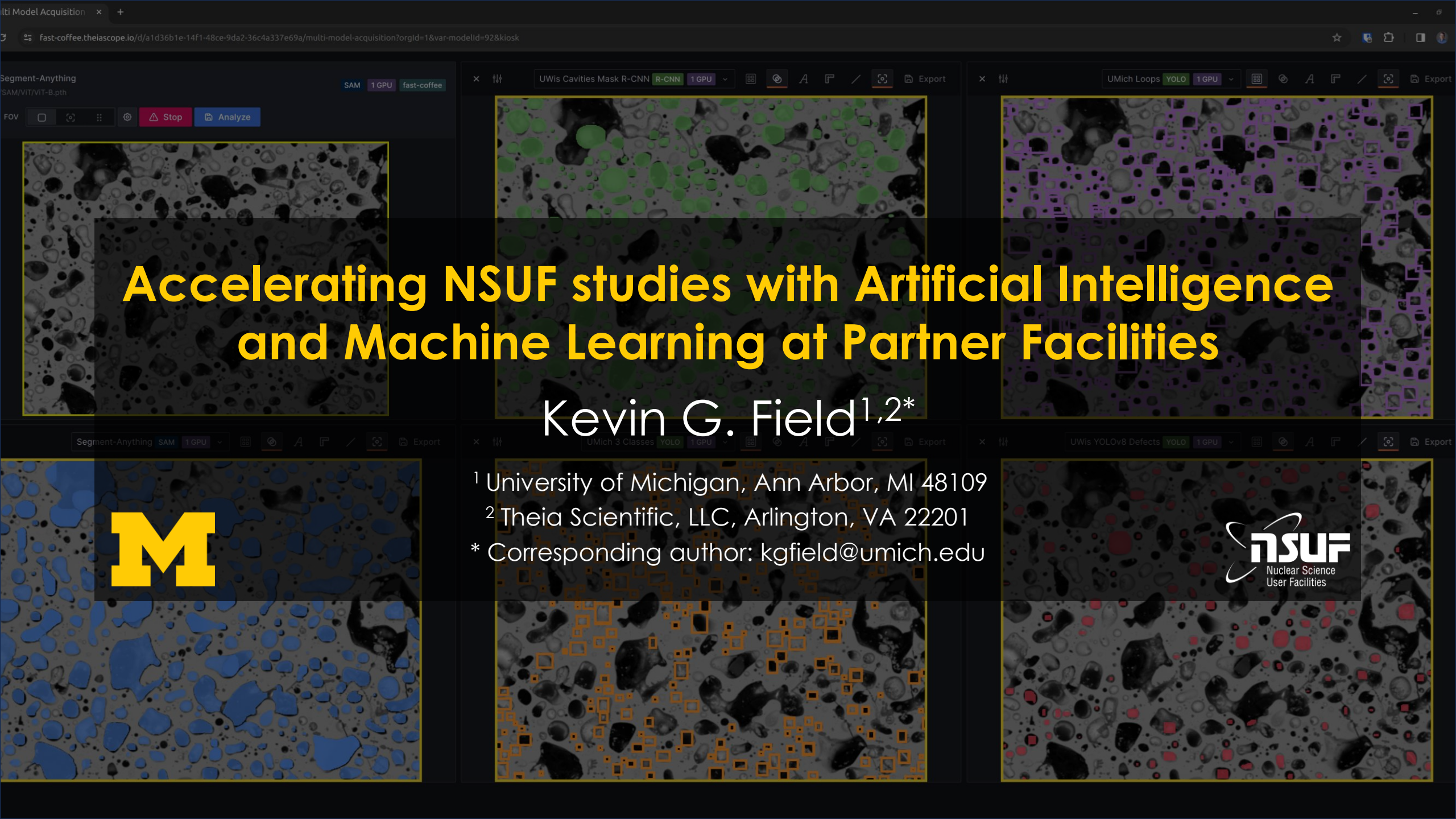


Accelerating NSUF studies with Artificial Intelligence and Machine Learning at Partner Facilities

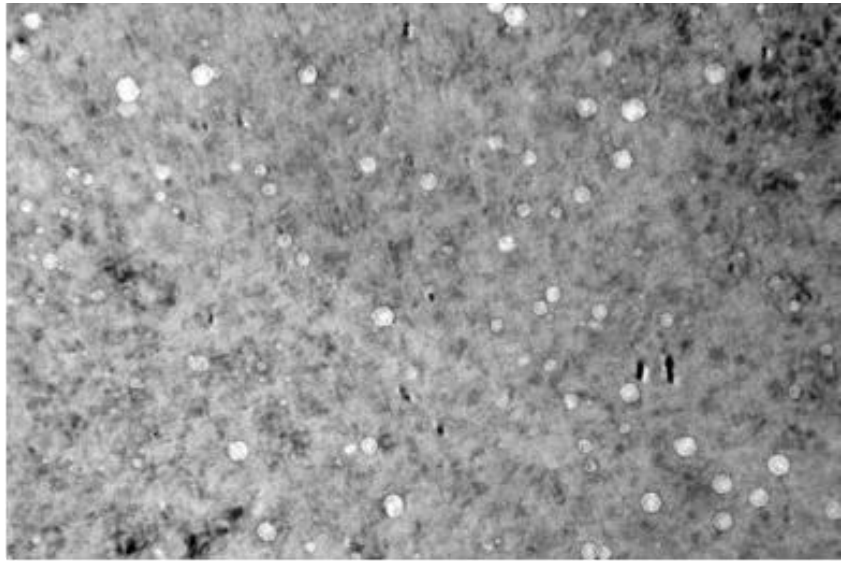
Kevin G. Field[1,2*]

[1] University of Michigan, Ann Arbor, MI 48109

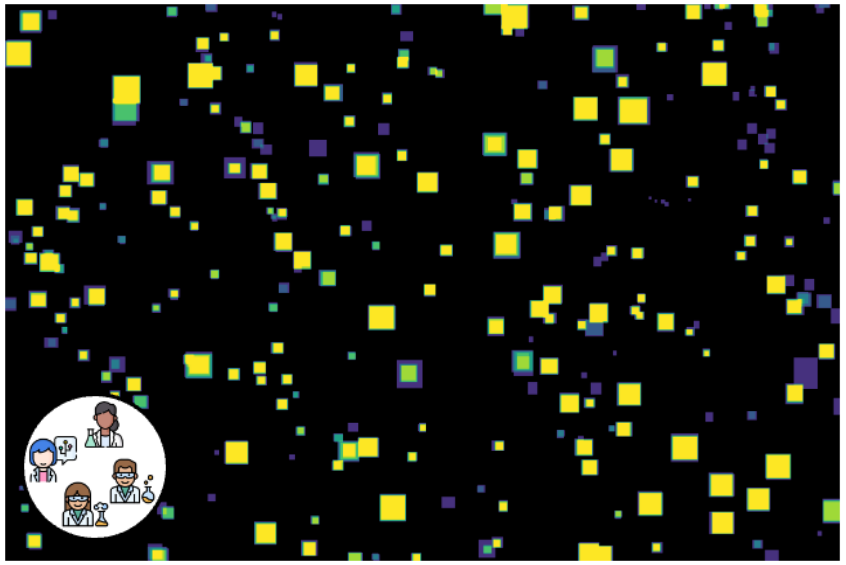
[2] Theia Scientific, LLC, Arlington, VA 22201

* Corresponding author: kgfield@umich.edu

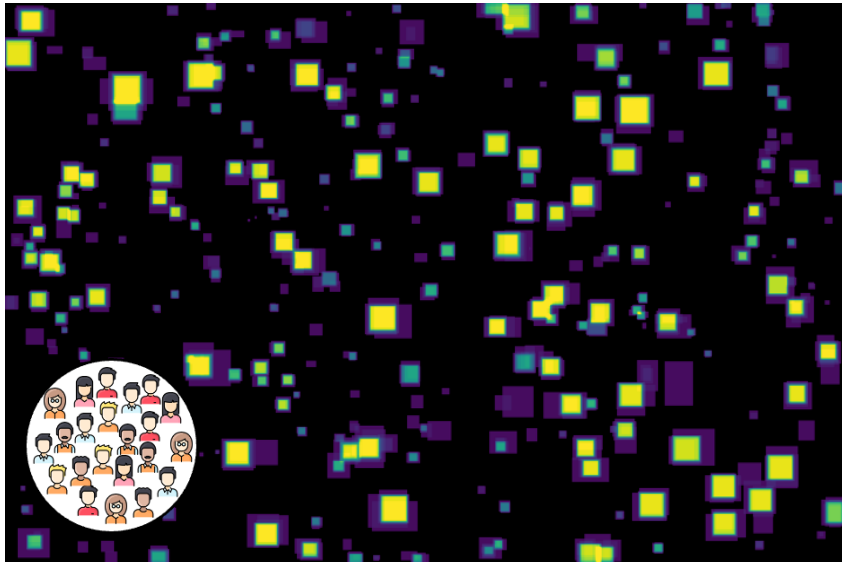
Applying machine learning can increase the quality and consistency of NSUF user data



Original Image



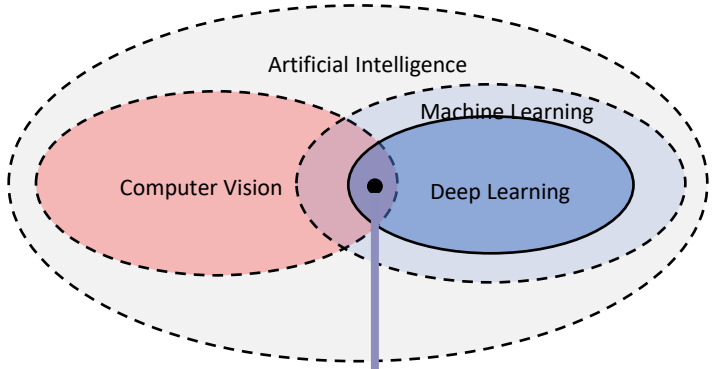
6 Experts

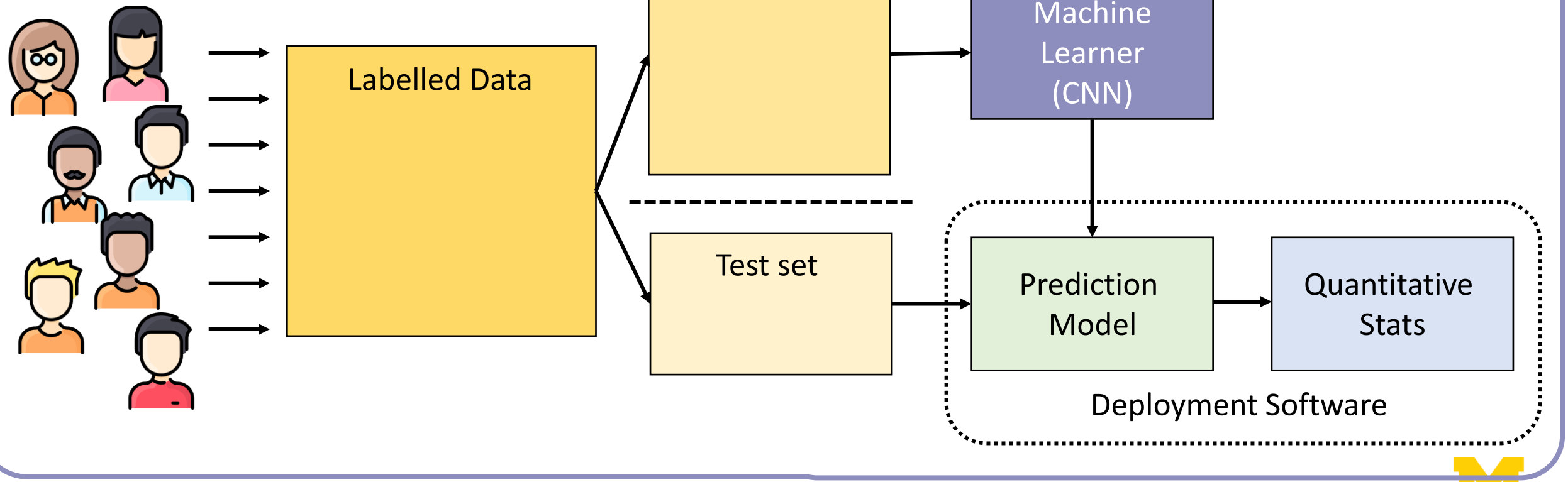


33 Non-Experts

- Only in rare instances are users likely to quantify a complex image the same
- ML methods like object detection will provide the same answer on the same image everytime

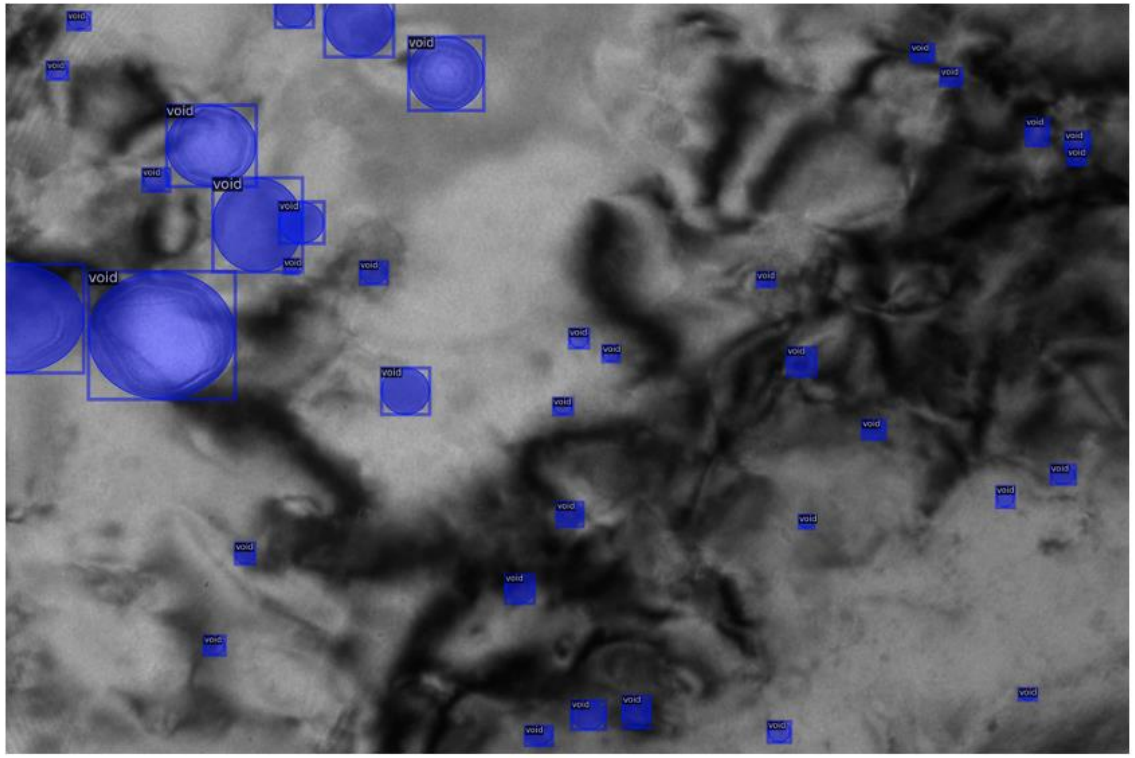
Our ML approach uses supervised learning (requires labelled data)



