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

Fall 2018 Semi-Annual Meeting
Colorado School of Mines, Golden, CO
October 2-4, 2018

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
- Passed PhD qualifying exam
- Uploaded radiography datasets from previous experiments to Mines server
- Familiarization with radiography data and experiments
- Scripting with ImageJ to process large datasets efficiently and produce animations for further analysis

Metrics		
Description	**% Complete**	**Status**
1. Literature review	30%	●
2. 6TB server established at Mines to store large radiography datasets for ease of access	100%	●
3. Radiography datasets from AET-6, APS, and pRad uploaded to server	20%	●
4. Image processing and analysis with ImageJ of datasets from AET-6, APS, and pRad	20%	●
5. Establish x-ray cabinet and perform laboratory x-ray imaging experiments	0%	●

Industrial Relevance

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- Identify defects in additively manufactured (AM) parts by non-destructive imaging
  - Qualification and certification
  - Technique limitations
- 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
  - Support current projects
  - Consideration of future projects from industry

Synchrotron X-Rays at APS

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Argonne NATIONAL LABORATORY

- High resolution
- Small fields-of-view
- << 150 keV energies
- Mostly useful for low atomic number metals
- About 60 operational beamlines
- Often over-subscribed
- Tight schedules

X-Ray Setup for Solidification Experiments

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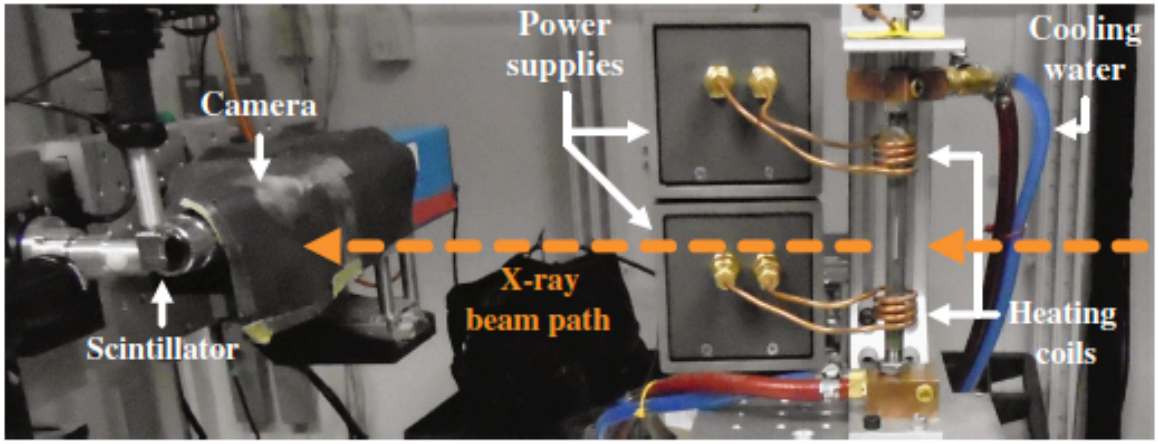

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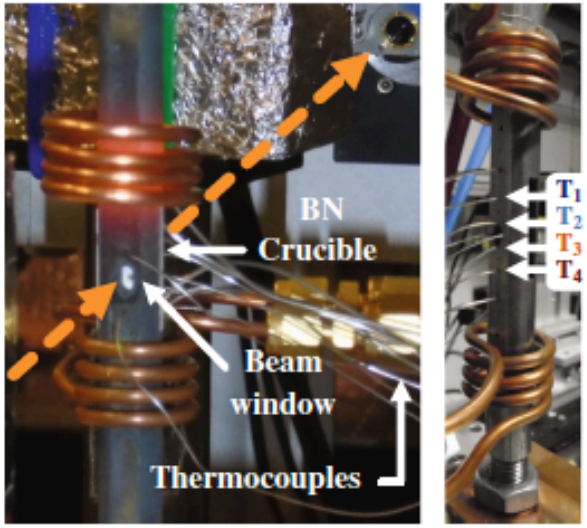

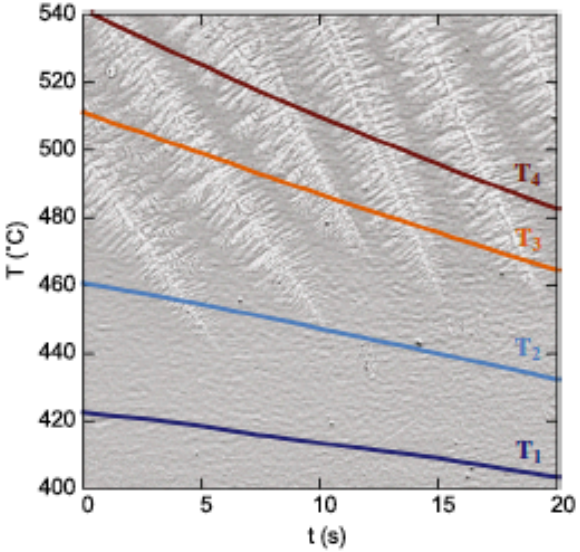

D. Tourret *et al.*, *Metall. Mater. Trans.*, (2017).

Solidification Study of Bi-Sn Alloys

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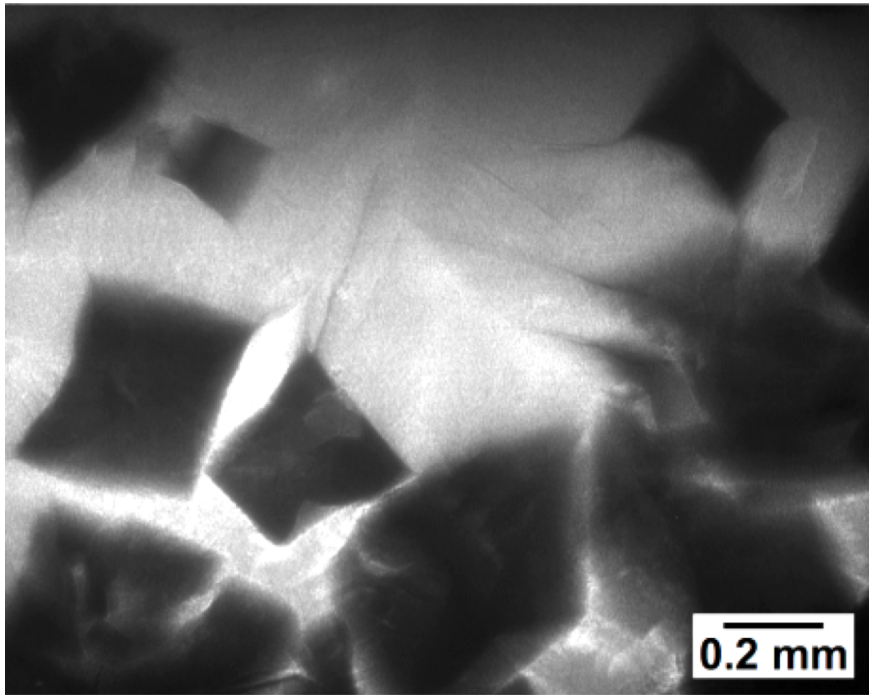
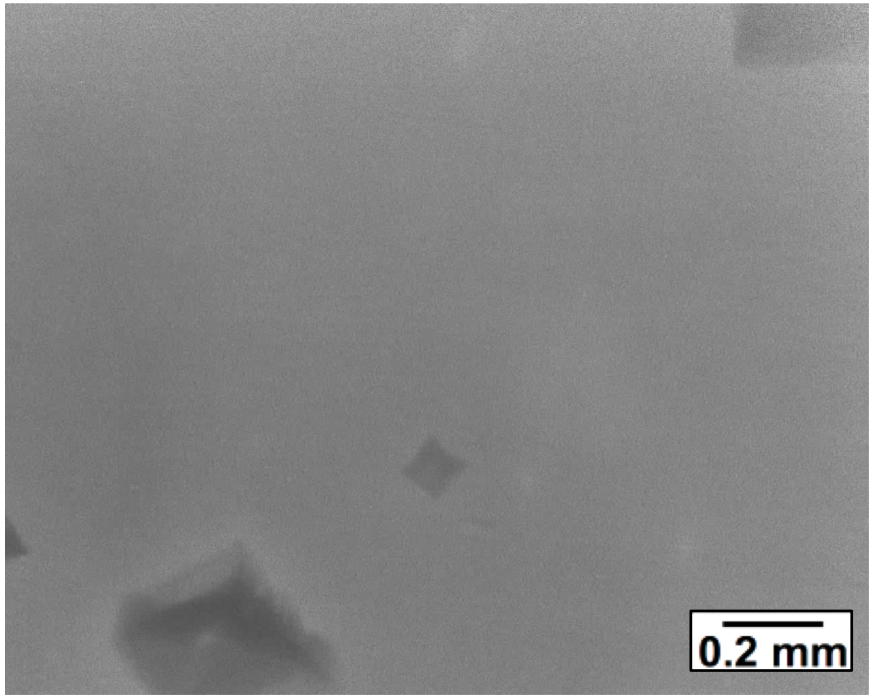


Bi-30 at.% Sn

Gibbs, P. J. et al., *JOM*, *66*(8), 1485–1492, (2014).



