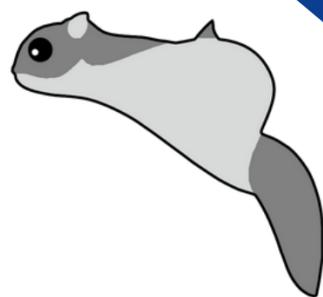
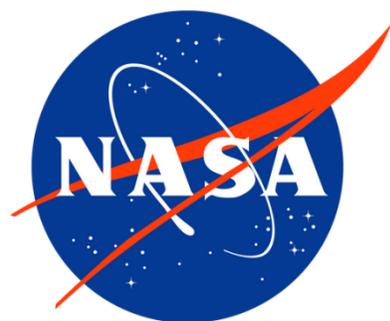


arcjetCV

Automating arc jet analysis

Ablation Workshop, November 2023



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Flying Squirrel

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NASA Ames Research Center

Introduction

Challenges:

- Ground tests are expensive ~\$100k/sample and complex but necessary to evaluate material performance.
- Material samples are only 3D scanned before and after a test, no in-situ sensing.
- Tracking recession from video is sufficiently difficult that it does not occur often.
- Non-linear recession and complex behaviours (e.g., melt, swelling, shrinkage) cannot be quantified without time-resolved recession.



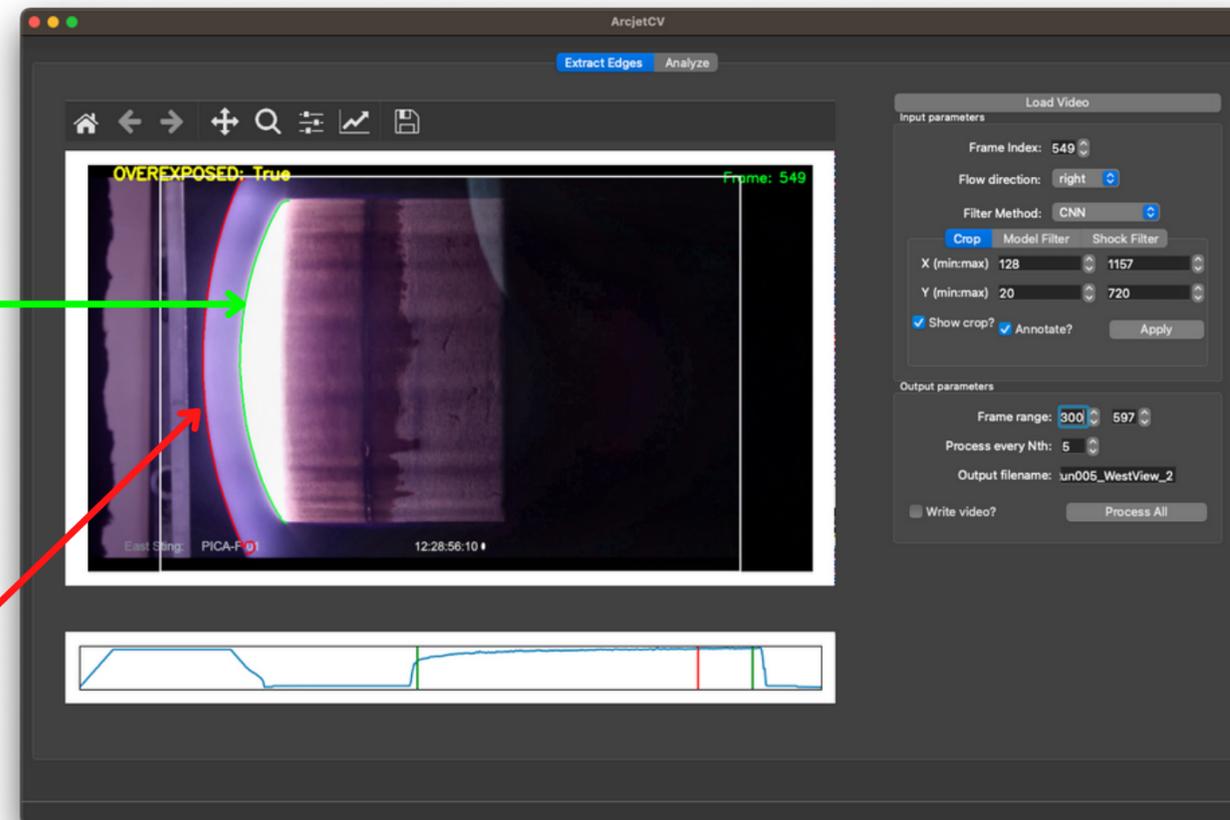
Introduction

Solution: arcjetCV

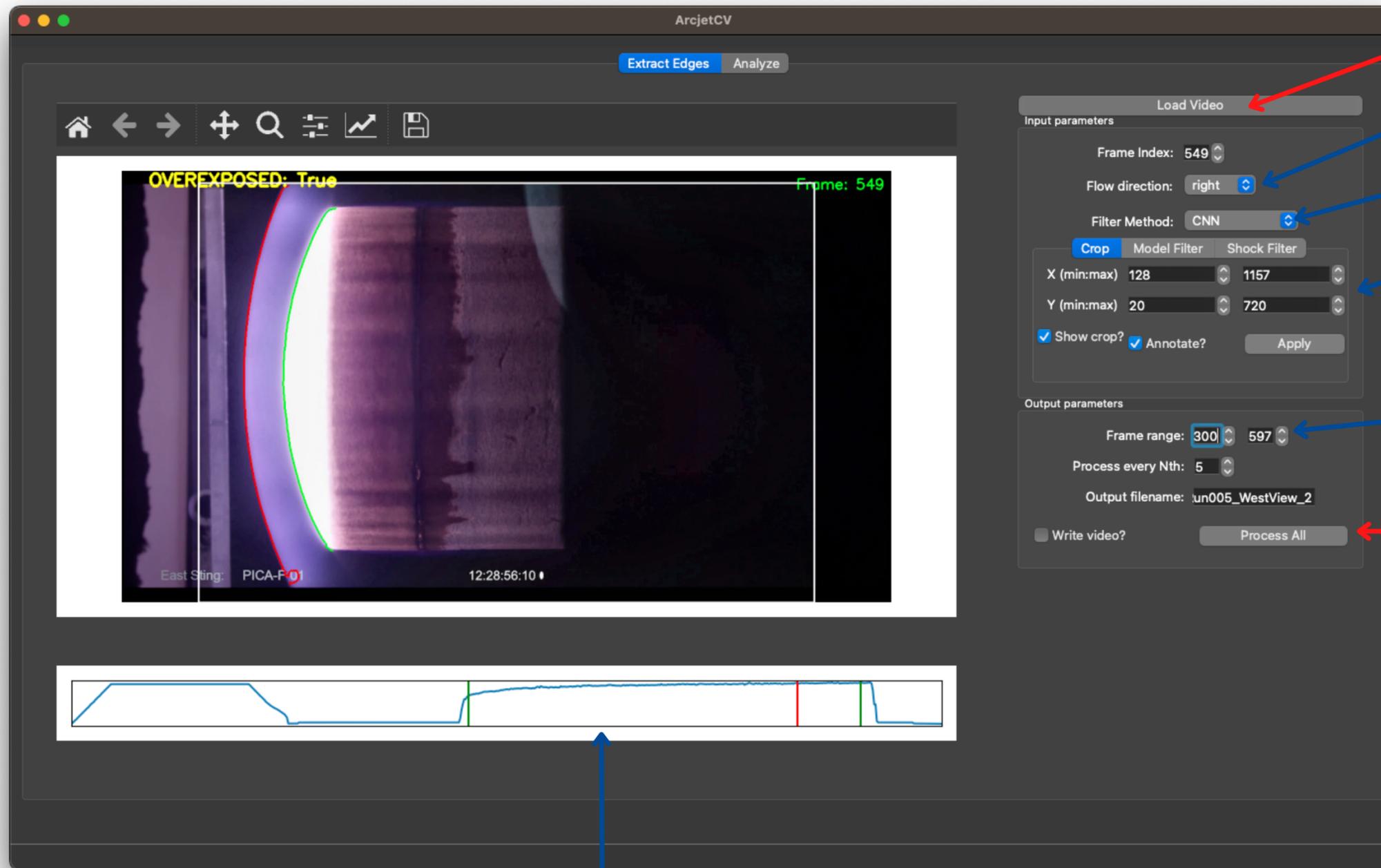
- Computer vision & machine learning automate software.
- Graphical user interface enables anyone to process video.
- Result:
 - New time-resolved recession tracking for all samples.
 - 2D and 3D verification and validation for coupled aerothermal, material codes.