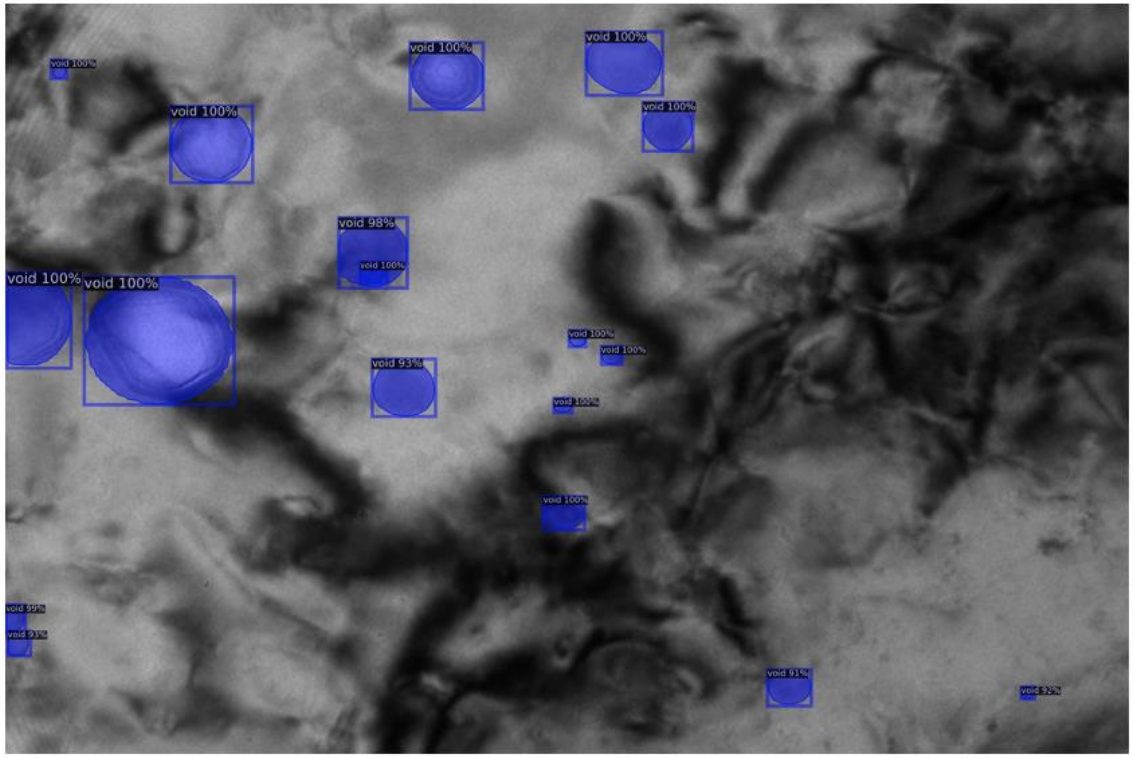


3

Example of our best Mask R-CNN detection model for cavities in irradiated materials



Human Expert

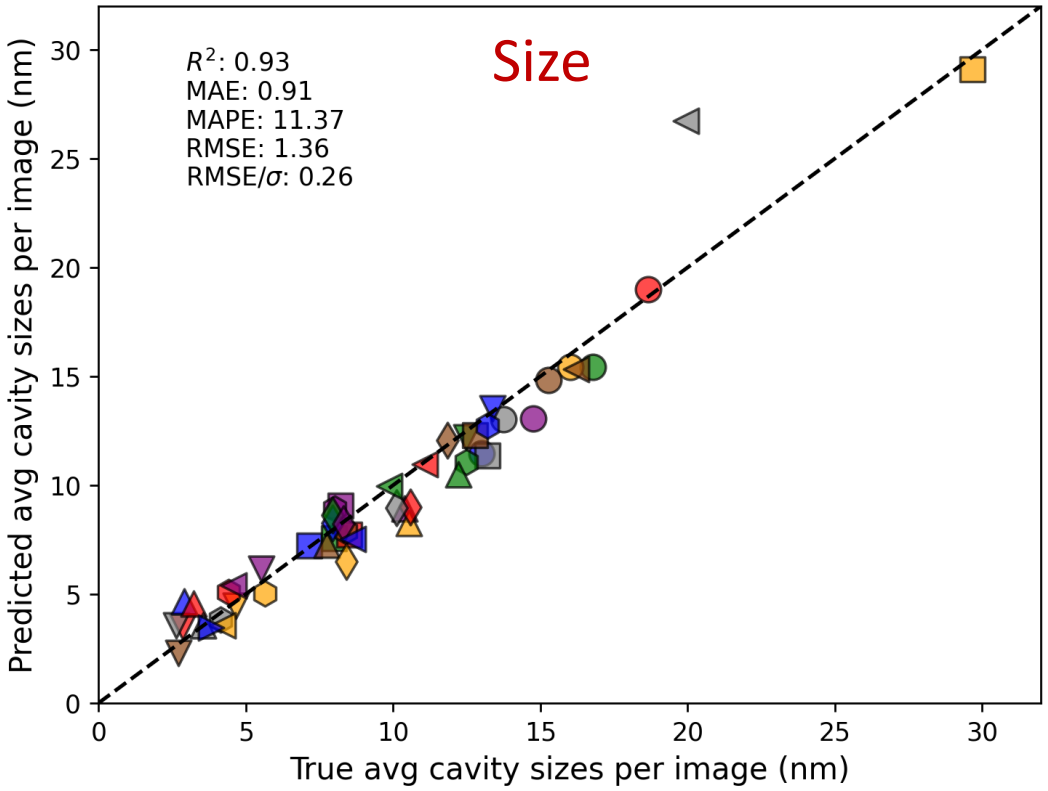


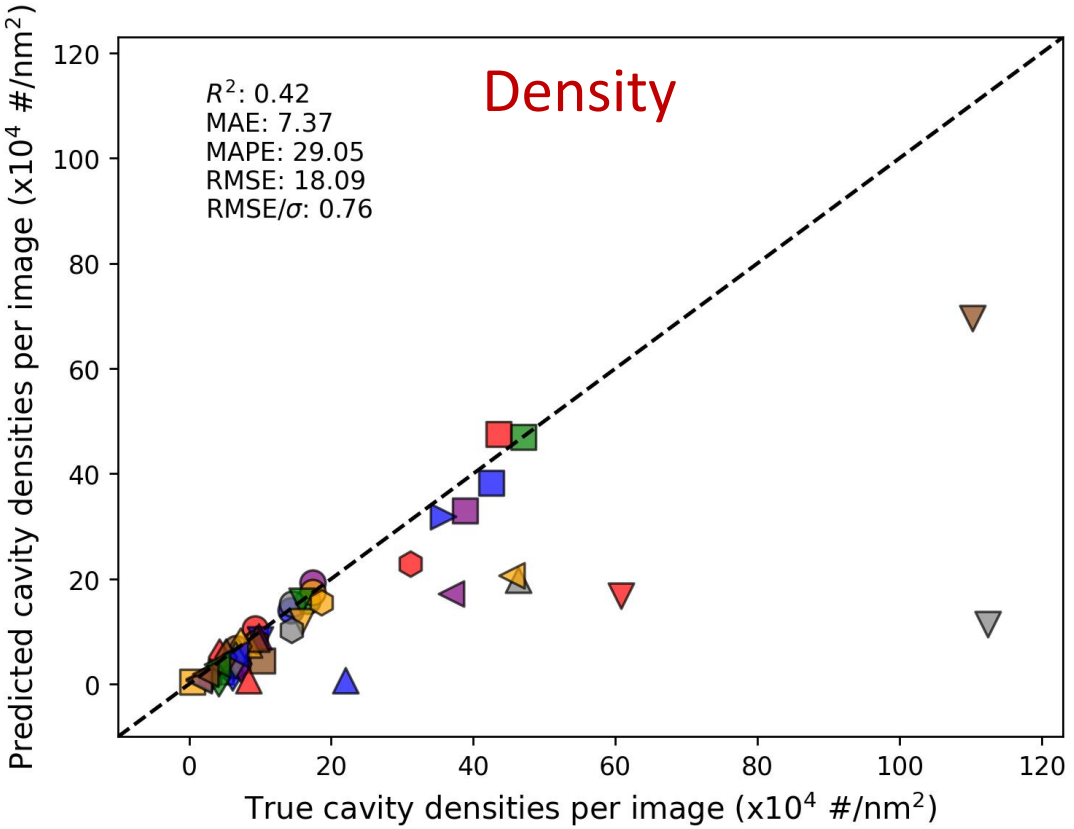
Mask R-CNN

Jacobs, R., Patki, P., Lynch, M.J. *et al.* Materials swelling revealed through automated semantic segmentation of cavities in electron microscopy images. *Sci Rep* **13**, 5178 (2023). https://doi.org/10.1038/s41598-023-32454-2

NUCLEAR ENGINEERING & RADIOLOGICAL SCIENCES
UNIVERSITY OF MICHIGAN

ML-based object detection using **c**onvolutional **n**eural **n**etworks (CNNs) enable human-like quantification in less than a second

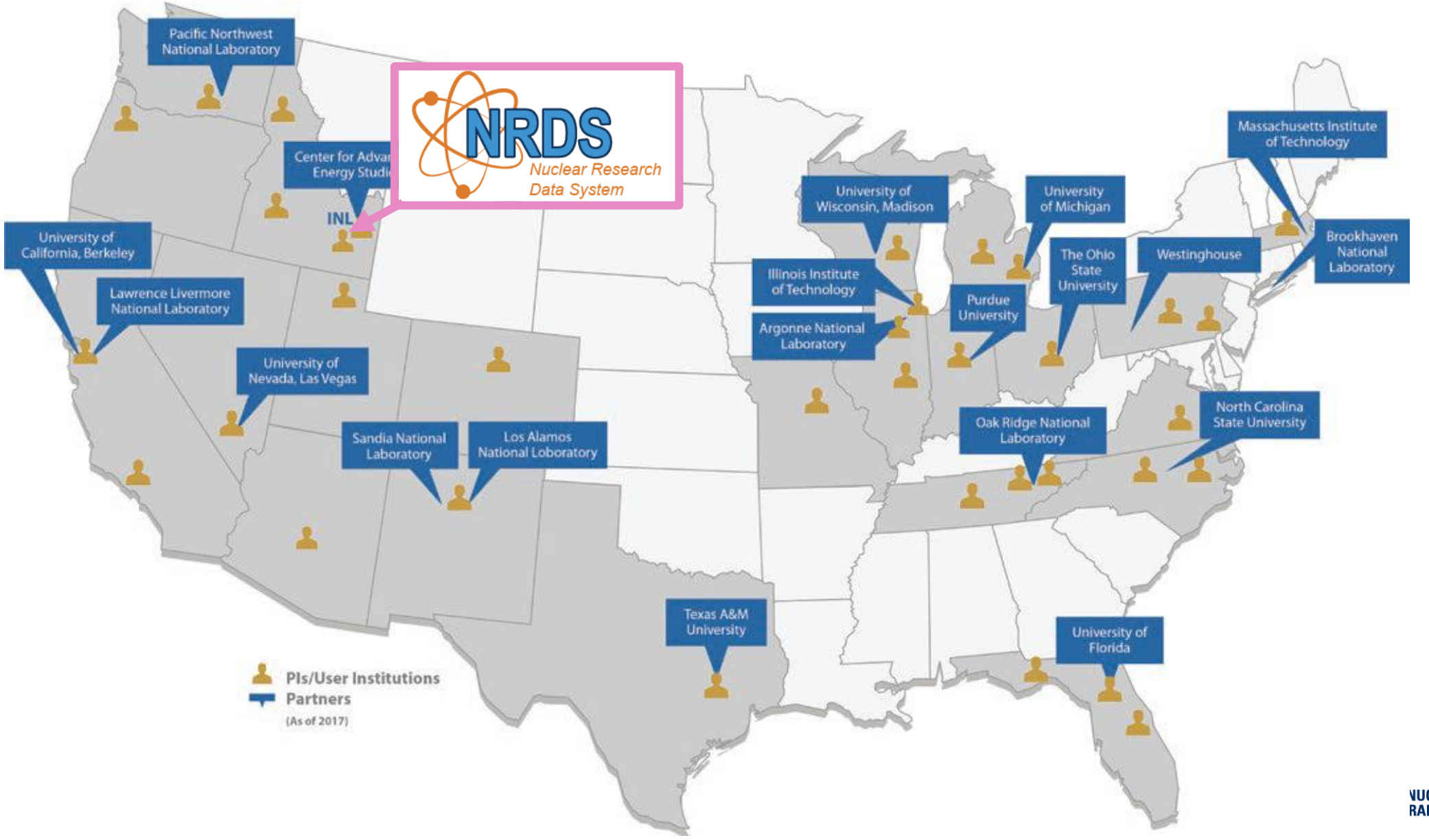




Jacobs, R., Patki, P., Lynch, M.J. *et al. Sci Rep* **13**, 5178 (2023). https://doi.org/10.1038/s41598-023-32454-2

