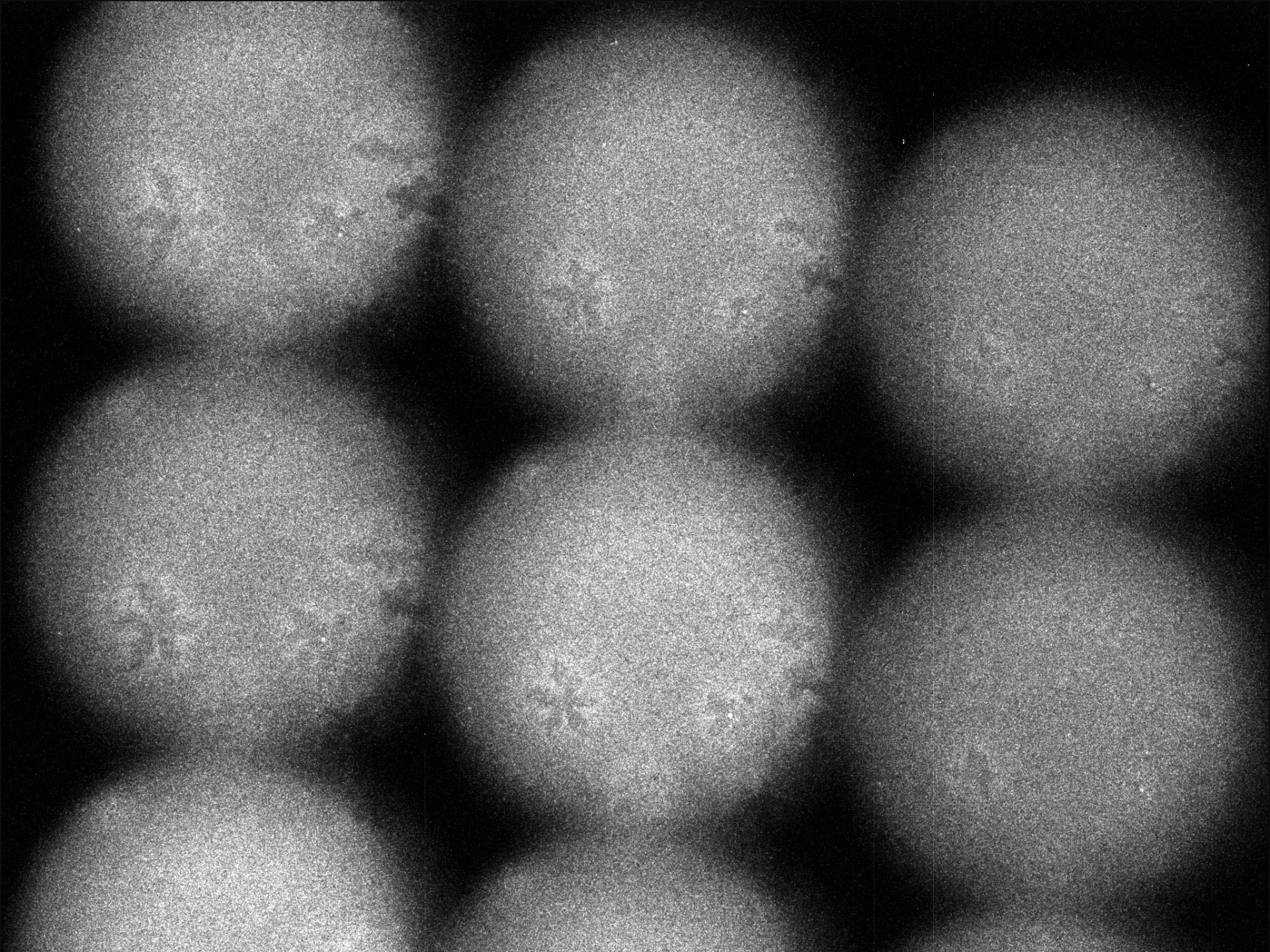
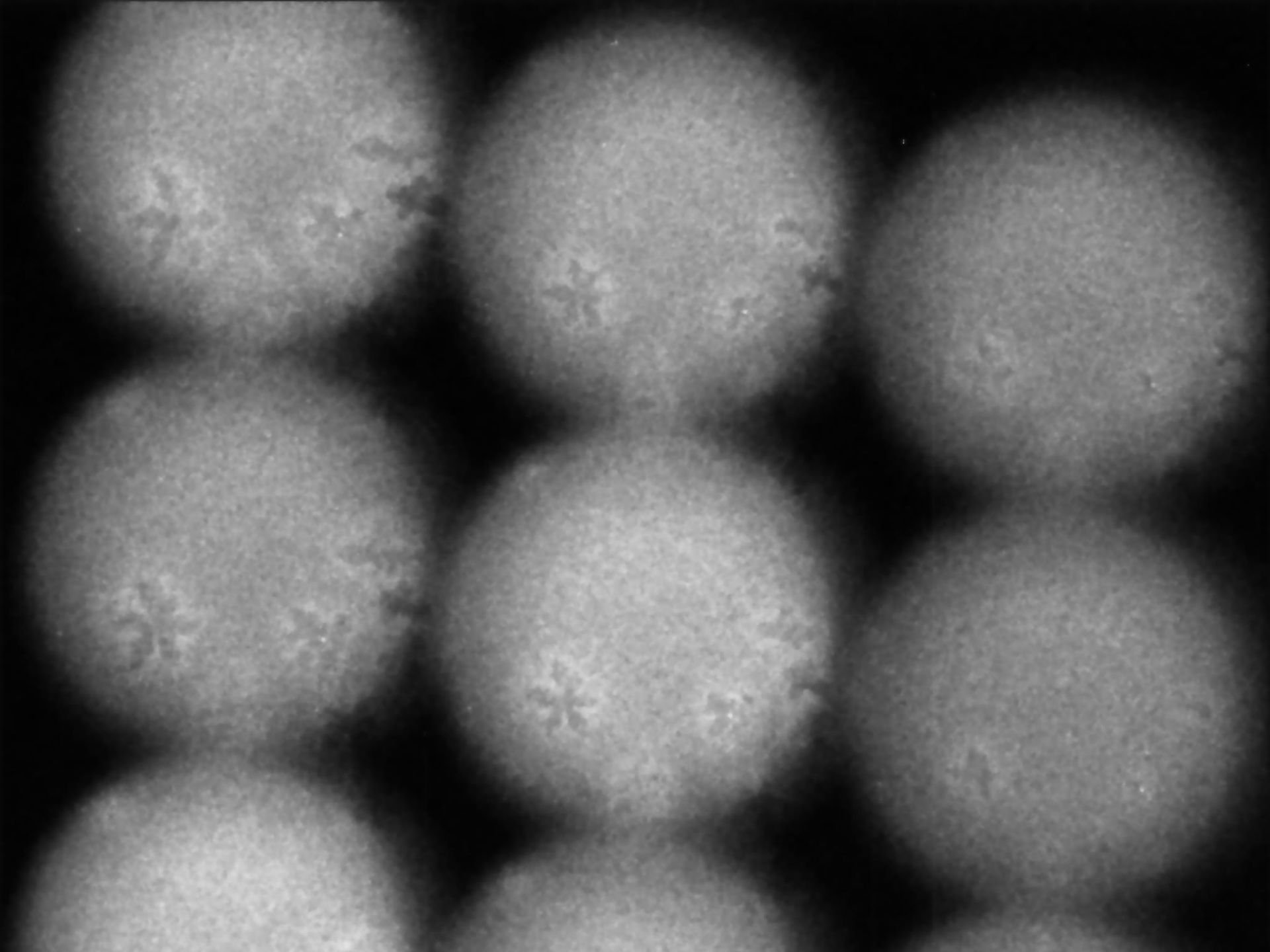
