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

Summer 2020 Videoconference

June 29 – July 1, July 8 – 10 2020

Student: C. Gus Becker (Mines)

Faculty: Dr. Amy Clarke (Mines)

Industrial Mentor: Dr. Michelle Espy (LANL)

NSF COLORADO SCHOOL OF MINES 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: 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 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
- Thesis proposal defense
- Python functions to fit polynomial to S-L interface position data from AM simulator experiments from the Advanced Photon Source (APS)
- 3D visualization investigation for CT data
- ImageJ macro to manually track the solid-liquid interface in AM simulator

Metrics

Description	% Complete	Status
1. Establish high-energy micro-focus x-ray capabilities at Mines	90%	●
2. Develop new solid-liquid interface tracking methodology for AM simulator experiments	100%	●
3. Develop software tool with GUI for solidification velocity measurements	10%	●
4. Develop 3D visualization routine for CT data using Al-Cu-Ag data	10%	●
5. Perform CT on AM lattice structures	0%	●

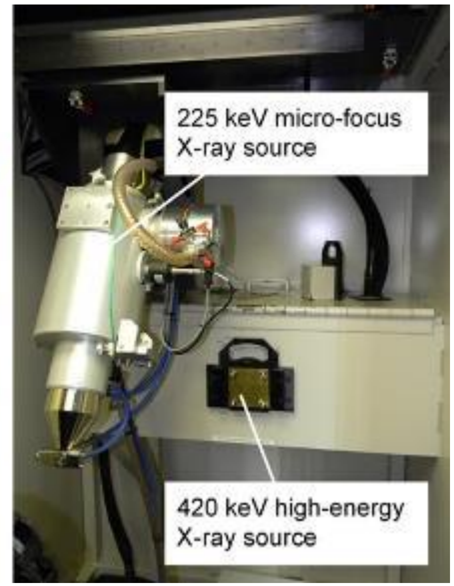
Thesis Objectives

- Develop image processing algorithms
  - Perform same routine across many images in a dataset
- Automatically extract quantitative information
  - Pixel intensity, location, and distribution
  - Evolution between images
- Develop software tools to enable automatic analysis of datasets

Thesis Objectives

- Develop microfocus x-radiography capabilities at Mines
  - Install refurbished x-ray cabinet
  - Processing algorithms
  - CT: Reconstruction algorithms
  - CT: Visualization program

Thesis Objectives



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	Electrical 80% Complete	In Progress	ETA: End of July

Thesis Objectives

- Provide commentary on technique limitations in the context of AM and solidification of metals
  - Larger field-of-view (FOV) with microfocus x-radiography
  - Higher spatial and temporal resolution with synchrotron radiography

Materials & Material Processes to Explore

- Microfocus x-radiography experiments
  - Directional Solidification
  - AM lattice structures
- Synchrotron x-radiography experiments
  - Al-Cu/Al-Ag/Al-Cu-Ag Precipitation
  - AM simulator

Materials & Material Processes to Explore

- Microfocus x-radiography experiments
  - **Directional Solidification**
  - AM lattice structures
- Synchrotron x-radiography experiments
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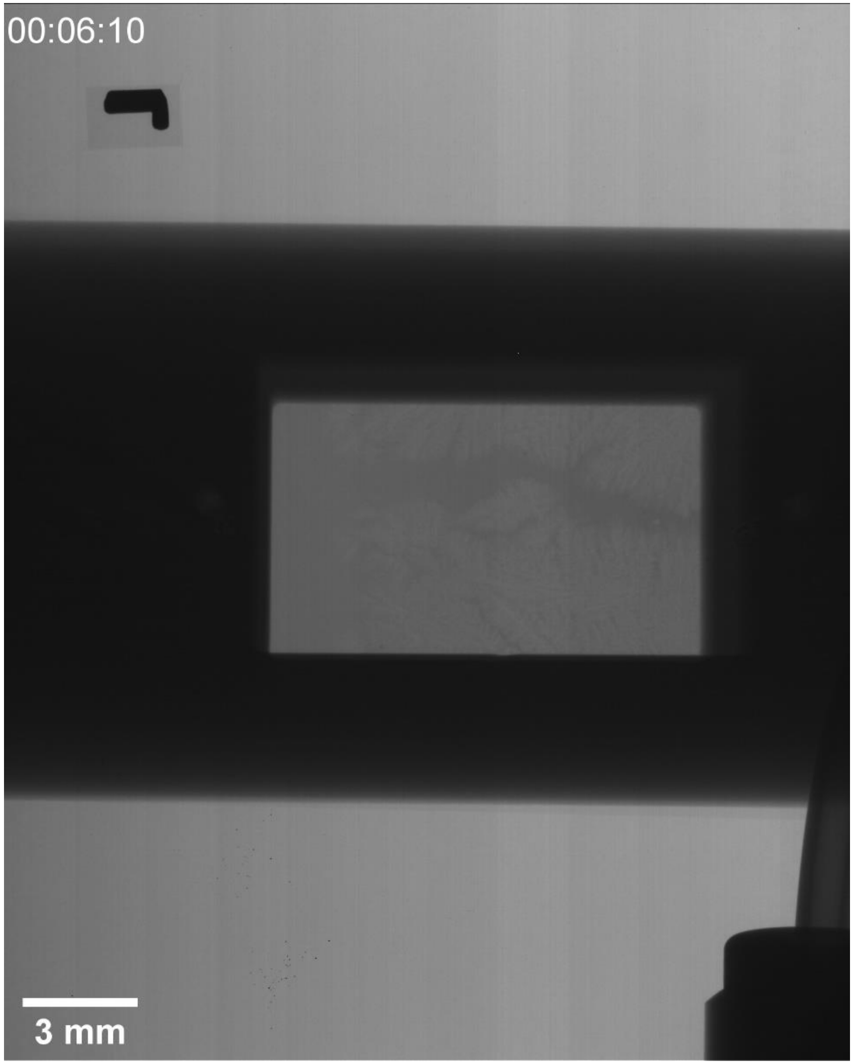
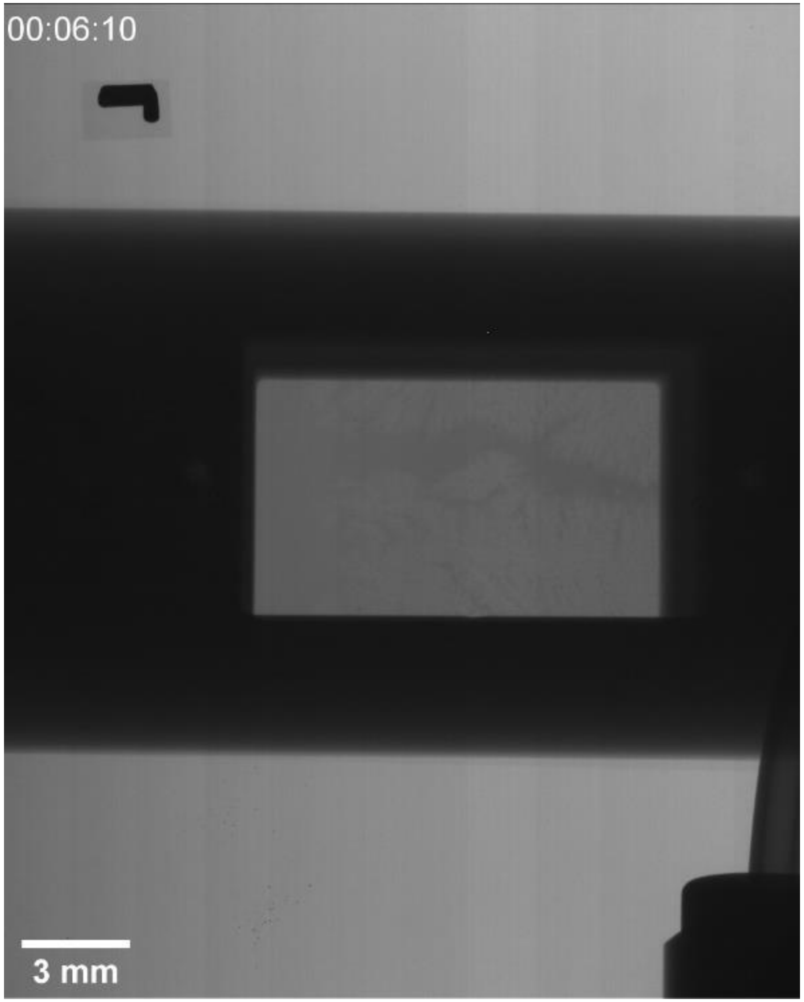
Directional Solidification