NUCLEAR ENGINEERING & RADIOLOGICAL SCIENCES
UNIVERSITY OF MICHIGAN

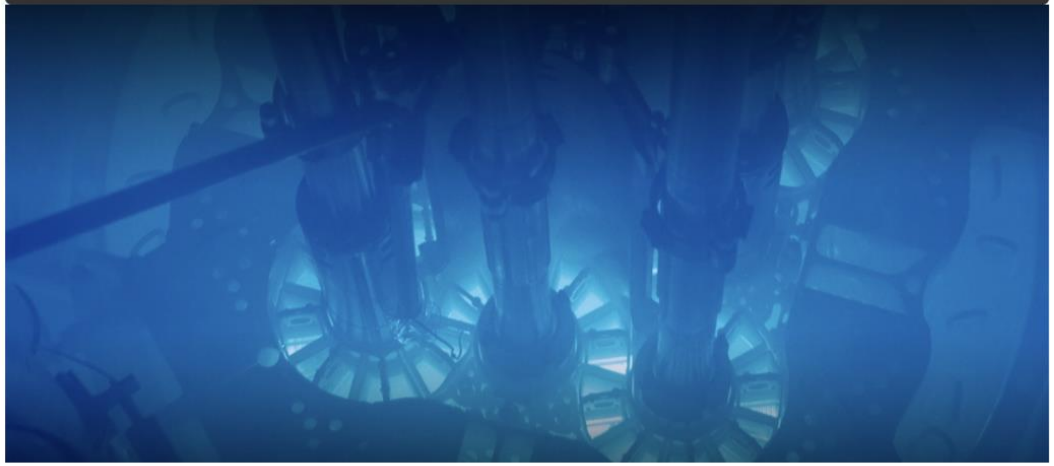
Theiascope™ systems are now at several partner facilities



Welcome to NRDS

The Nuclear Research Data Search (NRDS) site is a public-facing, long-term data storage solution and science data gateway featuring integrated compute resources such as artificial intelligence enabled hardware, and access to graphics processing units (GPUs). Operated out of the US Department of Energy Office of Nuclear Energy's Nuclear Science User Facilities (NSUF) program, NRDS takes publicly funded data from NSUF research and makes it accessible to the public without requiring a paywall or account and ensure all data meets the pFAIRe criteria.

Advanced Test Reactor



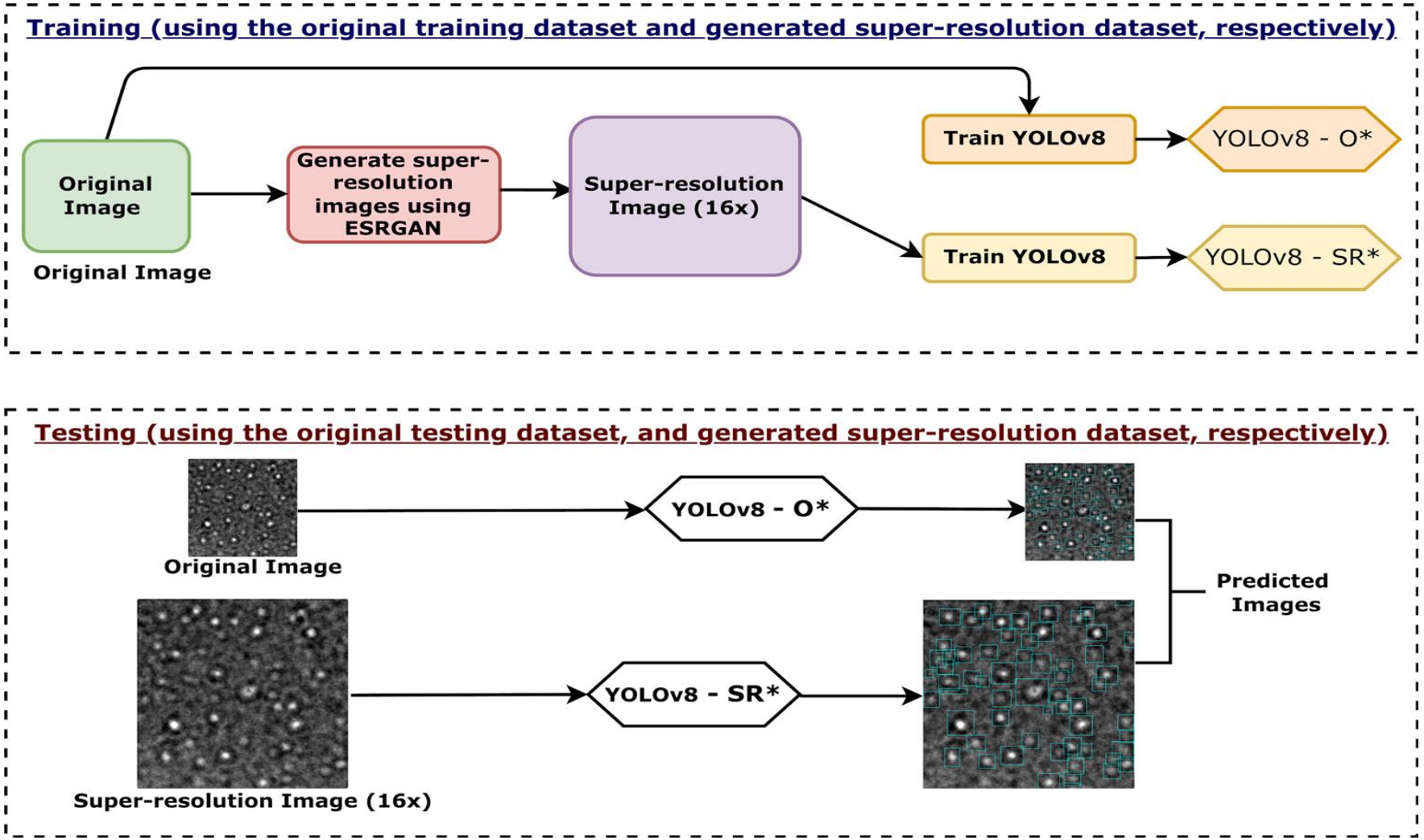
Search data

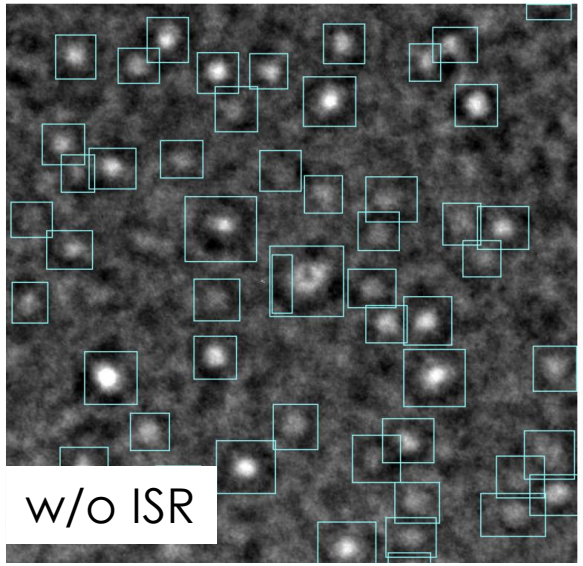
E.g. nuclear energy

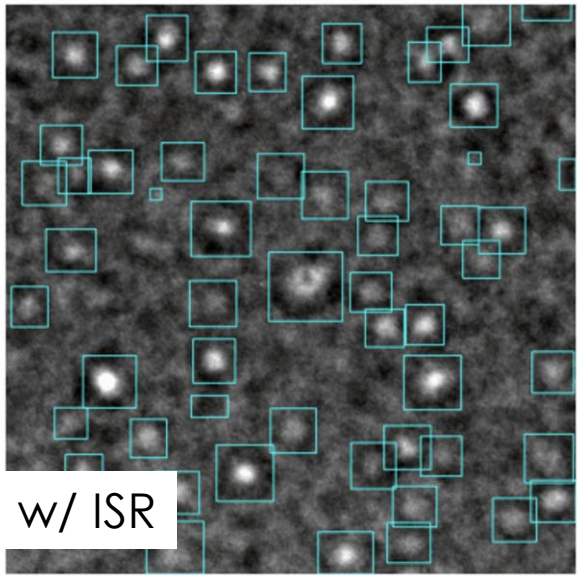
Current AI Analysis Features

Super Resolution - Low resolution to high resolution photos
Activity Detection - Locating temporal activities within a video
Dislocation Segmentation - Segment dislocation loop and line defects in an image
Dislocation Lines - Overlay dislocation lines on an image

Application of image super-resolution (ISR) like in NRDS can improve machine learning object detection







J. Olamofe, L. Qian, K.G.Field, *J. IEEE Access.*, **Under Revision**, 2025

Application of image super-resolution (ISR) like in NRDS can improve machine learning object detection

	Model O-M	Model SR-M
Total Predictions	**4775**	**3768**
Total ground-truth	**4259**	**4259**
True Positives	**2607**	**2475**
False Positives	**2168**	**1293**
False Negatives	**1652**	**1784**
Precision	**0.5459**	**0.6568**
Recall	**0.6121**	**0.5811**
F1	**0.5772**	**0.6167**

*** **Model O-M**: YOLOv8 model trained on original dataset and tested on original dataset for all modalities

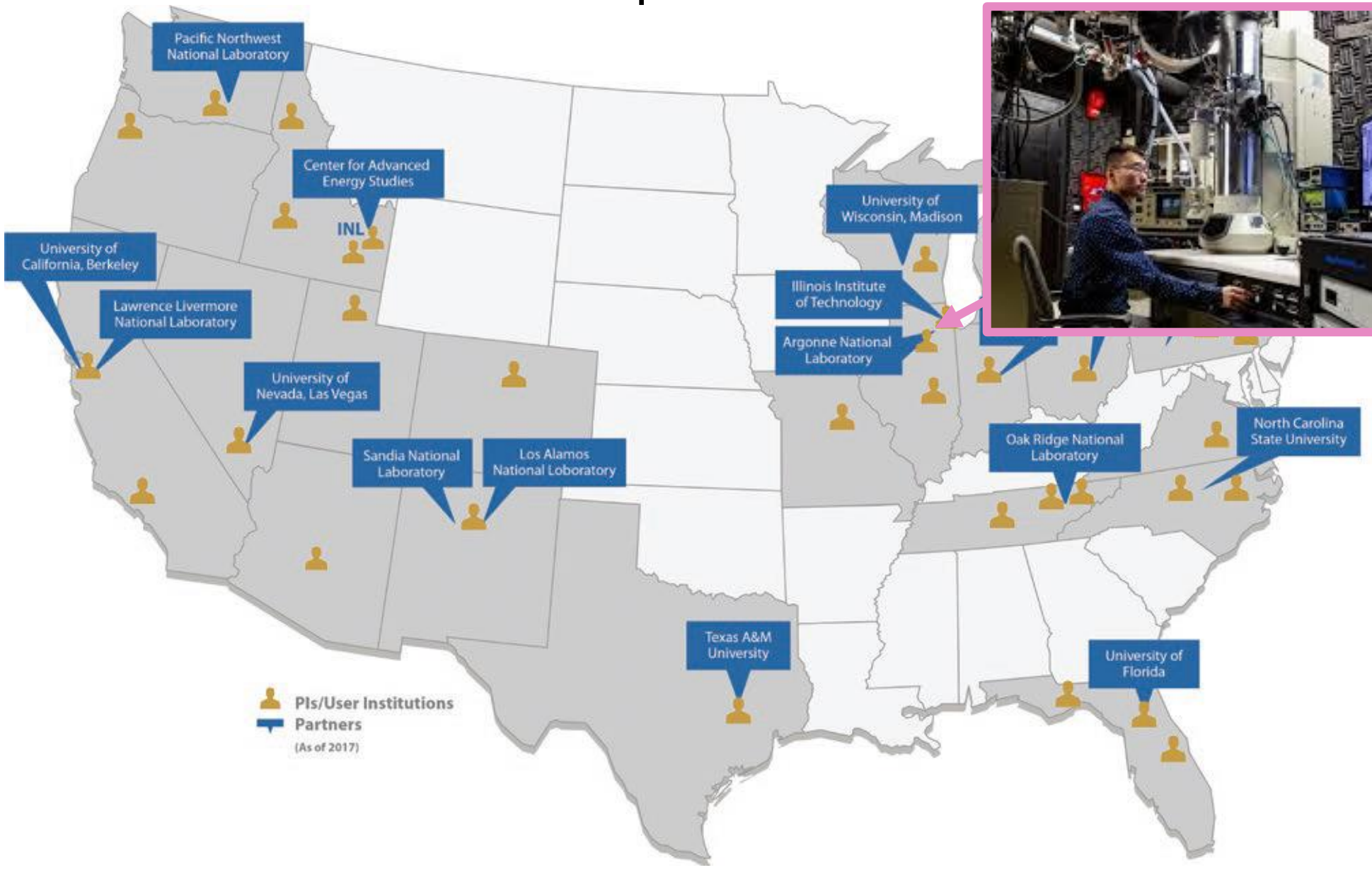
*** **Model SR-M**: YOLOv8 model trained on super-resolution dataset and tested on super-resolution dataset for all modalities