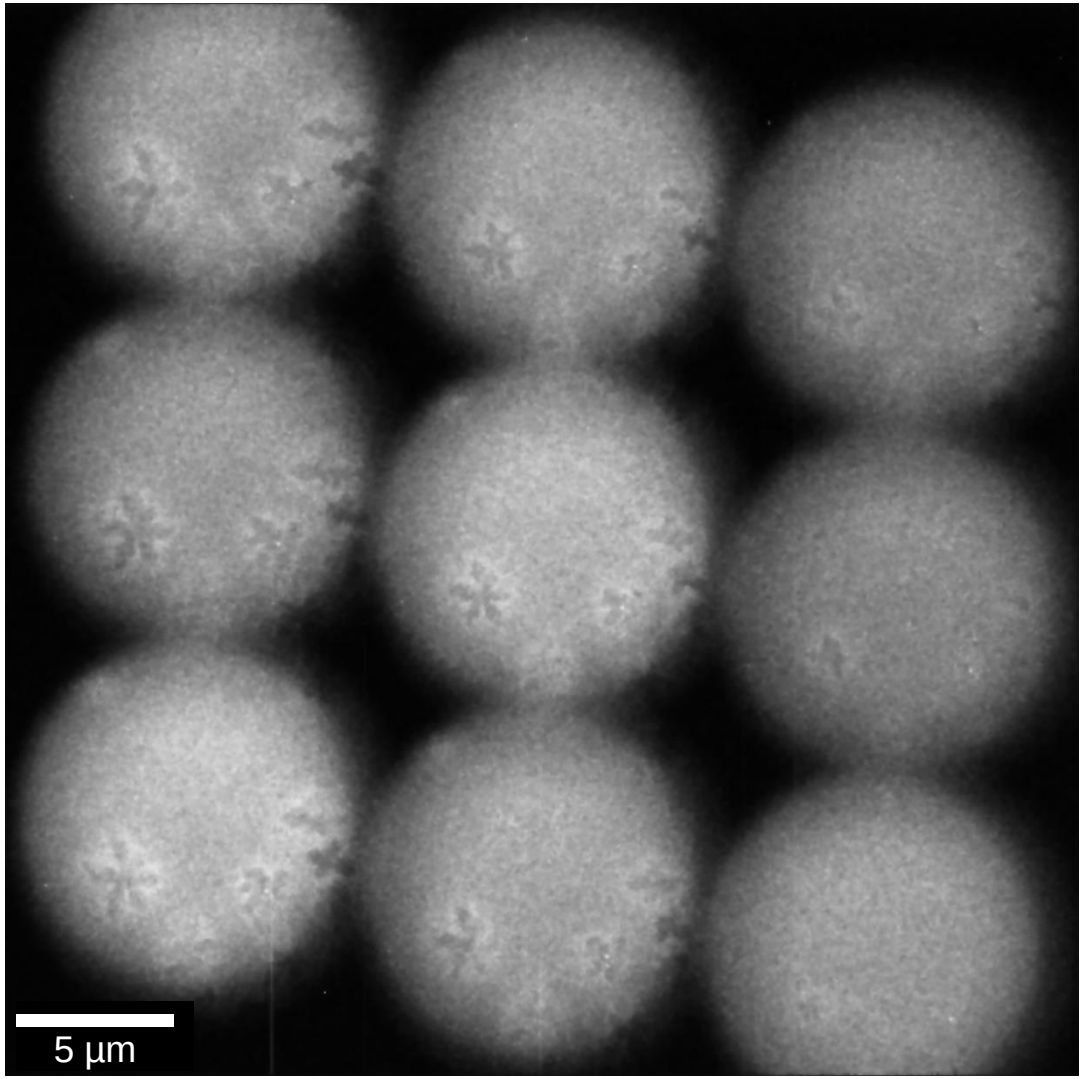