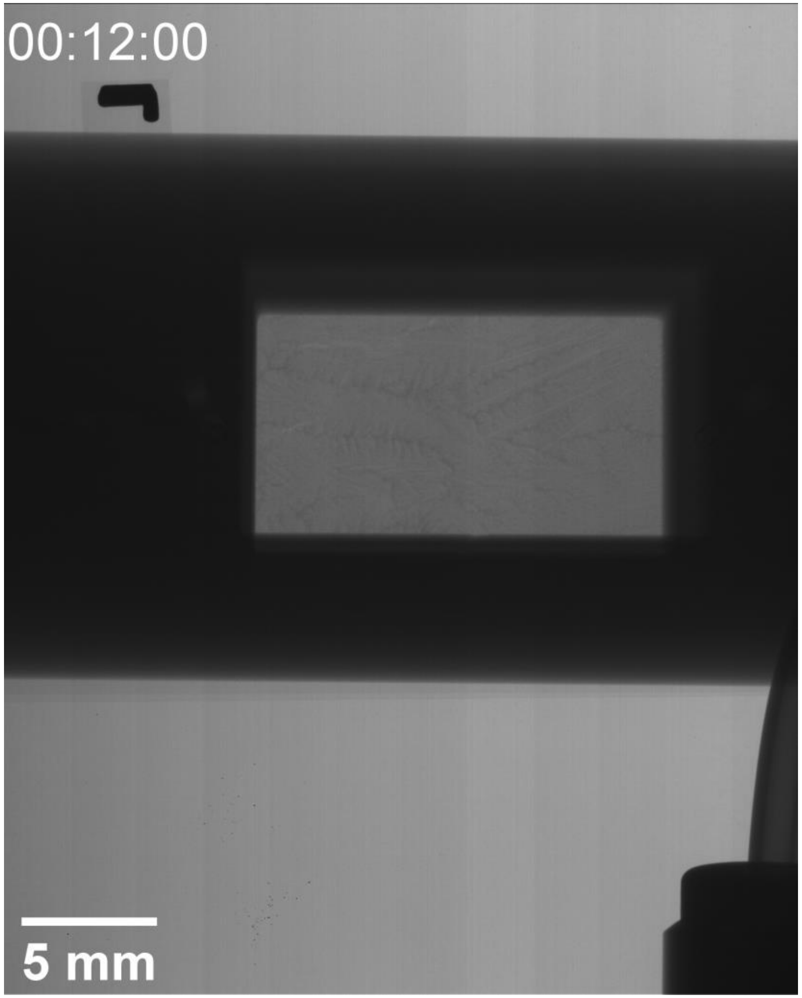
- High-energy micro-focus radiography
- APS setup
  - 15 mm steel bar
  - 7 x 12 mm window
- Al-30wt.%Ag
- Controlled directional solidification
- Through image processing:
  - Solidification velocity
  - Solute segregation

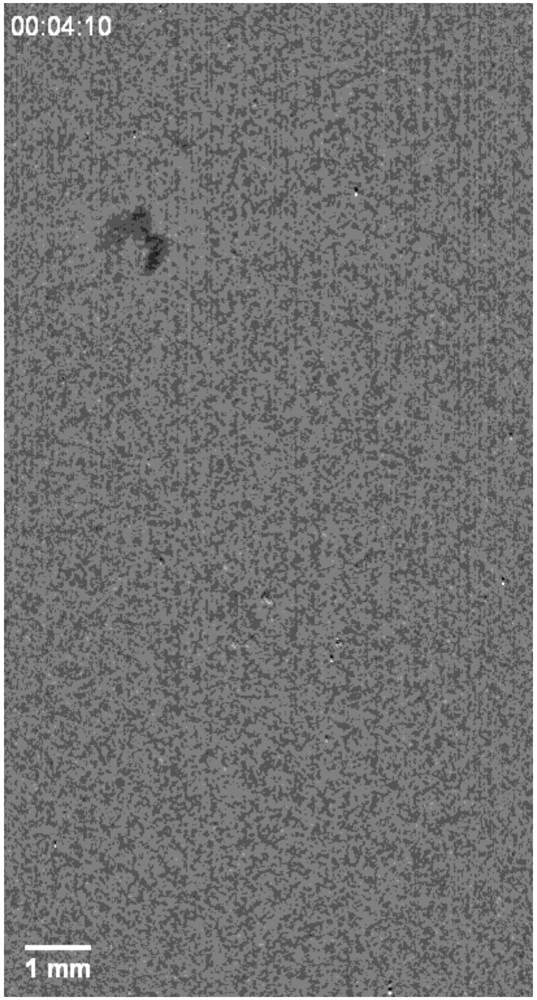


Directional Solidification



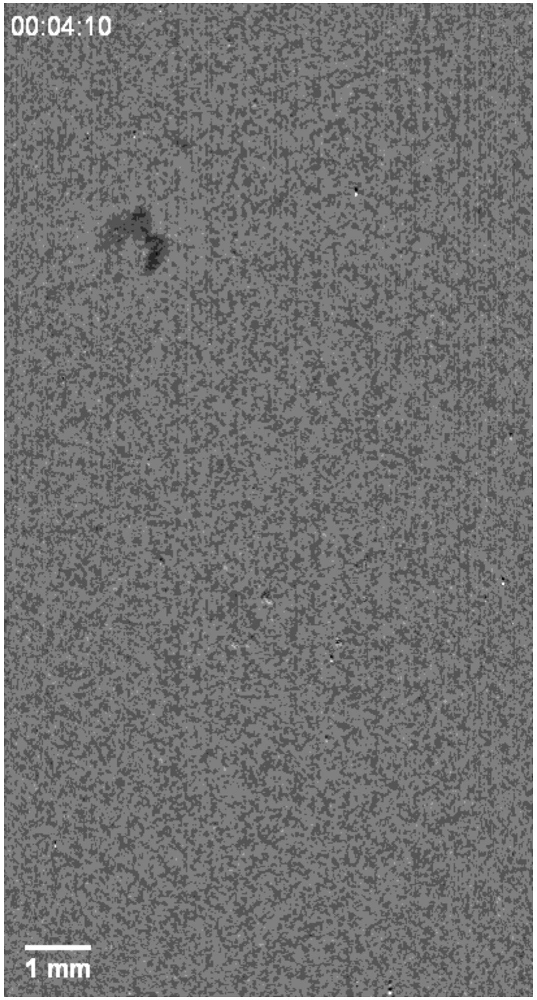
Directional Solidification





Directional Solidification

- Dendrite ID
  - Isolate by pixel intensity
  - Find centerline based on morphology evolution
- Solidification velocity
  - Dendrite tip movement
  - Measure change in position over time across the images



Materials & Material Processes to Explore

- Microfocus x-radiography experiments
  - Directional Solidification
  - **AM lattice structures**
- Synchrotron x-radiography experiments
  - Al-Cu/Al-Ag/Al-Cu-Ag Precipitation
  - AM simulator

AM Lattice Structures

- Structures from LLNL, SNL, & LANL
- Pre-COVID plans:
  - Image in ZEISS Xradia 520 Versa microCT on campus
  - Later compare with cabinet-based microfocus x-radiography

Ti-5553 Lattices from LLNL; ~11.4 mm and ~9.5 mm largest dimension

Materials & Material Processes to Explore

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- Microfocus x-radiography experiments
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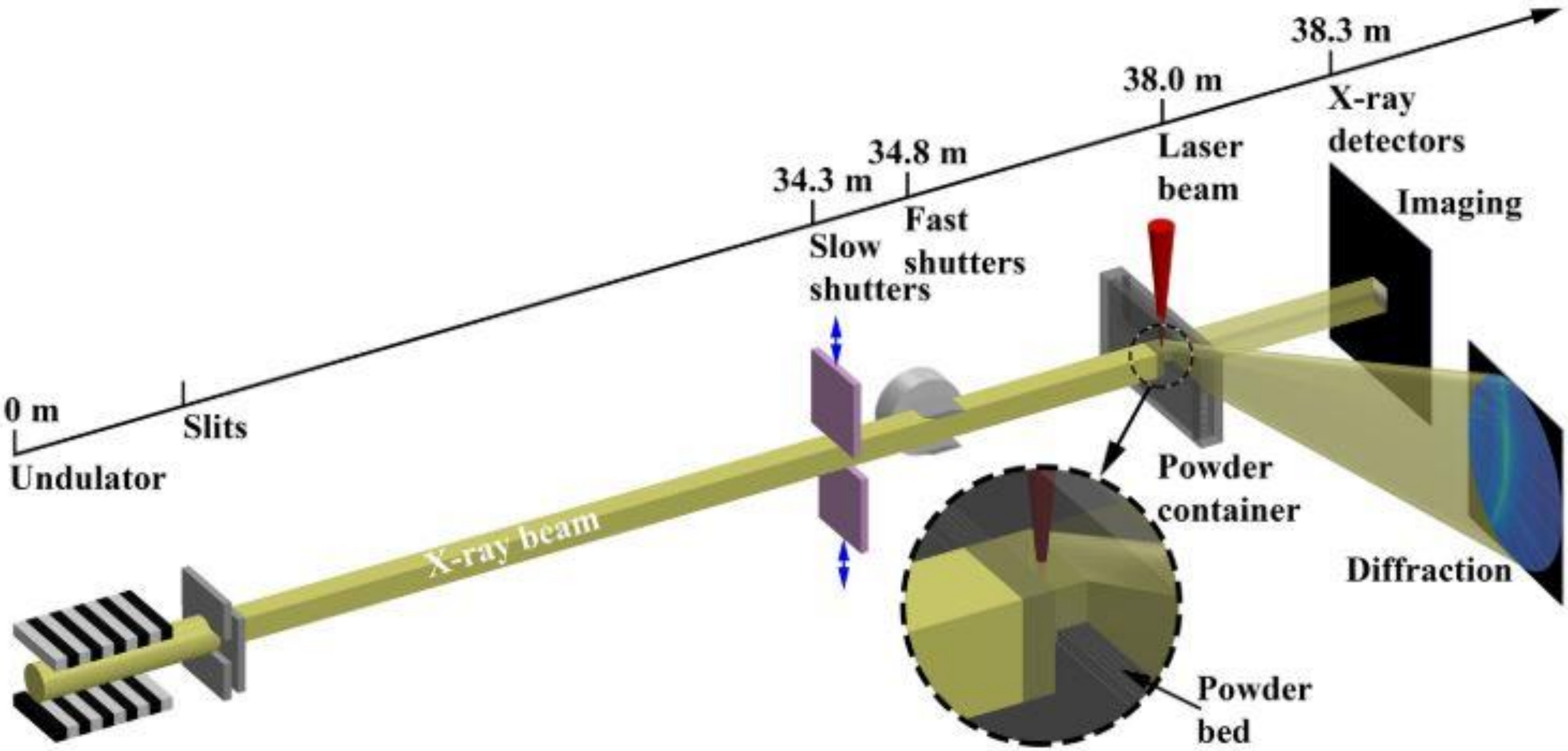
- Synchrotron x-radiography experiments
  - **AM simulator**
  - Al-Cu/Al-Ag/Al-Cu-Ag Precipitation

