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

Fall Meeting

October 13th – 15th 2020

- Student: C. Gus Becker (Mines)
- Faculty: Dr. Amy Clarke (Mines)
- Industrial Mentors: Dr. 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 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.

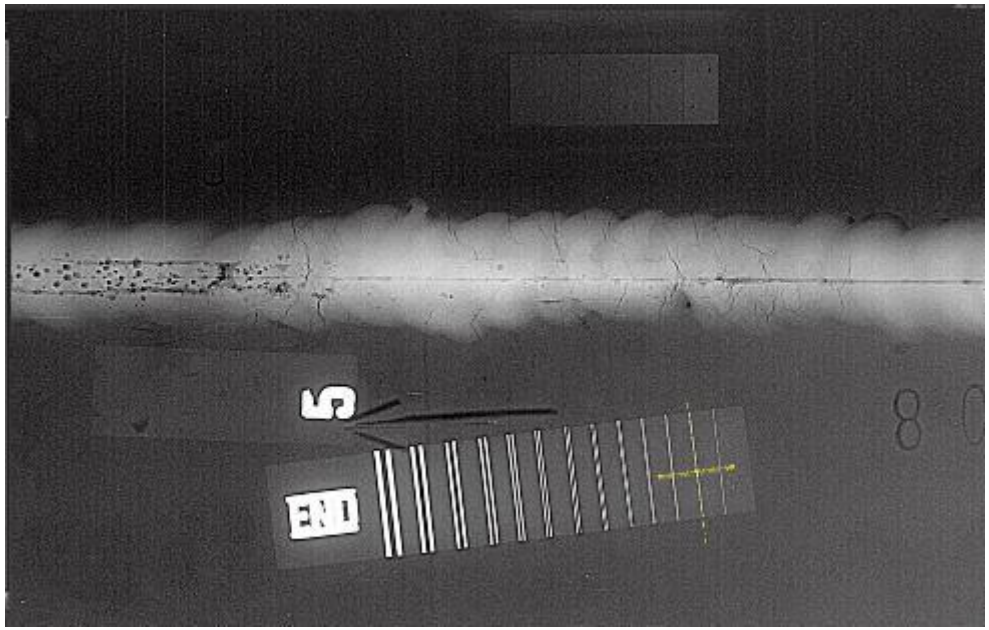
Recent Progress

- Performed XCT of AM lattice structures using Zeiss Xradia 520 Versa Micro-CT at Mines
- Segmented IDOX crystals in 3D XCT dataset of mock HE sample
- Deployed web app to fit polynomial expressions to interface location data from experiments at the the APS AM simulator

Metrics		
Description	**% Complete**	**Status**
1. Establishment of high-energy micro-focus x-ray capabilities at Mines	90%	●
2. XCT of SNL AM lattice structures Micro-CT at Mines	20%	●
3. Web app for solid-liquid interface velocity analysis of the APS AM simulator data	75%	●
4. Dynamic XCT of SNL AM lattice structures during deformation	0%	●
5. pRad of SNL AM lattice structures	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/

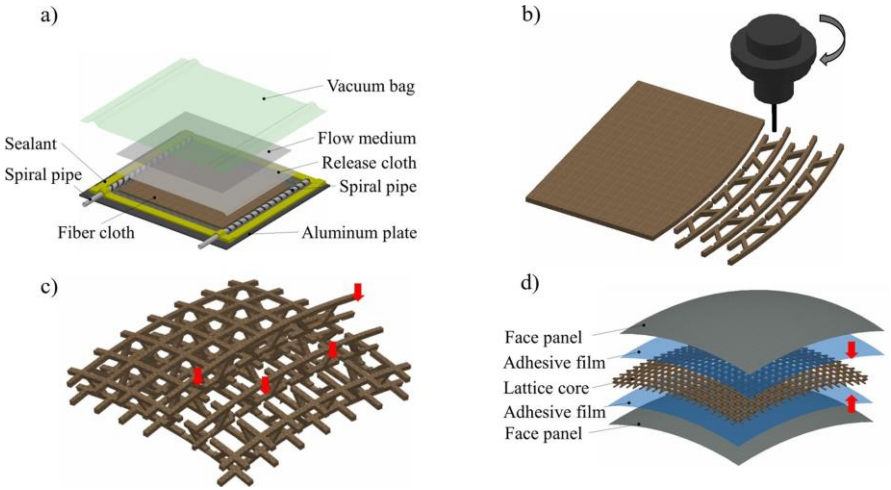
Industrial Relevance

- In-situ x-ray imaging of dynamic materials processes to inform model development

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

Industrial Relevance

- Applications of AM-built lattice structures
  - Lattice-sandwich engine hood: 25% of weight for better pedestrian safety performance
  - Spur gear using honeycomb lattice structure: 19% volume reduction with same strength



S. Yin et al., Compos Struct, 201 (2018) 131–140.

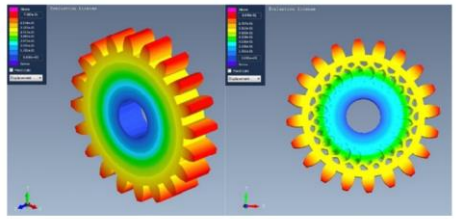


Fig. 2. Displacement on solid and optimized part.

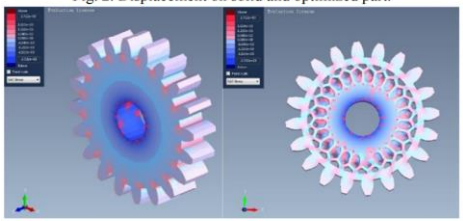
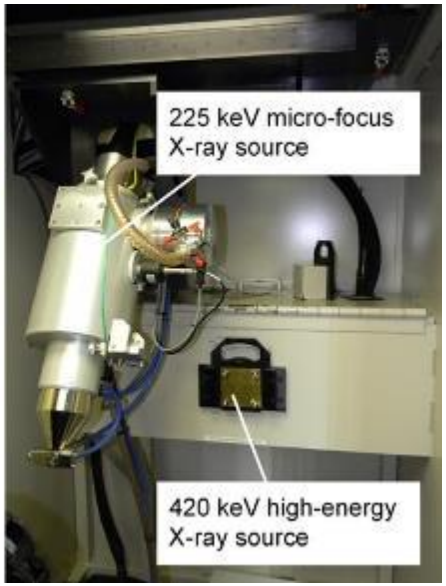


Fig. 3. Stresses on solid and optimized part.

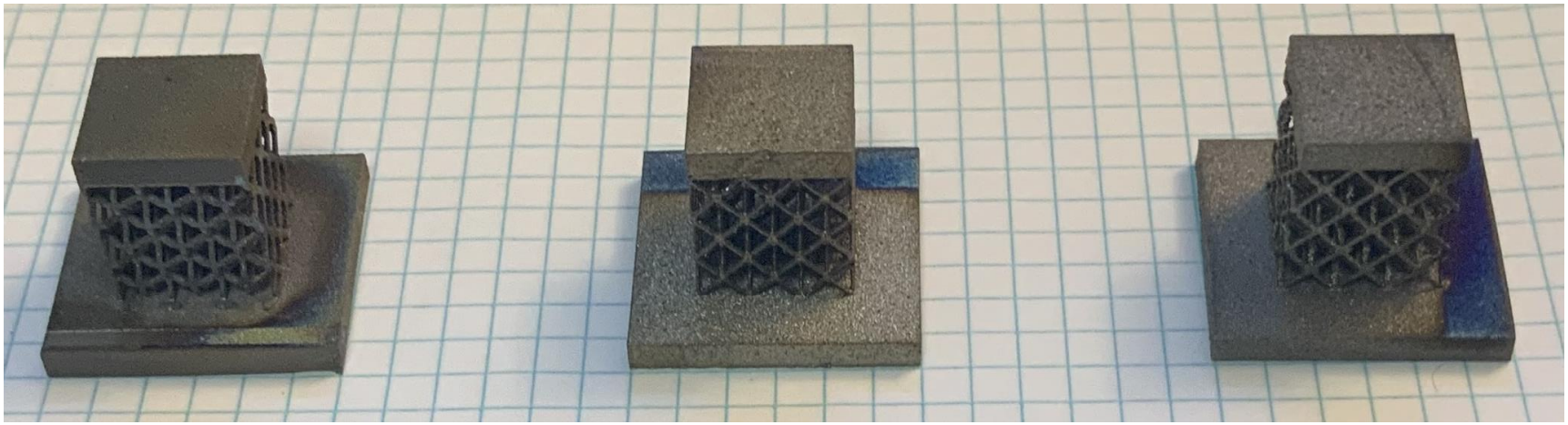
A. J. Kulangara et al., Mater Today, 5 (2018) 5068–5073.

Cabinet Timeline



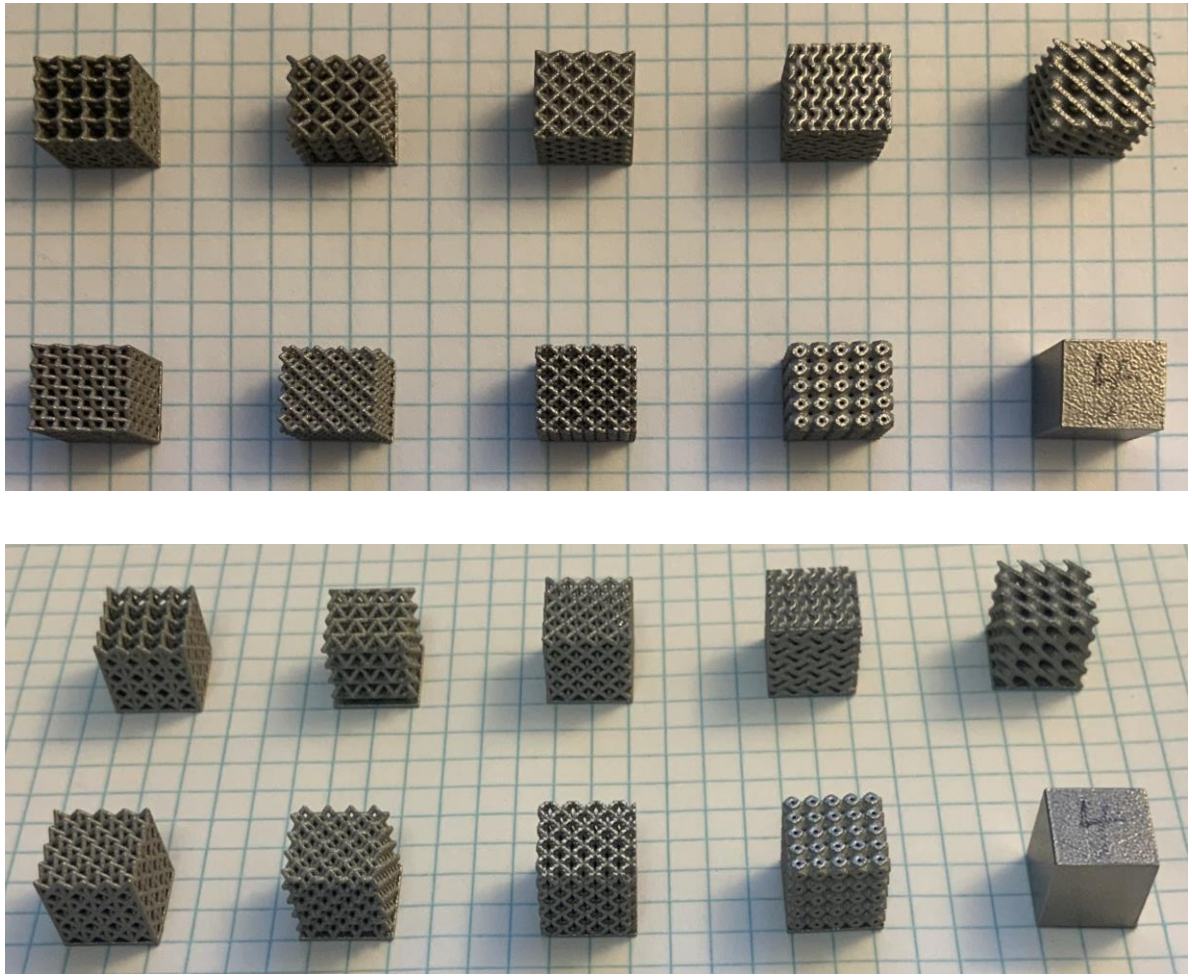
Process Donation Internally (LANL)	Ship to White Rock, NM	Ship to Santa Clara, CA for Refurbishing	Prepare Lab Space for System	Install New Micro-Focus System	Ship to Mines and Install
Complete	Complete	Complete	Ready	New Tube Shipped	ETA: December