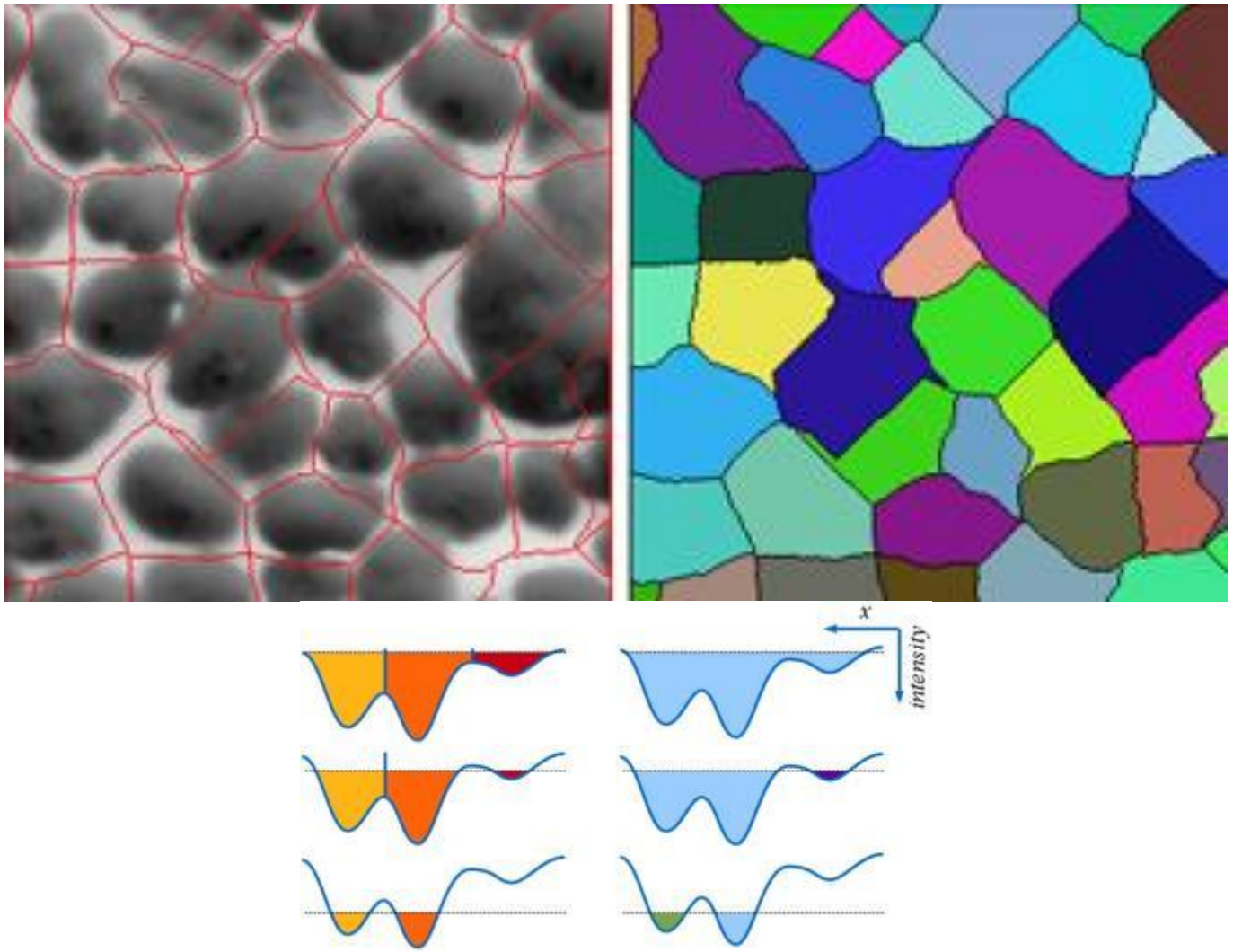




Separating Frames in DTEM Images



Watershed Segmentation



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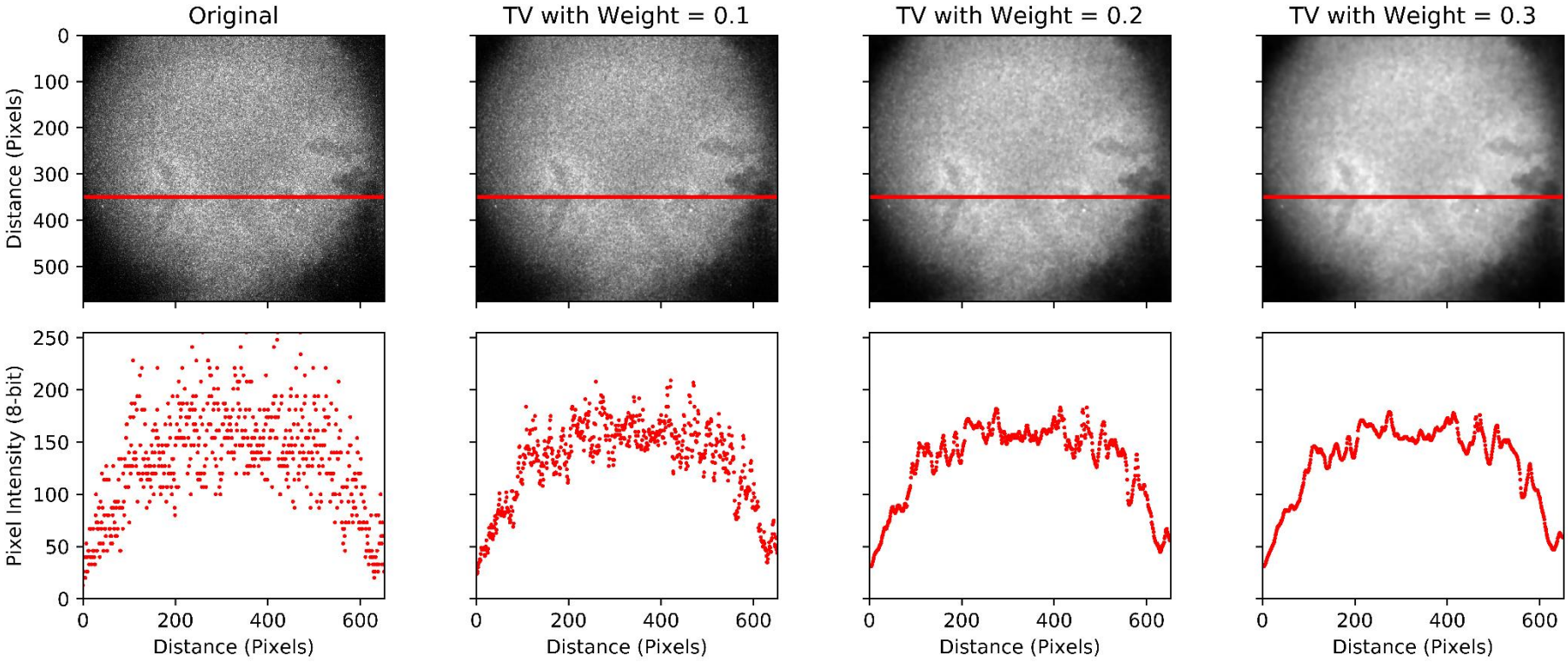
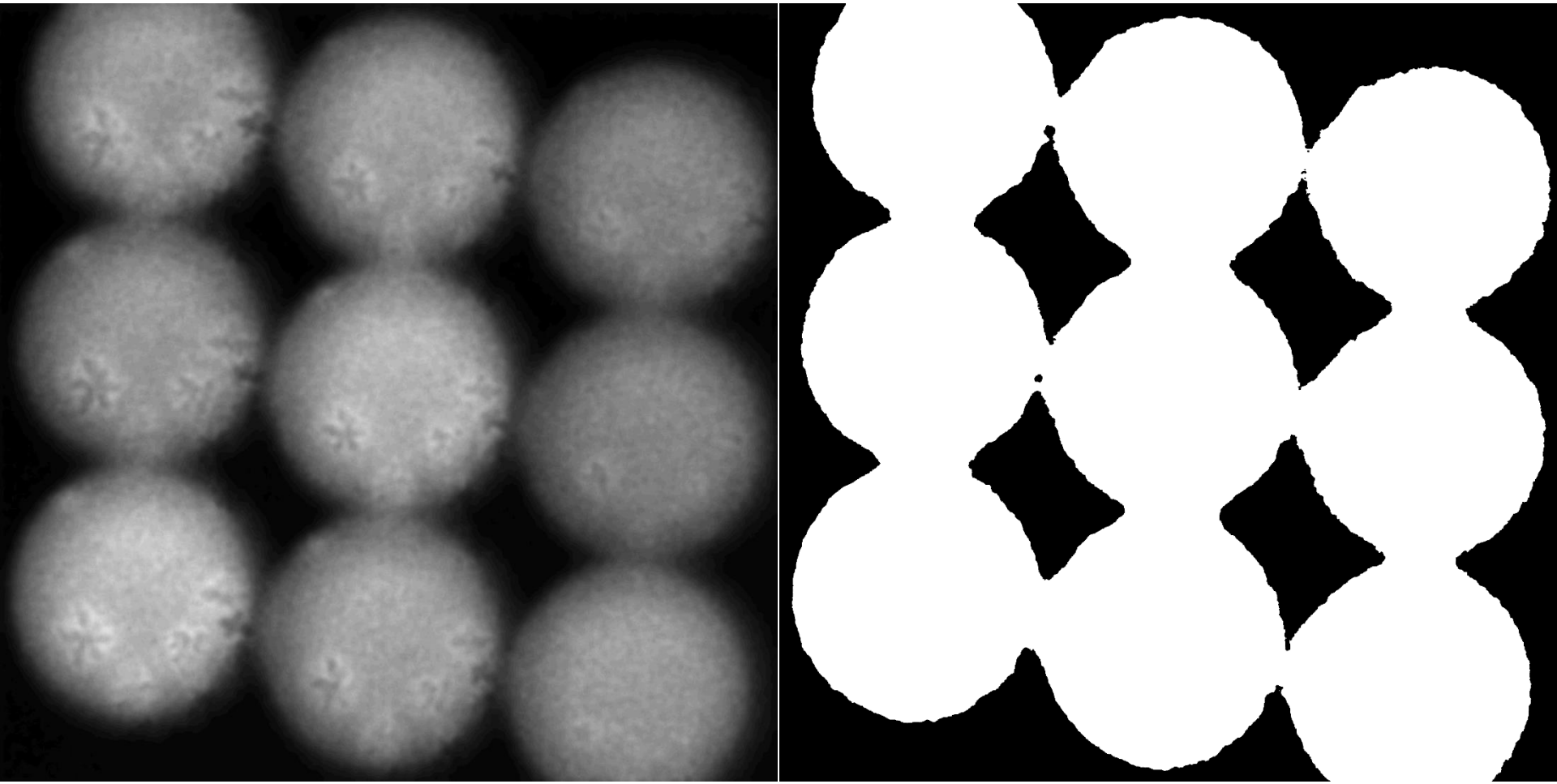