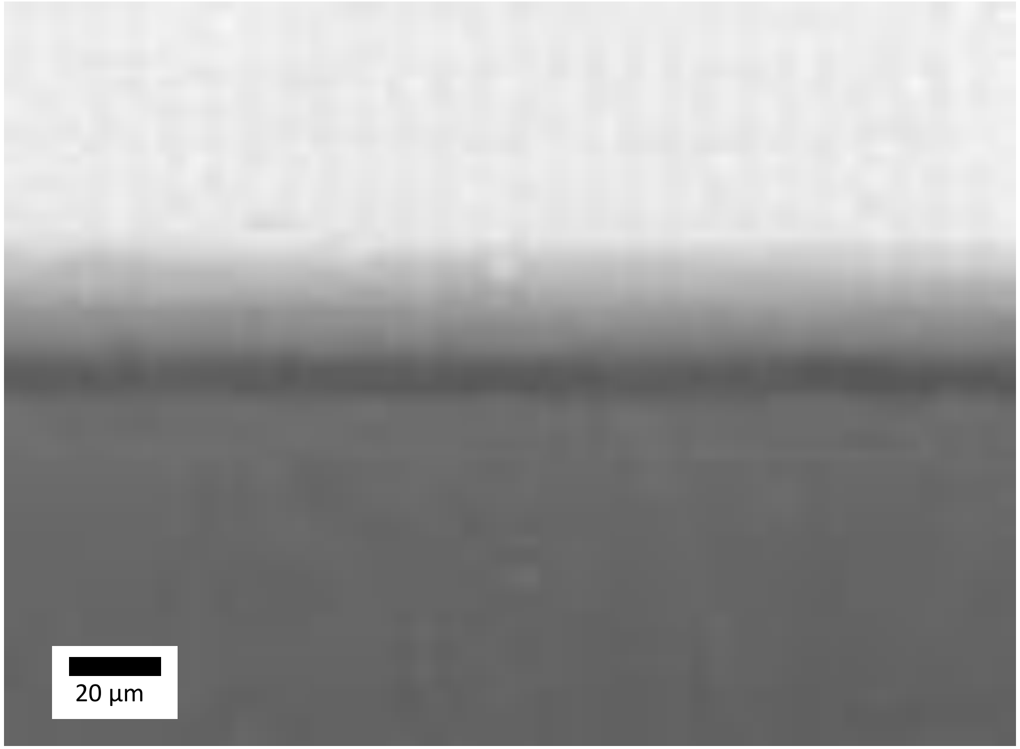
AM Simulator: Experimental Setup



C. Zhao et al., *Scientific Reports*, 7 (2017) 1-11.

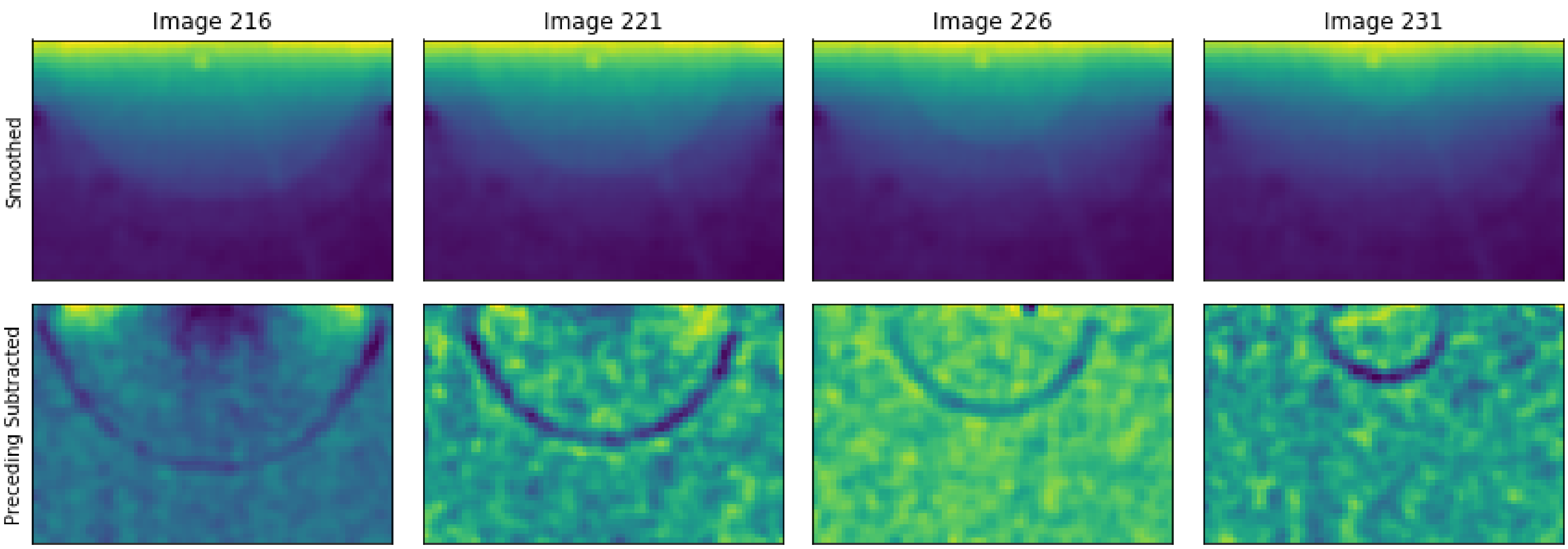
AM Simulator: Material

- Ni-based alloy
- Laser power: 108 W (20% max)
- 2 ms dwell time



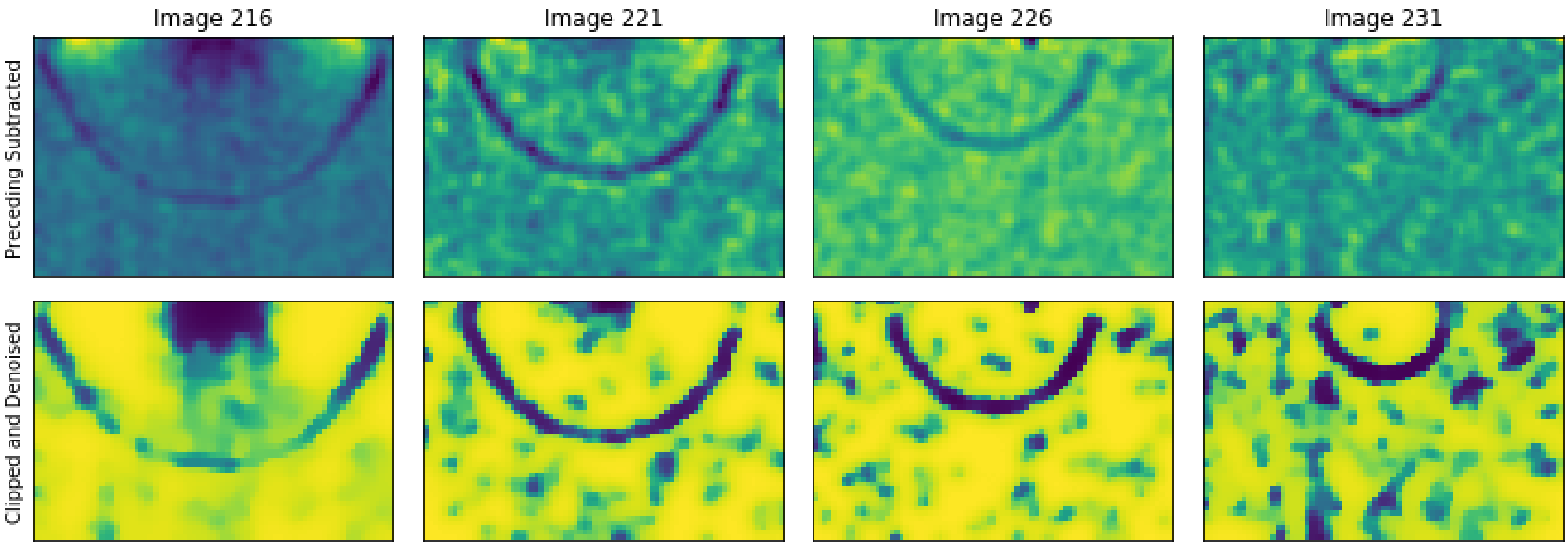
AM Simulator: Automatic Interface ID

- Subtract preceding image



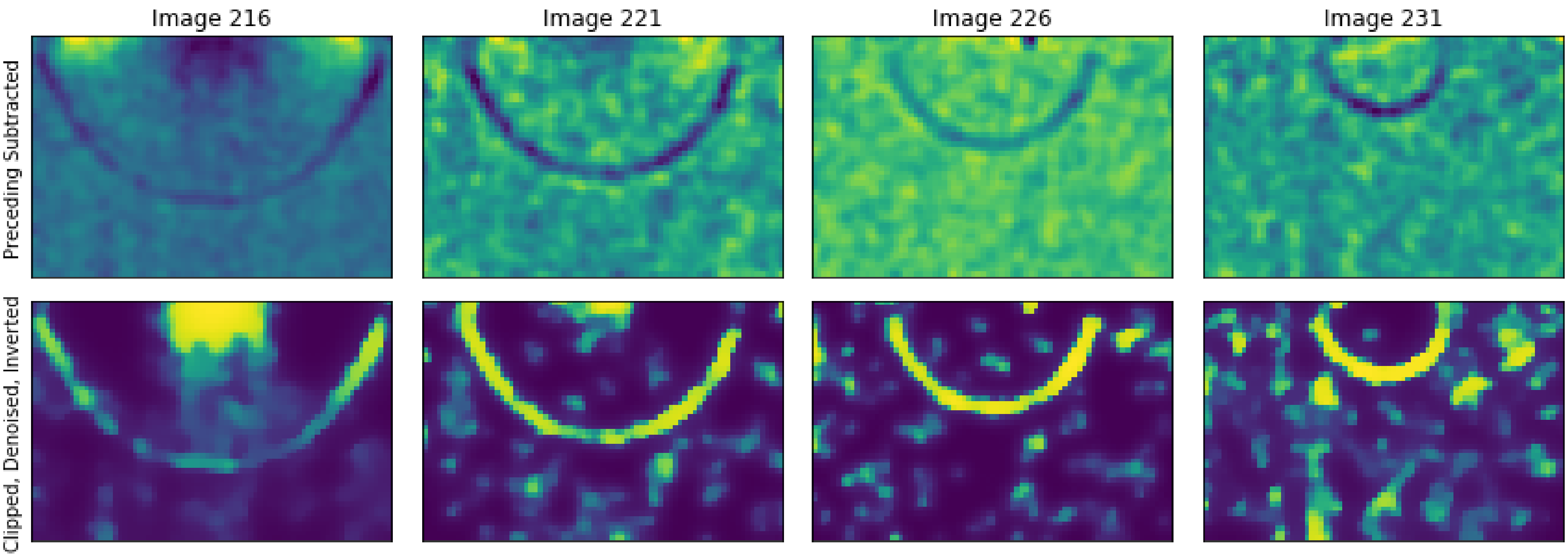