Bi-Sn

Clarke et. al unpublished

High-Energy Micro-Focus X-Rays

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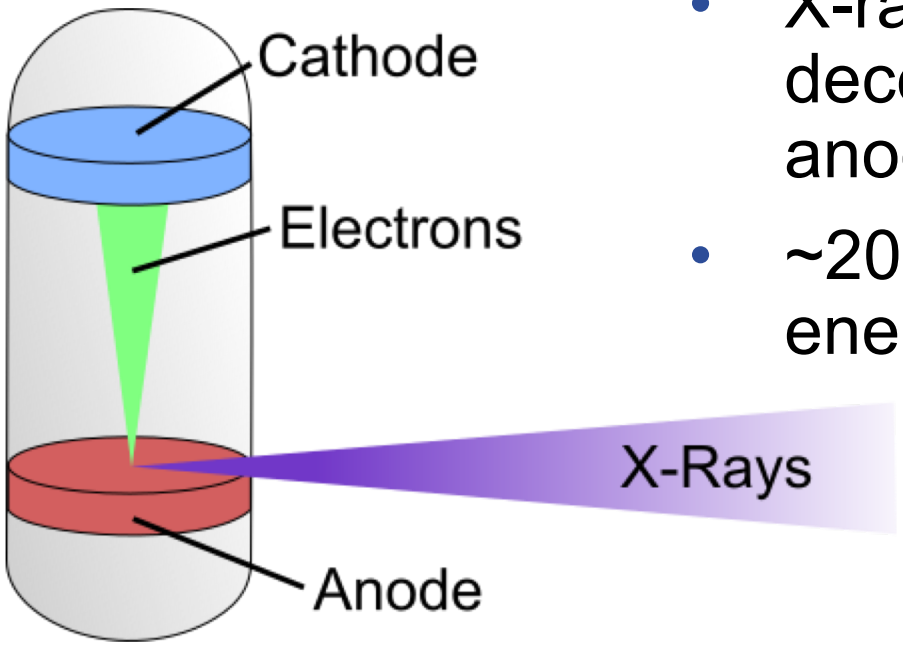

- High voltage power source accelerates electrons from cathode to anode in an evacuated tube
- X-rays produced upon deceleration of electrons at anode
- ~200 keV x-rays, with higher energies attainable at AET-6

High-Energy X-Rays at AET-6

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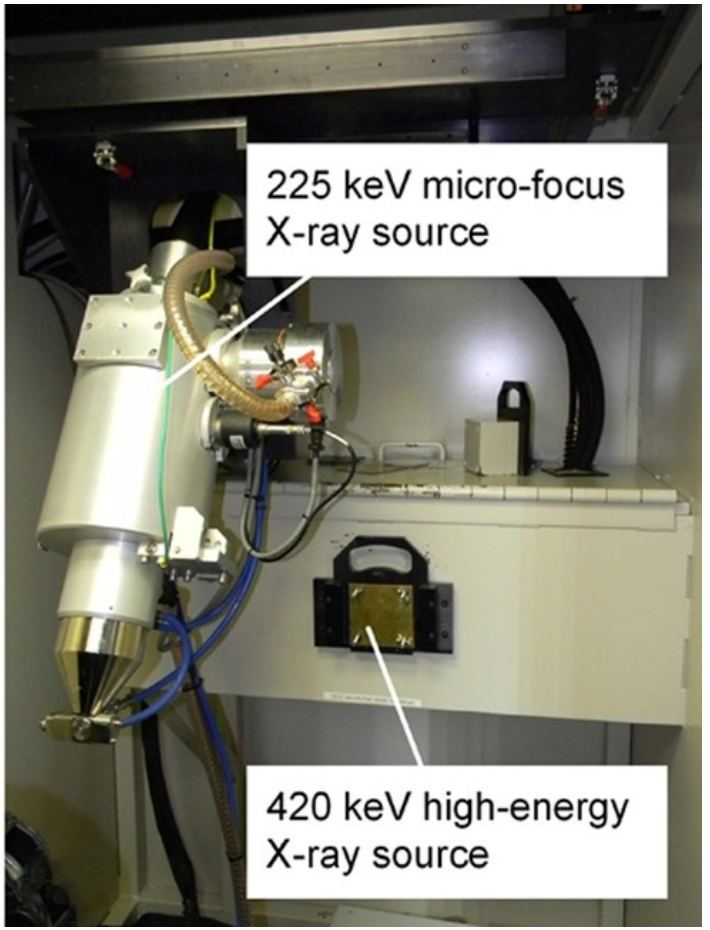

Unprocessed Radiographs

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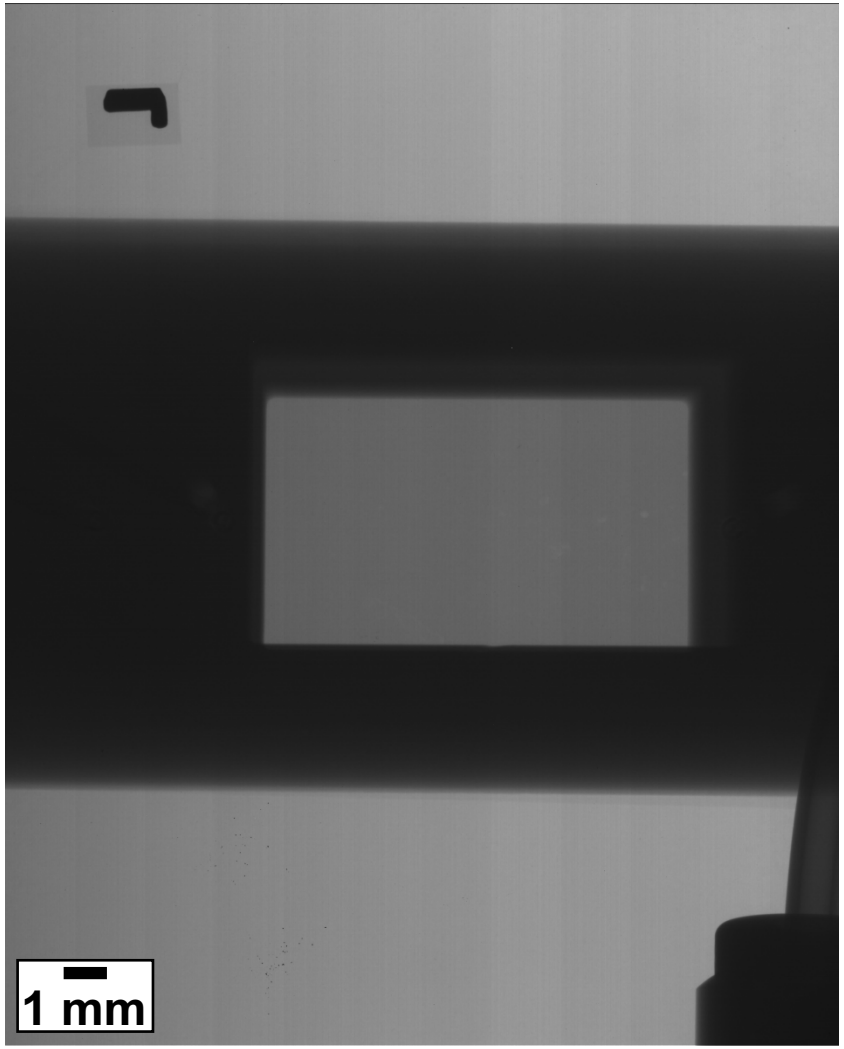