Binary Mask



Watershed Segmentation

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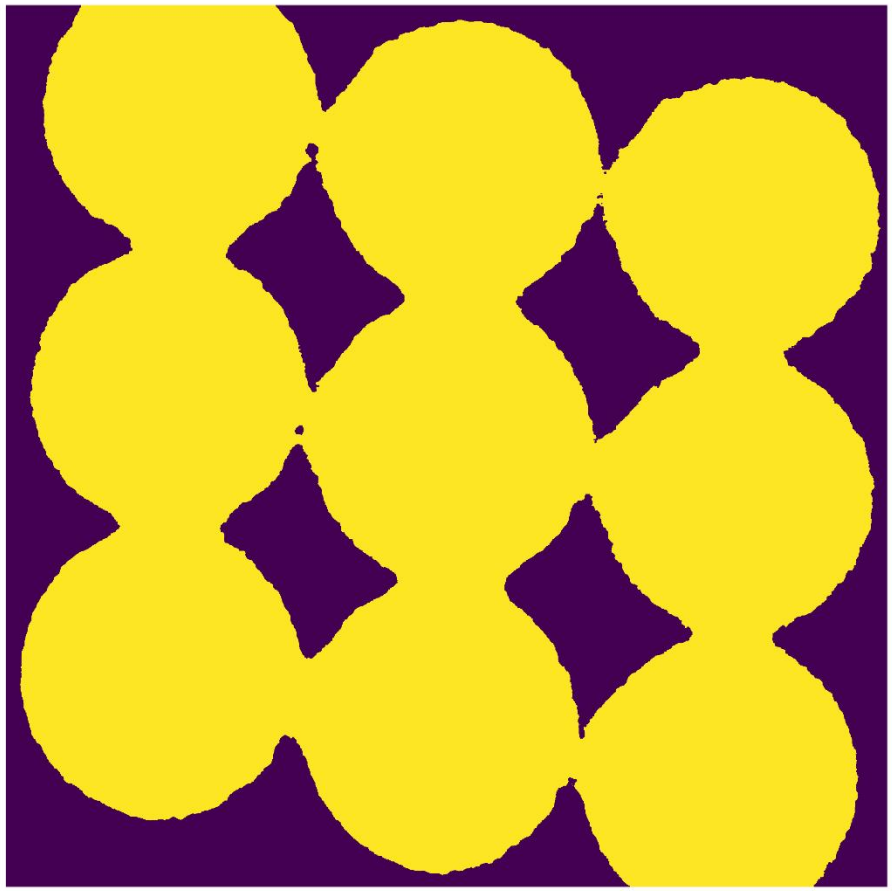
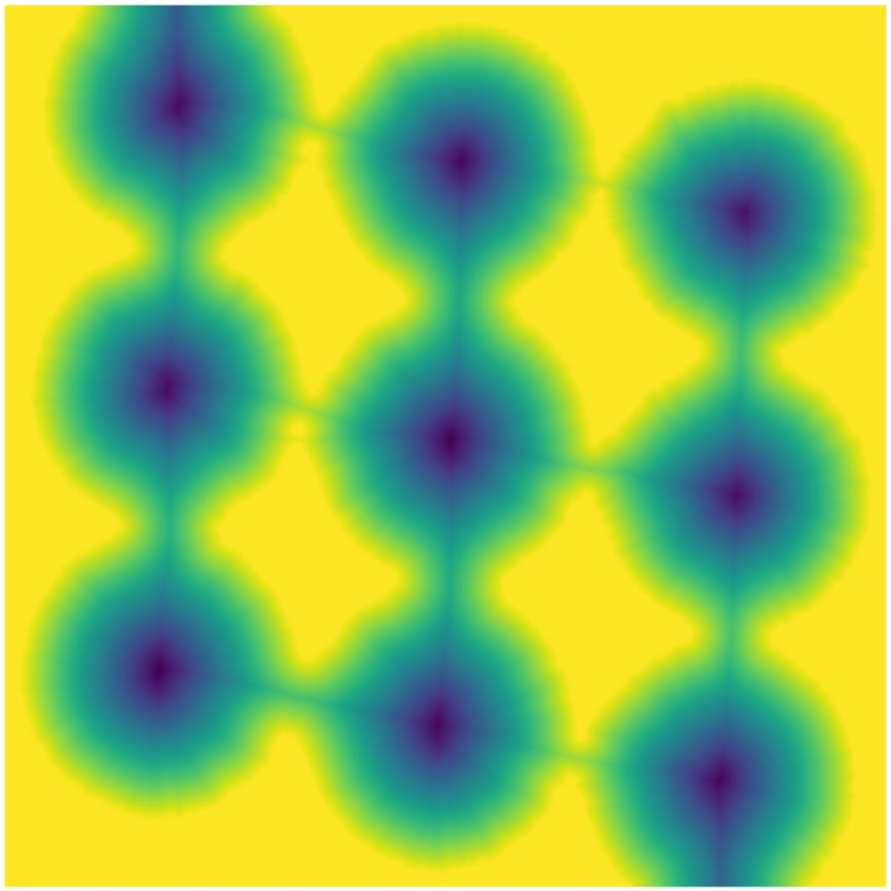
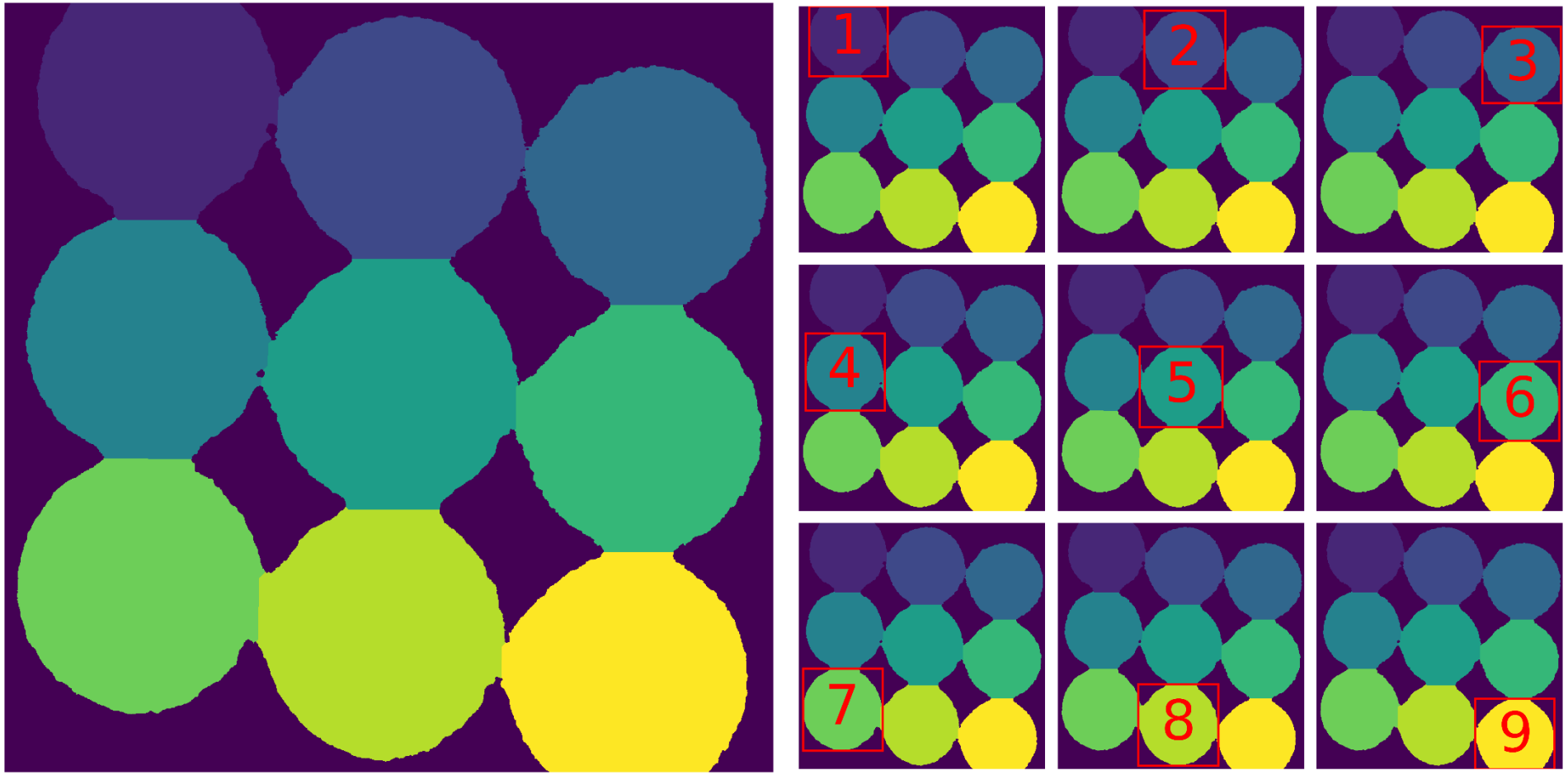
Image Binary