AM Simulator:
Automatic Interface ID

- Replace top and bottom 5% intensities



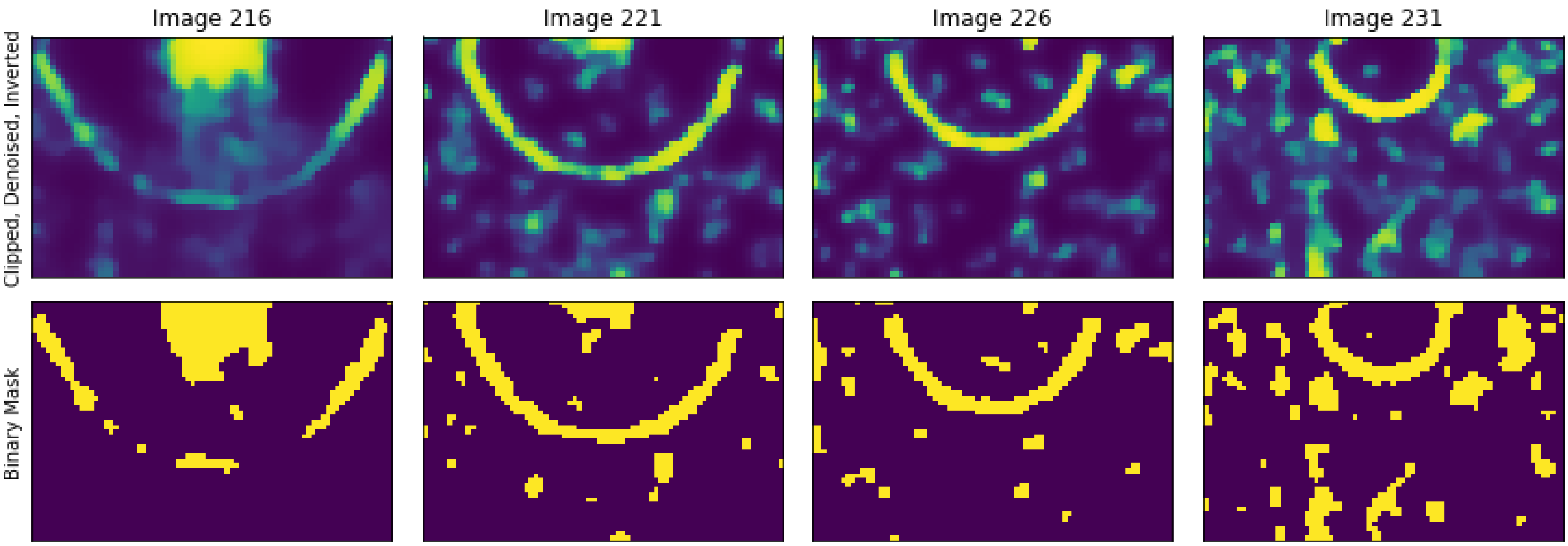
AM Simulator: Automatic Interface ID

- Invert for clarity



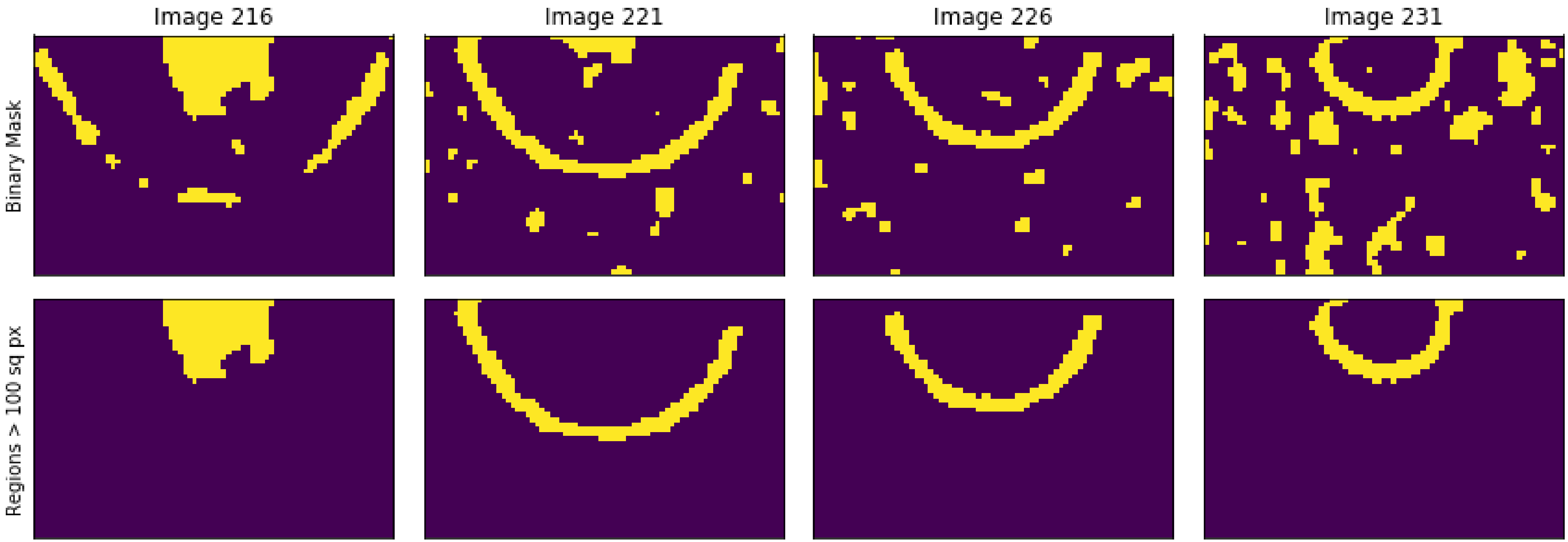
AM Simulator: Automatic Interface ID

- Create binary image



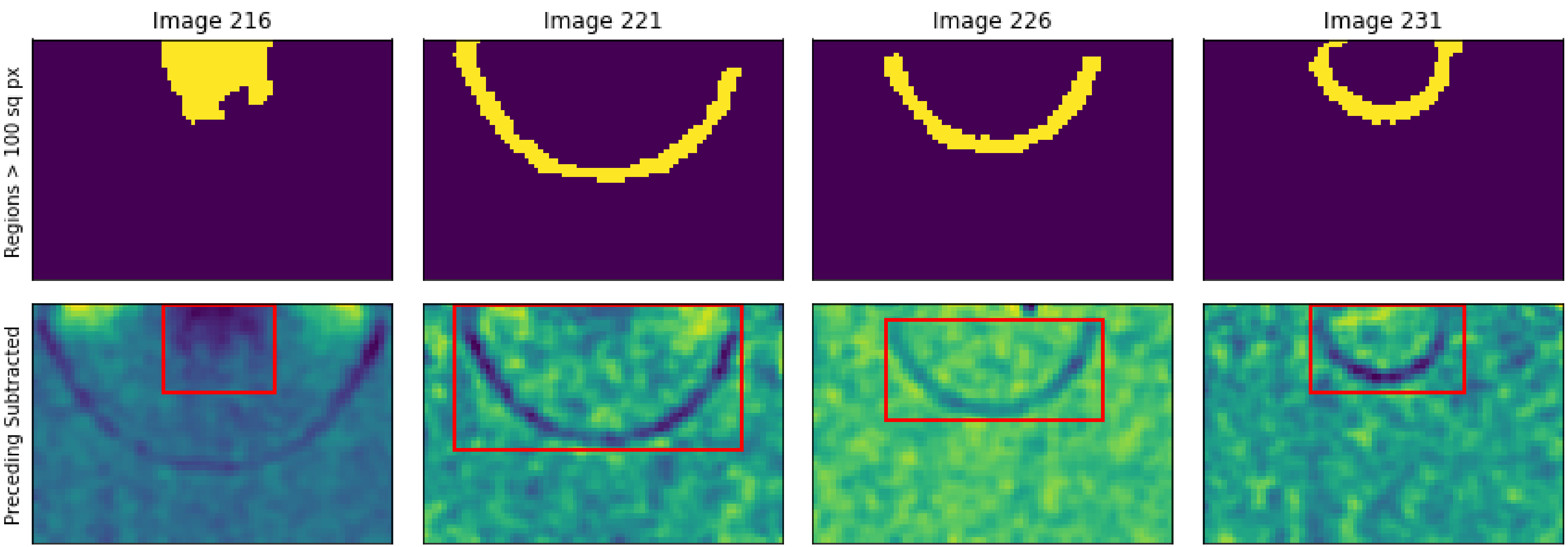
AM Simulator: Automatic Interface ID

- Remove smallest regions

