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

Spring 2019 Semi-Annual Meeting
Iowa State University, Ames, IA
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Student: C. Gus Becker (Mines)

Faculty: Amy Clarke (Mines)

Industrial Mentors: Michelle Espy (LANL, AET-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: Defect identification in AM metals and studies of solidification.

Recent Progress

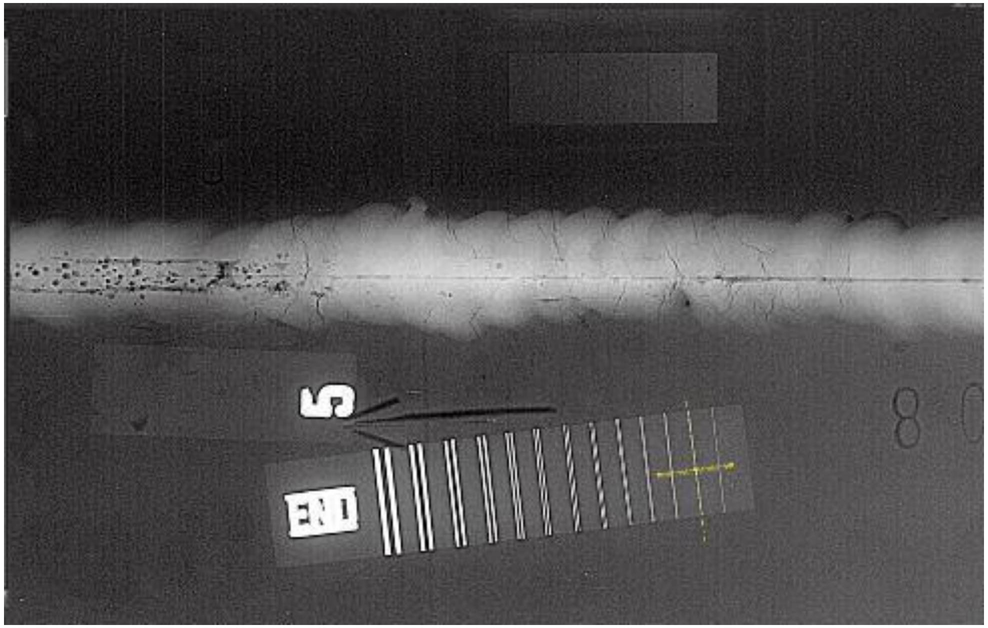
- Improvement of ImageJ skills though scripting
- Creation of modular image processing method to process large datasets efficiently
- Image processing of existing radiography datasets
- Aid fellow CANFSA students with in-situ data
- Started learning Python language for tomographic reconstructions and image/data analysis

Metrics

Description	% Complete	Status
1. Development of modular image processing method using ImageJ scripts	90%	●
2. Image processing and analysis of datasets from AET-6, APS, and pRad	70%	●
3. Literature review	50%	●
4. Establish x-ray cabinet and perform laboratory x-ray imaging experiments	50%	●
5. Material investigation with XCT (AM lattice experiments, solidification, etc.)	0%	●

Industrial Relevance

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

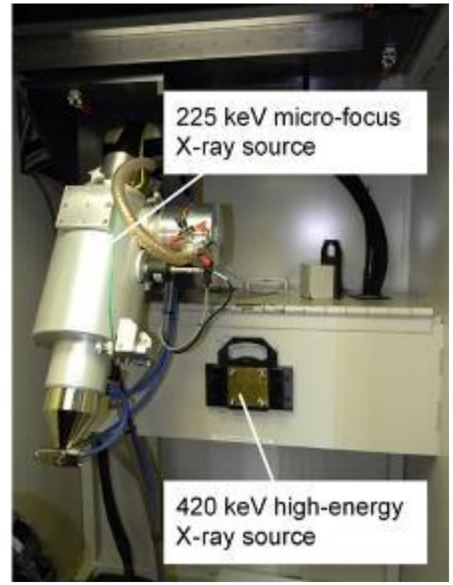


http://solutionsinimaging.com/industrial-applications/weld-inspection/

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.)

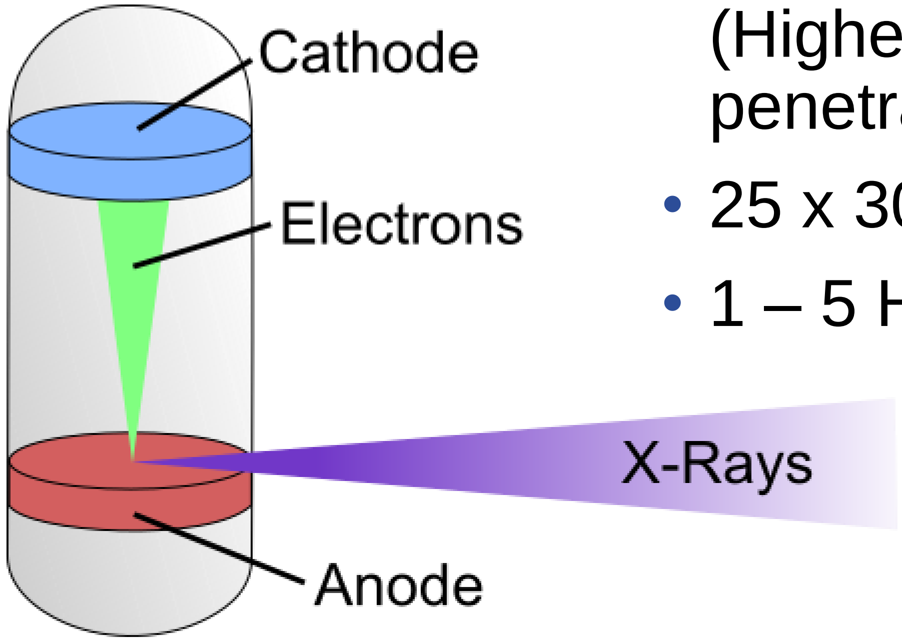
Cabinet Timeline



Process Donation Internally (LANL)	Ship to White Rock, NM for Refurbishing	Procurement	Refurbish at White Rock, NM	Ship from White Rock, NM to Mines	Set up on Mines Campus
Complete	Complete	Complete	3 - 4 month duration	TBD	TBD

Cabinet Specs

- Sealed source
- Energies up to 150 keV
- 5 µm spot size
- 10 – 12 µm spatial resolution (Higher resolution: not as much penetrating power)
- 25 x 30 cm field-of-view
- 1 – 5 Hz temporal resolution



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

- Process:

- File structure:

⌂ Original directory

  ⌂ Original radiographs

Modular Image Processing Method

- Process: Automatic resize

- File structure:

⌂ Original directory
  - ⌂ Original radiographs
  - ⌂ Automatic resize process
    - ⌂ Automatic resize radiographs
    - ⌂ Automatic resize animation

Modular Image Processing Method

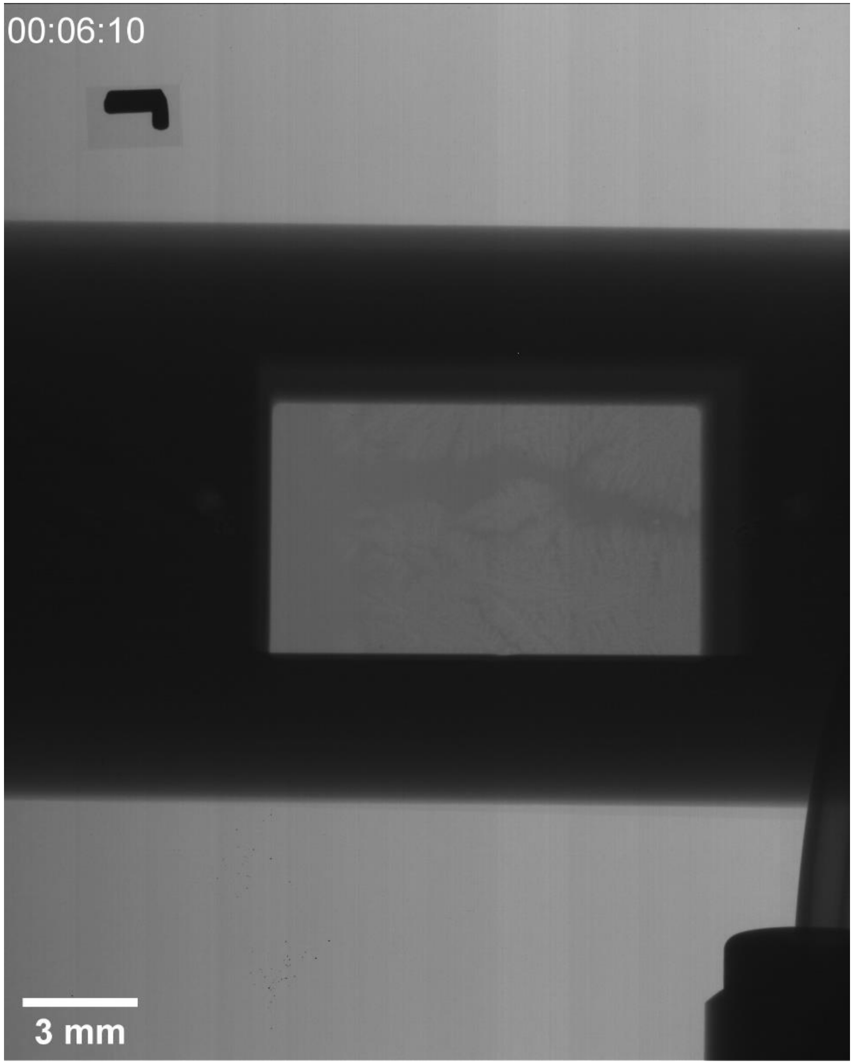
- Process: Automatic resize → Pseudocolor

- File structure:

⌂ Original directory
  - ⌂ Original radiographs
  - ⌂ Automatic resize process
    - ⌂ Automatic resize radiographs
    - ⌂ Automatic resize animation
    - ⌂ Pseudocolor process
      - ⌂ Pseudocolor radiographs
      - ⌂ Pseudocolor animation

Dynamic X-Ray Radiography

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

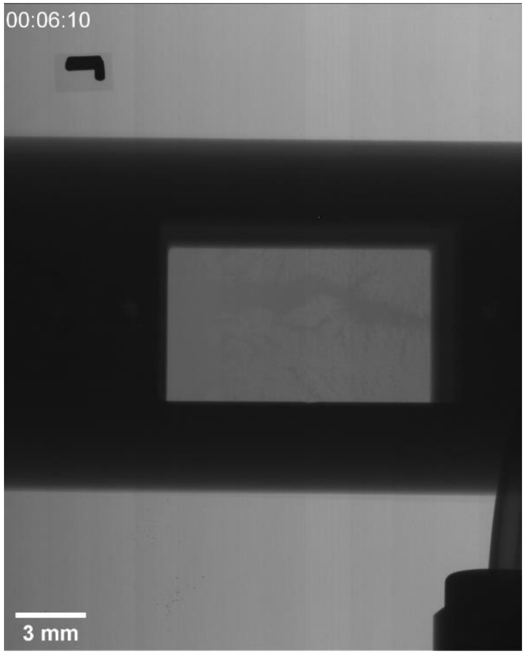


Modular Image Processing Method

- Automatic resize by thresholding

Resize by Thresholding

- Uses an automatic thresholding method to select region of image with different intensity, crops image to region, and rotates image



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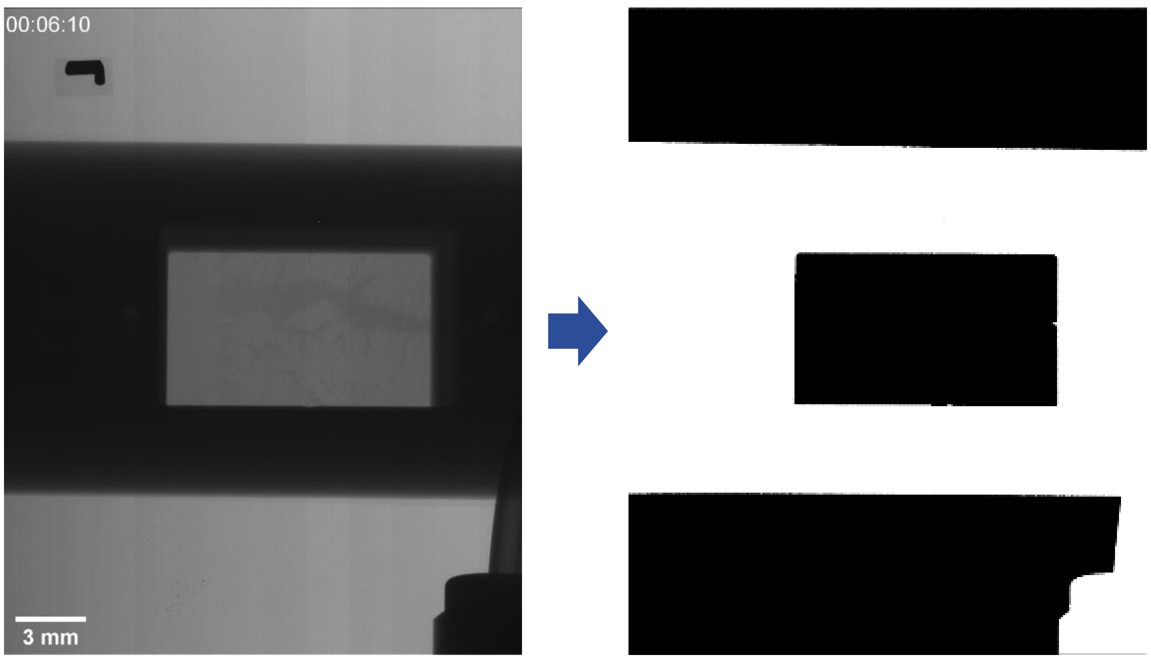

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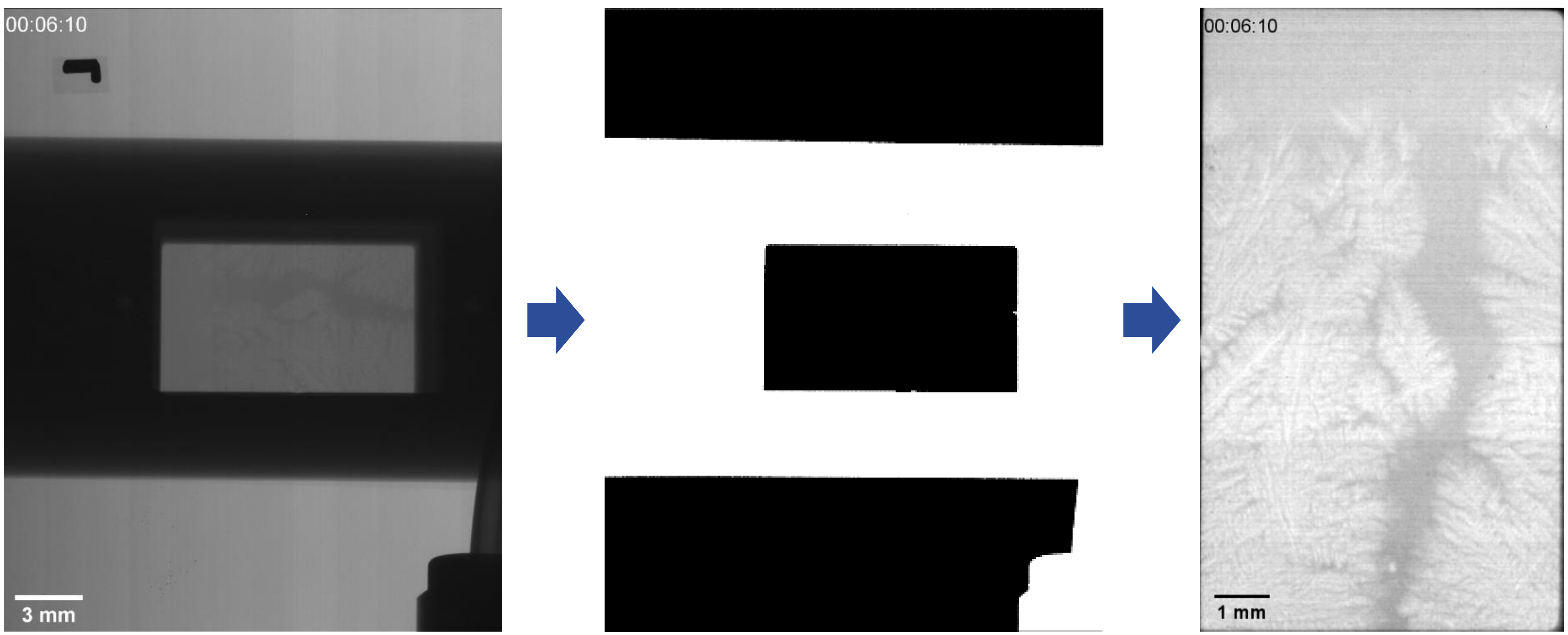

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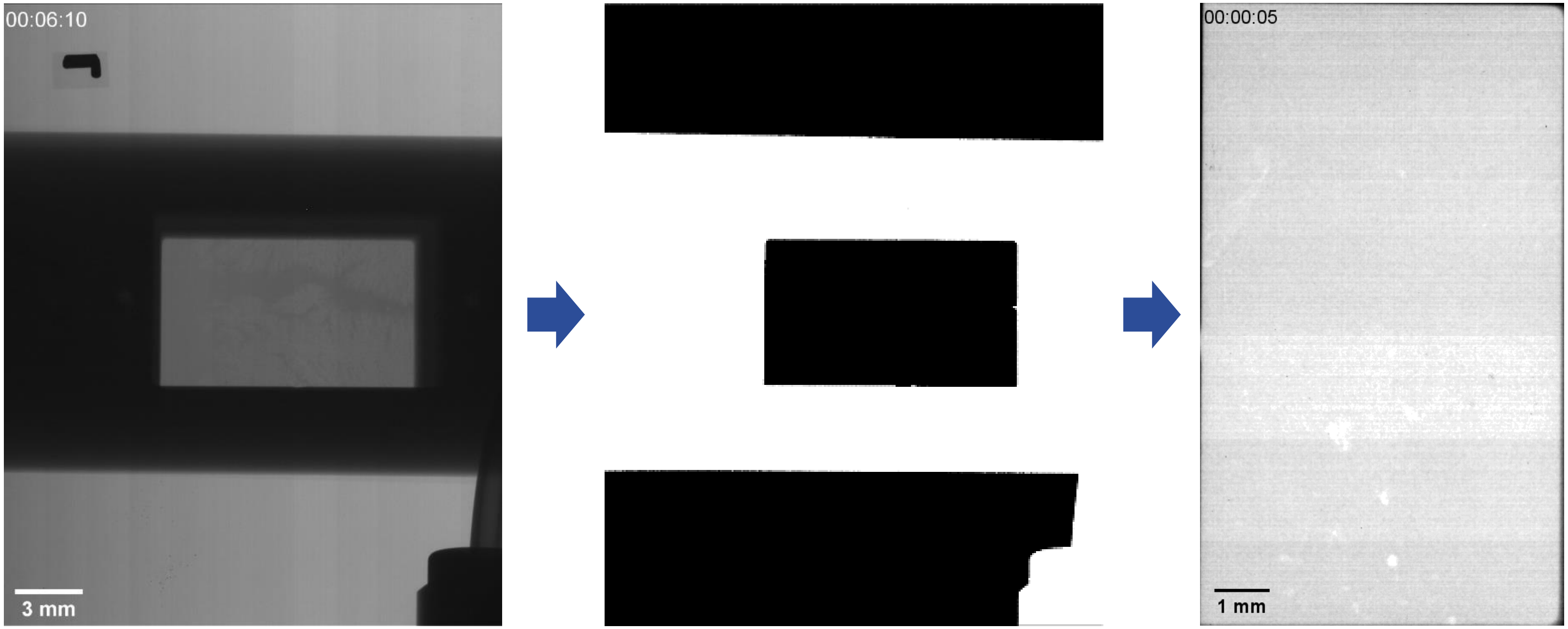