Ti-5553 Lattices from LANL



6 squares = 1 in

Ti-64 Lattices from SNL



6 squares = 1 in

Micro-CT with Zeiss Xradia 520 Versa at Mines

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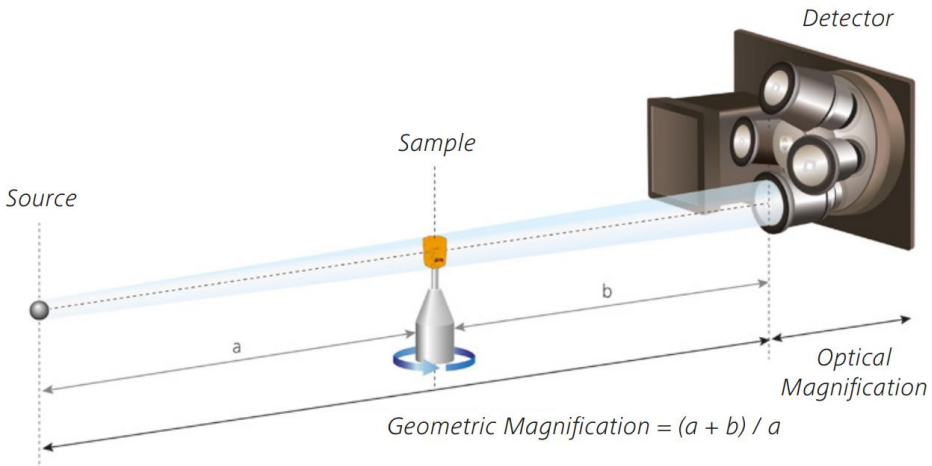
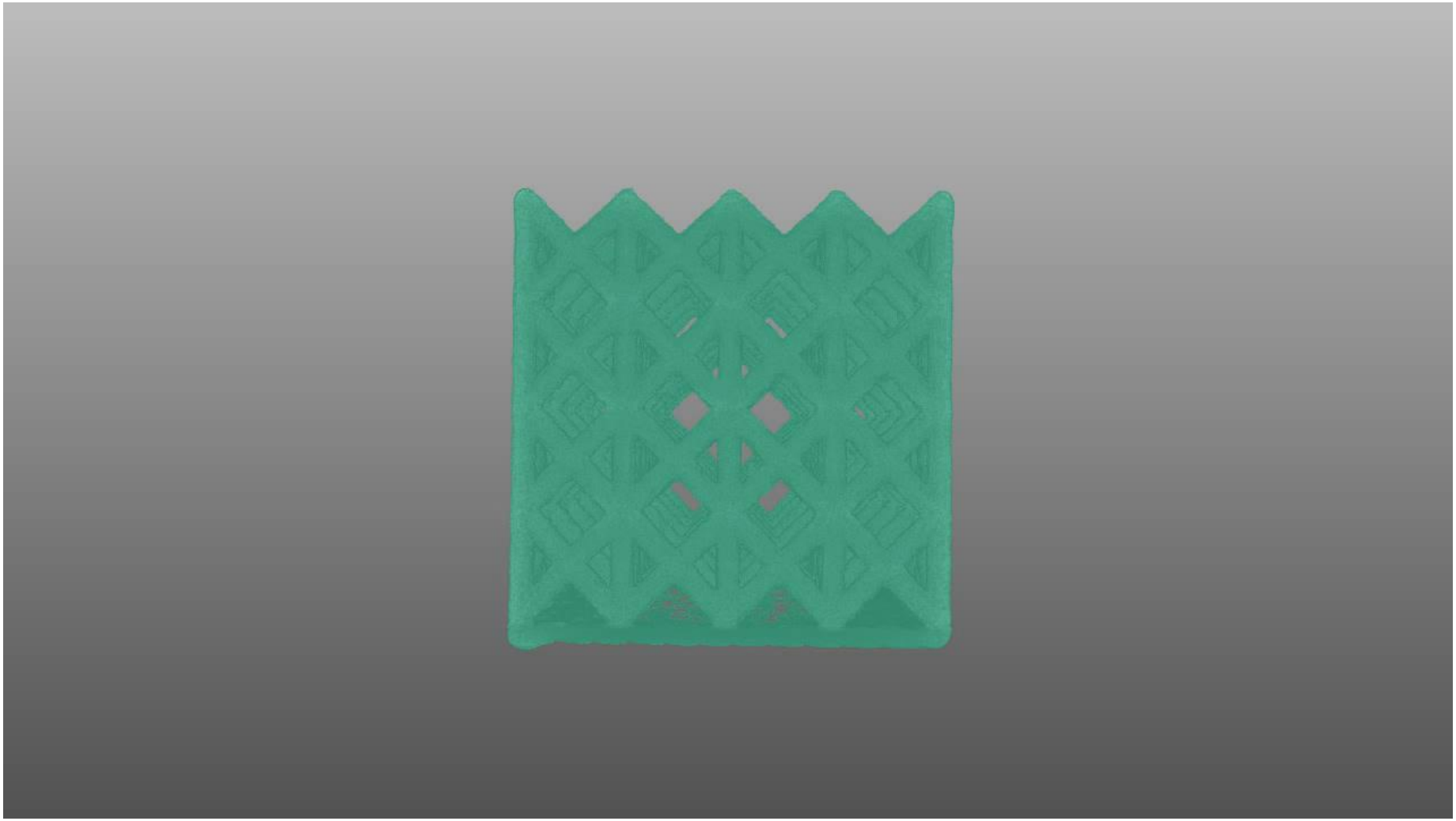
- 160 keV
- 10 W
- ~10.8 mm samples
- ~8 µm resolution

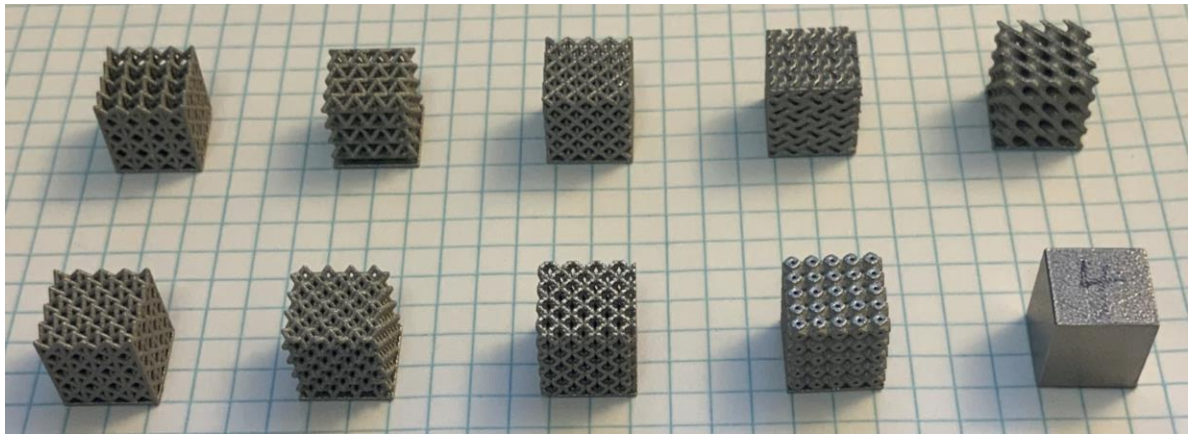


Ti-64 Lattice 01



Ti-64 Lattices

- Static imaging
- Proton radiography (pRad) at Los Alamos Neutron Science Center (LANSCE) in December
- Pick samples for deformation imaging

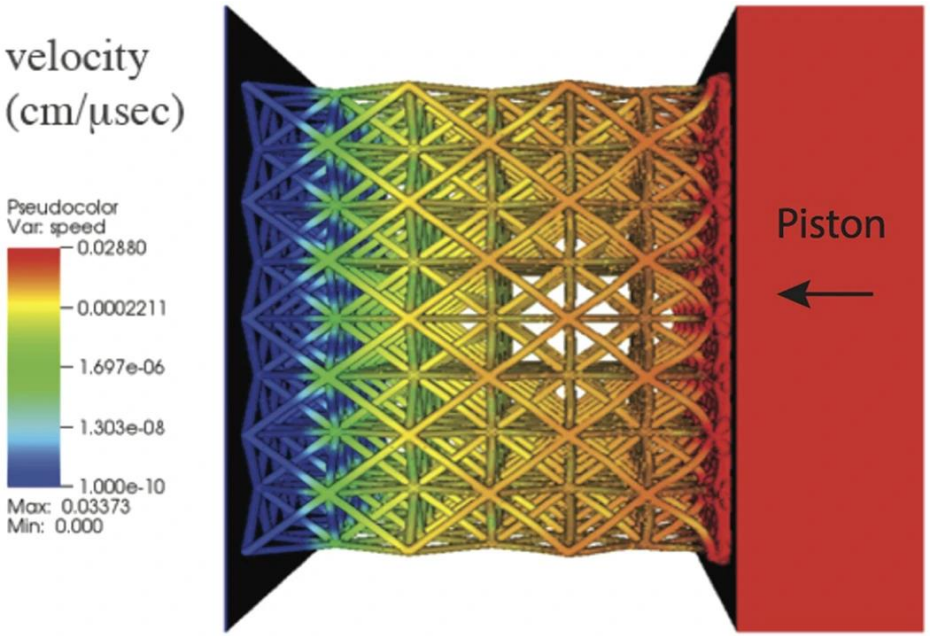


6 squares = 1 in

- **Lattice 01**
- **Lattice 02**
- Lattice 03
- Lattice 04
- Lattice 05
- Lattice 06
- Lattice 07
- Lattice 08
- Lattice 09
- Lattice 01

Mock-HE Lattices

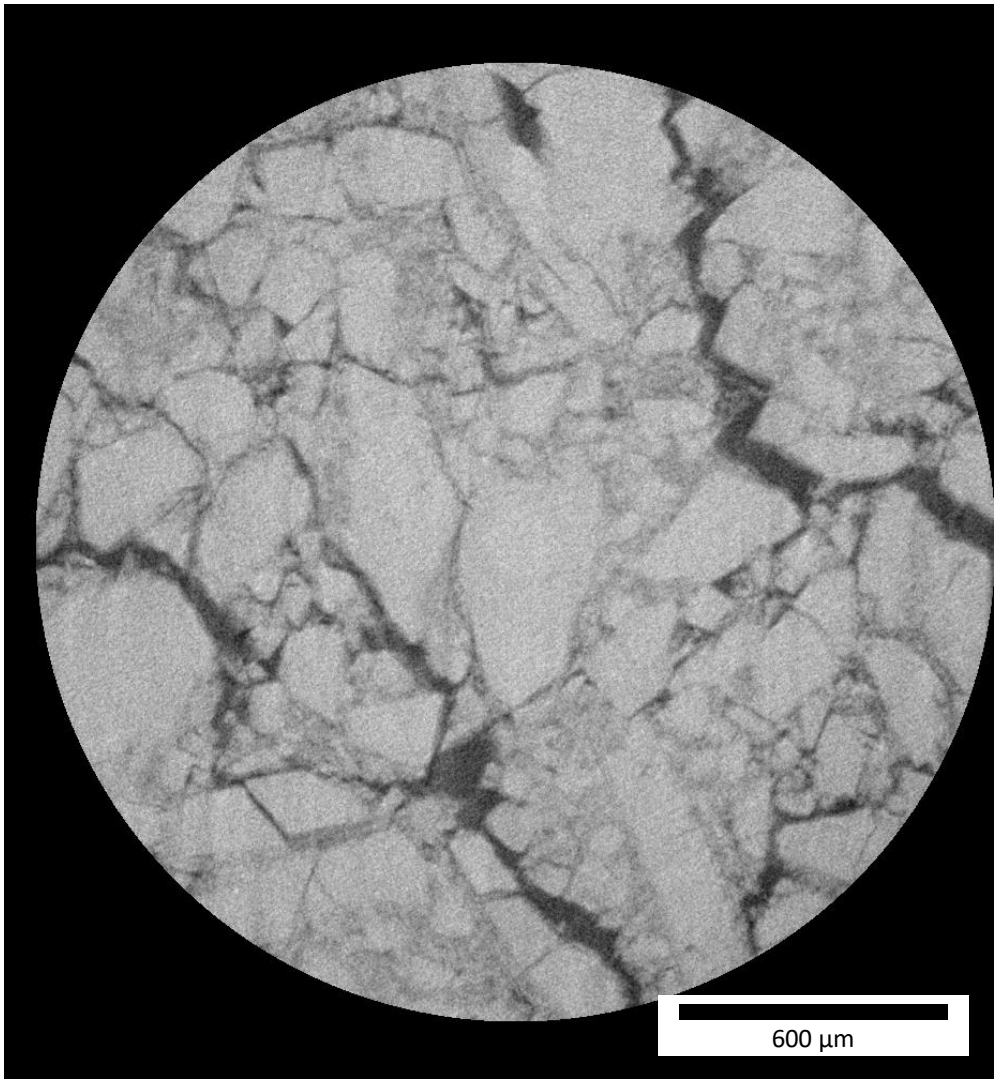
- Finite element simulation of AM-built 1,6-hexanedol diacrylate (HDDA)
- Simulates near instantaneous velocity rise at sample surface of gas gun loading