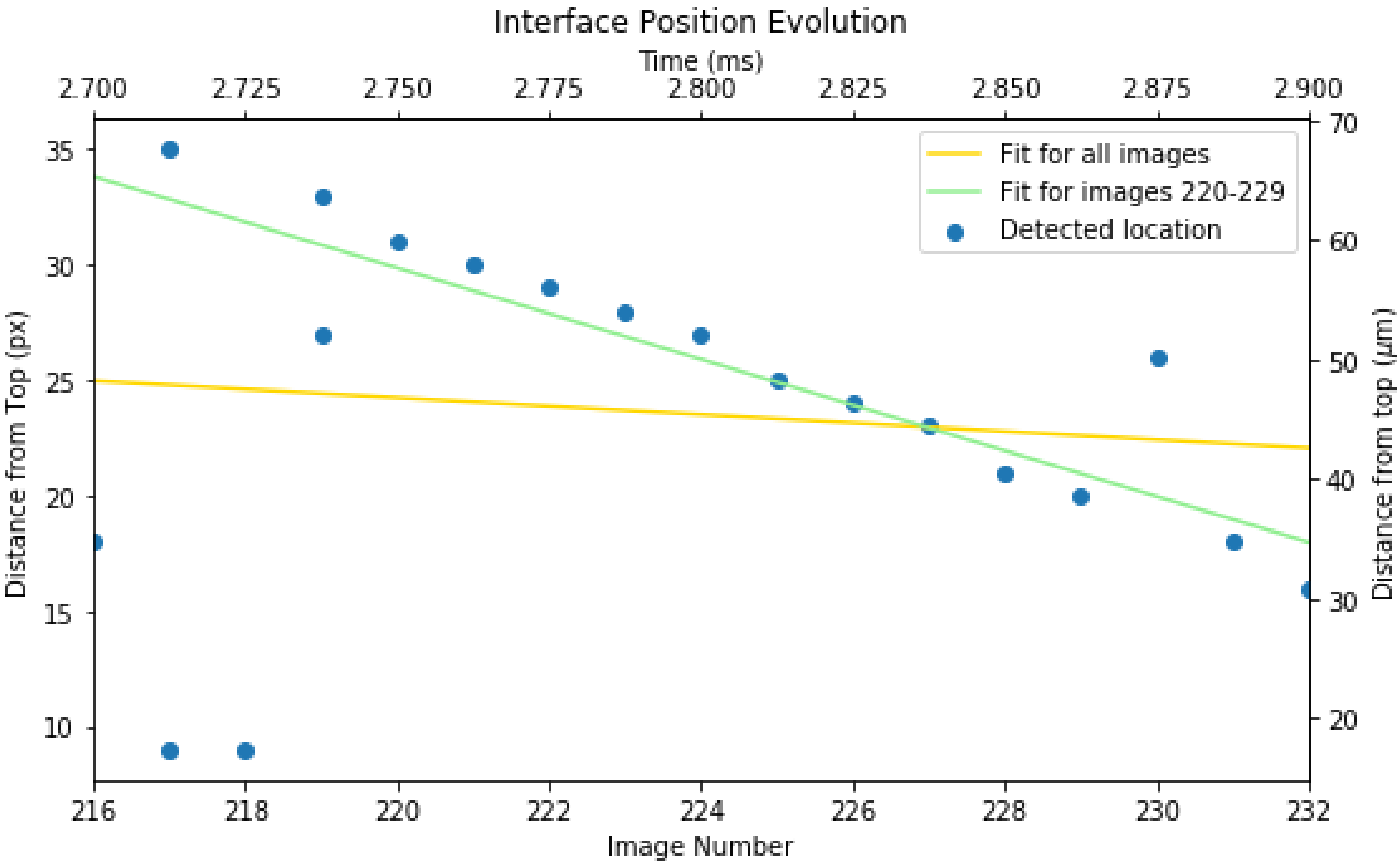


AM Simulator: Automatic Interface ID

- Create bounding box

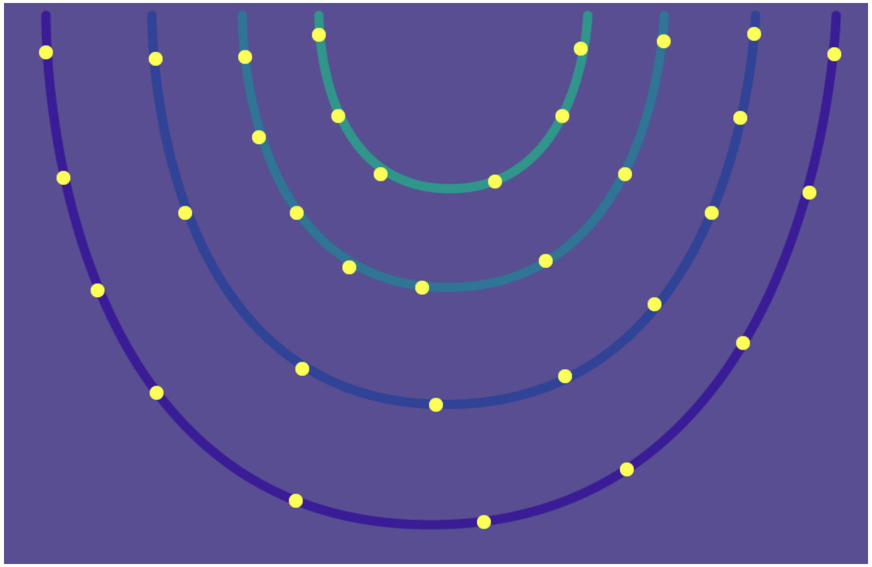


AM Simulator: Plot Interface Positions



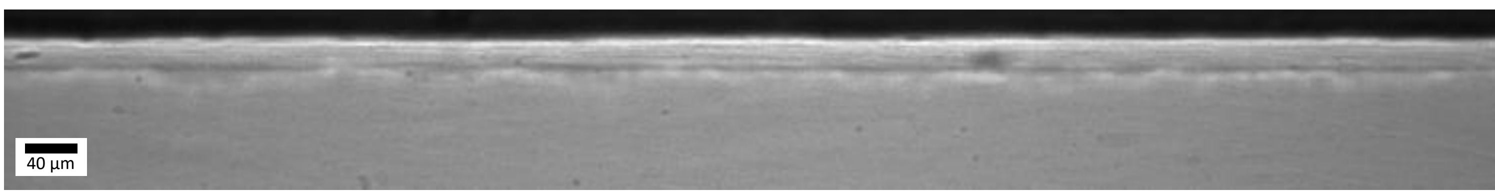
AM Simulator: Manual S-L Interface ID

- ImageJ macro for spots and rasters
- User sets increment between images
- S-L interface mapped and coordinates exported as .csv file