Measure the evolution of the sample recession

Measure the evolution of the shock position



Desktop Interface



1. Load a video

Select flow direction

Select filter method

Crop & filter parameters

Output settings

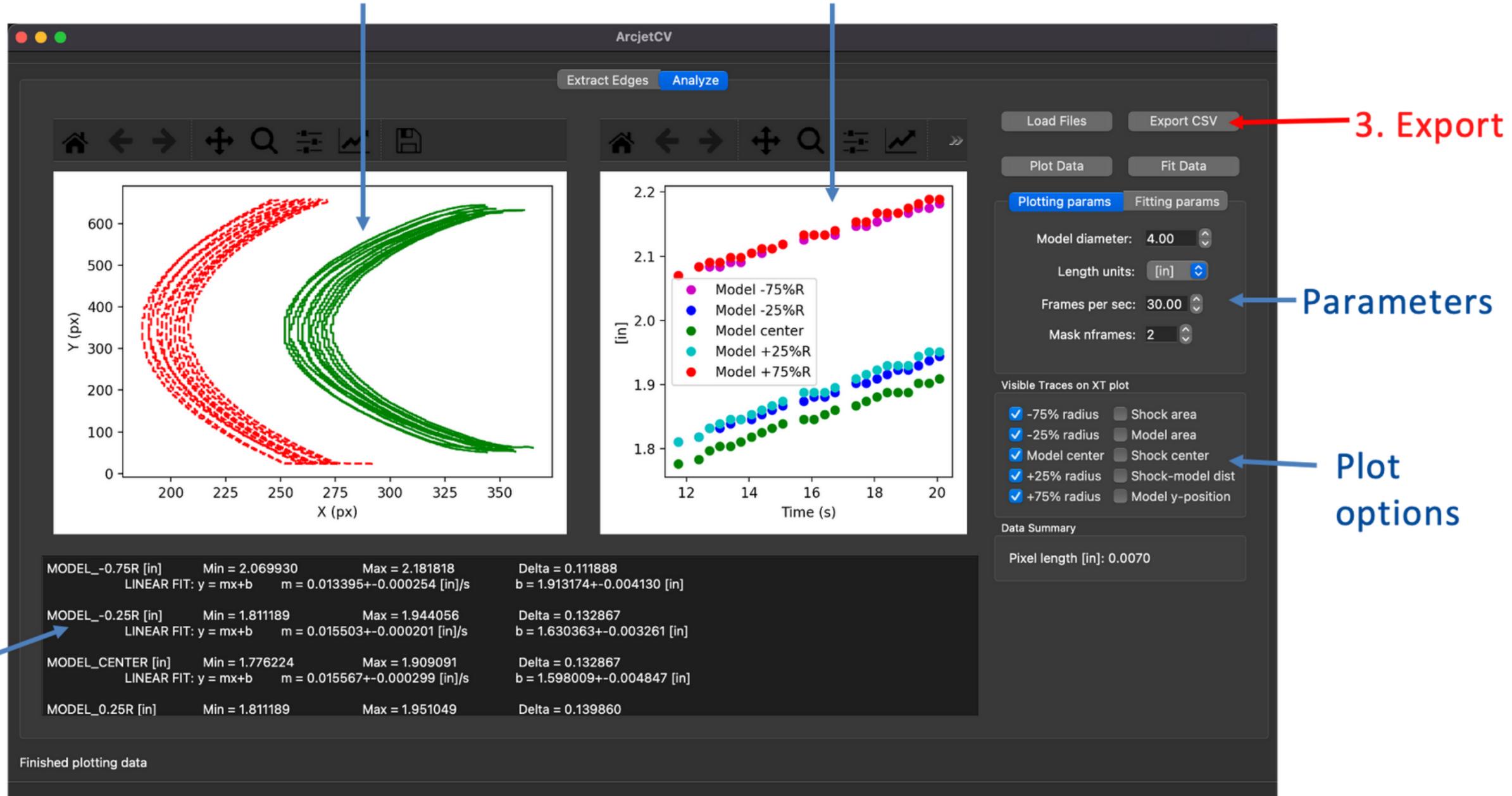
2. Process all frames

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

Desktop Interface

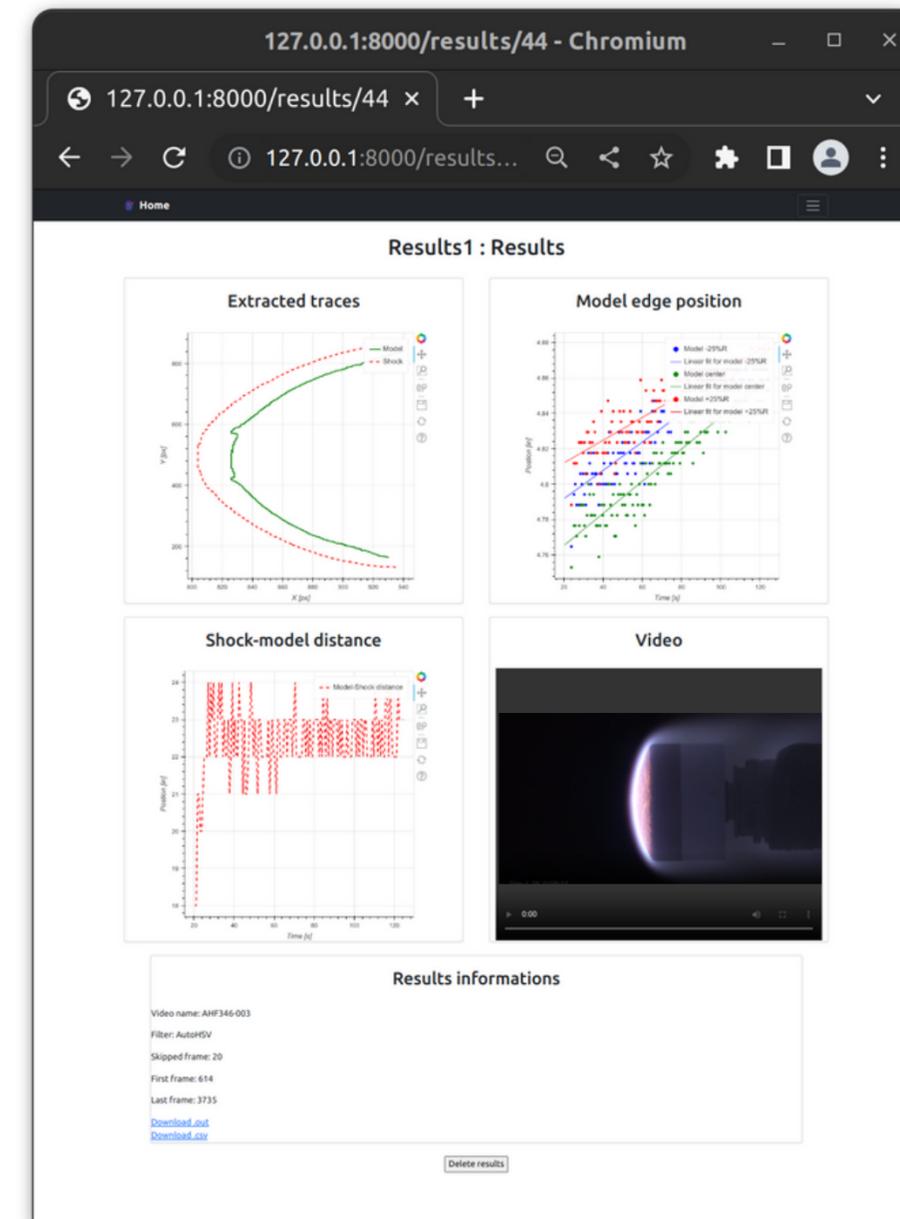
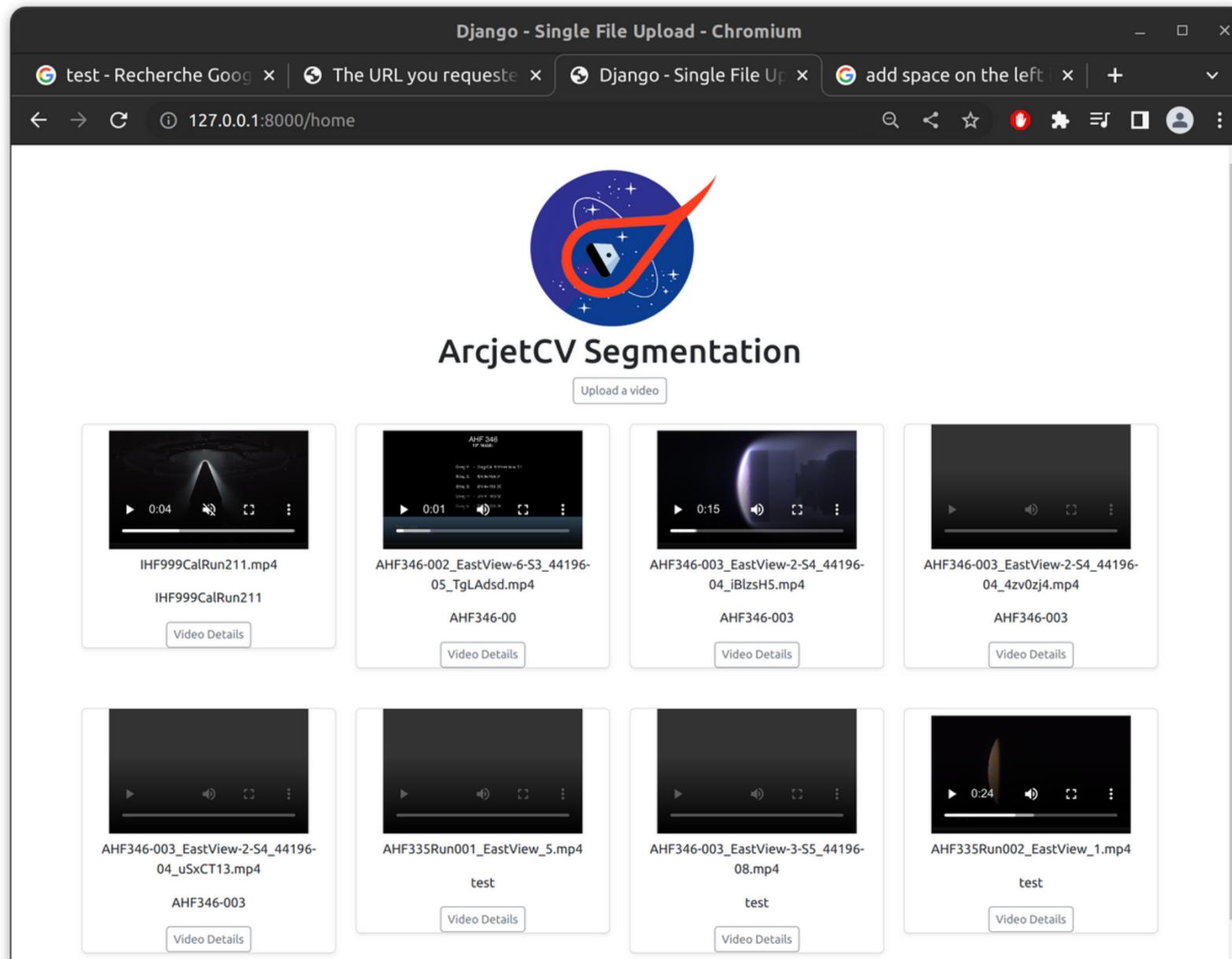
XY traces of shock and the sample edge