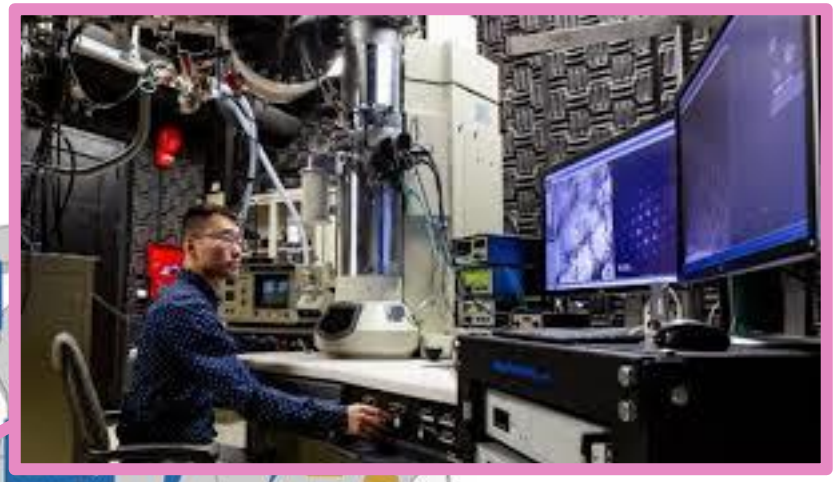
- **Super-Resolution (ISR) enhances precision (+20.5%)** by improving image clarity, making detections more reliable
- **A minor trade-off occurs with recall (-5.1%)**, meaning some true cavities might be overlooked.
- **F1-score (+6.8%) confirms an overall performance boost**, making ISR a valuable enhancement for cavity detection
- **False positives are drastically reduced (-40.3%)**, proving that ISR refines detection accuracy

J. Olamofe, L. Qian, K.G.Field, *J. IEEE Access.*, **Under Revision**, 2025

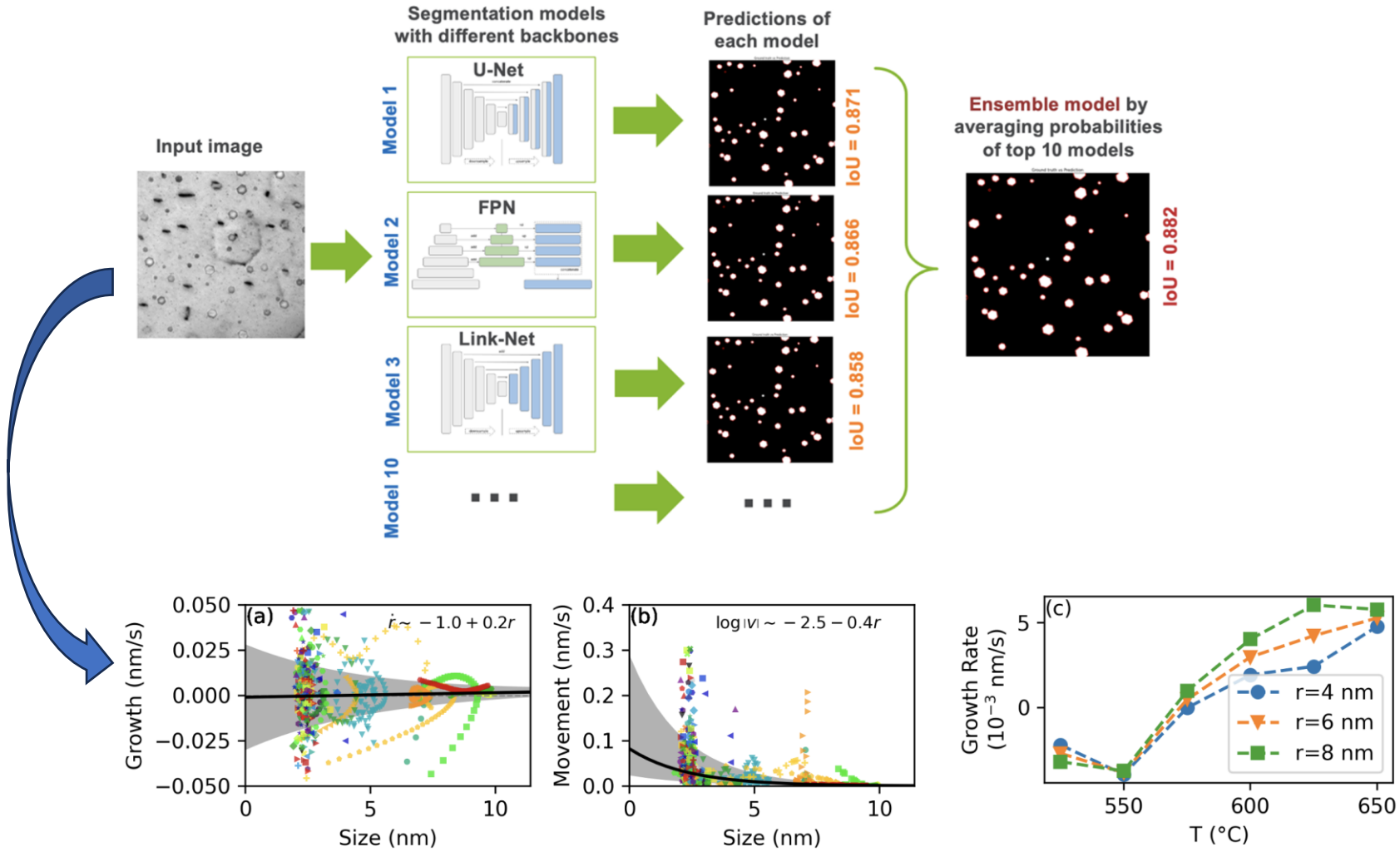
NUCLEAR ENGINEERING & RADIOLOGICAL SCIENCES
UNIVERSITY OF MICHIGAN

Development of DSCNNs and SORT-based tracking has been under development at ORNL





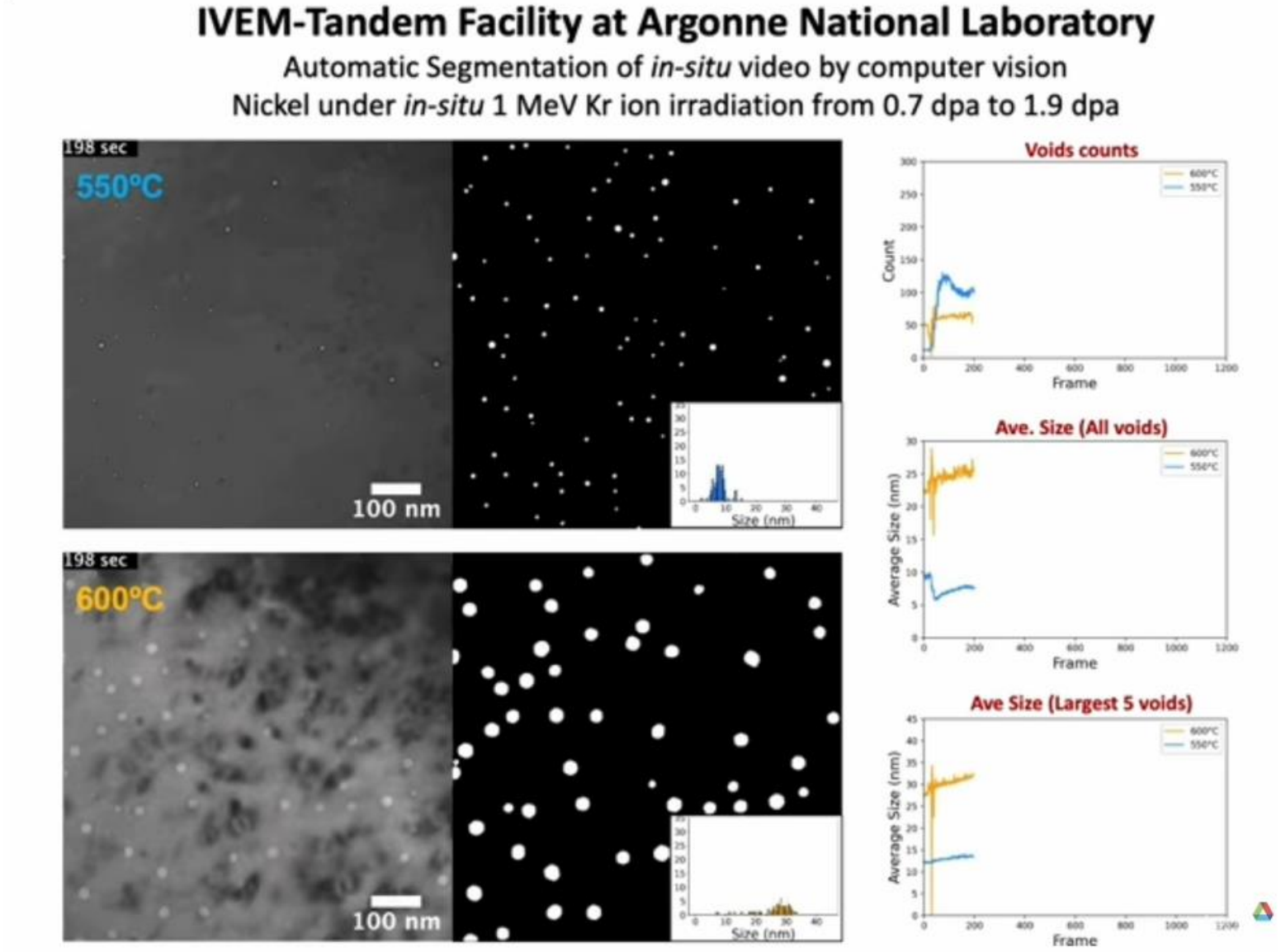
IVEM has developed machine learning methods that enable cavity tracking and extraction of cavity growth rates



W-Y Chen, et al., *OSTI ID 2447615*, Sept 2024

NUCLEAR ENGINEERING & RADIOLOGICAL SCIENCES
UNIVERSITY OF MICHIGAN

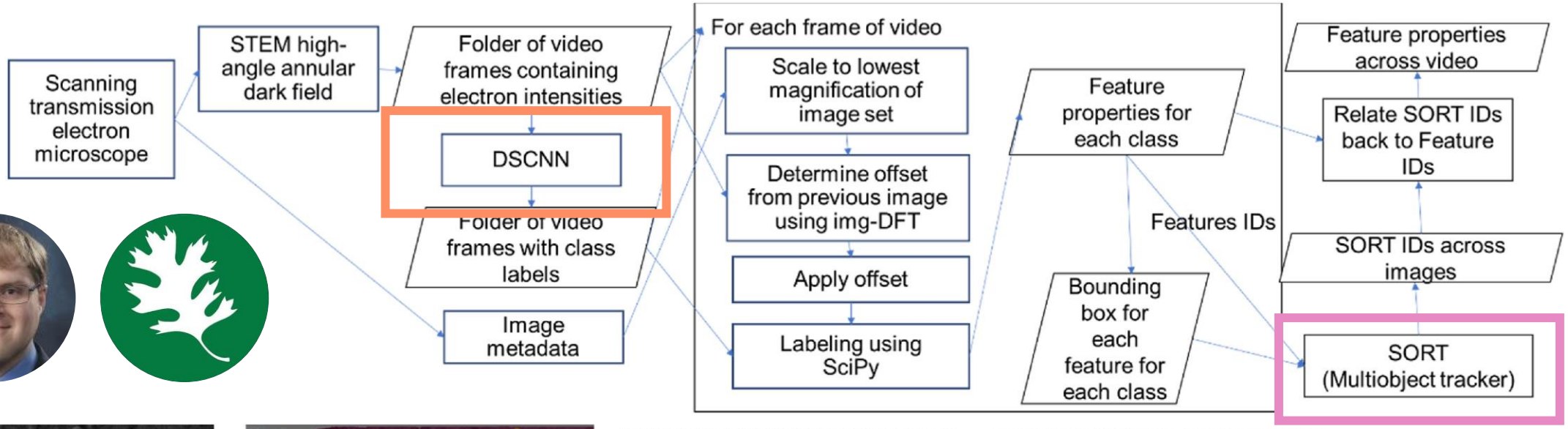
IVEM has developed machine learning methods that enable cavity tracking and extraction of cavity growth rates

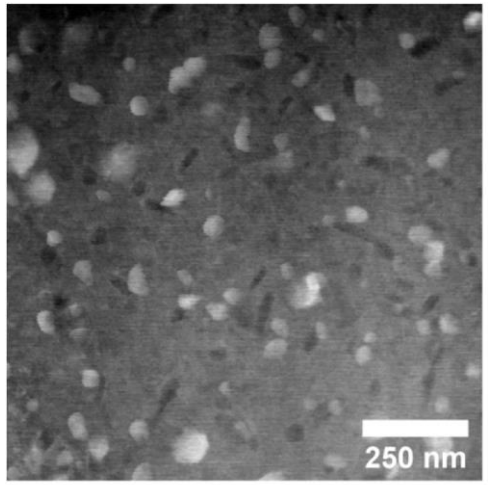


W-Y Chen, et al., *OSTI ID 2447615*, Sept 2024

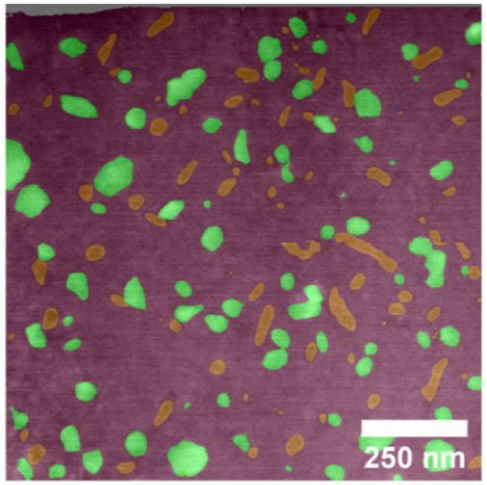
Development of DSCNNs and SORT-based tracking has been under development at ORNL

Other users of MiTEM are developing their own frameworks built on Convolutional Neural Networks and SORT algorithms