J. A. Hawreliak et al., *Scientific Reports, 6* (2016).

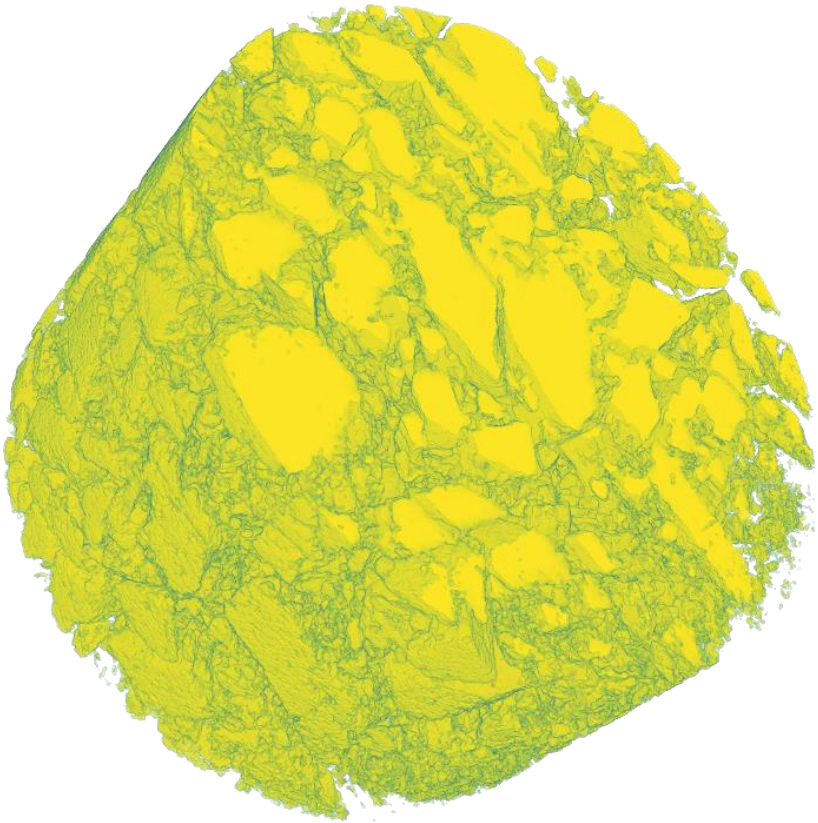
Mock HE from LANL

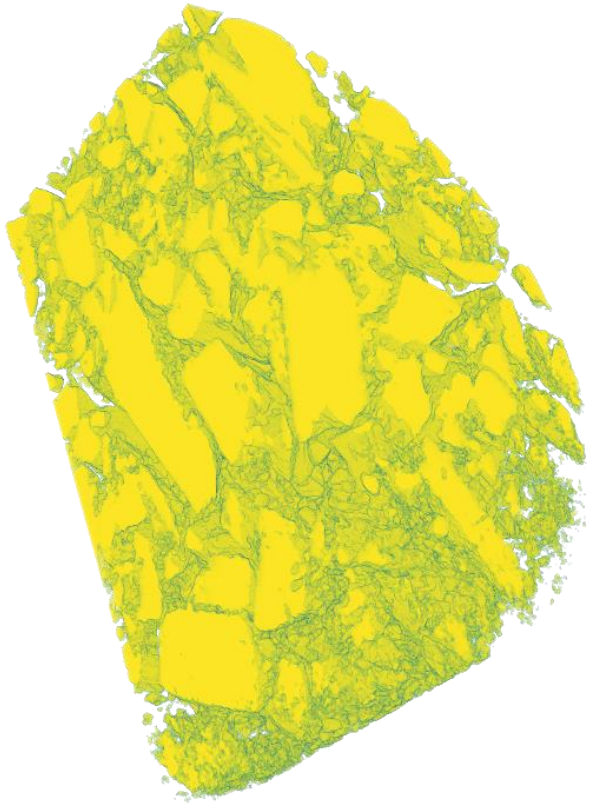
- High explosives (HE) replaced with mock HE during testing for safety
- 5-Iodo-2'-deoxyuridine (IDOX) crystals embedded in binder
- Surrogate for cyclotetramethylenetetran-itramine (HMX)



J.D. Yeager et al., J. Energ. Mater. 36 (2018) 253–265.

Mock HE from LANL

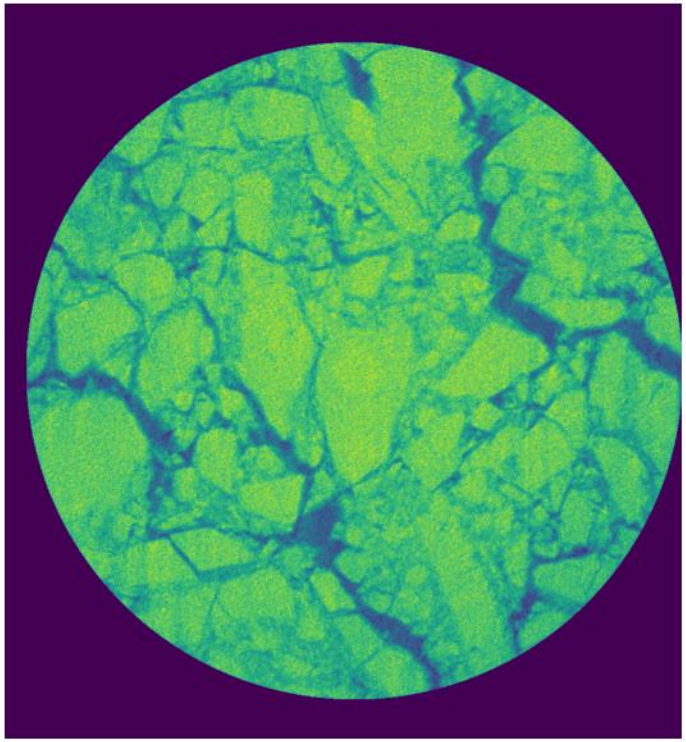


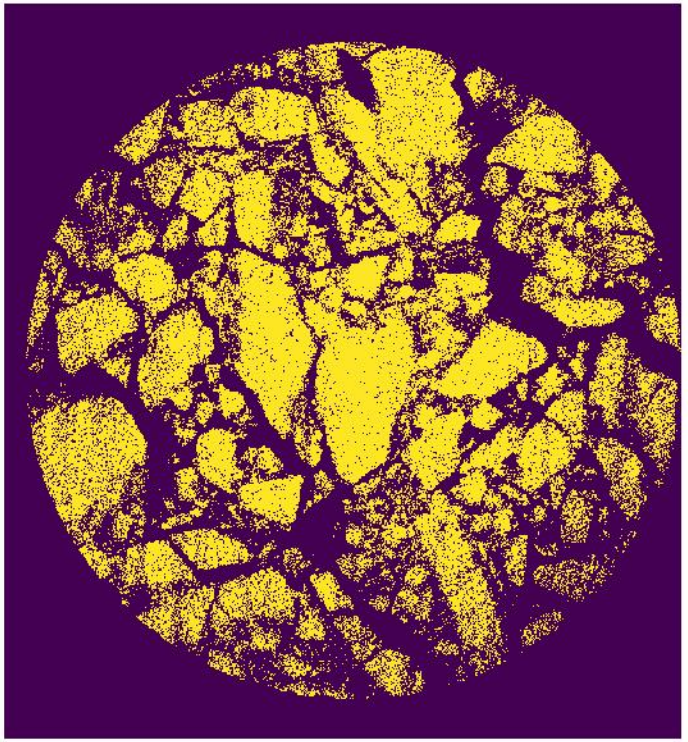


600 µm

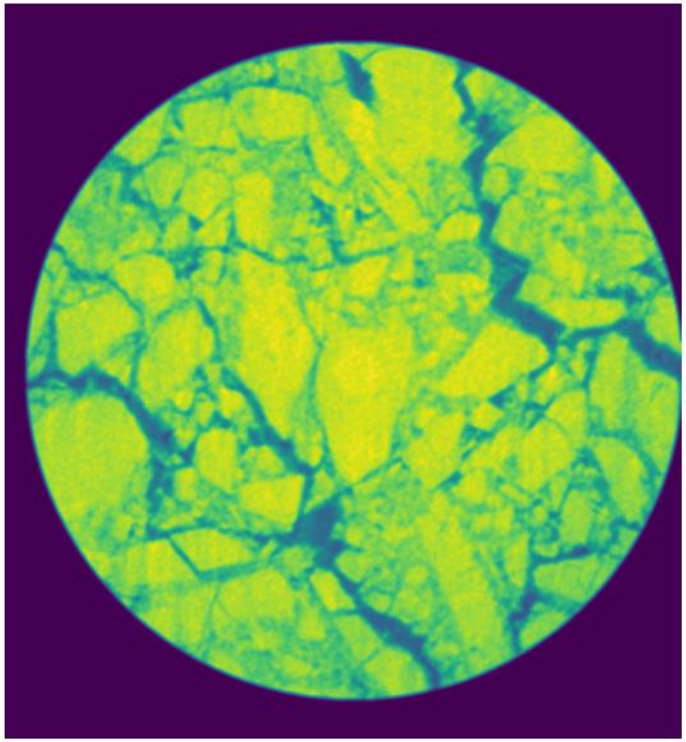
J.D. Yeager et al., J. Energ. Mater. 36 (2018) 253–265.

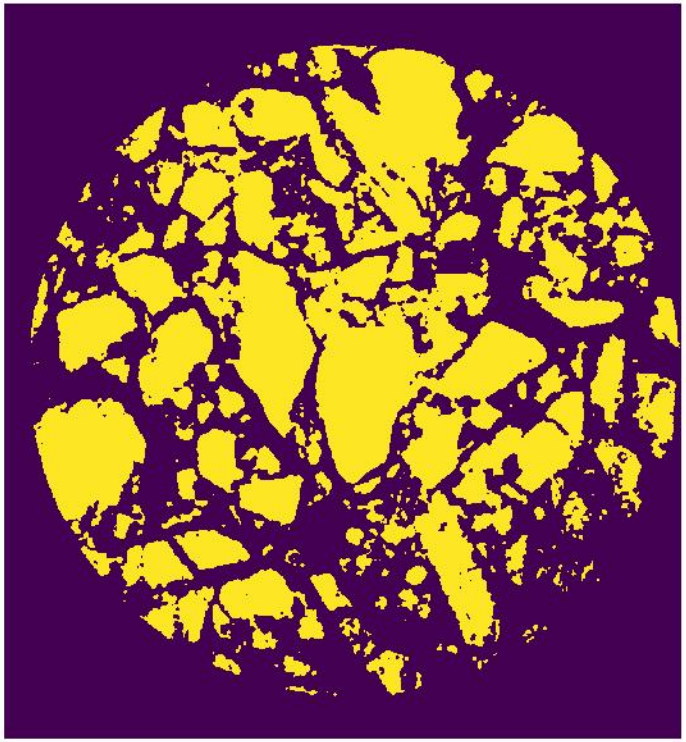
Segmenting IDOX Crystals





Segmenting IDOX Crystals





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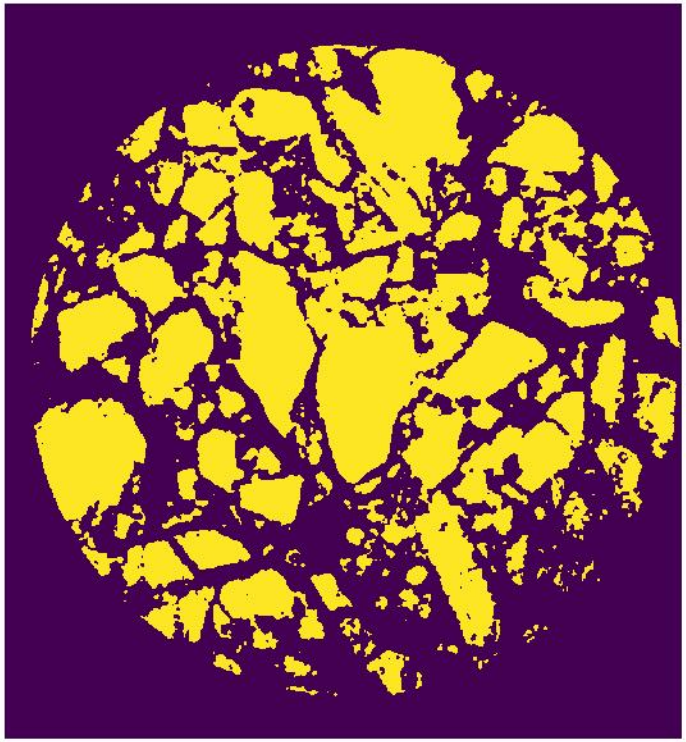