Time dependence plot

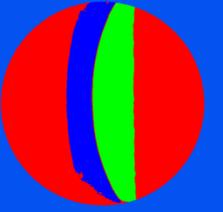


Web Browser Interface

Setup arcjetCV on a secure local server



CNN Theory



CNNs are neural networks designed to recognize patterns in images.

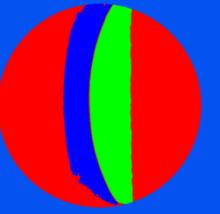
- Typically trained on manually labeled images.
- Robust performance compared to other methods.

arcjetCV uses a CNN with a VGG16-UNet architecture to classify a given image frame into 3 classes:

- material sample
- shock
- background

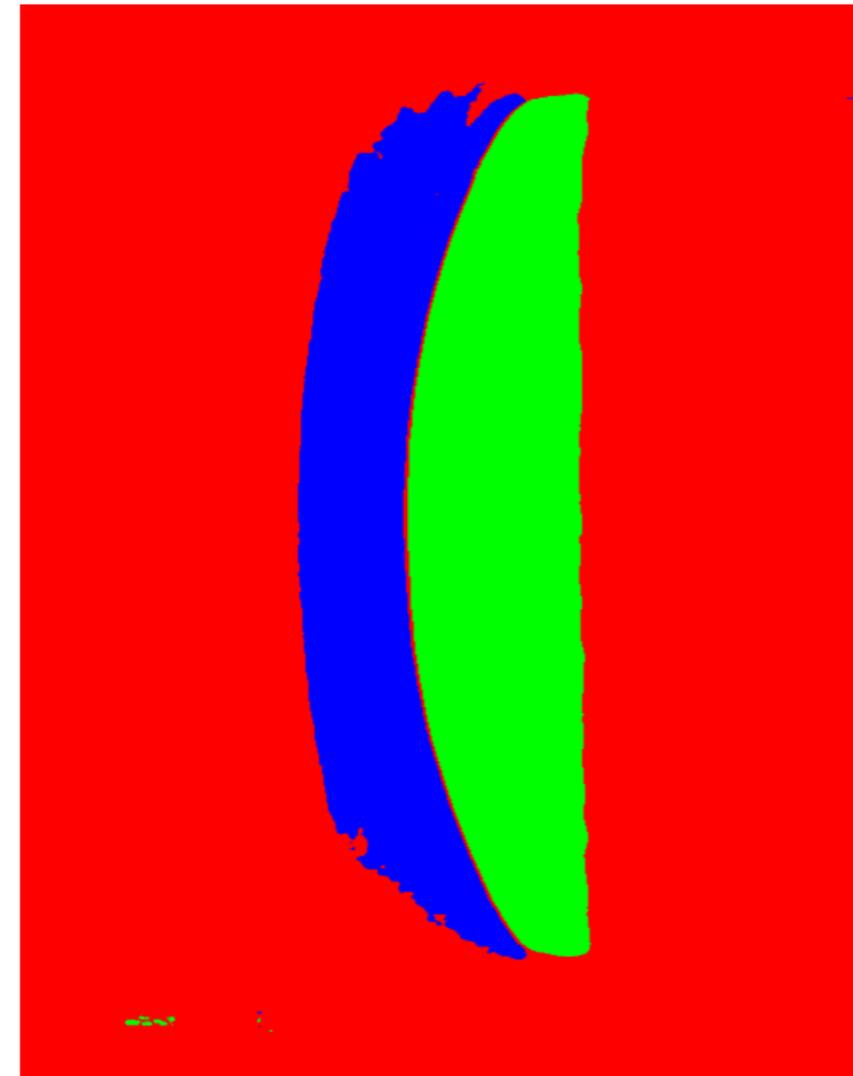
This segmentation is then passed through simple image processing methods to extract the leading edge of the sample.

CNN Results



Input frame

→
Convolutional
Neural Network



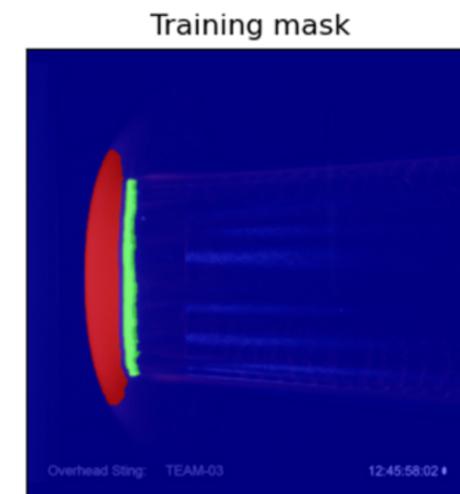
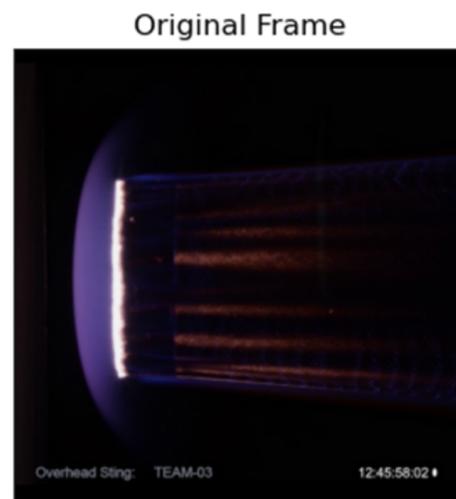
Output frame