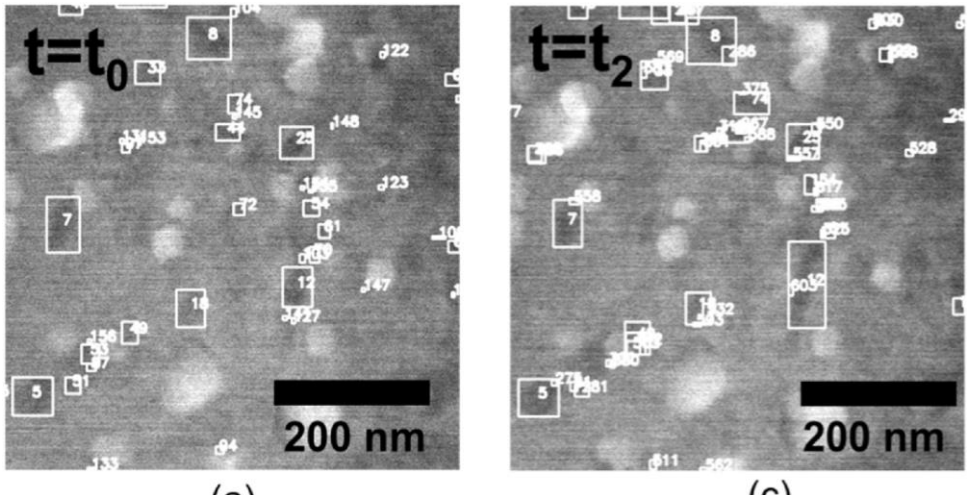




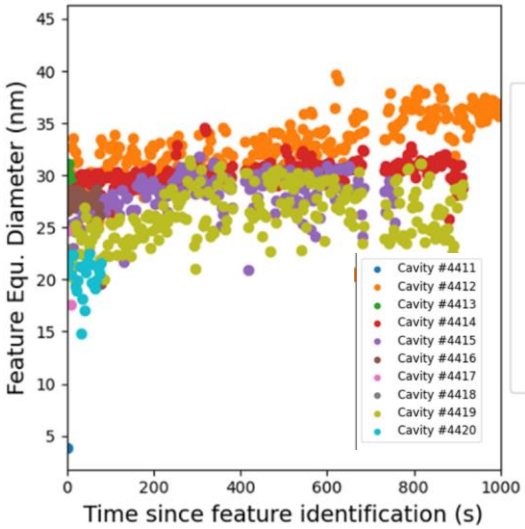
In-Situ STEM Ion Irr. of IN718



Semantic Segmentation of Phases



SORT based tracking of cavities in HAADF

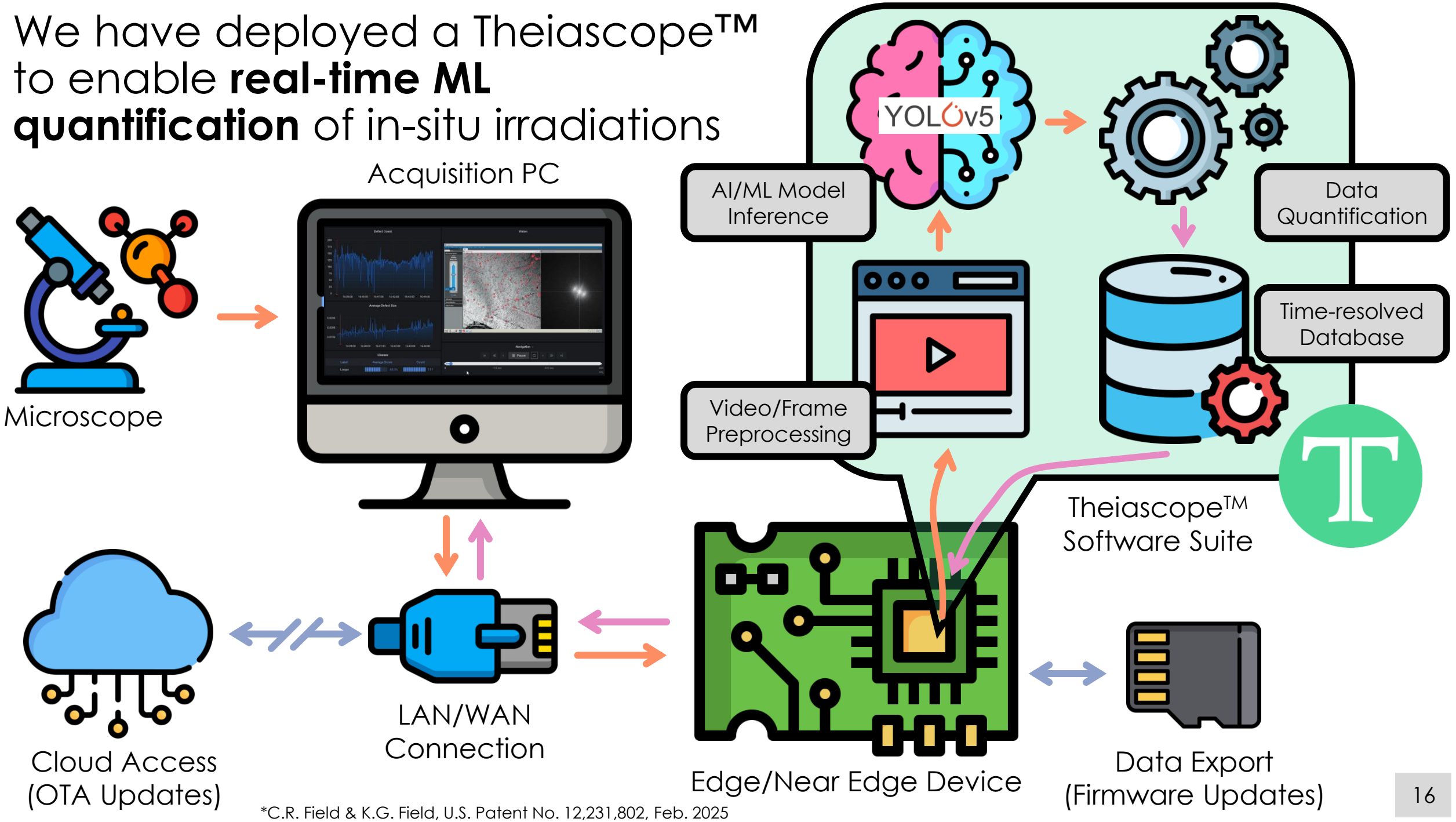


CNN+SORT based quantification

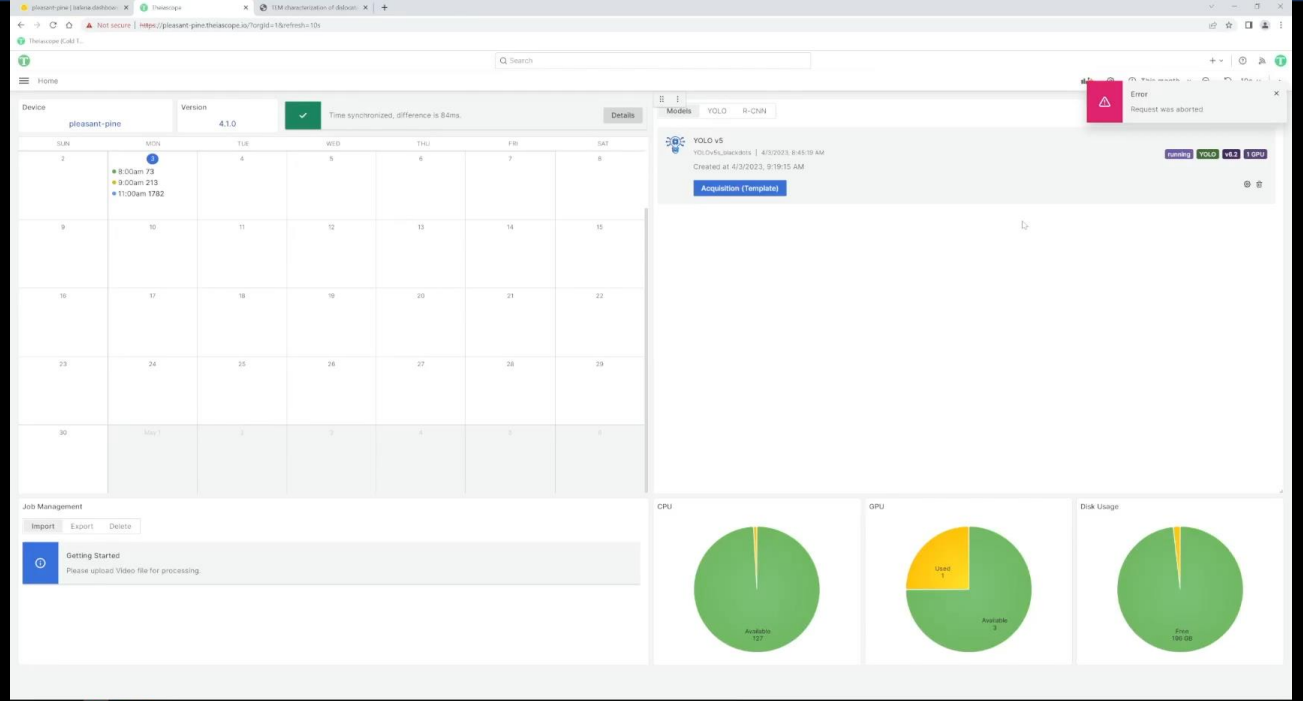
S. Taller, et al., Mat. Today. Adv., **21**, 2024

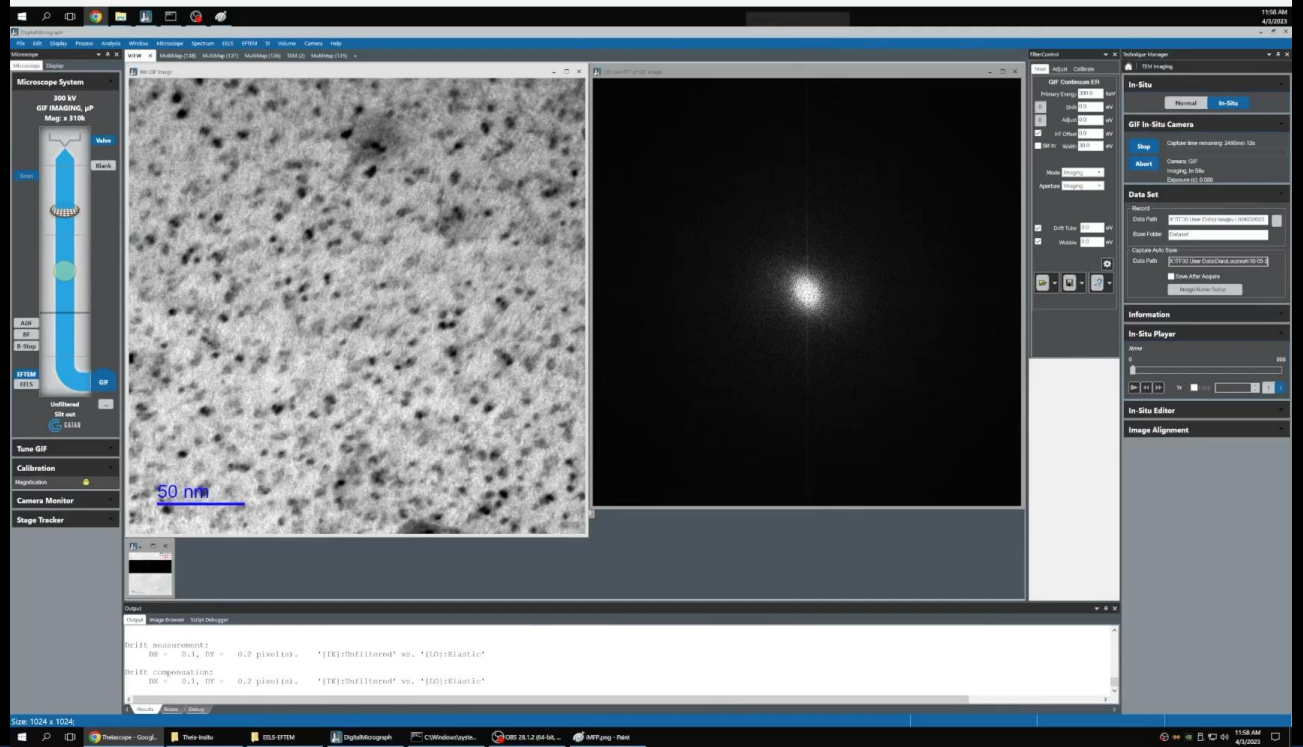
Theiascope™ systems are now at several partner facilities

We have deployed a Theiascope™ to enable **real-time ML quantification** of in-situ irradiations