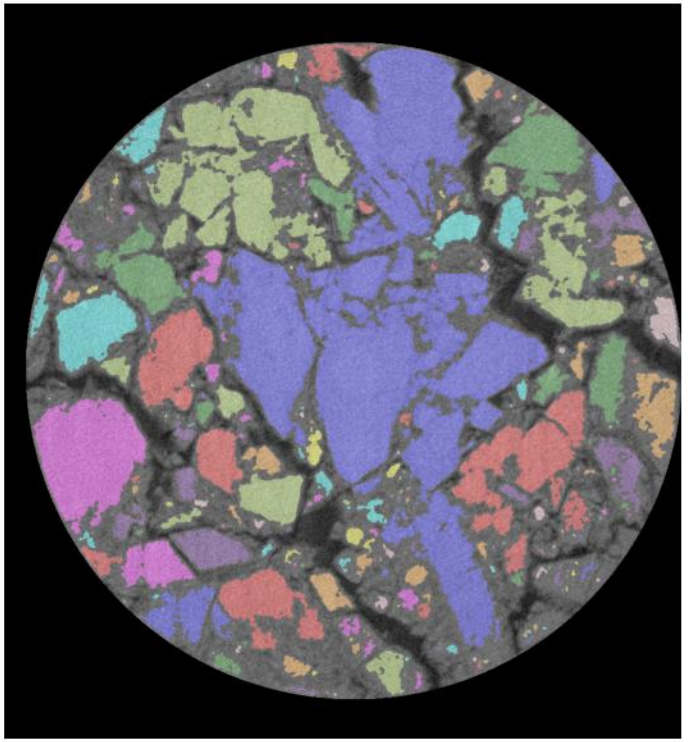

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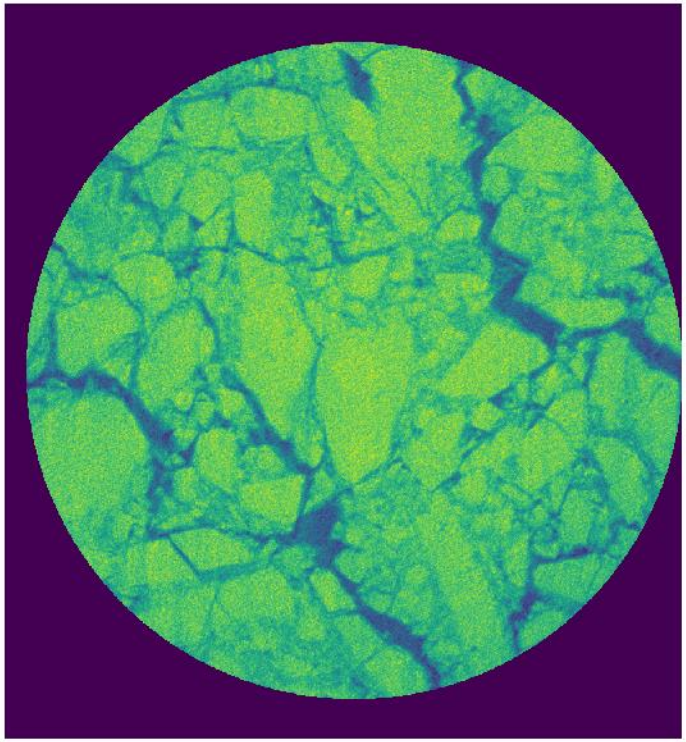

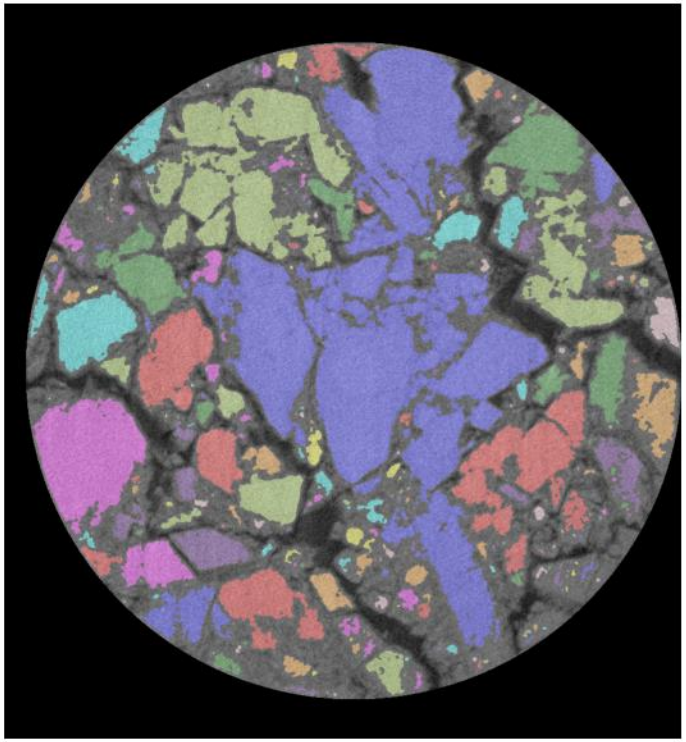

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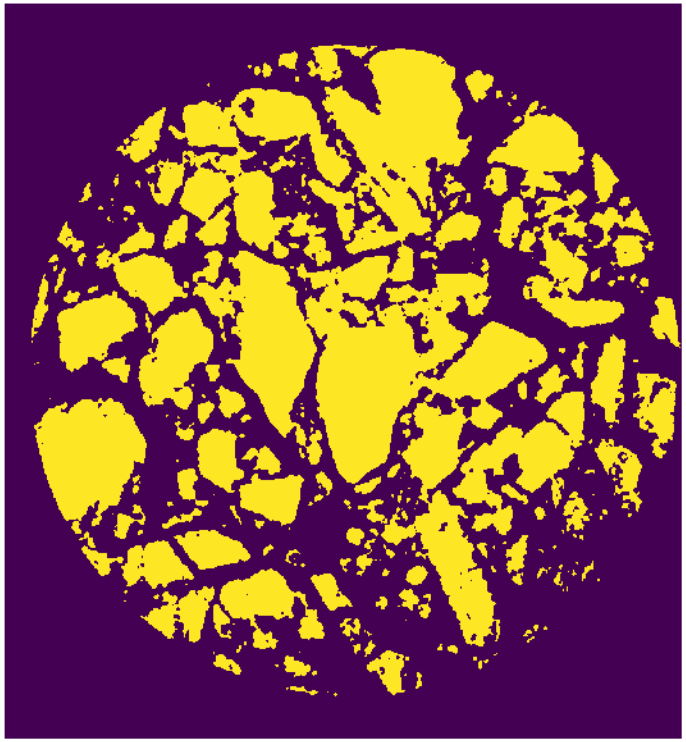
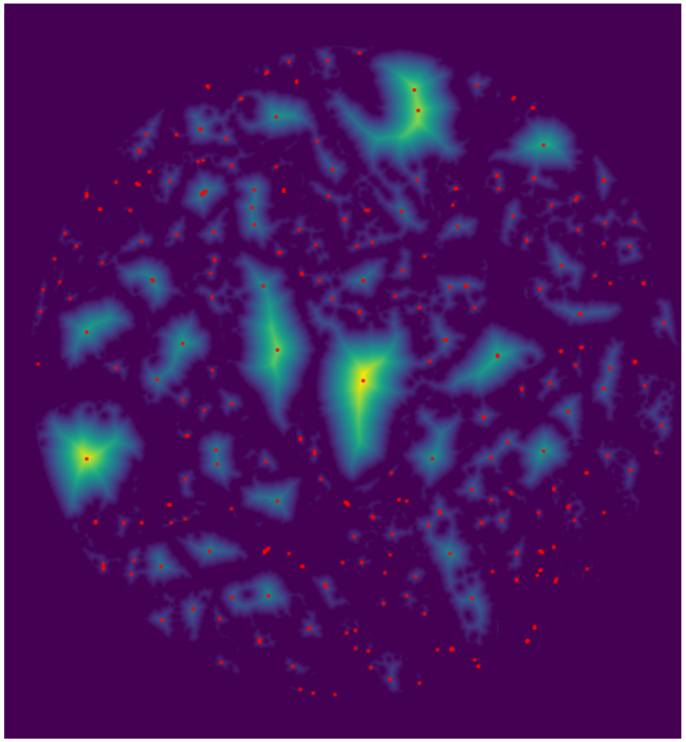
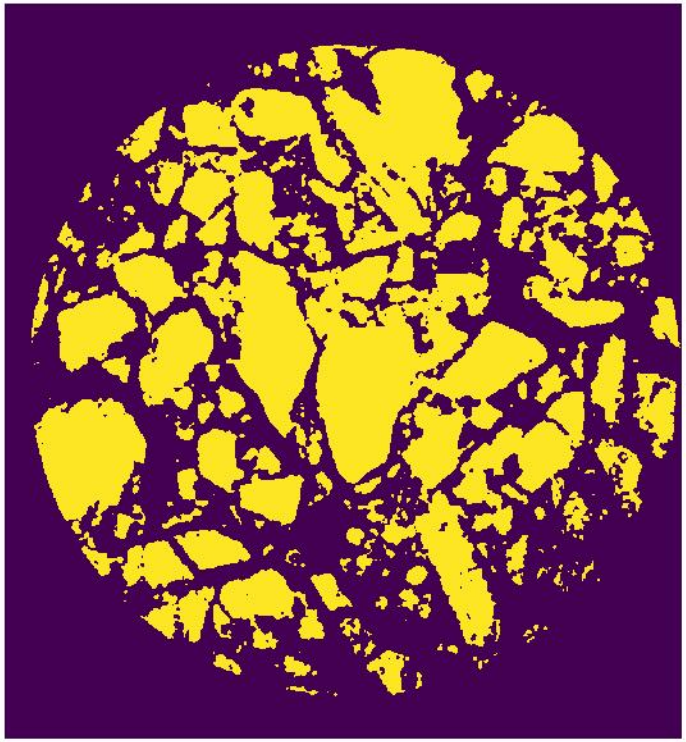
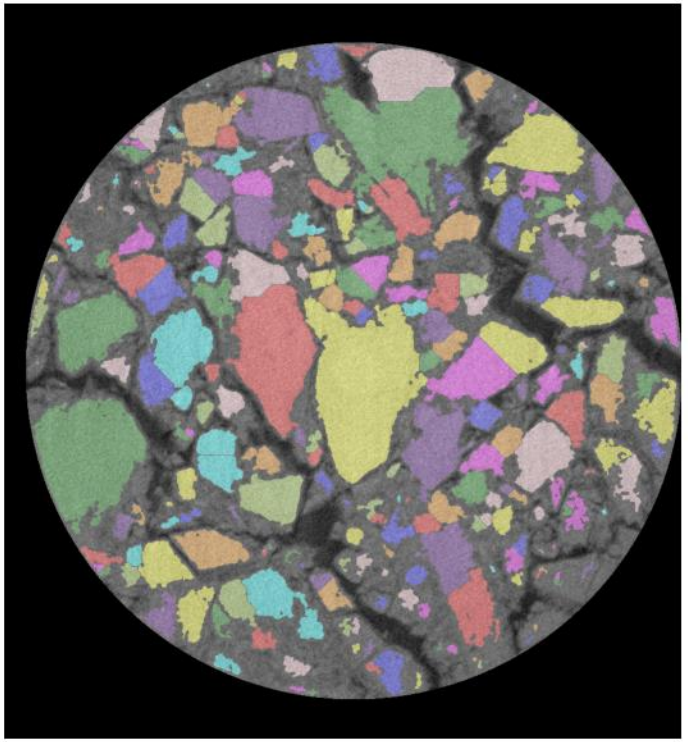