Shock
Sample
Background

CNN Training

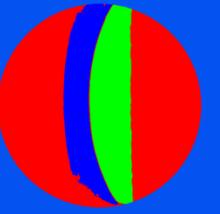
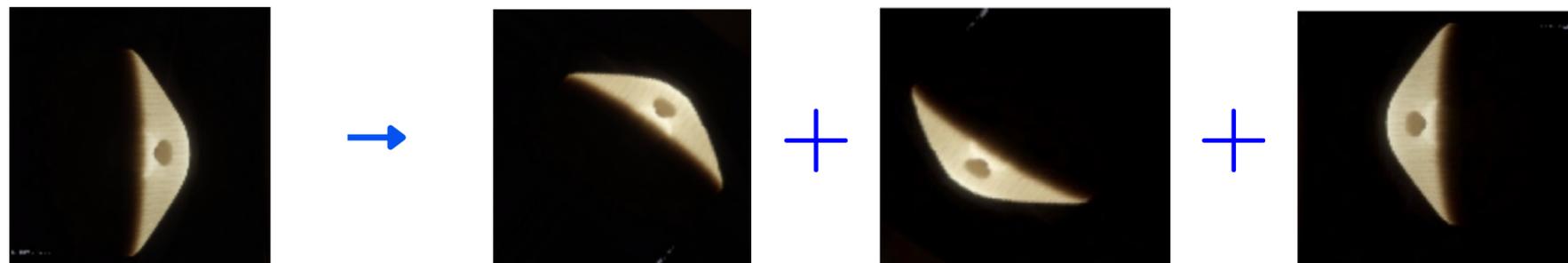
Data labelling

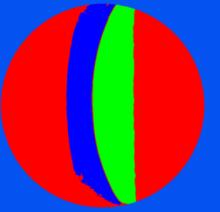
Label by hand with assistance



Training Set improvement = Data Augmentation

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





CNN Model

Important parameters for the choice of the model:

- Number of training images
- Size of the images
- Domain of the images

The VGG16-UNet architecture was chosen because it had the best performance out of the available encoder-decoder architectures tested (PSPNet, ResNet, UNet, miniUNet, SegNet, FCN, MobileNet, etc.)

VGG16-UNet

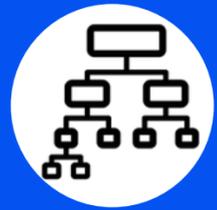
F1 score:

$$F_1 = \frac{2tp}{2tp + fp + fn}$$

tp = true positif
fp = false positif
fn = false negative

- Sample: 0.9494
- Shock: 0.9789

Accuracy: 0.9943



Decision Tree Theory

Decision tree = algorithm that only contains conditional control statements.

This model was developed to provide a **faster** segmentation model suitable for real-time feedback applications. It uses the **HSV** (hue, saturation, value) and **Laplacian filter** parameter space instead of RGB since the separation between target classes (sample, shock, background) is larger.

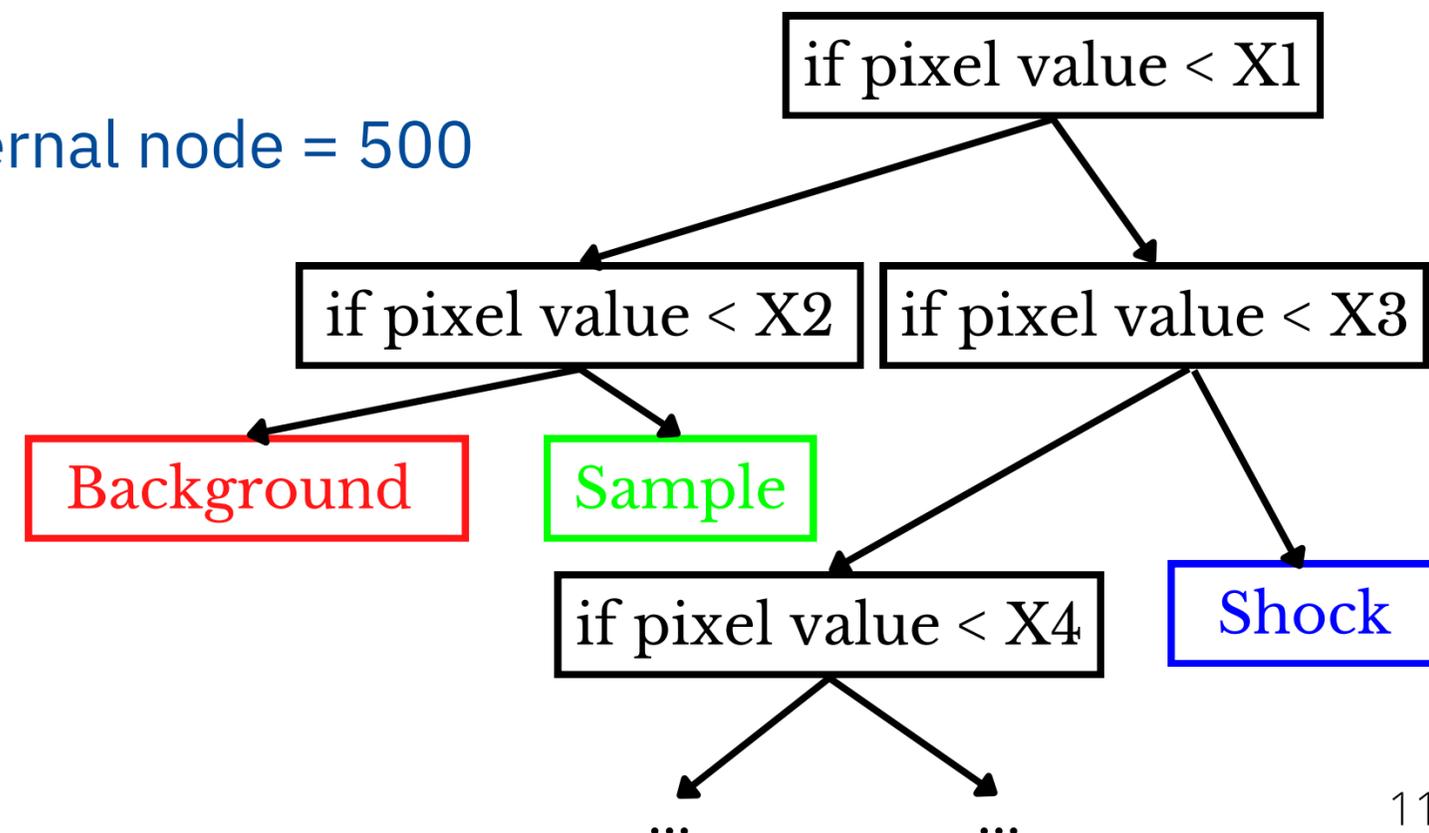
Accuracy: 0.93573

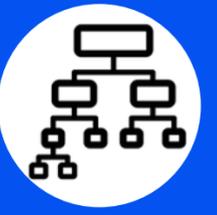
Parameters selected:

- Minimum number of samples required to split an internal node = 500
- Depth of the tree = 10
- Input params: HSV and laplacian HSV of single pixel
- Output: Sample, Shock, Background classification

Applications:

- Realtime feedback for arcjet arm positioning
- Realtime feedback for operators/customers