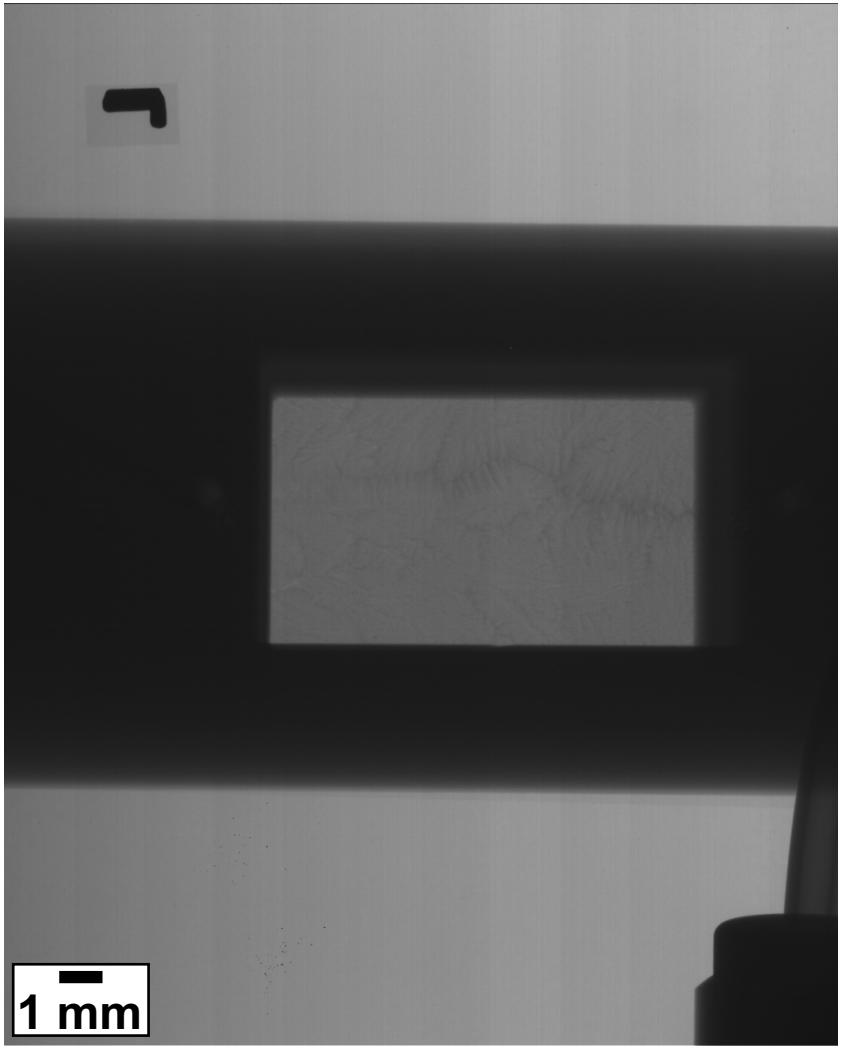

Unprocessed Radiographs

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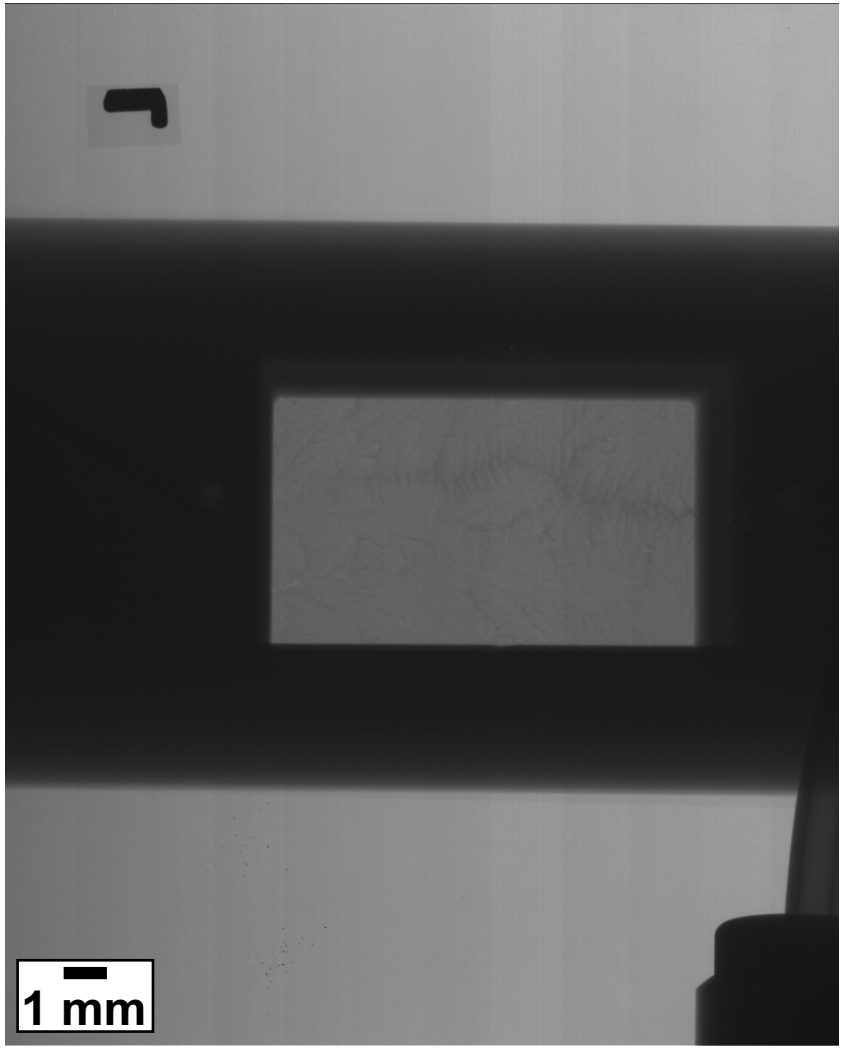