Distance to Edge



Watershed Transformation



Cropping Regions

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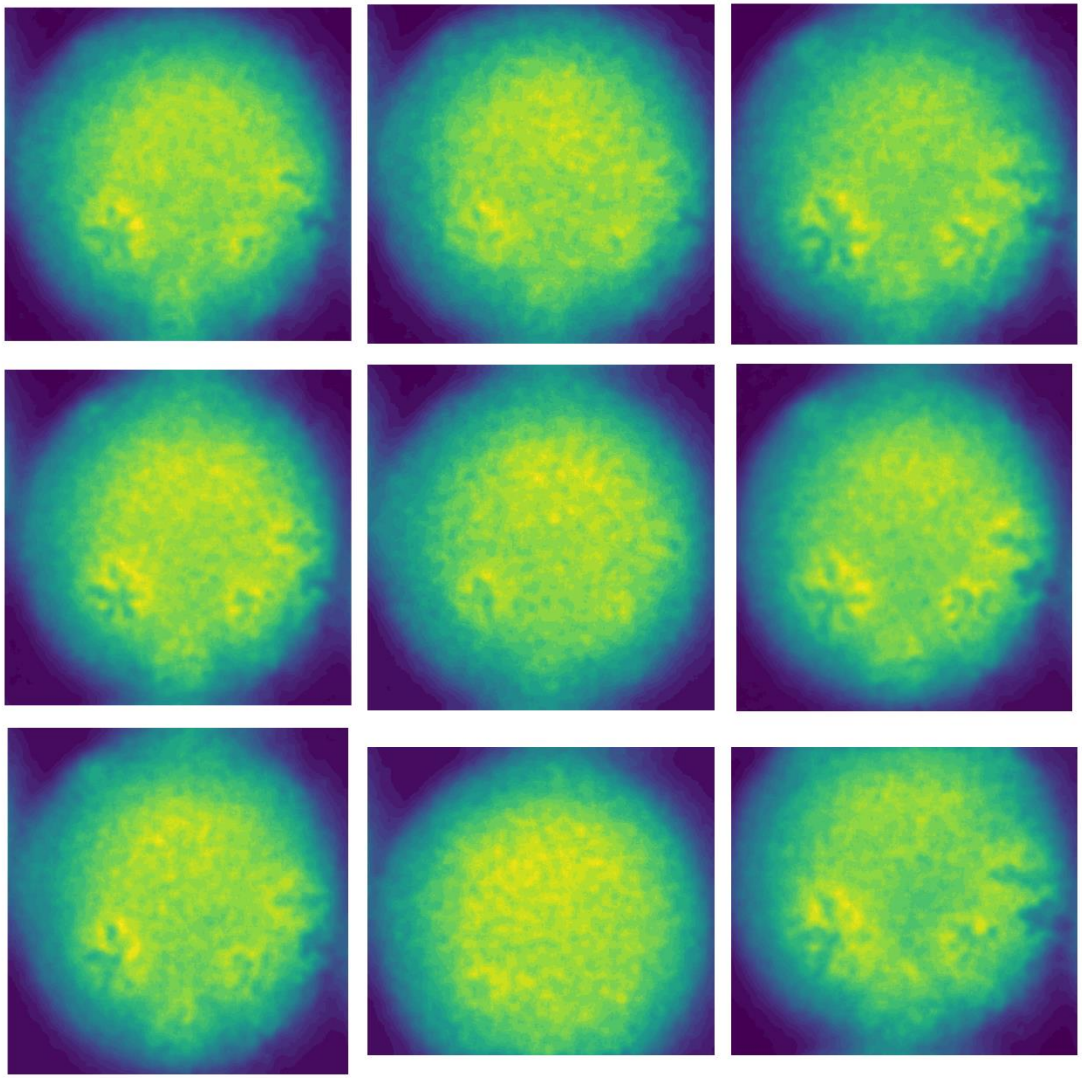

Animating Regions

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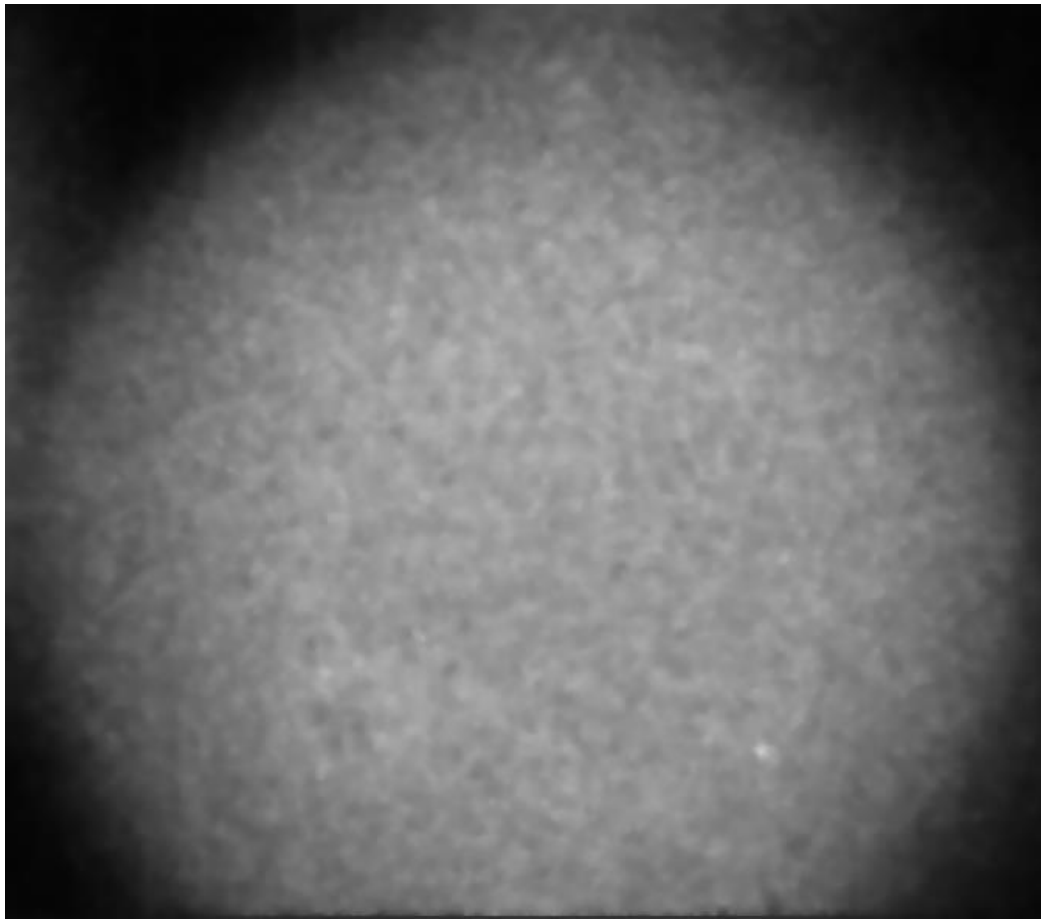

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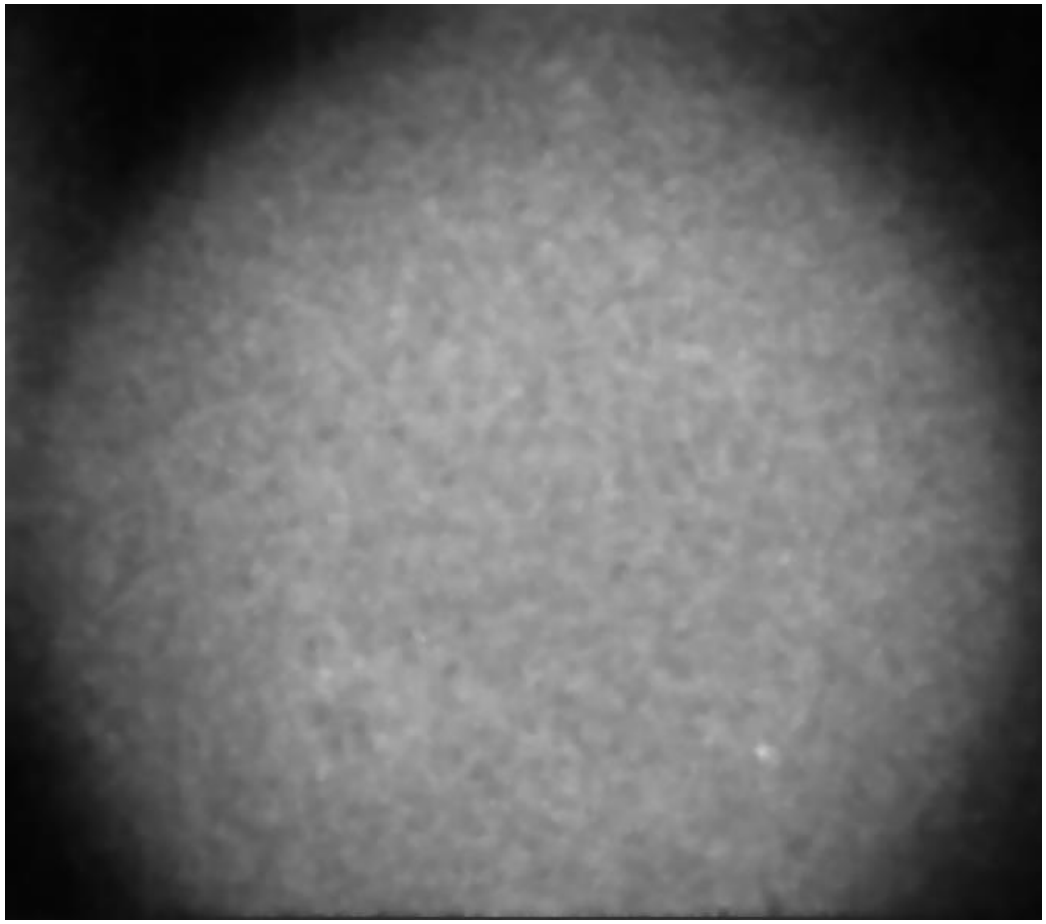