Modular Image Processing Method

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- Automatic resize by thresholding
- Trim edges

Trim Edges

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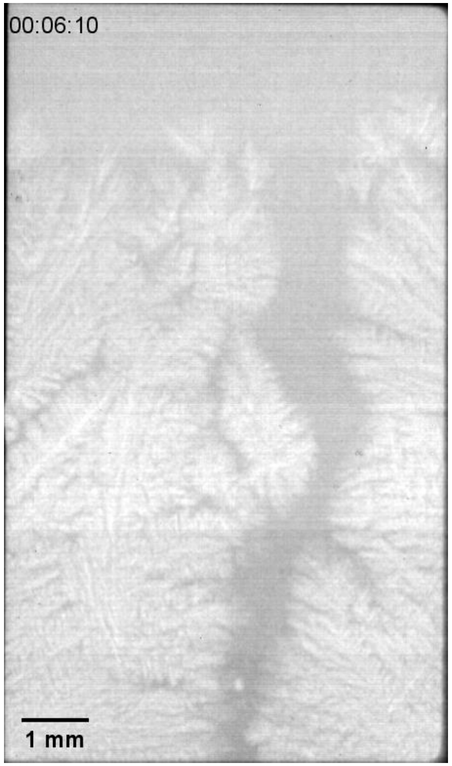
- Removes variable amount of pixels from each side of the image
- Allows for better contrast when normalized to all images



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Trim Edges

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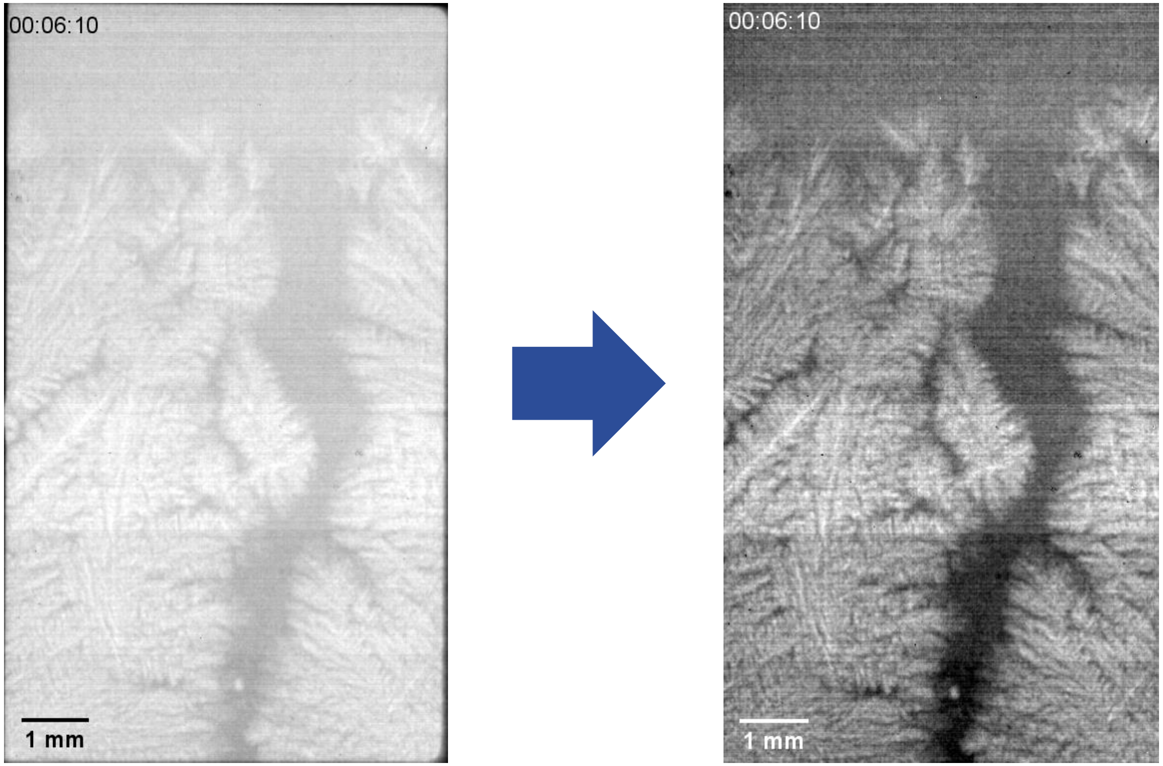

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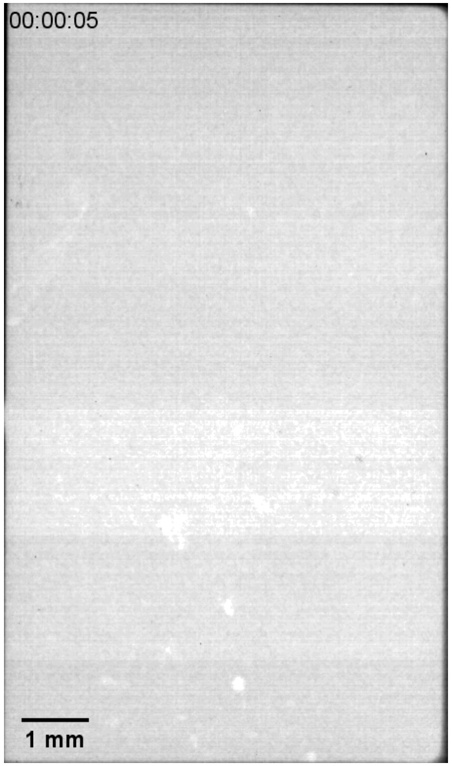
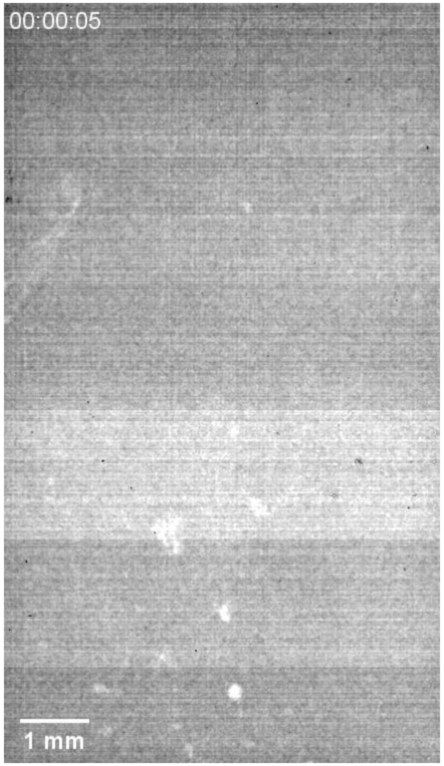




Modular Image Processing Method

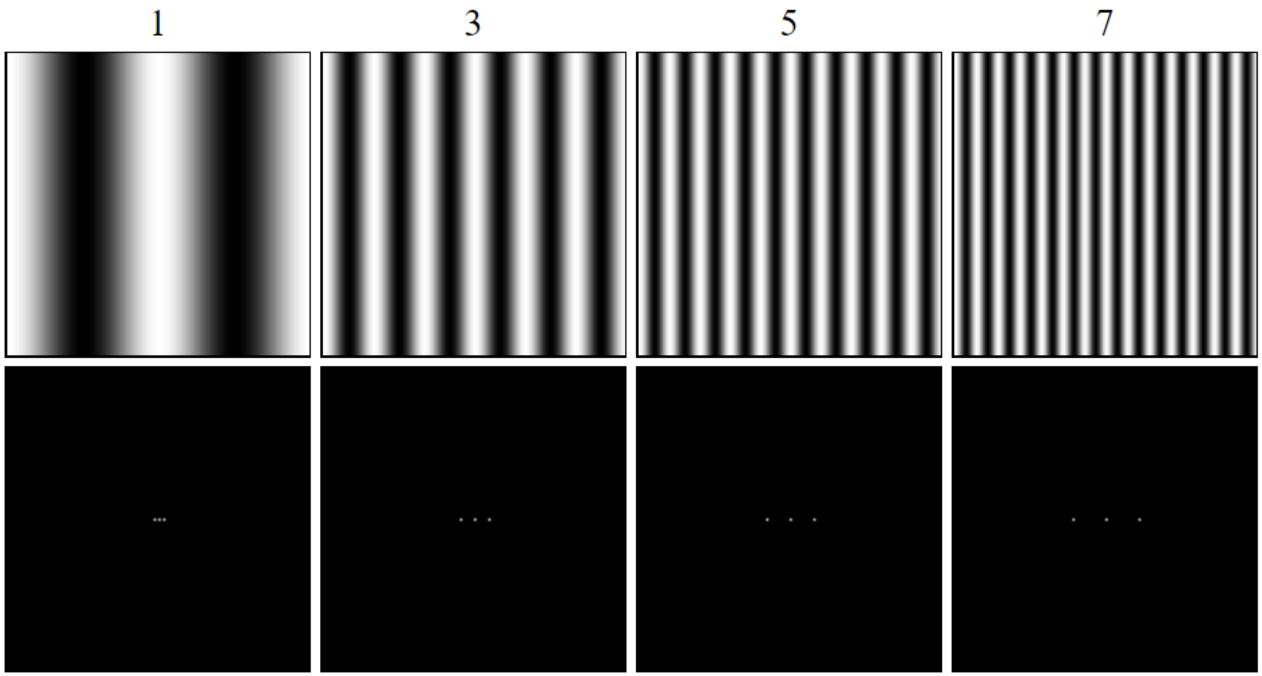
- Automatic resize by thresholding
- Trim edges
- Removal of band artifacts through fast Fourier transform filtering

FFT Filtering

Spatial Frequency

Image

Fourier Transform



FFT Filtering

Spatial Frequency

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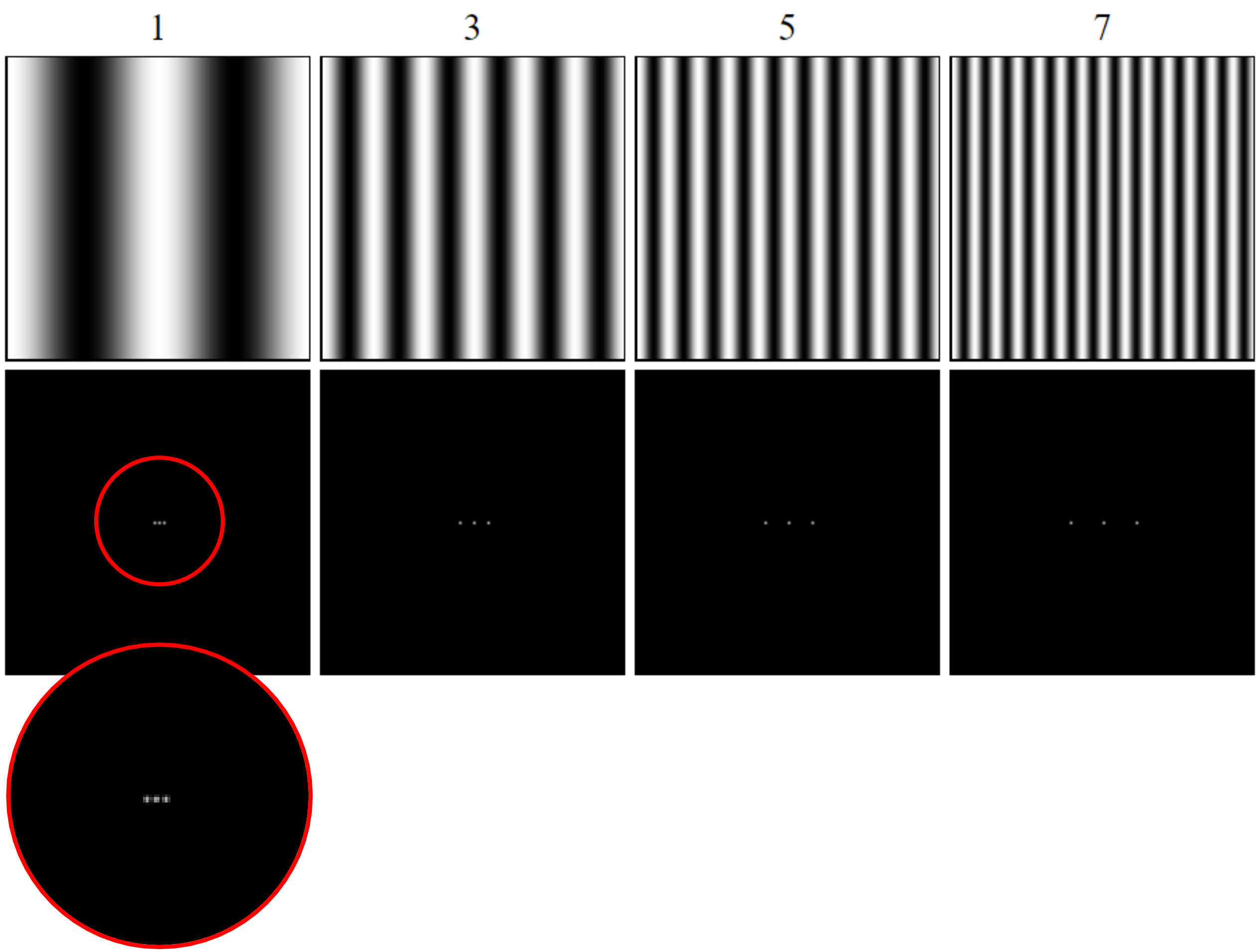
Fourier Transform



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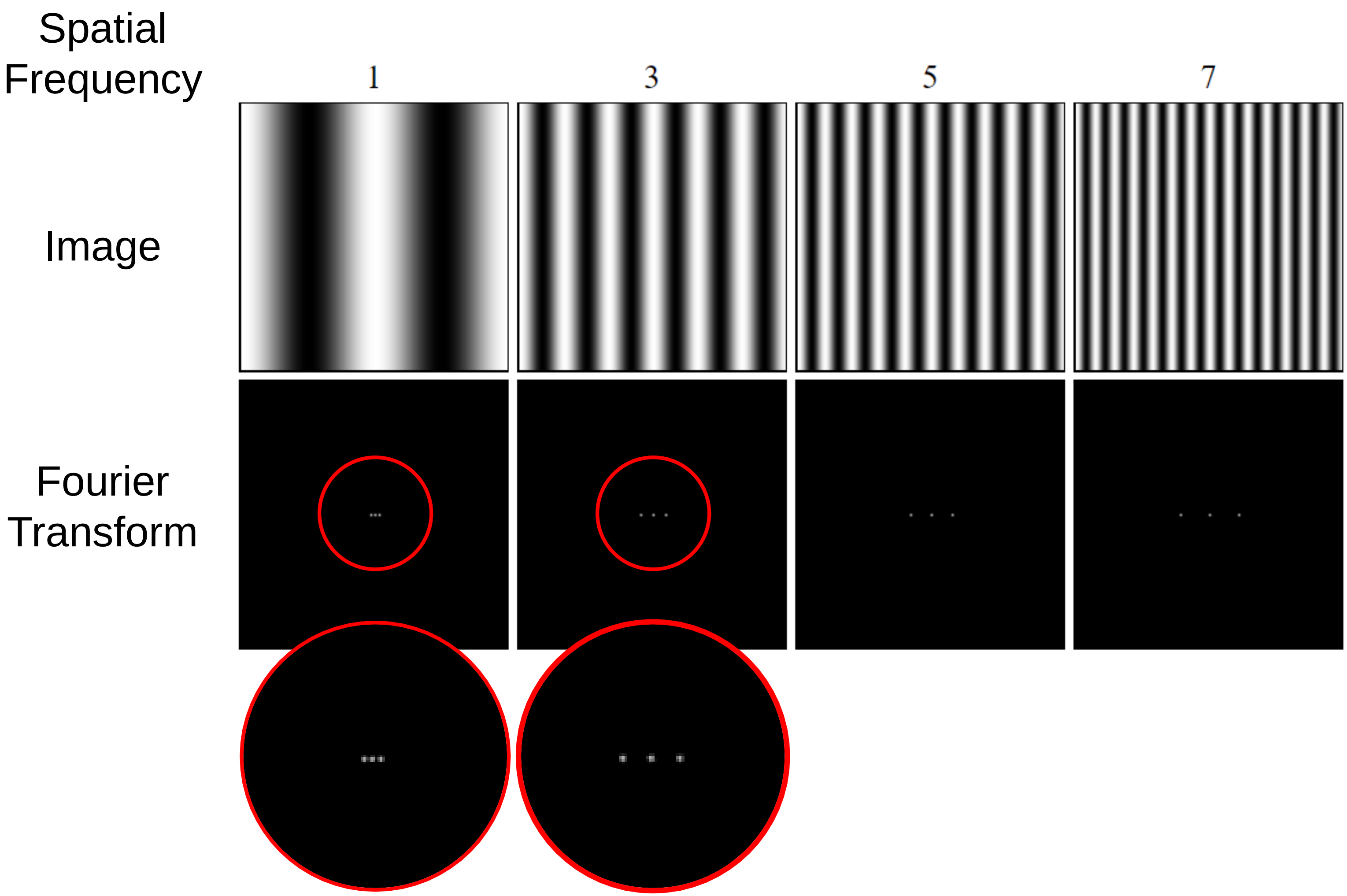