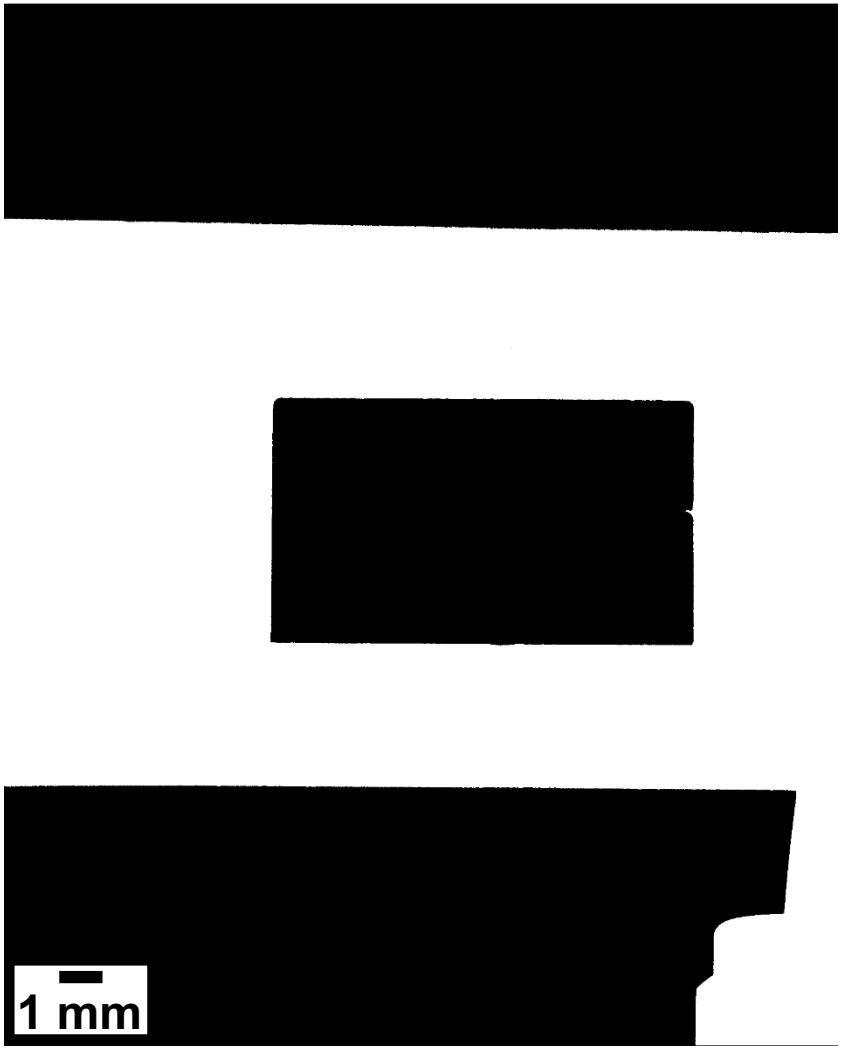

Unprocessed Radiographs

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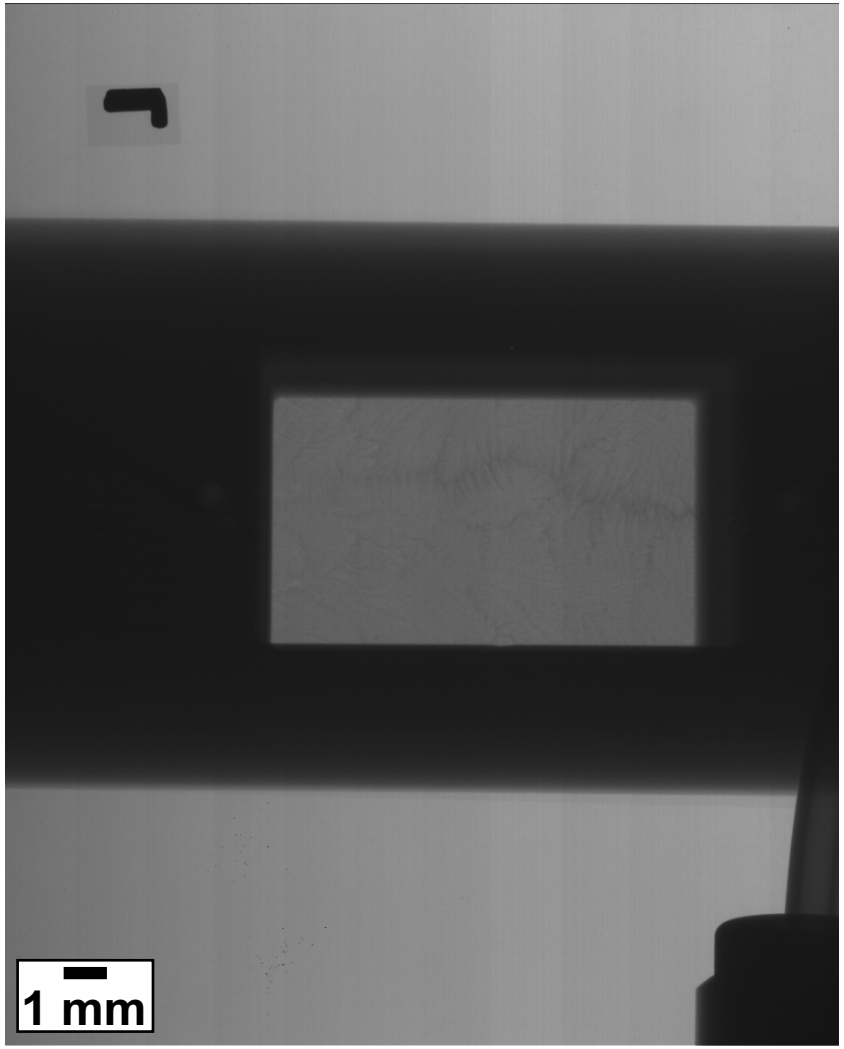

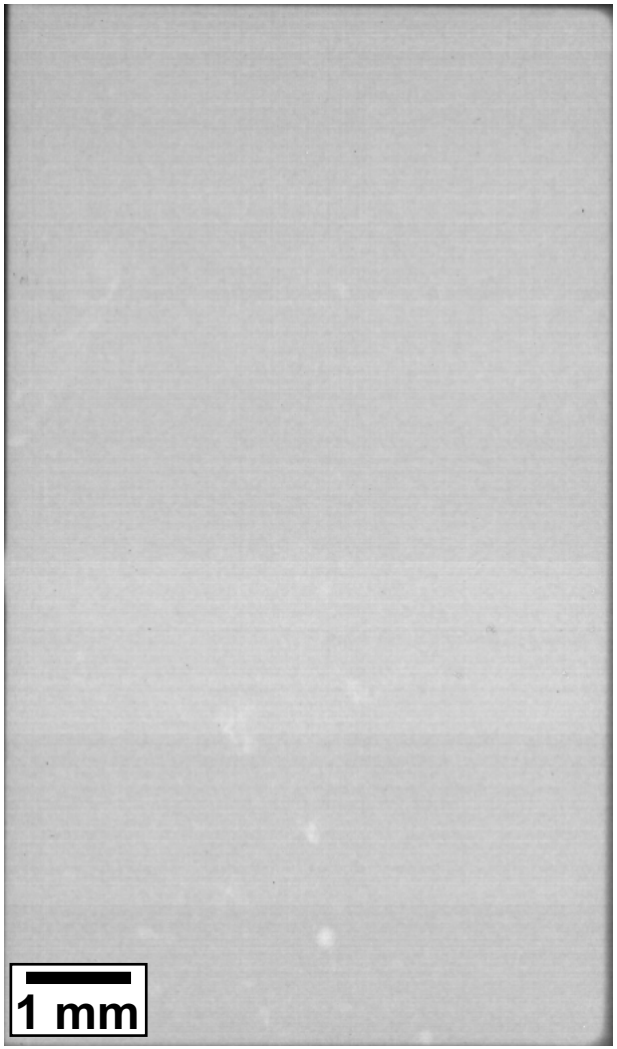

Solidification of Al-30 wt.% Ag

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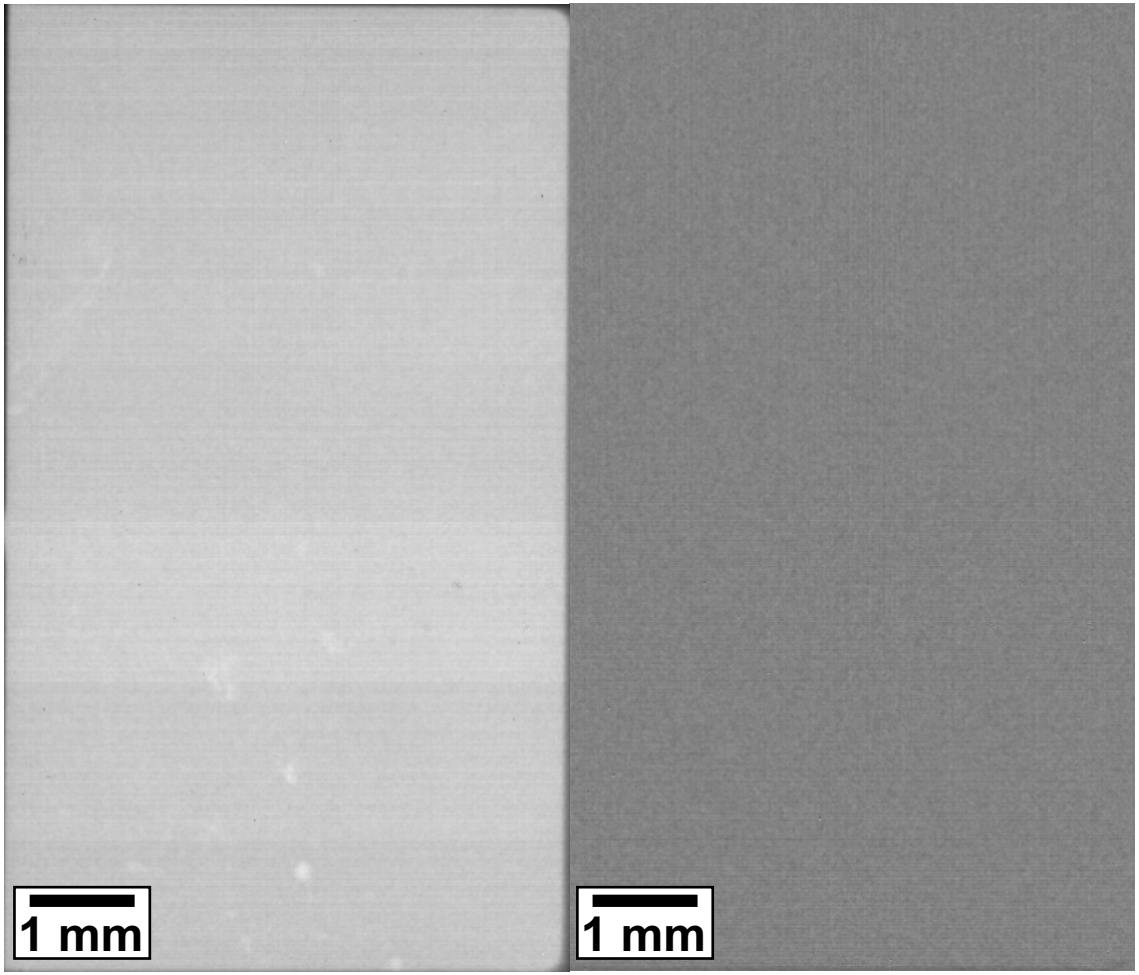
- APS setup (reason for window)
- X-ray and detector specs
  - Energy: 206 keV
  - Framerate: 5 fps
  - Duration: 20m4.4s
  - 6022 images
- Animation specs
  - Iteration: 25 images
  - Animation: 10 fps
  - Speed: 50x real