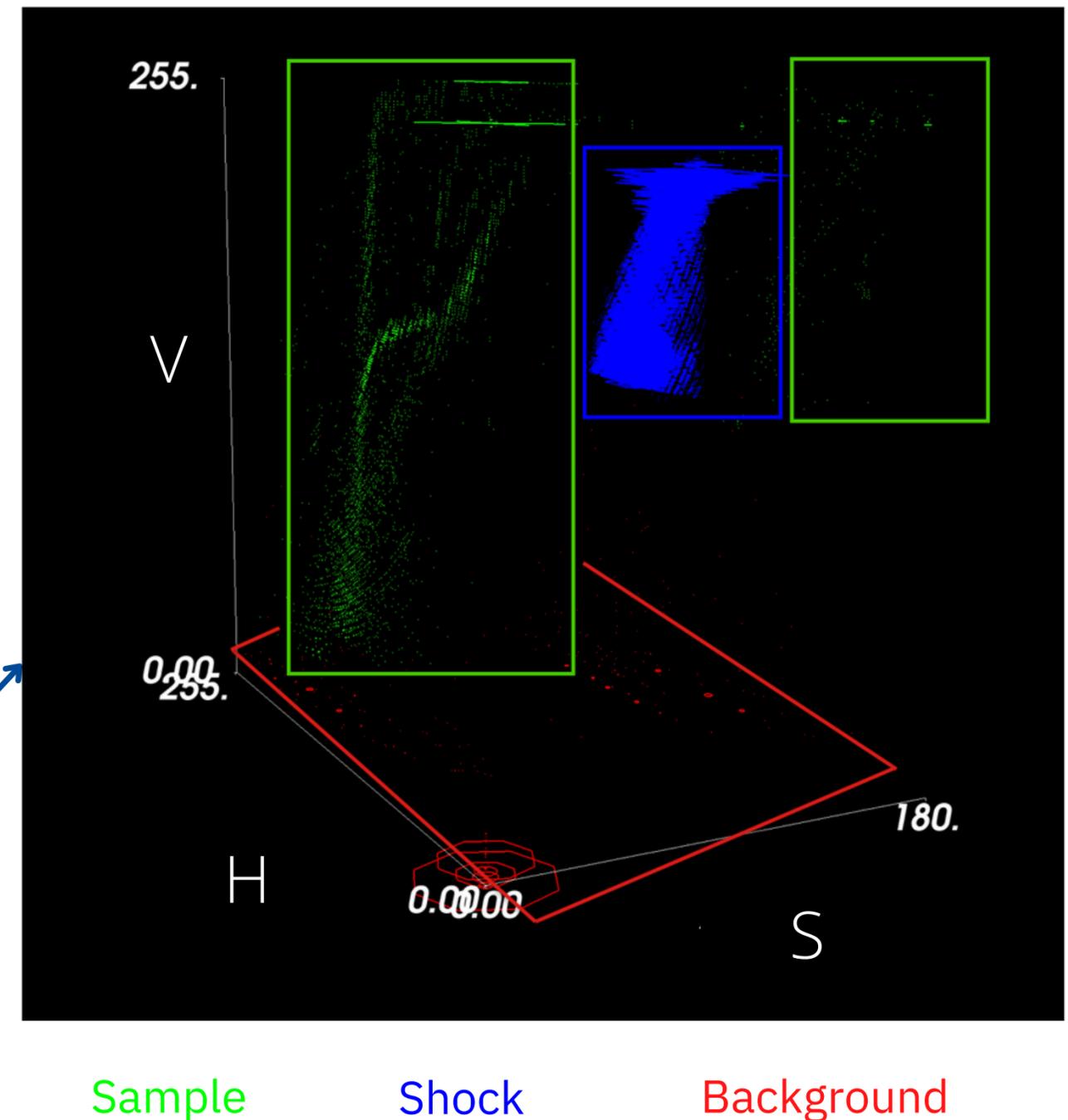


Decision Tree Results

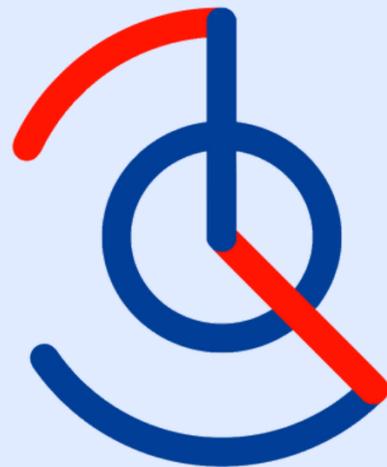
Why a decision tree ?

Model	CNN	Decision Tree
Performance	1Hz	20Hz
Accuracy	0.9943	0.93573
Conclusion	Slow but performs really good result	Faster and reasonably good

The decision tree works well because the different classes are mostly separated in HSV space



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**





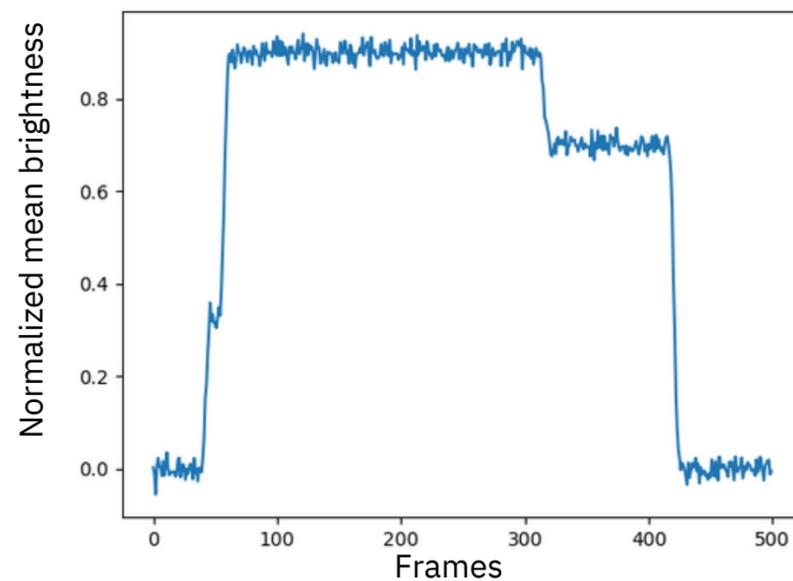
Time Segmentation

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

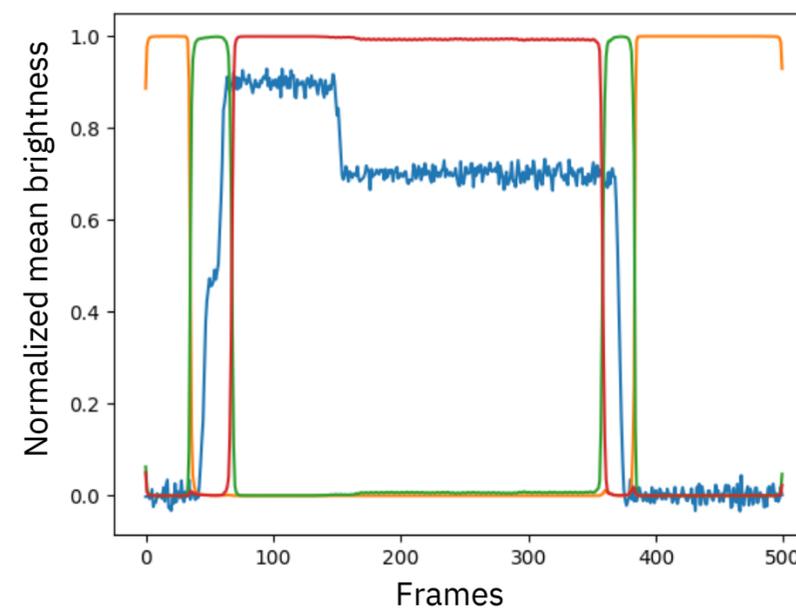
Training

Problem: Not enough data for the training.

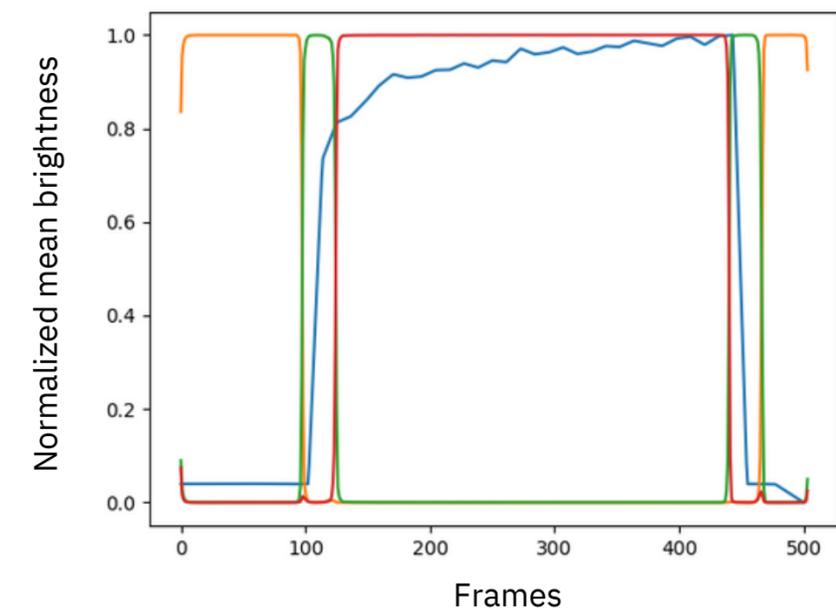
→ **Solution:** Create artificial data.