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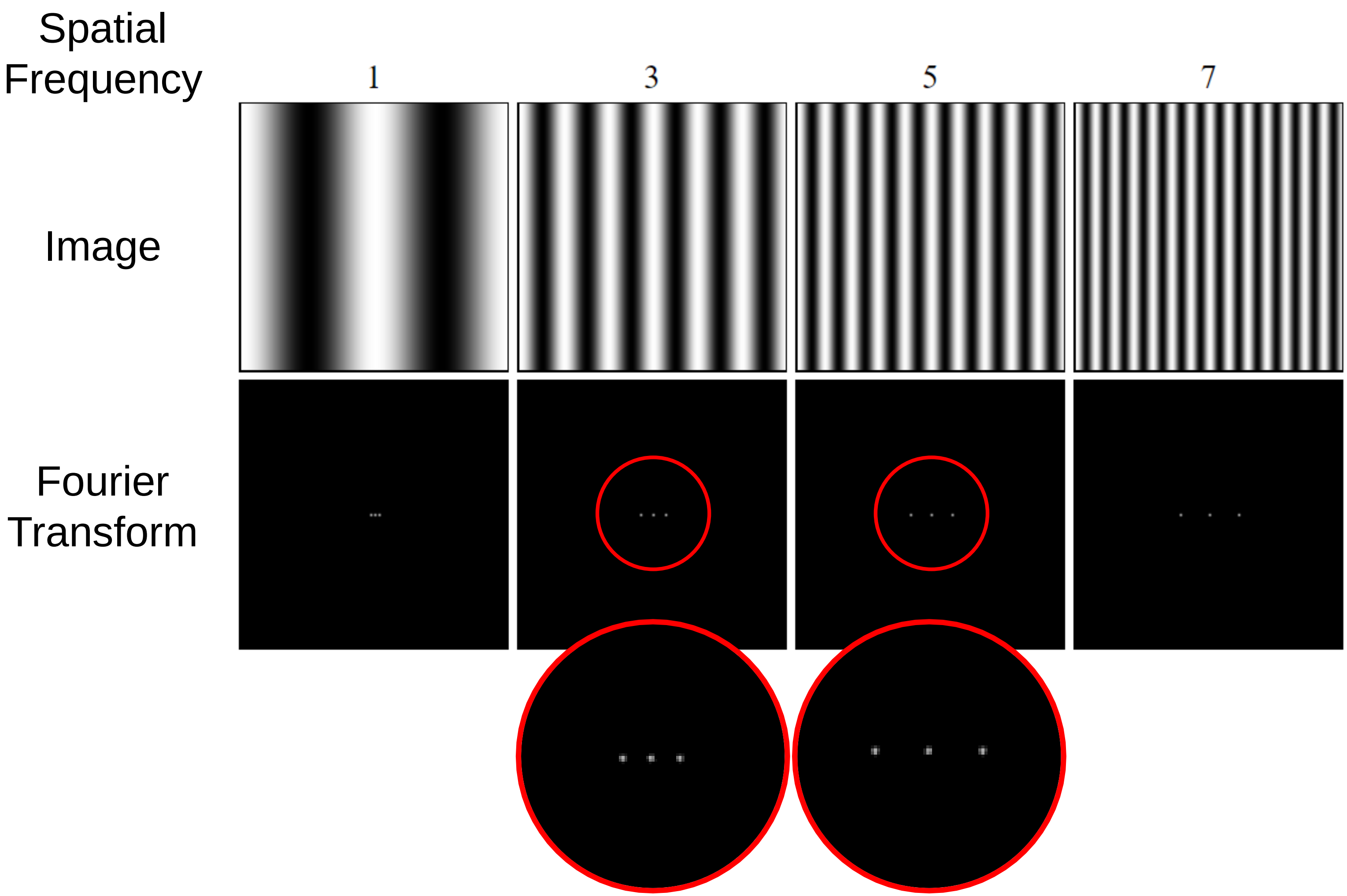

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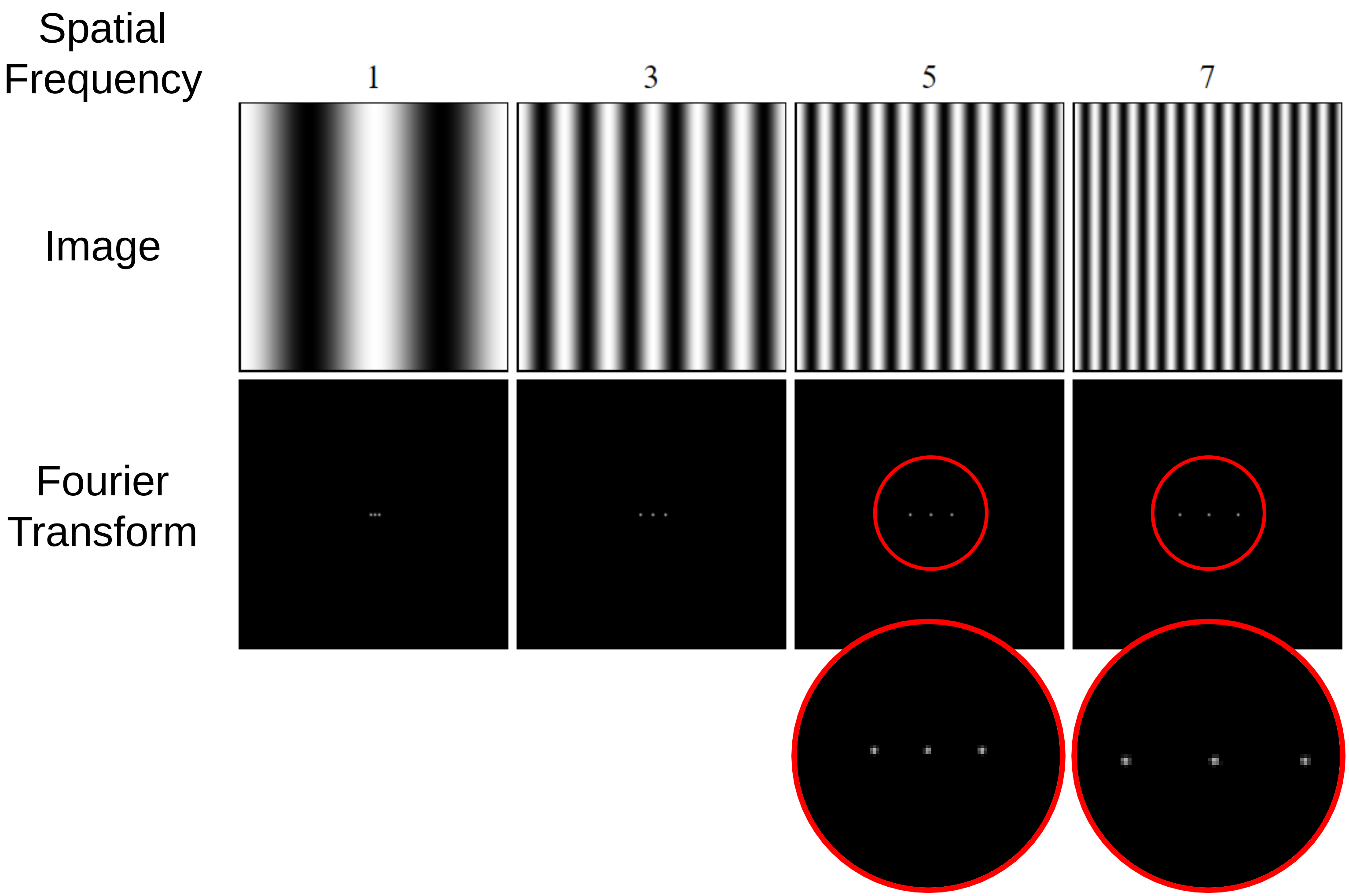

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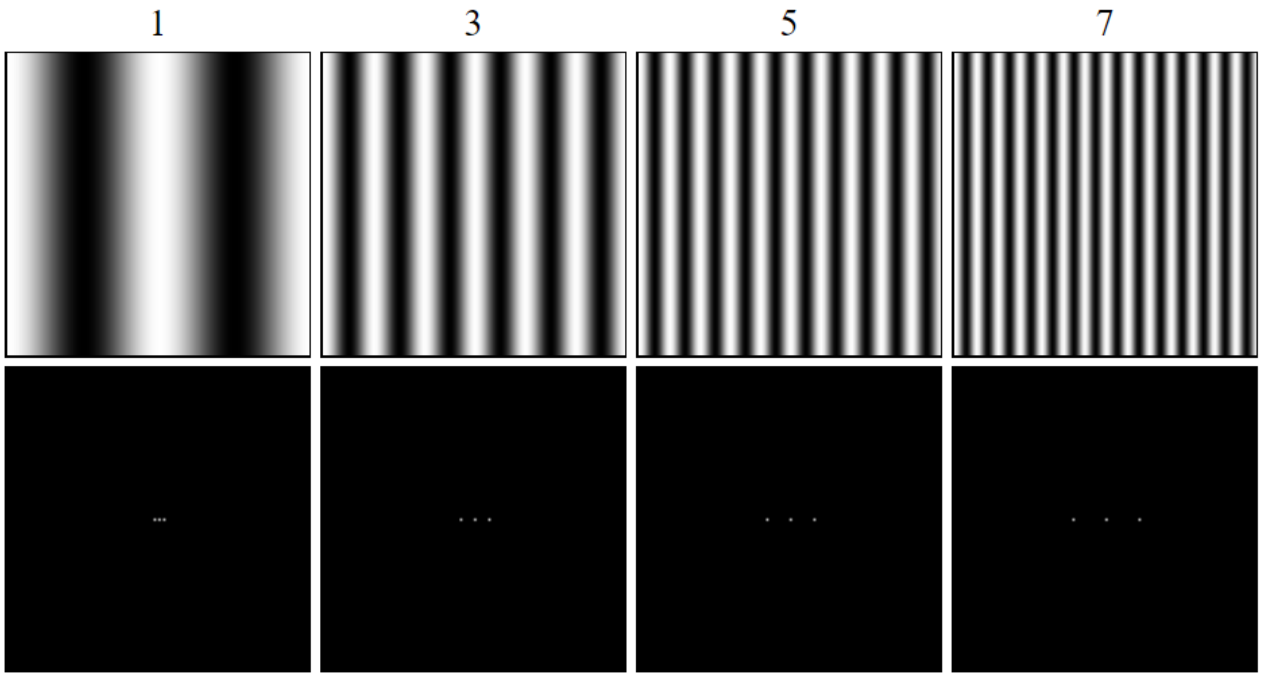

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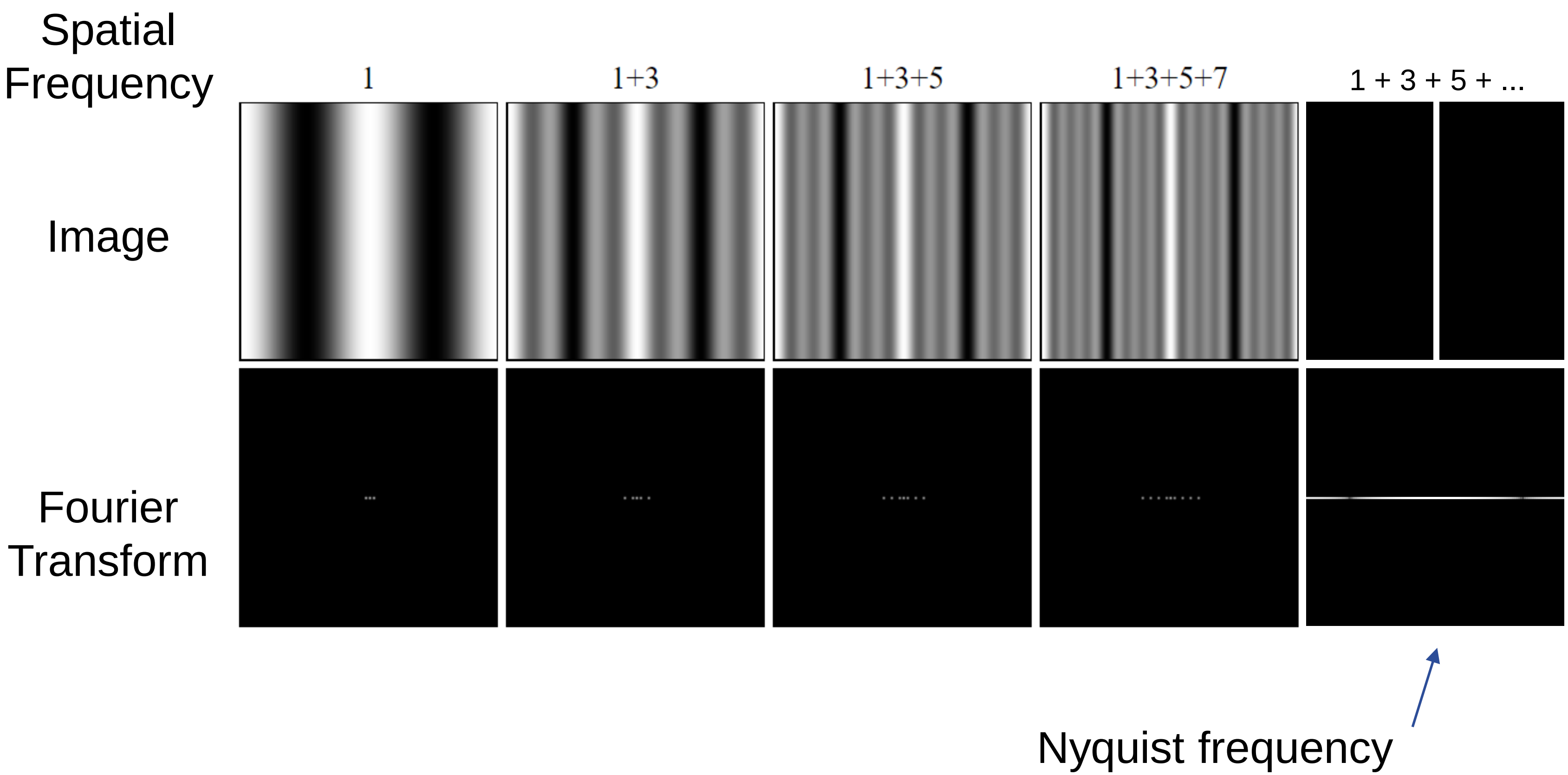

FFT Filtering

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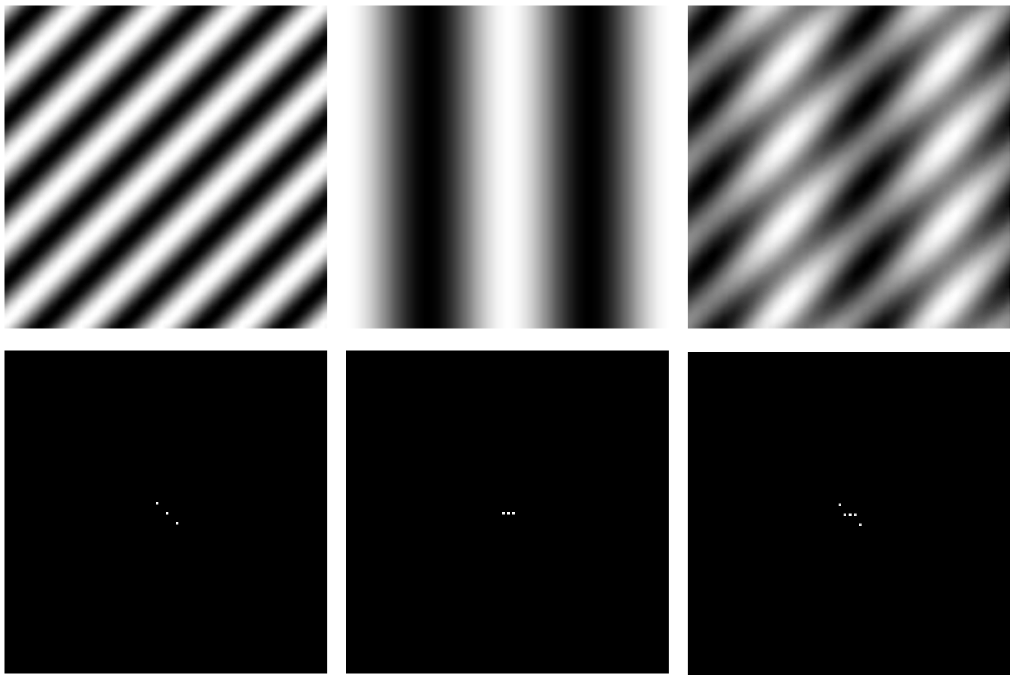

FFT Filtering

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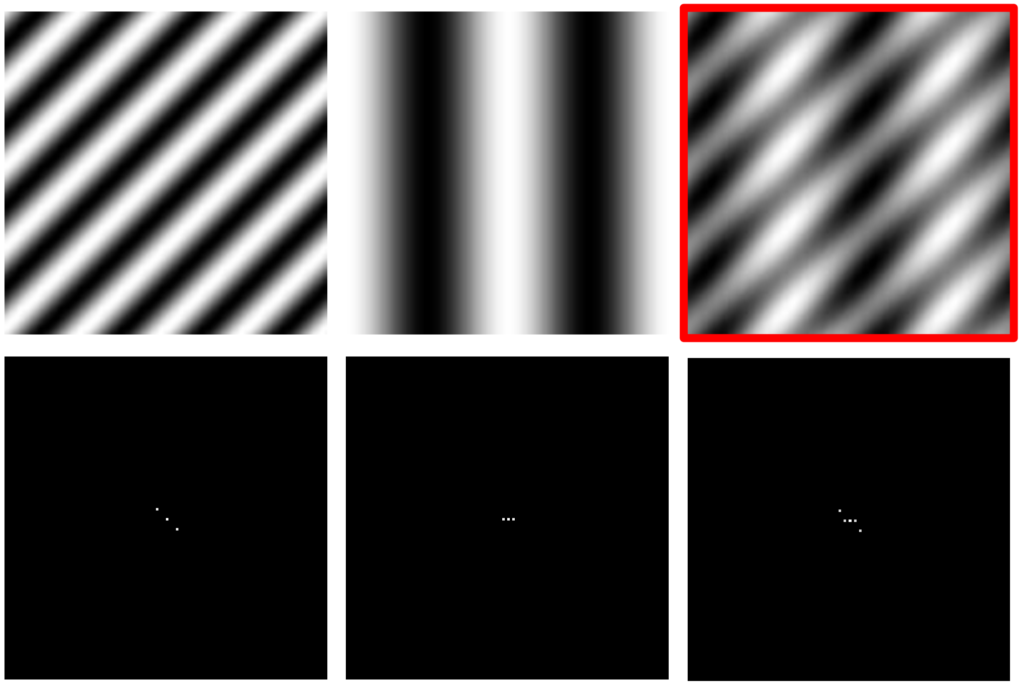
Image

Fourier Transform



FFT Filtering

Image

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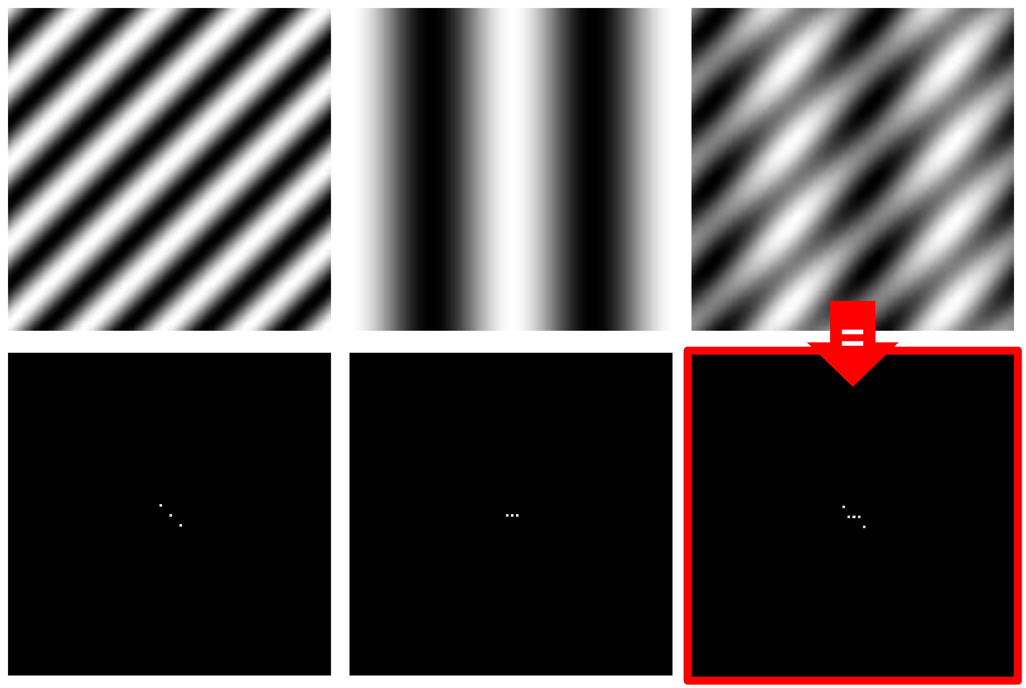