Segmenting IDOX Crystals





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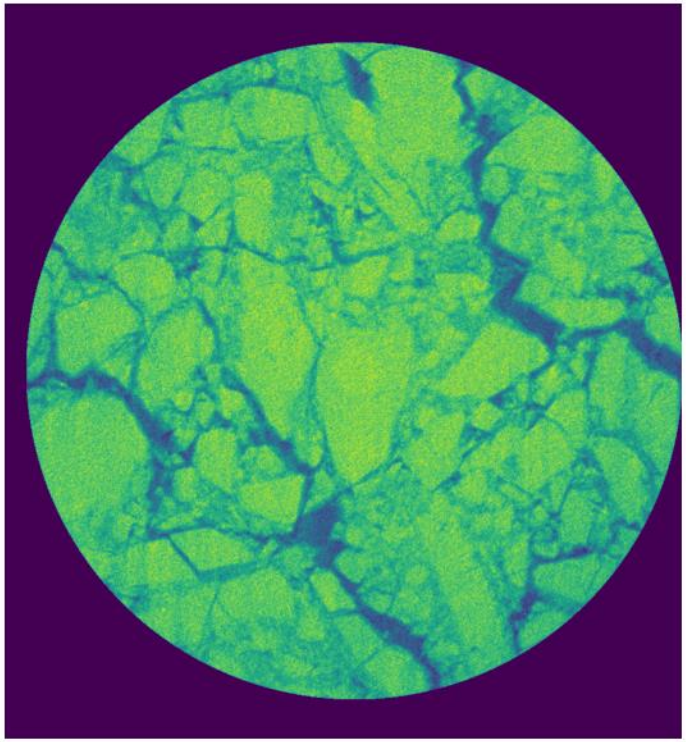
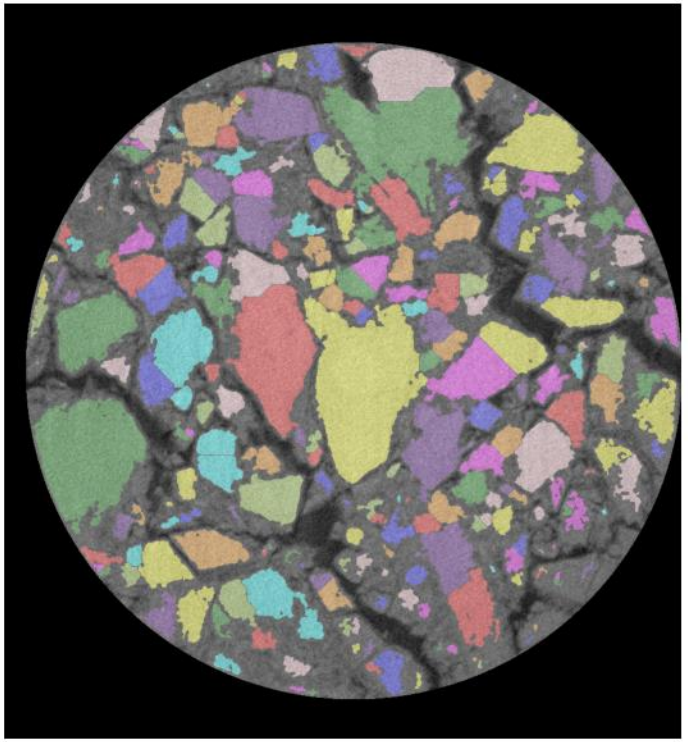
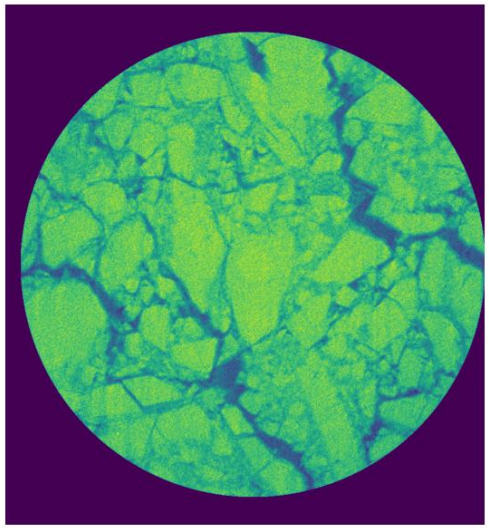
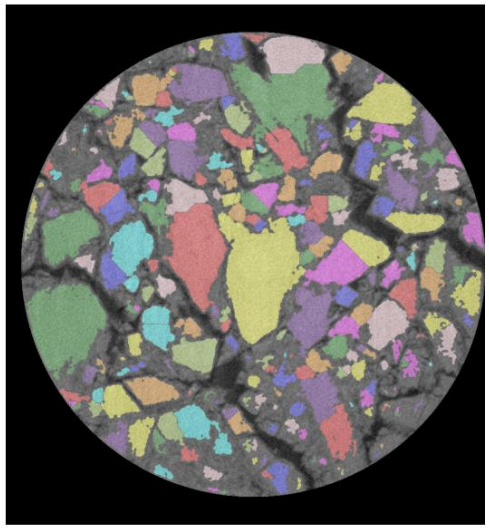




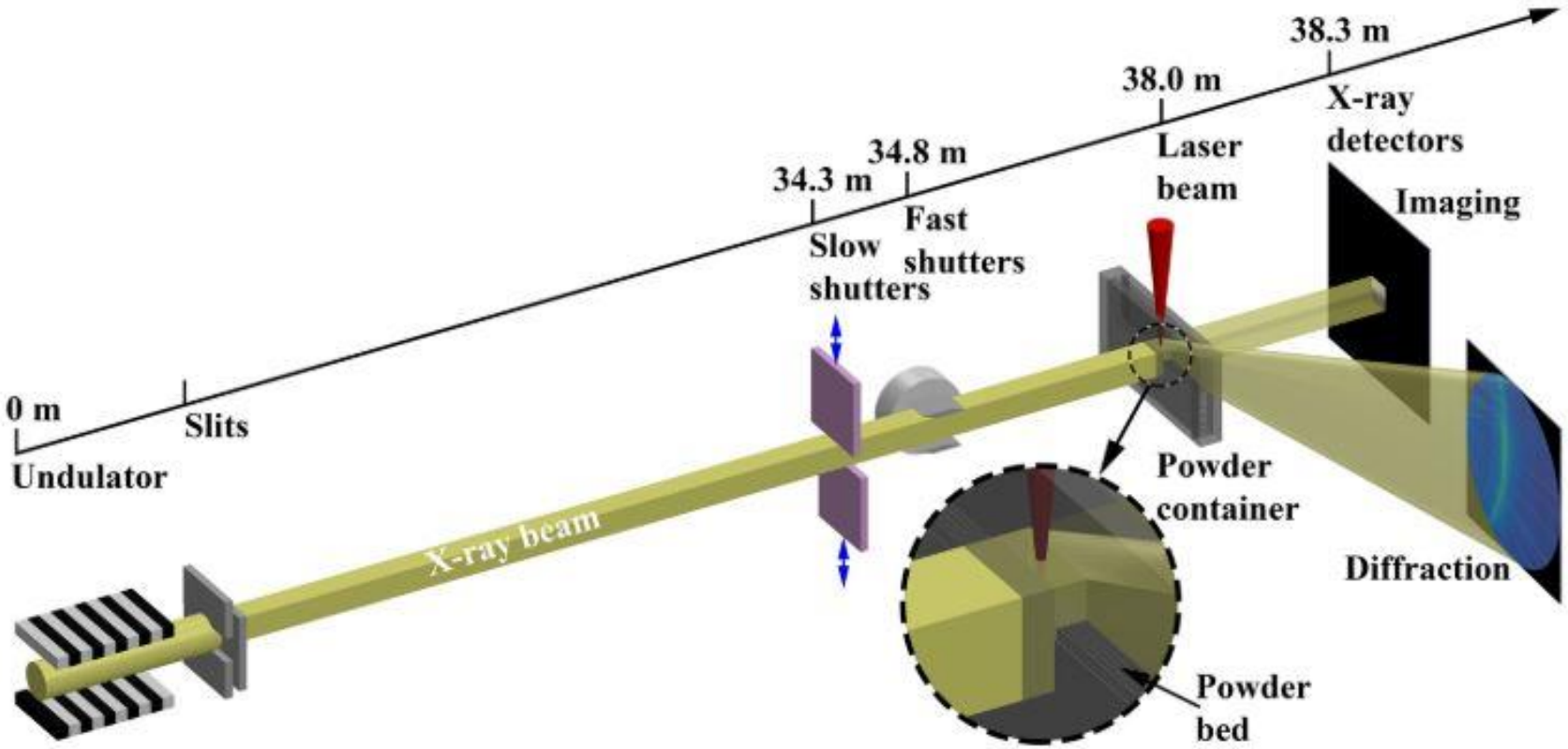
Segmenting IDOX Crystals

- Improve watershed segmentation
  - Improve seed from local max of distance
  - Psuedo-flatfield correction on base image to improve thresholding
- Bring segmentation to 3D
  - StarDist: Object detection with star-convex shapes
  - Pre-trained ML algorithms
  - ImageJ plugin
  - Python library





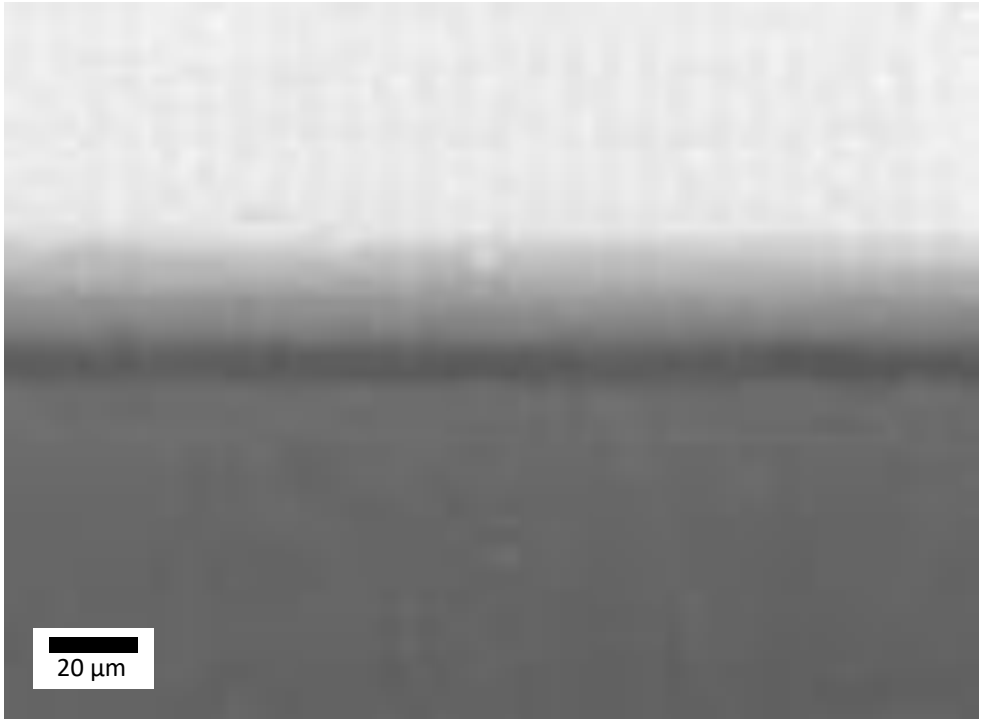
AM Simulator at the APS



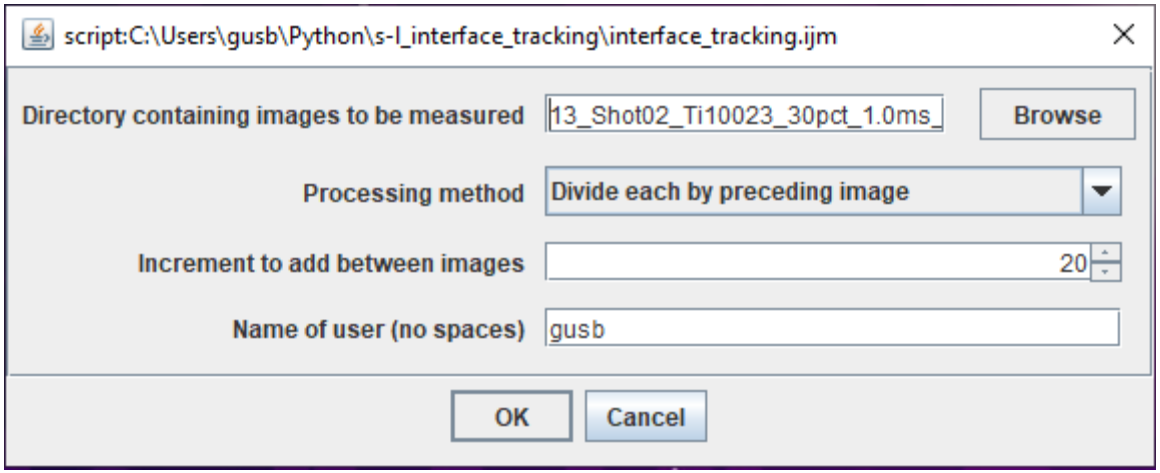
C. Zhao et al., *Scientific Reports,* 7 (2017) 1-11.

