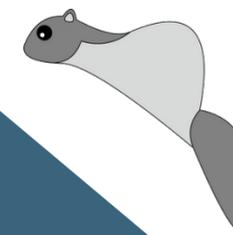


# BEAST

Building Sustainable Data Infrastructure for NASA Thermal Protection Research

**ABLATION WORKSHOP 2025**

November 2025



Alexandre Quintart

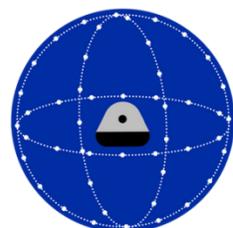
Flying Squirrel

Magnus Haw

NASA Ames Research Center

Sebastian Colom

Analytical Mechanics Associates



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[Conclusion](#)

# Introduction

Arcjet tests are **expensive** and **complex**, but they are **essential** for evaluating material behavior.

→ **Maximizing data** extraction from each test is essential !

Testing data infrastructure **should** enable:

- Cross-campaign, cross-test **comparisons**
- Material property provenance/**history**
- **Reproducibility**
- **Searchability**
- Facility configuration **management**



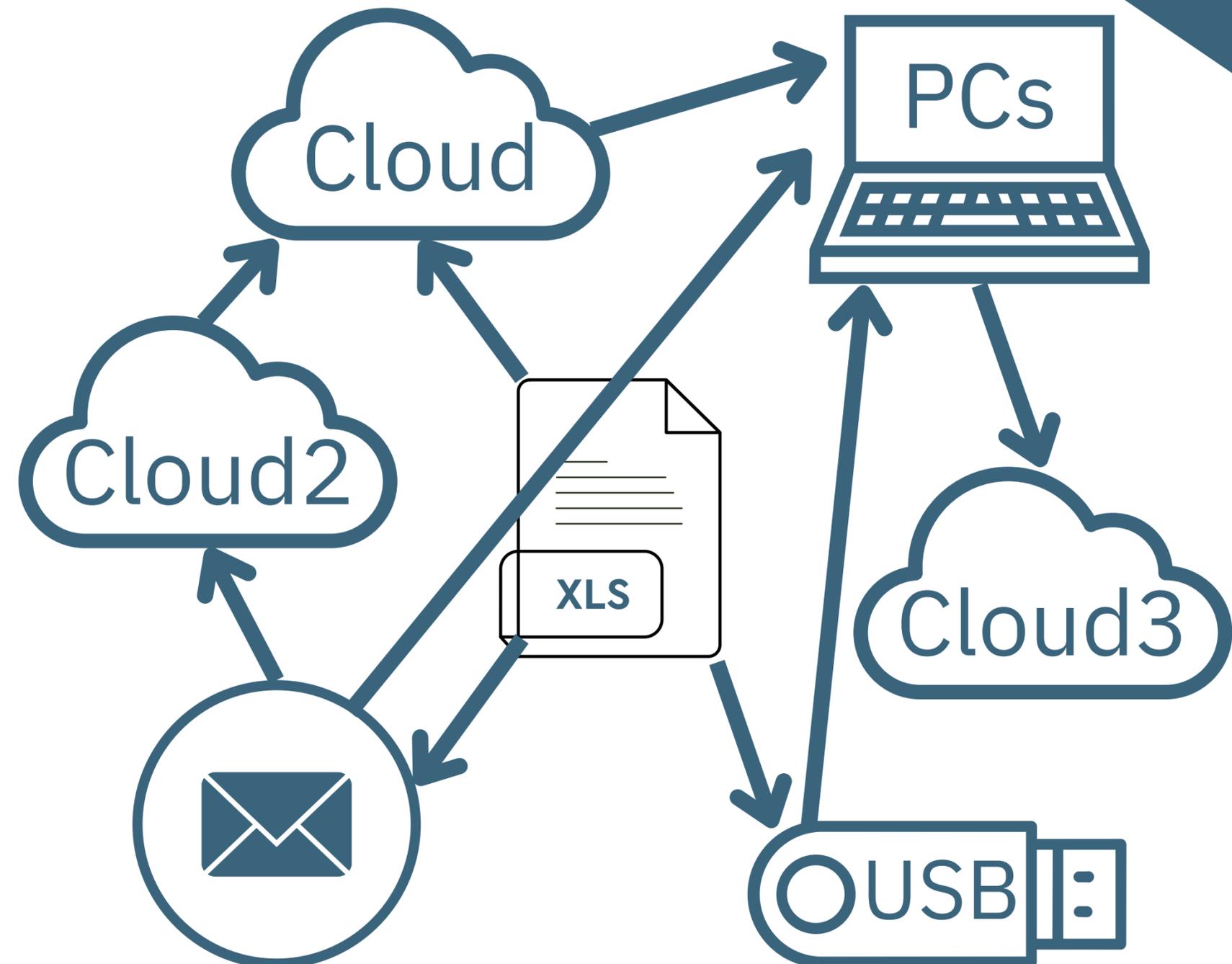
# The Challenge: Fragmentation

## What actually happens:

- **Isolated** campaign data.
- **Scattered** storage across dozens of mediums/formats.
- Limited provenance/**traceability**.
- **Manual** version control.

## → **Consequences**

- Poor institutional **memory**.
- Significant **time** spent searching for historical data.
- **Single-use** analyses/tools.

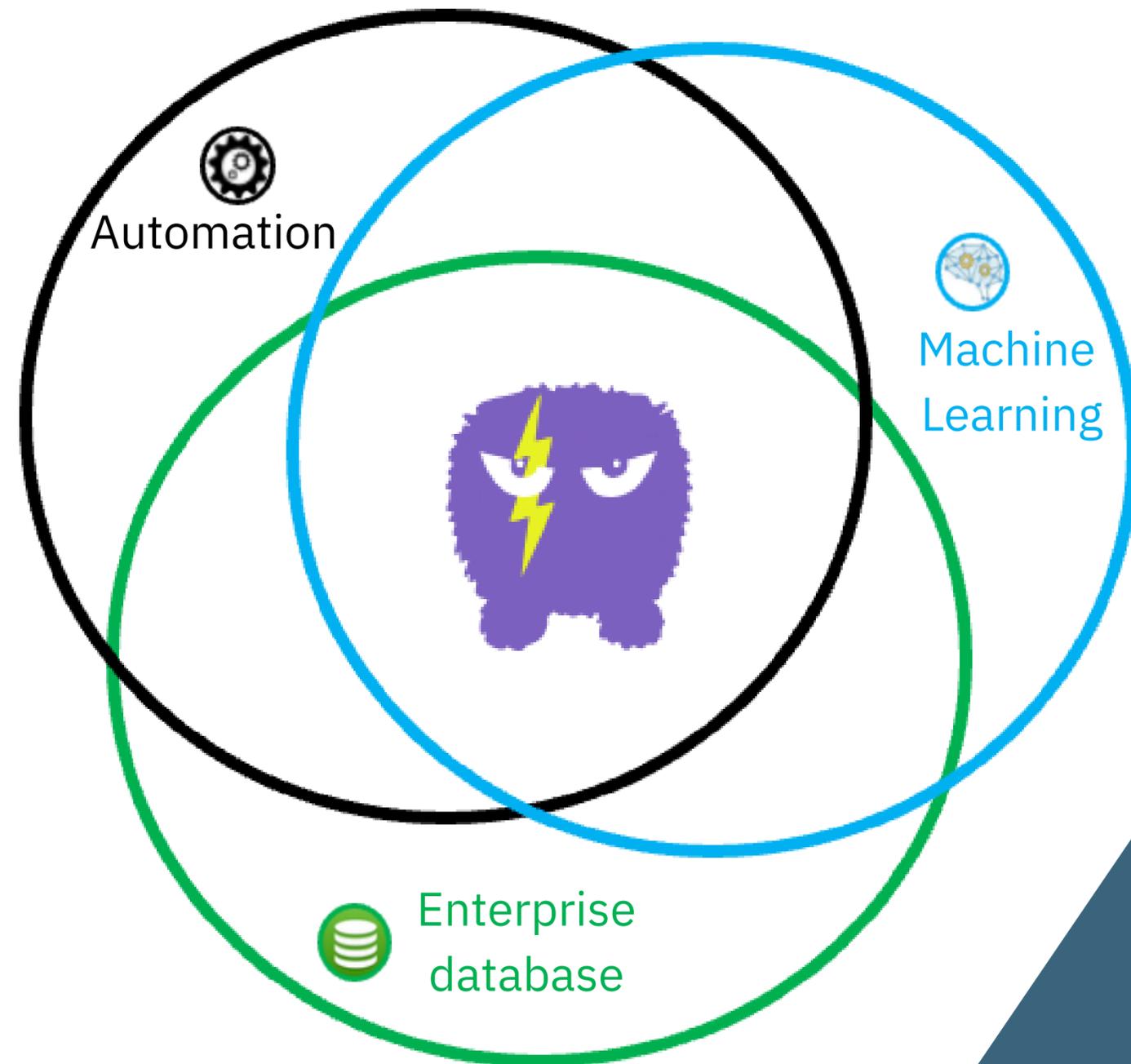


# Solution: BEAST

(Backend for Experiment Analysis, Storage, and Traceability)

## Minimum Requirements:

1. **Centralized repository.**
2. **Standardized formats.**
3. **Data traceability.**
4. **Searchable, structured access.**
5. **Facility configuration management.**

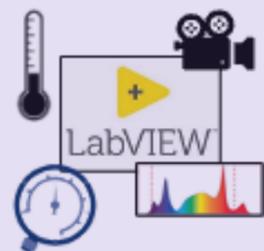


# Solution: BEAST

(Backend for Experiment Analysis, Storage, and Traceability)



## Scope



### Multi-modal storage

Timeseries, Video,  
Spectra, Meshes,  
Measurements, etc.



### Facility config management

(tracks settings, components,  
maintenance, calibrations,  
configuration)



### Knowledge management

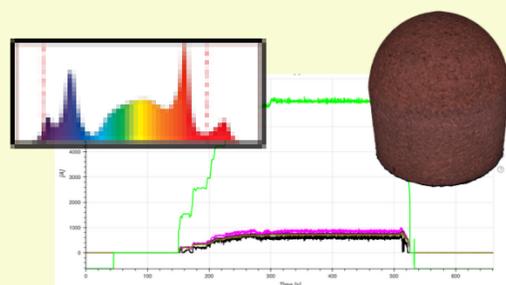
(wiki, reports, lessons  
learned, etc.)



### Material provenance

(billet tracking, sample  
history, version controlled  
material properties)

## Features



### Data visualization

(timeseries, spectra,  
meshes)



### Search

(runs, samples,  
meshes, metadata)



### Comparison

(timeseries, billets,  
spectra, meshes)



### Predictions/Modeling

(ML models for anomaly  
detection)

# BEAST Overview



The screenshot displays the ArcBEAST Operations Hub interface. At the top, a search bar is labeled "Search bar" with an arrow pointing to the "Search everything..." input field. The main header area is titled "ENGINEERING DATA CONSOLE" and "ArcBEAST Operations Hub v2.0", with a description: "Central console for apparatus records, campaign runs, and material references." Below this are buttons for "Apparatus Registry", "Run Archive", and "Materials Library". A "QUICK ACTIONS" panel on the right lists "Comparison Workspace" and "Record Data Upload".

Four data cards are shown below the main header:

- APPARATUS**: 4 items, with an "Open list" link.
- TEST CAMPAIGNS**: 21 items, with a "Campaign browser" link.
- RUN RECORDS**: 275 items, with a "Run explorer" link.
- MATERIAL ENTRIES**: 23 items, with a "Materials index" link.

Annotations on the right side of the image point to these features:

- "Parts, systems and apparatus management" points to the Apparatus card.
- "Test articles management" points to the Test Campaigns card.
- "Material database" points to the Material Entries card.
- "Runs database" points to the Run Records card.

The bottom section includes "Latest Run Records" (listing mARC006R023 and mARC006R020) and "Engineer Shortcuts" (listing "Advanced Condition Search" and "Compare Diagnostics Across Runs").

# BEAST Overview



ARCBEAST v0.1

Search everything...

Report issue aquintart

Home

DATA

- Test Data
- Apparatus
- Material Properties

ANALYSIS

- Search
- Compare
- Modeling
- Tools

ENGINEERING DATA CONSOLE

## ArcBEAST Operations Hub

v2.0

Central console for apparatus records, campaign runs, and material references.

Apparatus Registry Run Archive Materials Library

QUICK ACTIONS

Routine tasks for analysis and design teams.

- Comparison Workspace
- Record Data Upload

DJDT

APPARATUS 4 Open list

TEST CAMPAIGNS 21 Campaign browser

RUN RECORDS 275 Run explorer

MATERIAL ENTRIES 23 Materials index

Latest Run Records

- mARC006R023 April 3, 2025, 1:15 p.m. mARC
- mARC006R020 Jan. 27, 2025, 11:14 a.m. mARC

Engineer Shortcuts

- Advanced Condition Search
- Compare Diagnostics Across Runs

# Apparatus



BEAST includes an apparatus **tracking system** that monitors and logs the usage history of key hardware components within the test facility.

## Why Track Hardware?

- Enables **lifecycle** management of components
- Prevents unexpected **failures** during tests
- Allows correlation of data quality with hardware history
- Supports statistical reliability modeling over time

**FACILITY OVERVIEW**  
**miniature Arcjet Research Chamber**  
Upgraded version of mARC facility. Adds nozzle water cooling and larger chamber  
[View Incidents](#) [+ Add Test](#)

**TOTAL TESTS**  
7

**TOTAL RUNS**  
214

miniature Arcjet Research Chamber

**Subsystems** (8)

- Arc power supply (Electric)
- Distilled Water Loop (Thermal)
- Gas Subsystem (Gas)
- Insertion Stings (Mechanical)
- Optical Diagnostics (Optical)
- Sensor Water Loop (Thermal)
- Vacuum System (Vacuum)
- Vacuum Water Loop (Thermal)

**Configurations** (1)

CONFIGURATIONS  Filter by configuration, run, test, or component  Showing 1 of 1

**mARC004R026**

**OVERVIEW**  
**mARC004R026**  
1. Note Chamber pressure at a range of mass flow and current combinations 2. Confirm arc voltage diagnostic is operating correctly 3. Measure visible and near-IR emission of the jet and calibrate immediately after  
7 tests · 214 runs  
15 components · 13 connections  
Updated Oct 31, 2025

**COMPONENT SELECTION**

Search components

Showing 15 / 15 components

**All systems** Arc power supply Distilled Water Loop Gas Subsystem Insertion Stings

MAX200 Arc power supply Sage Flowmeter SIP-030-DC24-AIR Gas Subsystem  
mARC\_SweepArm Insertion Stings mARC\_SweepArm\_Center Insertion Stings  
mARC\_SweepArm\_East Insertion Stings mARC\_SweepArm\_West Insertion Stings  
mARC\_anode Arc power supply mARC\_cathode Arc power supply mARC\_chamber Arc power supply  
mARC\_disk1 Distilled Water Loop mARC\_disk2 Distilled Water Loop mARC\_disk3 Distilled Water Loop  
mARC\_gas\_flow Gas Subsystem mARC\_heater\_column Arc power supply  
mARC\_nozzle Distilled Water Loop

**Subsystem Layouts**

Arc power supply  
No components recorded.

**NETWORK DIAGRAM**

Nodes represent the components defined in the apparatus configuration. Edges show connection records and parent/subcomponent hierarchy.

**mARC\_disk2** (Active)  
Distilled Water Loop  
Subsystem Distilled Water Loop  
Component ID mARC\_disk2  
Notes --

# BEAST Overview



ARCBEAST v0.1

Search everything...

Report issue aquintart

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ENGINEERING DATA CONSOLE

## ArcBEAST Operations Hub

v2.0

Central console for apparatus records, campaign runs, and material references.

Apparatus Registry Run Archive Materials Library

QUICK ACTIONS

Routine tasks for analysis and design teams.

- Comparison Workspace
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DjDT

APPARATUS 4  
Open list

TEST CAMPAIGNS 21  
Campaign browser

RUN RECORDS 275  
Run explorer

MATERIAL ENTRIES 23  
Materials index

### Latest Run Records

- mARC006R023  
April 3, 2025, 1:15 p.m. mARC
- mARC006R020  
Jan. 27, 2025, 11:14 a.m. mARC

### Engineer Shortcuts

- Advanced Condition Search
- Compare Diagnostics Across Runs

# Tests

- Each test is registered in the system with detailed metadata, including facility conditions, configuration, and linked samples.
- The interface automatically links the test to the corresponding apparatus, material, and diagnostics used during the run.
- Pre/post images or 3D scans are visualized directly in the UI for quick comparison.

The screenshot displays the user interface for the mARC006 test. At the top, it shows the test name 'mARC006' and statistics: 24 runs and 1 article. Below this, there's an overview section with metadata like dates, access groups, and objectives. A 'Runs' table lists individual test runs with their dates and input settings. A 'Test Conditions' table provides detailed parameters for each run, such as gas types, flow rates, and nozzle sizes. The 'Test Articles' section lists associated models and shapes. Finally, the 'Media' section shows a side-by-side comparison of 'Pre-run' and 'Post-run' images, with a 3D model of the apparatus overlaid on the post-run image.

**TEST**  
**mARC006**  
Access Groups: [No groups assigned](#)  
Conducted at miniature Arcjet Research Chamber. Facility characterization: find edges of operational envelope (heat flux and stagnation pressure)  
[View Facility](#) [+ Add Run](#) [Upload Data](#) [Zip Data](#)

**RUNS** 24 **ARTICLES** 1  
**DATA PACKAGE** —

**Overview**  
DATES: Oct 3, 2024 —  
ACCESS GROUP: —  
FACILITY: miniature Arcjet Research Chamber  
OBJECTIVE: Facility characterization: find edges of operational envelope (heat flux and stagnation pressure)  
NOTES: —

**Quick Actions**  
DATA TOOLS:  
[+ Add Run](#)  
[Edit Test](#)  
[Upload Data](#)  
[Zip Data](#)  
EXPORTS:  
[LaTeX Summary](#)

**Runs** [+ Add Run](#)

Run	Date	Input Settings
<a href="#">mARC006R001</a>	2024-10-03	[{'arc_current_[a]': 40.0, 'main_gas_flow_[g/s]': 0.05}]
<a href="#">mARC006R002</a>	2024-10-03	—

**Test Conditions**

id	add_gas	apparatus	arc_current_[a]	main_gas	main_gas_flow_[g/s]	n_anodes	n_cathodes	n_disks	nozzle	plenum_disks	shield_gas
207	None	mARC	None	None	None	None	None	None	0.735 in	0.0	None
251	None	mARC	40	Air	0.25	1.0	1.0	2.0	mARC-18.67mm_5.56mm_throat	0.0	None

**Test Articles** [+ Add Article](#) [Spreadsheet](#)

Model	Shape	Runs	Conditions	Sting Arm	Position	Dwell
<a href="#">test</a>	8in_Wedge	mARC006R023, mARC006R020, mARC006R018, mARC006R024	—	—	—	—

**Media**  
Images Video Meshes

[test](#)

**Pre-run**  
VKI9\_pre\_aligned.ply

**Post-run**  
VKI9\_post.obj



# Runs



**RUN**  
**mARC006R023**  
Access Groups: [No groups assigned](#)  
Conducted Apr 3, 2025 13:15 for mARC006 at mARC. No objective recorded yet.

[+ Add Run](#) [▶ Process](#) [📄 Upload Data](#) [🗨 Display Mode](#)

**TEST ARTICLES** 1 **DIAGNOSTICS** 0 **CONDITIONS** 1  
**IMAGES** 3 **VIDEOS** 1

**Quick Actions**

**EXPORTS**

- JSON Summary
- Timeseries TSV
- LaTeX Summary

**TEST ARTICLES**

test

**FILE ATTACHMENTS**

- test\_video VID
- test IMG
- test2 IMG
- test3 IMG

**Overview**

DATE: Apr 3, 2025 13:15 TEST: mARC006 FACILITY: mARC

**Objective**

**Procedure**

**Notes**

**Configuration**

Parameters Test Articles Conditions Sting Config Channel Hookups Component Setup

```
object {12}
  start_time: 2025-01-27T11:14:01-08:00
  dt: 0.000125
  facility: miniature Arcjet Research Chamber
  test_gas: air
  run_id: mARC006R020
  input_settings [0]
  test_engineer: Unknown
  principal_investigator: null
  operator: null
  run: mARC006R023
  test: mARC006
  heater_settings {2}
```

**Datasets**

Timeseries Images Video Spectra

Search videos by name...

Sting 4: PICA-F-03

test\_video

Each run captures an individual execution of a test, with:

- Timestamped metadata (start time, test gas, facility, etc.)
- Automatic links to test article, apparatus, and diagnostics
- Attached images, videos, and configuration files
- Export options: JSON, LaTeX, time-series TSV

# BEAST Overview



**ARCBEAST** v0.1

Search everything...

Report issue aquintart

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Engineer Shortcuts

- Advanced Condition Search
- Compare Diagnostics Across Runs

# Materials



BEAST material database provides a centralized, structured way to track and manage all information related to materials tested in arcjet facilities.

**MATERIALS**  
**TSM Material Database**

Browse thermal protection materials, review published versions, and manage bulk imports or exports.

[Bulk Import](#) [Bulk Export](#)

**MATERIALS** **23** **LAST UPDATE** **Sep 19, 2025**

**Material Library**

<b>Copper</b> pure copper  VERSIONS No versions published yet. <a href="#">Material summary</a>	<b>AI_5056_hc_2in</b> No description available.  VERSIONS <b>1.01</b> <a href="#">Material summary</a>	<b>EA-9394</b> No description available.  VERSIONS <b>1.1</b> <a href="#">Material summary</a>
<b>FRSI-Nomex</b> No description available.  VERSIONS <b>2.00</b> <a href="#">Material summary</a>	<b>FRSI-RTV-10mil</b> No description available.  VERSIONS <b>2.00</b> <a href="#">Material summary</a>	<b>HT-424</b> No description available.  VERSIONS <b>1.00</b> <a href="#">Material summary</a>
<b>LI-2200_(air)</b> No description available.  VERSIONS <b>1.02</b> <a href="#">Material summary</a>	<b>LI-2200/RCG</b> No description available.  VERSIONS <b>1.03</b> <a href="#">Material summary</a>	<b>SIP</b> No description available.  VERSIONS <b>1.00</b> <a href="#">Material summary</a>

# Materials: Billets



The BEAST billet tracking system provides a structured way to register, trace, and manage the origin and usage of raw material billets across all test campaigns.

**BILLET OVERVIEW**

## Demo Billet 01

Material: [Demo Ablator](#)

[Back to billets](#) [Save changes](#)

**MANUFACTURED** **RECEIVED**

**Dec 12, 2024 06:30** **Jan 03, 2025 02:00**

### Billet metadata

**Name**  
Demo Billet 01

**Material**  
Demo Ablator

**Description**  
Hand-laminated billet for tutorials.

**Manufactured** **Received**

2024-12-12 06:30:00 2025-01-03 02:00:00

**Procedures** Hold %/Ctrl for multi-select

**Notes**  
Stored in lab freezer. Use for walkthroughs only.

### Billet JSON data

Tree Text

```
Sélectionner un nœud...
└─ object {4}
  └─ lot : QA-2025-001
  └─ batch_mass_kg : 2.8
  └─ orientation : 0/90 layup
  └─ flags [2]
```

# BEAST: Development & Deployment



## Development plan

- **Developed with regular inputs/requests from stakeholders**
  - MSR, ESM, Orion, test engineers, PIs, Universities
- Simple codebase (part-time 2-person dev team)
- Sufficiently abstract for deployment to non-arcjet facilities

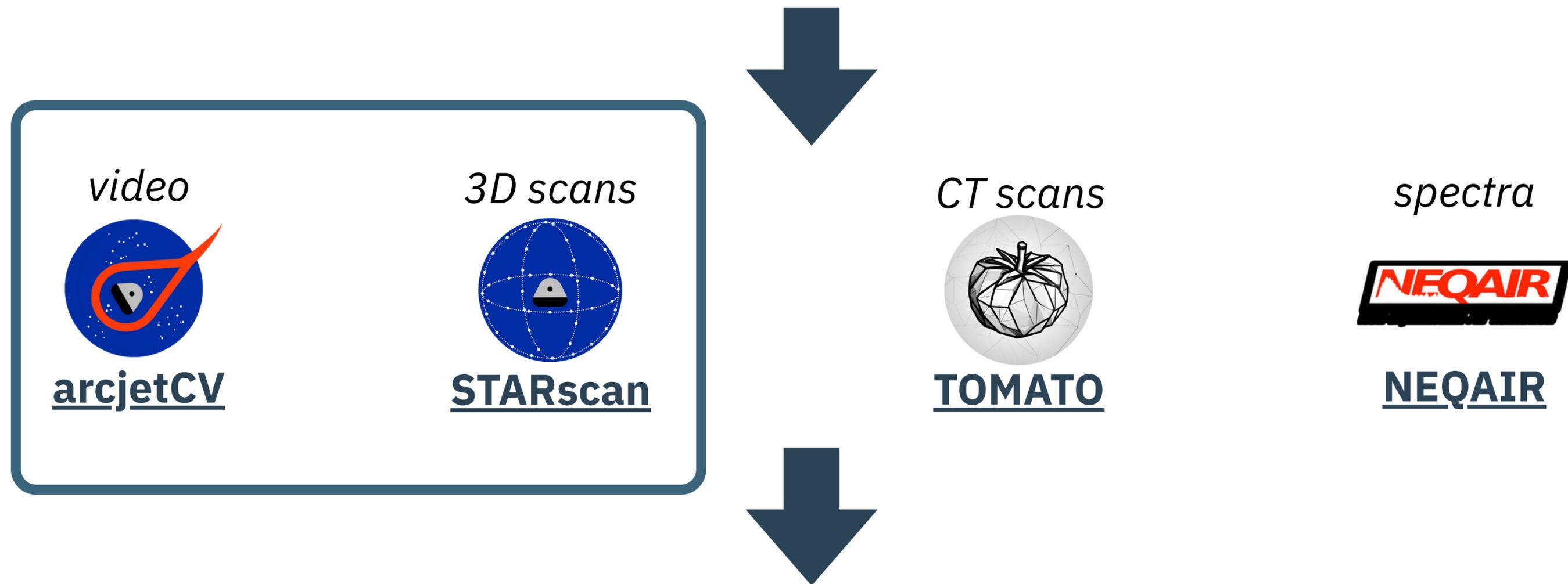
## Deployment plan

- Pilot BEAST deployment at Ames
  - miniature Arcjet Research Chamber
  - ARCTRON (NASA Ames ICP)
  - TSM material database, MSR, Orion data
- Pilot deployment for AHF/IHF/HyMETS starting FY26
- **Open source release expected before Dec 2026**

# BEAST: Scaling beyond the basics

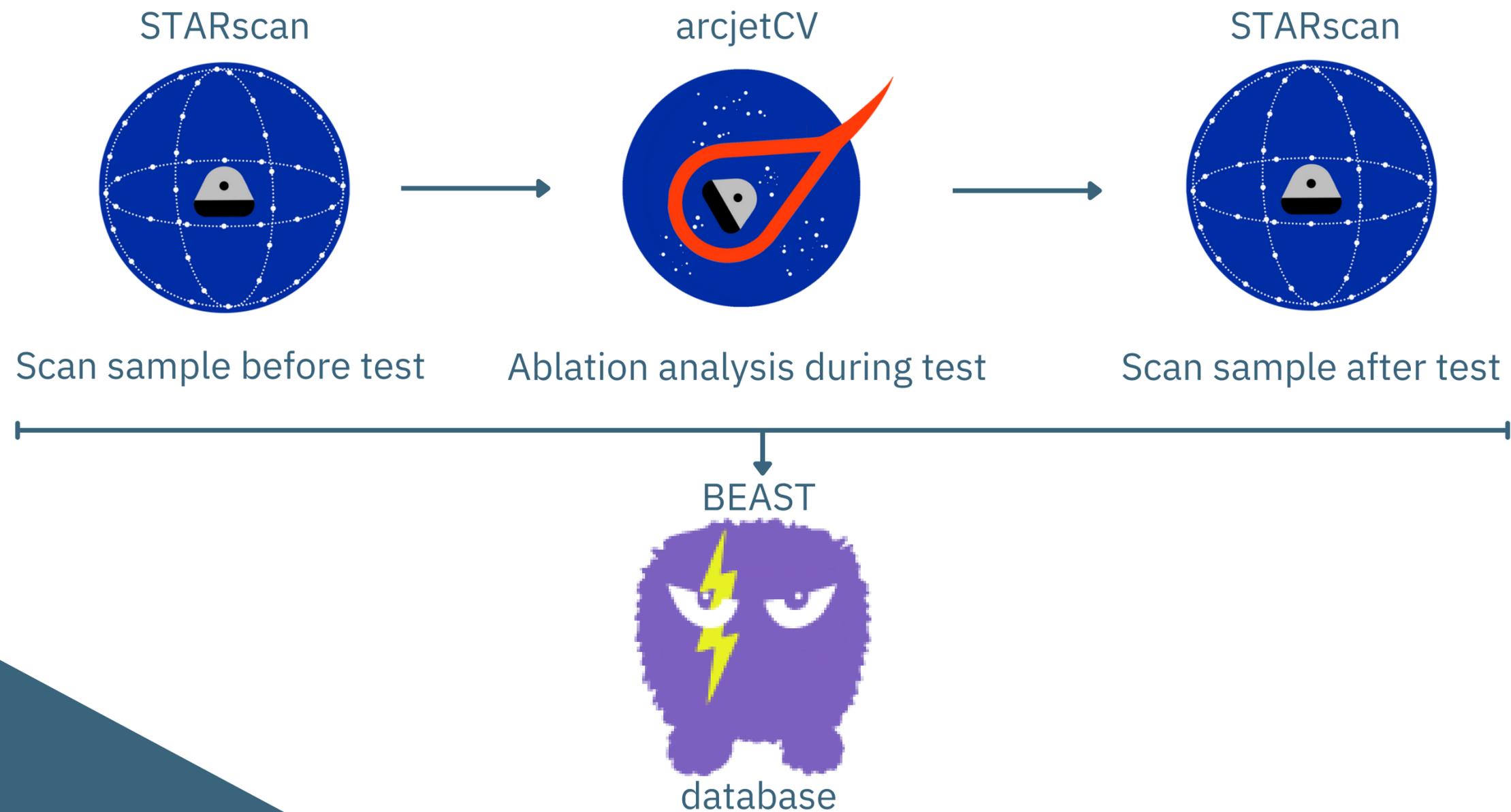


BEAST enables us to tackle traditionally difficult data types in a reproducible & traceable manner with consistent formats