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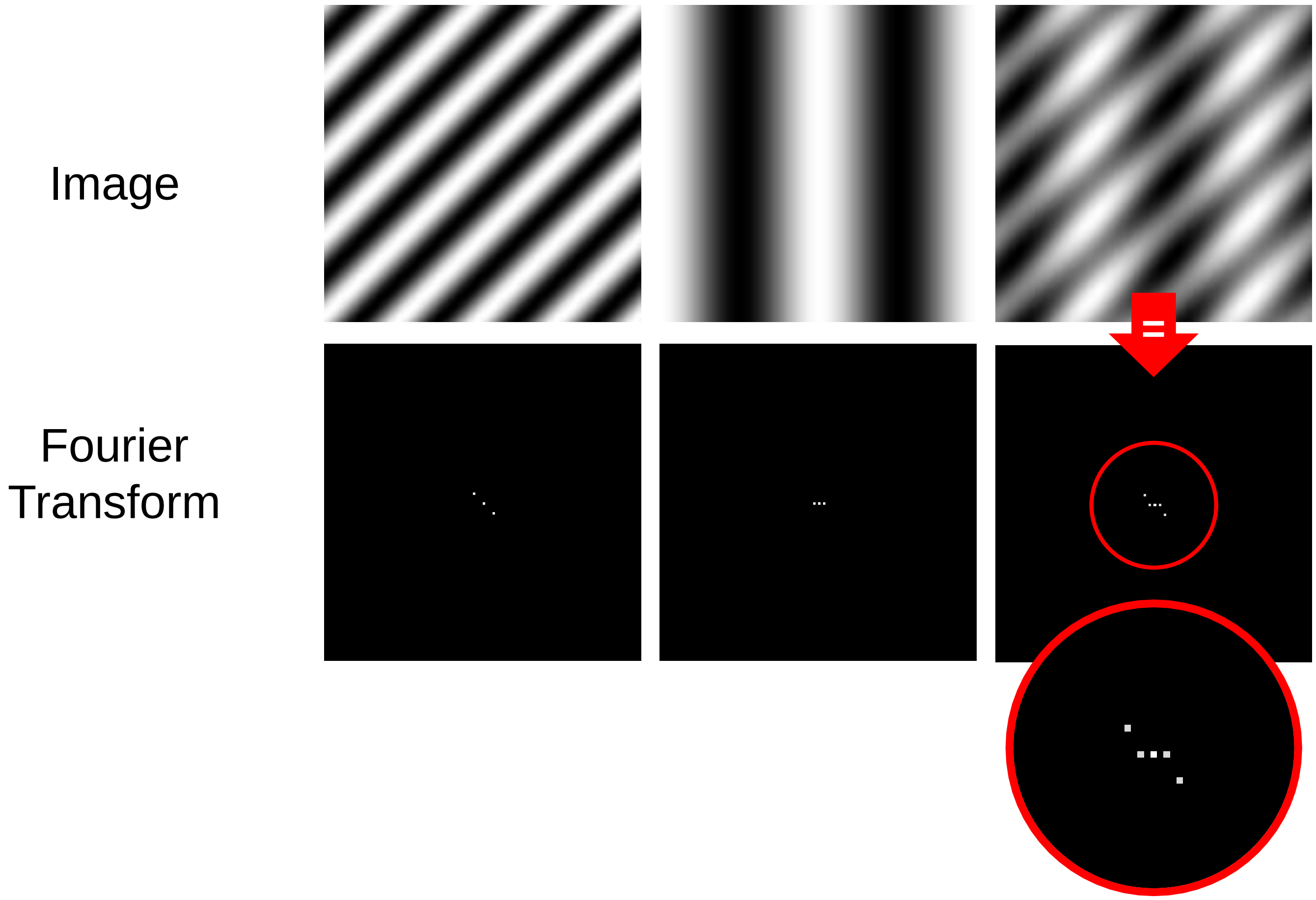

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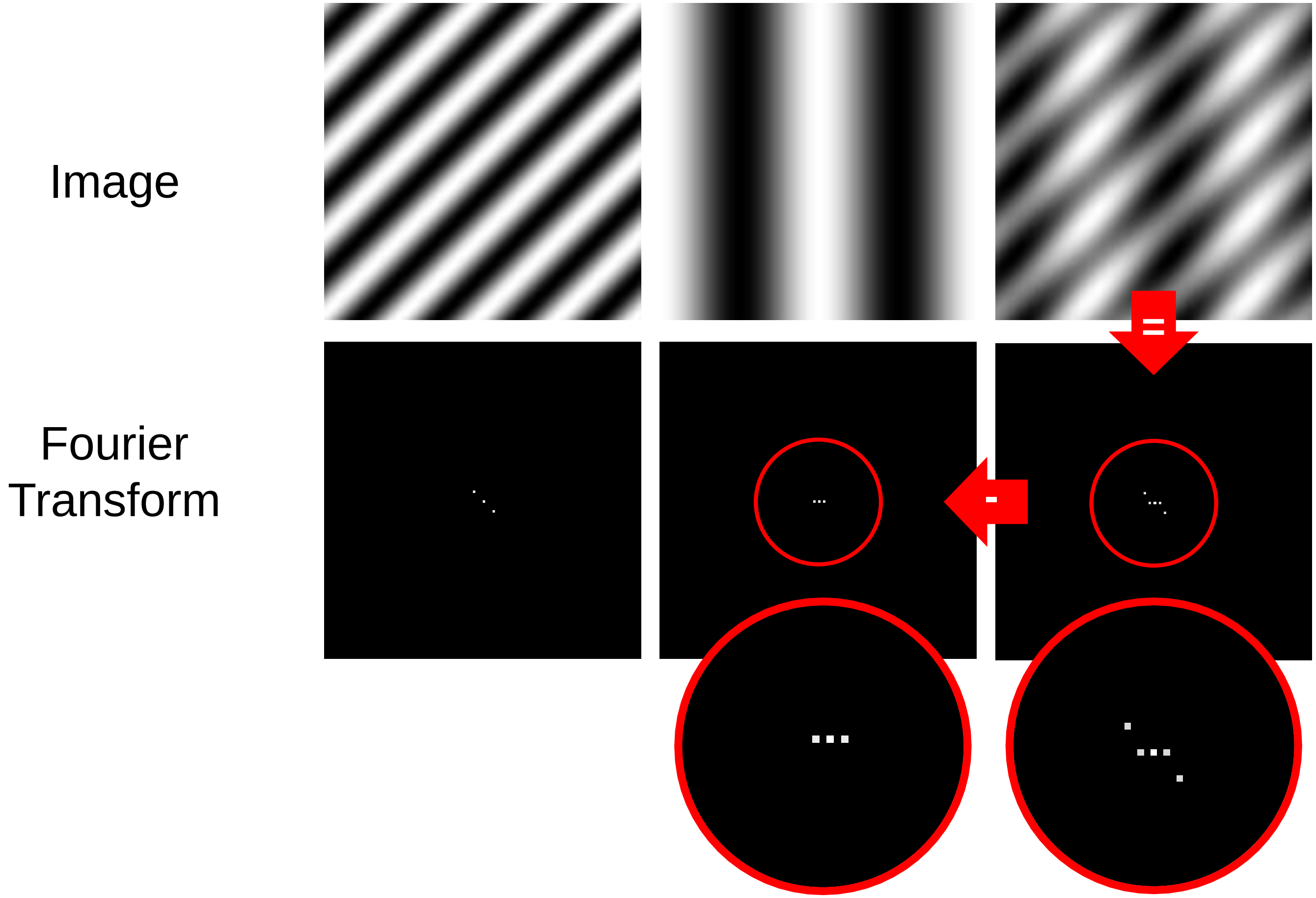

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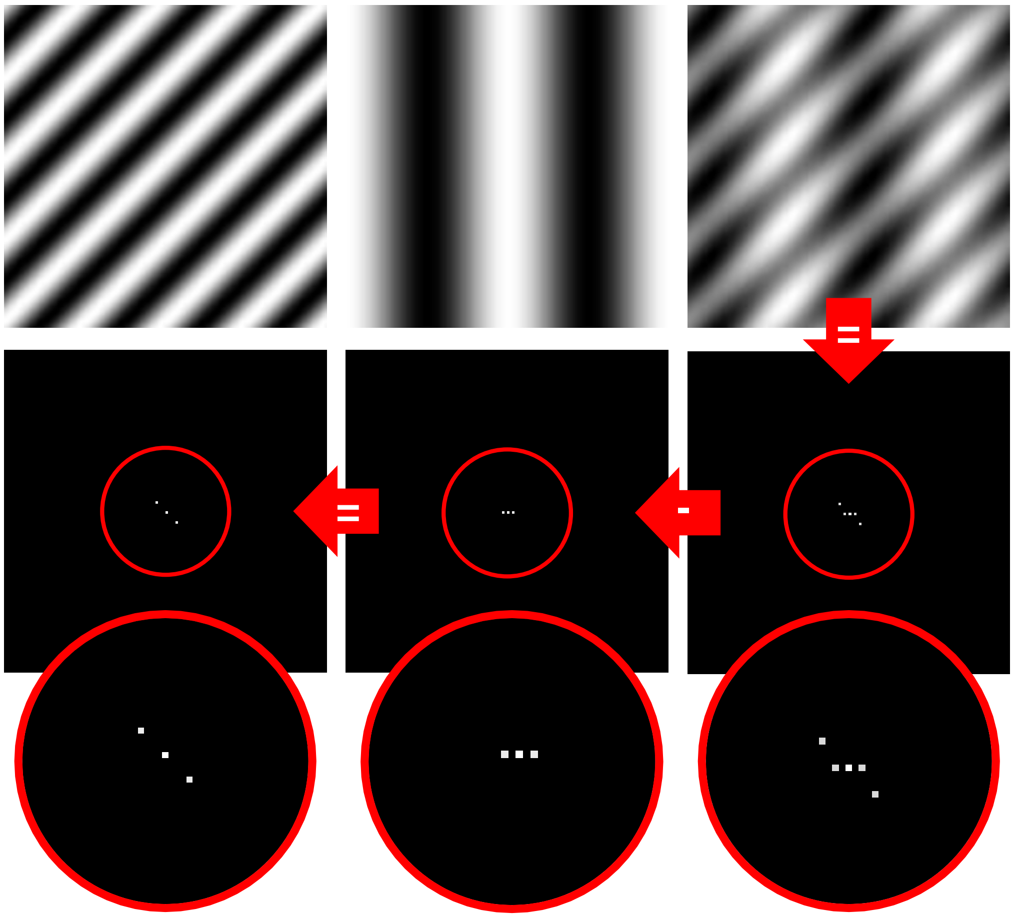

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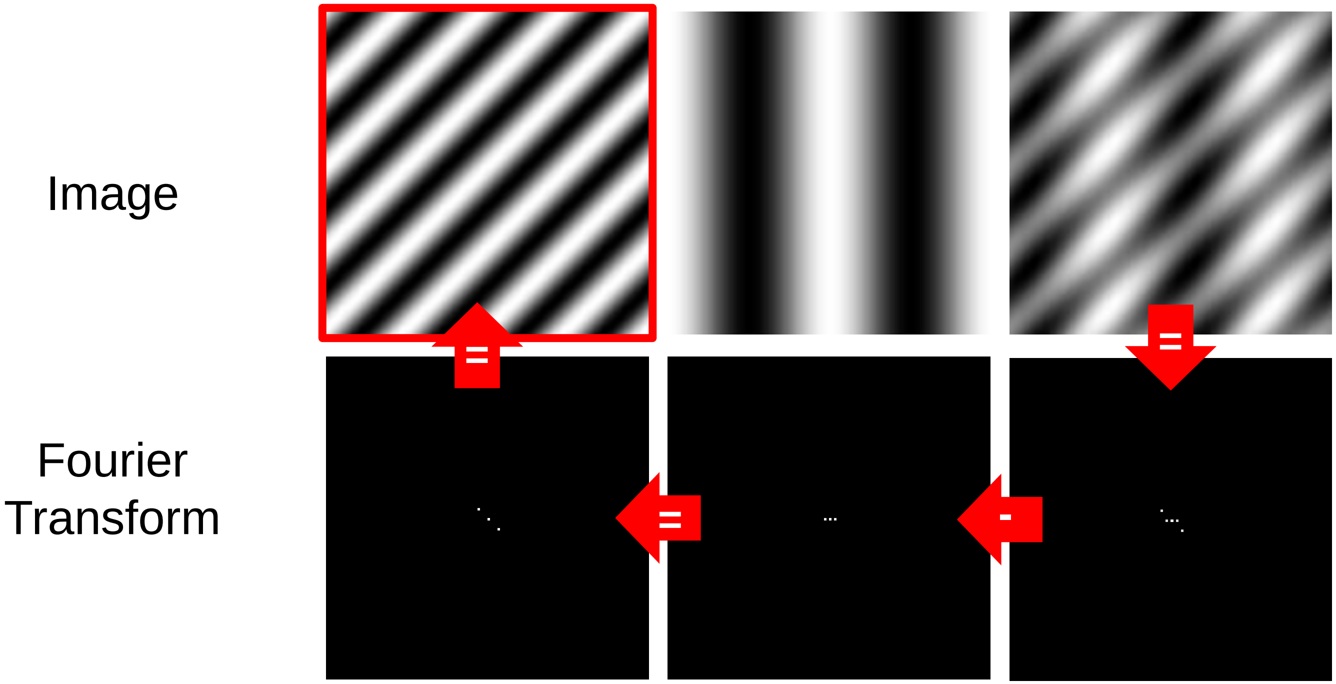
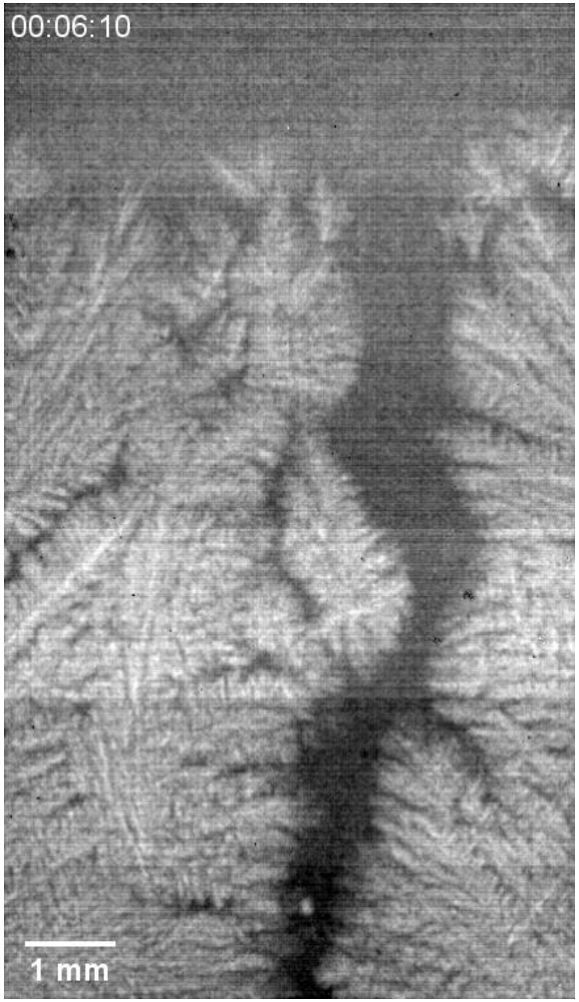
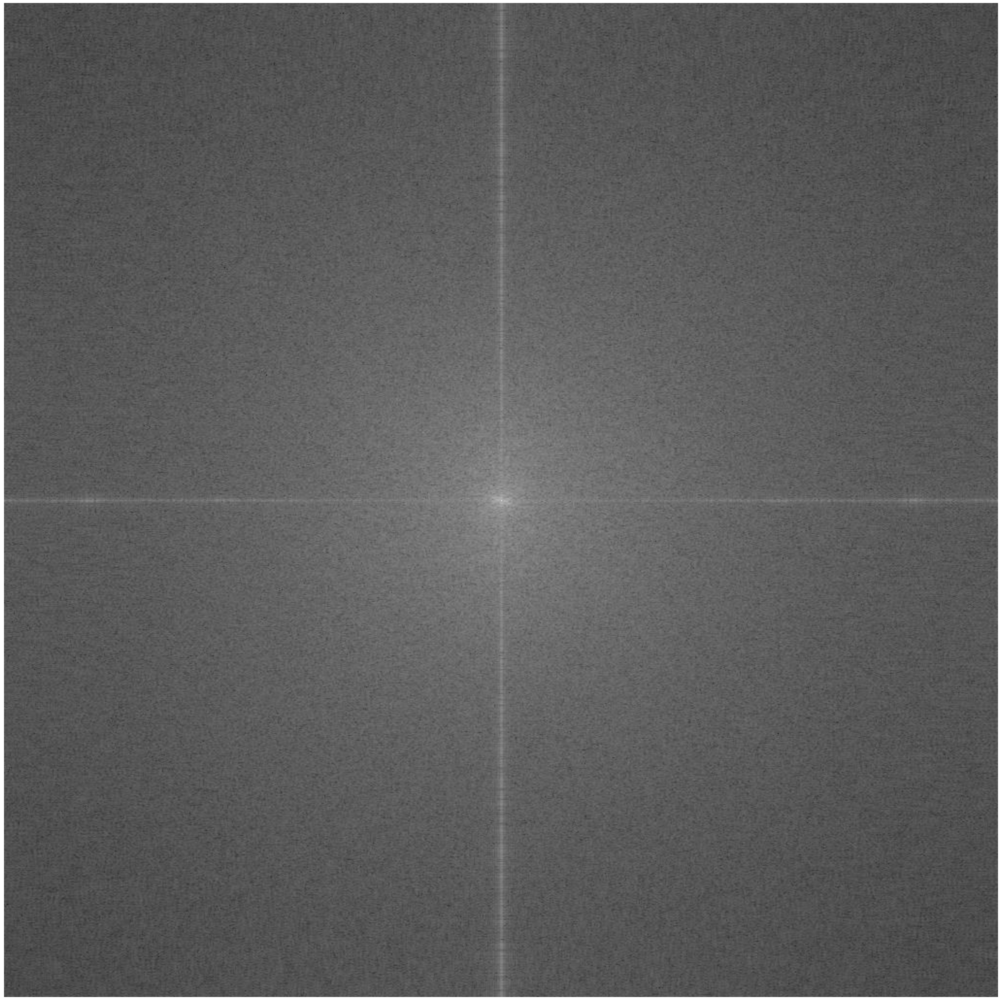