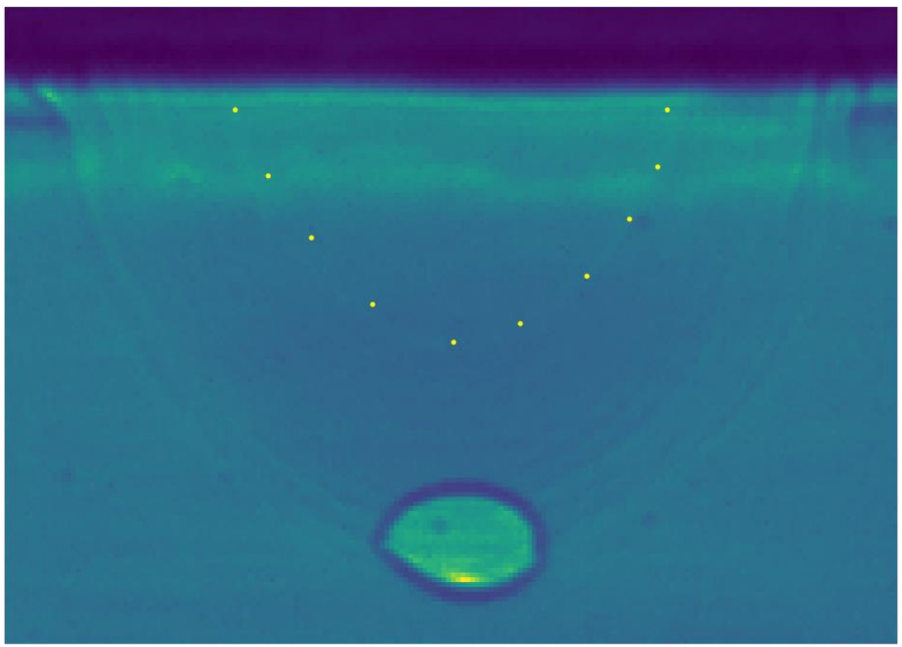
AM Simulator: Manual Interface ID

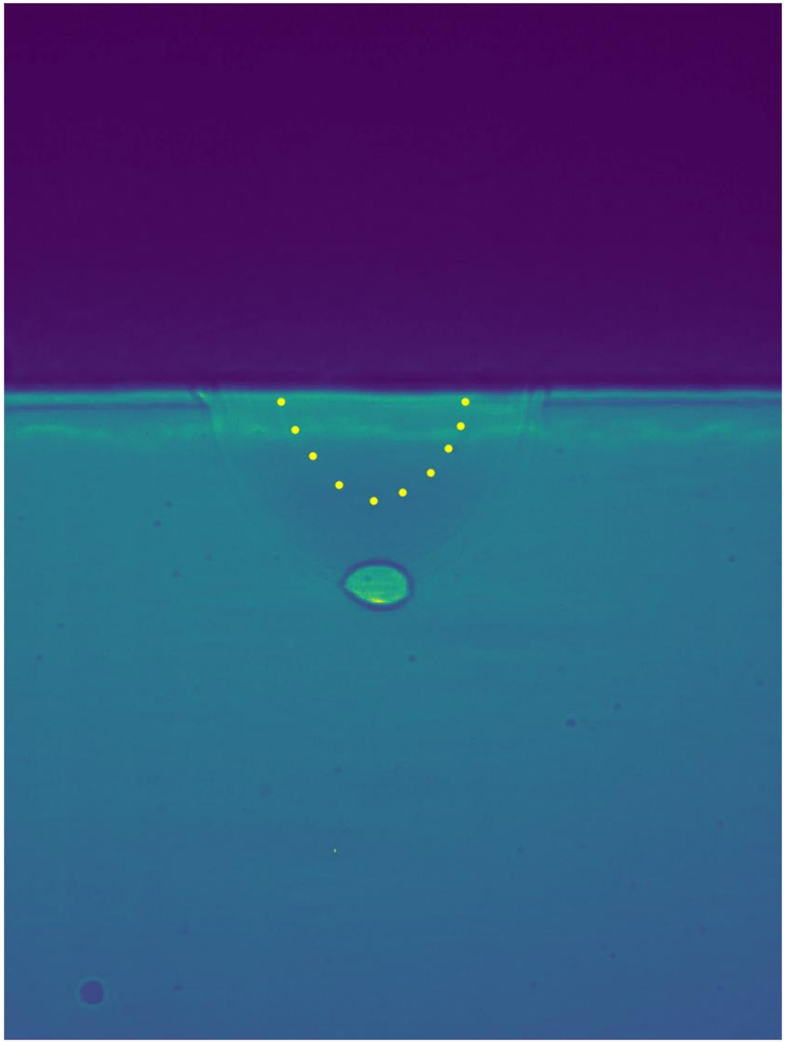
- Ti 1023
- Laser power: 162 W (30% max)
- 5 mps raster speed
- 1.5 mm line



AM Simulator: Python Program Progress

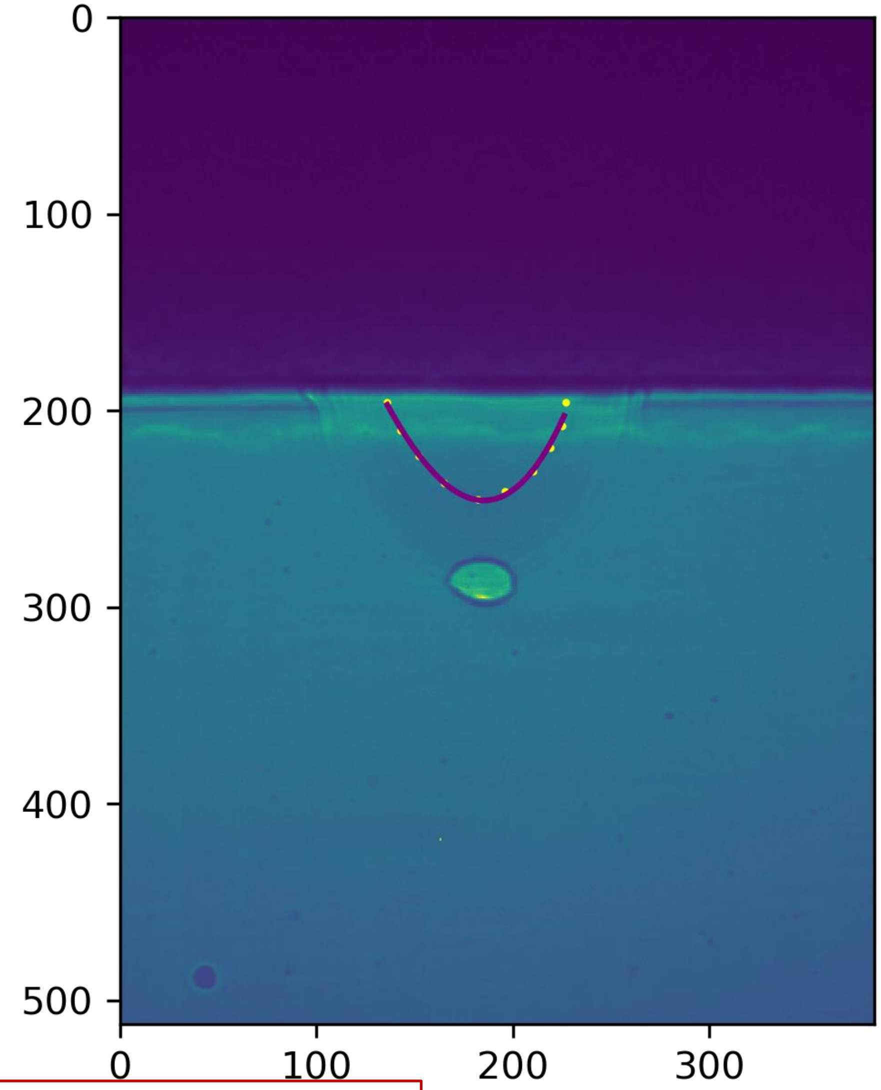
- Points overlaid on image (cropped and full)





AM Simulator: Python Program Progress

- Fit cubic polynomial to points
- Can be automated to apply to each image
- Intersections with a defined line can be used to measure velocity