*C.R. Field & K.G. Field, U.S. Patent No. 12,231,802, Feb. 2025

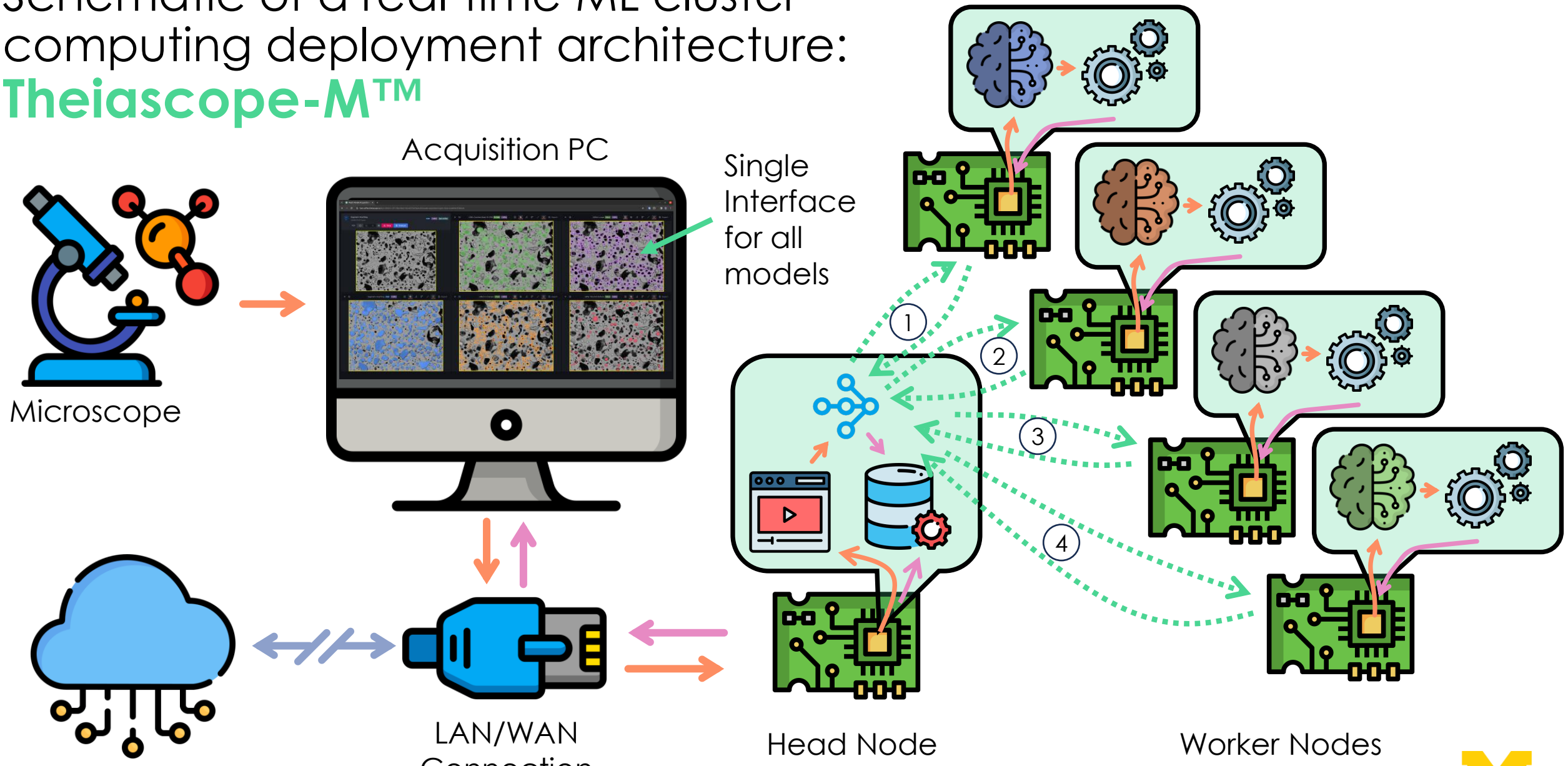




In-situ TEM irradiation of an FeCrAl alloy in MIBL-(MC)²

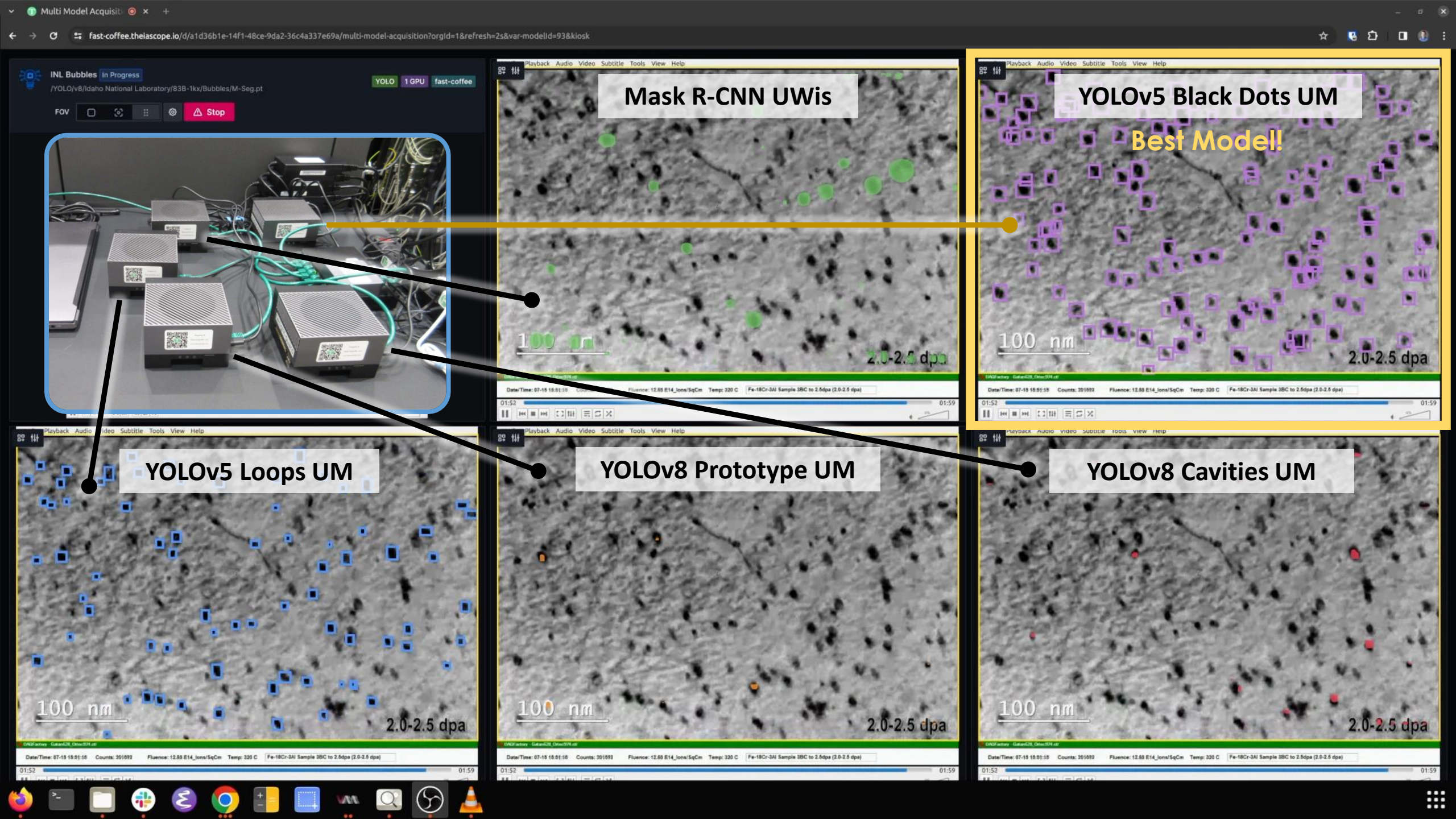
Results courtesy of K. Sun and H. Li (UM)

Schematic of a real-time ML cluster computing deployment architecture: Theiascope-M™



*C.R. Field & K.G. Field, U.S. Patent No. 12,231,802, Feb. 2025

NUCLEAR ENGINEERING & RADIOLOGICAL SCIENCES
UNIVERSITY OF MICHIGAN


Multi Model Acquisiti
fast-coffee.theiascope.io/d/a1d36b1e-14f1-48ce-9da2-36c4a337e69a/multi-model-acquisition?orgId=1&refresh=2s&var-modelId=93&kiosk
INL Bubbles
In Progress
/YOLO/v8/Idaho National Laboratory/83B-1kx/Bubbles/M-Seg.pt
YOLO
1 GPU
fast-coffee
FOV
Stop
Mask R-CNN UWis
YOLOv5 Black Dots UM
Best Model!
YOLOv5 Loops UM
YOLOv8 Prototype UM
YOLOv8 Cavities UM
100 nm
2.0-2.5 dpa

4 Model Acquisition

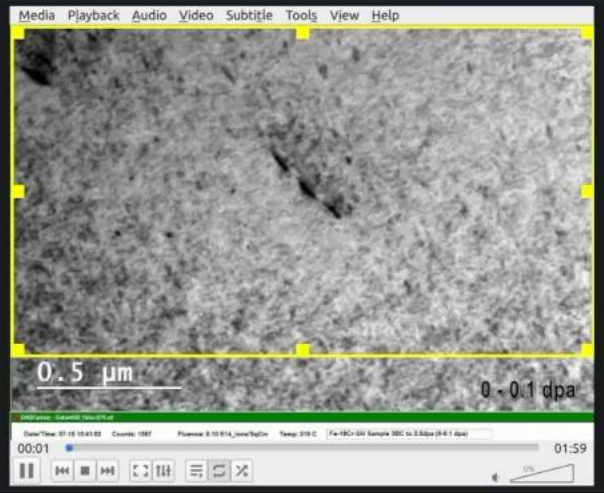
f362224e55164694347f80290f72bab4.balena-devices.com/d/c3dc83be-5bc2-40aa-a52b-c157b88e2ca9/4-model-acquisition?orgId=1&refresh=2s&var-modelId=31&kiosk

UWis Cavities Mask R-CNN In Progress

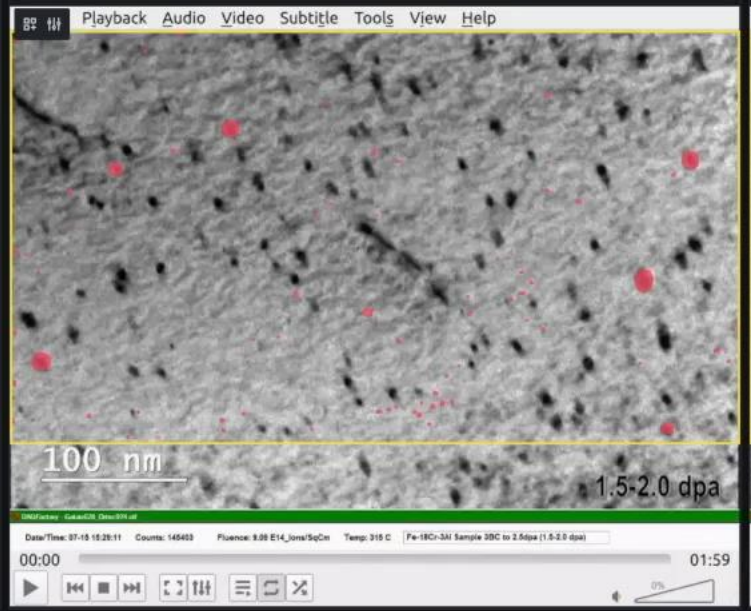
/R-CNN/Mask/University of Wisconsin/Cavities/R50-FPN_3x