FFT Filtering to Remove Bands





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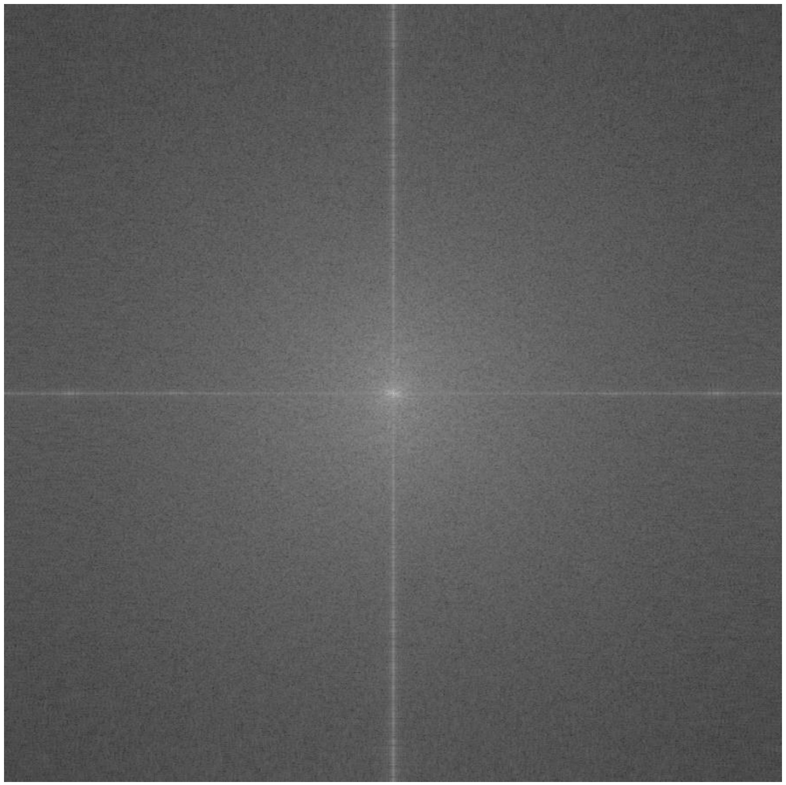

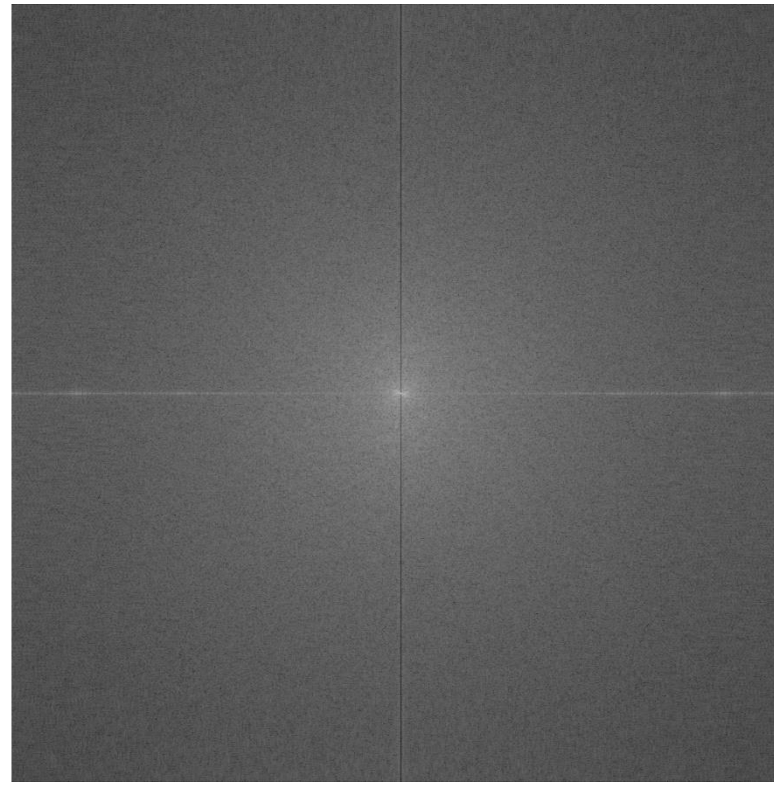

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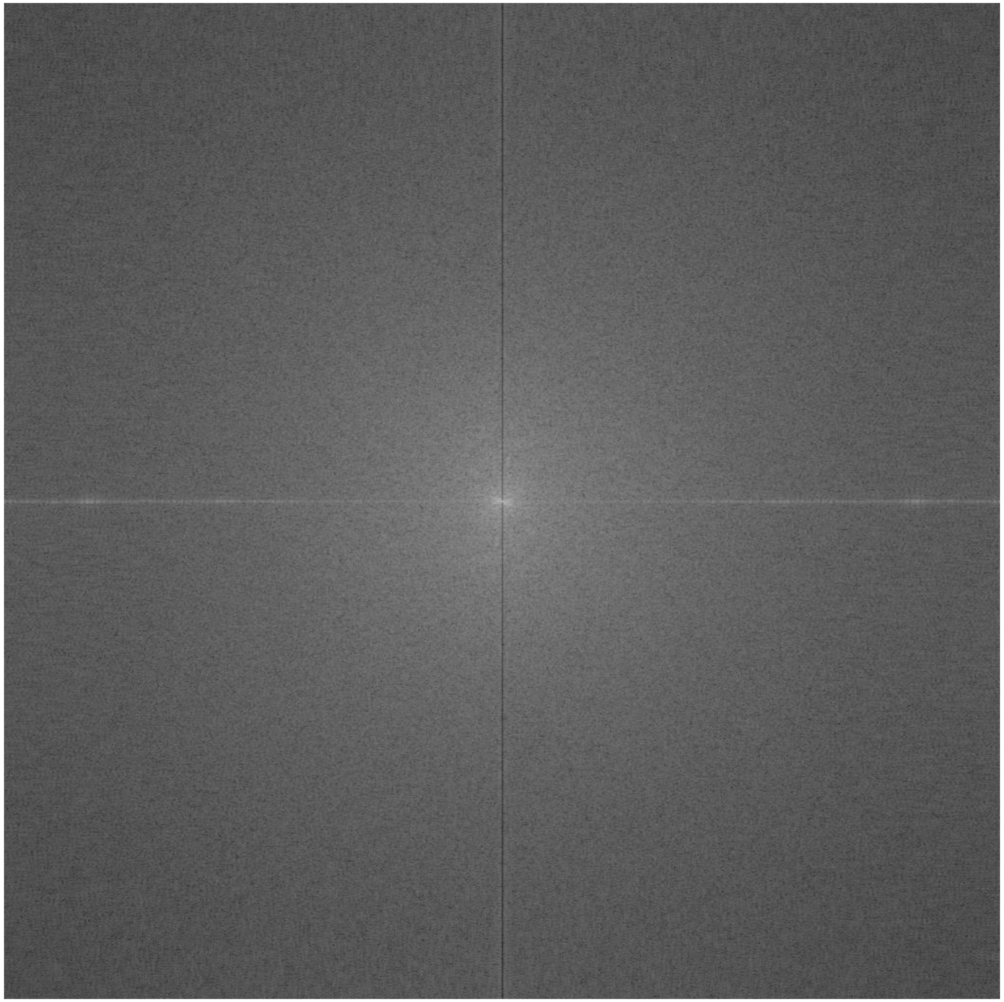

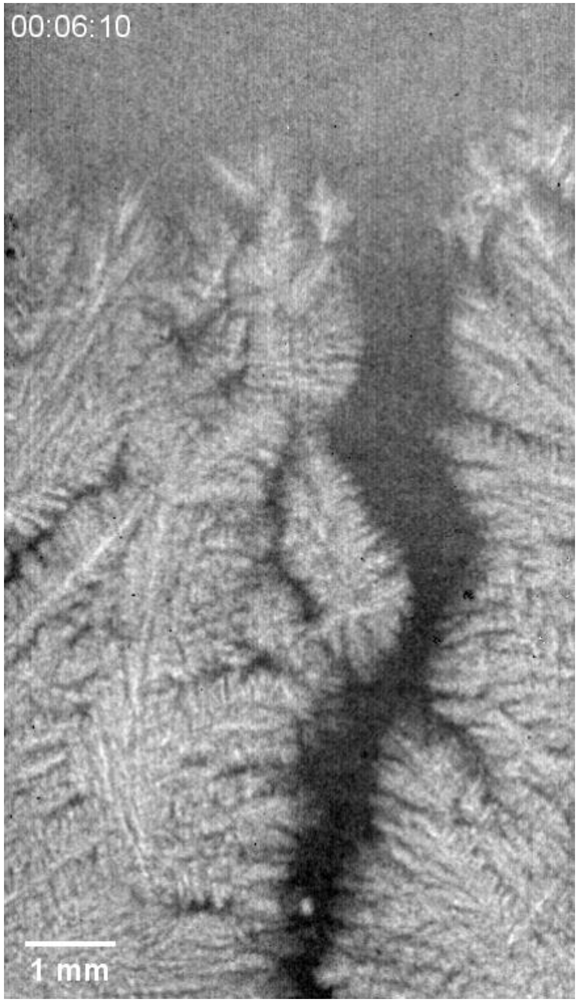

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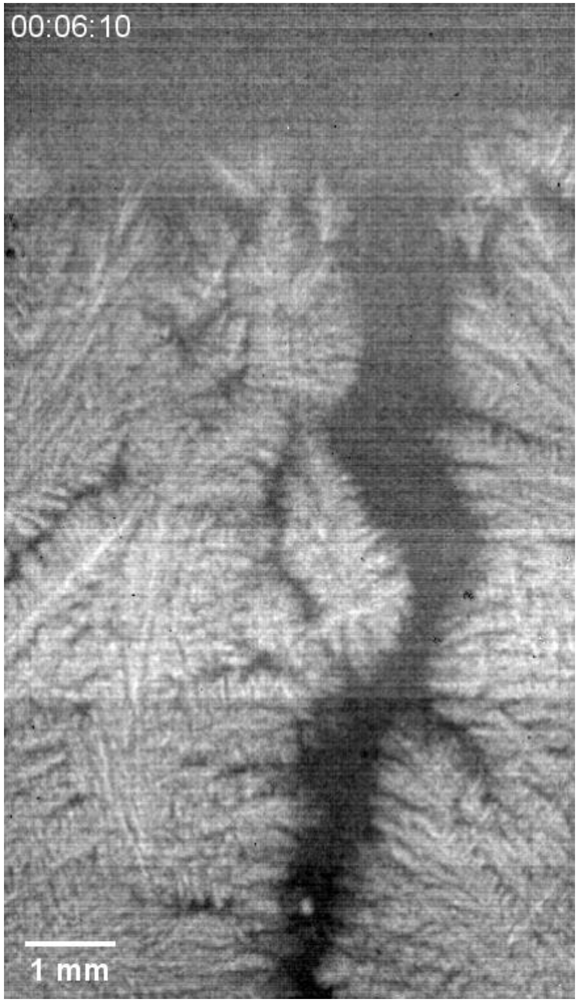

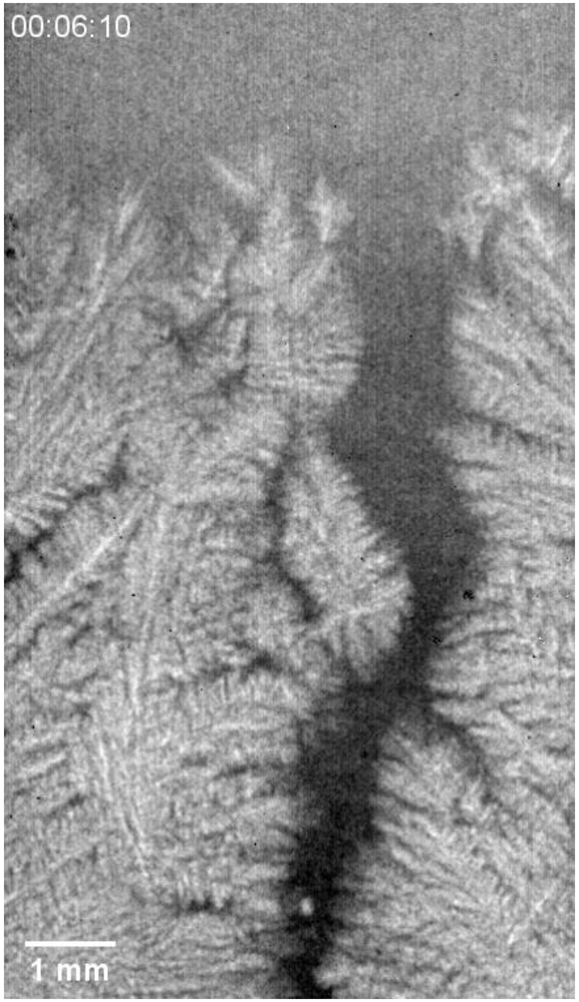

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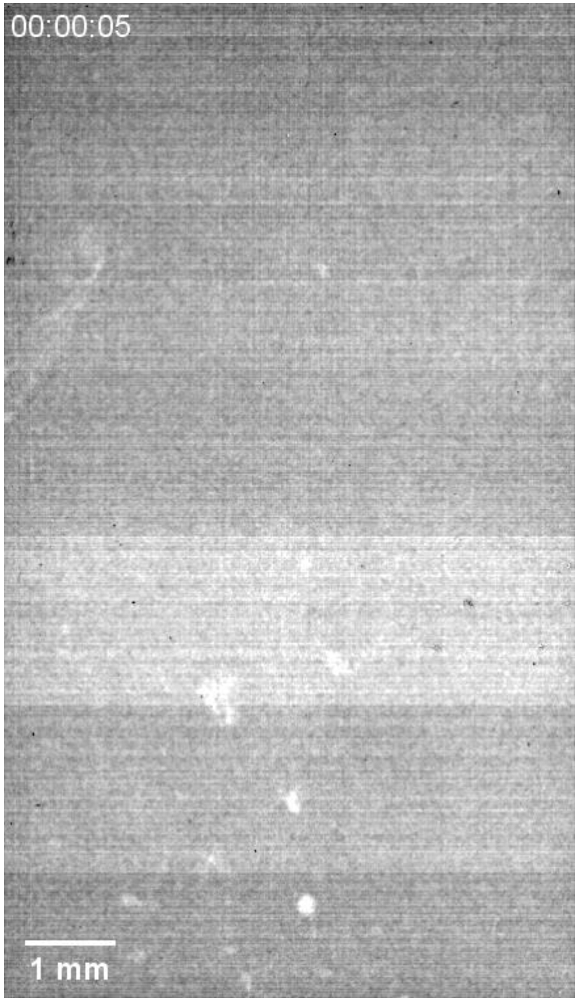
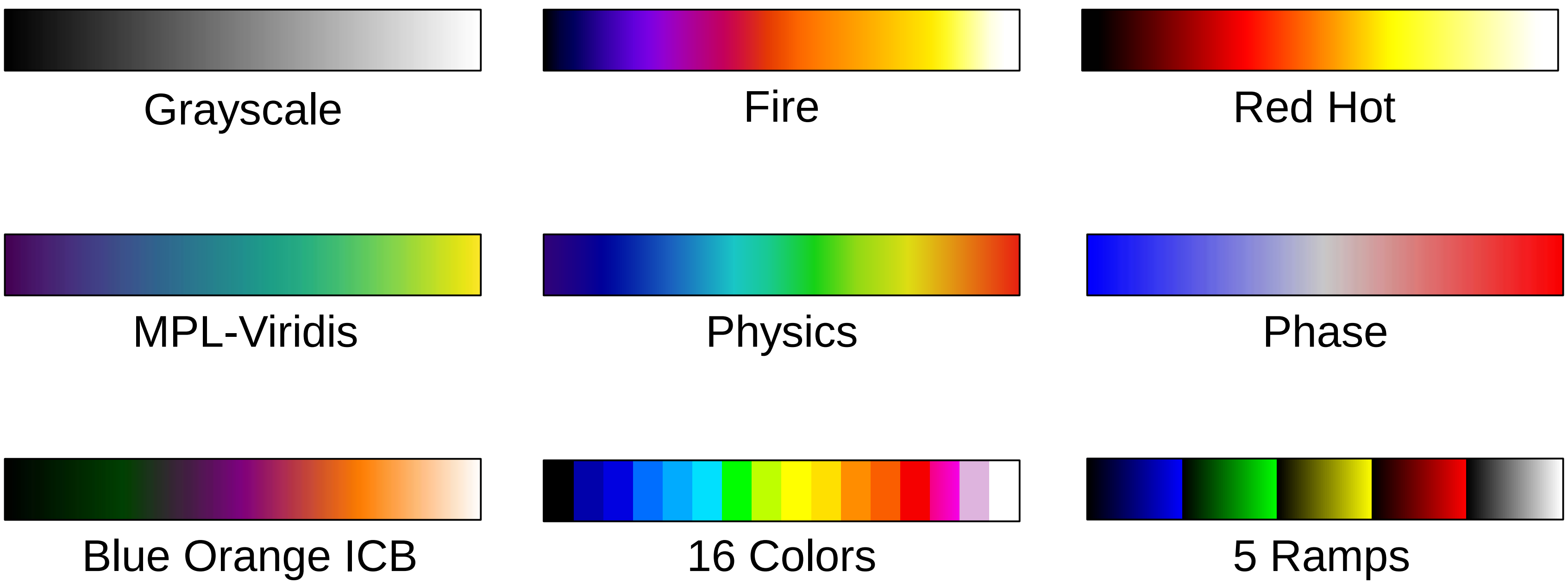


Modular Image Processing Method

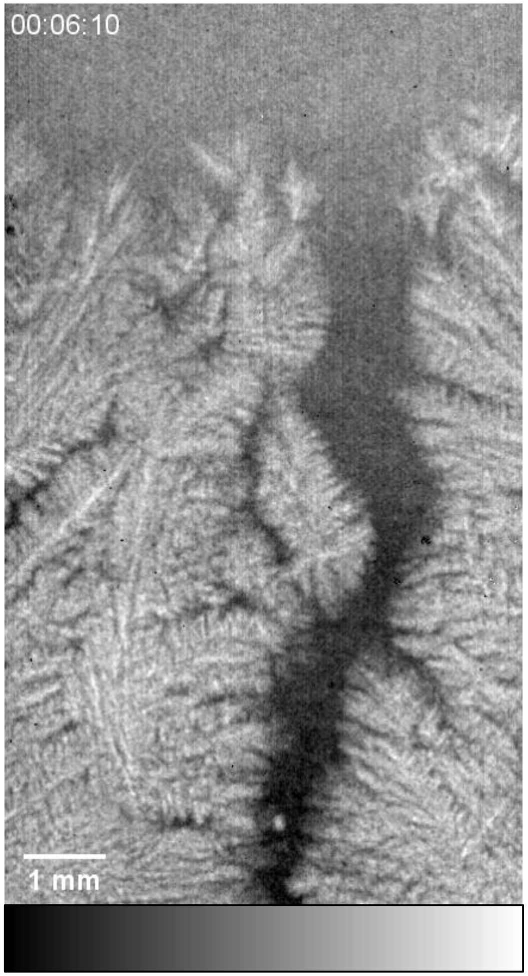
- Automatic resize by thresholding
- Trim edges
- Removal of band artifacts through fast Fourier transform filtering
- Pseudocolor mapping of pixel intensities with lookup tables