BEAST ensures **standardization** & **traceability** for external analysis pipelines

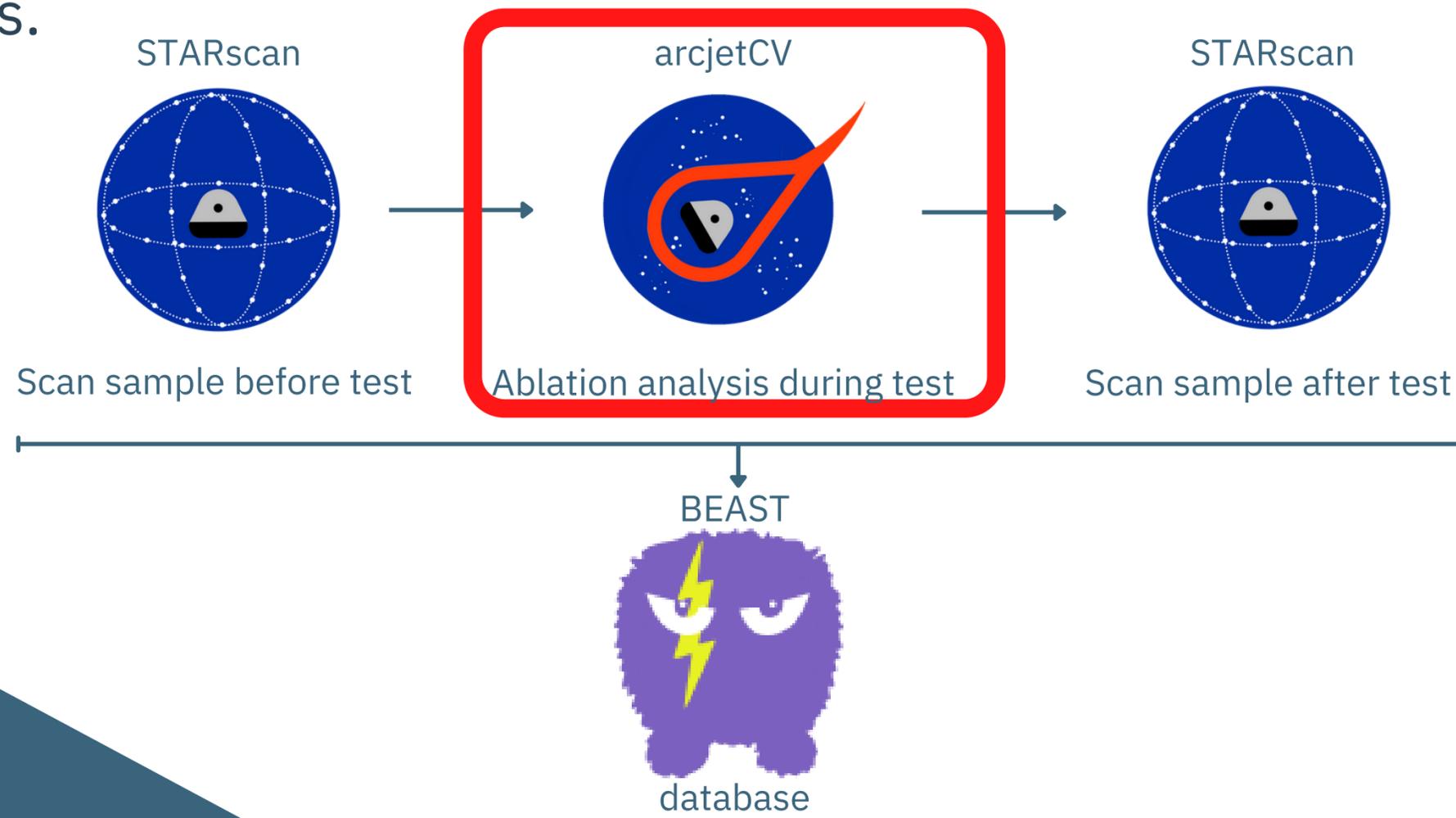
# Feeding the BEAST



# arcjetCV

## Motivations

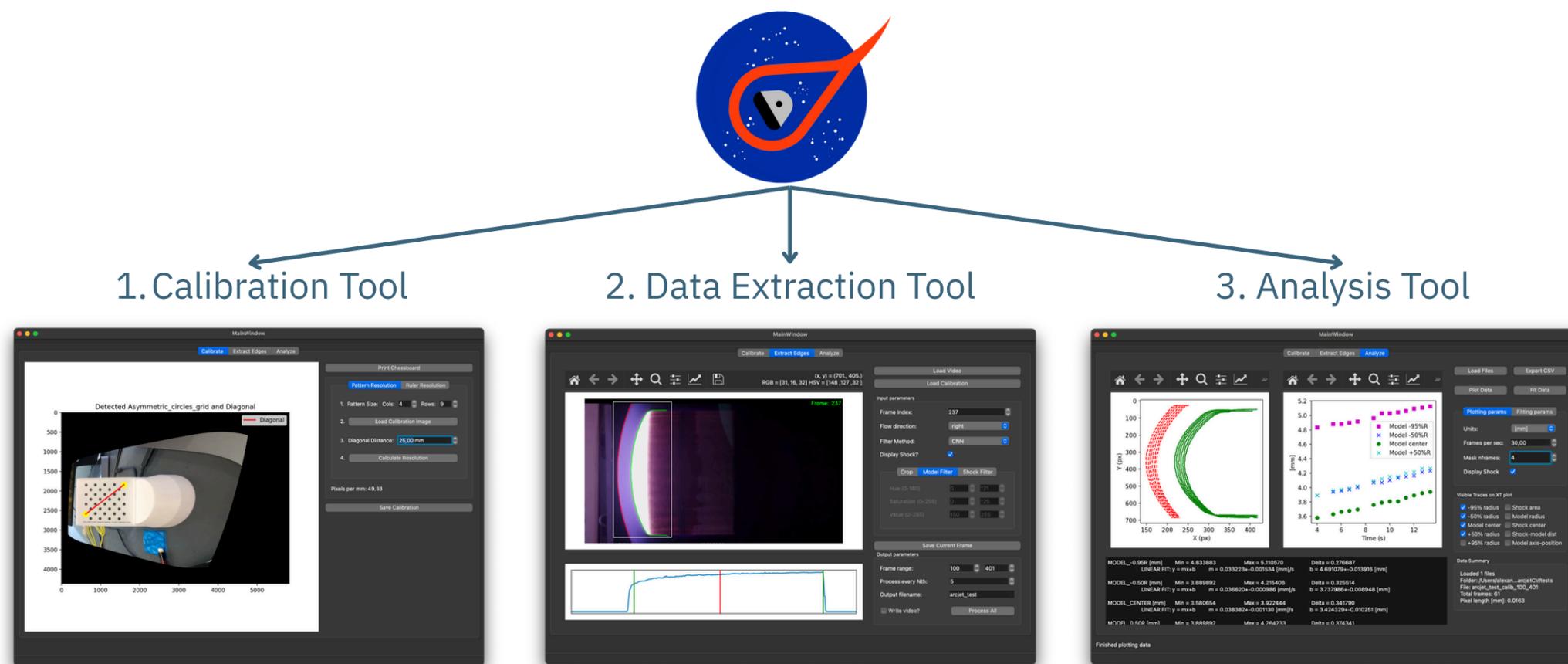
- No existing tool could **automatically** extract time-resolved recession from arc-jet videos.
- Manual frame-by-frame analysis is **slow**, subjective, and not scalable.
- NASA needed a **reproducible** and traceable method for TPS recession measurements.



# arcjetCV Overview

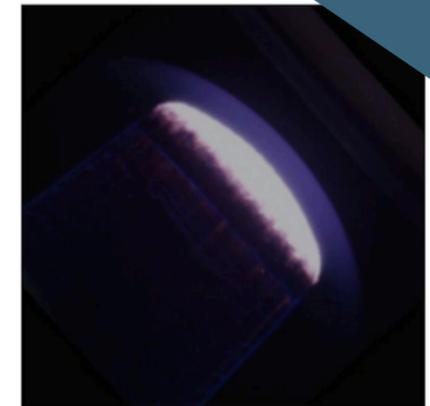
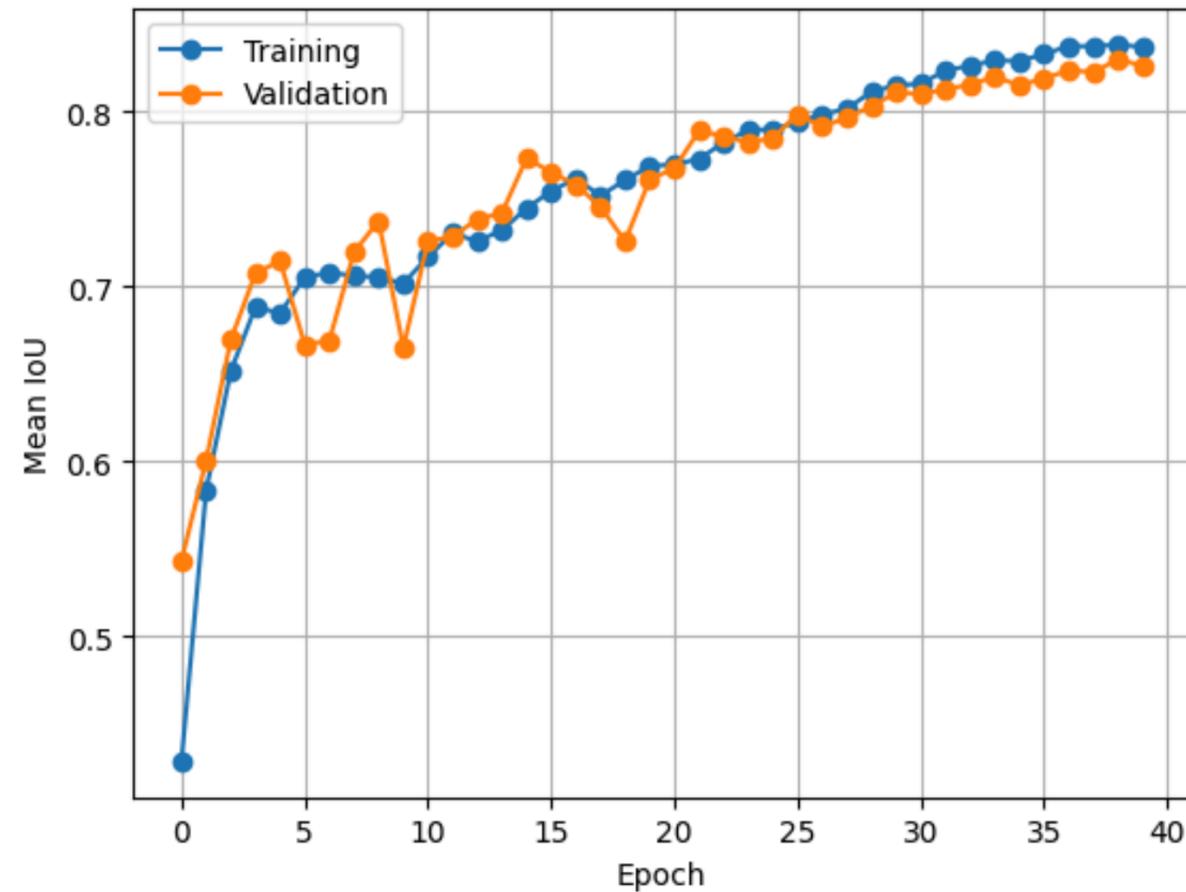
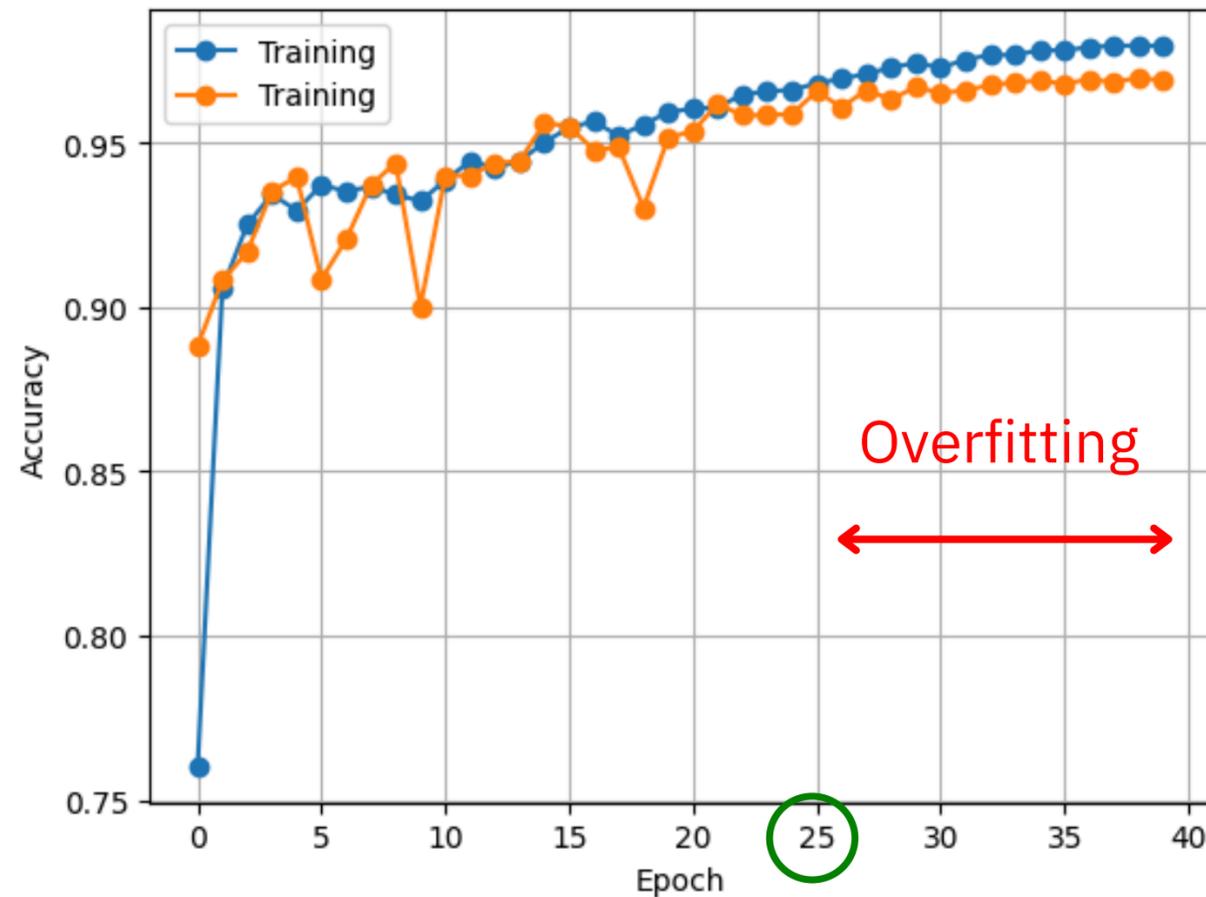


- **open-source software** tool for analyzing heatshield material performance during arcjet tests.
- **Machine learning** (CNN) models for automated video segmentation.
- Tracks **time-dependent** material **recession** and shock **standoff distance**.
- GUI for **user-friendly** operation; API for batch processing.

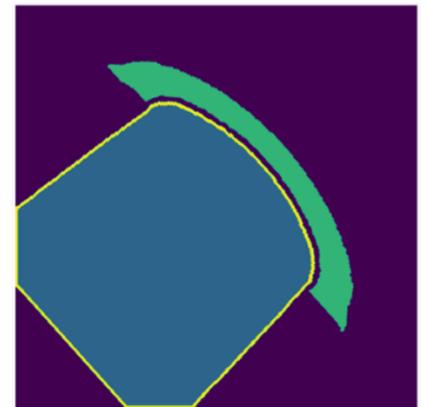




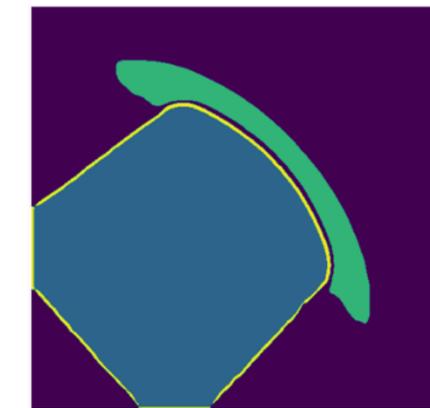
# ML architecture performance



Challenging video frame



Ground truth masks



Xception prediction

Model with 25 epochs	Pixel Accuracy	mIoU
Xception	0.9687	0.8005

## → Handles Class Imbalance

where  $N$  = Total number of classes.

where:

- True Positive (TP) = Pixels correctly predicted for class  $i$ ,
- False Positive (FP) = Pixels incorrectly predicted as class  $i$ ,
- False Negative (FN) = Pixels of class  $i$  that were missed.

Mean Intersection over Union (mIoU):

$$mIoU = \frac{1}{N} \sum_{i=1}^N IoU_i \quad IoU_i = \frac{TP_i}{TP_i + FP_i + FN_i}$$

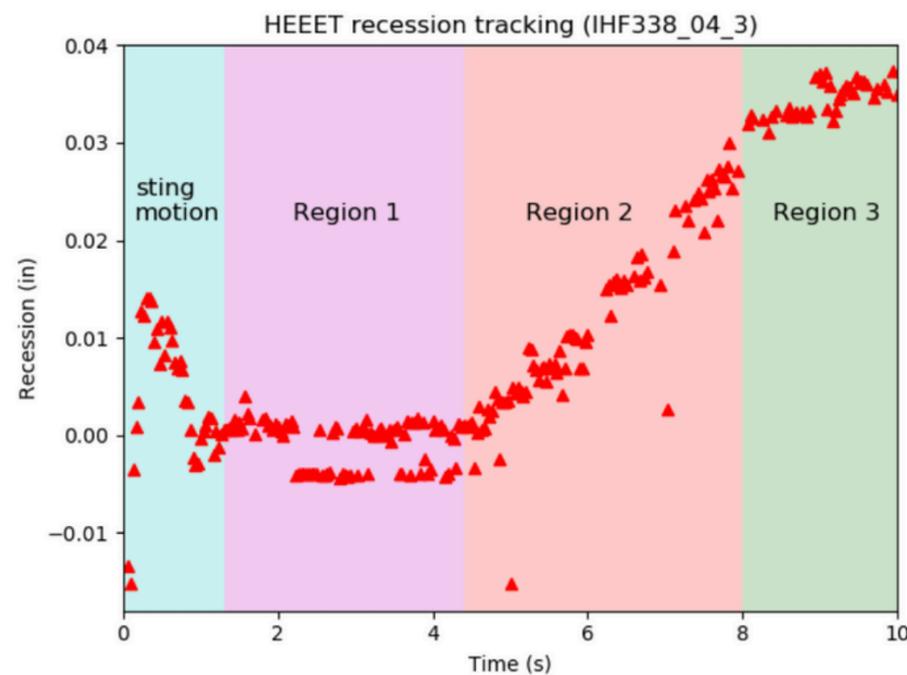


# arcjetCV: Observations

## 1. Non-linear Recession

**With arcjetCV:** 3 Regions:

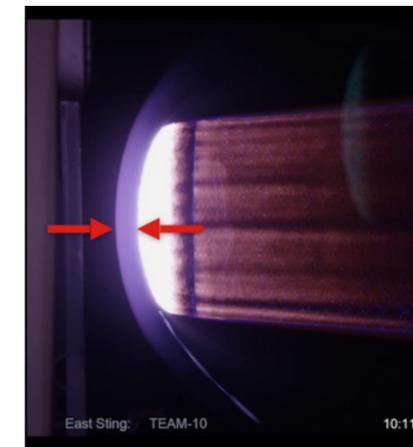
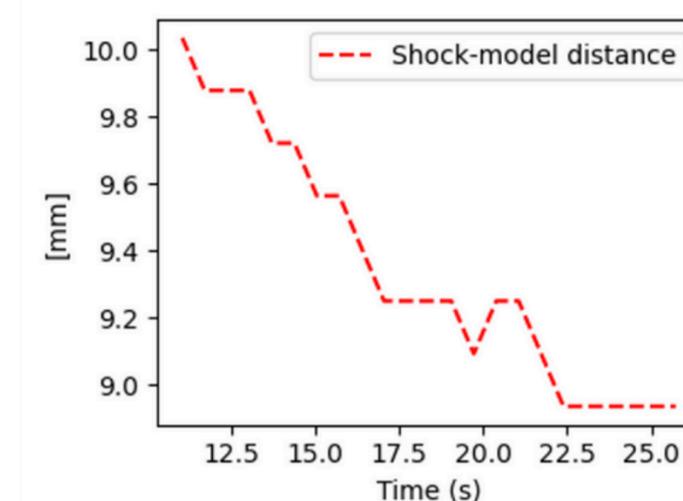
- *Region 1:* Nearly no recession
- *Region 2:* Constant recession rate
- *Region 3:* reduced recession rate



## 2. Shock standoff

Shock-sample distance decrease implies that the pressure at the sample surface is changing with time:

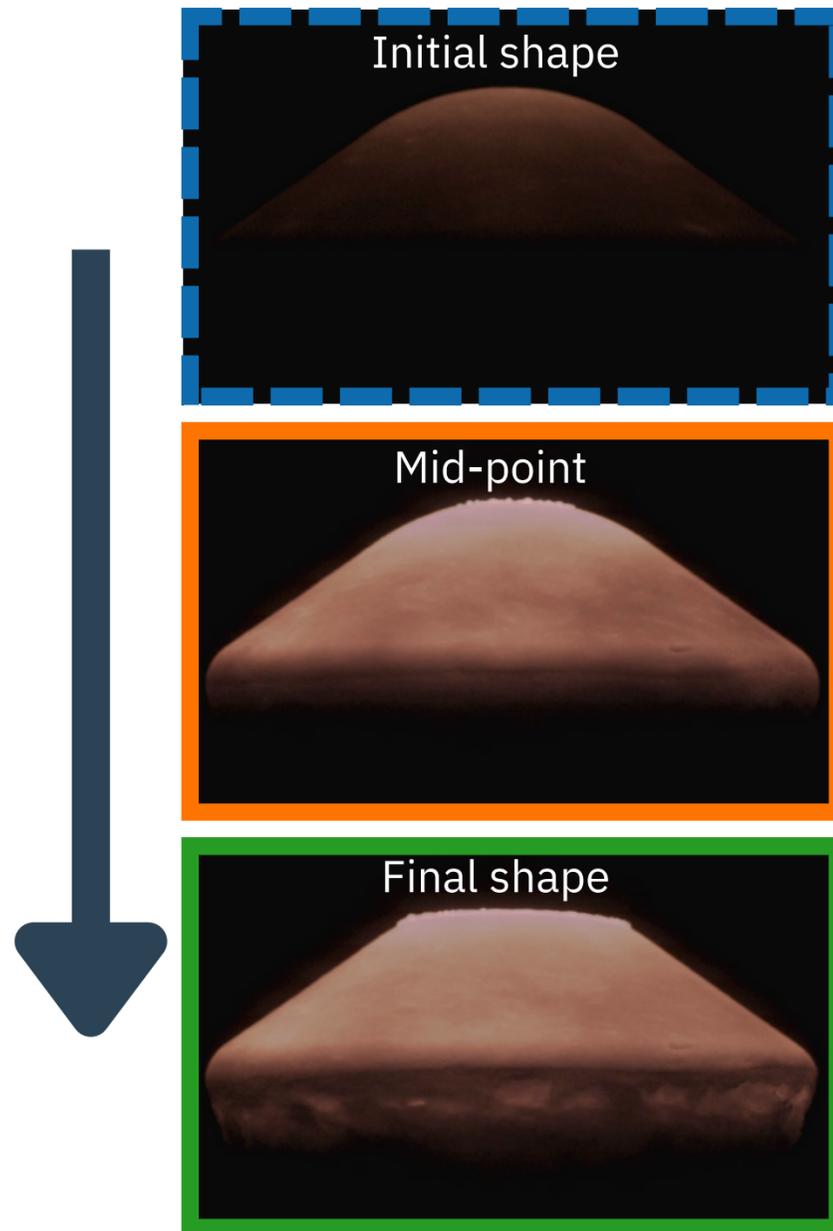
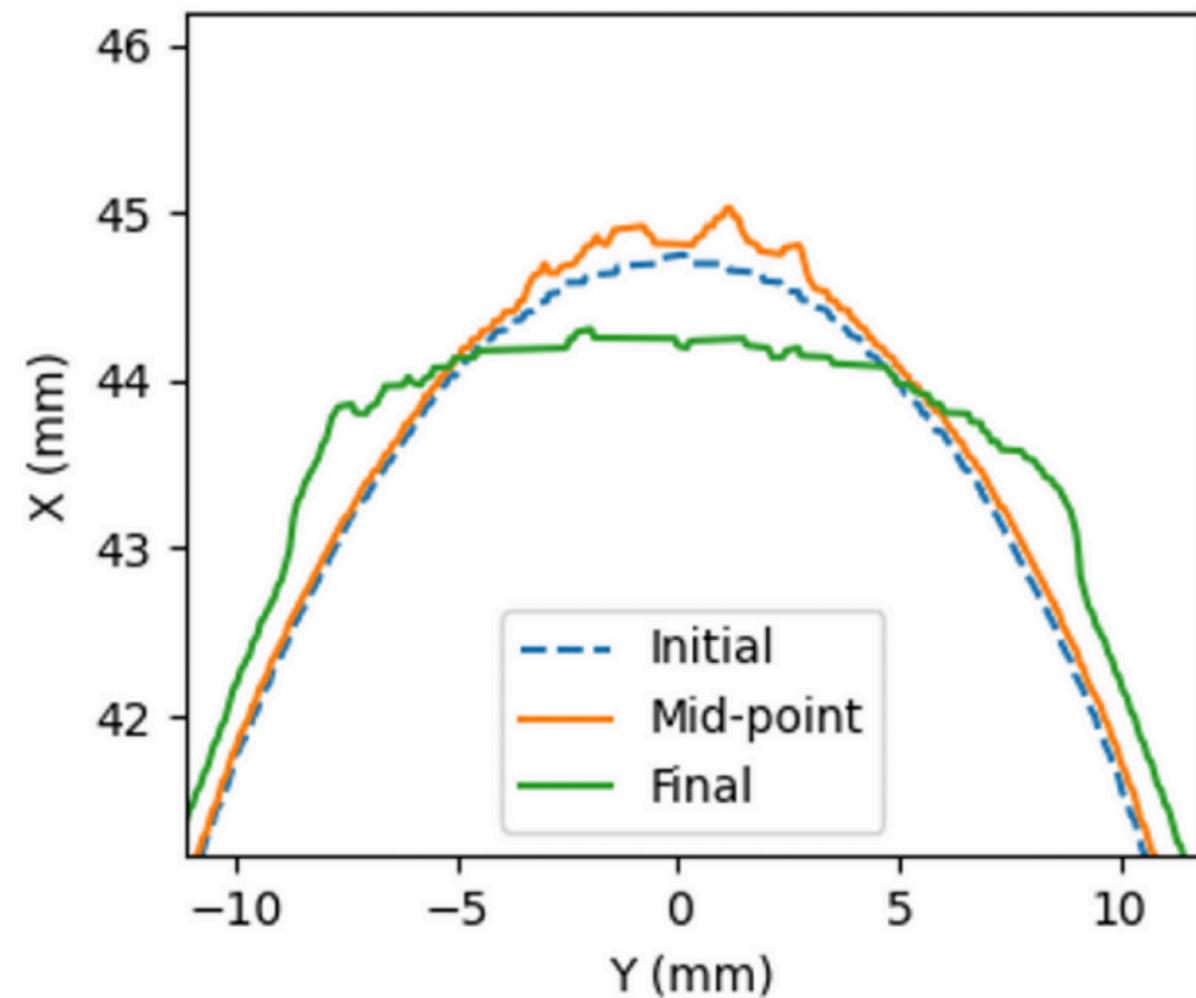
→ Pyrolysis gas pressure is changing





# arcjetCV: Observations

## 3. Shape change



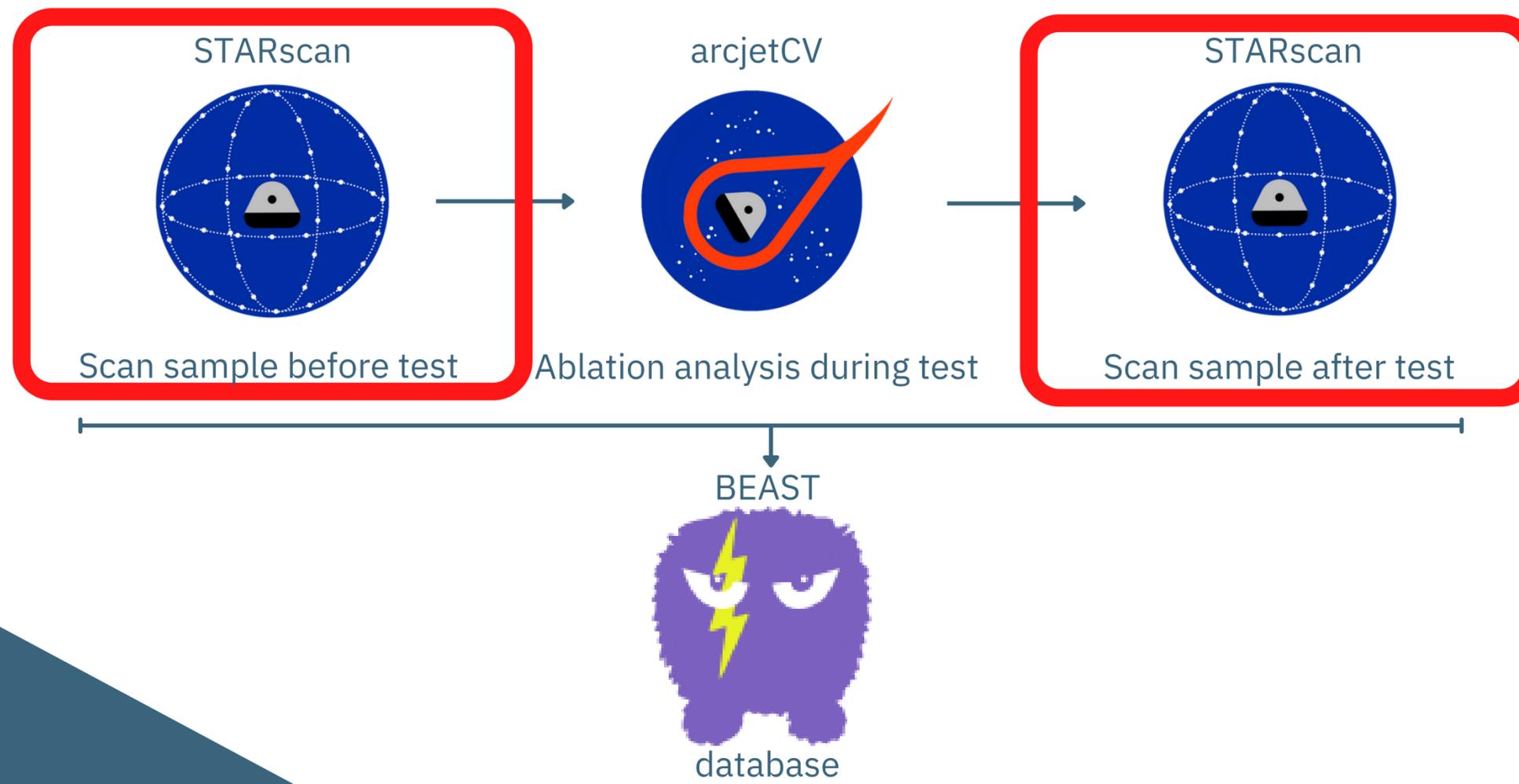
- Surface develops millimeter scale ripples/bubbles

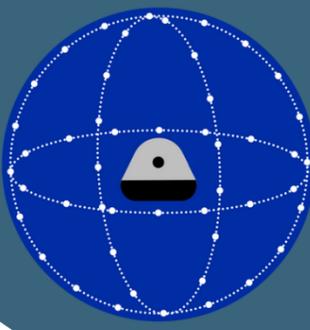
- Sample deforms/flattens at the nose.
- The entire sample is expanding (e.g. negative recession at the edges).