R-CNN 1 GPU pleasant-pine

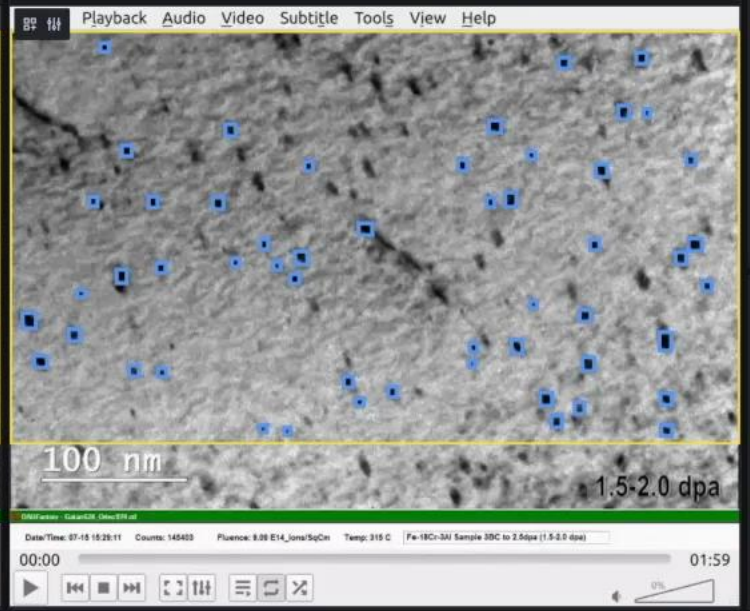
FOV Stop



UWis Mask R-CNN Cavities



UMich YOLOv5 3 Classes Loops



UWis Mask R-CNN Cavities

72

UMich YOLOv5 3 Classes Loops

52

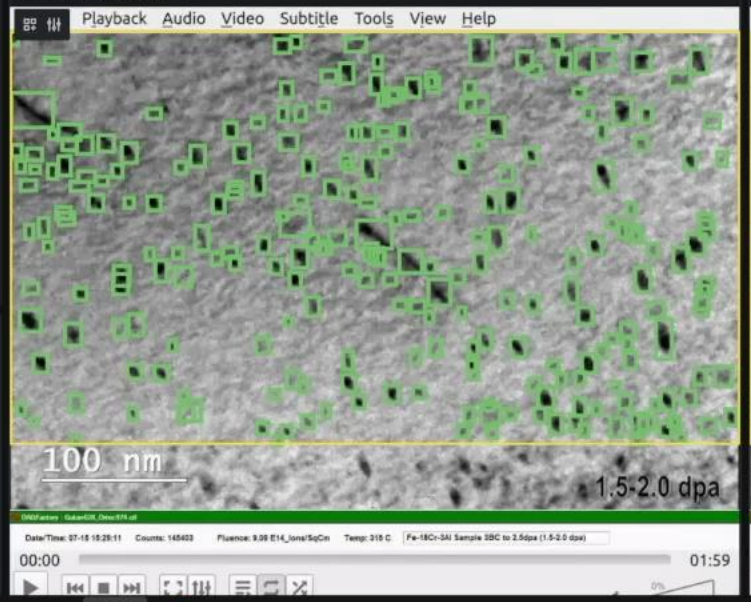
UWis Mask R-CNN Cavities

7.69

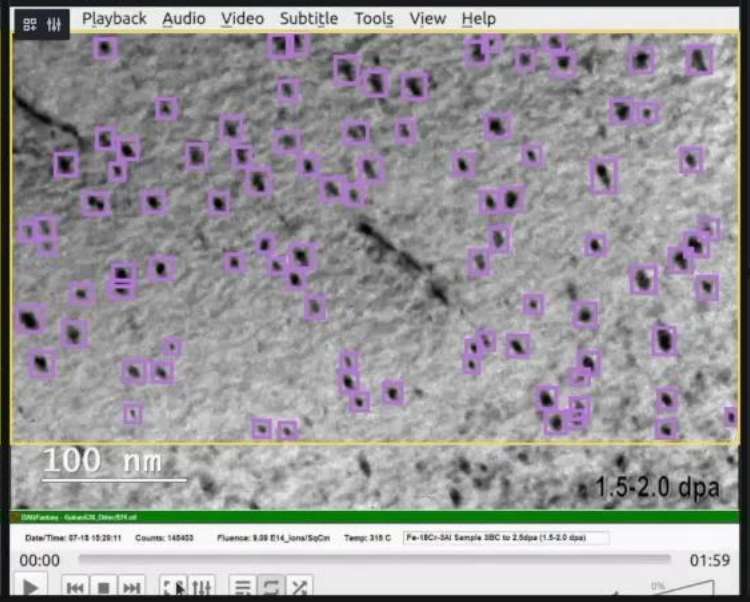
UMich YOLOv5 3 Classes Loop

62.6

UWis YOLOv8 Defects



INL YOLOv8 Bubbles



JHU YOLOv5 Emily

240

JHU YOLOv5 Emily

65.8

UMich YOLOv5 Blackdots

78.8

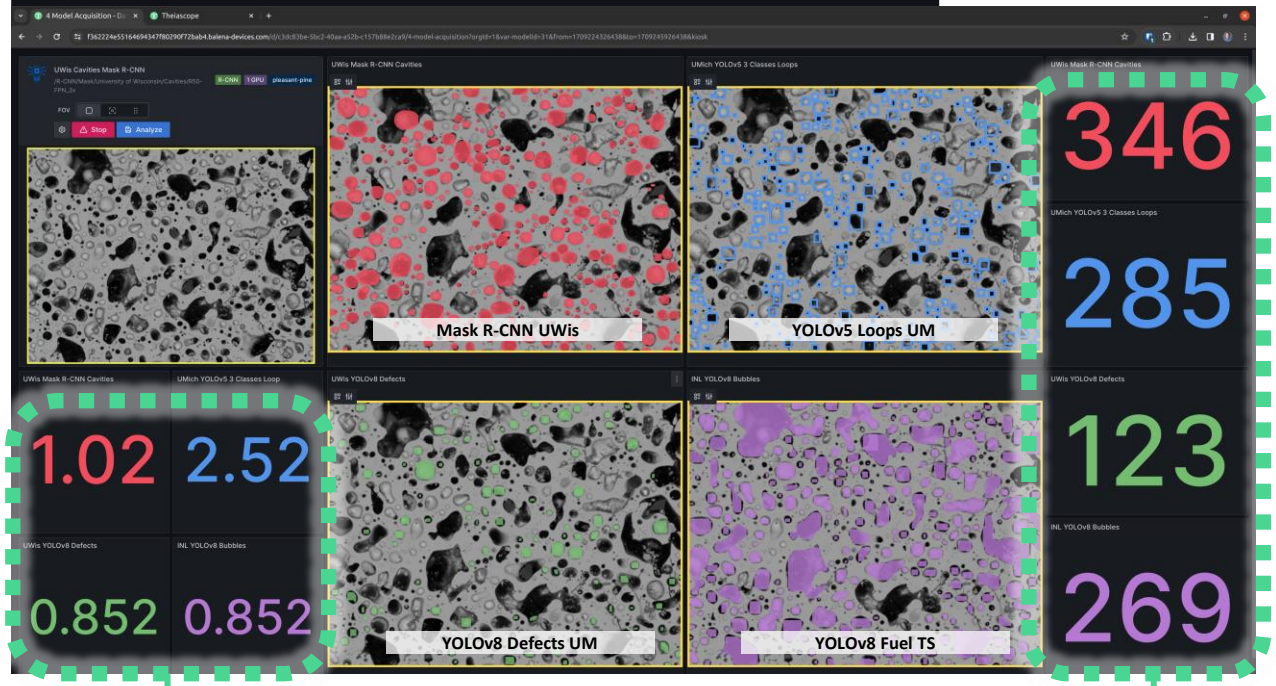
UMich YOLOv5 Blackdots

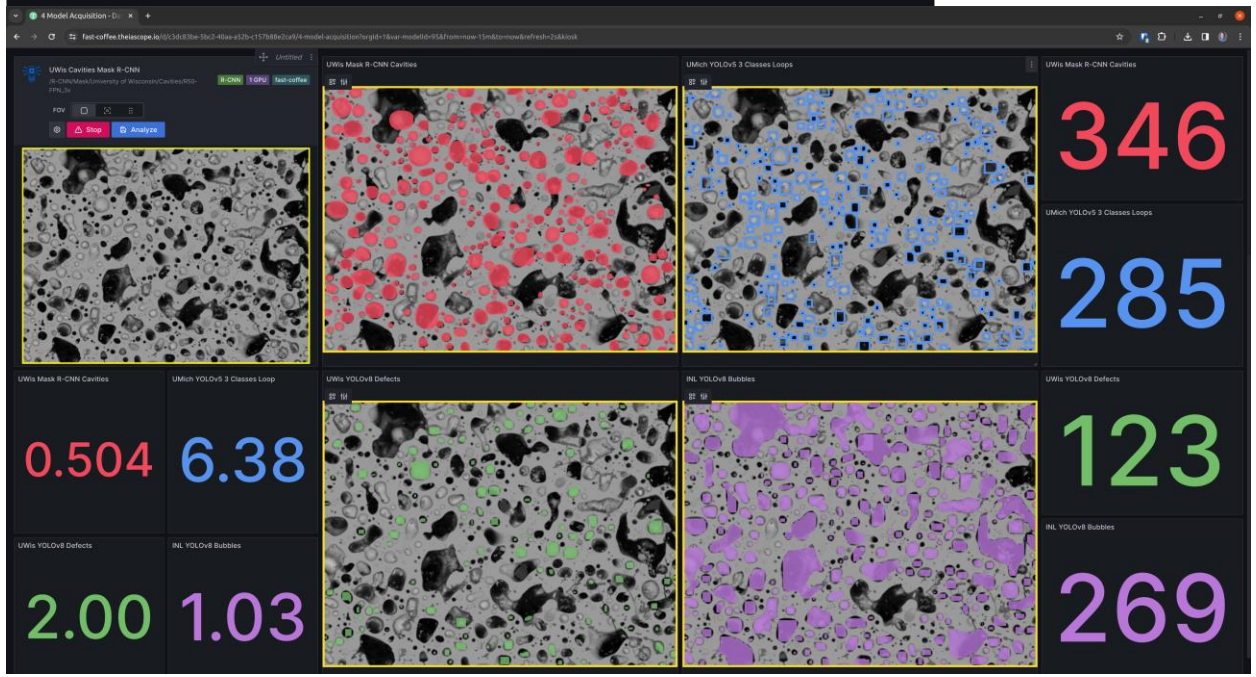
93

The new architecture enables a ***fully scalable*** ad-hoc heterogenous cluster for ***real-time ML***-enable microscopy

4 GPU-enabled edge-computing devices with intra-node data dispatching

1 Near-edge workstation with 4 GPUs and inter-GPU data dispatching



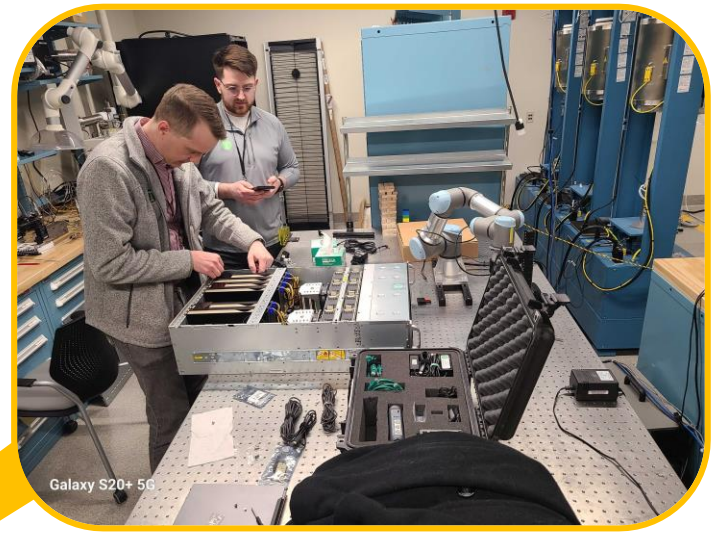


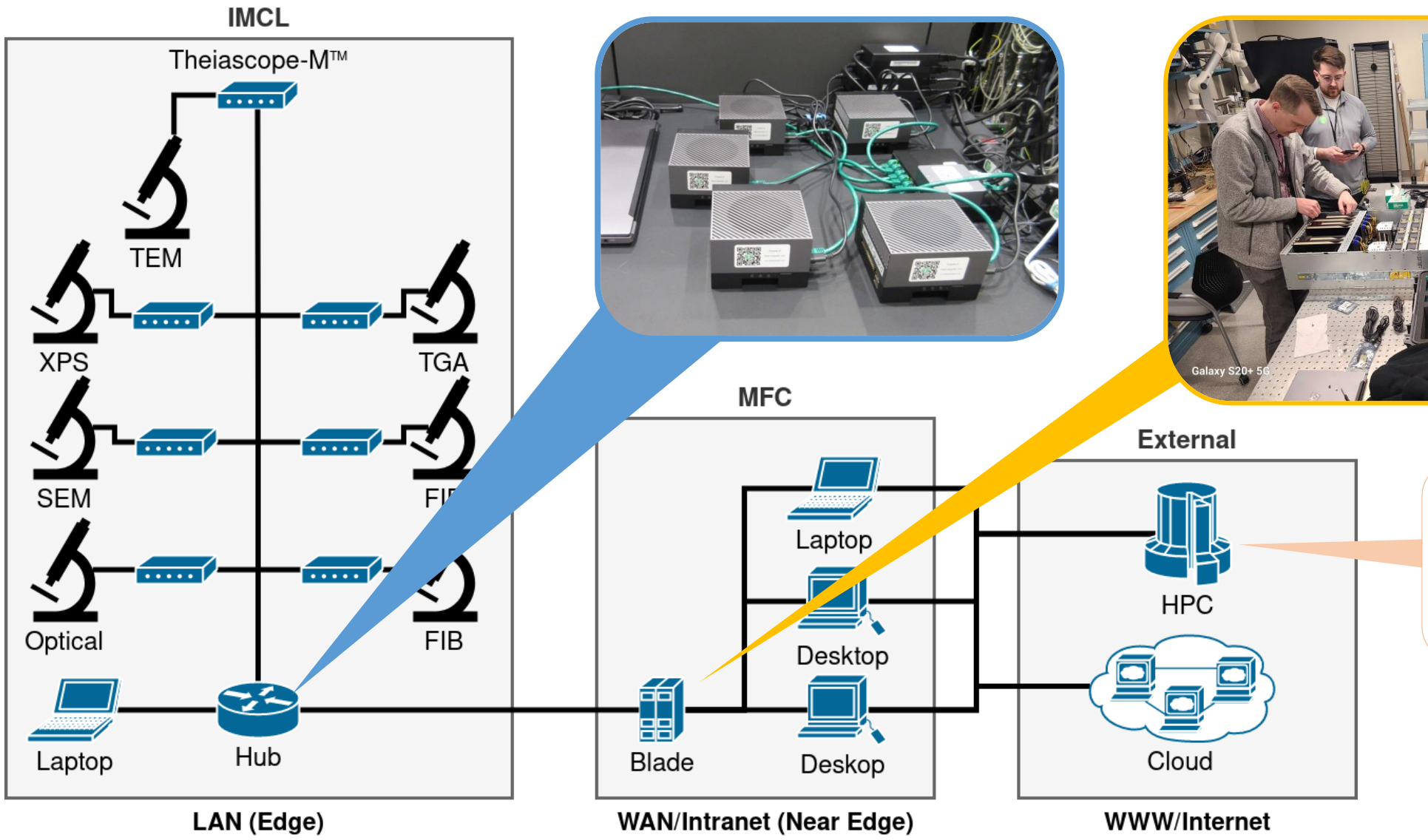
ML Model FPS

Feature Count

Identical Response!