AM Simulator: ML Approach

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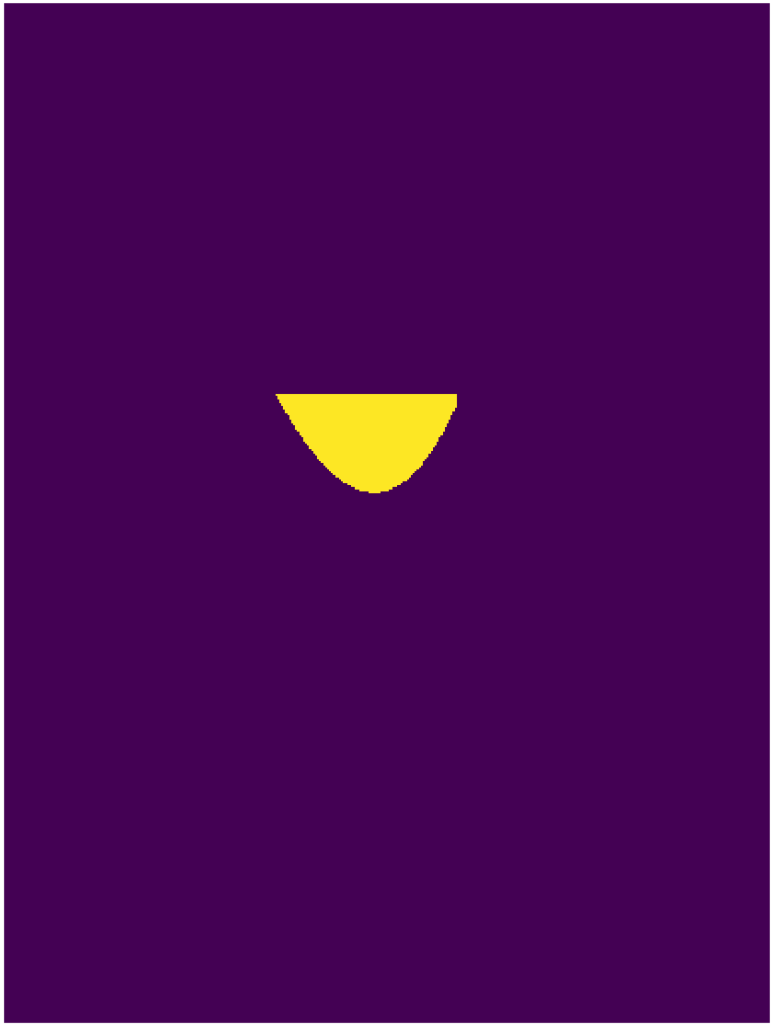
- ML requires labeled data to train model
- Binary images with labeled regions of interest



Materials & Material Processes to Explore

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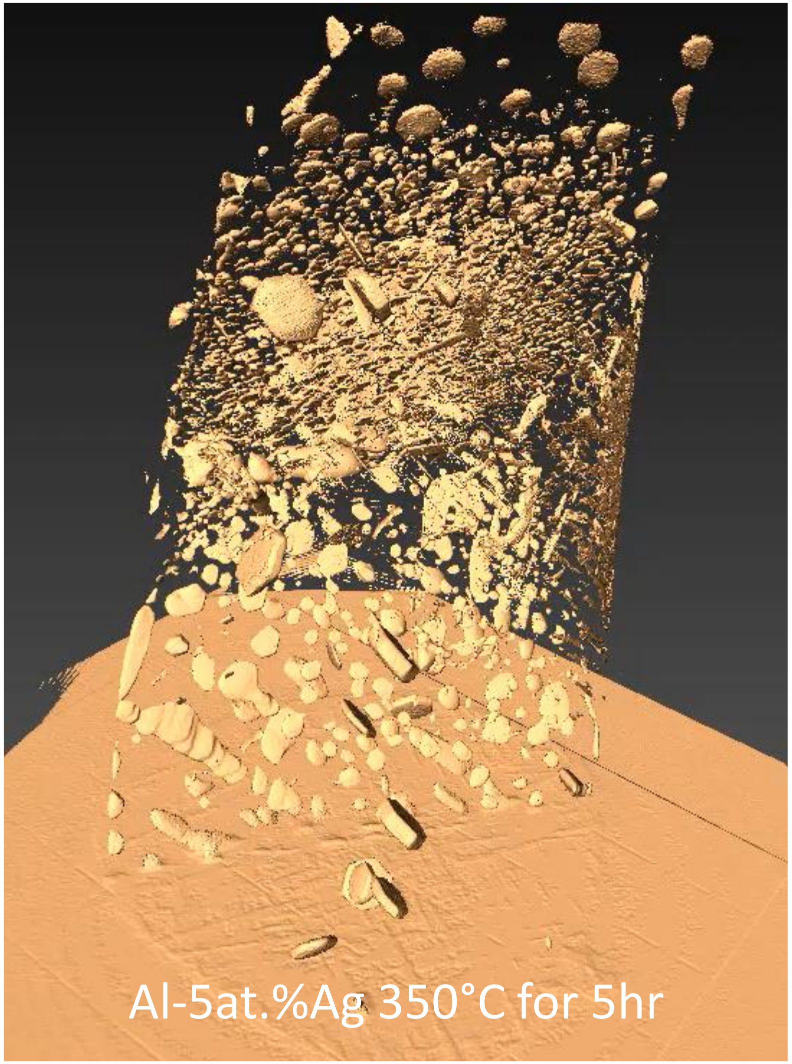
- Synchrotron x-radiography experiments
  - AM simulator
  - **Al-Cu/Al-Ag/Al-Cu-Ag Precipitation**

Al-Cu/Al-Ag/Al-Cu-Ag Precipitation

- Electropolished to 20 nm
- Interrupted aging at 350 °C
- CT at the APS



Advanced Visualization: Blender

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- Free and open source 3D creation suite
- Modeling, rigging, animation, simulation, rendering, compositing, motion tracking, video editing, game creation
- API for Python scripting
  - Customize application
  - Write specialized tools/add-ons

Advanced Visualization: Blender

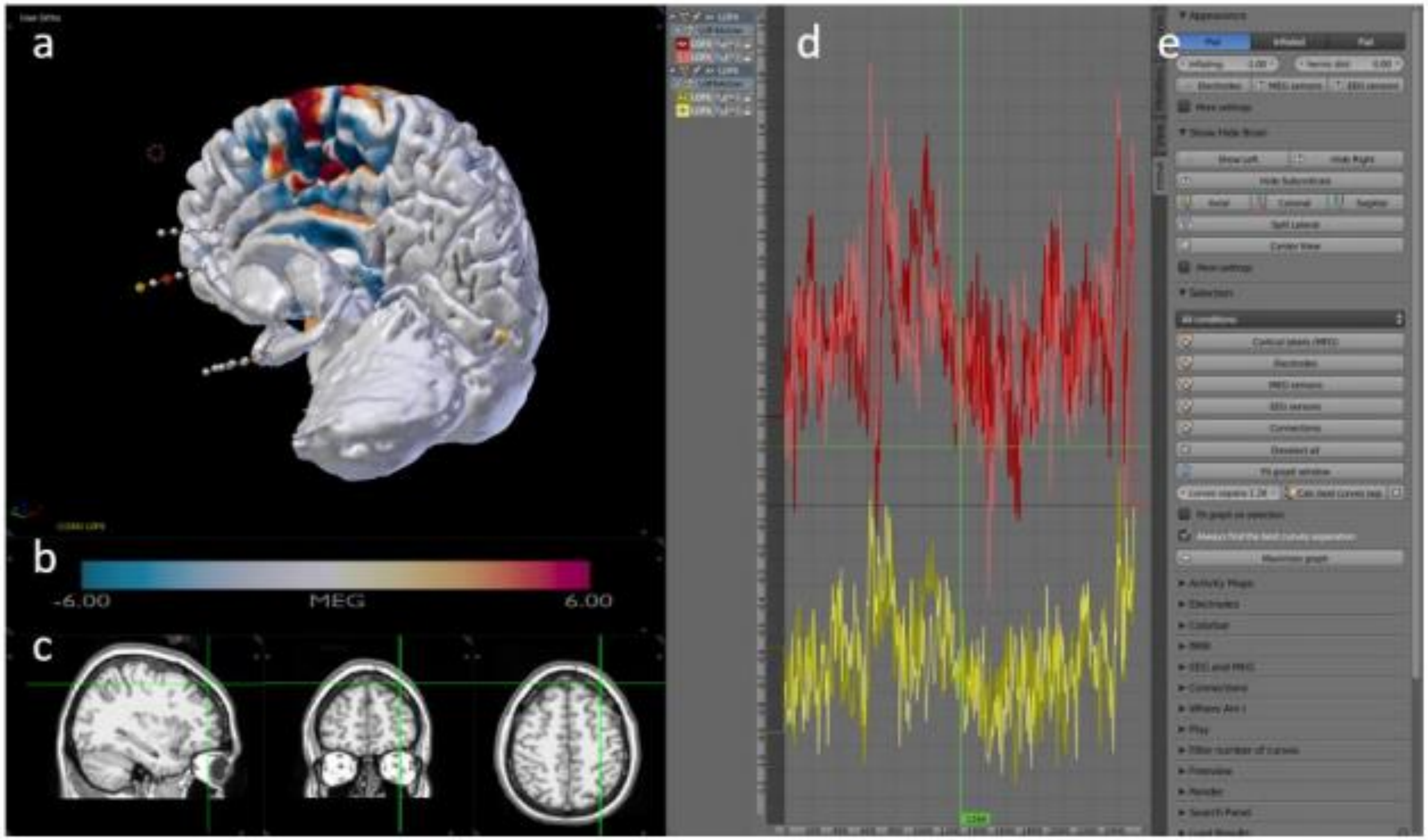
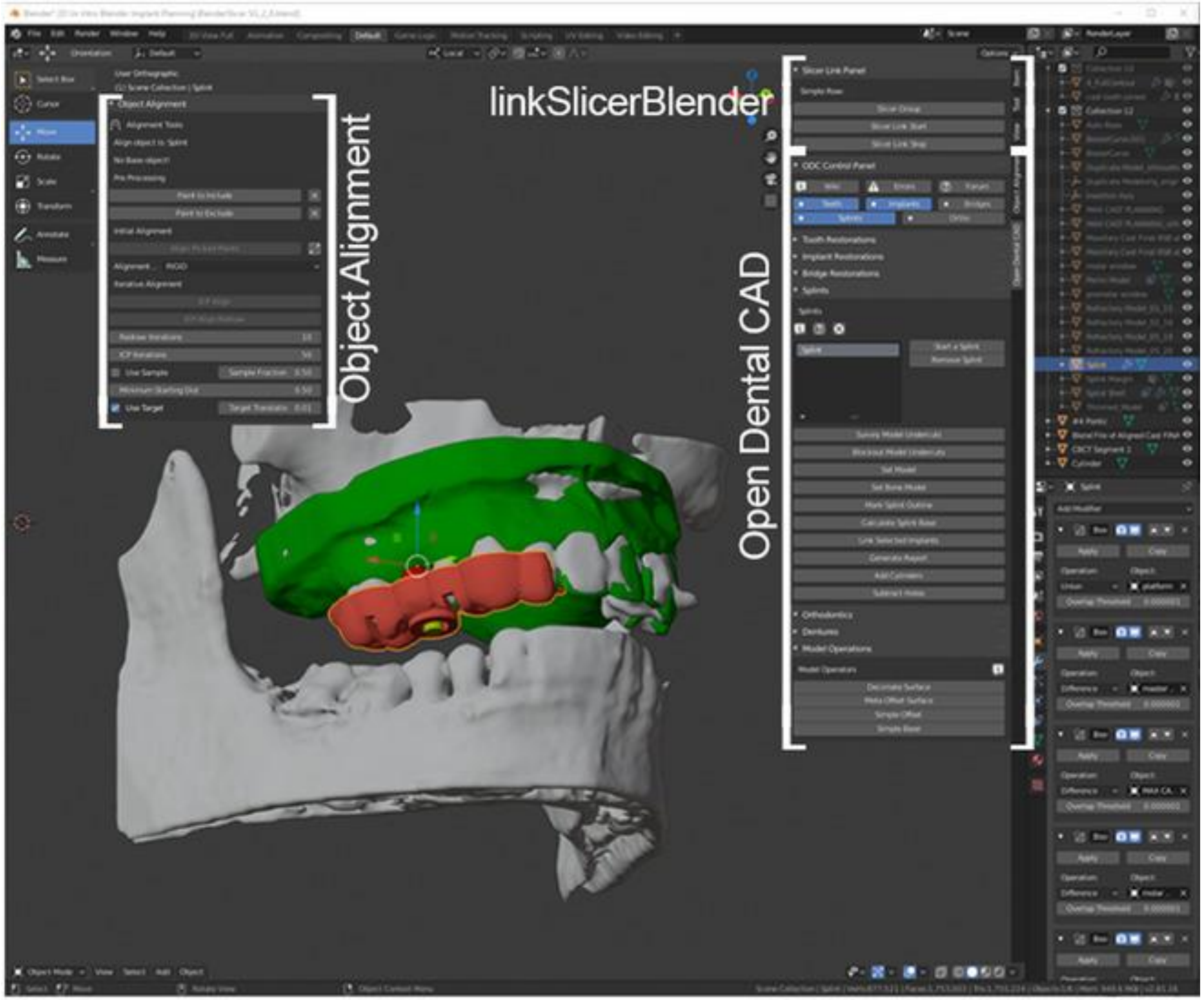