Pseudocolor Mapping

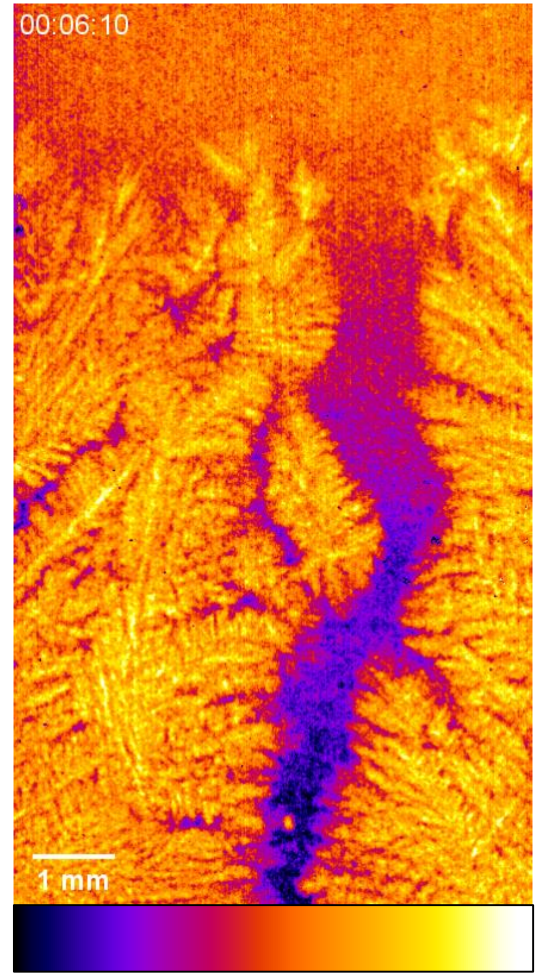
- Maps a pixel intensity value from a grayscale spectrum to a spectrum consisting of colors
- Many options, can be created/edited



Pseudocolor Mapping

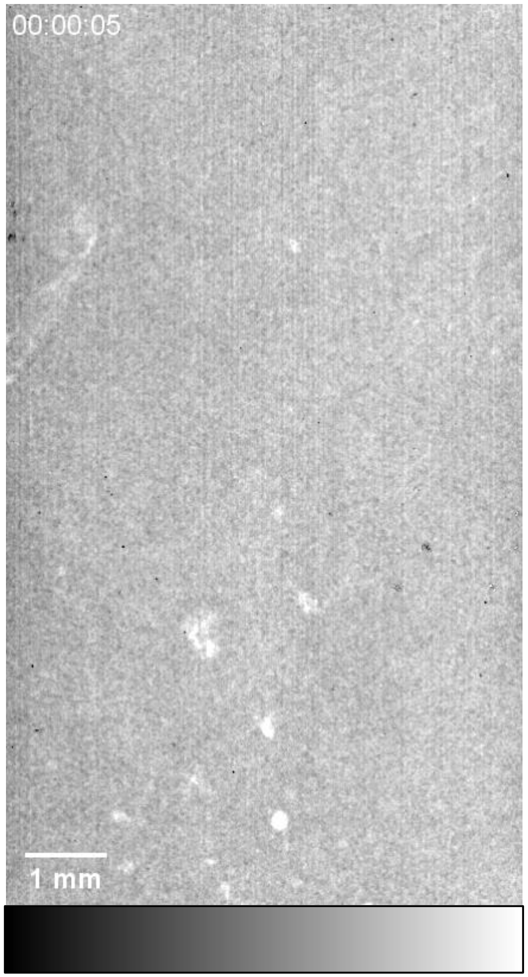


Grayscale

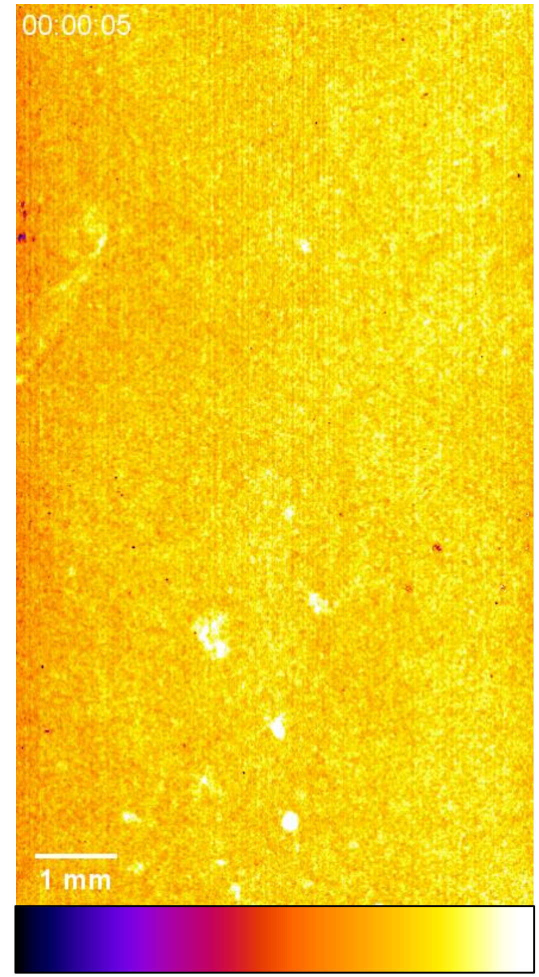


Fire

Pseudocolor Mapping



Grayscale

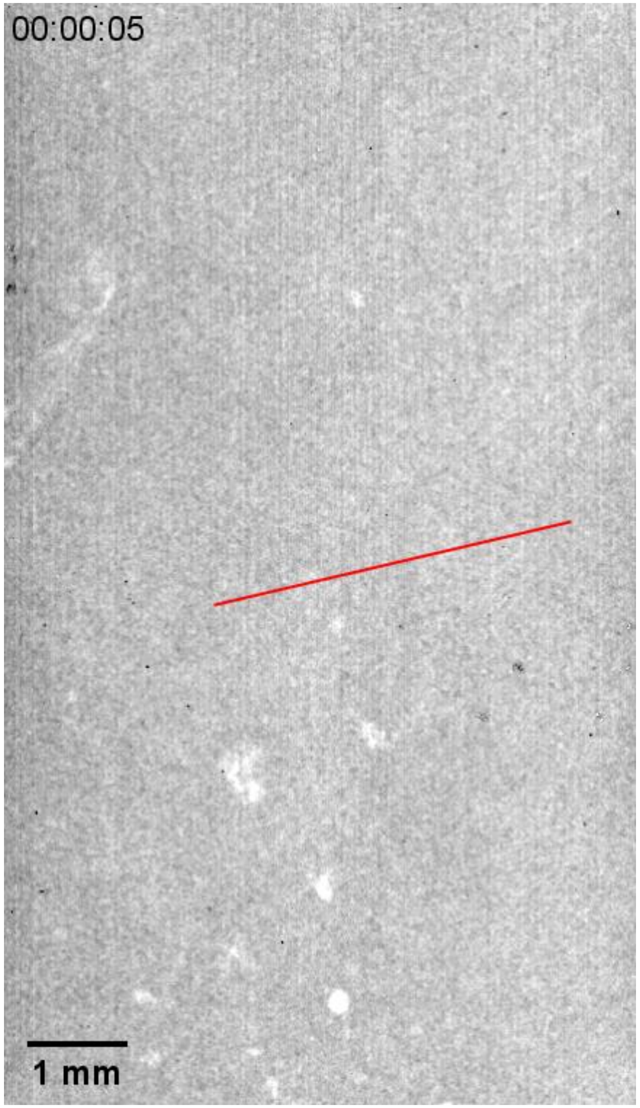


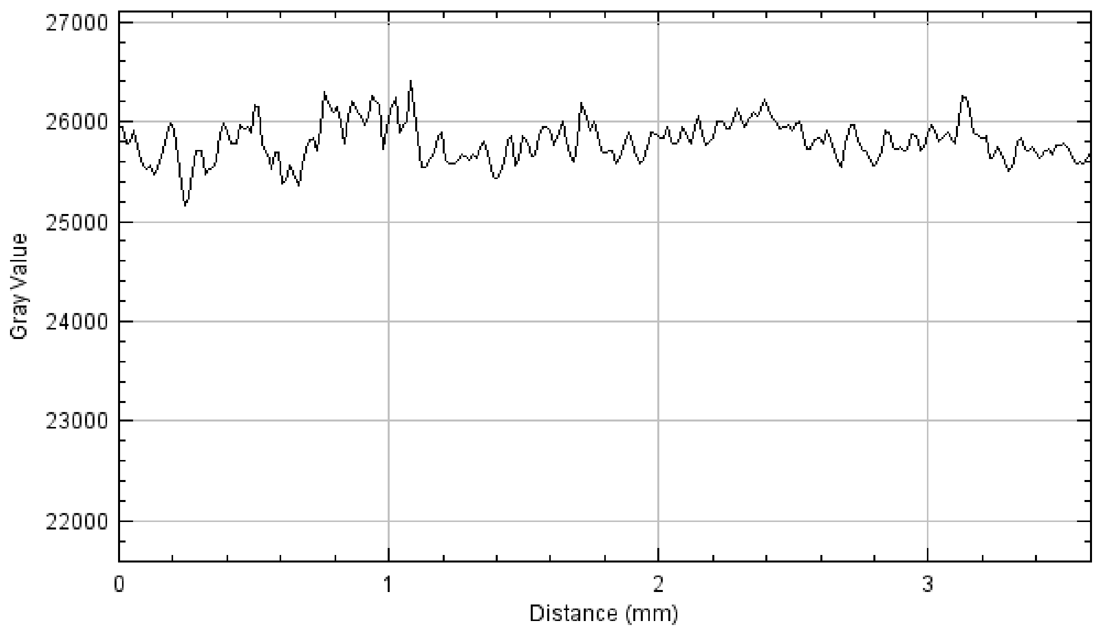
Fire

Modular Image Processing Method

- Automatic resize by thresholding
- Trim edges
- Removal of band artifacts through fast Fourier transform filtering
- Pseudocolor mapping of pixel intensities with lookup tables
- Plotting pixel profile along a line

Plotting Pixel Profile





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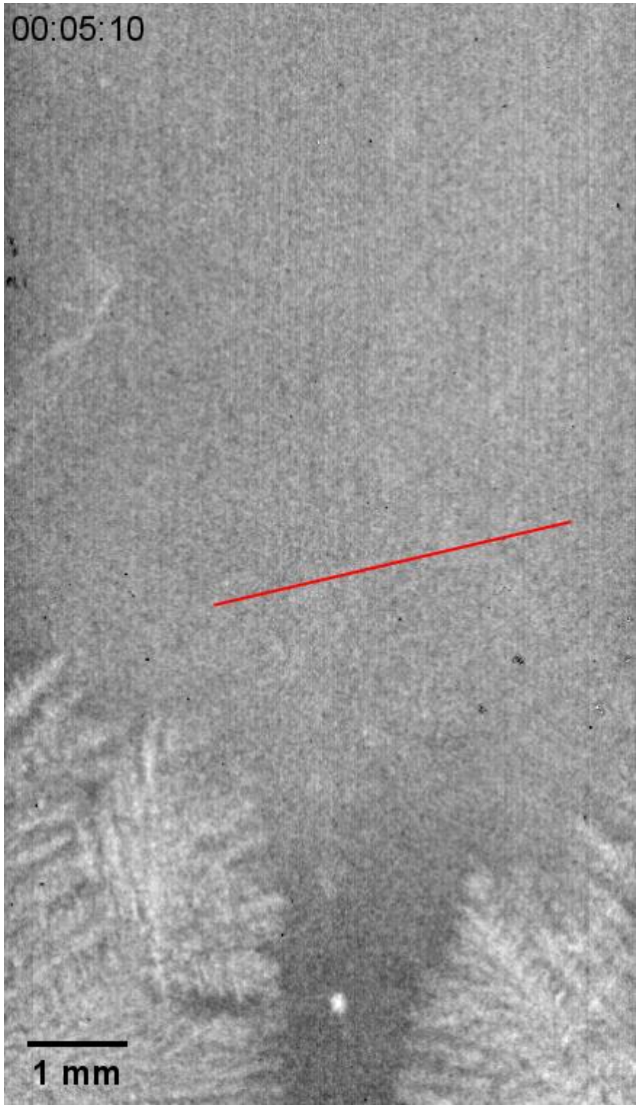

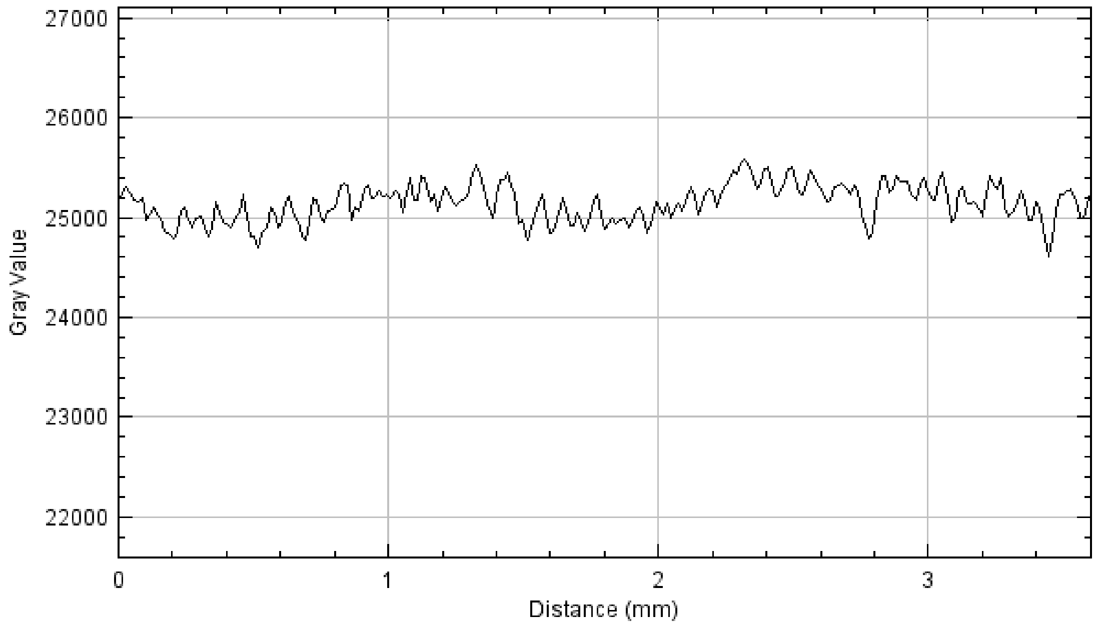

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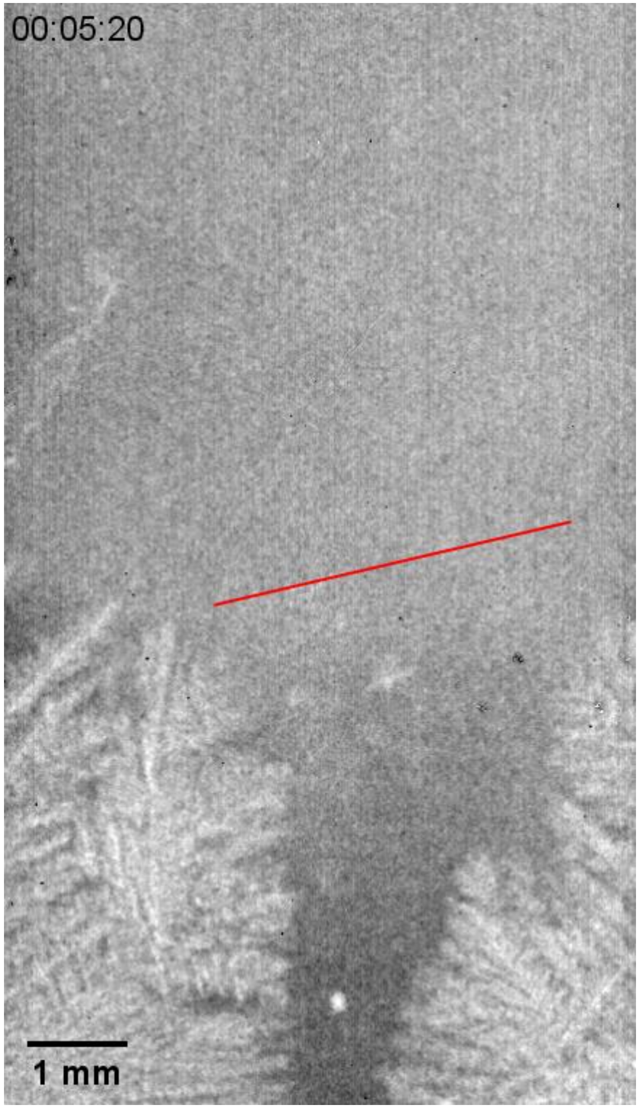

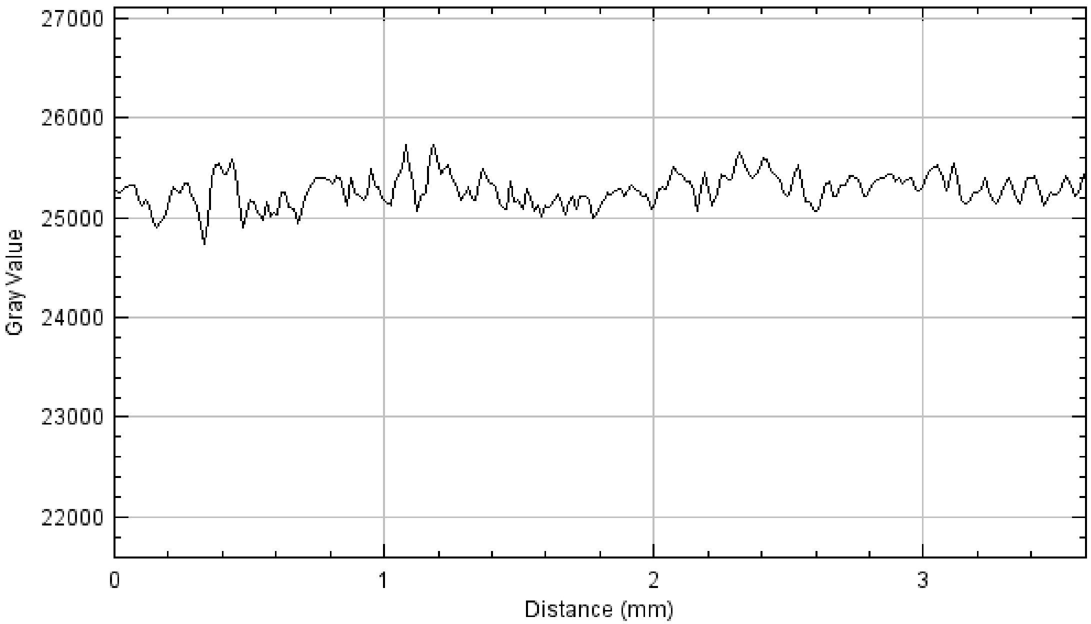

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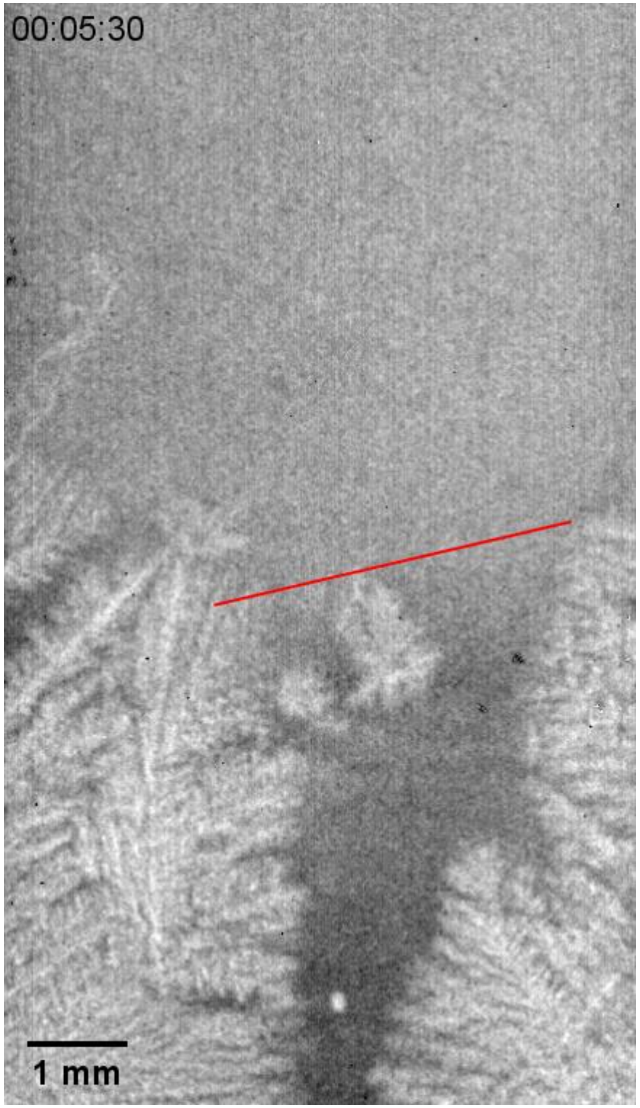