# STARscan

## Motivations

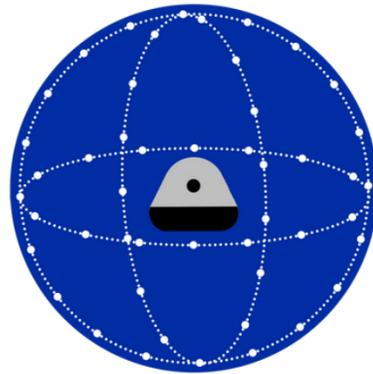
- Traditional lab scanners are **slow** to set up, and both scanning and post-processing require significant **time**.
- NASA/VKI needed a **fast, repeatable** workflow to document sample recession and geometry changes across test campaigns.



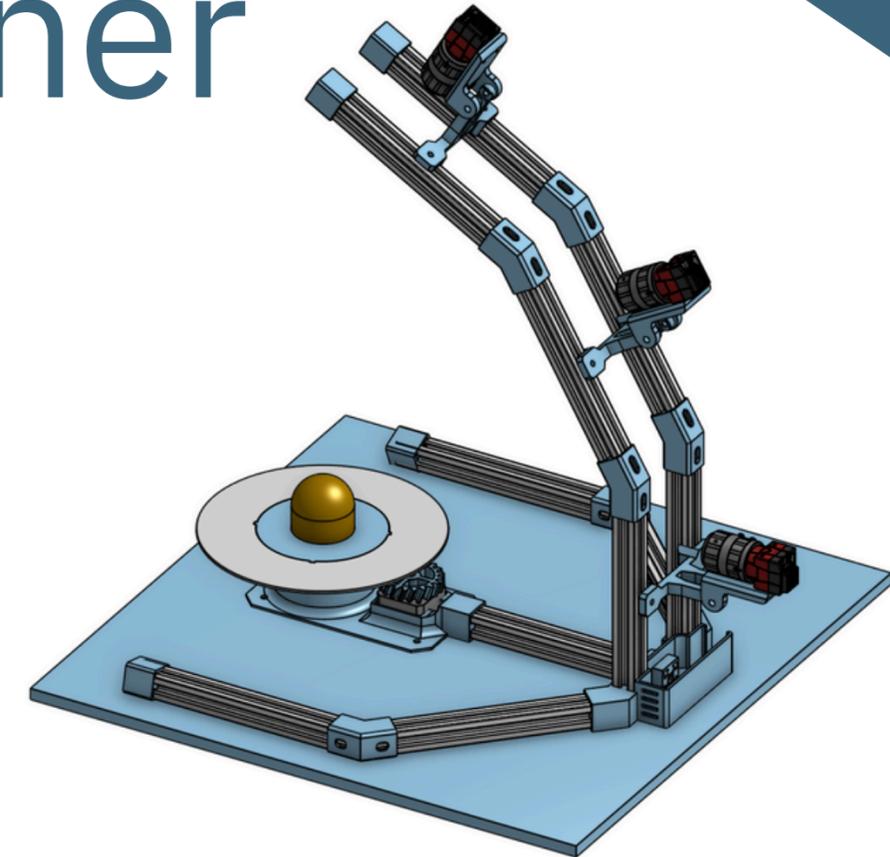


# Photogrammetry scanner

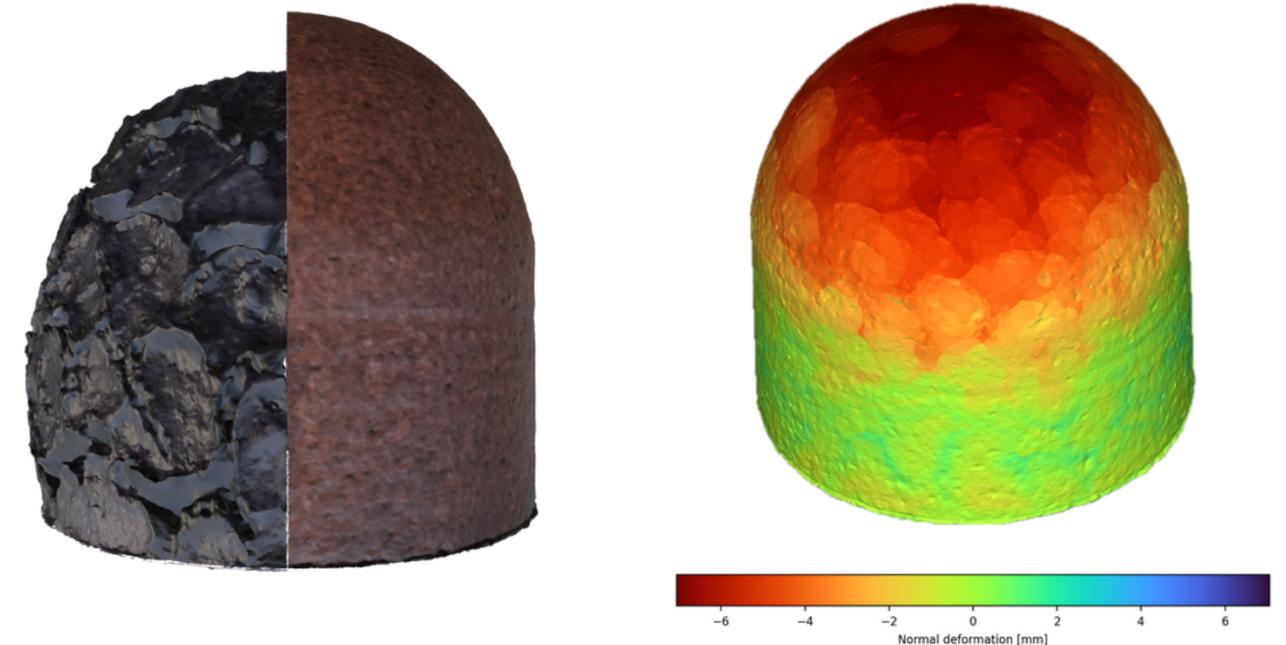
STARscan



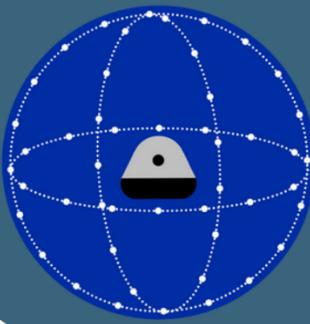
Scan sample before and after test



- Three custom **3D scanning systems** built to accelerate and streamline scanning and analysis of arcjet test articles.
- **Software** that provides analysis of the shoulder **curvature**, **roughness** and **recession**.
- **Principle:** Photogrammetry
- **Accuracy:** ~ 0.35mm
- **Scan time:** 2 min



# new version: miniSTARscan



## Simpler hardware

- Uses 3 instead of 6 cameras and makes use of the turntable to acquire more images
- Design uses standard 20x20x200 mm t-slotted rails instead of 25x25 mm x-sections with varied lengths.

## Improved alignment

- Sample turntable is fixed to camera rig for consistent imaging/focus
- Smaller camera rig optimizes for standard 1-4" diameter samples

## Additional Calibration Patterns

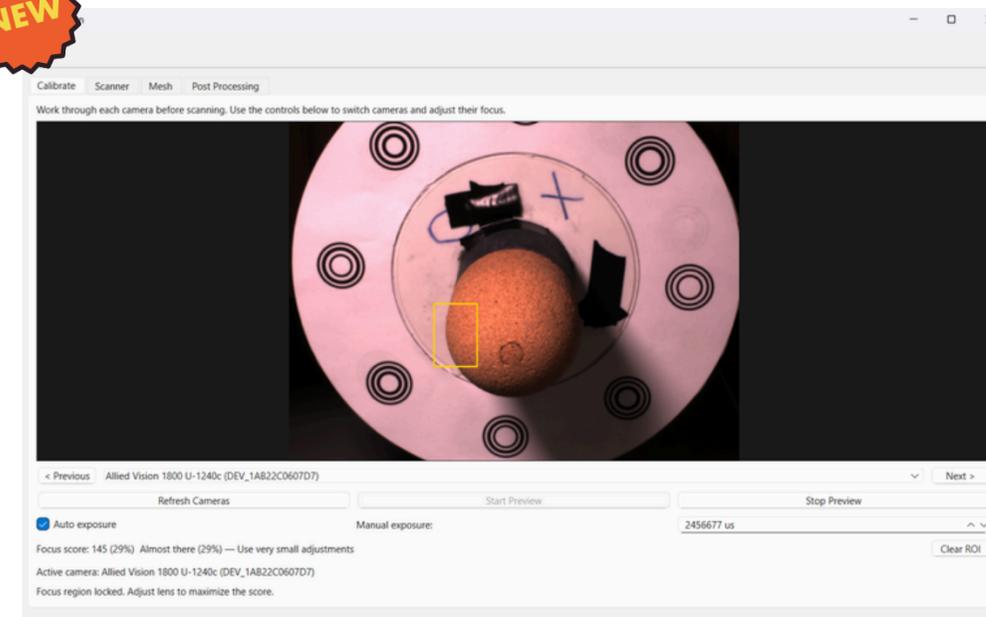
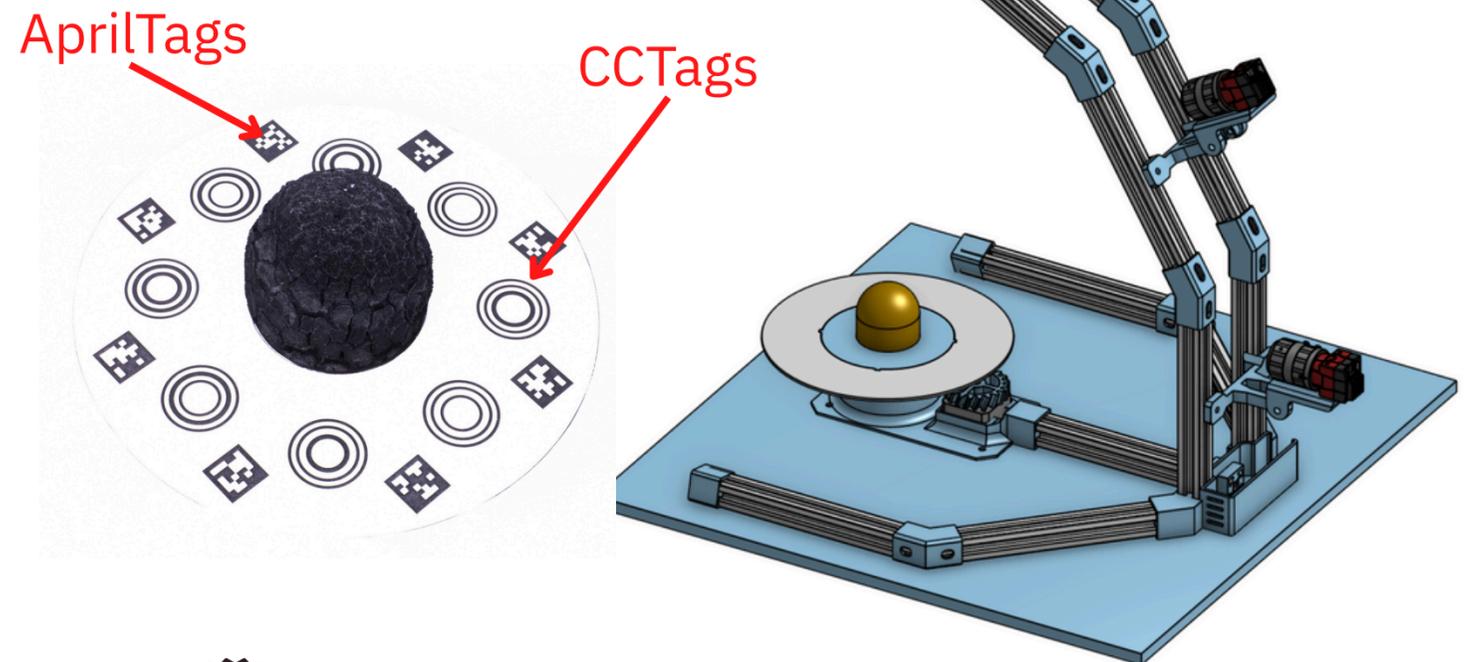
- Uses both CTags and April tags to be compatible with both Meshroom and RealityCapture
- Tags built into turntable platform for auto-calibration every scan

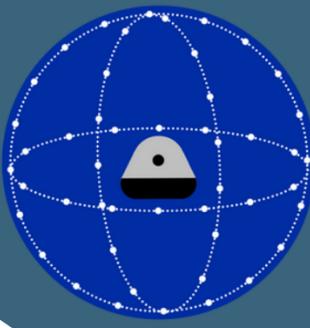
## Lighting improvements

- Lighting is now mounted onto the rig instead of on separate independent posts (more consistent lighting)
- Posterboard light box more consistent than paper backing.

## Calibration tab

- Live preview with user selectable ROI for each camera
- Realtime quantified sharpness with focus score.





# new version: miniSTARscan

## Simpler hardware

- Uses 3 instead of 6 cameras and makes use of the turntable to acquire more images
- Design uses standard 20x20x200 mm t-slotted rails instead of 25x25 mm x-sections with varied lengths.

## Improved alignment

- Sample turntable is fixed to camera rig for consistent imaging/focus
- Smaller camera rig optimizes for smaller samples

## Additional Calibration Parameters

- Uses both CCTags and ArUco markers for alignment
- Meshroom for post-processing
- Tags built into sample for consistent alignment every scan

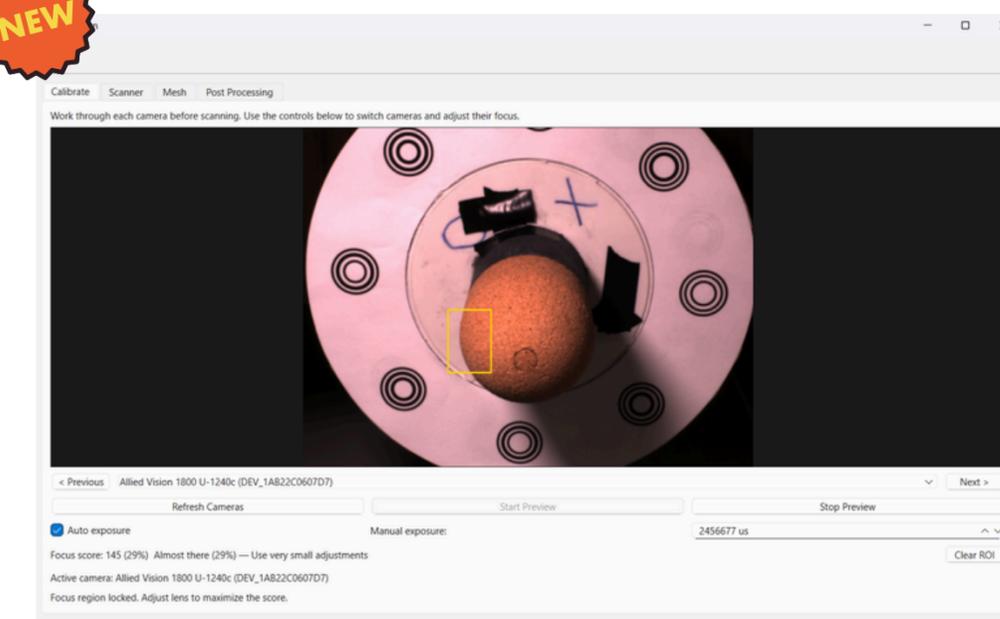
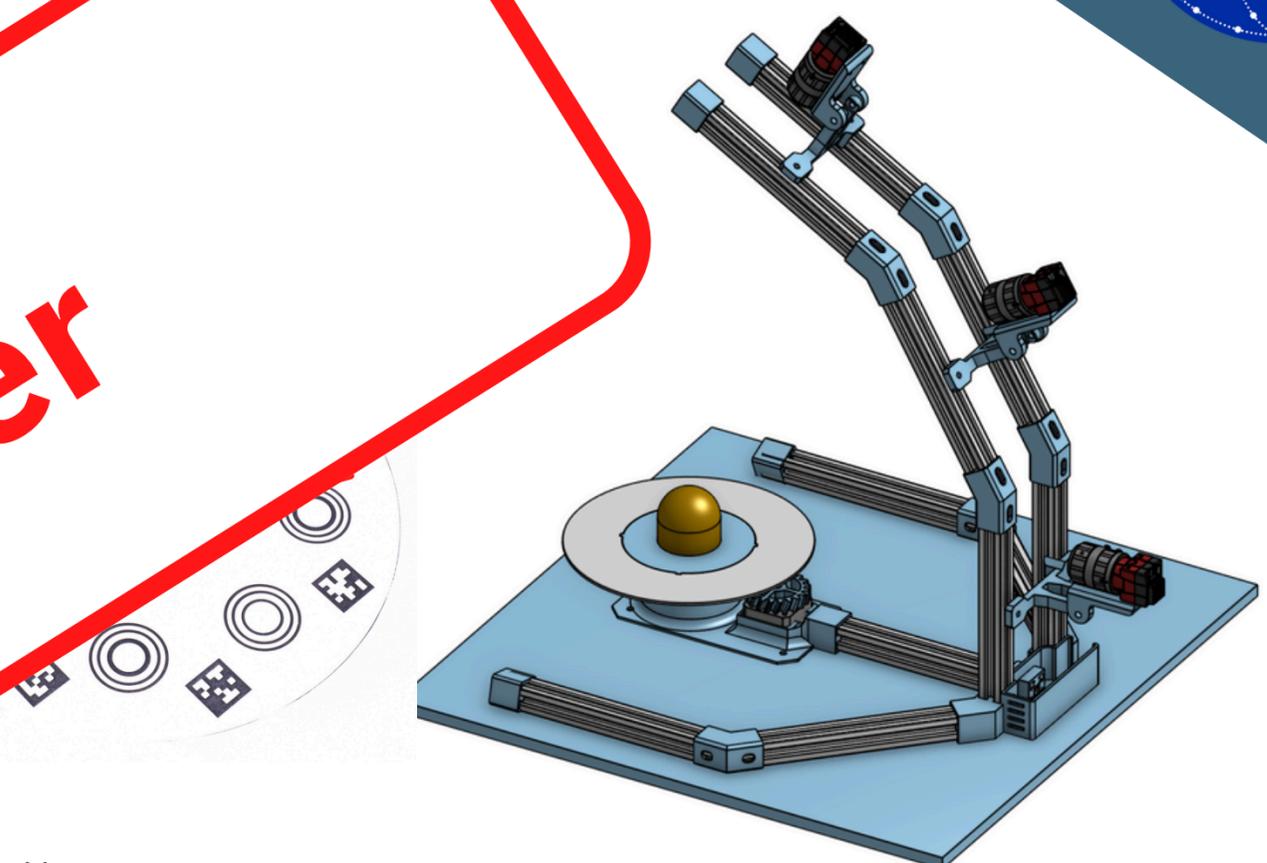
## Lighting

- Light sources on separate turntable (independent lighting)
- Posterboard (more consistent than paper backing).

## Calibration table

- Live preview of detectable ROI for each camera
- Realtime quantitative sharpness with focus score.

See the poster



# BEAST Initiative Summary



## Provides

1. **Centralized** repository
2. **Standardized** formats
3. Data **traceability**
4. **Searchable**, structured access
5. Facility configuration **management**

## Benefits

1. Facility efficiencies (data processing, search, report automation, etc.)
2. Research and development (data consistency, data search, data volume)
3. Long-term stewardship of high-enthalpy test data

## Enables

1. Cross-campaign **analysis**
2. Automated, **traceable** data processing
3. Improved test **coordination**/planning
4. **ML** modeling
5. Detailed cataloguing of higher-dim data types
6. Video, spectra, CT, surface **meshes**
7. Attaches metadata to externally processed datasets

→ A new paradigm for a modern facility data system

# Thank you for your attention !

**Want to collaborate on BEAST, STARscan, or arcjetCV?**

## **Contact us:**

Alexandre M. Quintart - alex@flying-squirrel.space

Magnus A. Haw - magnus.haw@nasa.gov

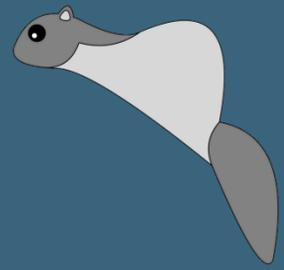
Interested by  
the project ?



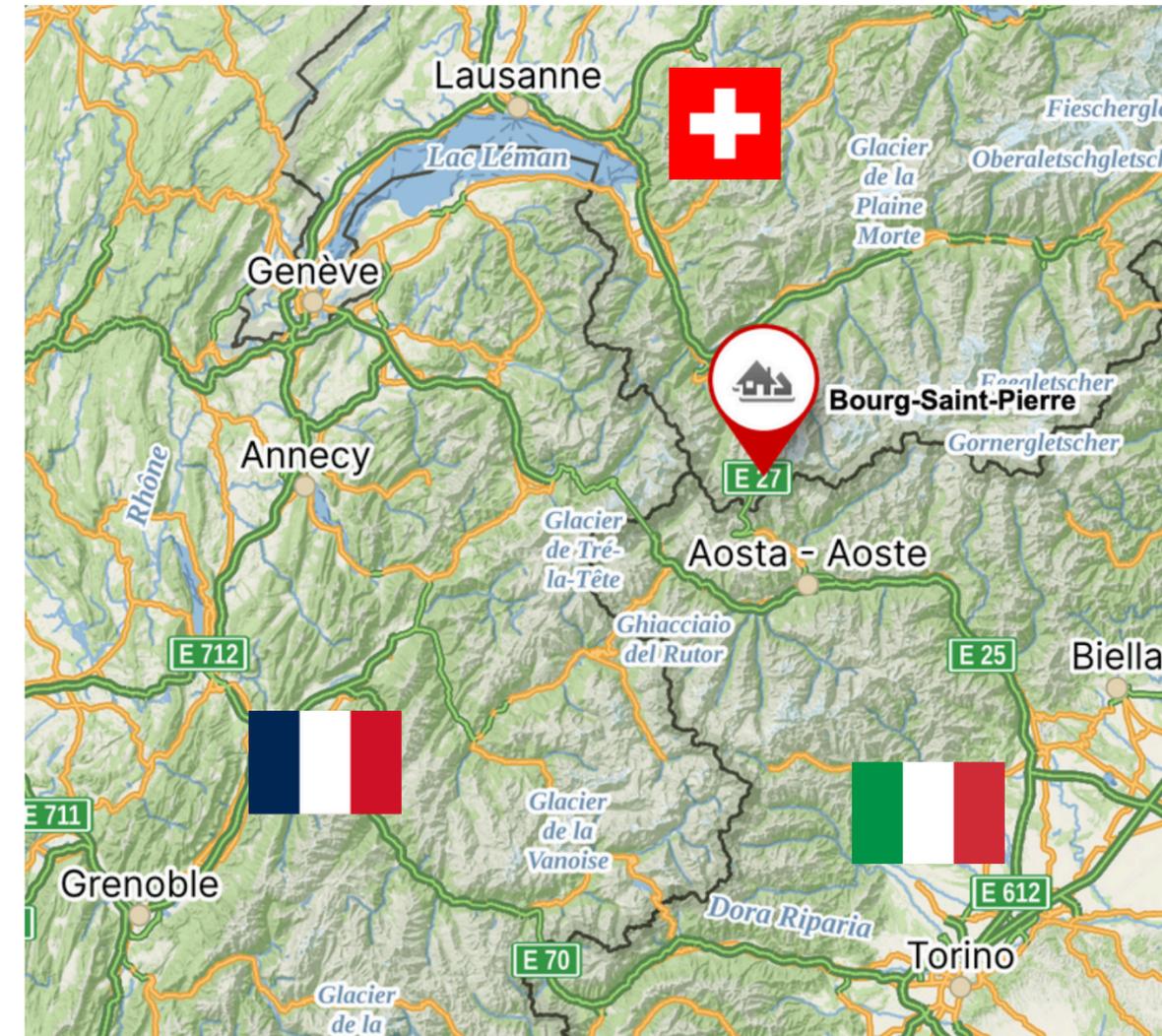
## **Funding:**

- Mars Sample Return Project
- Entry Systems Modeling Project
- TSM Branch IRAD

# Flying Squirrel

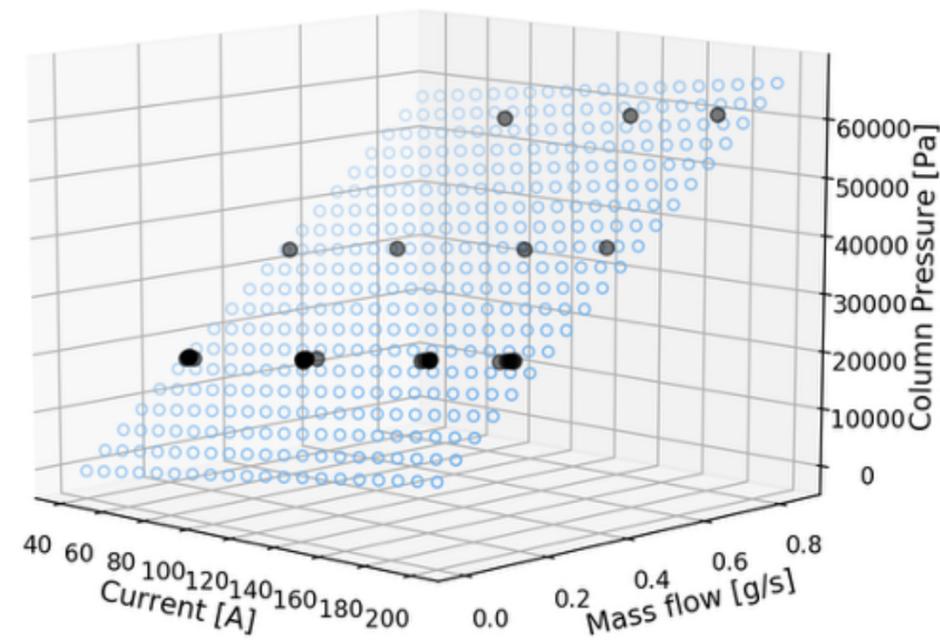


- Based in Swiss Alps.
- Contracting for:
  - NASA Ames Research Center
  - Von Karman Institute for Fluid Dynamics (VKI)
  - Analytical Mechanics Associates
- Developing tools to improve diagnostics and data analysis for arcjet & plasmatron tests.
- Focused on computer vision, 3D scanning, and data platforms to maximize scientific return from ground tests.