Figure 3. Main MMVT GUI. (a) A 3D brain view, **(b)** Color-bar that being updated automatically according to the activity being plotted, **(c)** Slices viewer for MRI (T1, T2, and FLAIR) and CT, **(d)** Time-domain and frequency-domain graphs, and (e) MMVT panels and buttons.

O. Felsenstein et al., arXiv Prepr. (2019).

Advanced Visualization: Blender



G. Talmazov, S. Bencharit et al., J. Prosthodont. (2020).

Advanced Visualization: VisPy

- Python library for interactive scientific visualization
- GPU accelerated
- Large datasets in real-time

Accessible Software Tools: Source Code

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- Git for version control
  - Maintain previous versions
  - Test features without breaking code
- GitHub to host source code
  - Allow other developers to view, download, and submit development requests

git

GitHub

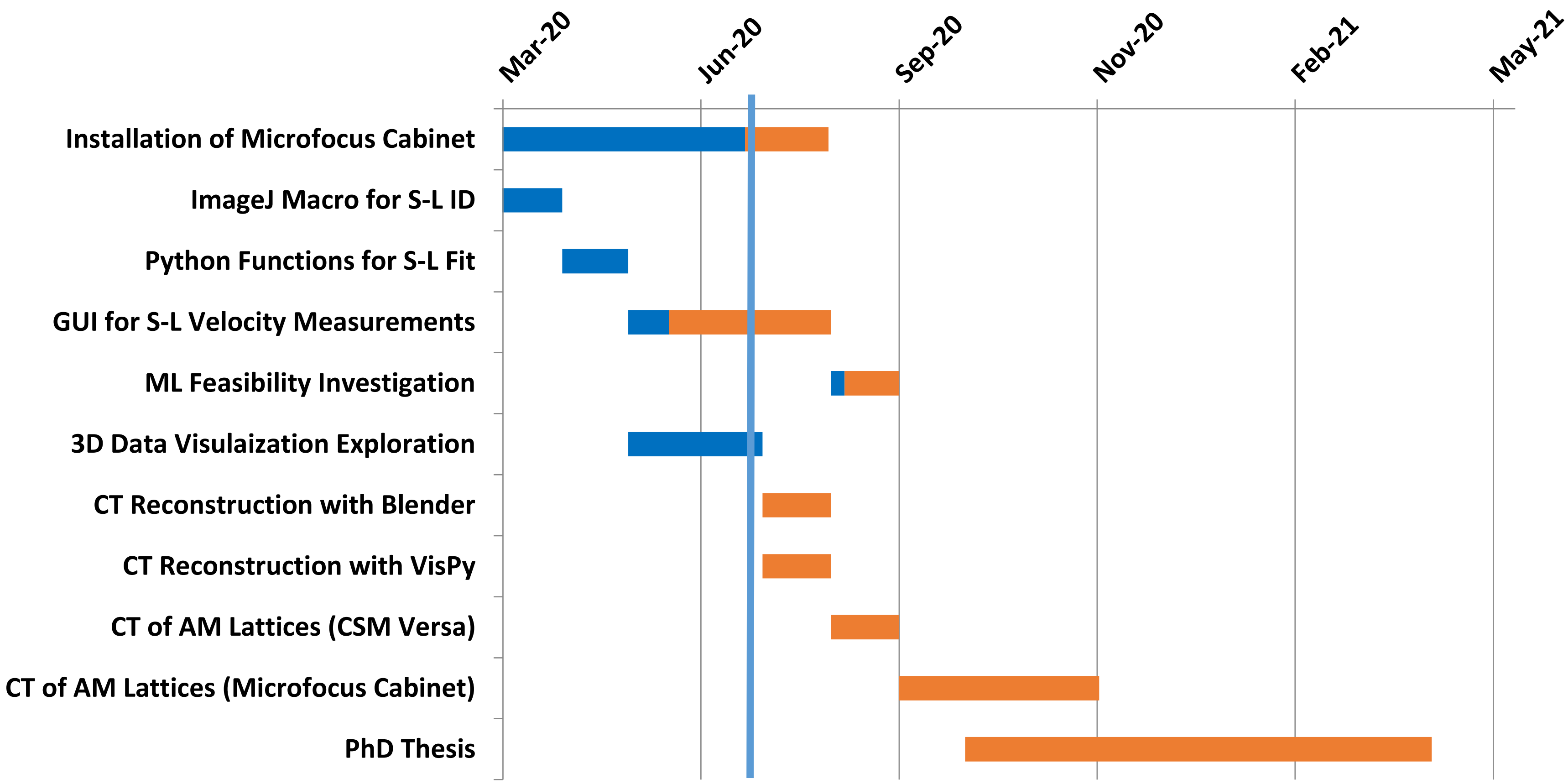
Accessible Software Tools: Dependencies

- Include requirements.txt to specify packages and versions
- Specific versions of packages can be installed from the Python Package Index to ensure project runs even after dependencies are updated
- Python virtual environment tools allow for different Python dependencies for different projects

Making Software Tools Accessible: Distribution

- Python packages can be installed and registered with the Python Package Index
- Certain Python packages can be used to freeze code so that it “just works”
  - Creates .exe
  - Correct version of Python doesn’t have to be installed to run
  - pyInstaller, py2exe, cx_Freeze

Progress



Mar-20
Jun-20
Sep-20
Nov-20
Feb-21
May-21
Installation of Microfocus Cabinet
ImageJ Macro for S-L ID
Python Functions for S-L Fit
GUI for S-L Velocity Measurements
ML Feasibility Investigation
3D Data Visulaization Exploration
CT Reconstruction with Blender
CT Reconstruction with VisPy
CT of AM Lattices (CSM Versa)
CT of AM Lattices (Microfocus Cabinet)
PhD Thesis

Challenges & Opportunities

- Usefulness of GUI for feature measurements
- Incomplete success with automated interface ID to ML investigation
- Blender as 3D scientific visualization tool

Thank you!

C. Gus Becker

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References

[1] C. Zhao et al., *Scientific Reports,* 7 (2017) 1-11.

[2] O. Felsenstein et al., arXiv Prepr. (2019).

[3] G. Talmazov, S. Bencharit et al., J. Prosthodont. (2020).