Melting & Solidification of Al-62 wt.% Ge

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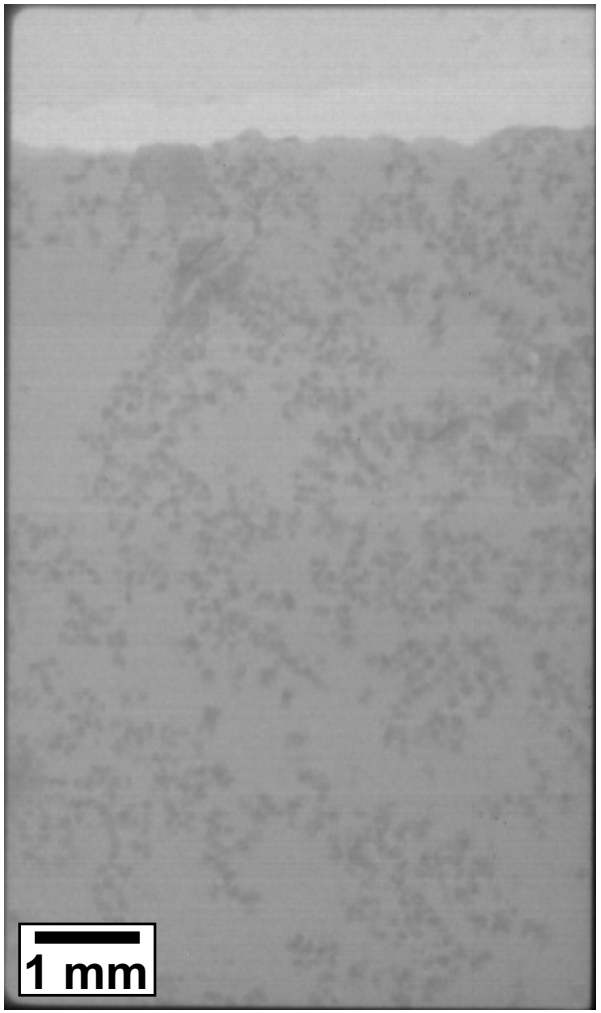
- APS setup
- X-ray and detector specs
  - Energy: 120 keV
  - Framerate: 5 fps
  - Duration: 23m20s
  - 7000 images
- Animation specs
  - Iteration: 25 images
  - Animation: 10 fps
  - Speed: 50x real



Melting & Solidification of Al-62 wt.% Ge

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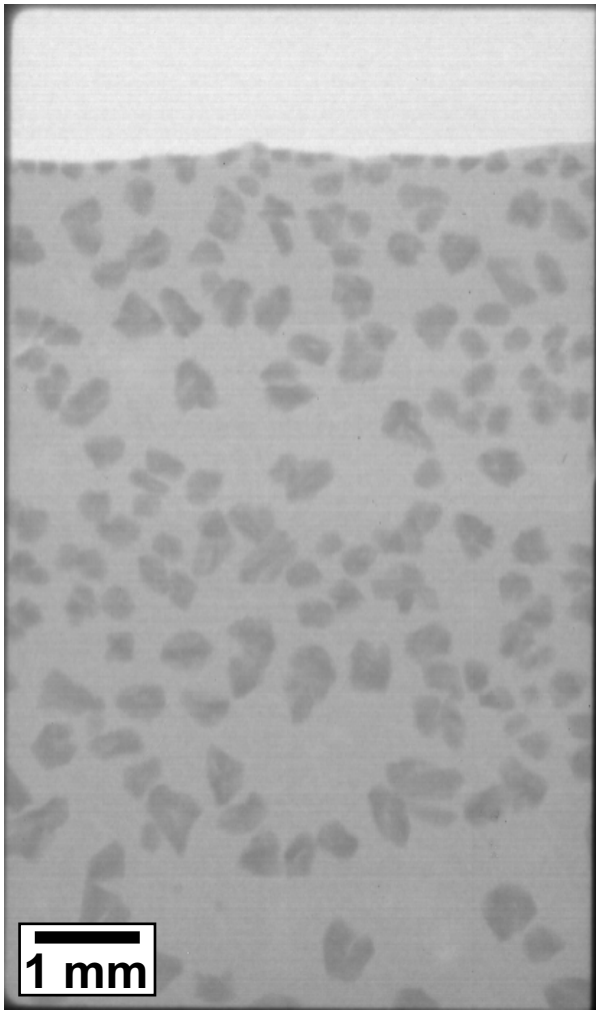
- APS setup
- X-ray and detector specs
  - Energy: 120 keV
  - Framerate: 5 fps
  - Duration: 11m16s
  - 8000 images
- Animation specs
  - Iteration: 25 images
  - Animation: 10 fps
  - Speed: 50x real



Casting of Bi-30 wt.% Sn

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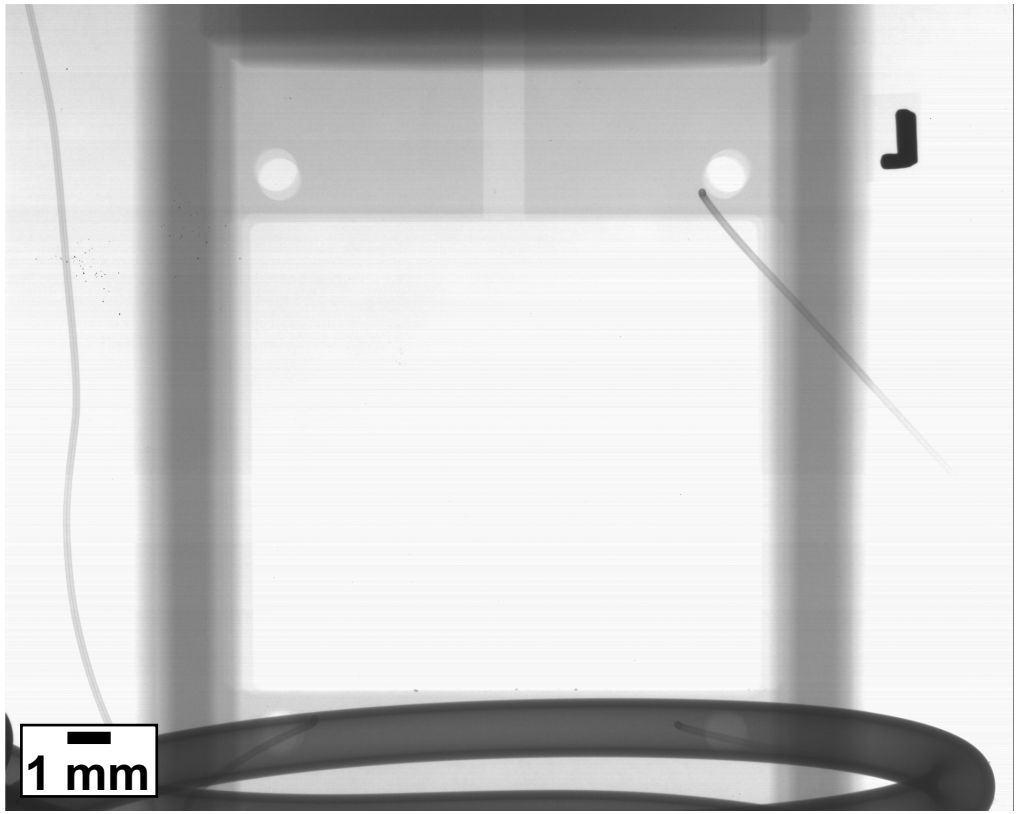
- X-ray and detector specs
  - Energy: 205 keV
  - Framerate: 1 fps
  - Duration: 17s
  - 17 images
- Animation specs
  - Iteration: 1 image
  - Animation: 2 fps
  - Speed: 2x real