AM Simulator Example Experiment from the APS

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



AM Simulator: S-L Interface Analysis Pipeline



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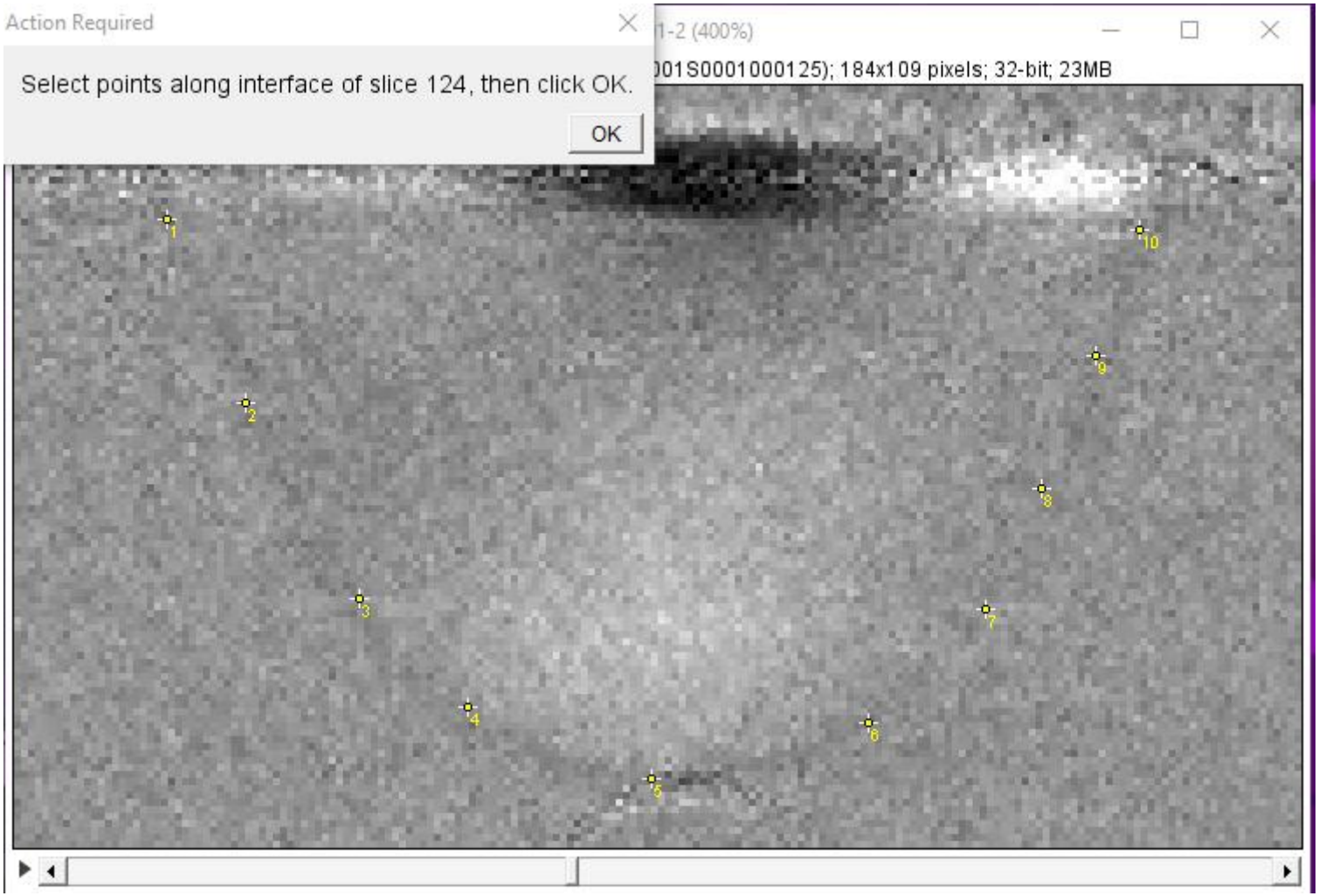

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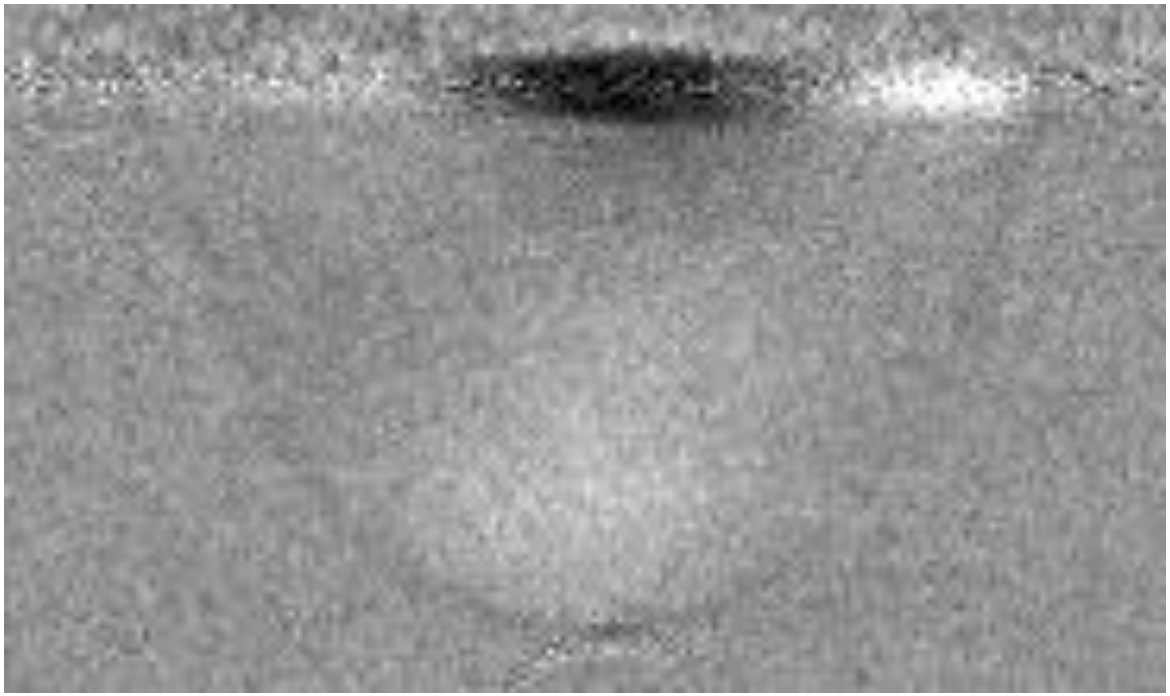

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2	1	22	14	124
3	2	25	26	124
4	3	34	49	124
5	4	47	74	124
6	5	66	94	124
7	6	94	102	124
8	7	125	91	124
9	8	144	70	124
10	9	154	46	124
11	10	162	24	124
12	11	33	14	144
13	12	39	33	144
14	13	48	52	144
15	14	60	67	144
16	15	77	82	144
17	16	102	90	144
18	17	125	78	144
19	18	140	61	144
20	19	149	41	144
21	20	156	18	144

AM Simulator: S-L Interface Analysis Pipeline

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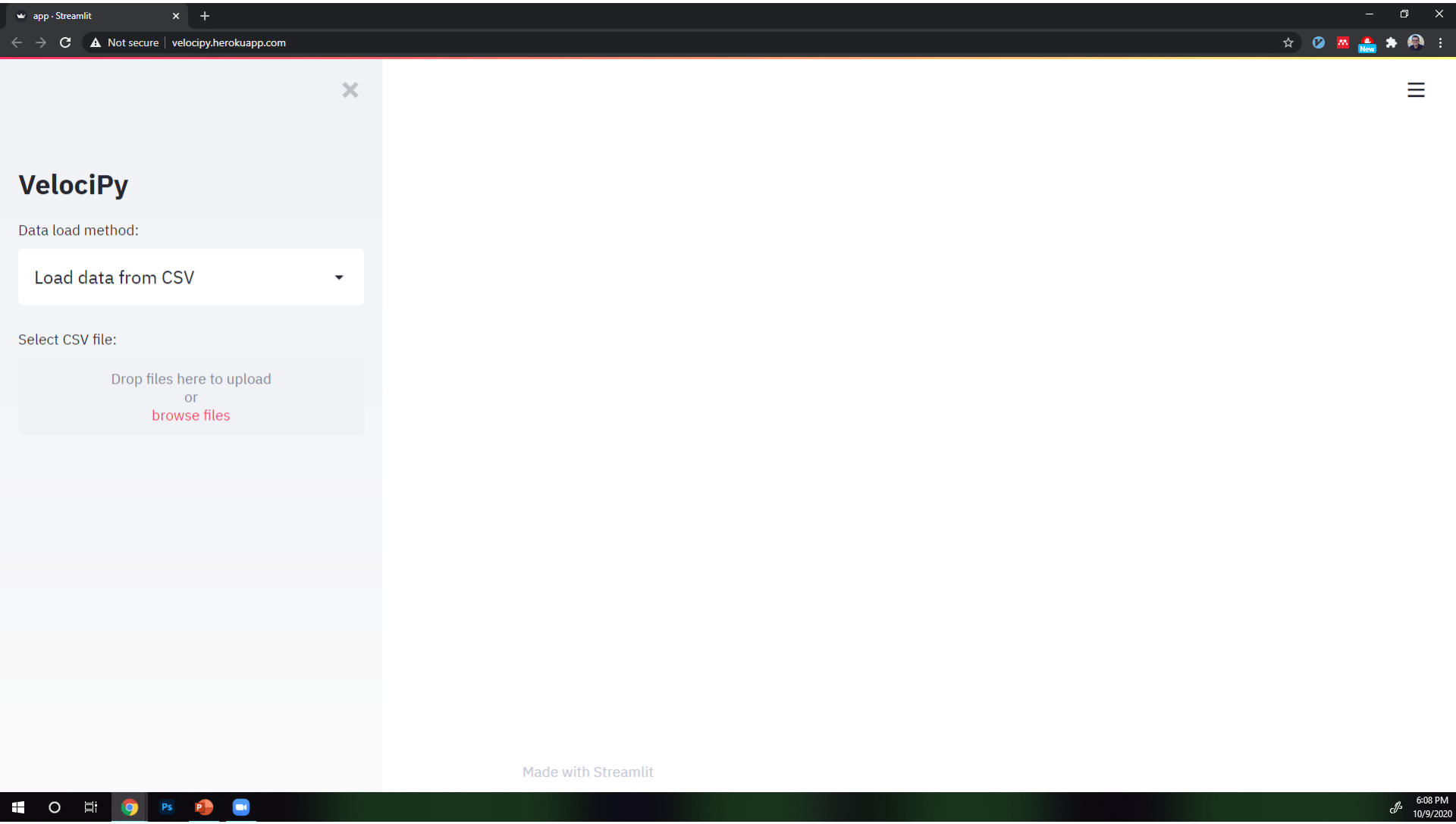
http://velocipy.herokuapp.com/

AM Simulator: S-L Interface Analysis Pipeline



AM Simulator: S-L Interface Analysis Pipeline

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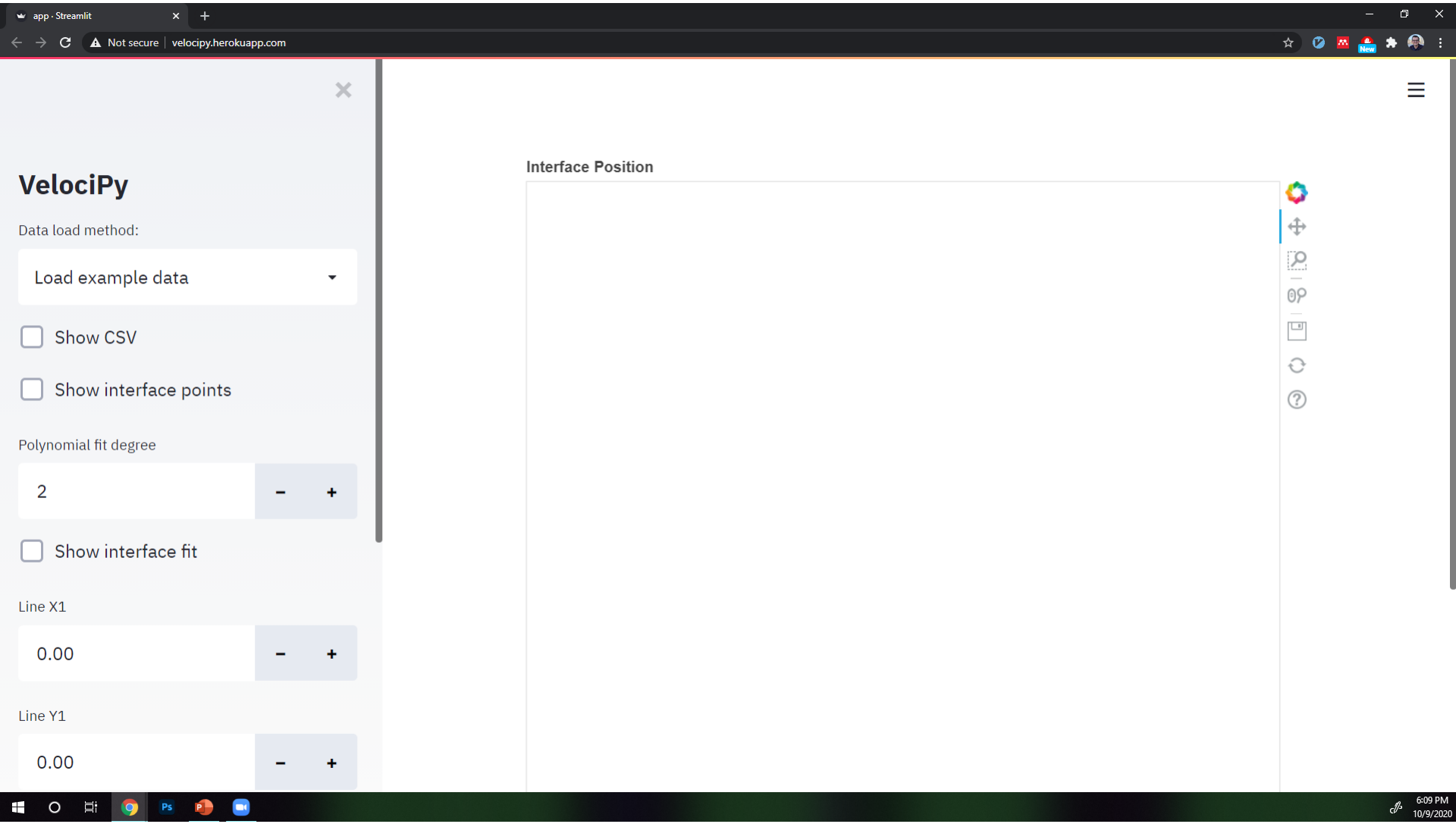