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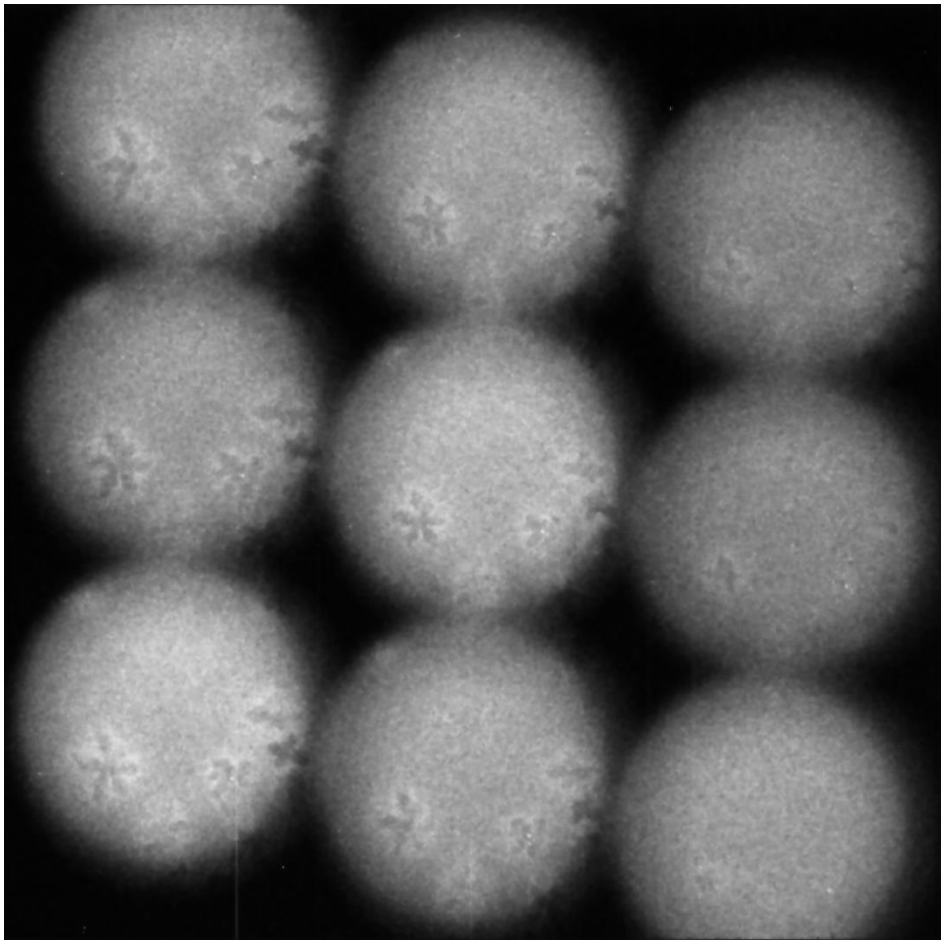

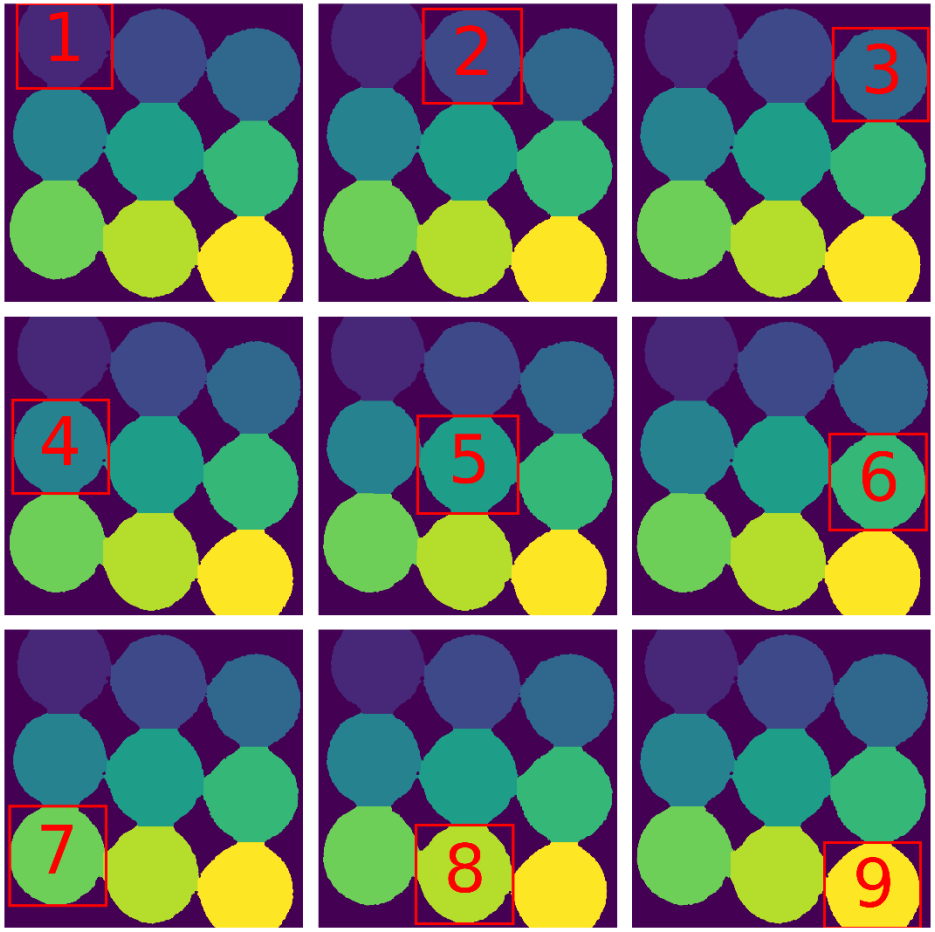

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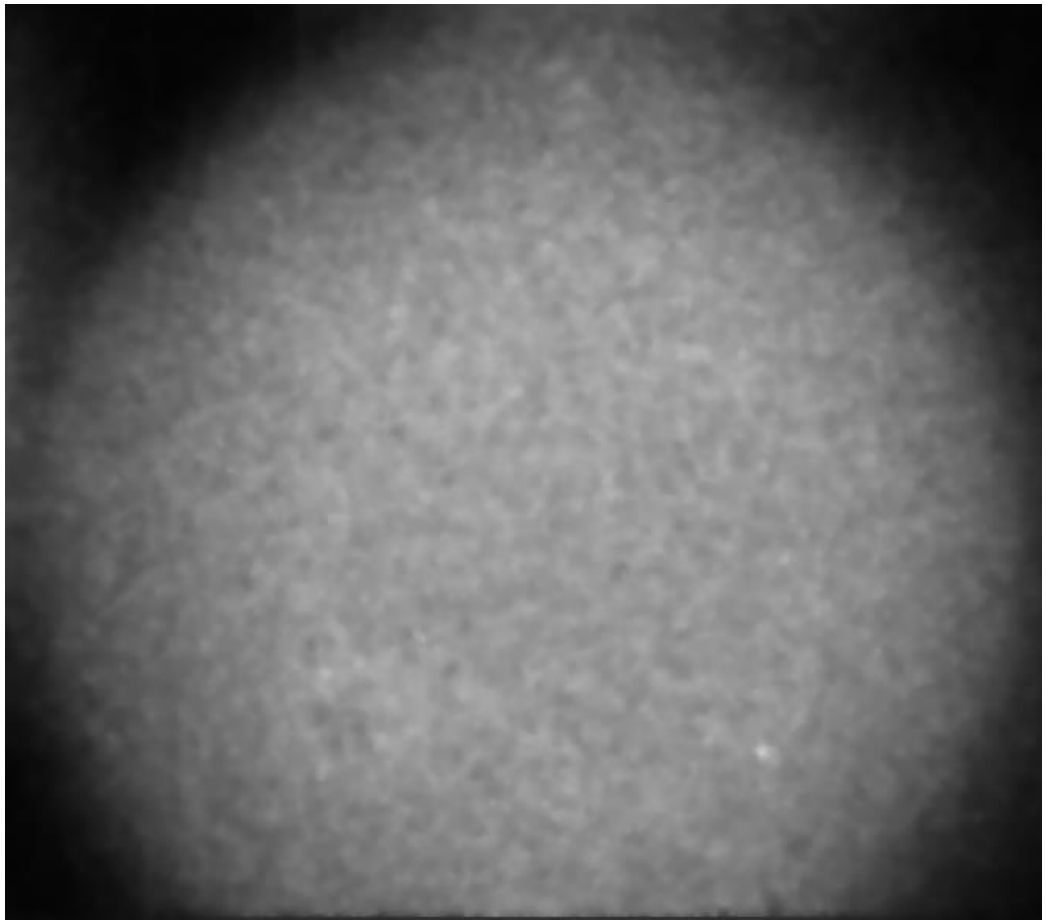