Artificial signal



Training data segmentation



Signal prediction

Sample in the frame

No sample

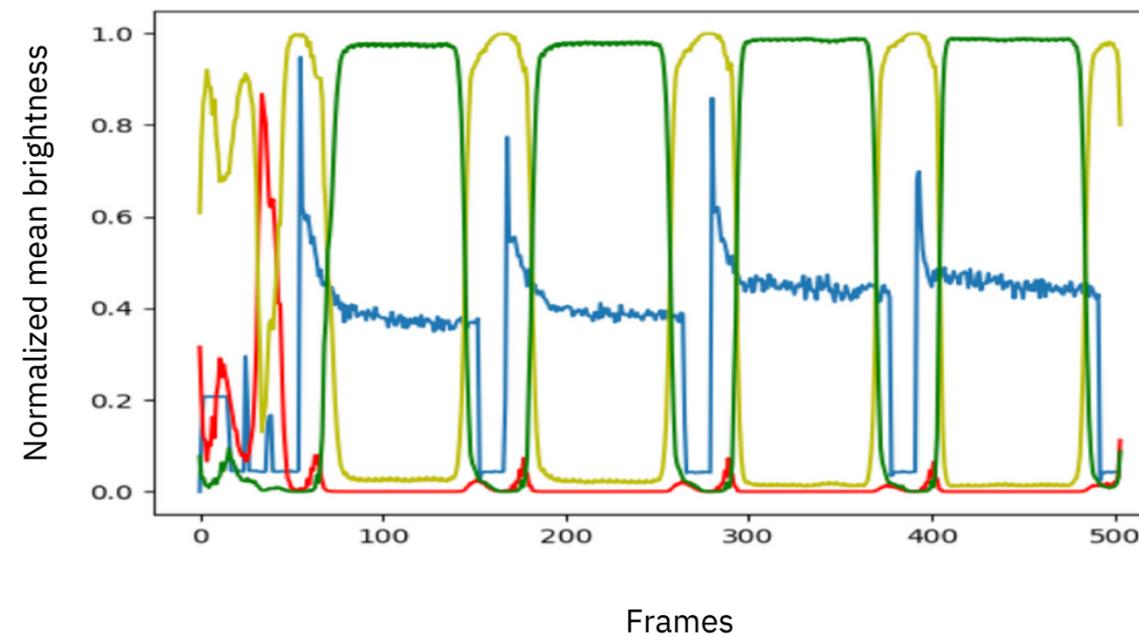
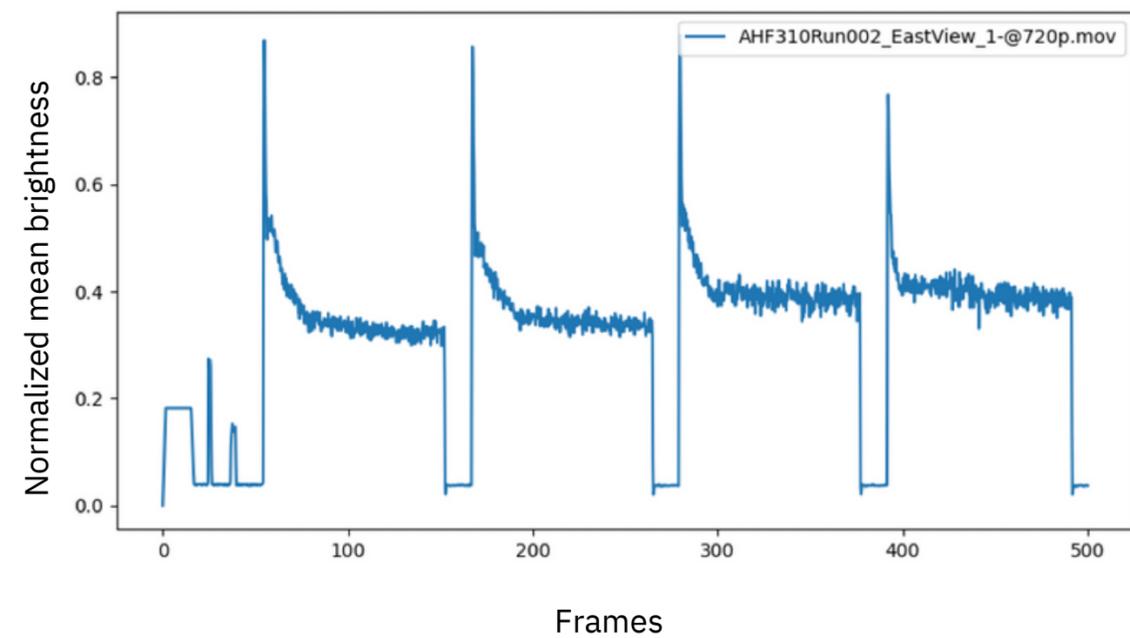
Transitional area



MultiTraces Tool

Idea: Make a tool to segment multiple model insertions in a single video.

Use the work done for the time segmentation but retaining it for multiple tests.



Sample in the frame

Transitional area

No Sample

Segmentation GUI

Why a labelling tool?



Continuous improvement of the dataset.



Customization of ML models by creating new class.



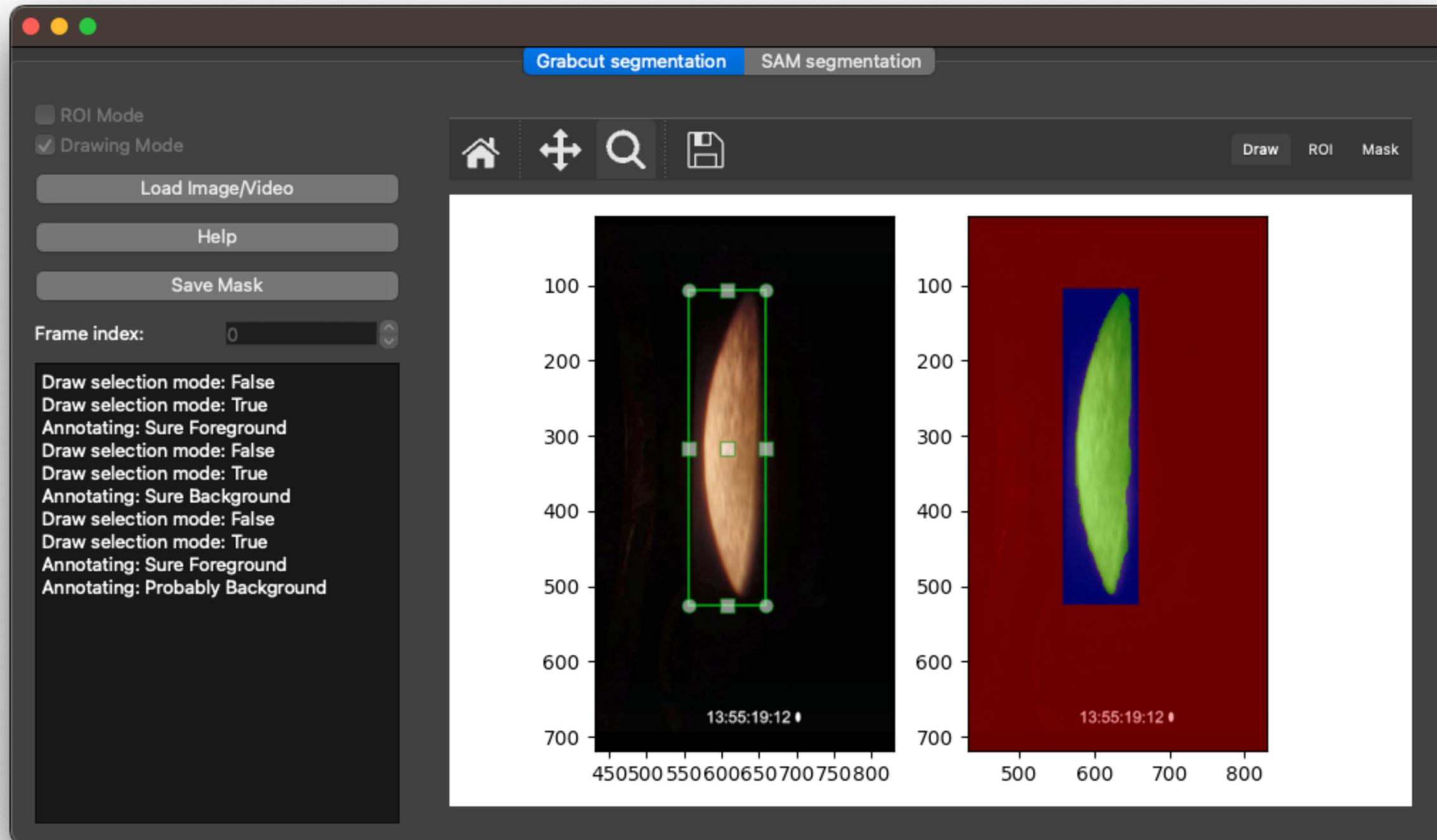
Highest fidelity segmentation for specific frames.



Create new datasets to create new ML models.