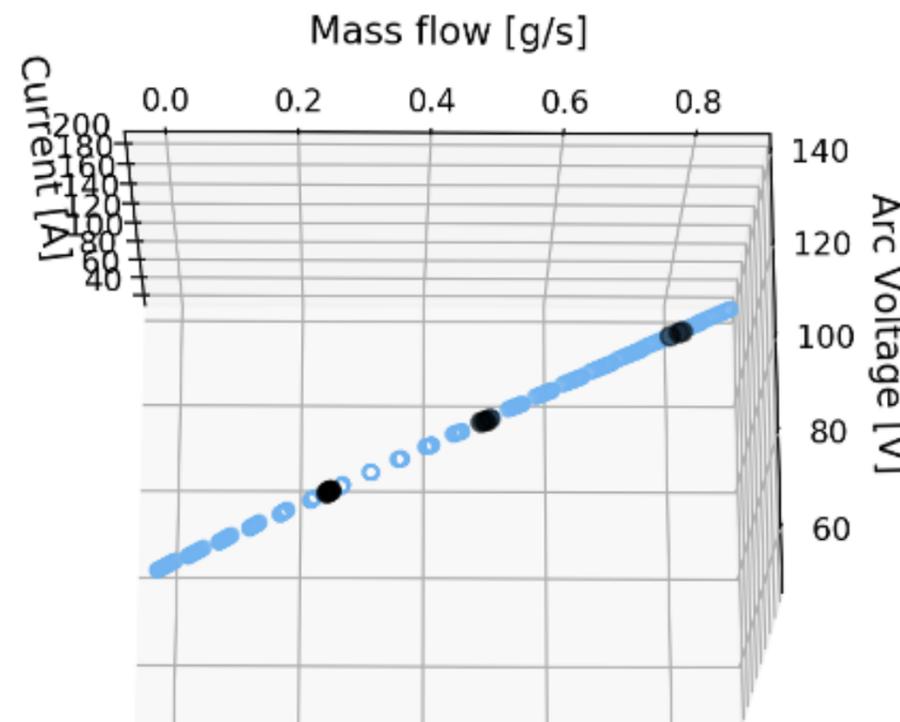
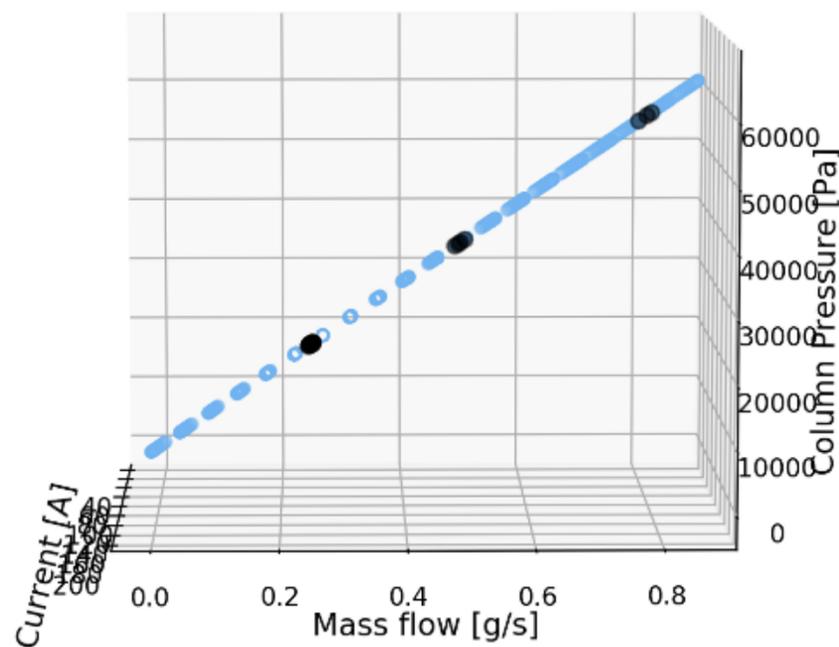
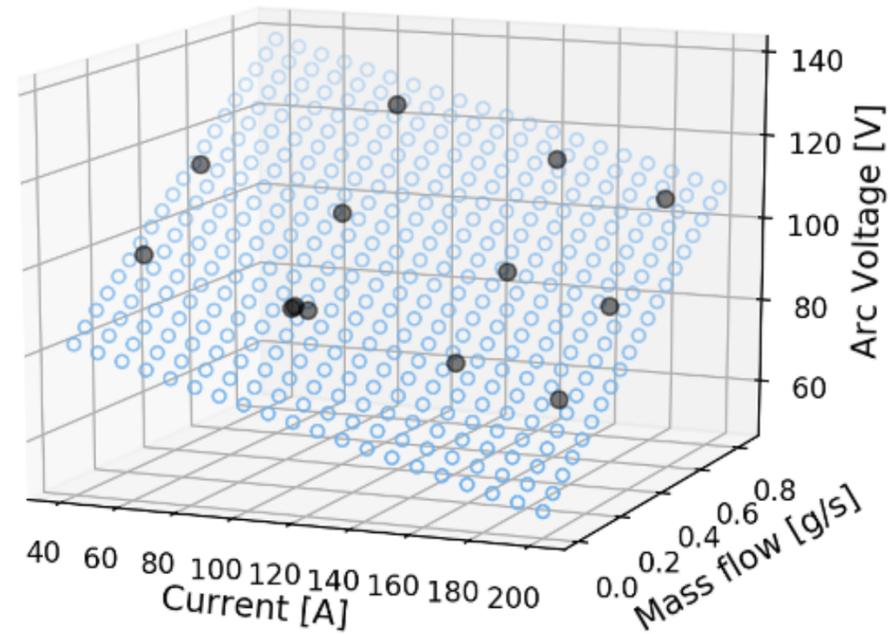


# Example BEAST Machine Learning (mARC facility)

Predicts pressure (+- 1%)



Predicts voltage (+- 2%)

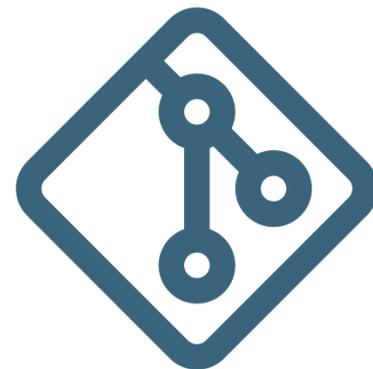


Built-in ML using linear models

- Inputs: settings + facility config
- Output: diagnostic of choice
- Auto-updates models when new data is added
- Useful for anomaly detection and facility predictions

# What a Sustainable Arcjet Data System Should Provide:

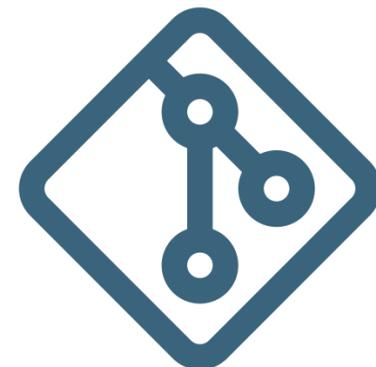
1. **Unified storage** for raw and processed data across campaigns
2. **Standardized metadata + provenance** for every dataset, instrument, and configuration
3. **Searchable and structured** access to time-series data, imagery, geometry, and sample lineage.
4. **Version control** for data, imports, analysis scripts, and facility settings
5. **Operational support:** automated reporting, configuration tracking, and sample history
6. **Standardized analysis tools:** traceable analysis versions & automation for big data



# BEAST: A Unified Data Backbone for Testing

(**B**ackend for **E**xperiment **A**nalysis, **S**torage, and **T**raceability)

1. **Centralized ingestion + storage** for time-series, imagery, geometry, and metadata
2. **Structured, enforced schema** capturing materials, samples, facility configuration, and test conditions
3. **Provenance-first model**: every dataset is versioned, traceable, and reproducible
4. **Searchable access** across campaigns, materials, instruments, and facilities
5. **Automated workflows** for reporting, run summaries, and component-usage tracking
6. **Shared web interface** for analysts, operators, and PIs—coordinated planning and review





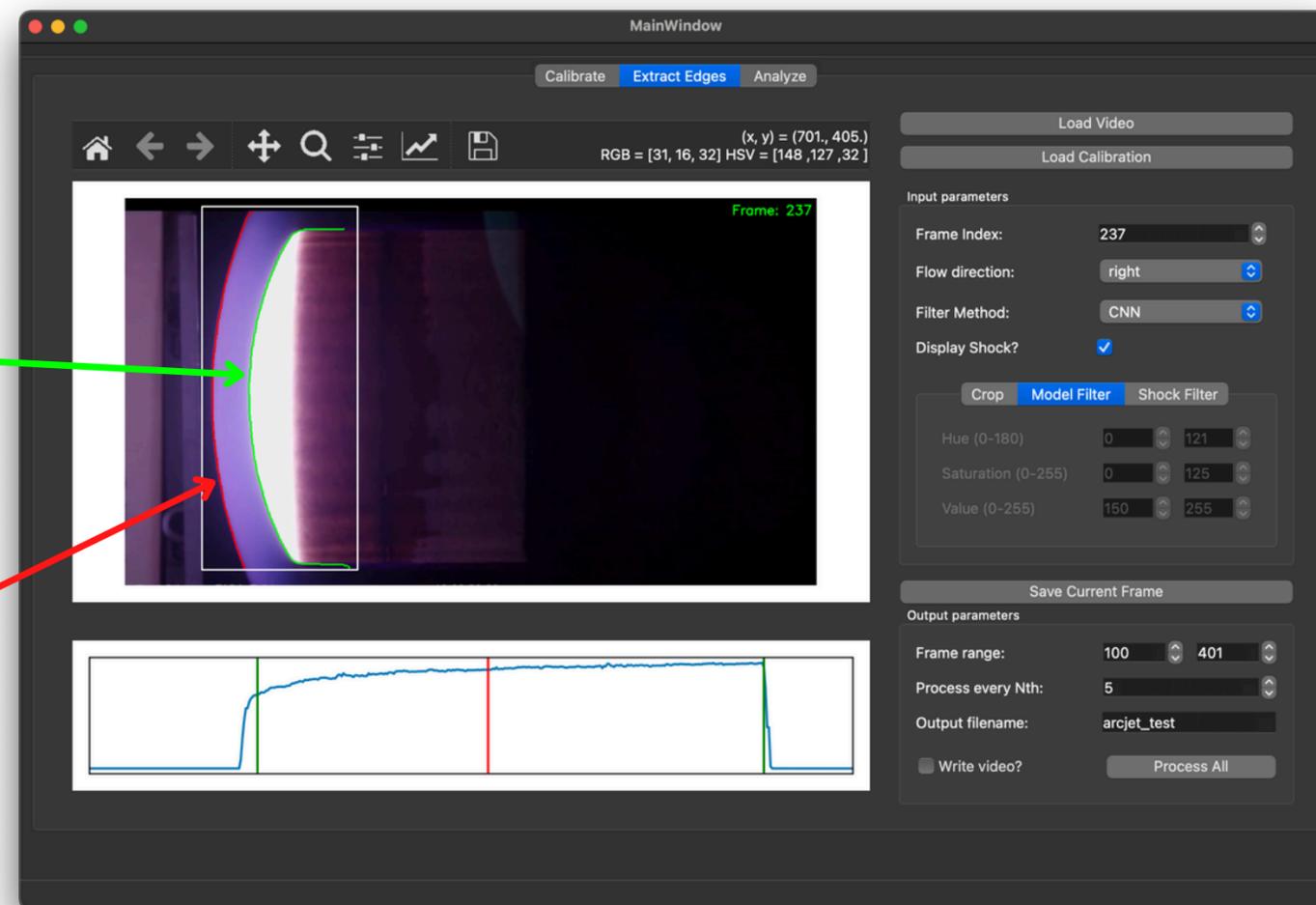
# Motivation

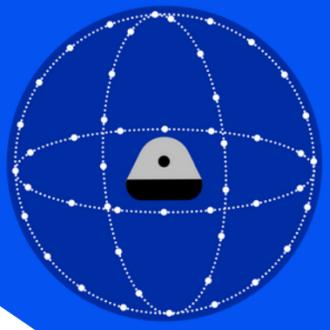
## Solution: arcjetCV

- Computer vision & machine learning automate software.
- Graphical user interface enables anyone to process video.
- Result: new time-resolved recession tracking for all samples.

Measure the evolution of the sample recession

Measure the evolution of the shock position

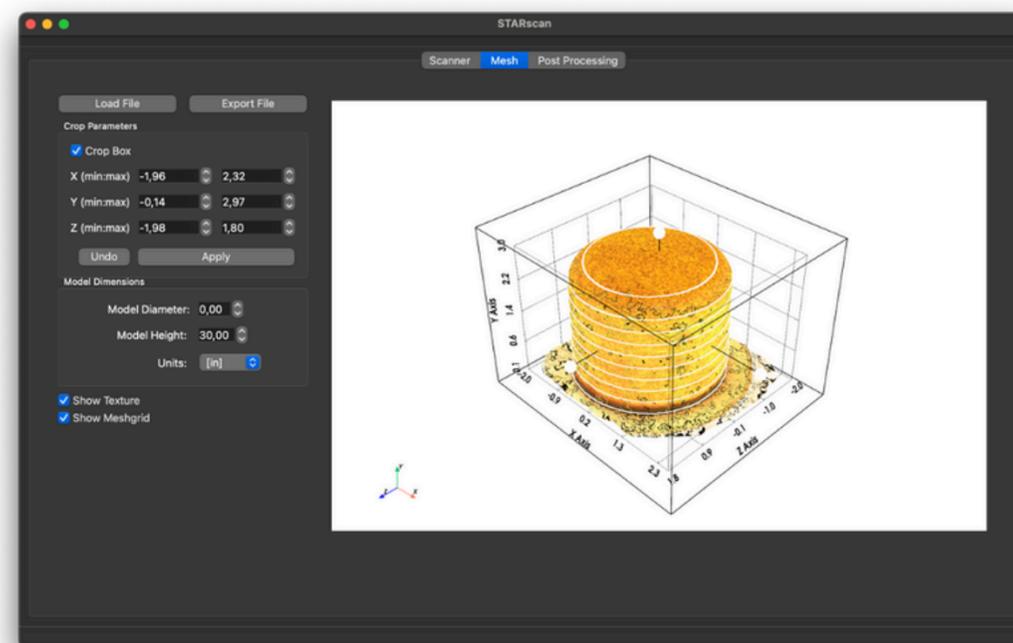




# Motivation

## Solution: STARscan

- High-resolution 3D surface scanning system.
- Automates roughness and recession quantification from post-test samples.
- Provides standardized surface metrics for model validation (e.g., RMS roughness, cavity depth, surface topology).
- Enables reproducible comparisons across tests and facilities.

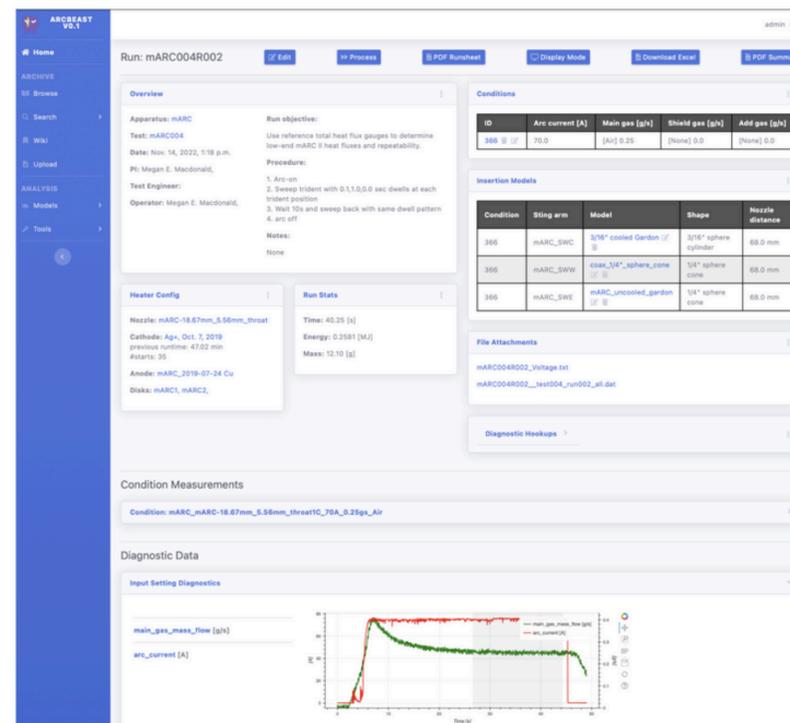




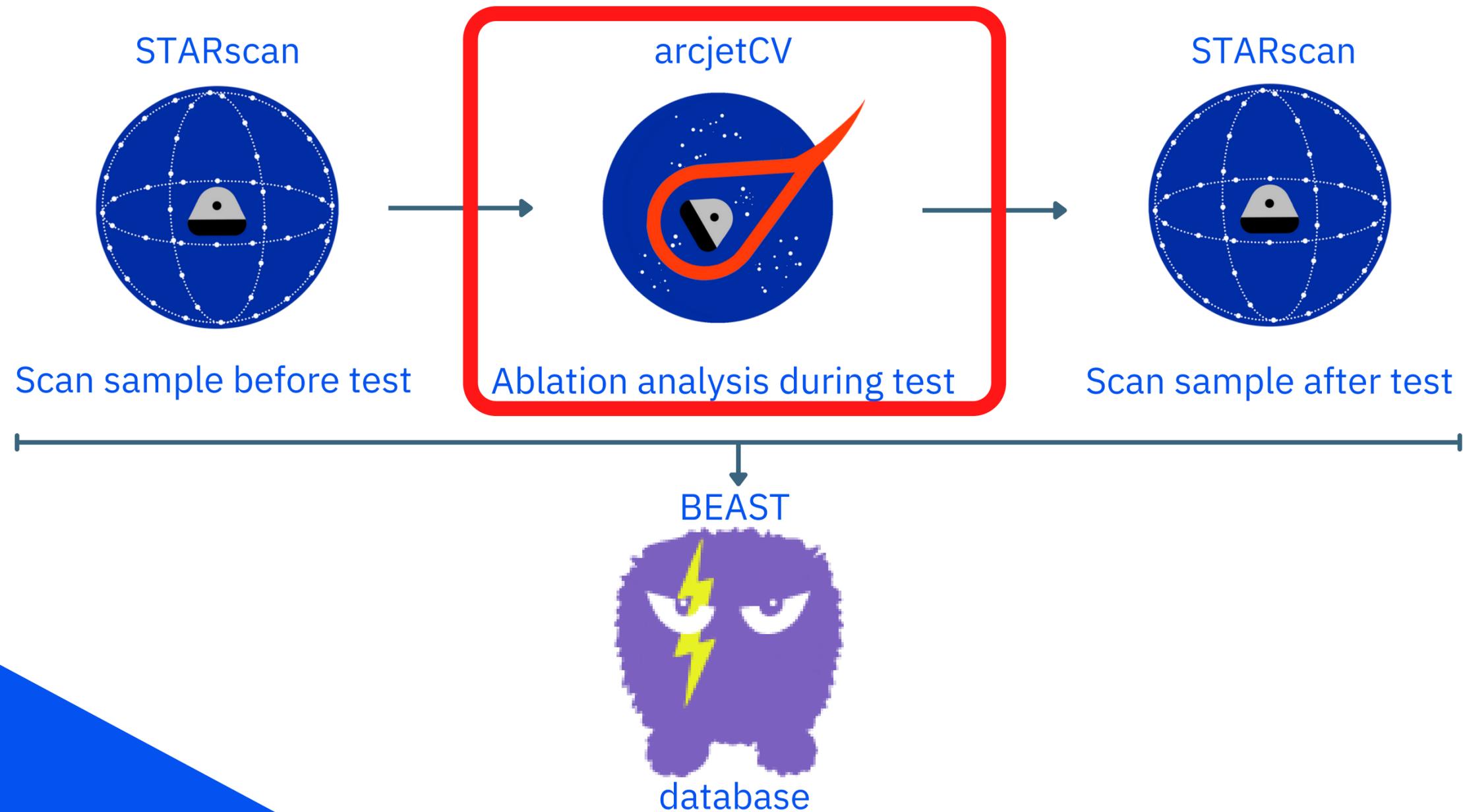
# Motivation

## Solution: **BEAST** : **B**ig-data **E**fficient and **A**utomated **S**cience **T**ransfer

- Centralized database and web platform for arcjet/plasmatron test data.
- Stores diagnostic series (video, surface scans, recession curves, etc.) in a structured format.
- Provides tools for visualization (3D meshes, plots) and cross-test comparison.
- Ensures long-term preservation and accessibility of experimental datasets.



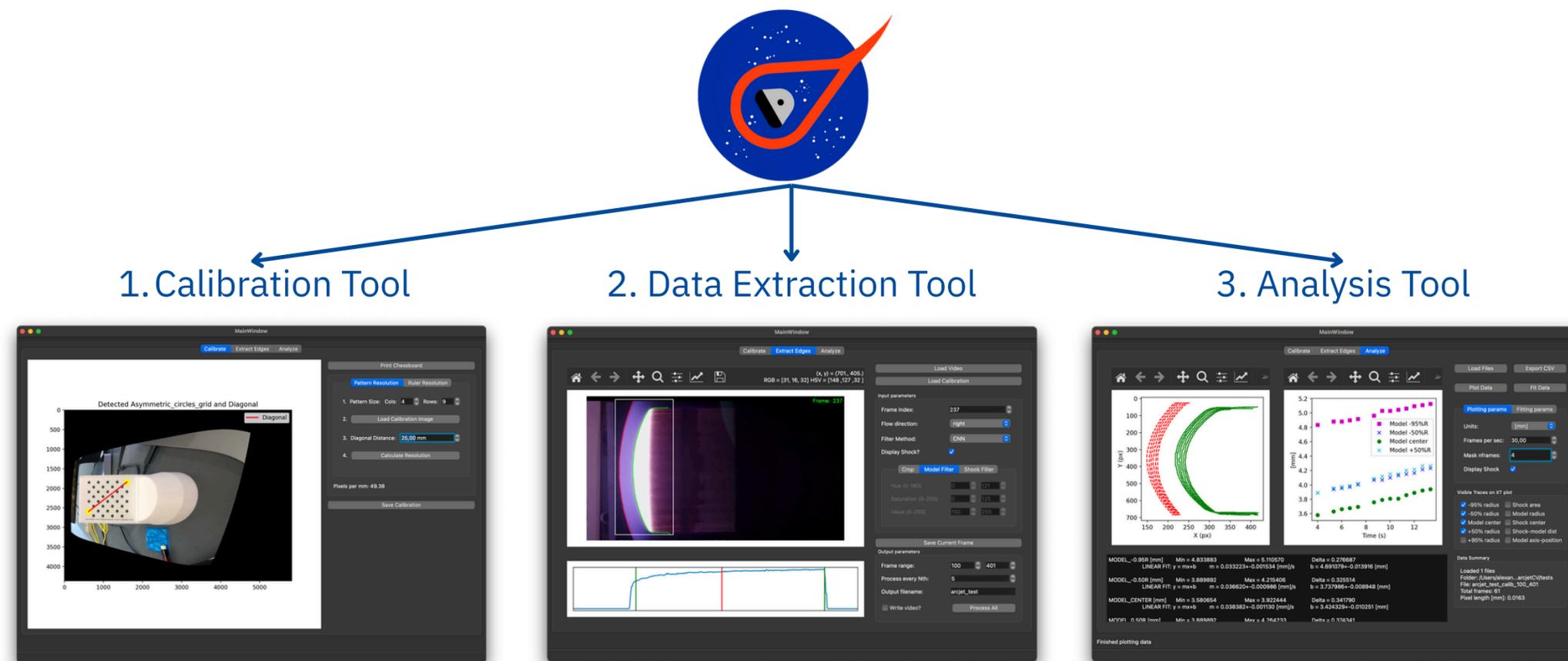
# arcjetCV





# arcjetCV Overview

- **open-source software** tool for analyzing heatshield material performance during arcjet tests.
- **Machine learning** (CNN) models for automated video segmentation.
- Tracks **time-dependent** material **recession** and shock **standoff distance**.
- GUI for **user-friendly** operation; API for batch processing.





# Open source python packages



Python



OpenCV



Conda



PyTorch



Qt



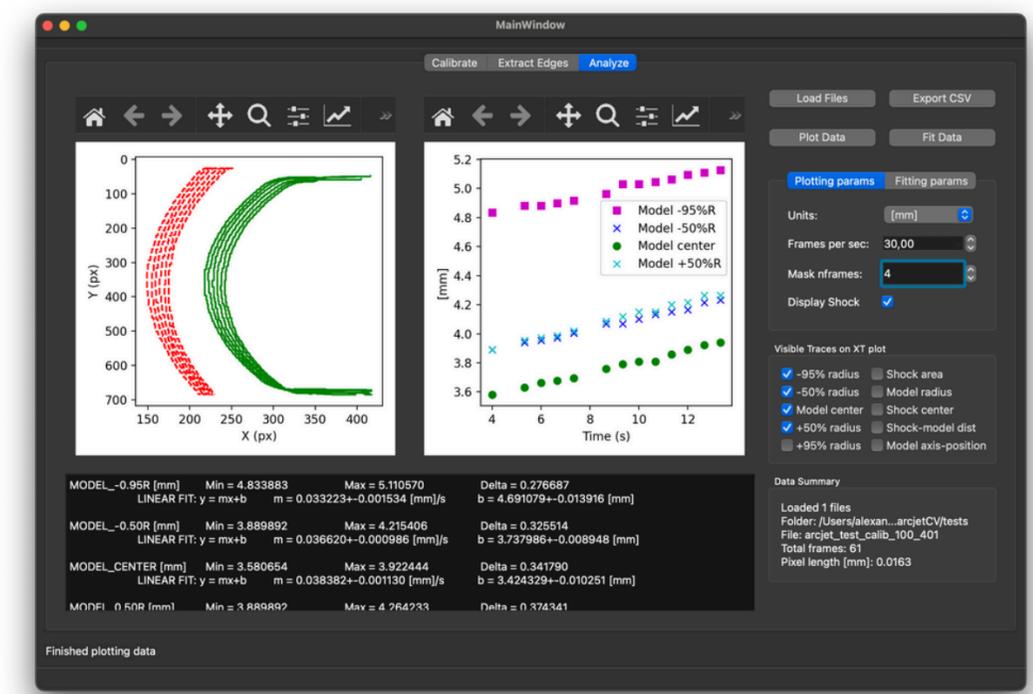
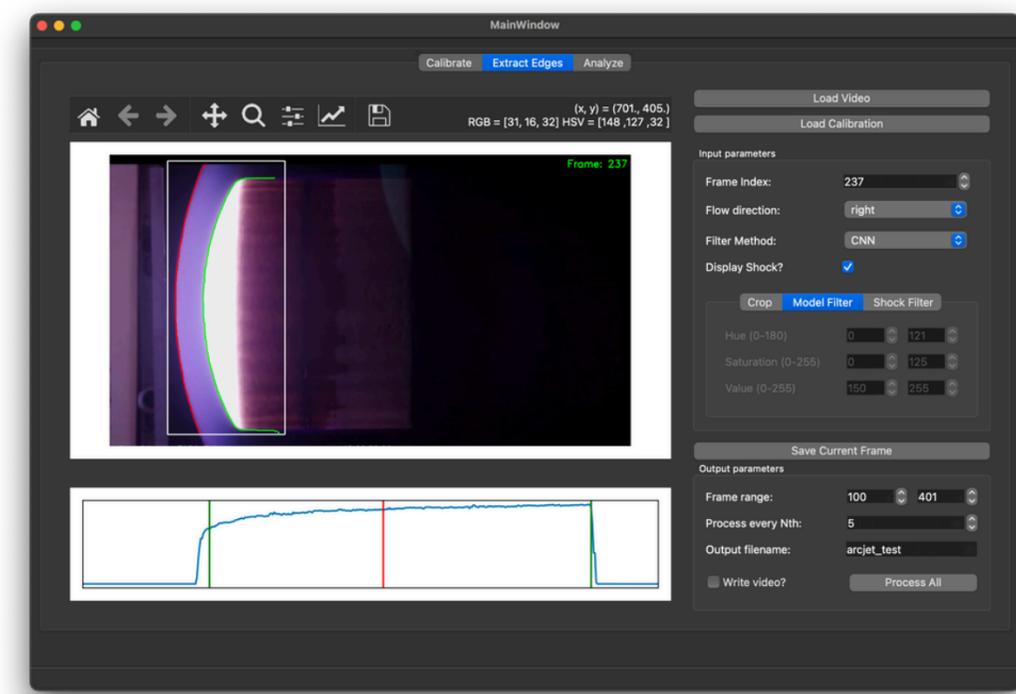
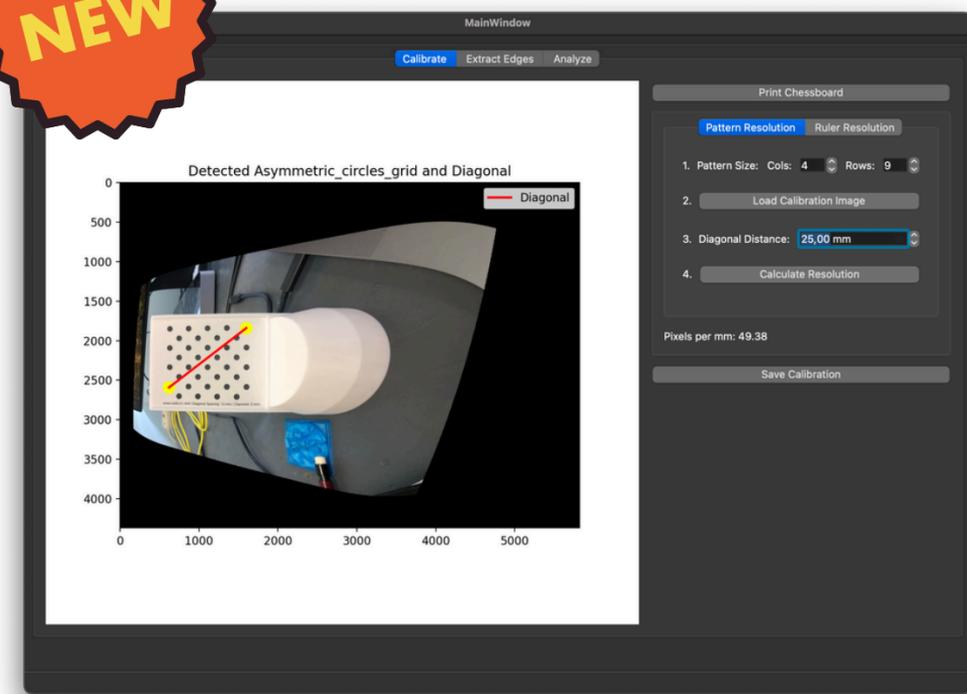
# arcjetCV 1.1 desktop interface