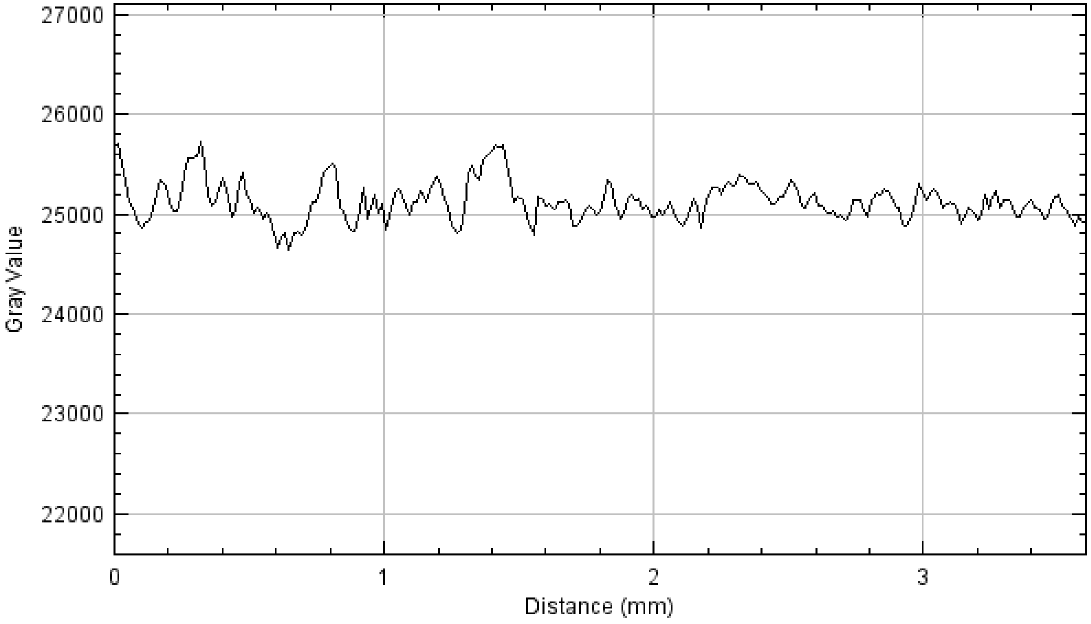

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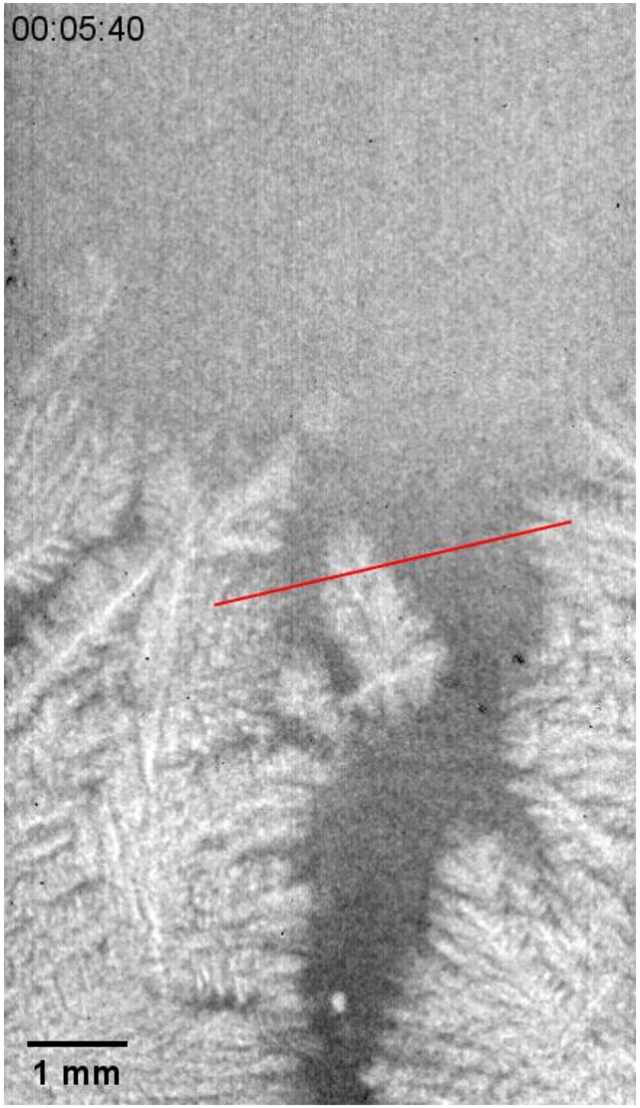

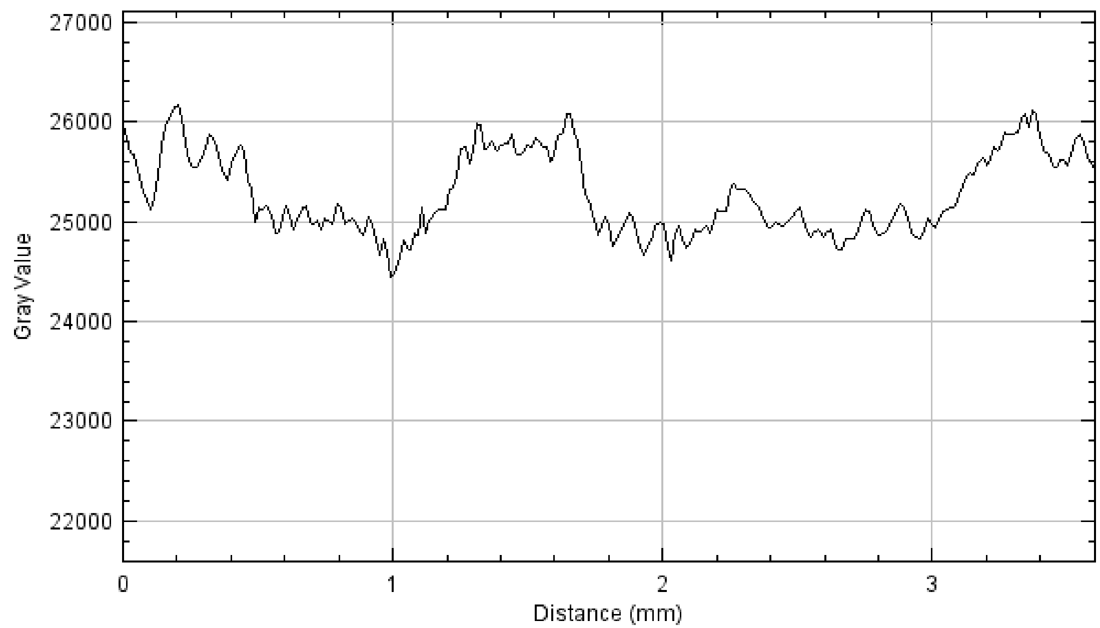

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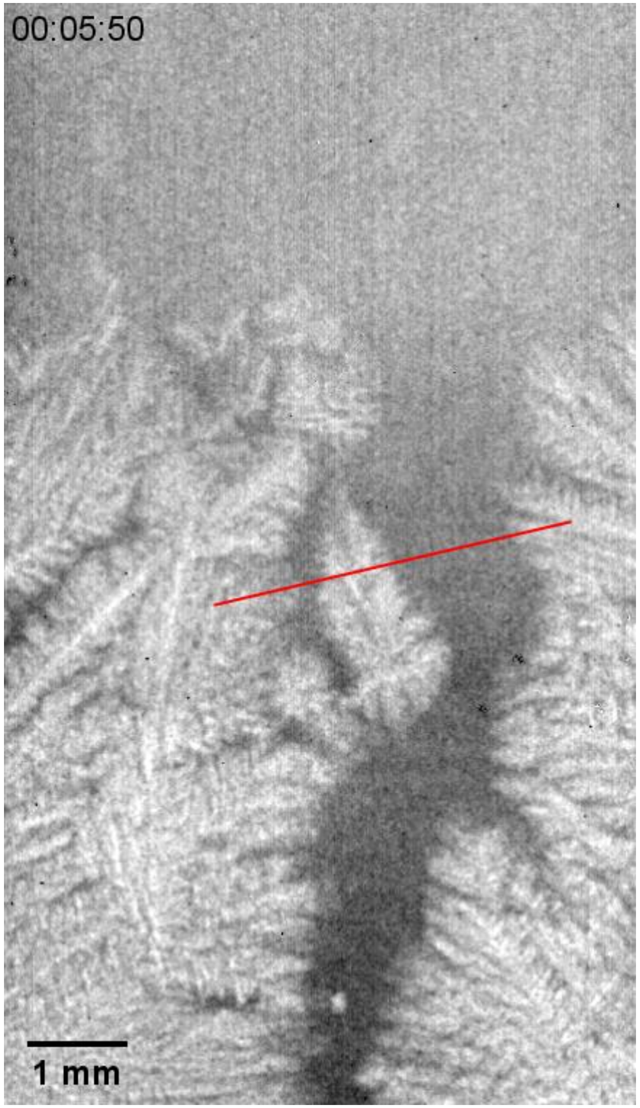

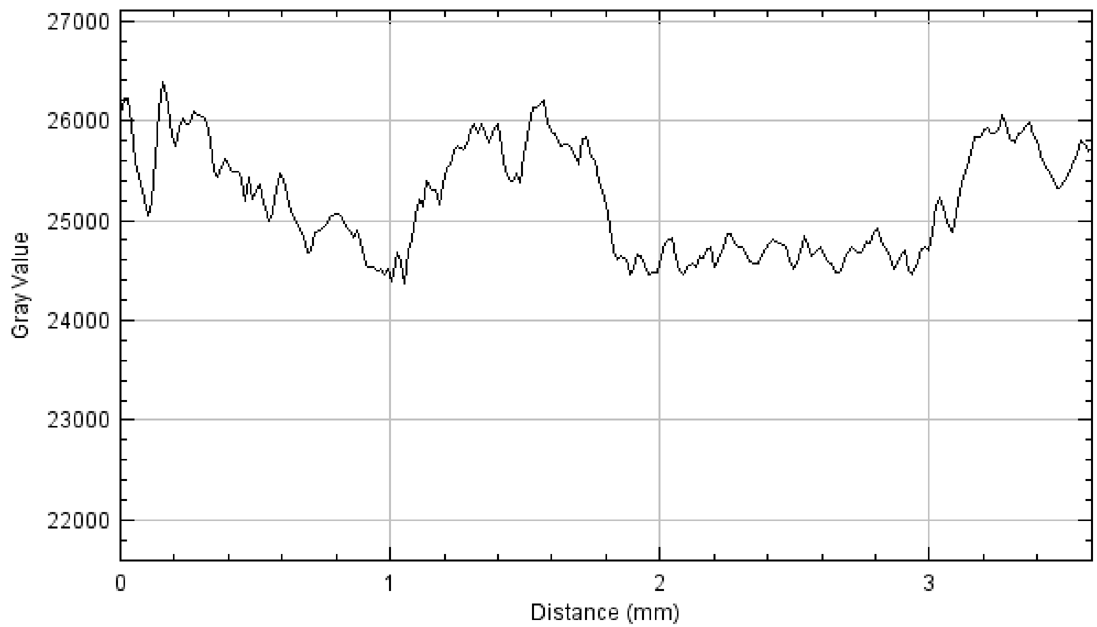

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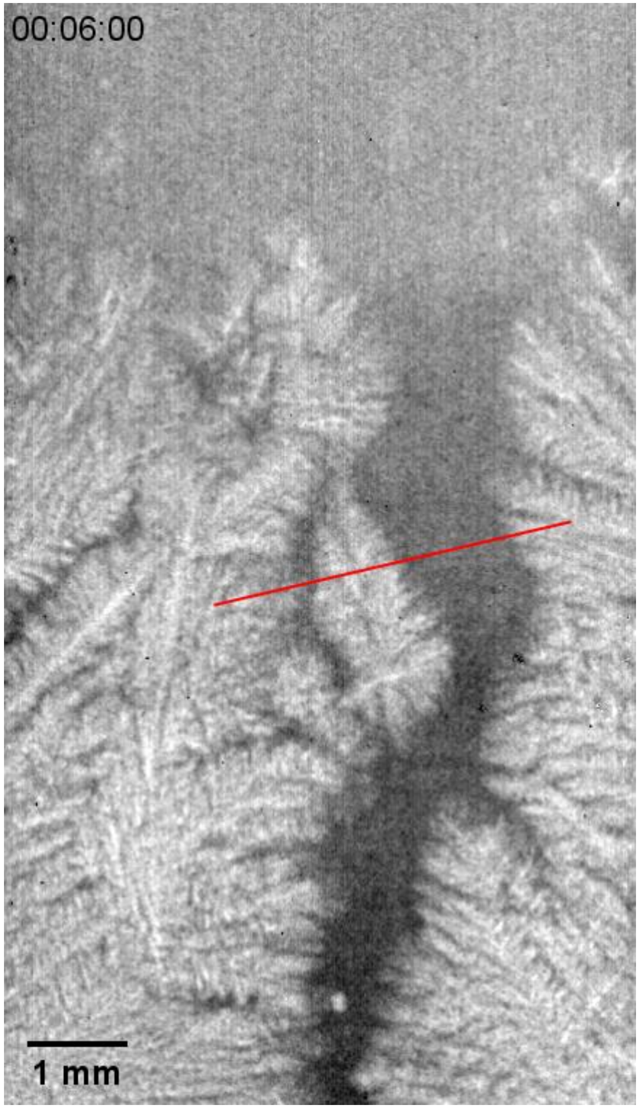

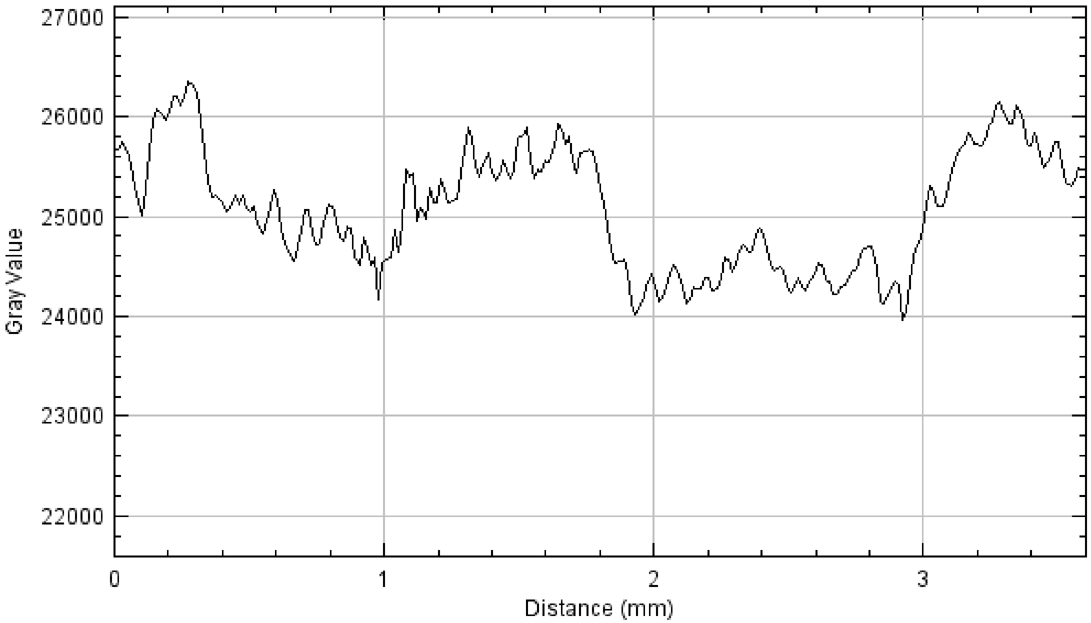

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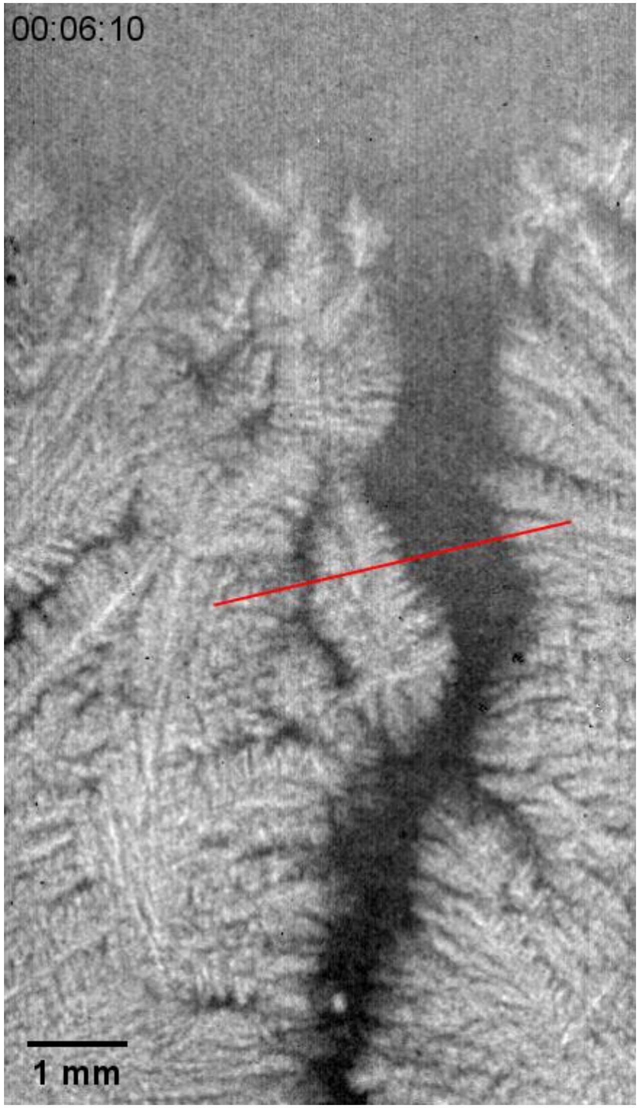