AM Simulator: S-L Interface Analysis Pipeline

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VelociPy

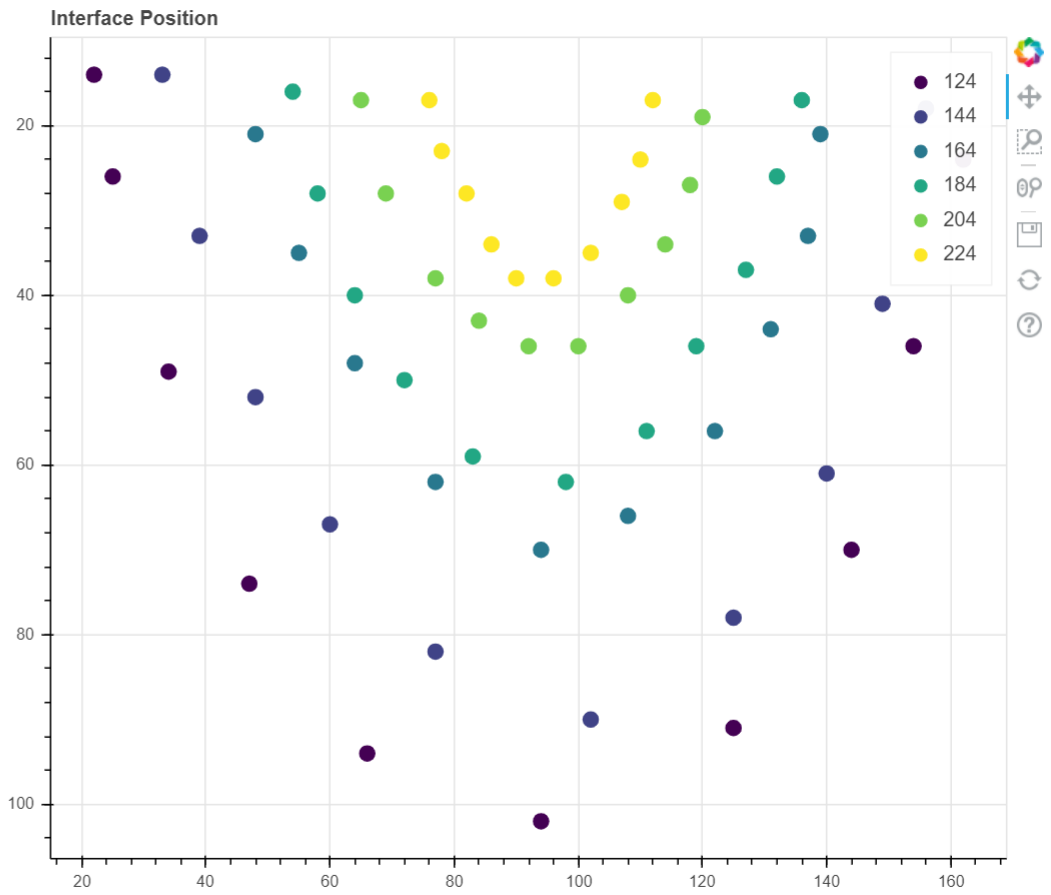
Data load method:

Load example data

Show CSV

		X	Y	Slice
0	1	22	14	124
1	2	25	26	124
2	3	34	49	124
3	4	47	74	124
4	5	66	94	124
5	6	94	102	124
6	7	125	91	124
7	8	144	70	124
8	9	154	46	124
9	10	162	24	124
10	11	33	14	144

Show interface points



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10/9/2020

AM Simulator: S-L Interface Analysis Pipeline

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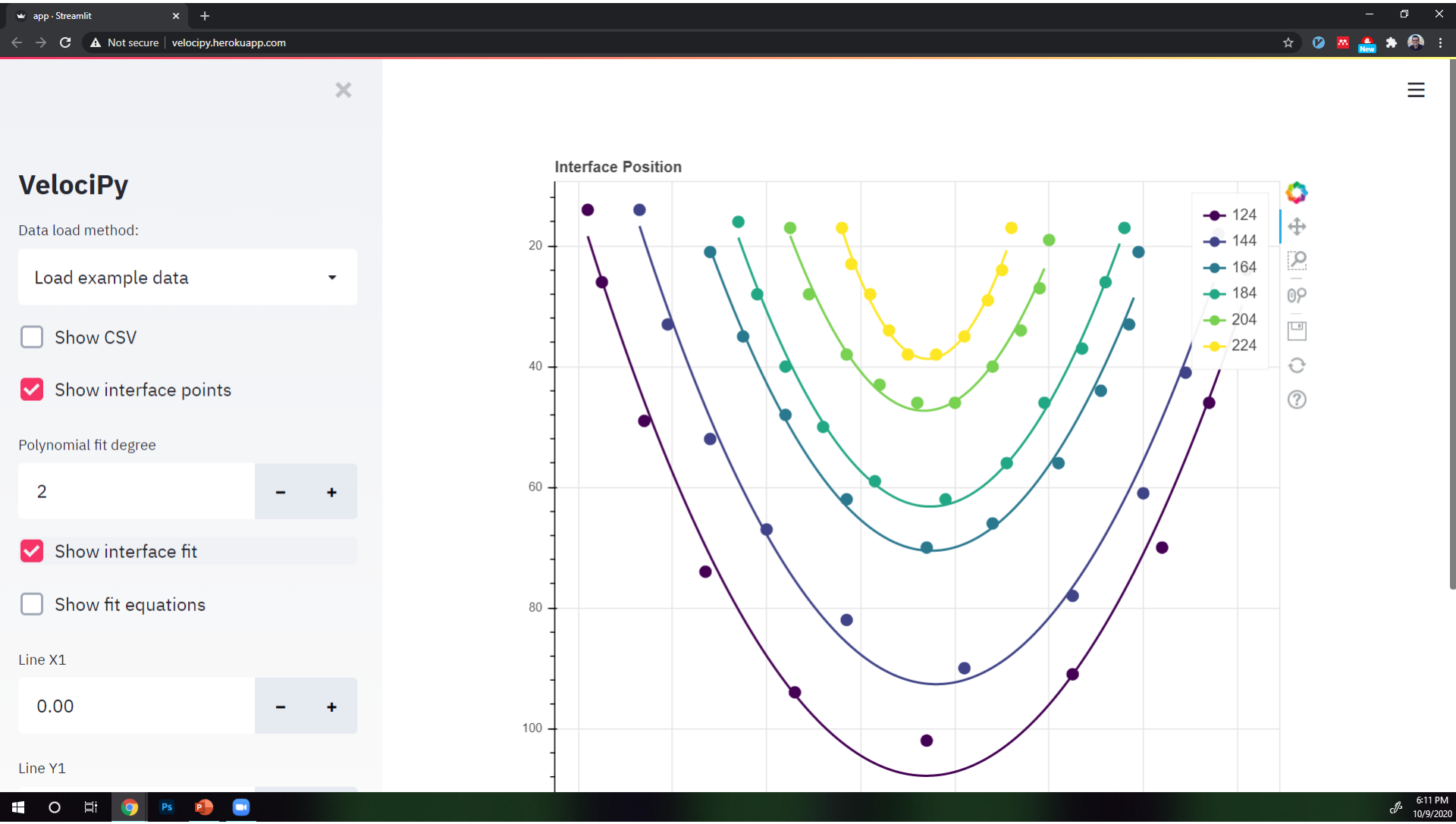

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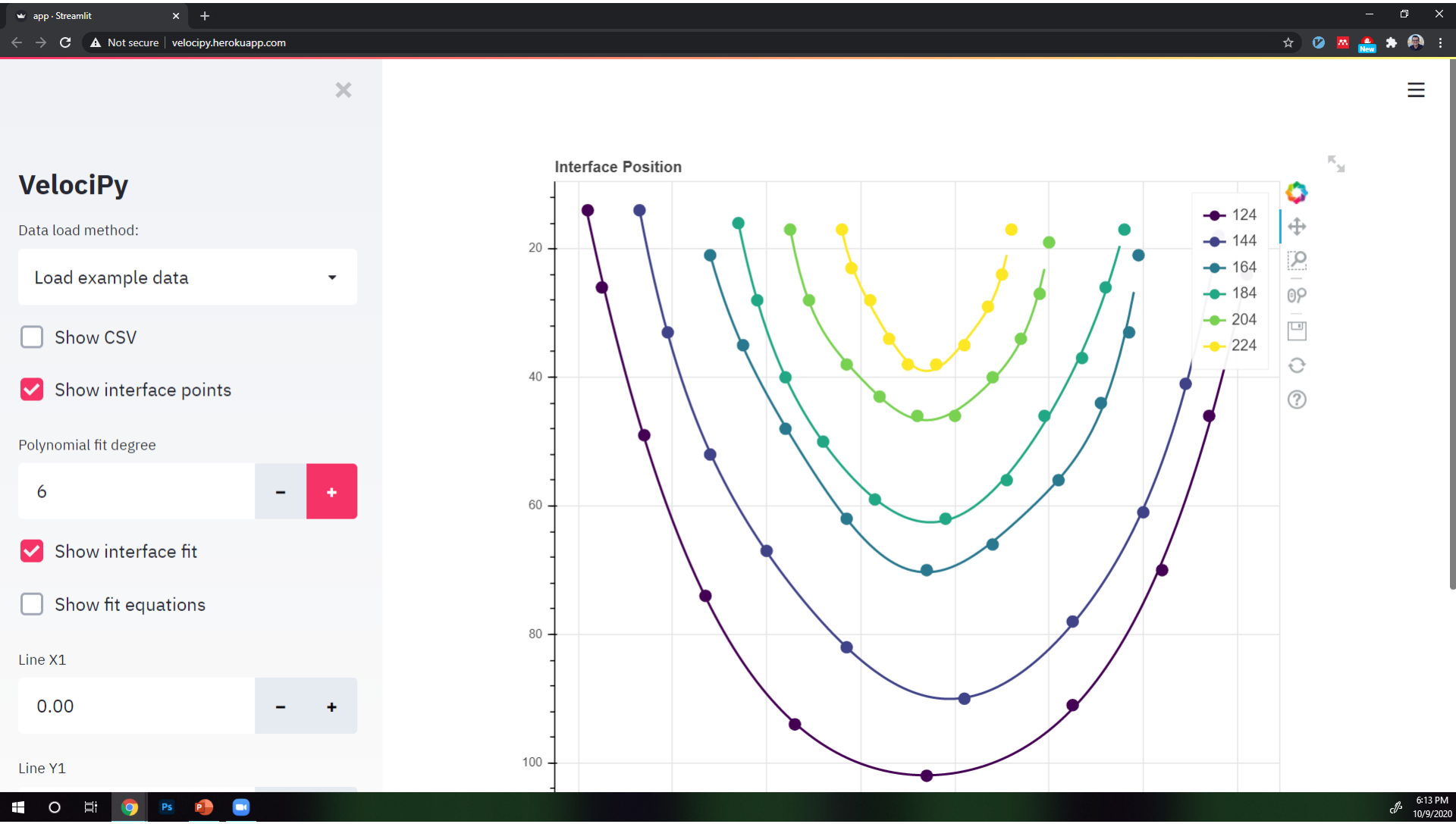

AM Simulator: S-L Interface Analysis Pipeline

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- [x] Show interface fit
- [ ] Show fit equations