1. Calibration Tool

2. Data Extraction Tool

3. Analysis Tool





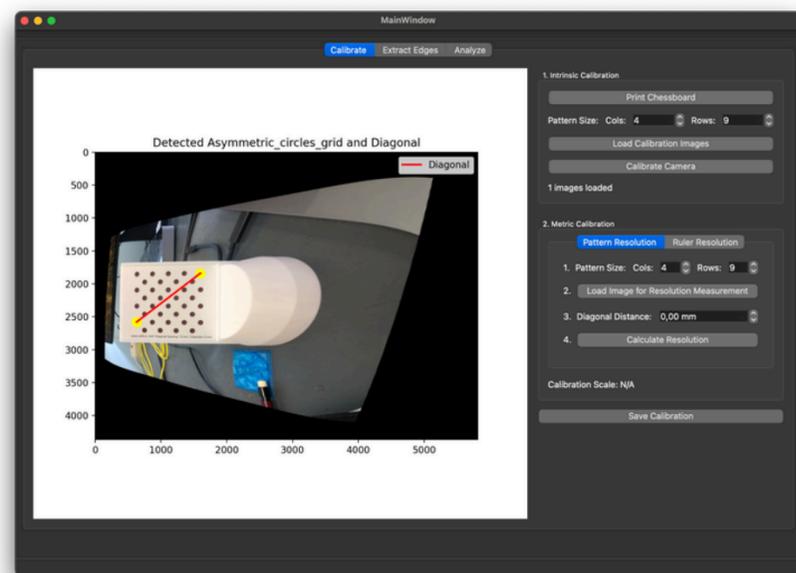
# arcjetCV: Calibration Tool

**Problem:** Frames are distorted, misaligned, and lack an accurate pixel-to-millimeter ratio.

**Solution:** Add a calibration section to:

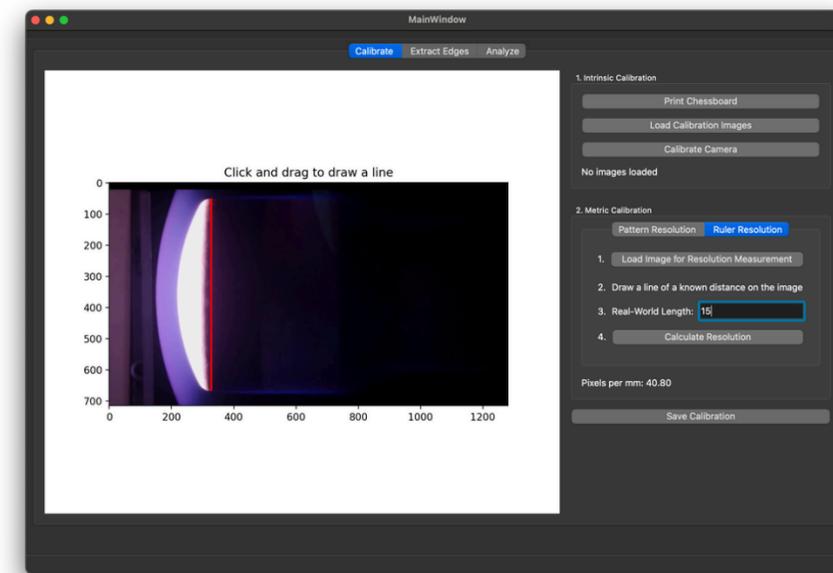
- Correct lens distortion
- Improve frame alignment
- Accurately determine the pixel/mm ratio for metric measurements

## Pattern Calibration



OR

## Ruler Calibration

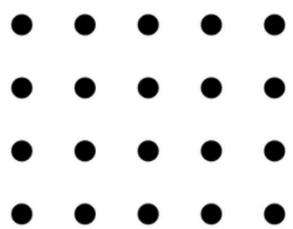




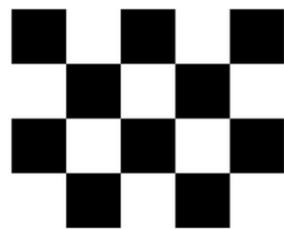
# Pattern Calibration

A full calibration workflow using printed checkerboards or dot grids:

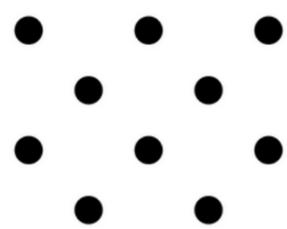
- Detects structured patterns (checkerboard, circle, asymmetric grid).
- Computes:
  - Lens undistortion: corrects radial/tangential distortion.
  - Homography: aligns grid with image axes (planar rectification).
  - Metric scale: derived from known grid size.



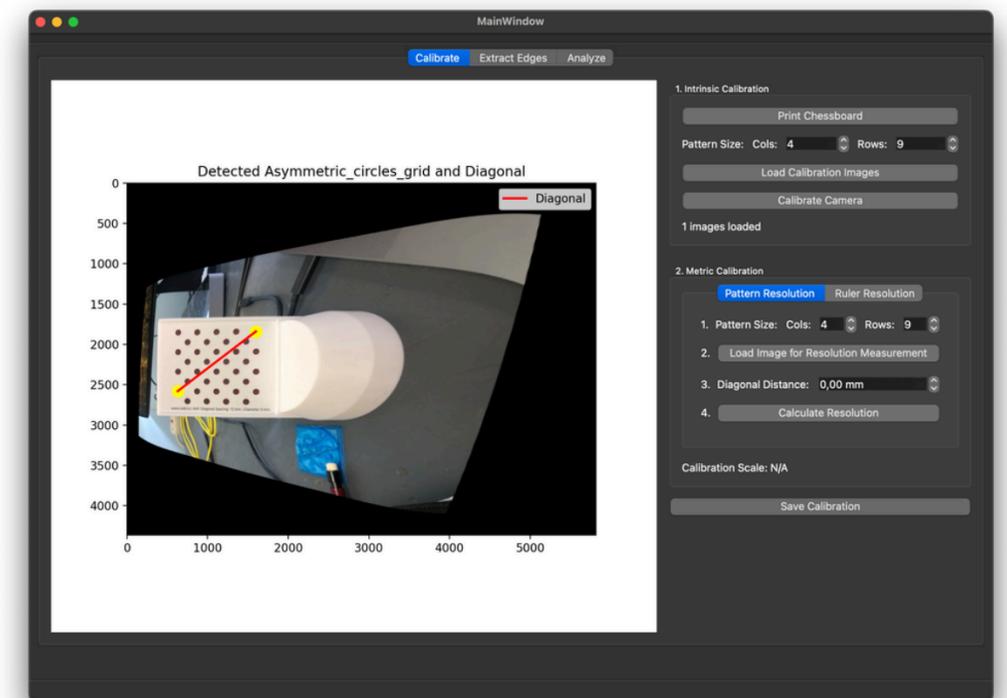
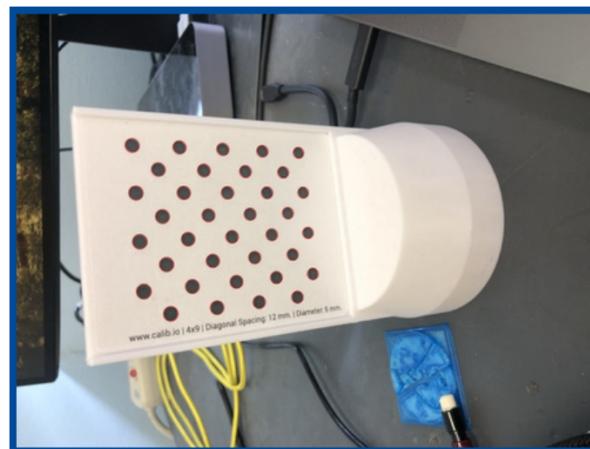
circles



checkerboard



asymmetric  
circles





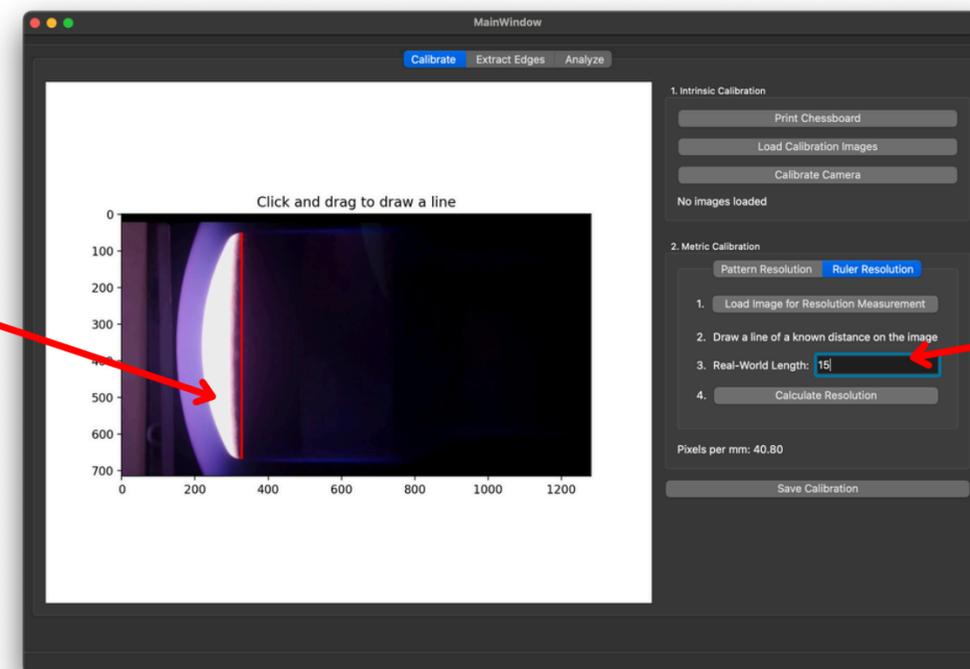
# Ruler Calibration

**A fast, practical method for test videos without calibration patterns:**

- User draws a line over a known-length object.
- arcjetCV computes the **pixel-to-mm scale** from the drawn segment.
- **No lens correction:** only metric scaling, sufficient when distortion is minimal

→ Interesting for **legacy videos** where pattern calibration hasn't been performed.

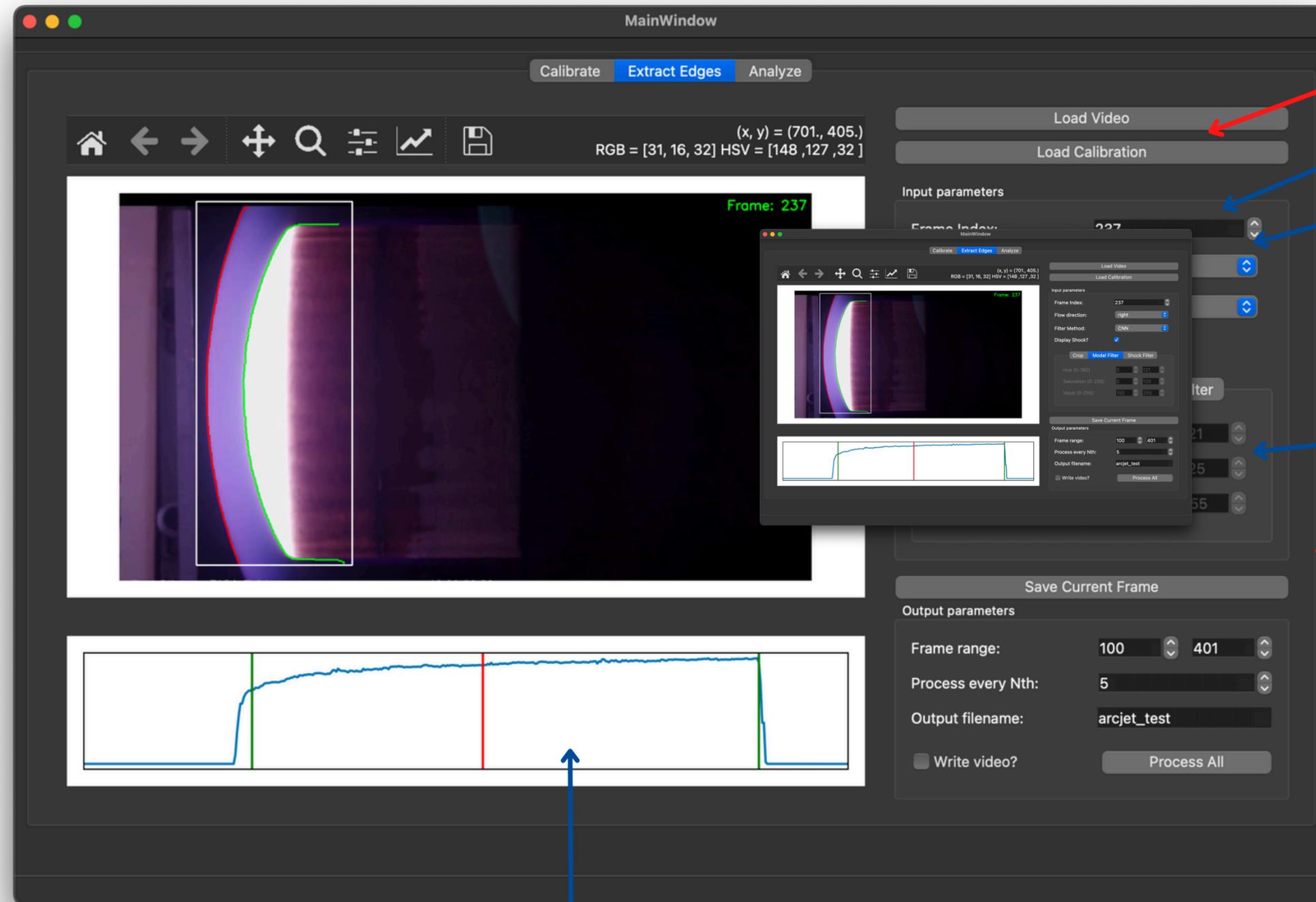
1. Draw a known distance



2. Real-world length



# Data Extraction Tool



1. Load a video

Select flow direction

Select filter method

Crop & filter parameters

Output settings

2. Process all frames

Clickable navigation bar: displays integrated frame intensity, start/stop frames (green lines) and current frame (red line).

# CNN

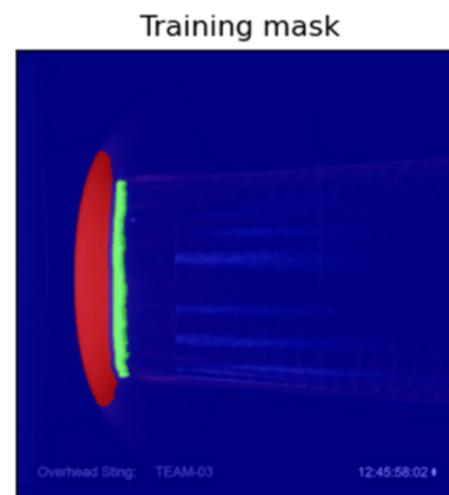


CNNs are neural networks designed to recognize patterns in images.

- Typically trained on manually labeled images.
- Robust performance compared to other methods.

Initially **arcjetCV** uses a CNN to classify a given image frame into 3 classes:

- material sample
- shock
- background

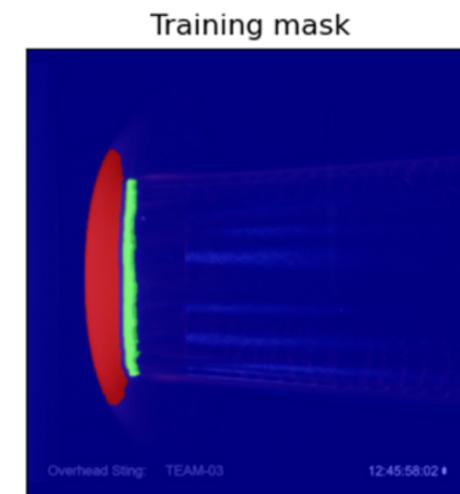
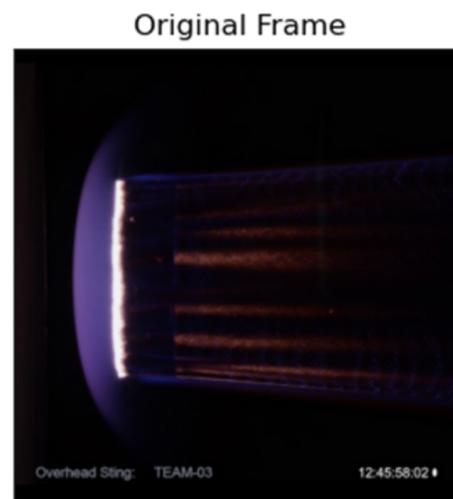




# CNN - Training

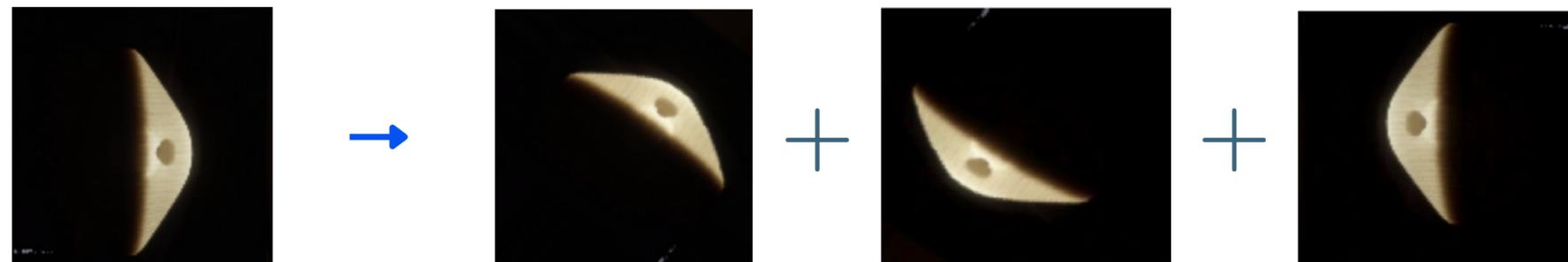
Data labelling

Label by hand with assistance



Training Set improvement = Data Augmentation

Increasing the dataset by changing the orientation and the position of the samples





# arcjetCV 1.1 Improvements

## Goals:

- Increase the accuracy of the convolutional neural network detection.
- Simplify software distribution.

## Improvements:

- New edge class
- New architecture
- Expanded training dataset
- Distribution on pypi (Python Package Index)
- Available as an executable for Windows (.exe) and macOS (.app).



# arcjetCV 1.1: New Edge class

## Problem:

- Standard CNN architectures may **struggle** with accurate **edge detection** in samples where boundary details are critical.
- Misclassification or blurring of edge regions can lead to **errors** in measuring **recession**.

## Solution:

- Introduce a **dedicated class** for sample edges.
- This class specifically labels boundary areas where material recession occurs, allowing the model to **focus** on fine **edge** details.

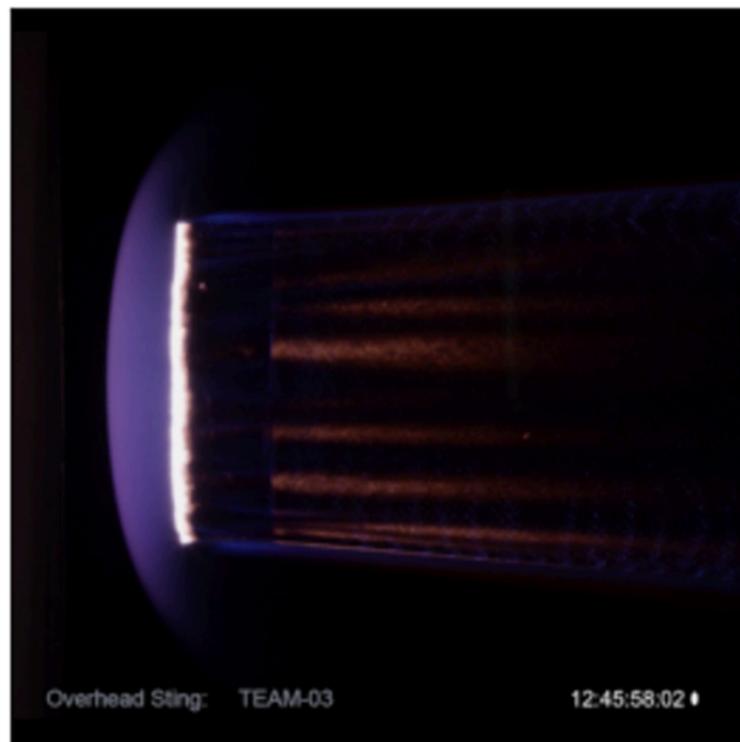
## Advantage:

- **Reduced misclassification:** By distinguishing edge from non-edge pixels more effectively, minimizing errors in recession measurement.

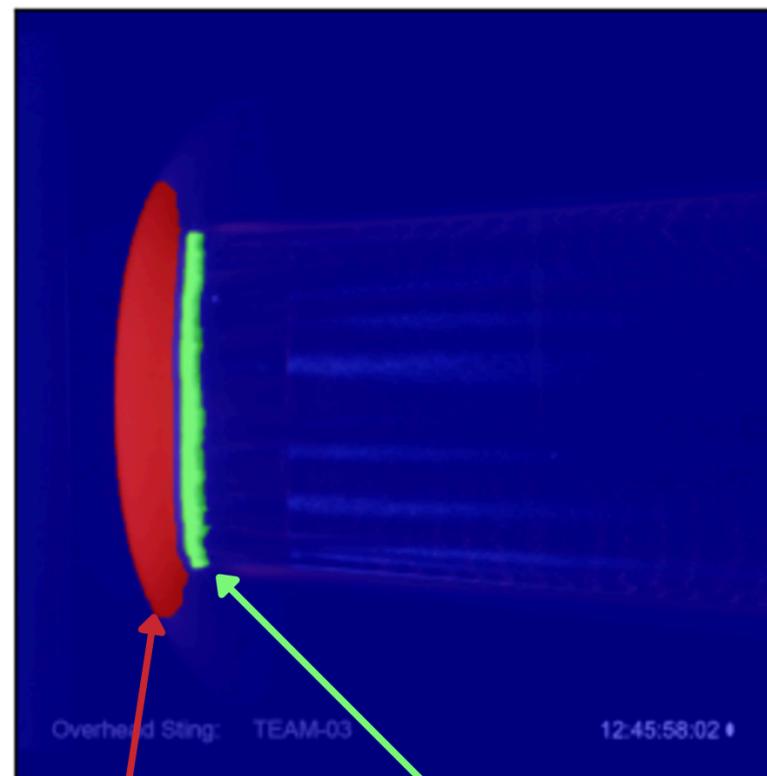


# arcjetCV 1.1: New edge class

Original frame



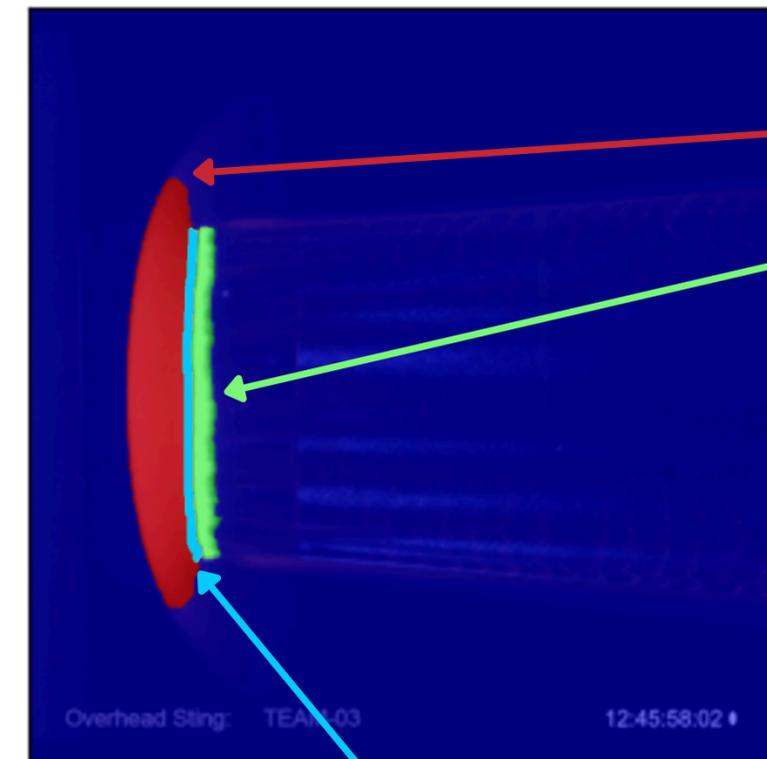
Old training mask



Shock class

Sample class

New training mask



Shock class

Sample class

Edge class



# arcjetCV 1.1: New architecture

## Xception

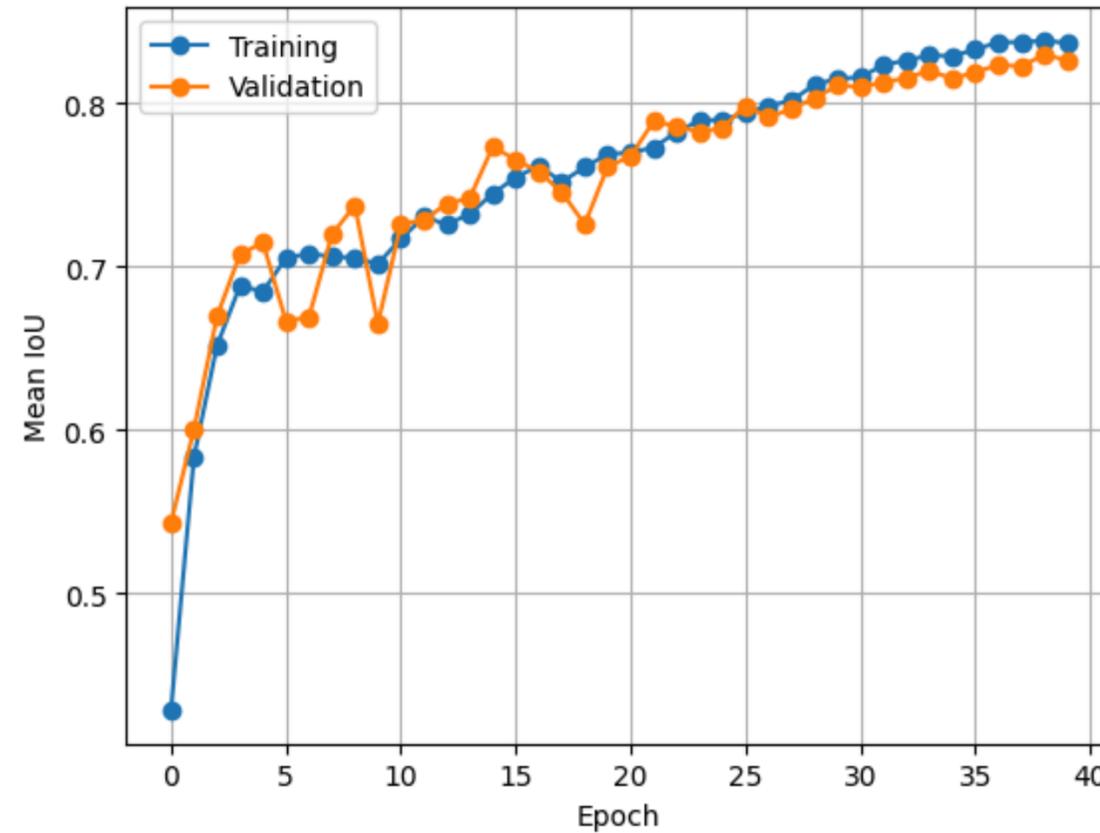
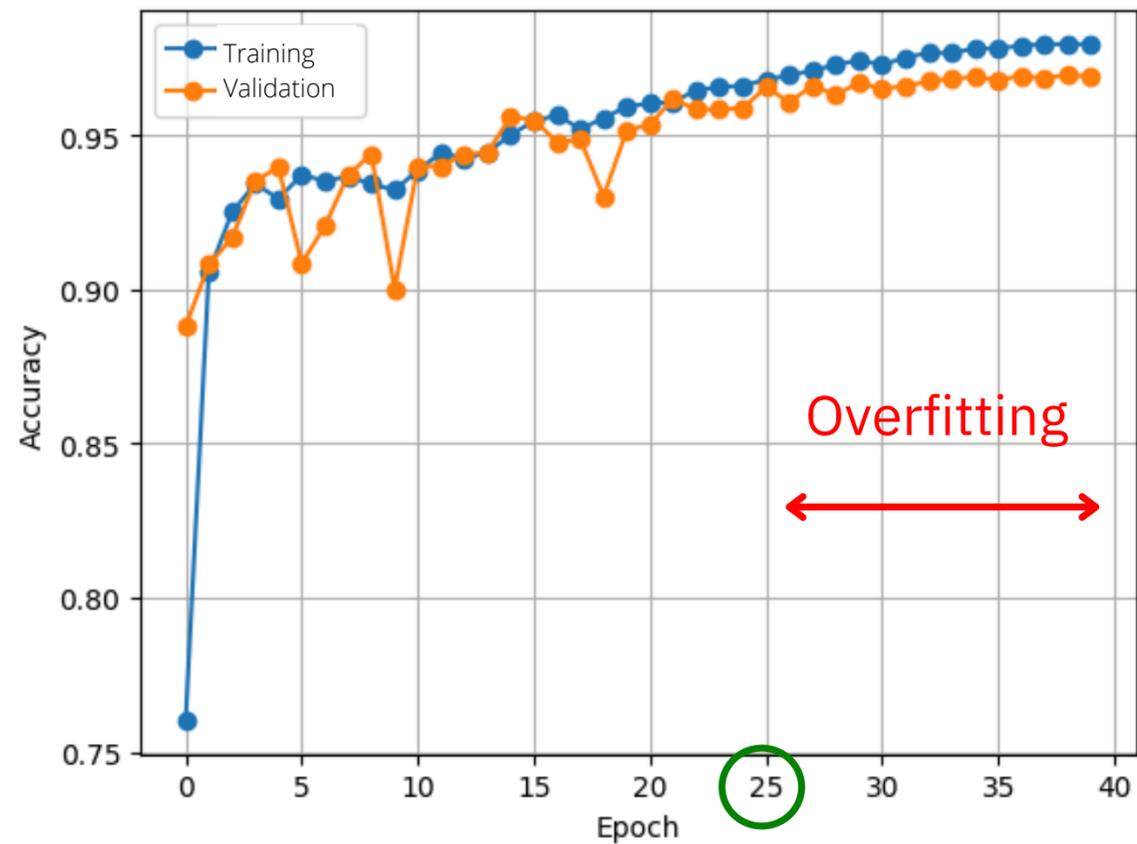
### Key Advantages:

- **Improved Edge Detection:** Xception captures fine details, making it ideal for tasks needing precise segmentation.
- **Superior Feature Extraction:** Residual connections in Xception improve feature learning over VGG16's standard convolutions.
- **Higher Accuracy & Lower Cost:** Xception delivers better accuracy and is computationally more efficient, despite its deeper architecture.