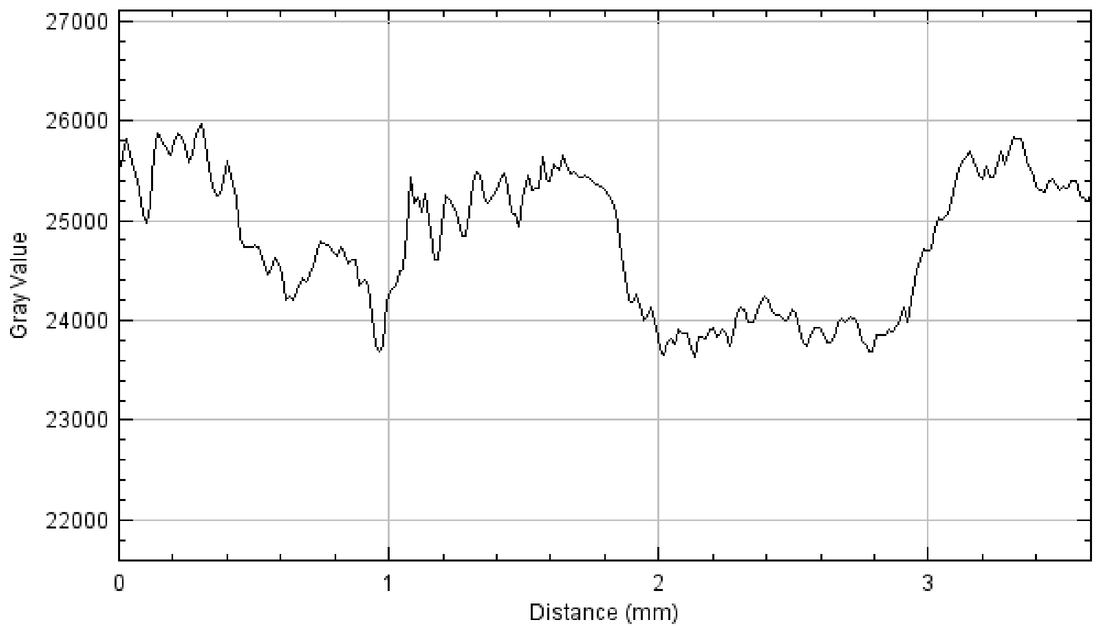

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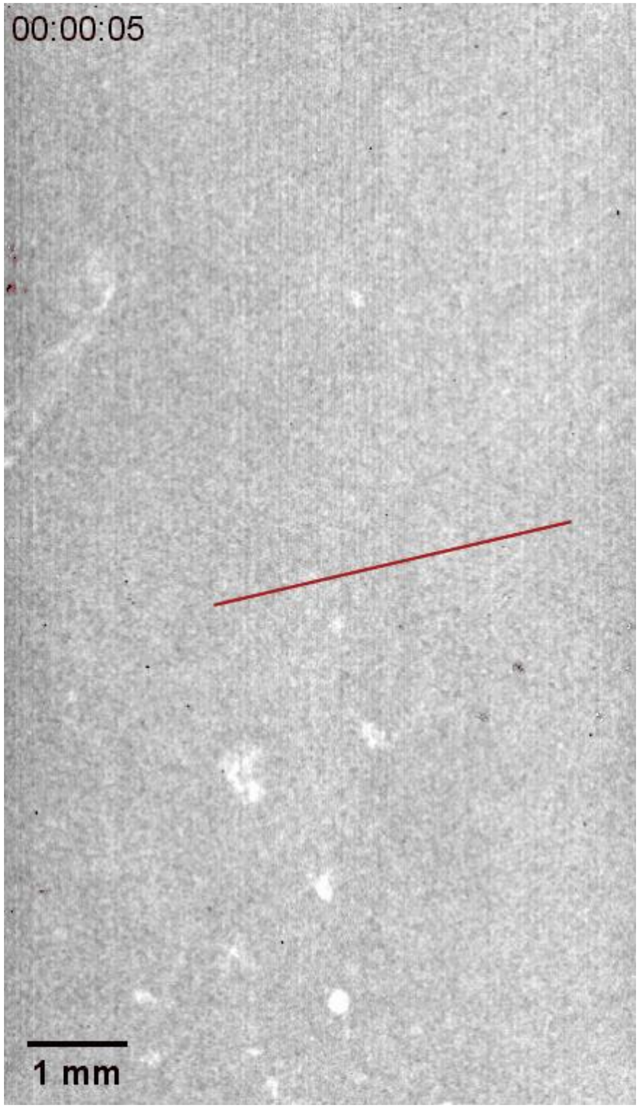
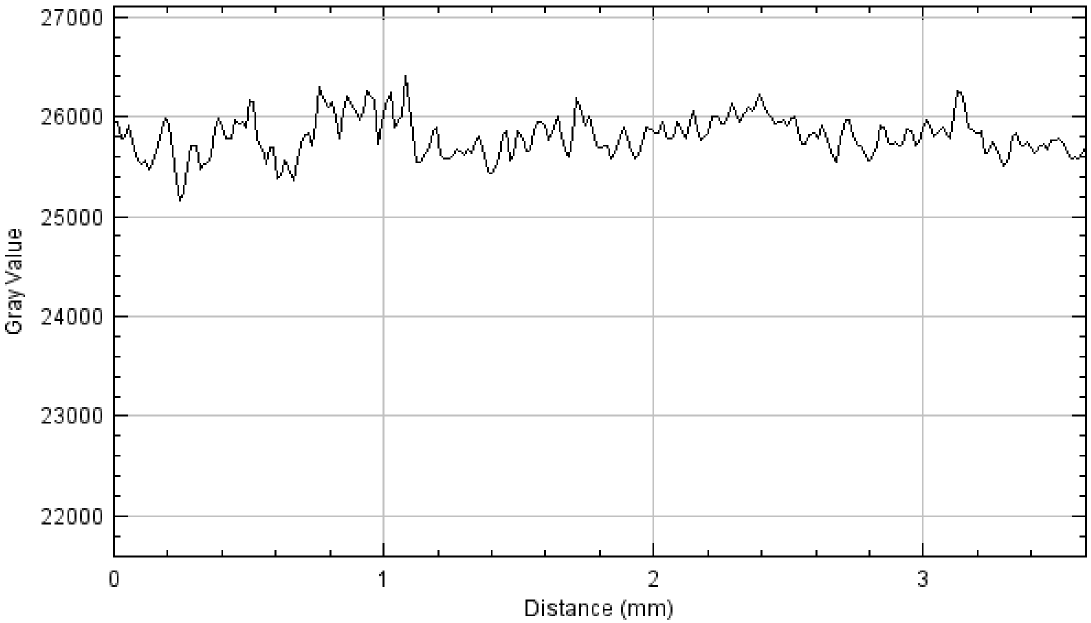


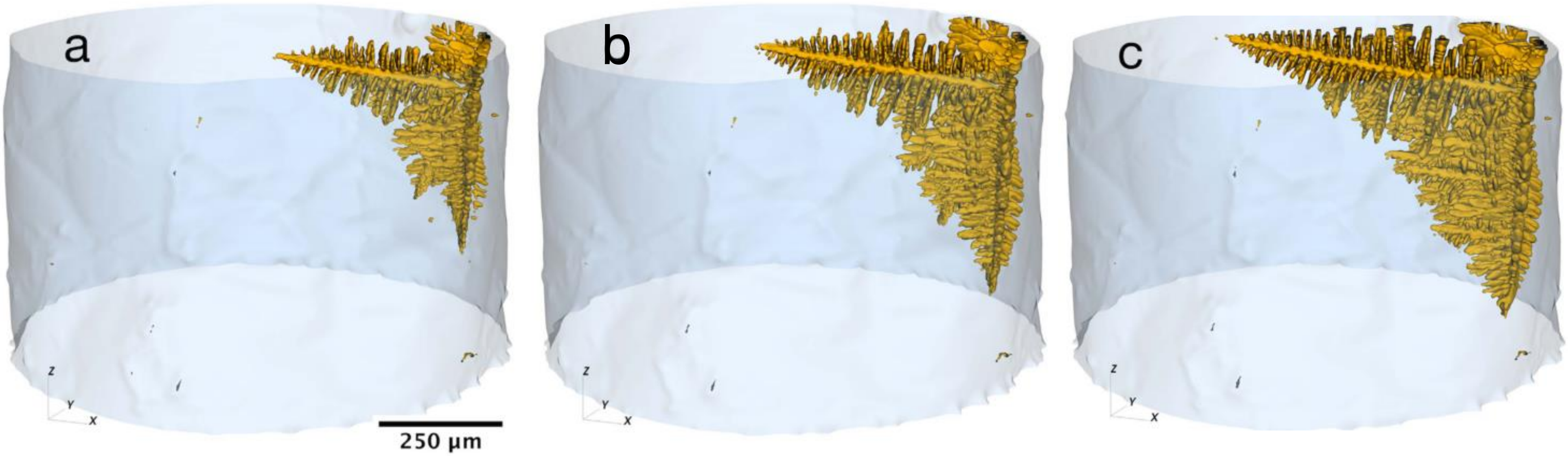


Future Work

- Modular Image Processing
  - Customize pseudocolor mapping to better emphasize microstructural features
  - Normalize intensities between frames
- Develop reconstruction abilities for computed tomography
- Train on cabinet-based x-ray radiography at LANL
- Develop experiments for cabinet-based x-ray radiography at Mines (AM lattices)

Future Work: 4D Reconstructions

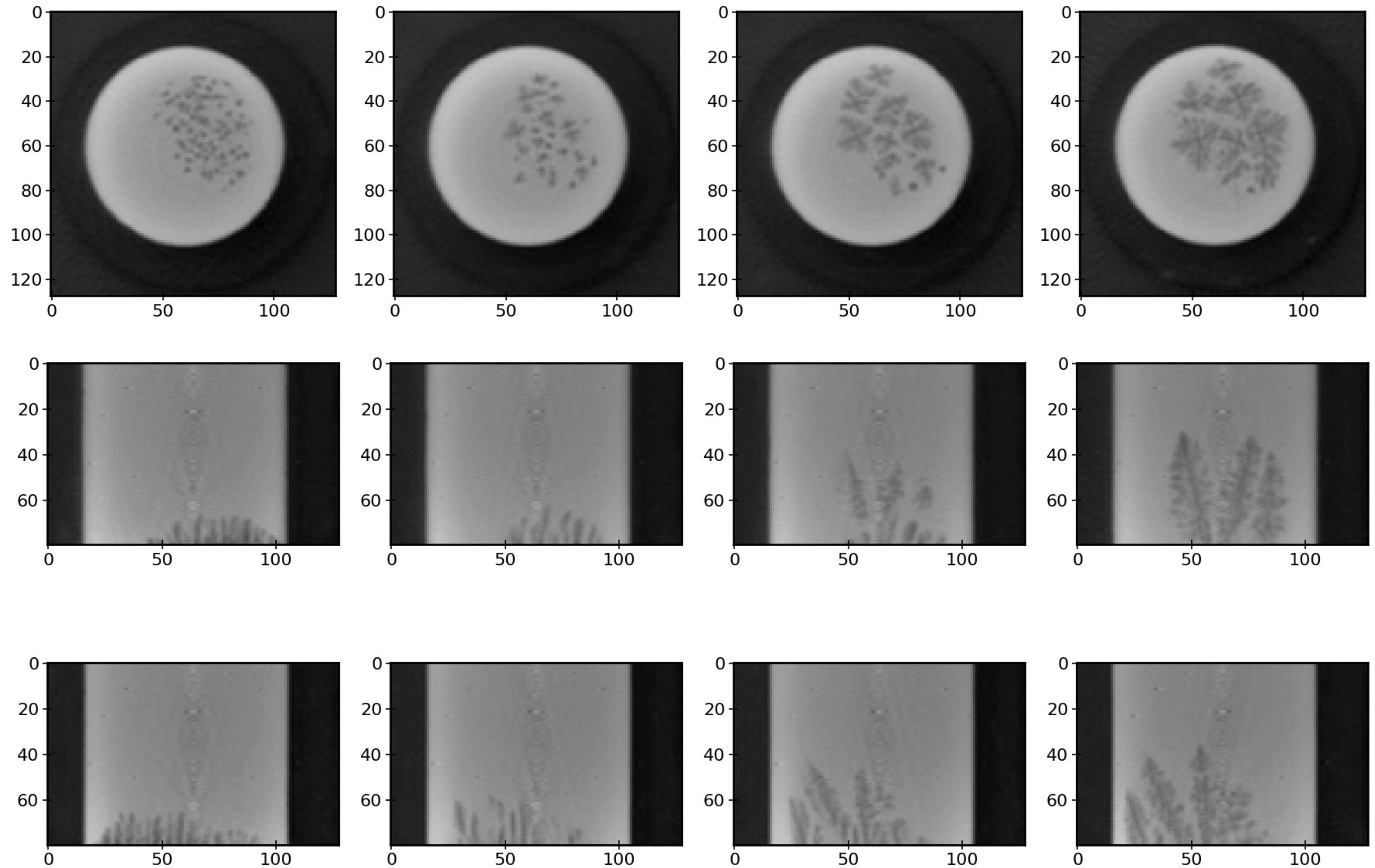
- 3 spatial dimensions + time (Clarke et al., in collaboration with LANL)
- Collaborate with Voorhees' group at Northwestern



Gibbs *et al.*, *Sci. Rep.*, 2015.

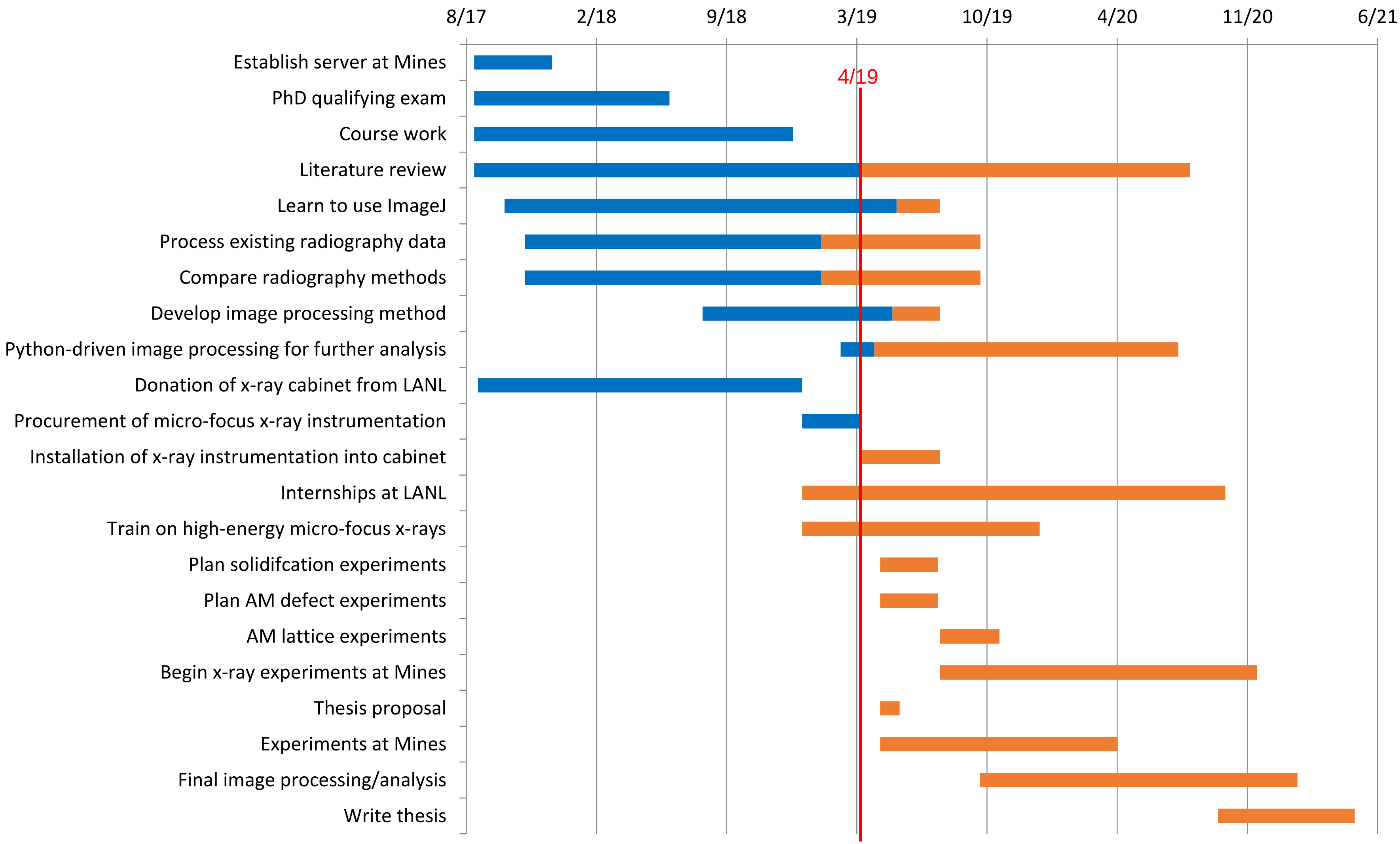
Future Work: 4D Reconstructions

- 4D x-ray tomography of Al-24wt.%Cu



Clarke et al., *unpublished.*

Progress



8/17
2/18
9/18
3/19
10/19
4/20
11/20
6/21
4/19
Establish server at Mines
PhD qualifying exam
Course work
Literature review
Learn to use ImageJ
Process existing radiography data
Compare radiography methods
Develop image processing method
Python-driven image processing for further analysis
Donation of x-ray cabinet from LANL
Procurement of micro-focus x-ray instrumentation
Installation of x-ray instrumentation into cabinet
Internships at LANL
Train on high-energy micro-focus x-rays
Plan solidifcation experiments
Plan AM defect experiments
AM lattice experiments
Begin x-ray experiments at Mines
Thesis proposal
Experiments at Mines
Final image processing/analysis
Write thesis

Thank you!

C. Gus Becker
chbecker@mines.edu

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

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.

Program Goal

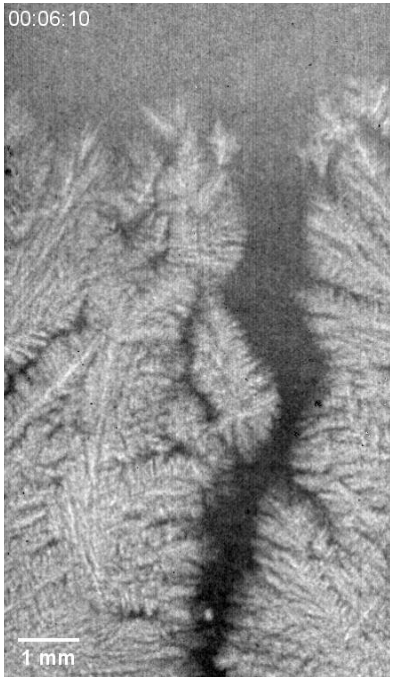
- Industrial processes of metals such as casting and additive manufacturing can benefit from radiography studies performed in the laboratory

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



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.