The Theiascope-M™ is currently available to users at Idaho National Laboratory after successful install at MFC



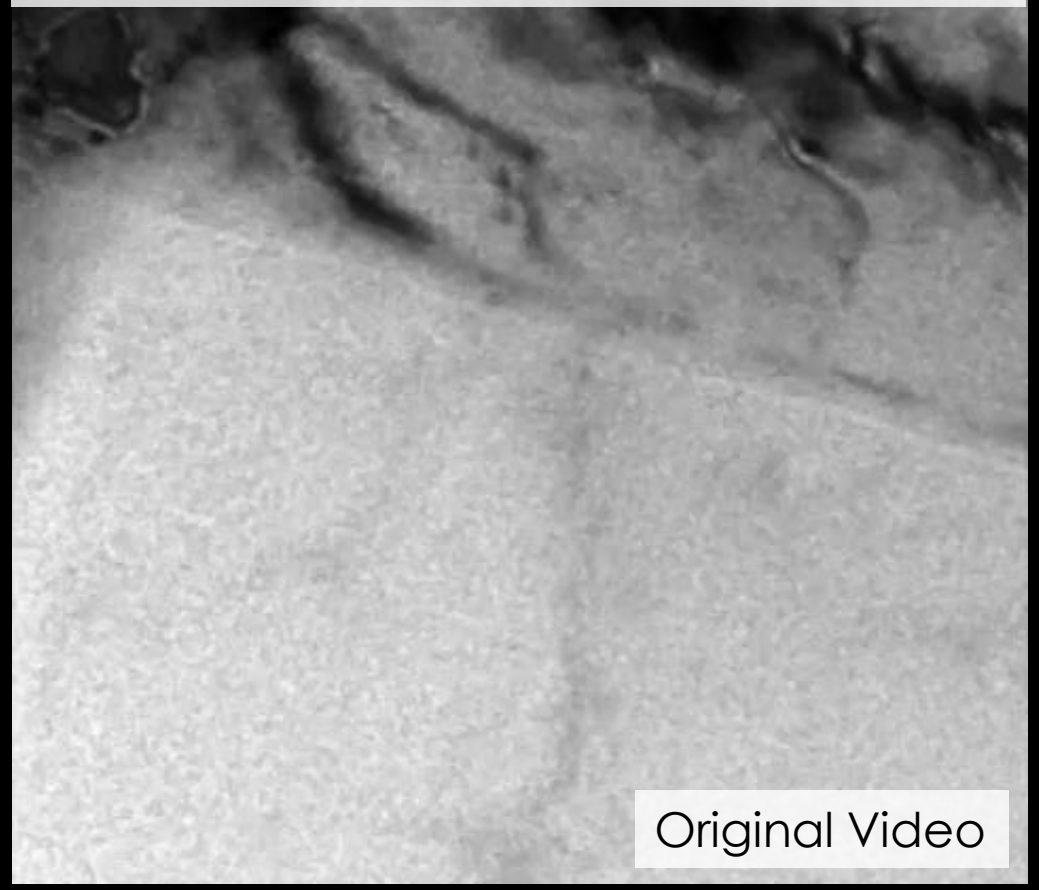


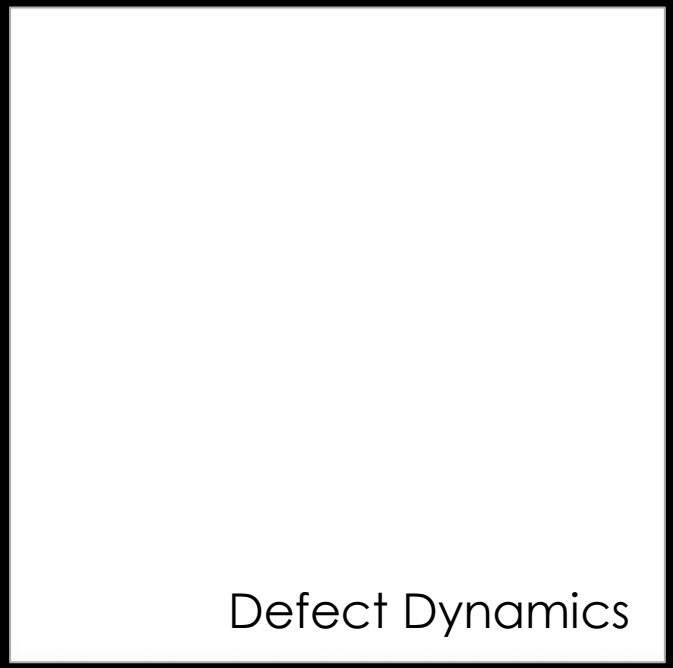
?

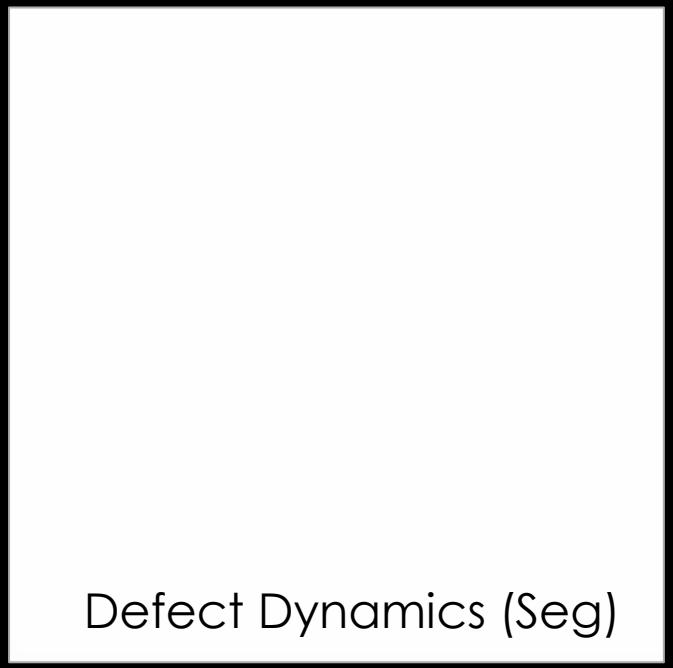
Can you run your algorithms on the Theiascope™ at partner facilities?

TRACS+SAHI with the Theiascope™ facilitates **dynamic quantification and drift correction** during in-situ TEM investigations at MIBL

316L implanted with 100 appm He and annealed at 500°C for 1 hr

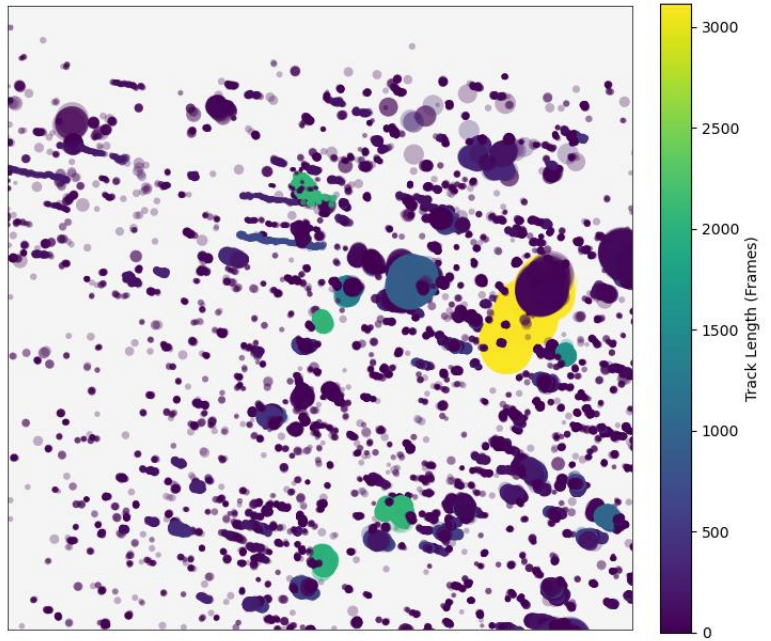


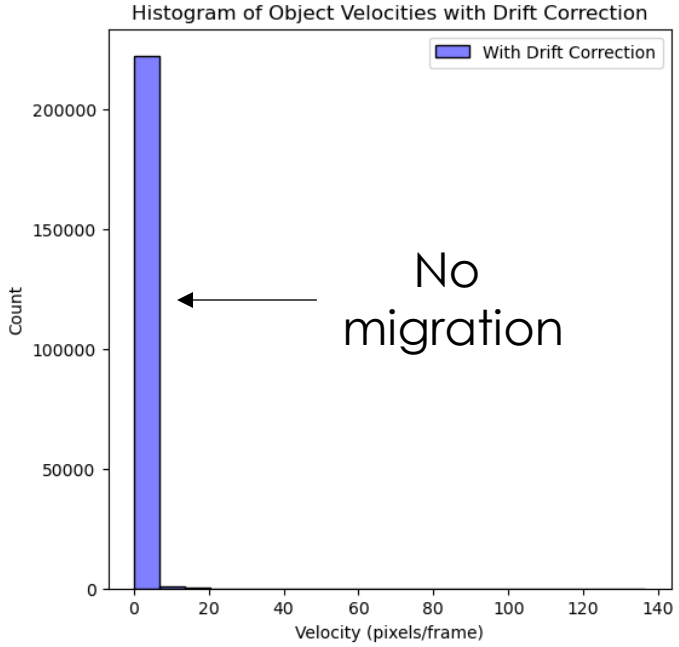


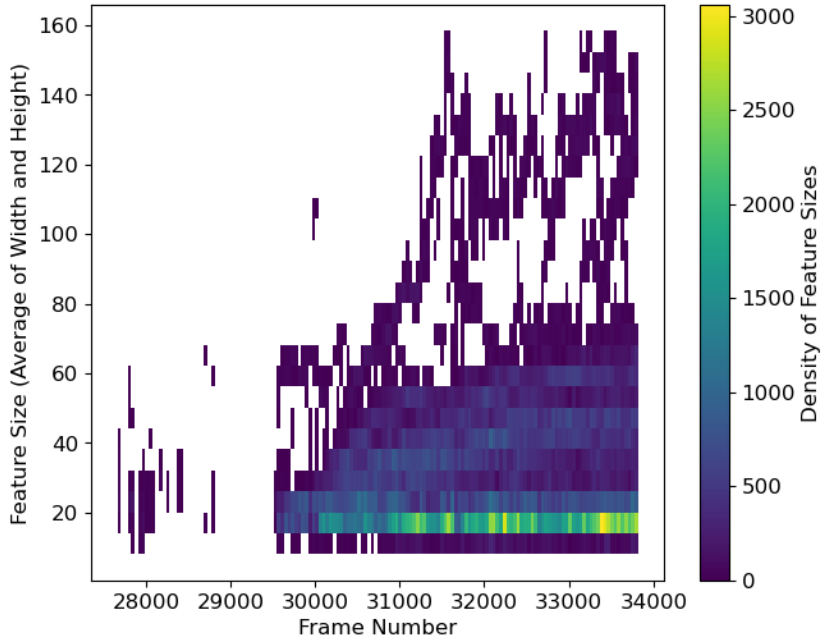


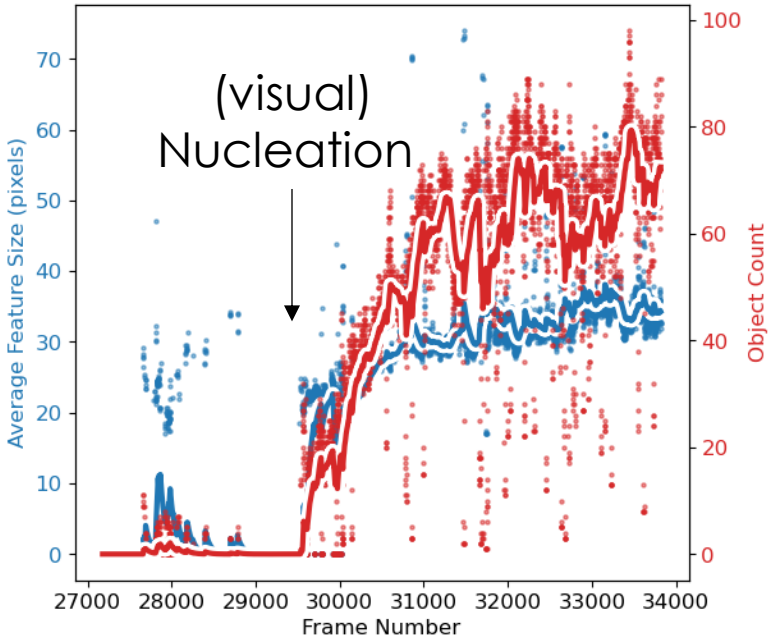
TRACS + SAHI provided **high temporal and spatial fidelity** on cavity evolution

- Cavities under annealing in 316L did not migrate → only 'movement' was **preferential directional growth**
- Cavities nucleated and grew with limit additional nucleation after initial growth

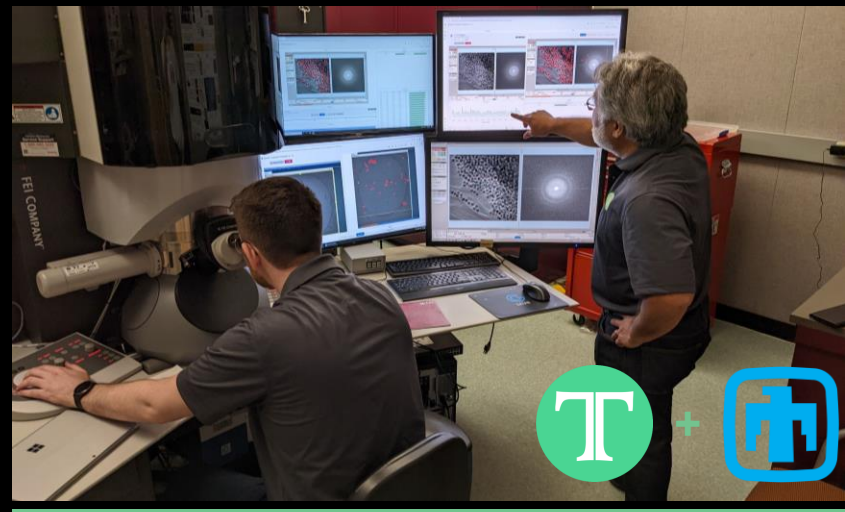


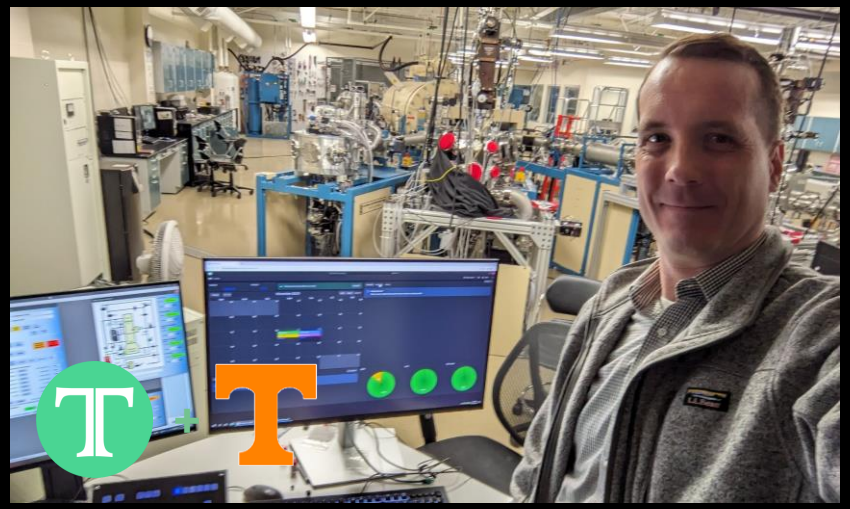






Post-acquisition ML quantification and ***real-time ML microscopy*** is now available to NSUF users through NRDS, the user community, and through the Theiascope™ systems existing at NSUF partner facilities





Questions?