**Conclusion:** Xception is a more effective model for high-precision tasks like edge segmentation.



# ML architecture performance



$$\text{Pixel Accuracy} = \frac{\text{Number of Correctly Classified Pixels}}{\text{Total Number of Pixels}}$$

Mean Intersection over Union (mIoU):

→ **Handles Class Imbalance**

$$\text{mIoU} = \frac{1}{N} \sum_{i=1}^N \text{IoU}_i$$

where N = Total number of classes.

$$\text{IoU}_i = \frac{\text{TP}_i}{\text{TP}_i + \text{FP}_i + \text{FN}_i}$$

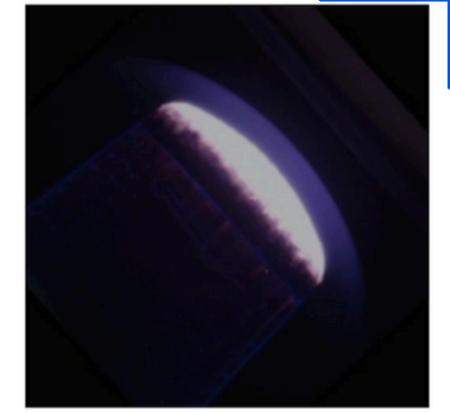
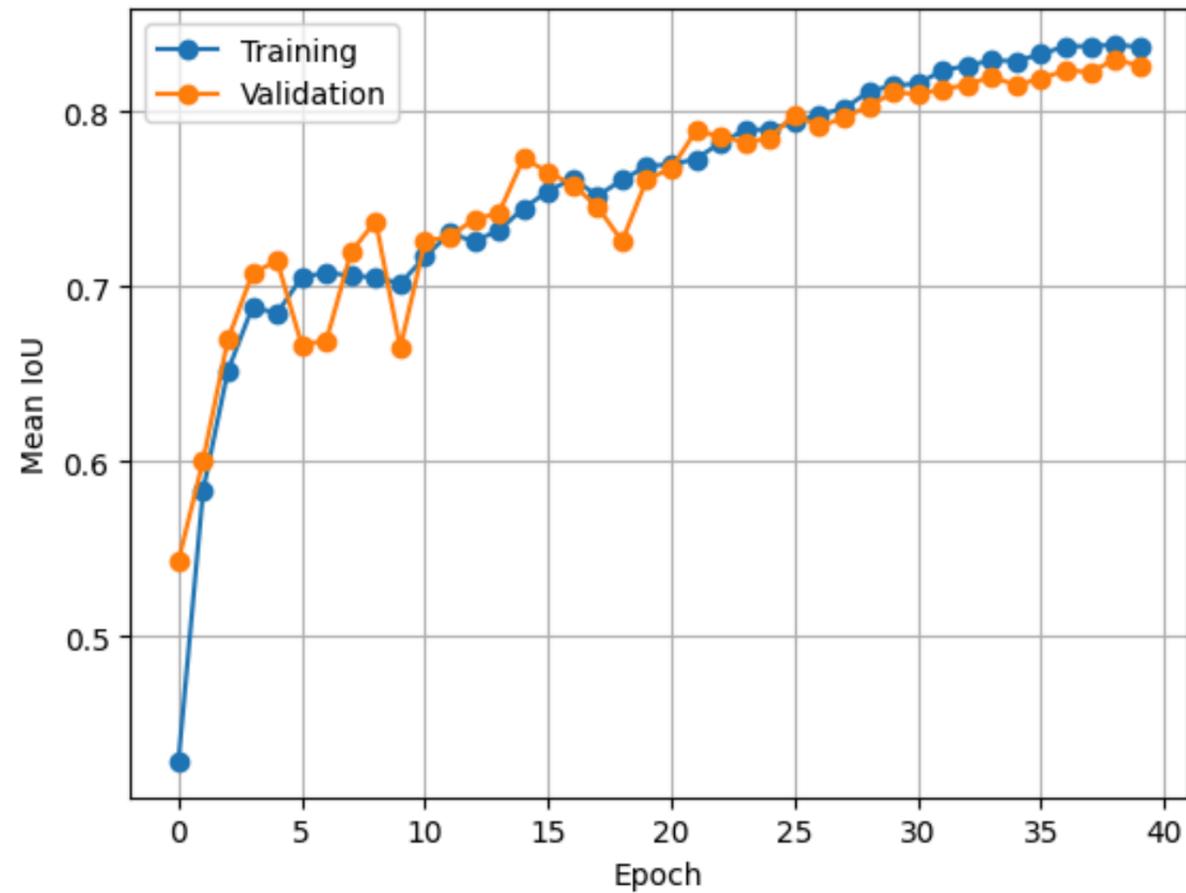
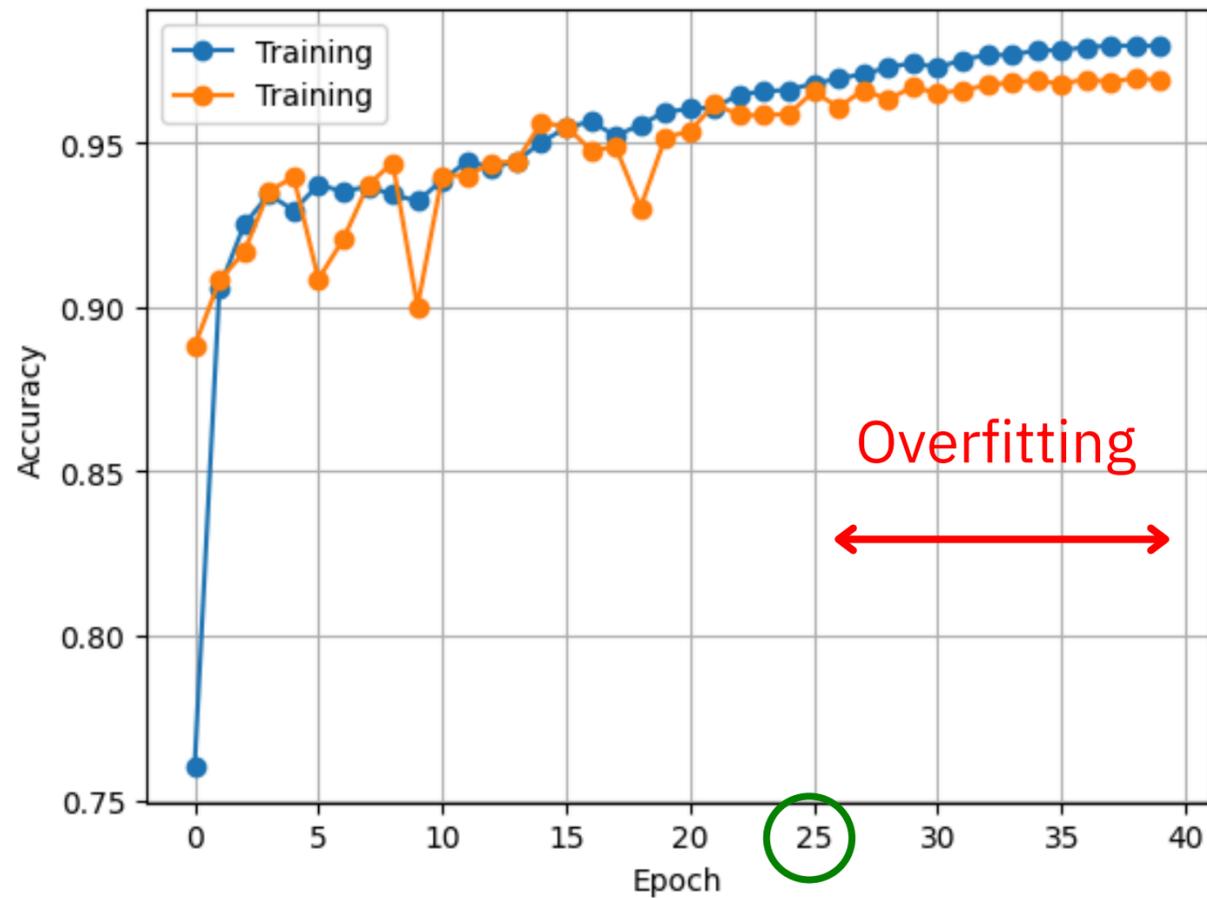
where:

- True Positive (TP) = Pixels correctly predicted for class i,
- False Positive (FP) = Pixels incorrectly predicted as class i,
- False Negative (FN) = Pixels of class i that were missed.

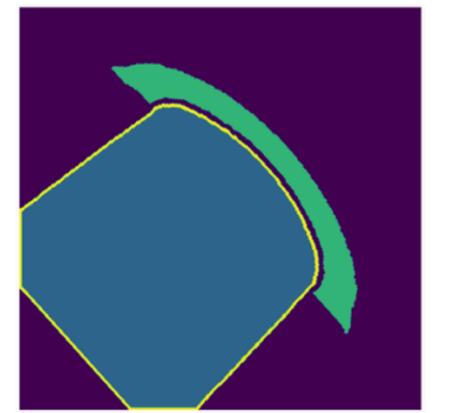
Model with 25 epochs	Pixel Accuracy	mIoU
<b>VGG16 (Old model)</b>	0.9411	0.7311
<b>ResNet18</b>	0.9413	0.7543
<b>Xception</b>	<b>0.9687</b>	<b>0.8005</b>



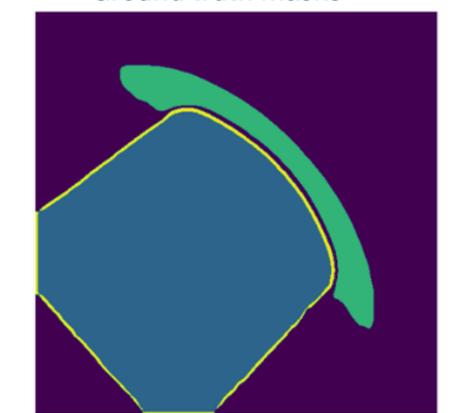
# ML architecture performance



Challenging video frame



Ground truth masks



Xception prediction

Model with 25 epochs	Pixel Accuracy	mIoU
Xception	0.9687	0.8005

## → Handles Class Imbalance

where N = Total number of classes.

where:

- True Positive (TP) = Pixels correctly predicted for class i,
- False Positive (FP) = Pixels incorrectly predicted as class i,
- False Negative (FN) = Pixels of class i that were missed.

Mean Intersection over Union (mIoU):

$$mIoU = \frac{1}{N} \sum_{i=1}^N IoU_i \quad IoU_i = \frac{TP_i}{TP_i + FP_i + FN_i}$$

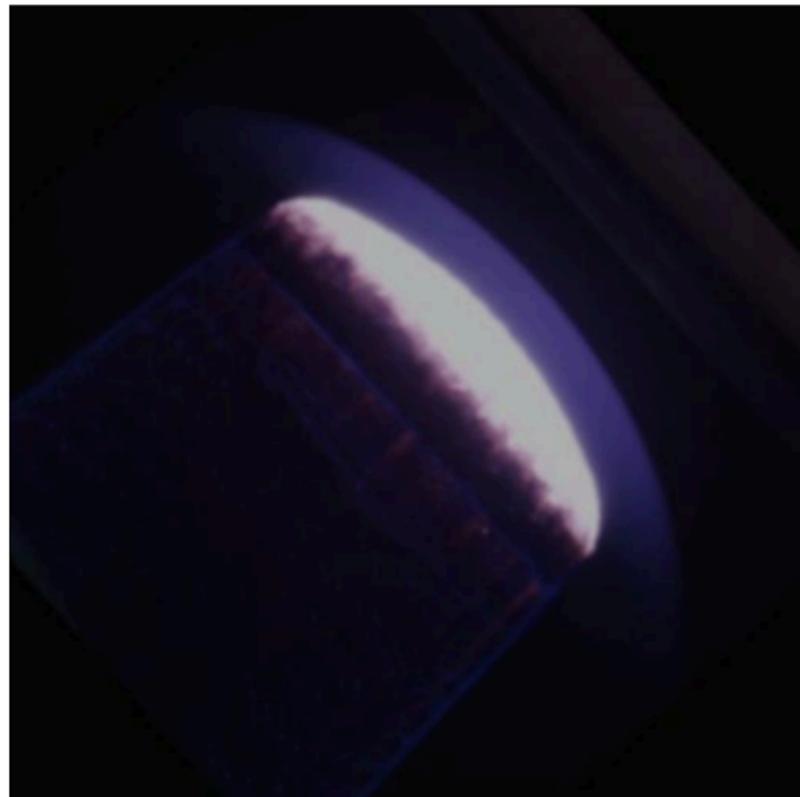


# arcjetCV 1.1: Augmented training dataset

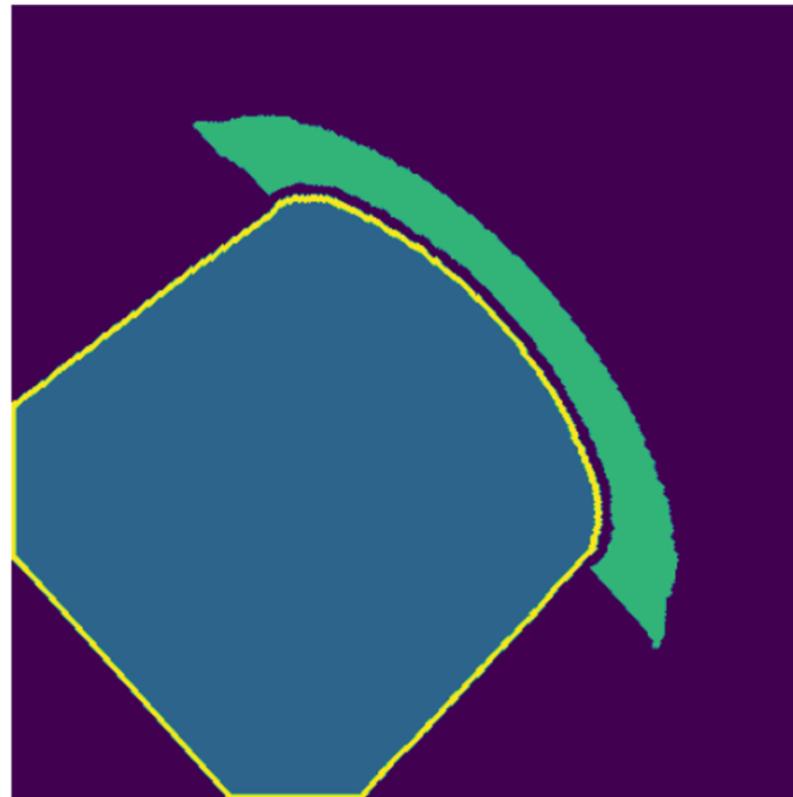
- New frames from different facilities.
  - VKI
  - UIUC
- New frames from new tests.
  - Size of the new dataset: **1778** training frames.



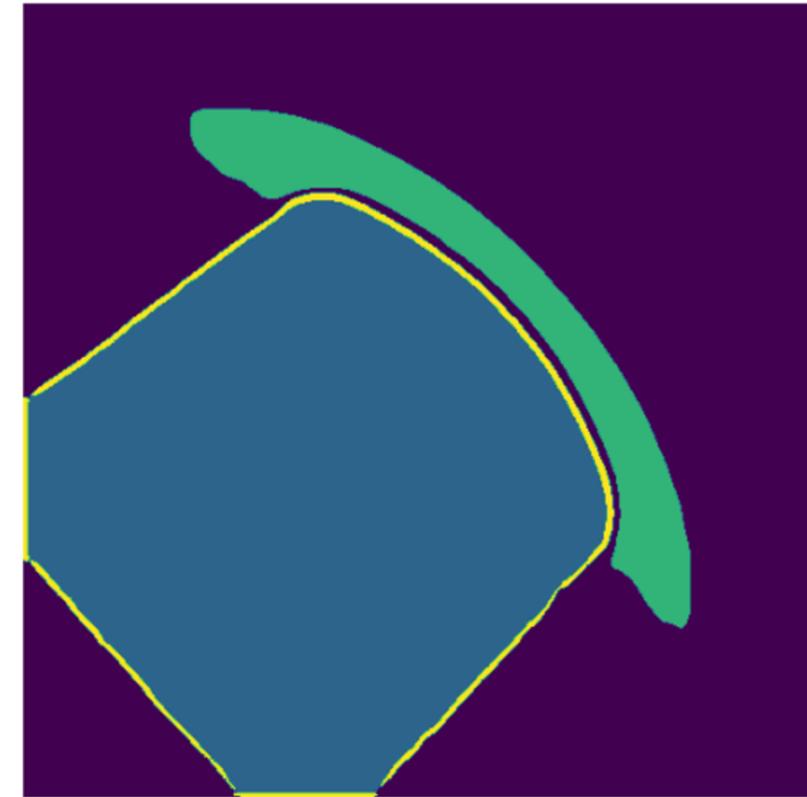
# arcjetCV: New model result



Challenging video frame



Ground truth masks



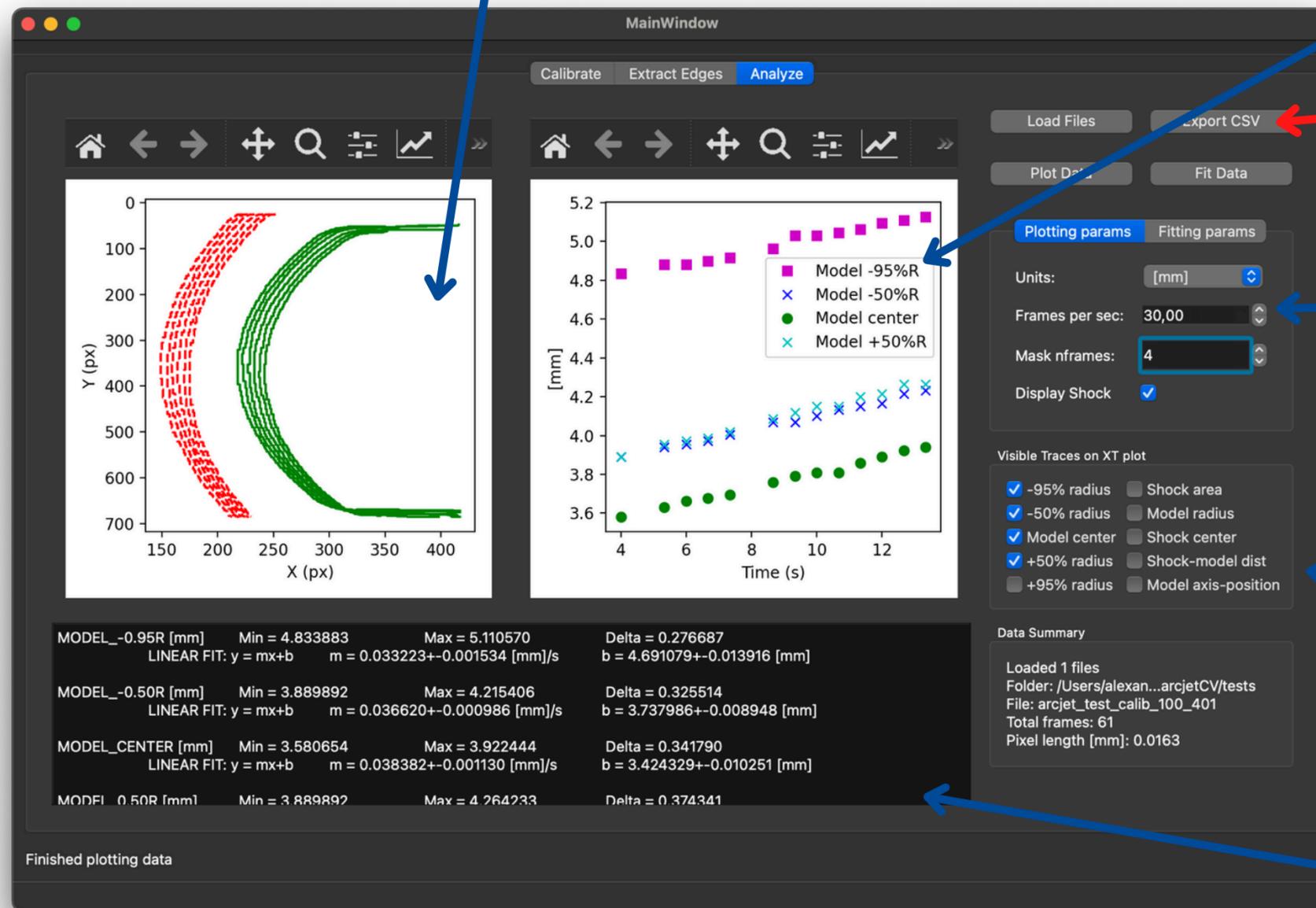
Xception prediction



# Analysis Tool

Time-dependence plot

XY Traces of Shock and Sample Edge plot



3. Export

Parameters

Plot options

Linear fits

# The segmentation GUI

Easy creation of dataset for ML trainings



# Why a dataset creation tool?



Continuous improvement of the dataset.



Customization of ML models by creating new class.



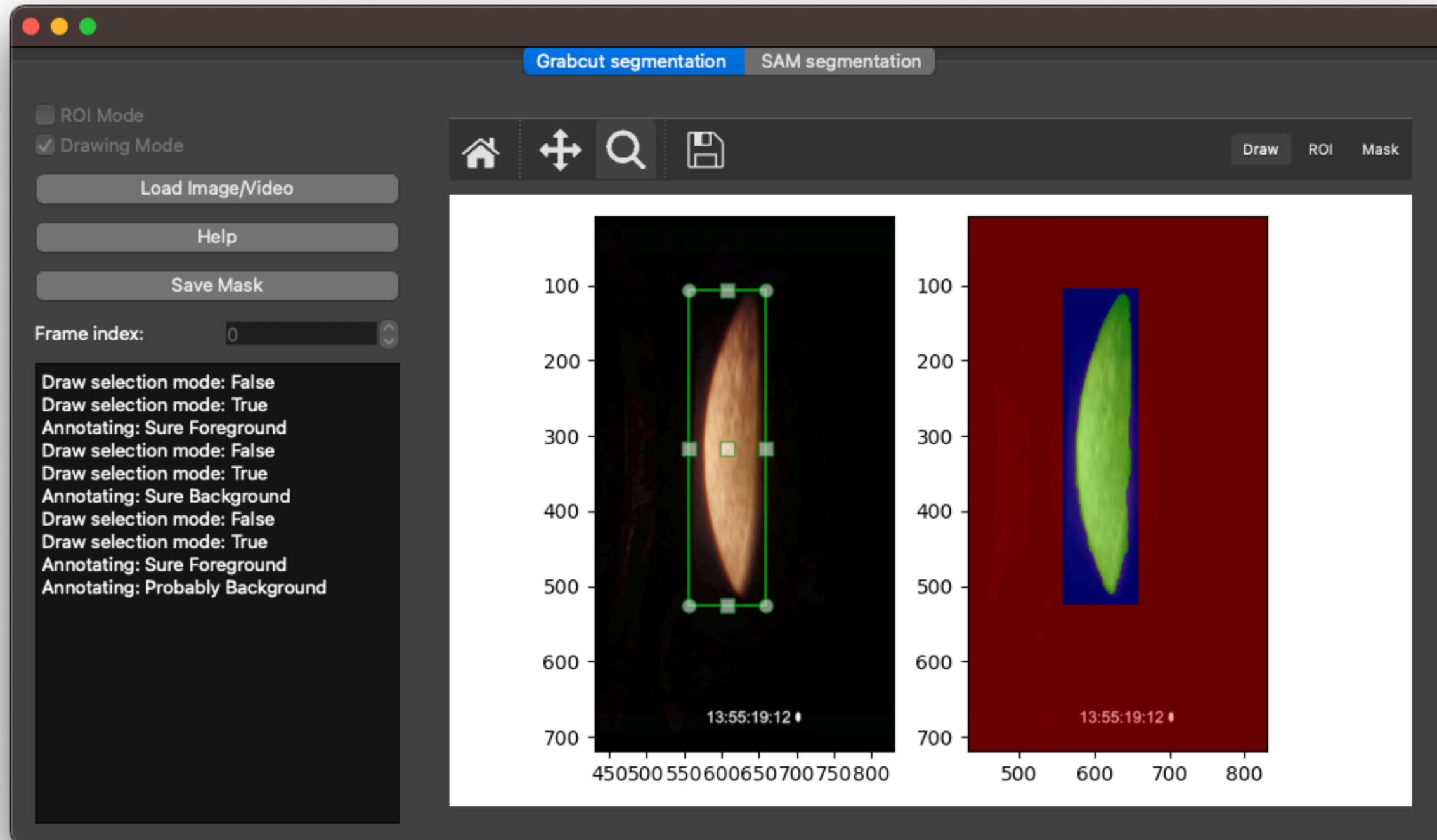
Highest fidelity segmentation for specific frames.



Create new datasets to create new ML models.

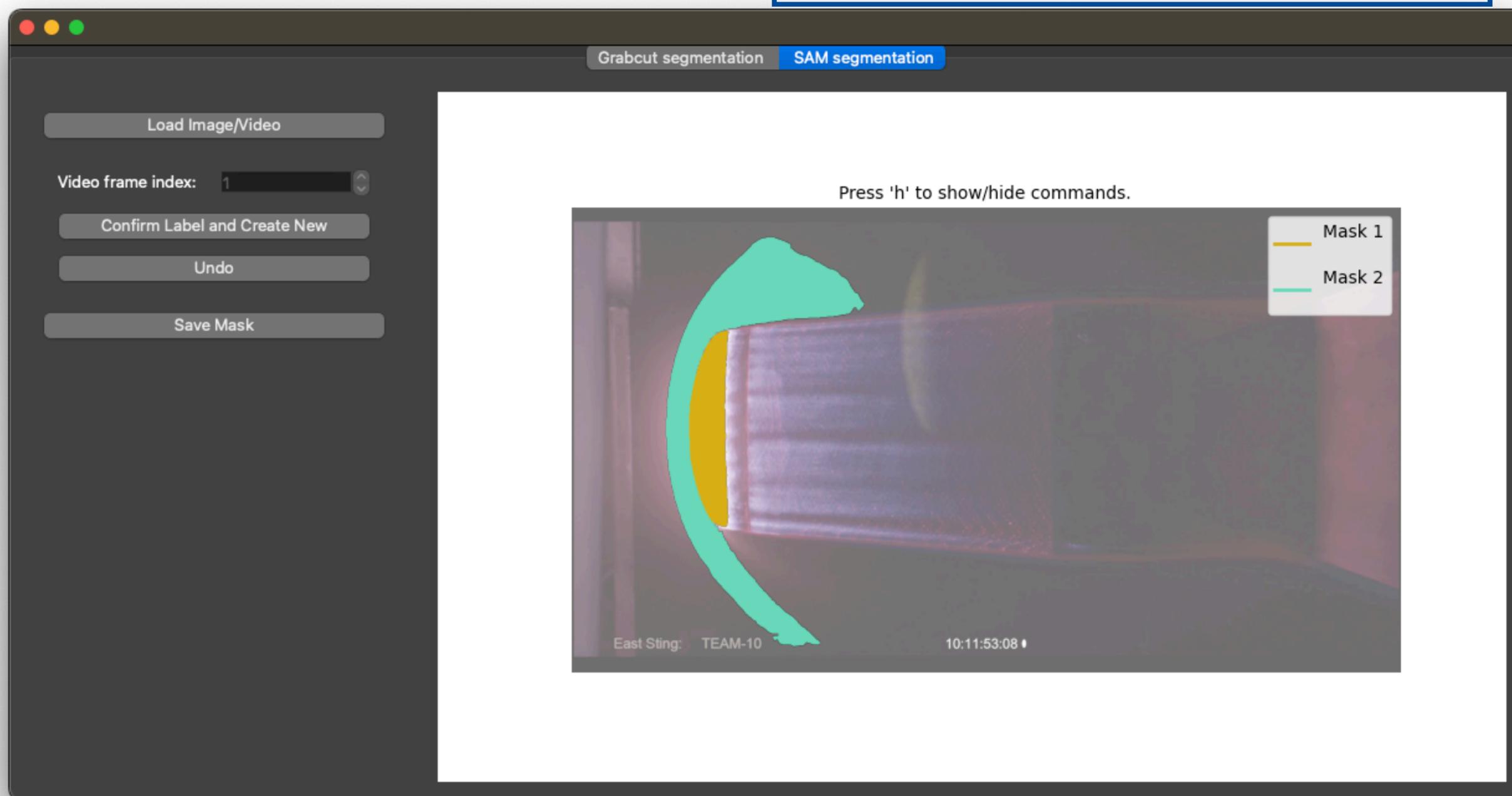
# GrabCut

Segmentation through iterative graph cuts using color probability.