Casting of Bi-27 wt.% Sn

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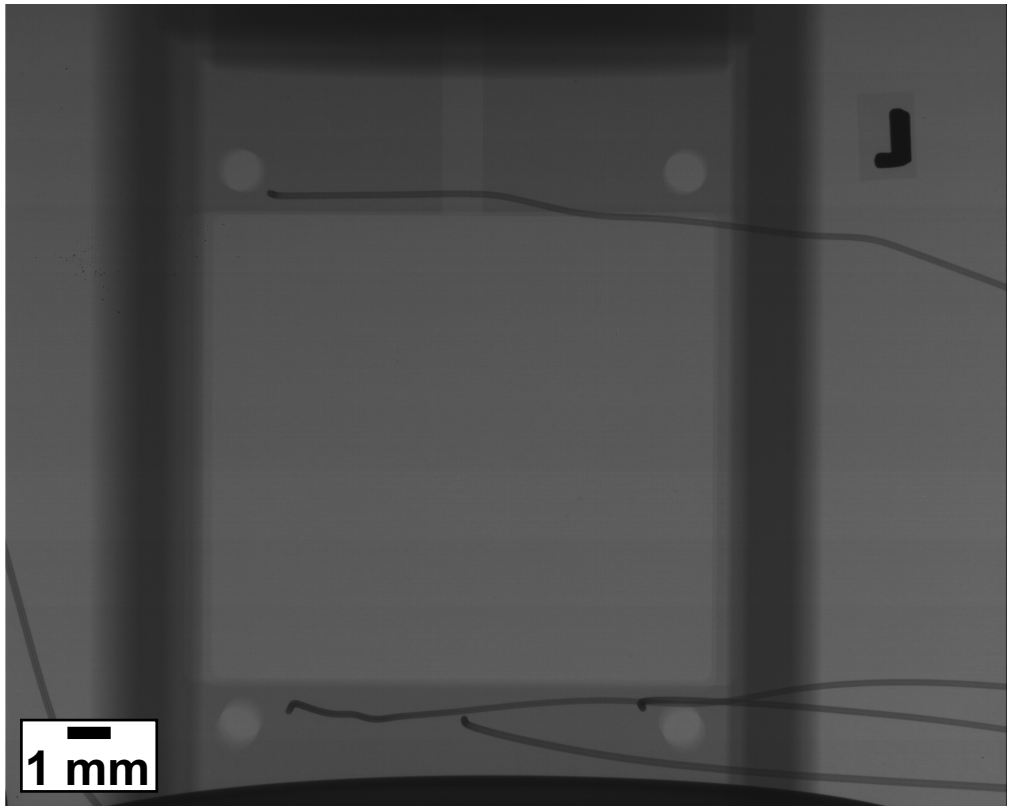
- X-ray and detector specs
  - Energy: 180 keV
  - Framerate: 5 fps
  - Duration: 3m40s
  - 44 images
- Animation specs
  - Iteration: 1 image
  - Animation: 4 fps
  - Speed: 20x real



Plan Moving Forward

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- Create animations that can inform process models

Model Informed by Proton Radiography of Sn-27at% Bi

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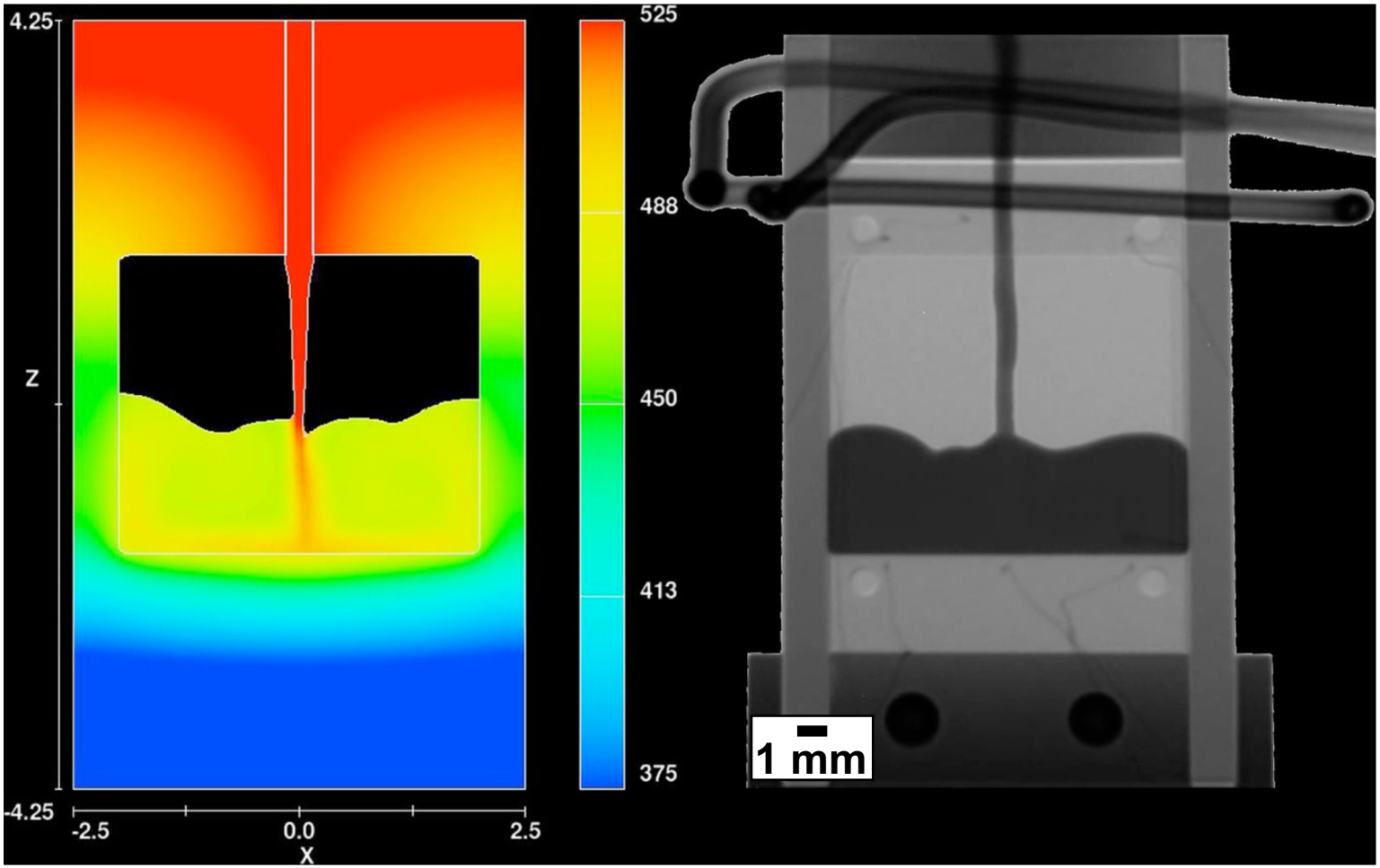

Plan Moving Forward

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- Create animations that can inform process models
- Training to produce tomographic reconstructions of static imaged samples (solidification microstructure, AM defects)

Proton Tomography of Chelyabinsk Meteorite

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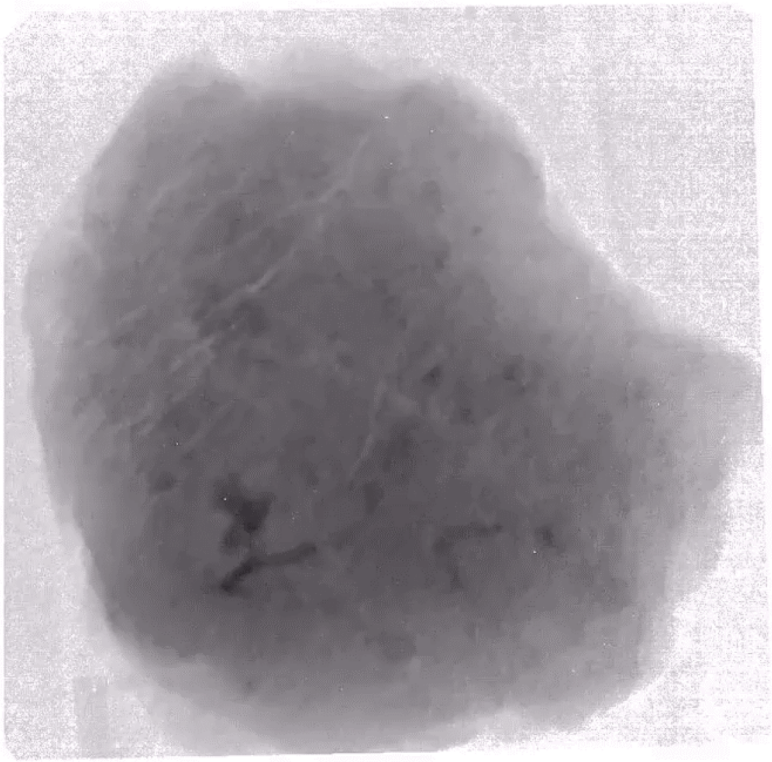