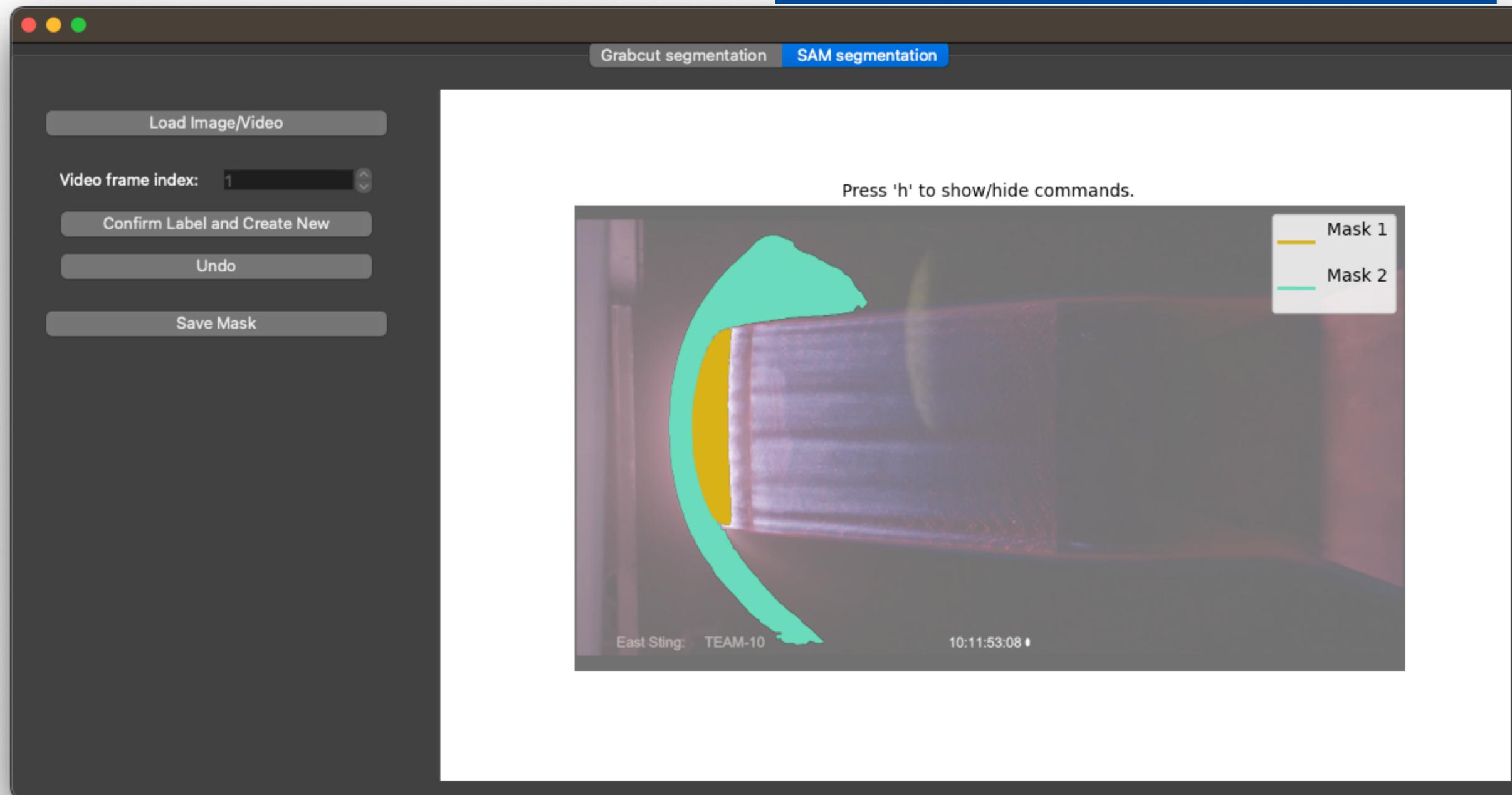
GrabCut

Segmentation through iterative graph cuts using color probability.



autoSAM

Segmentation using the Segment Anything Model (SAM) of META



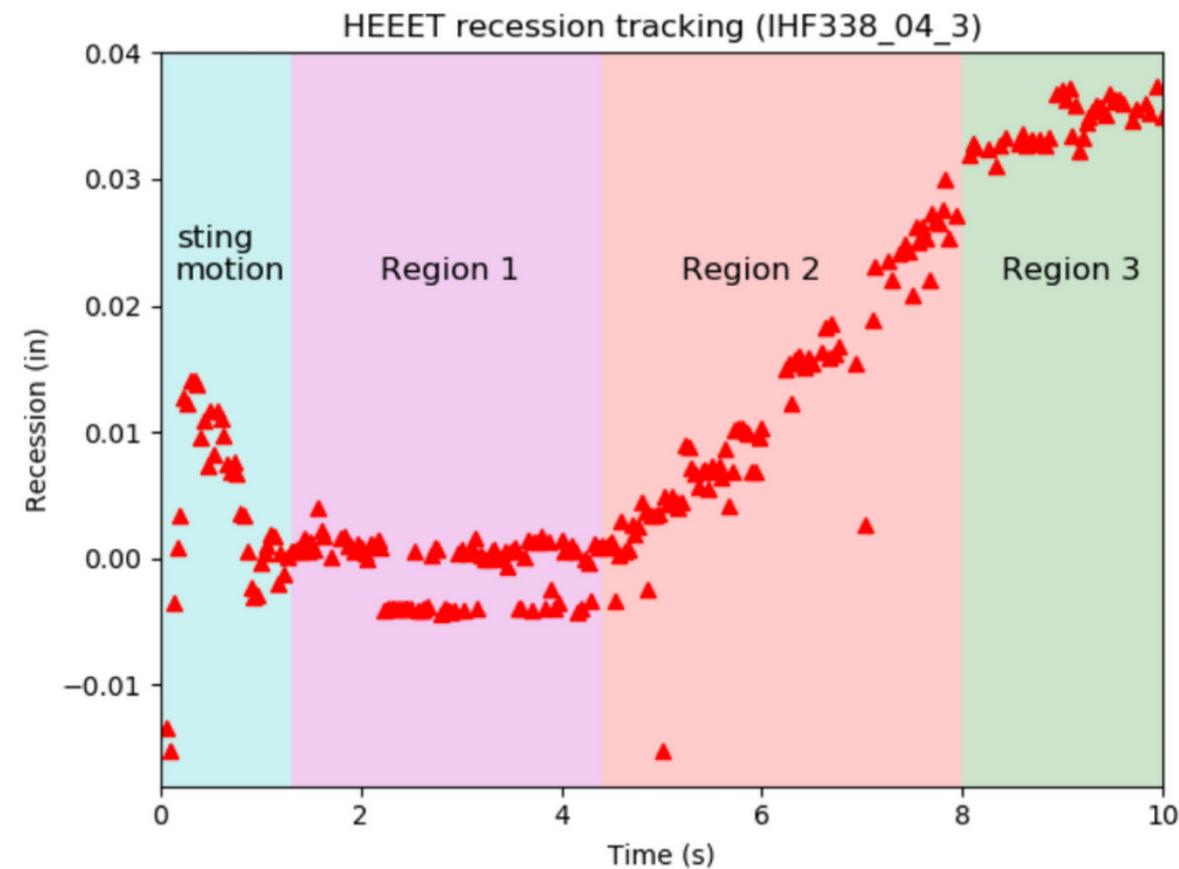
Based on the Segment Anything GUI co developed with Federico Semeraro.

Non-linear Recession

Before: Recession considered linear

With arcjetCV: 3 Regions:

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

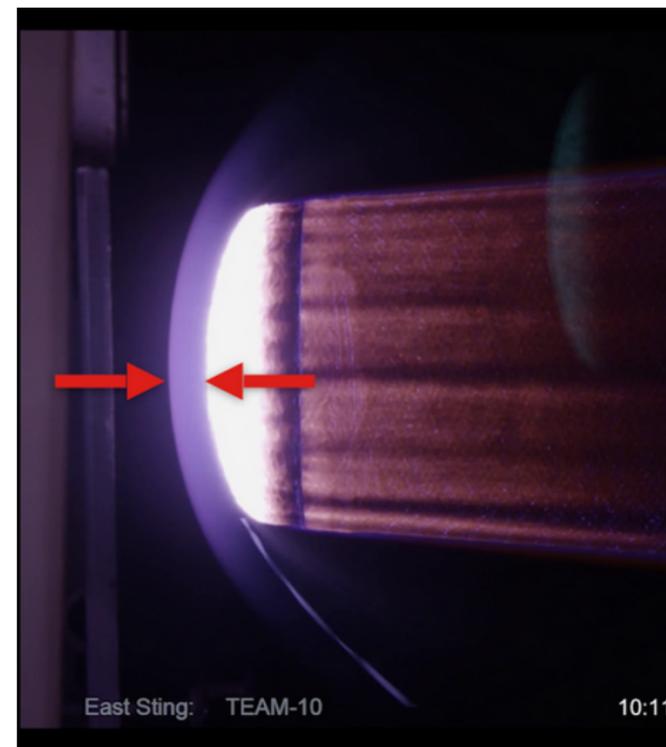
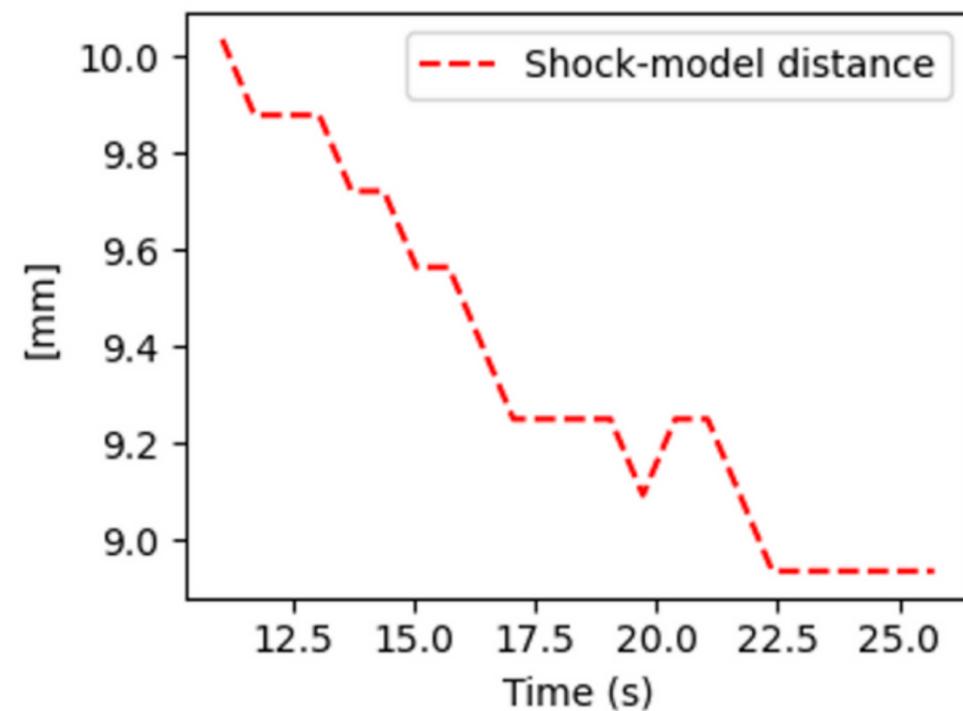