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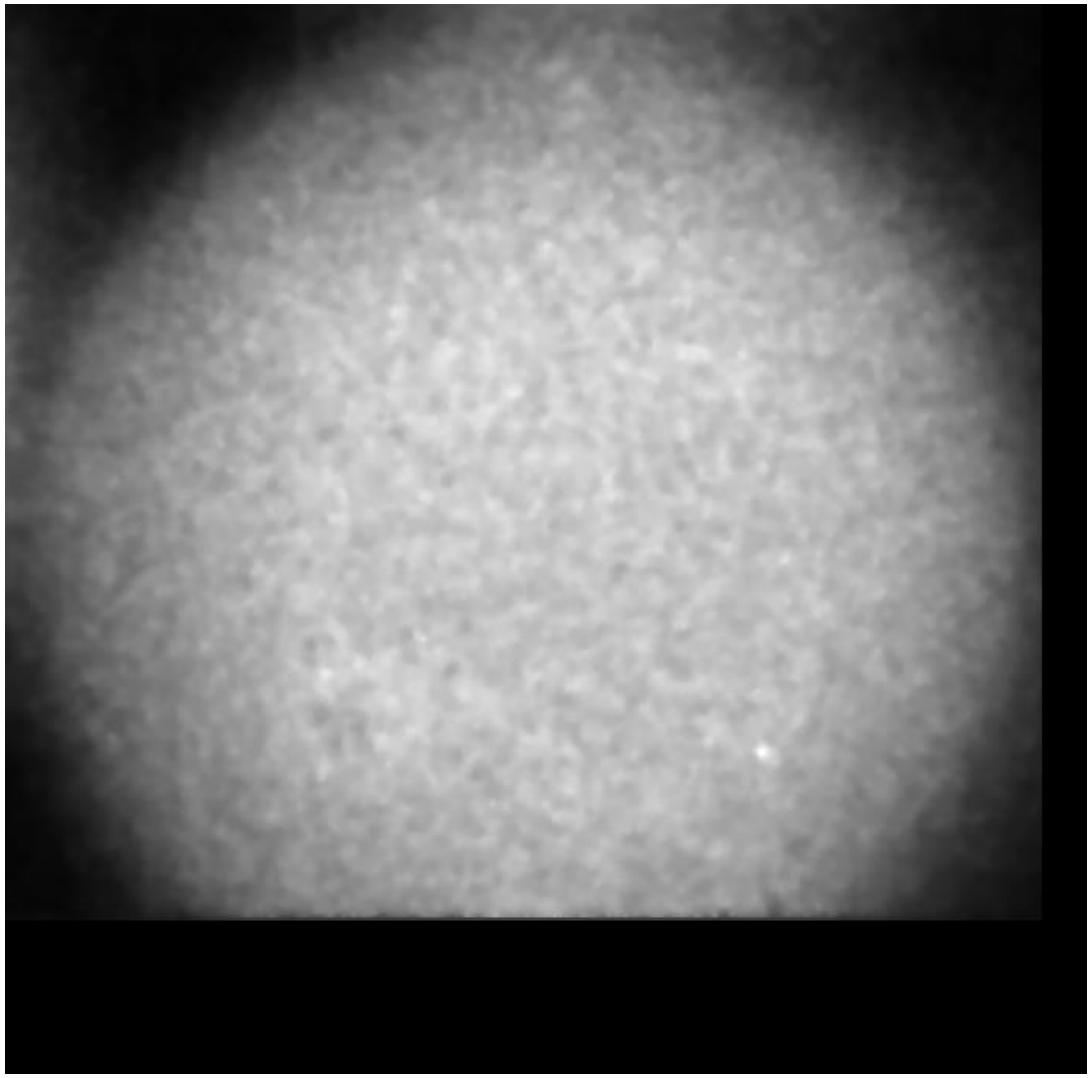
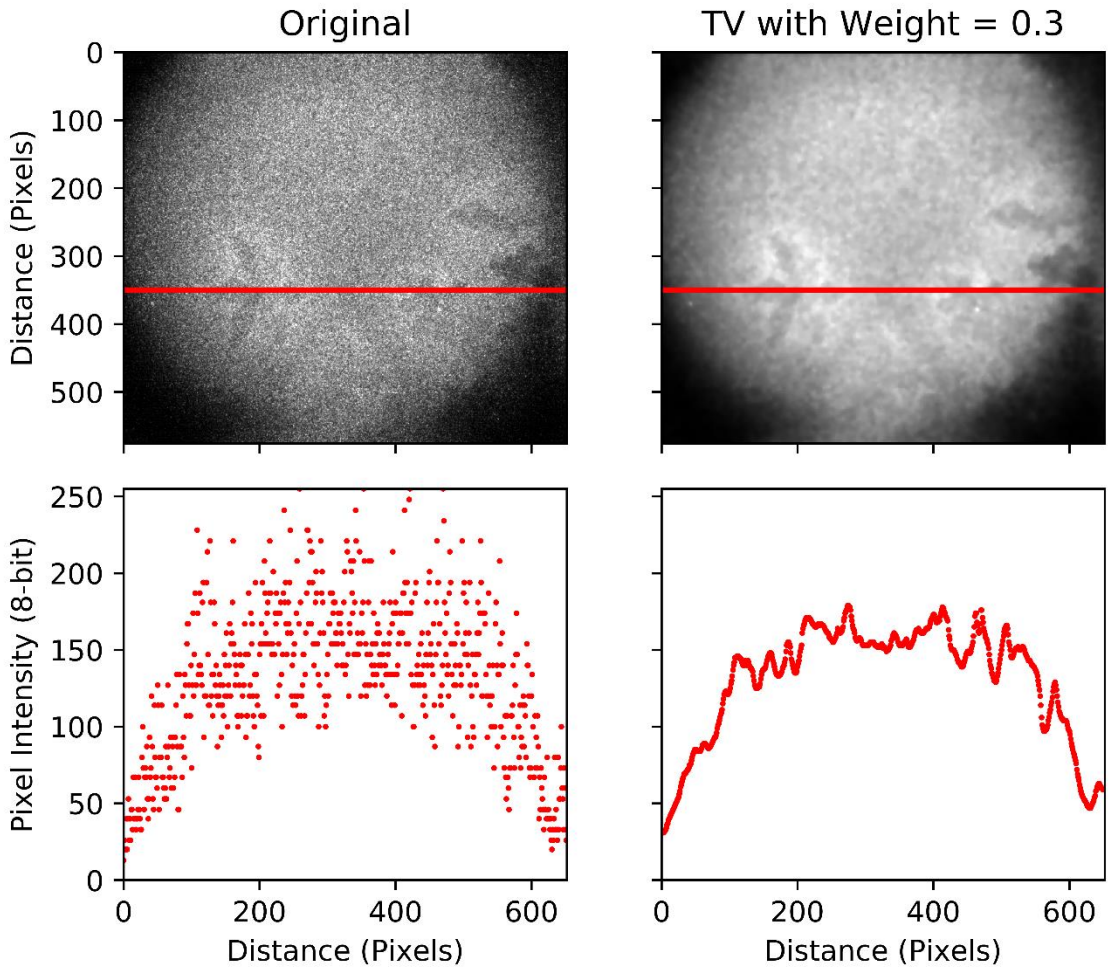
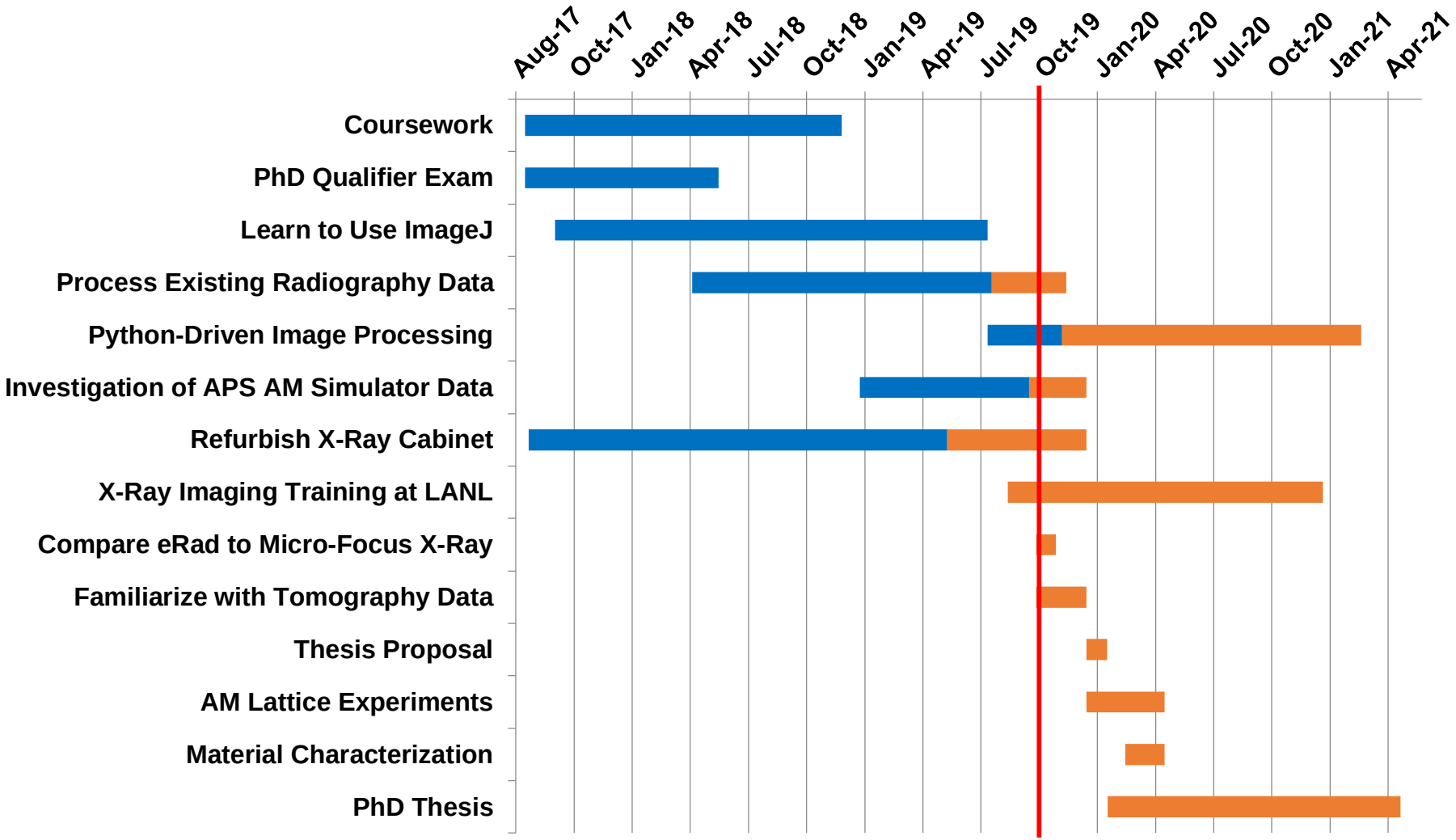