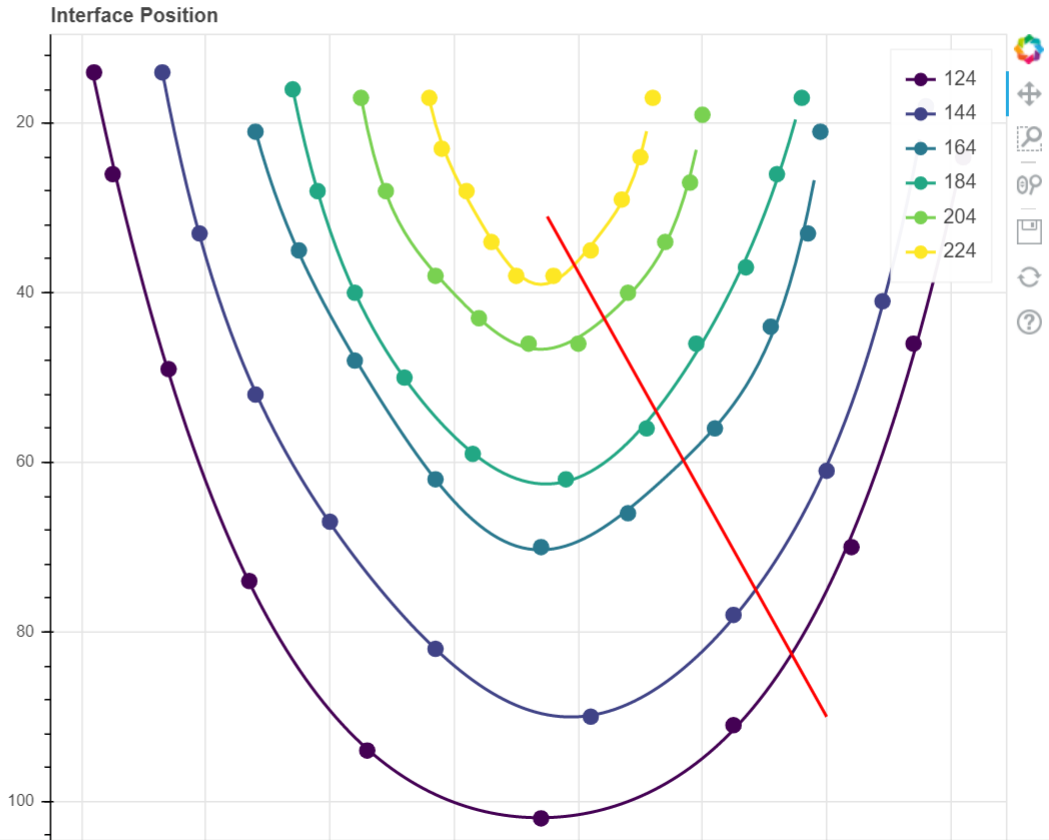
Line X1
95.00 − +

Line Y1
31.00 − +

Line X2
140.00 − +

Line Y2
90.00 − +

- [x] Show line
- [ ] Show line equation
- [ ] Show intersection calculations



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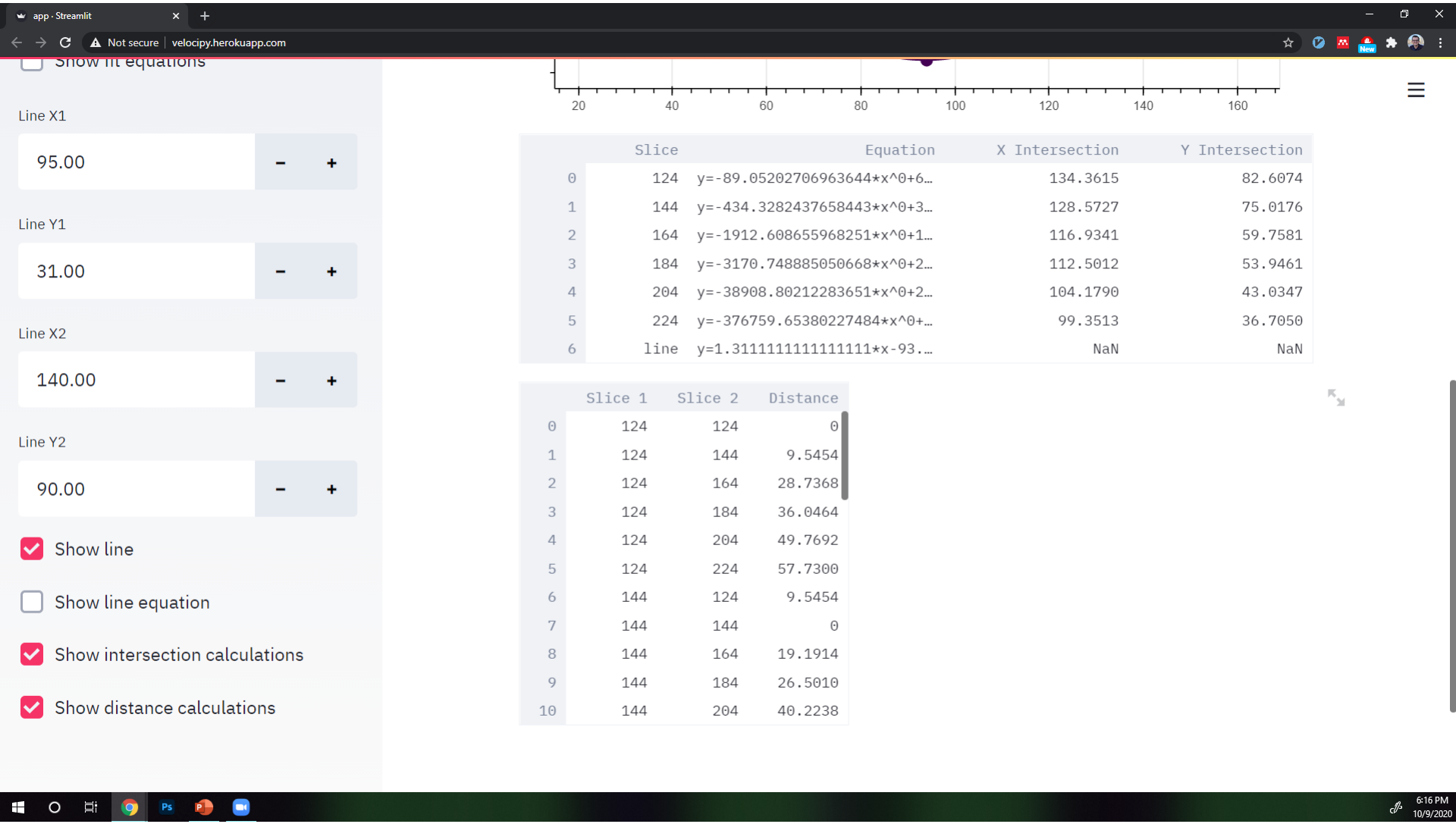
AM Simulator: S-L Interface Analysis Pipeline

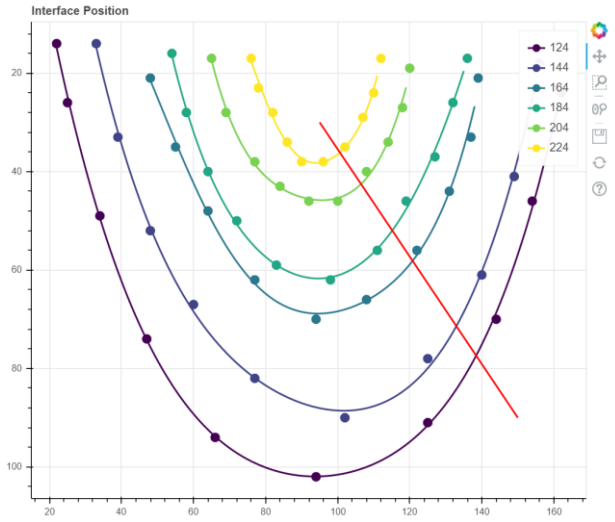


	Slice	Equation	X Intersection	Y Intersection
0	124	y=-89.05202706963644*x^0+6…	134.3615	82.6074
1	144	y=-434.3282437658443*x^0+3…	128.5727	75.0176
2	164	y=-1912.608655968251*x^0+1…	116.9341	59.7581
3	184	y=-3170.748885050668*x^0+2…	112.5012	53.9461
4	204	y=-38908.80212283651*x^0+2…	104.1790	43.0347
5	224	y=-376759.65380227484*x^0+…	99.3513	36.7050
6	line	y=1.3111111111111111*x-93.…	NaN	NaN

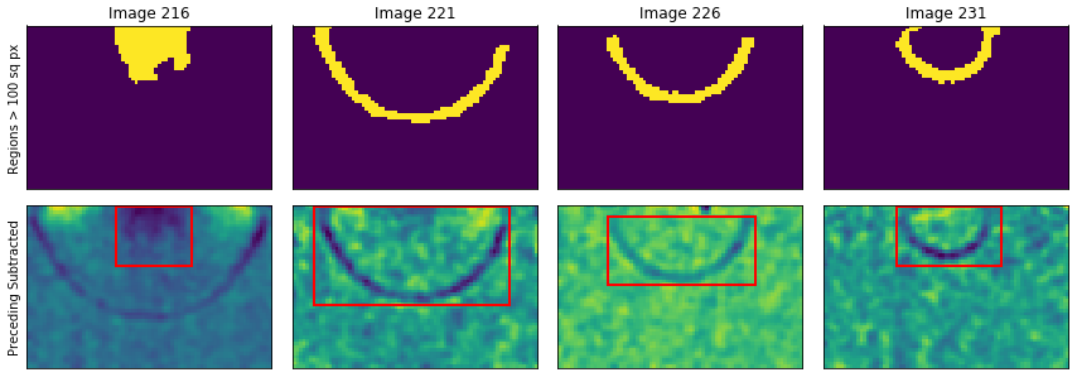
	Slice 1	Slice 2	Distance
0	124	124	0
1	124	144	9.5454
2	124	164	28.7368
3	124	184	36.0464
4	124	204	49.7692
5	124	224	57.7300
6	144	124	9.5454
7	144	144	0
8	144	164	19.1914
9	144	184	26.5010
10	144	204	40.2238

AM Simulator: S-L Interface Analysis Pipeline

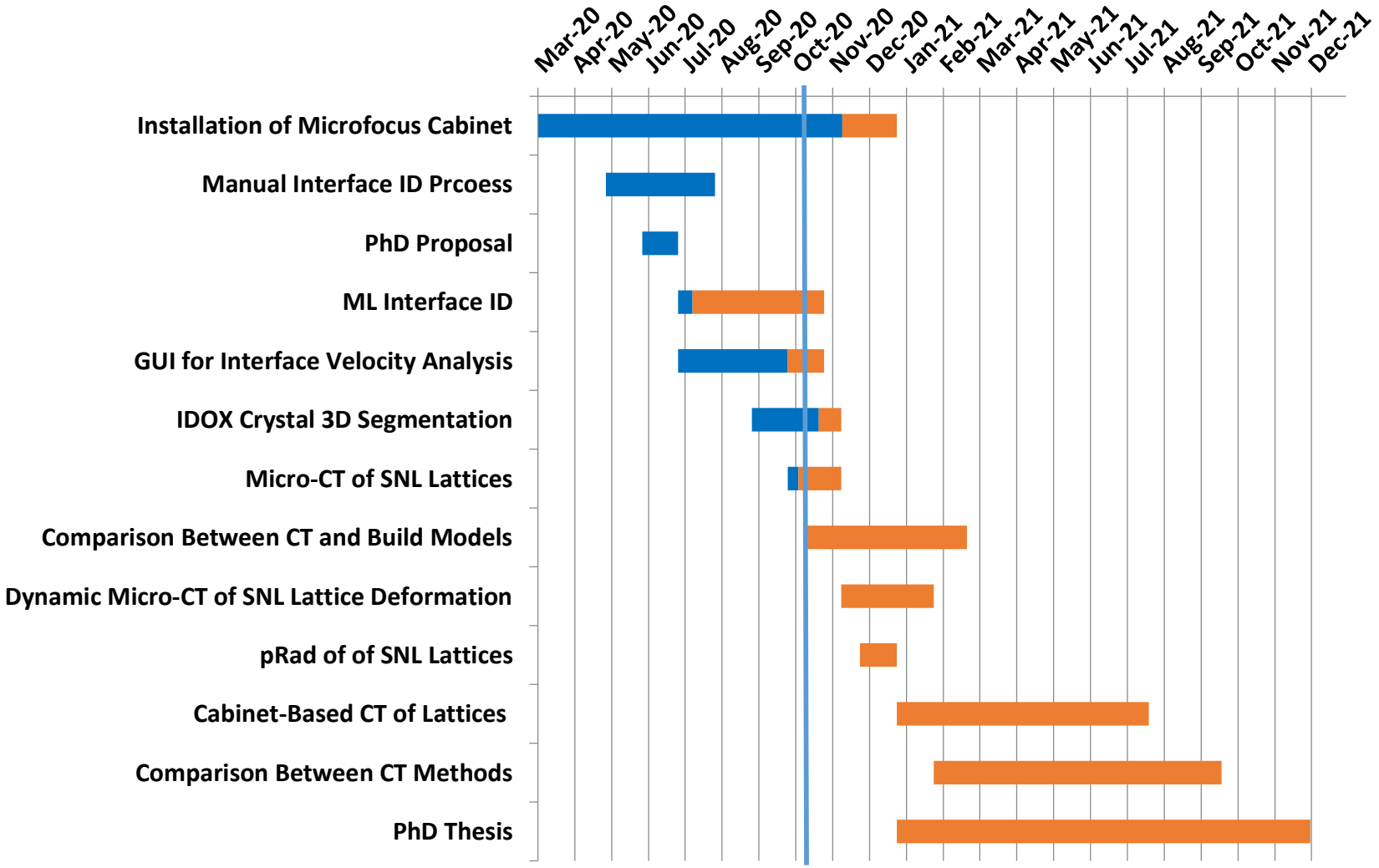
- Things to add to VelociPy:
  - Add ability to import image as background
  - Add different file types for exporting data
  - Add control for which data is exported
  - Add more diverse colormap options



- Further down the data processing pipeline:
  - Improved automated interface identification
  - ML interface identification



Progress



Challenges & Opportunities

- Cabinet-based x-radiography possibilities
- Streamlit and Heroku for deployable data science GUIs like VelociPy
  - http://velocipy.herokuapp.com/
- Automating the S-L interface analysis pipeline
  - Traditional image processing
  - ML model deployment

Thank you!

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