# autoSAM

Segmentation using the Segment Anything Model (SAM) of META



Based on the Segment Anything GUI co developed with Federico Semeraro

# Installation



# arcjetCV 1.1: installation

## PyPi

1) Open your terminal

2) Install arcjetCV

```
pip install arcjetCV
```

3) Run arcjetCV:

```
arcjetCV
```

## Git

1) Open your terminal

2) Install arcjetCV

```
git clone https://github.com/magnus-haw/arcjetCV.git
cd arcjetCV
conda env create -f env/arcjetCV_env_[cpu/gpu].yaml
conda activate arcjetCV
python -m pip install -e .
```

3) Run arcjetCV:

```
conda activate arcjetCV
arcjetCV
```

### Prerequisites:

- git-lfs
- Miniconda or Anaconda
- Xcode Command Line Tools (macOS)

see the Git



Easiest BUT Slower



# arcjetCV 1.1: Executable installation

Download the executable .exe or .app here:



Windows Version 1.1 Available **Soon**

Download arcjetCV

For Windows:

- arcjetCV Windows for CPU
- arcjetCV Windows for GPU

For macOS:

- arcjetCV macOS

# Observations

- 1 Non-linear recession
- 2 Shock standoff
- 3 Shape changes

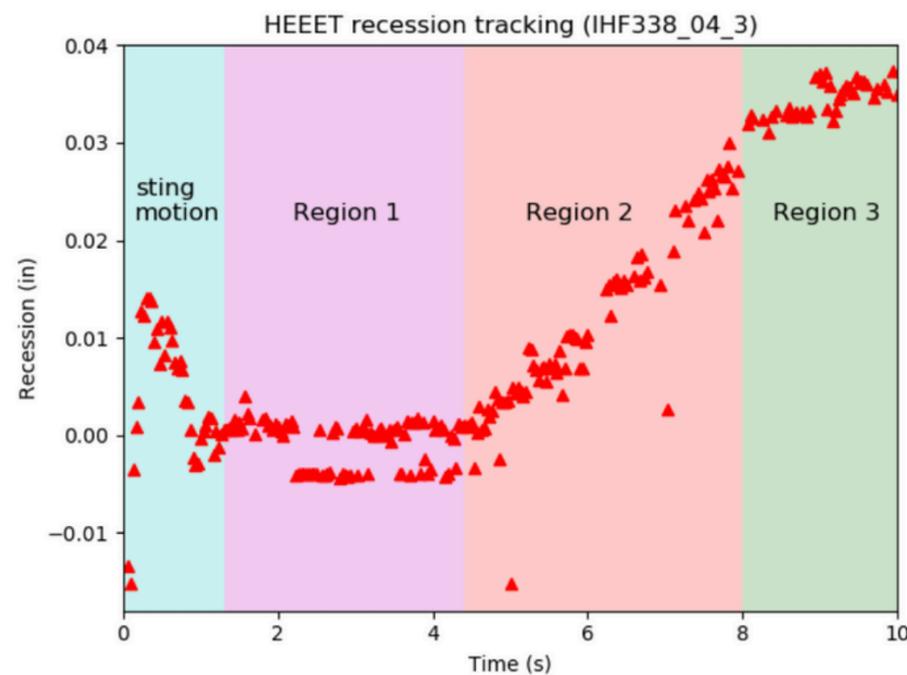


# arcjetCV: Observations

## 1. Non-linear Recession

**With arcjetCV:** 3 Regions:

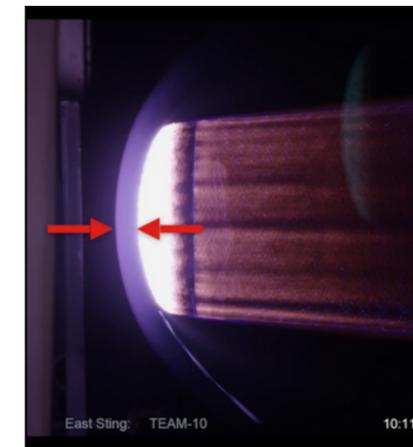
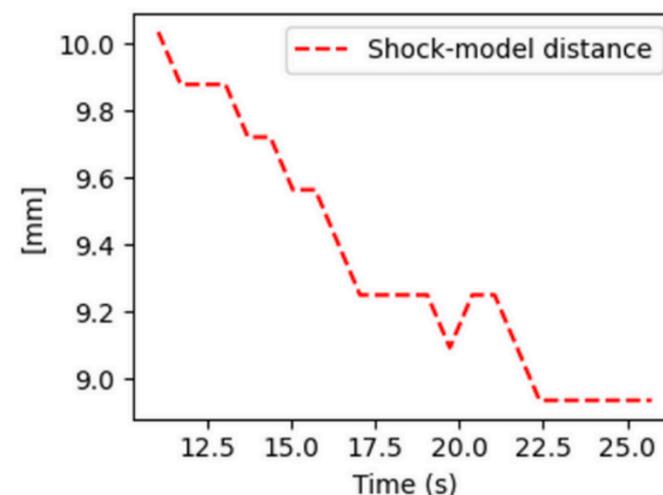
- *Region 1:* Nearly no recession
- *Region 2:* Constant recession rate
- *Region 3:* reduced recession rate



## 2. Shock standoff

Shock-sample distance decrease implies that the pressure at the sample surface is changing with time:

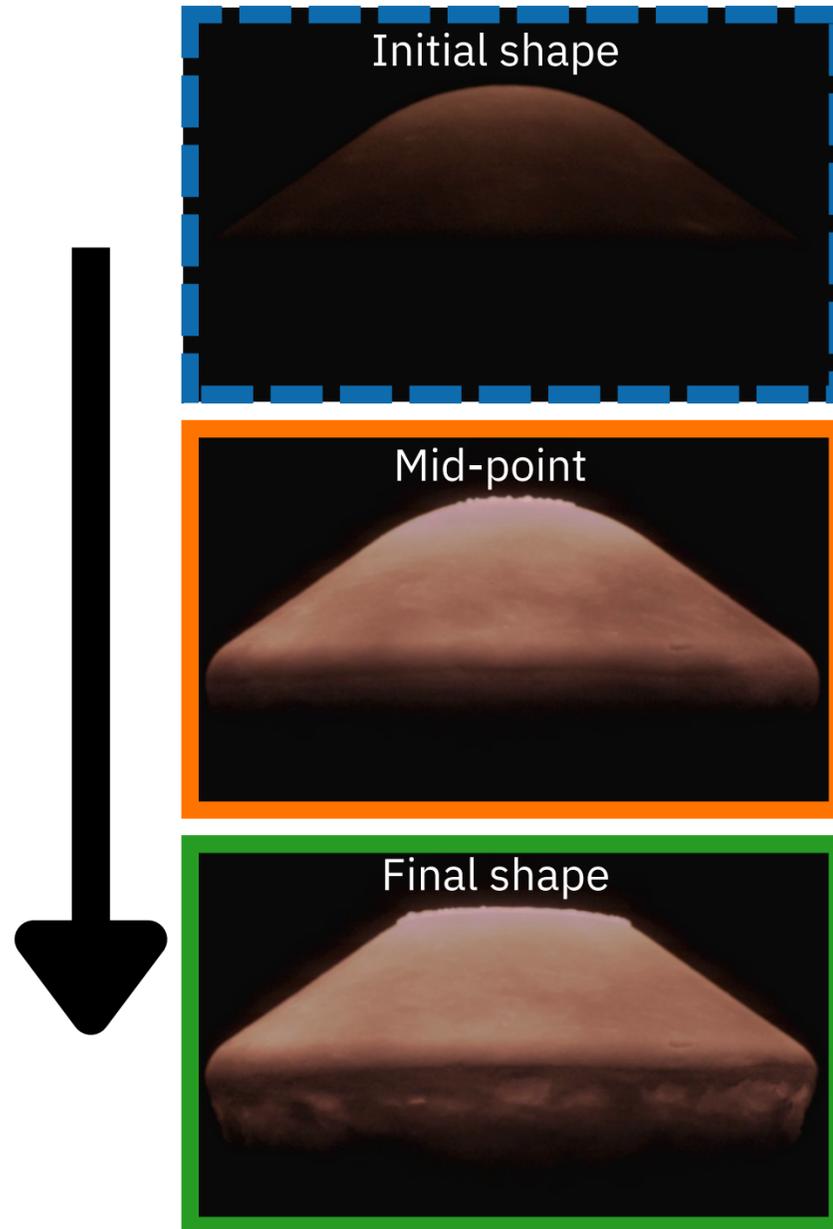
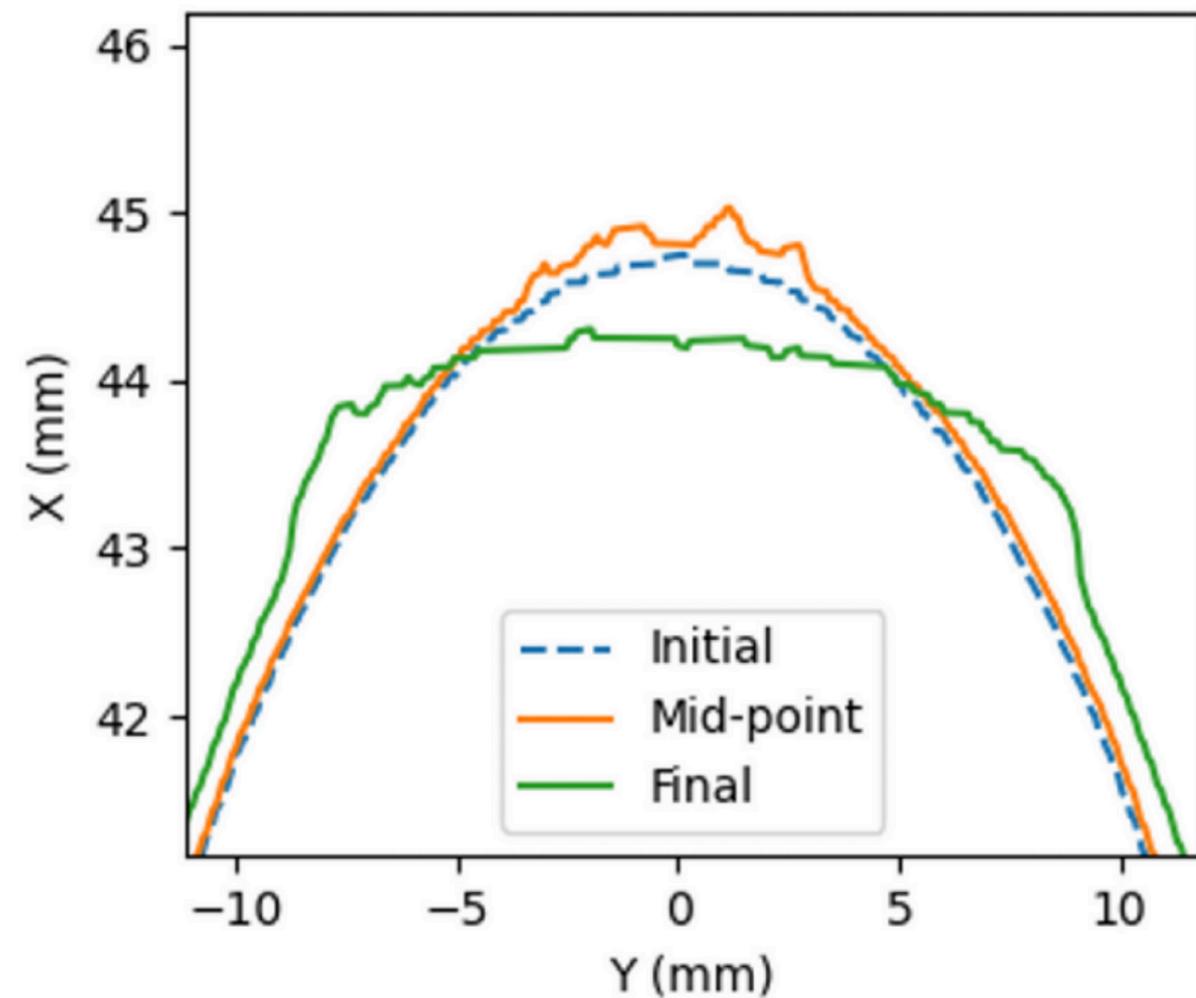
- Aerothermal conditions are changing
- The sample is becoming more porous
- Pyrolysis gas pressure is changing





# arcjetCV: Observations

## 3. Shape change



- Surface develops millimeter scale ripples/bubbles

- Sample deforms/flattens at the nose.
- The entire sample is expanding (e.g. negative recession at the edges).

# Future Work



## 1. Integrated Physical Reference Markers

- Add fixed visual markers (e.g., laser dots, sample holder markage). That can be used as a reference for the recession.
- Improve robustness to camera shifts.

## 2. Integrate a Kalman Filter for Resolution Improvement

- Tracks edge motion smoothly across video frames.
- Reduces noise and small fluctuations in edge detection.
- Helps get cleaner, more precise results — even if the video is noisy.



# arcjetCV Conclusion

**arcjetCV** enables:

- Automated recession statistics.
- 2D model validation.
- Time resolved validation.

## arcjetCV 1.1

New Class

Expanded Dataset

New Architecture

3 Installation Ways

New Calibration

## arcjetCV users :

Ames arcjet facilities

Orion

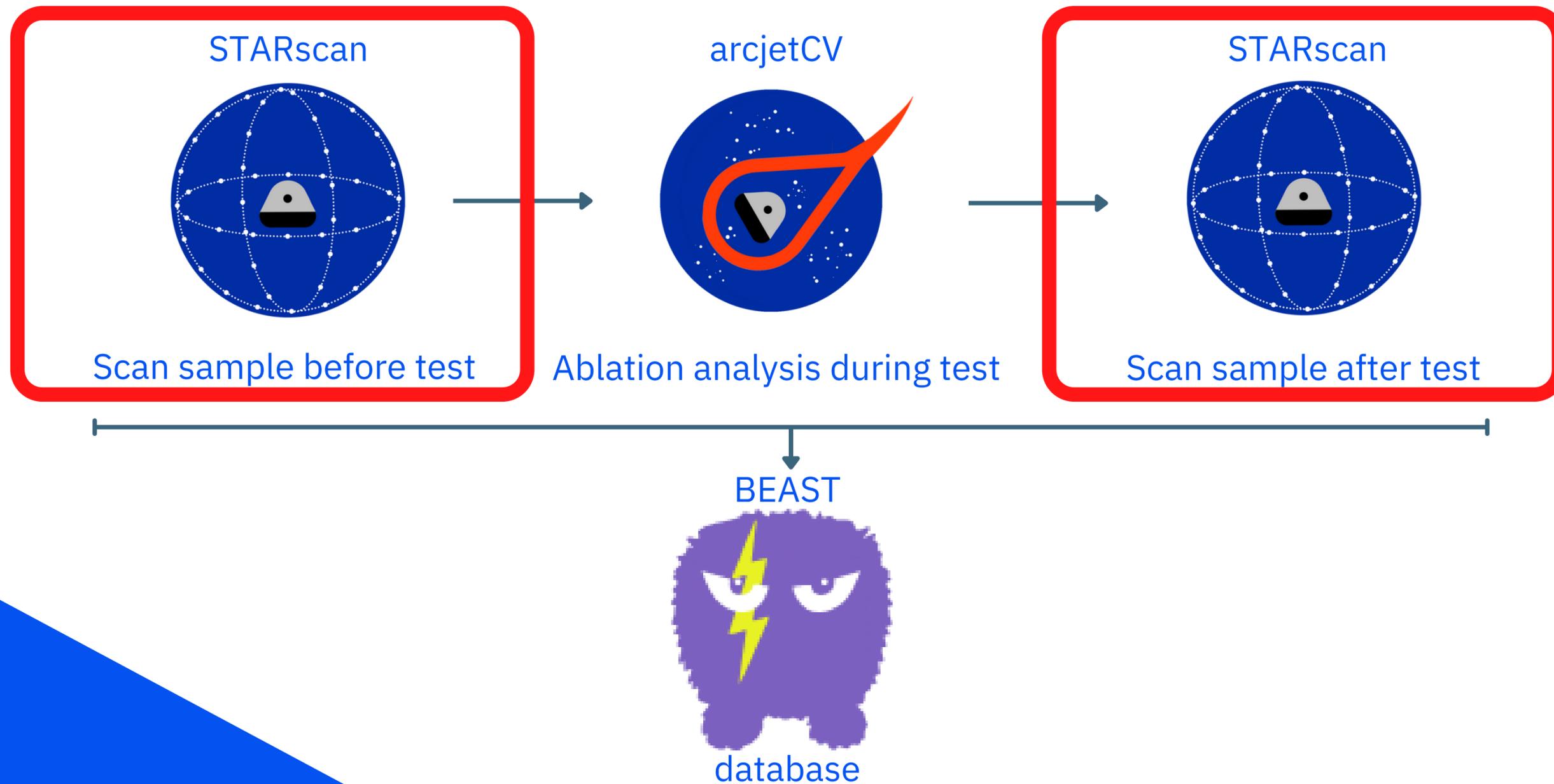
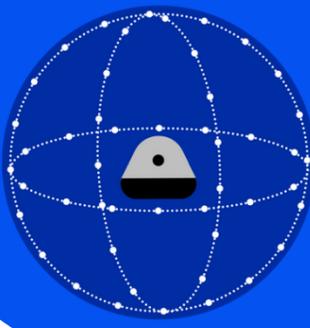


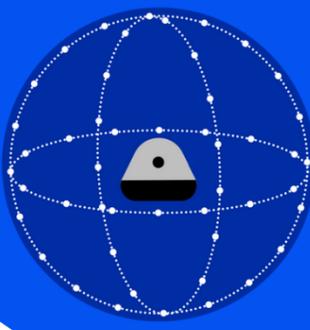
MSR



→ Better mission planning and risk management.

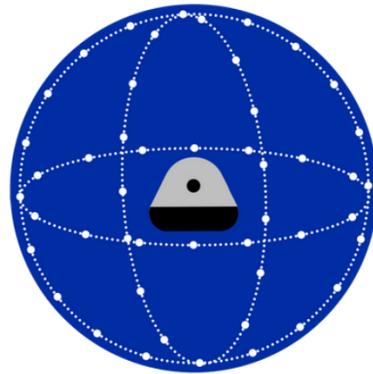
# STARscan



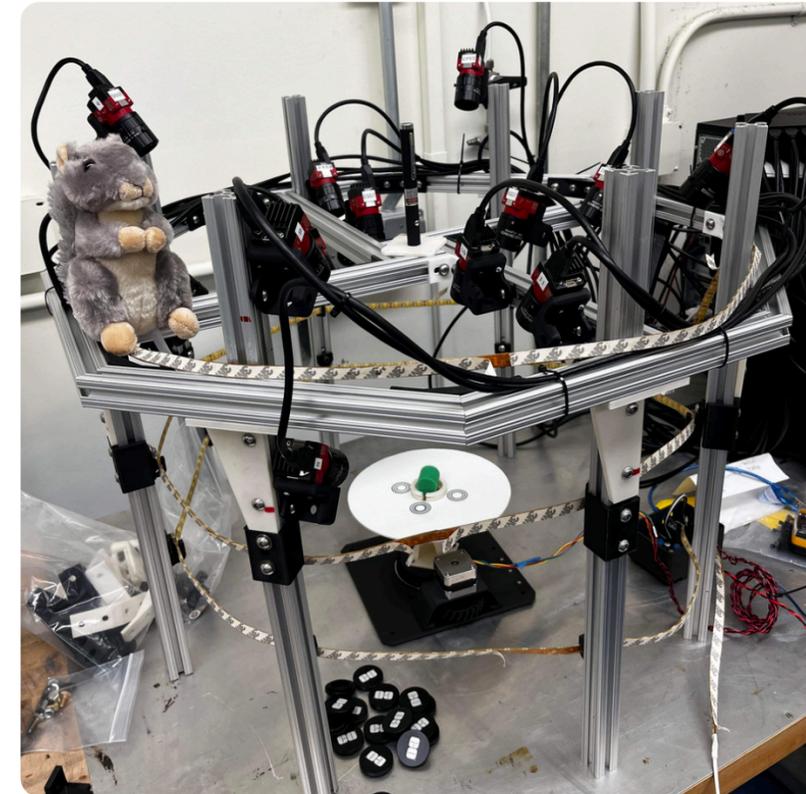


# Photogrammetry scanner

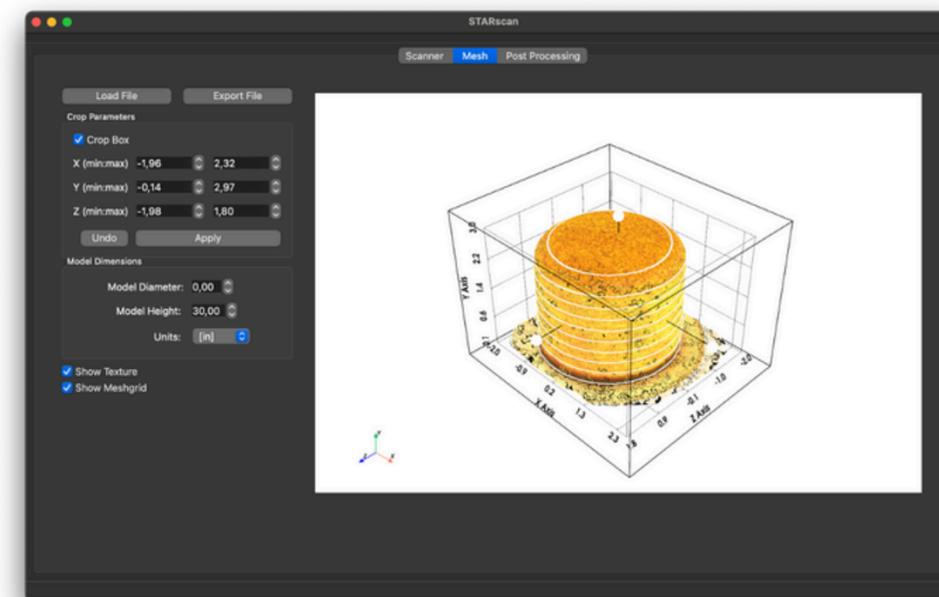
STARscan

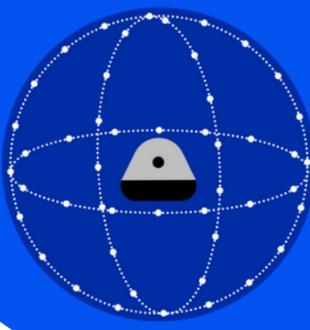


Scan sample before and after test



- Two custom **3D scanning systems** built to accelerate and streamline scanning and analysis of arcjet test articles.
- **Software** that provides analysis of the shoulder **curvature**, **roughness** and **recession**.
- **Principle:** Photogrammetry
- **Accuracy:** ~ 0.35mm
- **Scan time:** 2 min

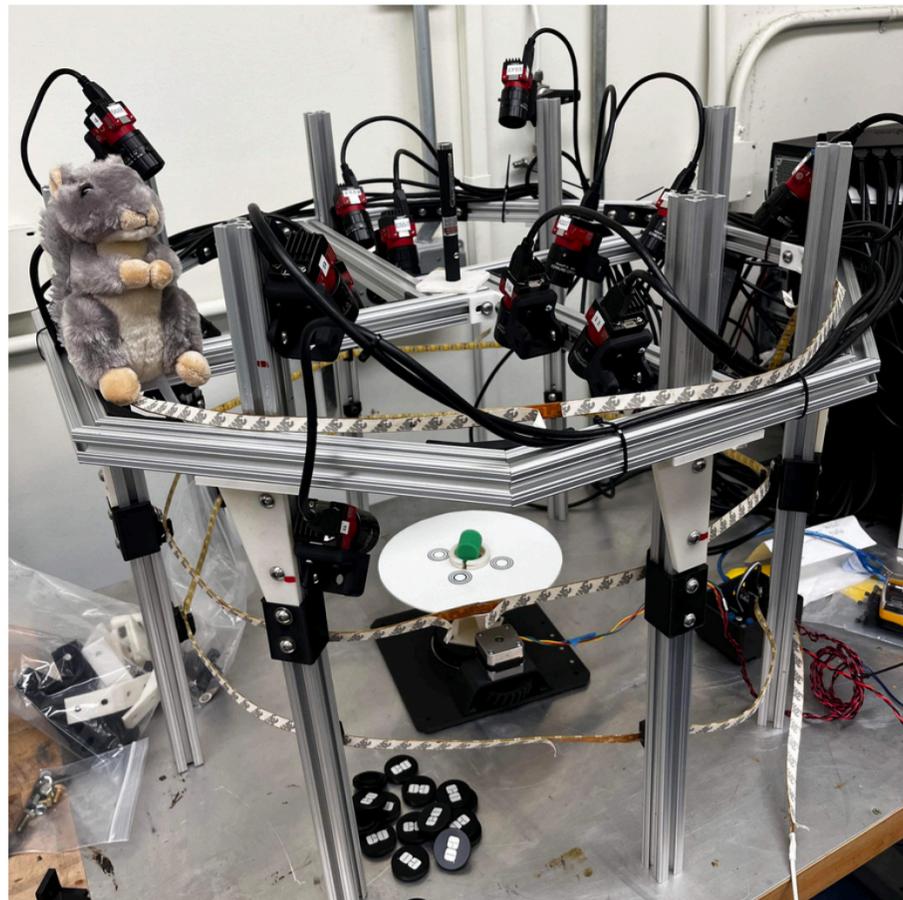




# STARscan Scanners

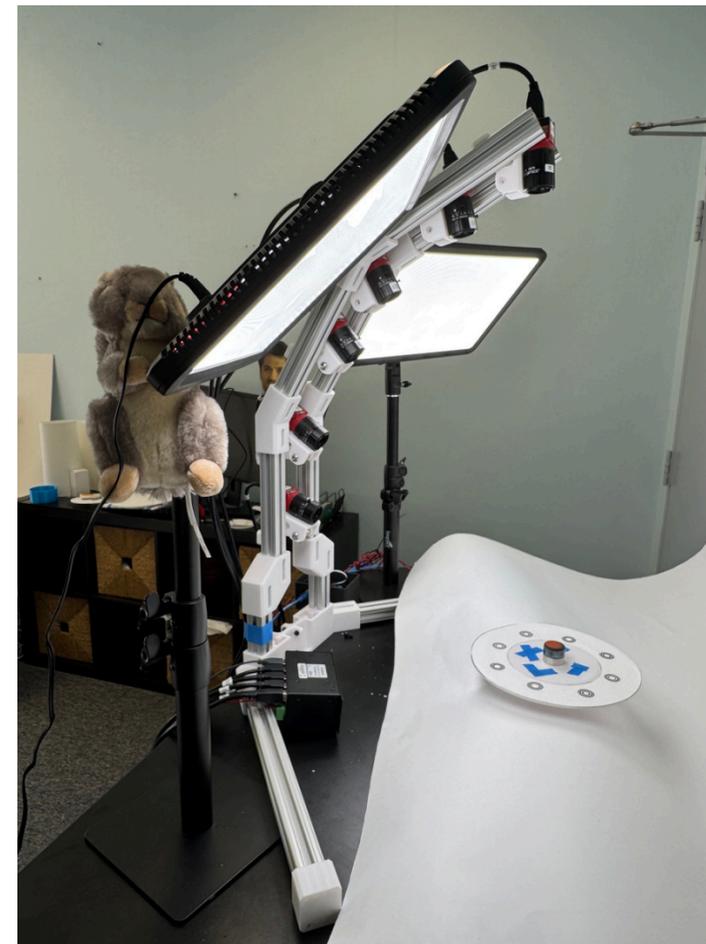
## Static Config (16+ cameras)

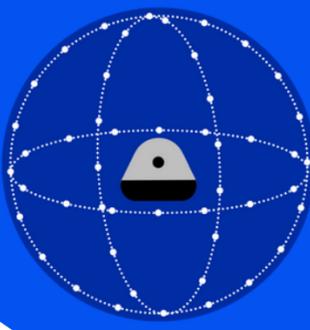
- Expensive (more cameras)
- Not portable
- Longer calibration
- + Faster scan



## Turntable Config (6 cameras)

- + Cheaper (fewer cameras)
- + Portable
- + Fast to calibrate
- Longer to scan





# STARscan Scanners Hardware



- **Cameras:**

AlliedVision 12MP, VimbaX API, 16mm f/1.6 lens, Min iris: ~F13



- **Rig:**

8020 bars & 3D connectors, flexible T-nut mounts



- **CCTags:**

Circular patterns for scaling and alignment



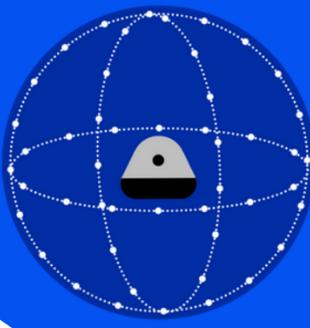
- **Turntable:**

3D printed, stepper motor, Arduino-controlled



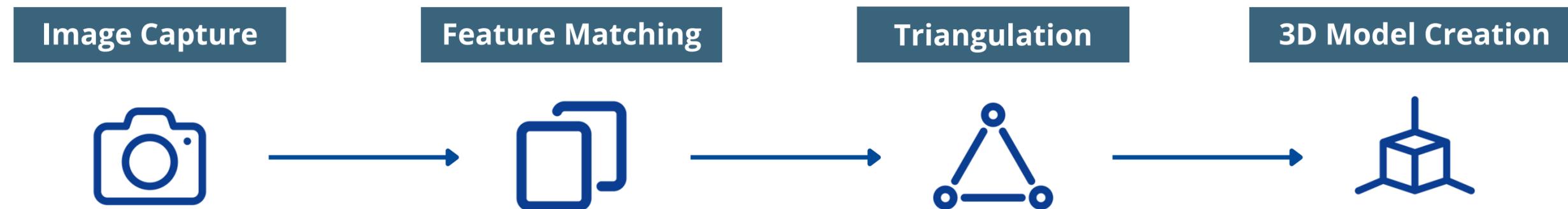
- **Lighting:**

LED panels/strips, white sheets for background masking



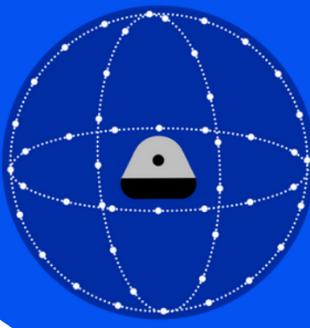
# 3D mesh from photos

- 1. Image Capture:** Take multiple overlapping photos of the object or area from various angles.
- 2. Feature Matching:** Software identifies common points or features across different images.
- 3. Triangulation:** Uses geometry to calculate the position of points in 3D space based on camera positions.
- 4. 3D Model Creation:** Combines all points to form a 3D model, adding texture and detail.