Chelyabinsk Meteorite

Micro-Computed Tomographic Reconstructions of Al-7at.% Cu

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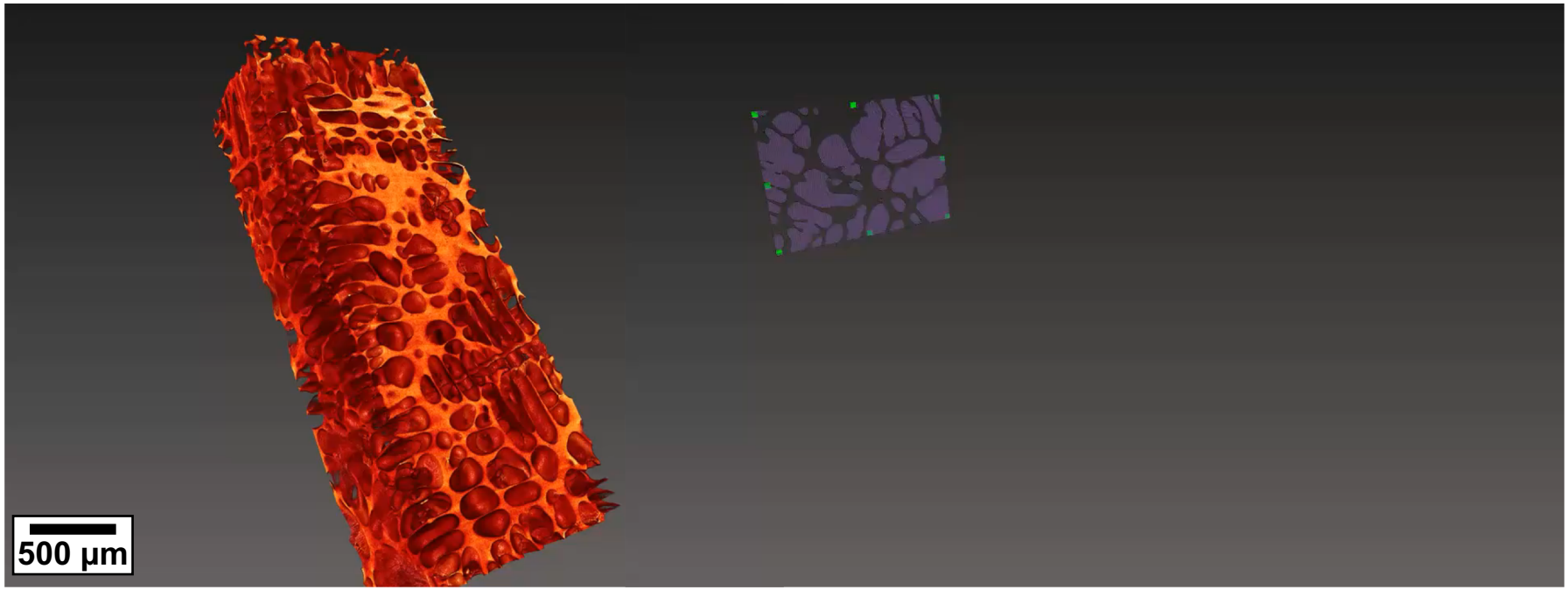

Patterson et al., *Mater. Charact.*, (2014).

Plan Moving Forward

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- Create animations that can inform process models
- Training to produce tomographic reconstructions of static imaged samples (solidification microstructure, AM defects)
- Retrofit x-ray cabinet with necessary hardware for transfer to Mines

High-Energy Micro-Focus X-Ray Cabinet

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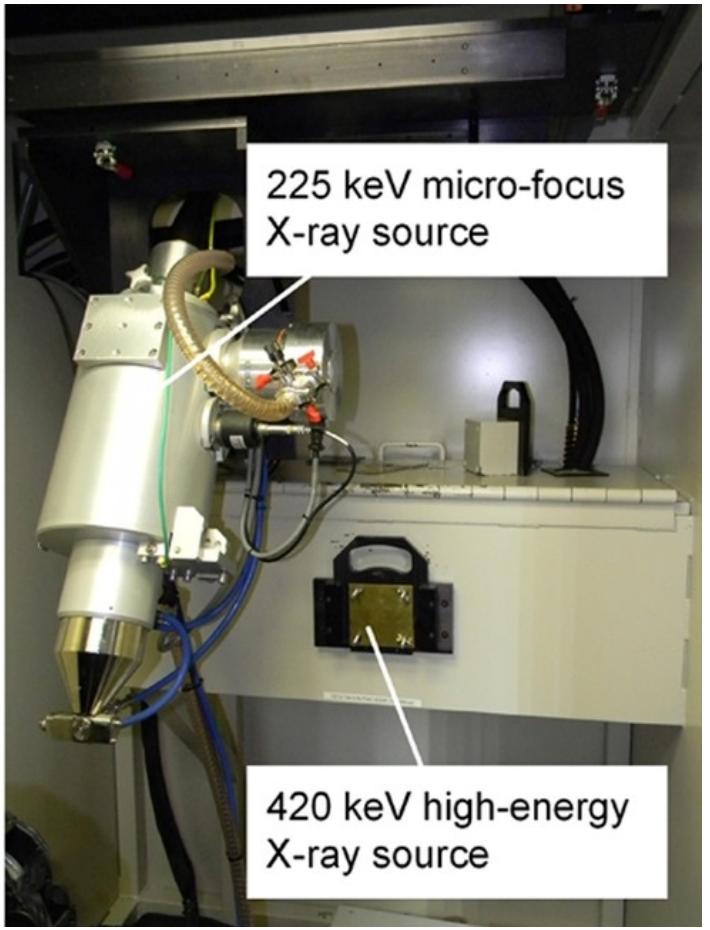