Moving Forward…

- Object detection
- Edge filters

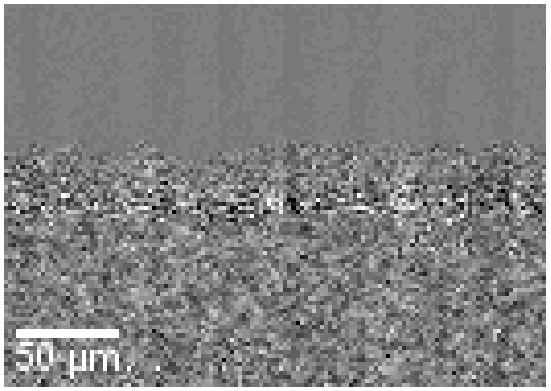


Progress



Challenges & Opportunities

- Automation to reduce bias
- Object detection and quantification in images
- Identification of phase/composition from relative intensity



Thank you!

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chbecker@mines.edu

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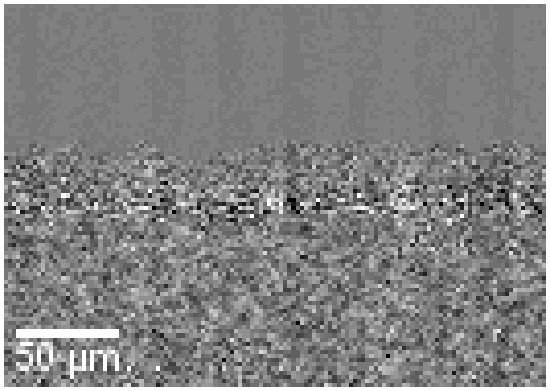

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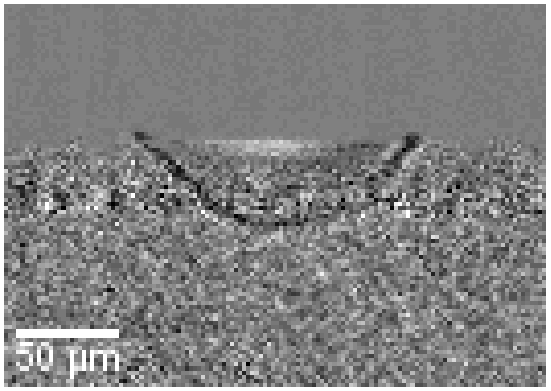

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Student: *C. Gus Becker*

Faculty: *Amy Clarke*

Industrial Partners: *LANL (Michelle Espy)*

Project Duration: *Aug. 2017 – May 2021*

High-energy micro-focus x-ray cabinet for use in laboratory setting.

Mines cabinet will achieve energies up to 150 keV.

Achievement

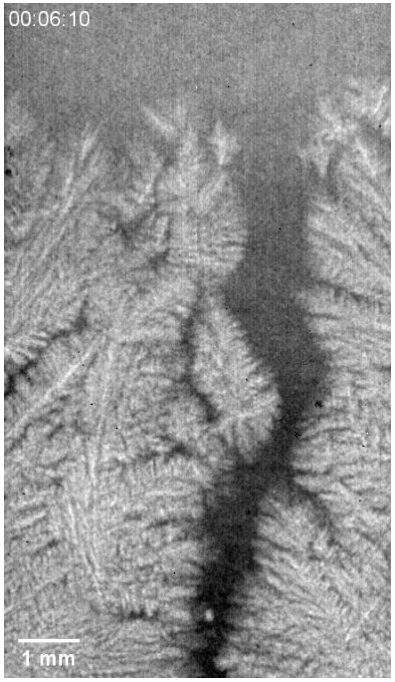
- Processing of radiography data from laboratory high-energy micro-focus and synchrotron x-ray sources

Significance and Impact

- Development of advanced image processing techniques allows for quantitative information to be extracted from image data

Research Details

- ImageJ and Python-based image processing techniques to explore 2D radiography data and 3D computed tomography (CT) reconstructions



Micro-focus x-ray radiography of Al-Ag controlled directional solidification.

Segregation of Ag-rich solute from Al-rich dendrites is seen as dark region towards the bottom of the large channel.

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High-energy micro-focus x-ray cabinet for use in laboratory setting.

Mines cabinet will achieve energies up to 150 keV.

Program Goal

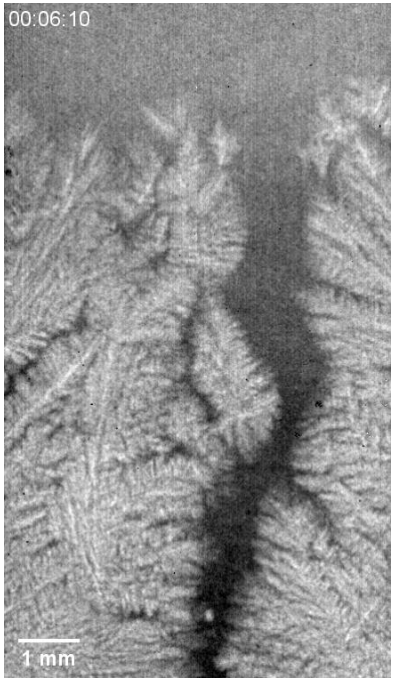
- Industrial processes of metals such as casting and additive manufacturing can benefit from radiography studies performed in the laboratory

Approach

- Analyze current radiography data and establish cabinet-based x-ray radiography capabilities at Mines for further experimentation

Benefits

- Defect identification in AM metals and studies of solidification microstructure to inform casting models



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