STARscan uses Meshroom from AliceVision for photogrammetry-based 3D reconstruction [1].

[1] AliceVision Meshroom. Available at: <https://alicevision.org/#meshroom>

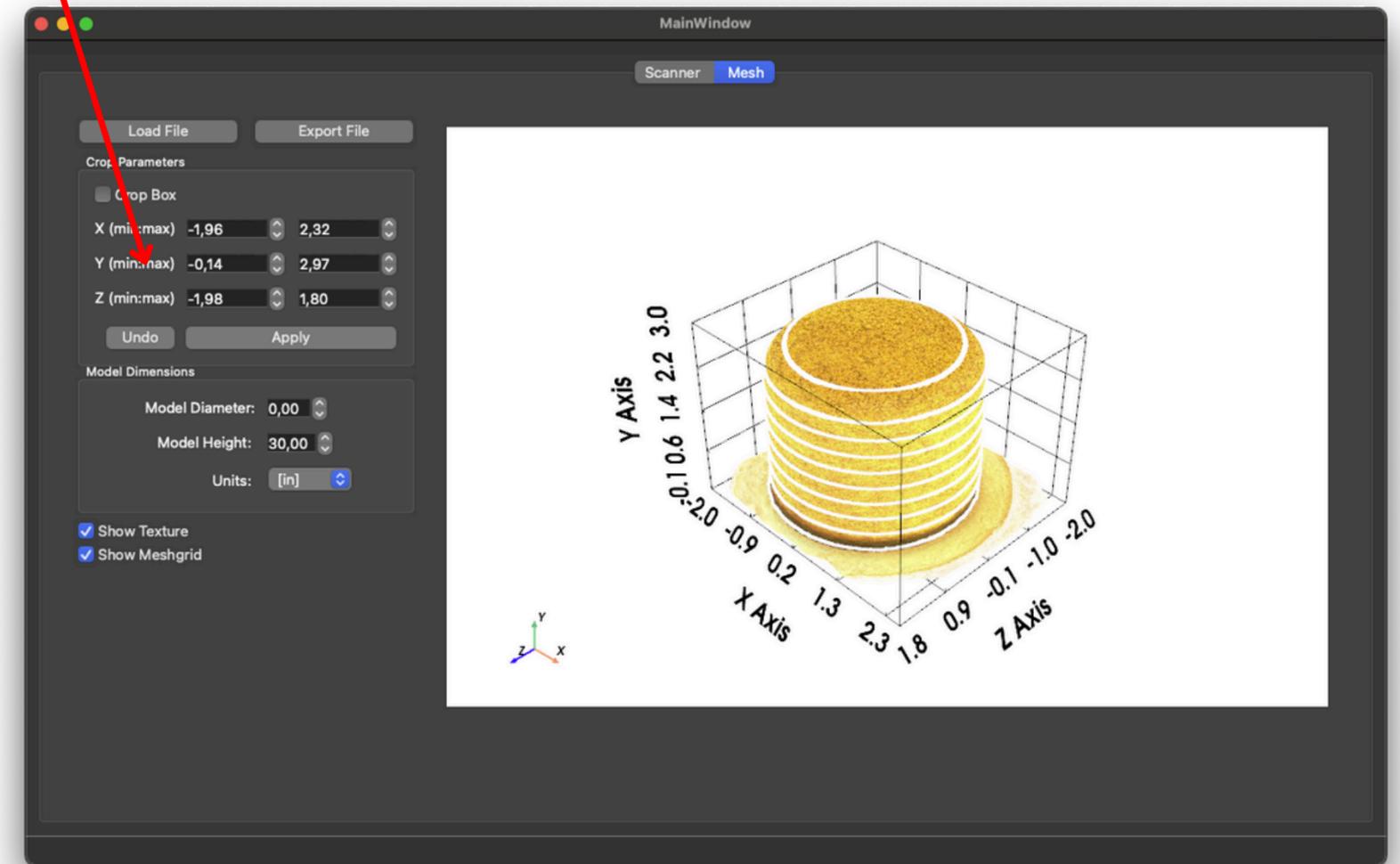
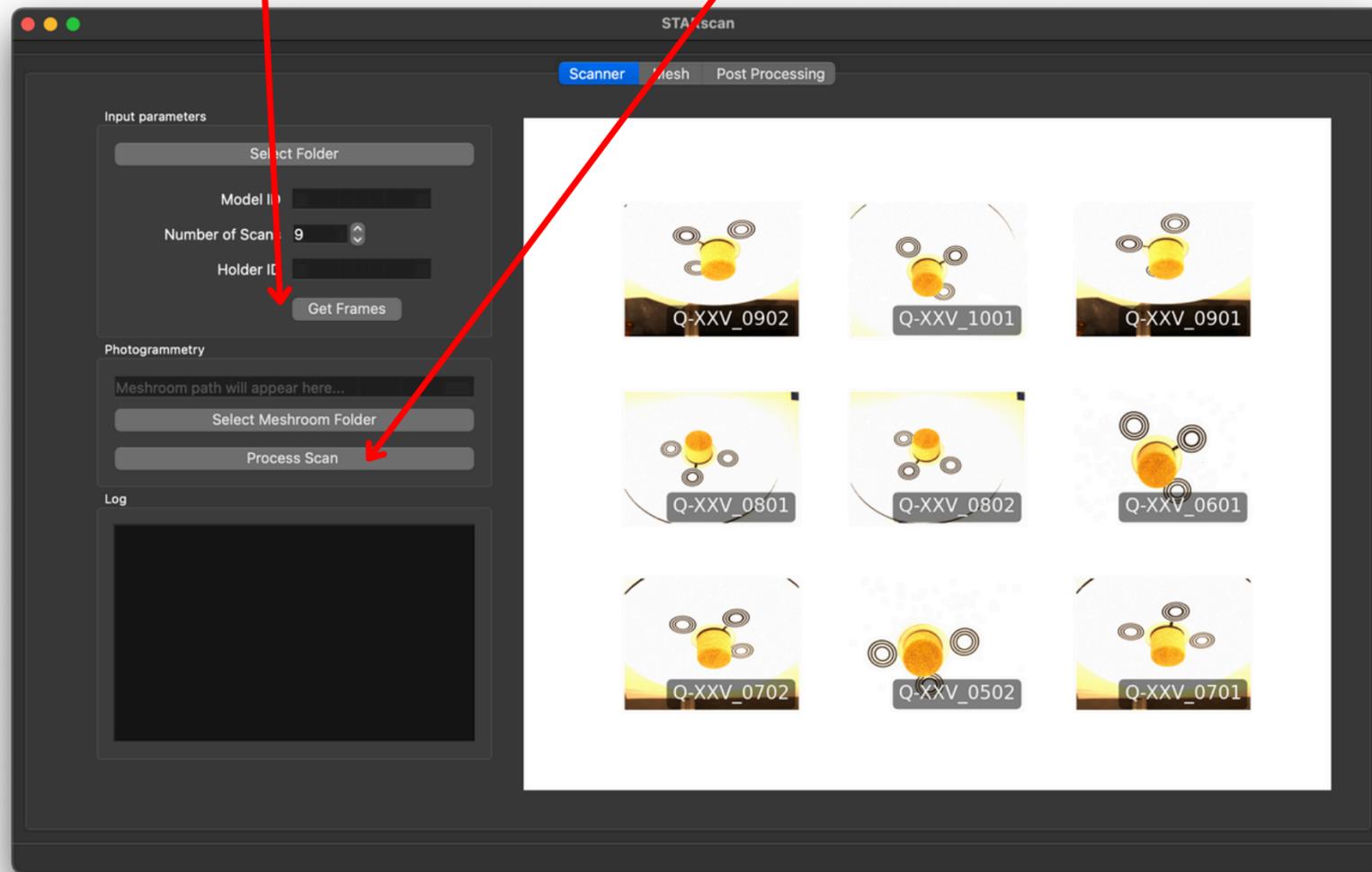


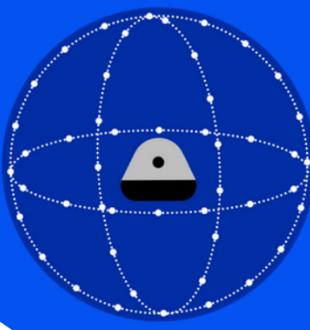
# STARscan GUI

1) Get the frames

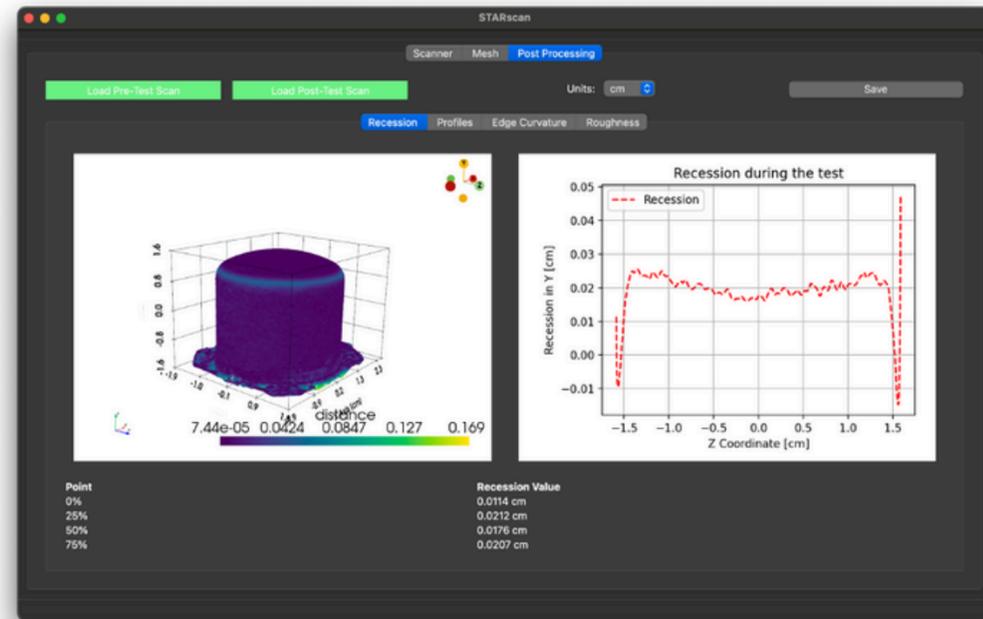
2) Generate Mesh

3) Crop



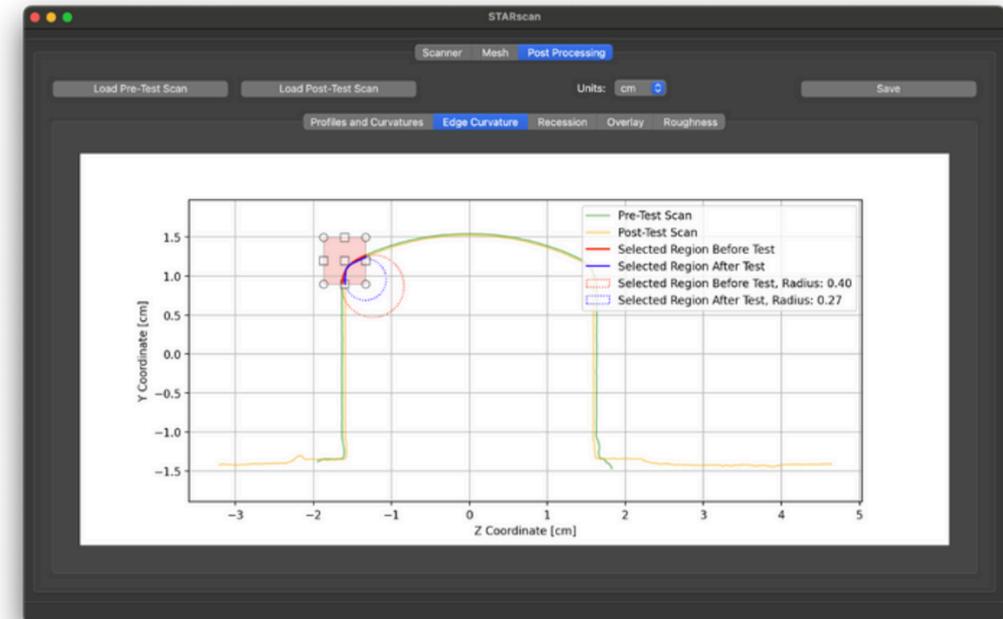


# STARscan GUI: Post-processing



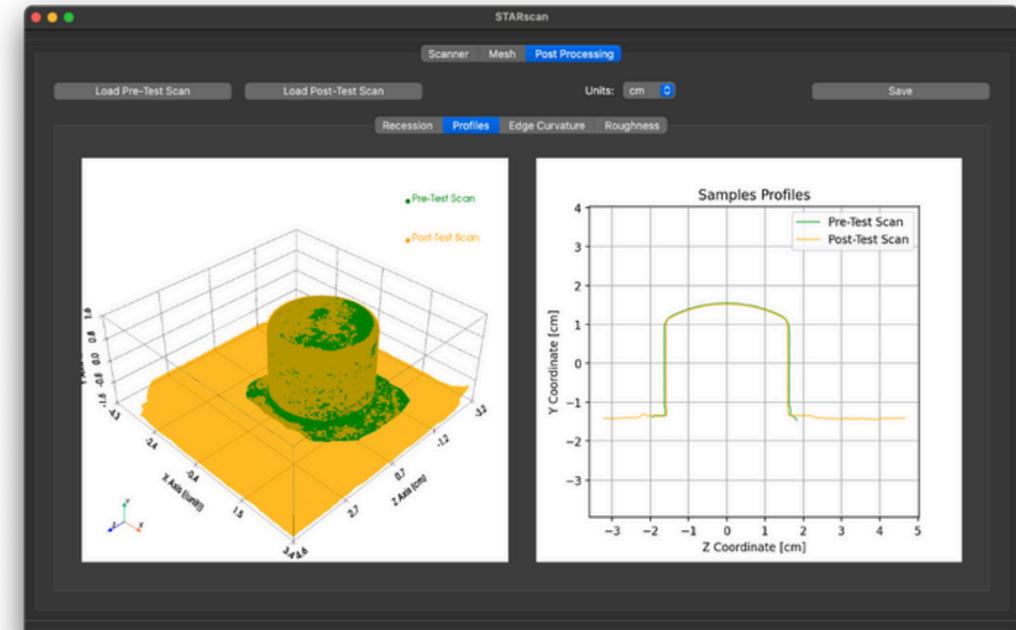
Recession

Shoulder Curvature

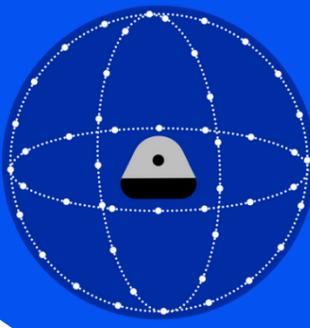


Roughness

Profiles

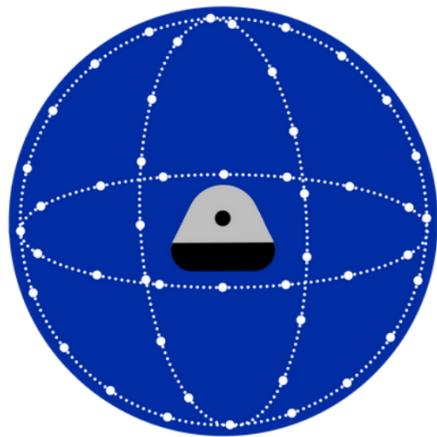


# Future Work

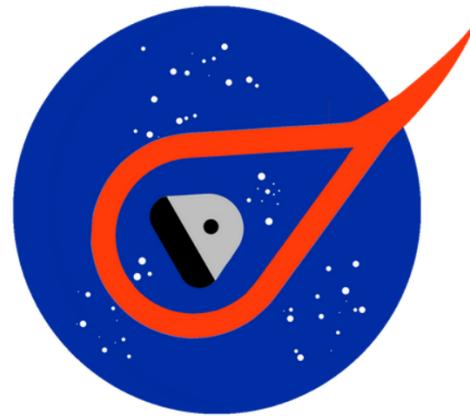


## 3D arcjetCV Using Photogrammetry

STARscan



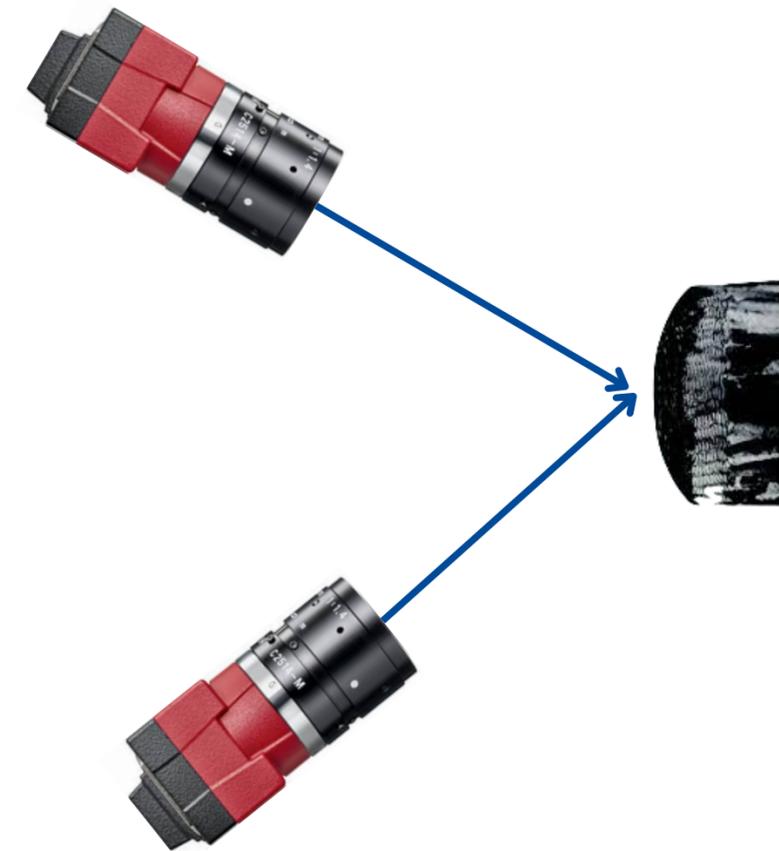
arcjetCV



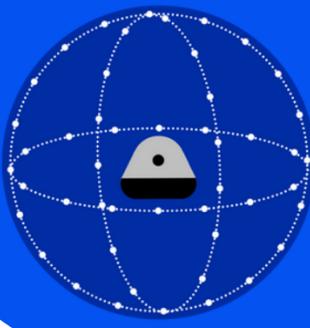
3D Scan of sample  
before/after test

2D recession analysis  
during test

3D Reconstruction **during** test



**Inspired by** Loehle et al. (2014), who used photogrammetry for ablative surface tracking in high-enthalpy flows.



# STARscan Conclusion

## STARscan enables:

- Automated 3D scanning before & after tests
- Fast, standardized roughness & recession measurements
- Accurate shape/shoulder curvature analysis
- Reproducible comparisons across facilities

## STARscan users :

Ames arcjet facilities

VKI (soon)

→ Removes scanning bottlenecks, speeds up analysis, and provides consistent 3D surface data

## STARscan is:

2 Scanners

1 User Interface

4 Postprocessing Features

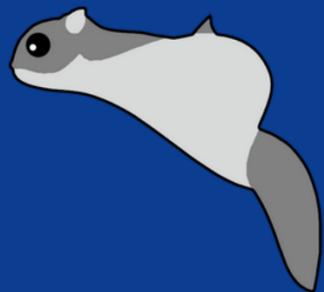
# Acknowledgments

- Federico Semeraro – NASA Ames Research Center
- Jeremie Meurisse – NASA Ames Research Center
- Magnus Haw – NASA Ames Research Center
- Sebastian Colom – NASA Ames Research Center
- Margaret Stackpoole – NASA Ames Research Center

## **Fundings:**

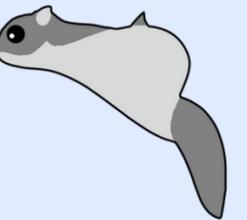
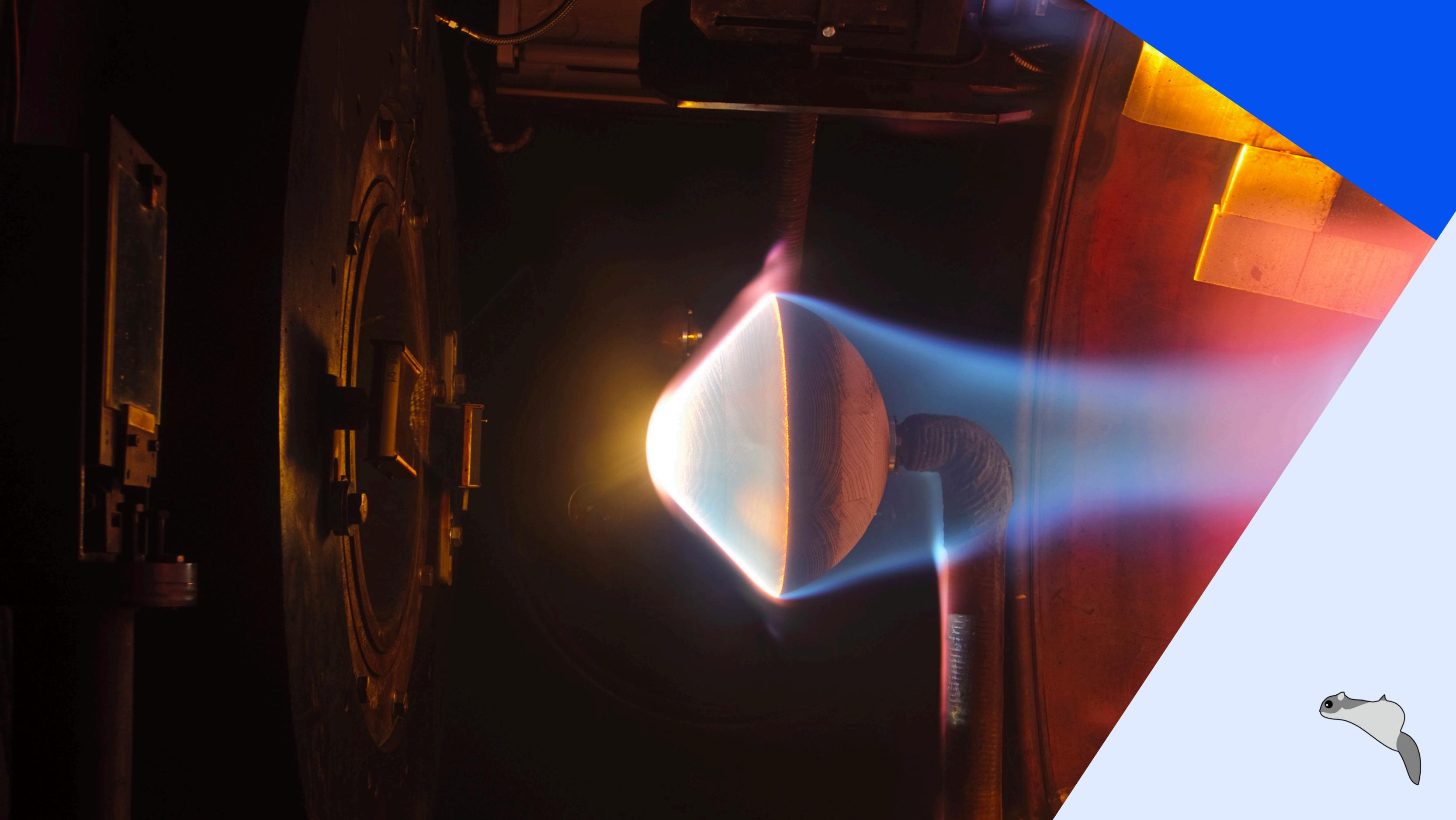
- MSR
- ESM
- TSM Branch IRAD

# Thank you for your attention !

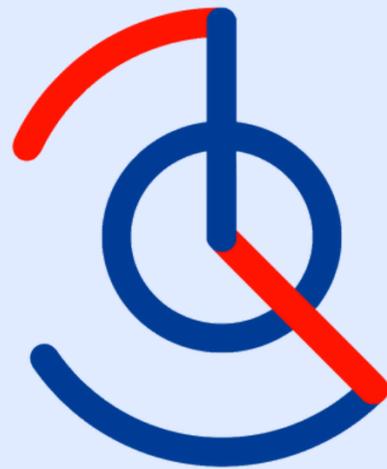


Get updates





# 4.3 Time Segmentation



**Problem:** Detecting the sample insertion manually is a time bottle neck.



**25 MINUTES 240 FPS  
50 GB**

MANUALLY CROPPING EACH SAMPLE INSERTION IS **HARD WORK**





# 4.3 Time Segmentation

**Solution:** Apply a CNN on the mean brightness trace of the video and find the sample insertion

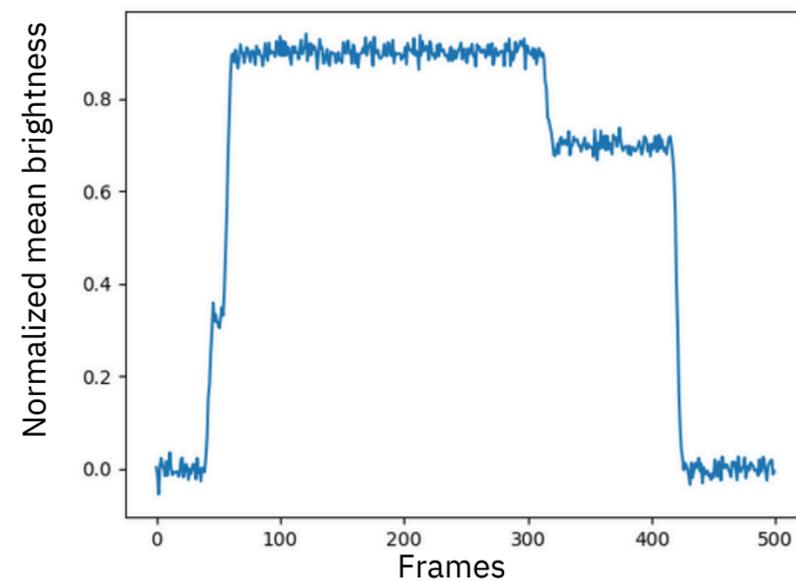
## Training

**Problem:** Not enough data for the training  
→ **Solution:** Create artificial data

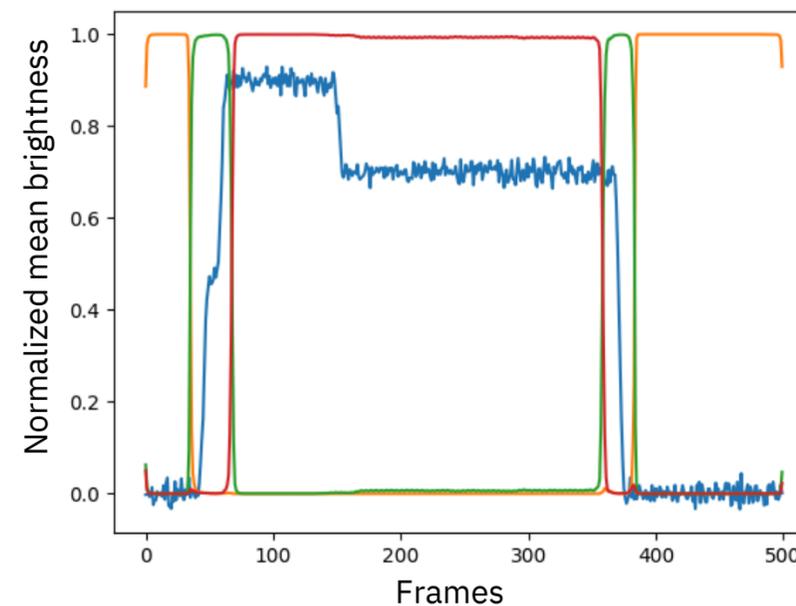
Sample in the frame

No sample

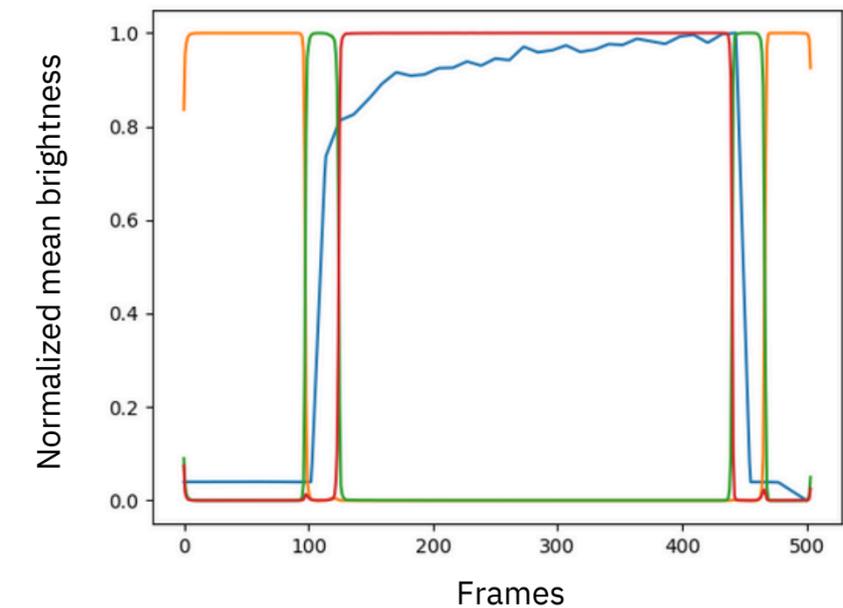
Transitional area



Artificial signal



Training data segmentation



Signal prediction