NEW PHENOMENON! NOT POSSIBLE TO OBSERVE WITHOUT ARCJETCV

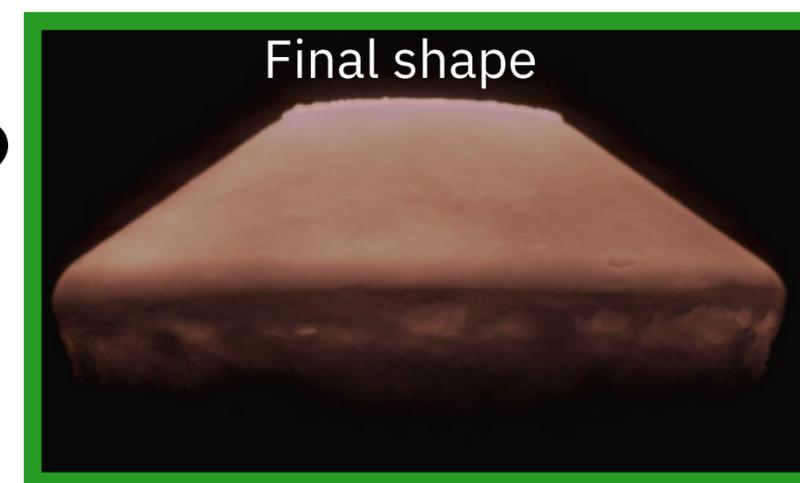
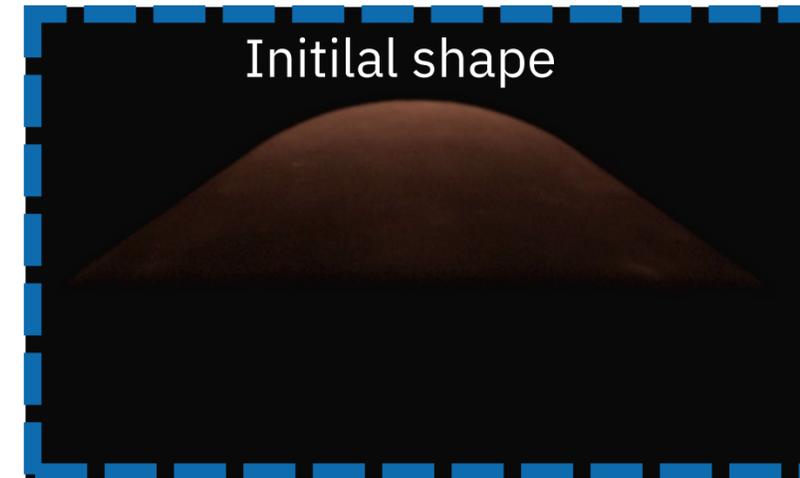
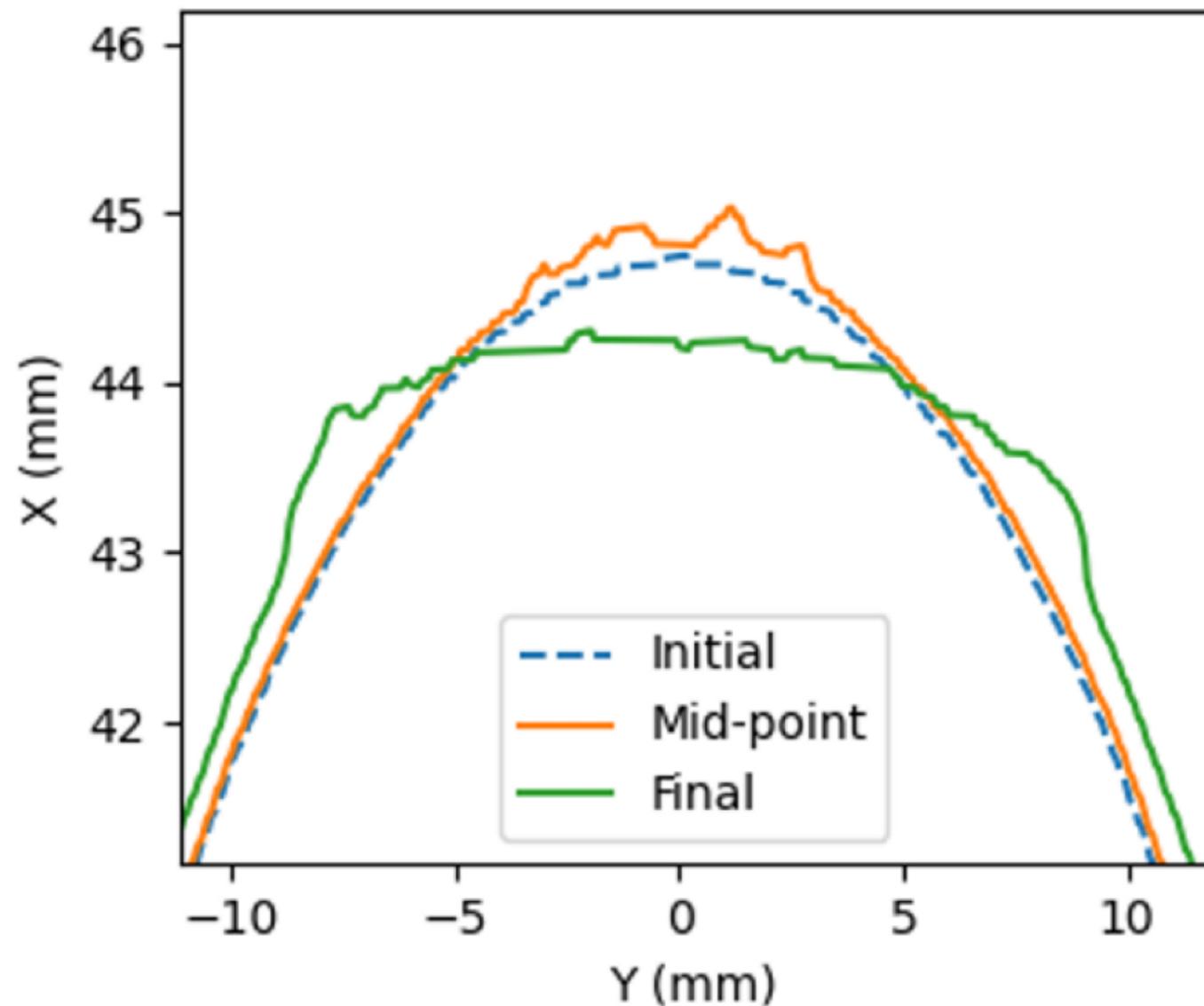
Shock standoff

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



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).

→ Provide the first validation for the new 3D material simulations.

Conclusion

arcjetCV is:

4 ML models

2 interfaces

3 operating systems

ArcjetCV enables new capabilities:

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

→ Better mission planning and risk management



arcjetCV users :

Ames arcjet facilities

Orion



MSR



Acknowledgments

- Federico Semeraro – Analytical Mechanics Associates
- Jeremie Meurisse – Analytical Mechanics Associates
- Magnus Haw – NASA Ames Research Center
- Margaret Stackpoole – NASA Ames Research Center

Thank you for your attention !

For more information come see our **poster**

To get updates about the opensource **release**
new features
and **installation**