Plan Moving Forward

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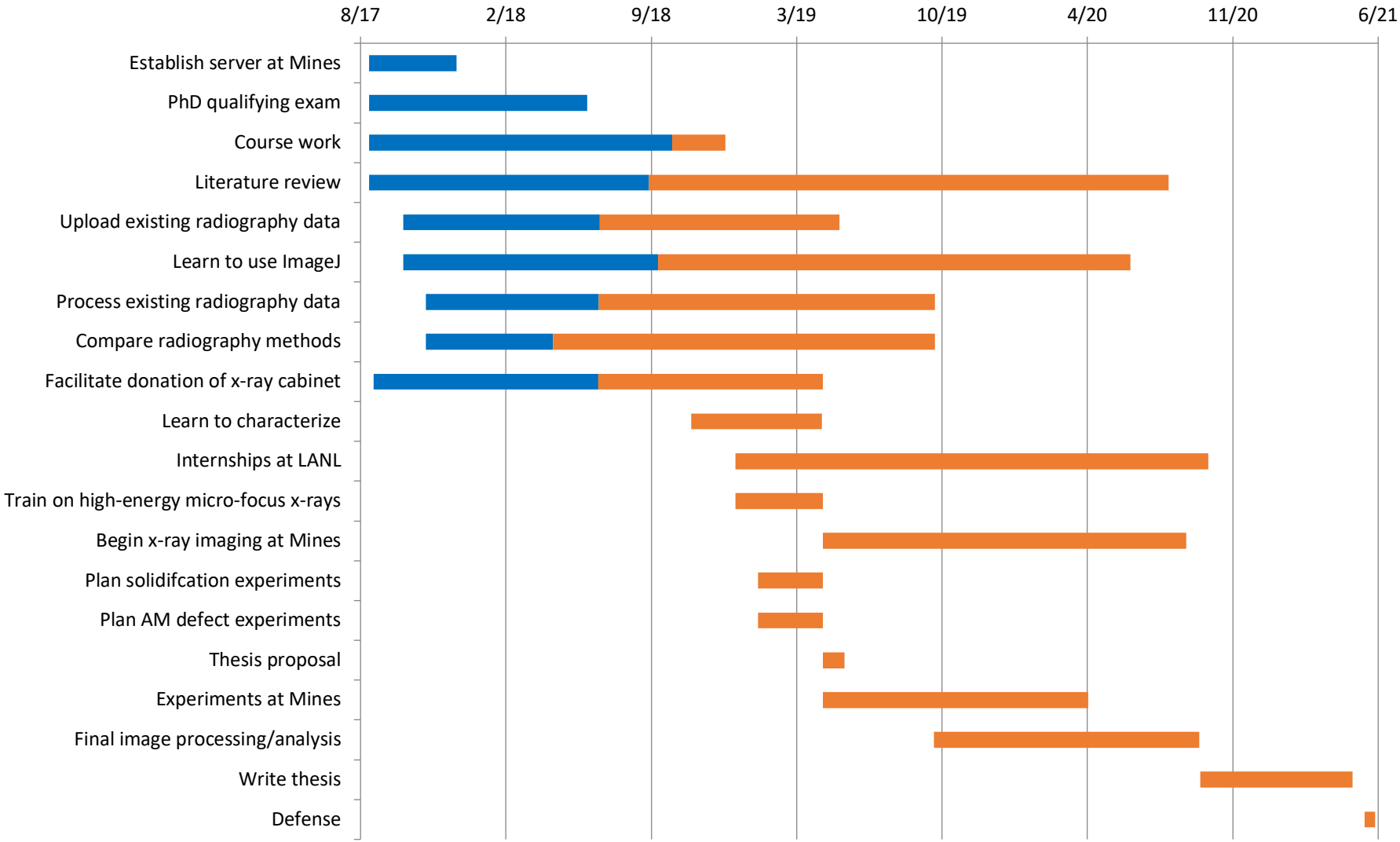
- Create animations that can process inform models
- Training to produce tomographic reconstructions of static imaged samples (solidification microstructure, AM defects)
- Retrofit x-ray cabinet with necessary hardware for transfer to Mines
- Compare different radiography and tomography methods

Progress



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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*

Achievement

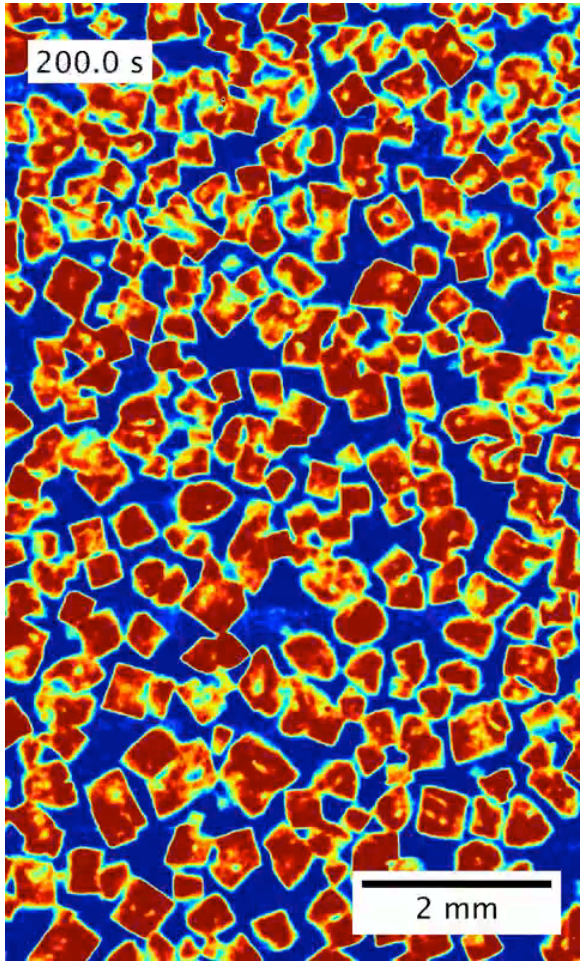
- Data processing and characterization of high-energy micro-focus x-ray radiographs of static and dynamic metal systems

Significance and Impact

- Cabinet-based x-ray radiography and computed tomography allow for large fields-of-view, high-Z, non-destructive imaging of metals in the laboratory

Research Details

- Analysis of processed x-ray image data to allow for in-depth study of solidification microstructure and defects in AM parts



Blocky crystal growth in Bi-Sn alloy

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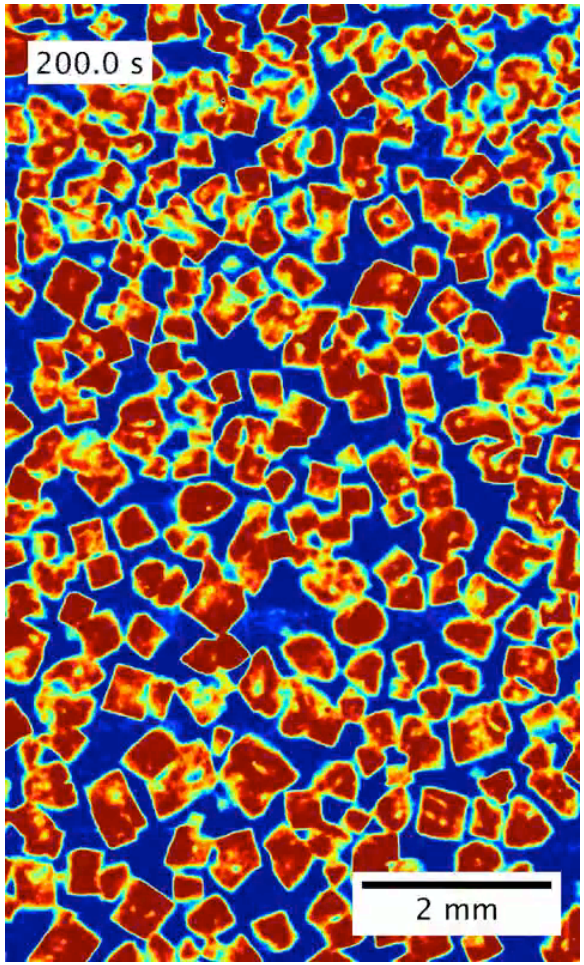

Blocky crystal growth in Bi-Sn alloy

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Student: *C. Gus Becker*

Faculty: *Amy Clarke*

Industrial Partners: *LANL (Michelle Espy)*

Project Duration: *Aug. 2017 – May 2021*

Program Goal

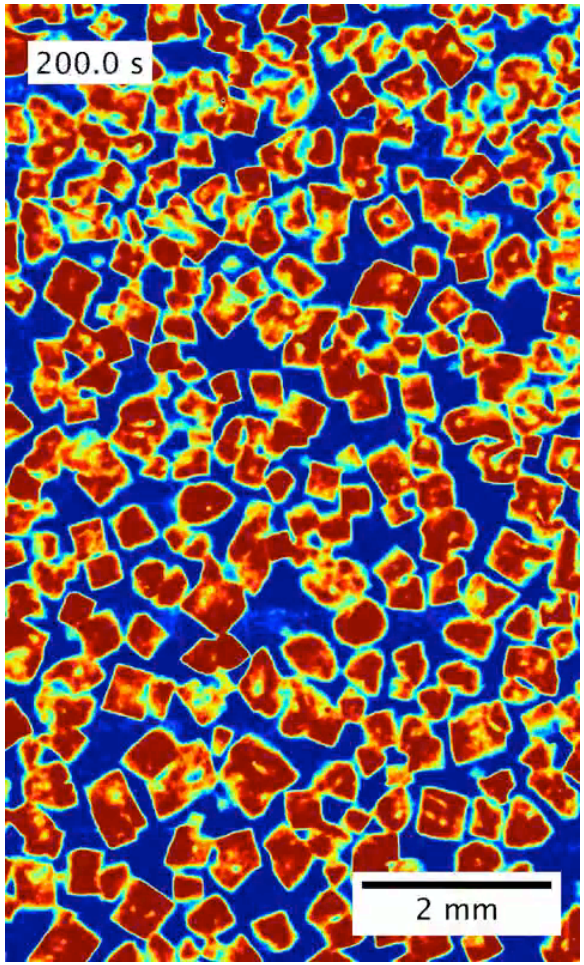
- Industrial processes of metals such as casting and additive manufacturing can benefit from radiography studies performed in the laboratory

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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