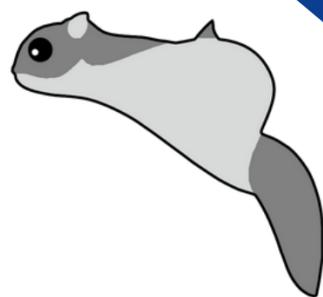
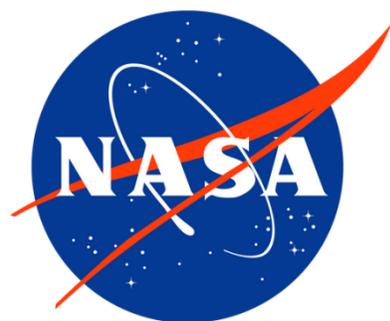


# arcjetCV

Automating arc jet analysis

Ablation Workshop, November 2023



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# 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.



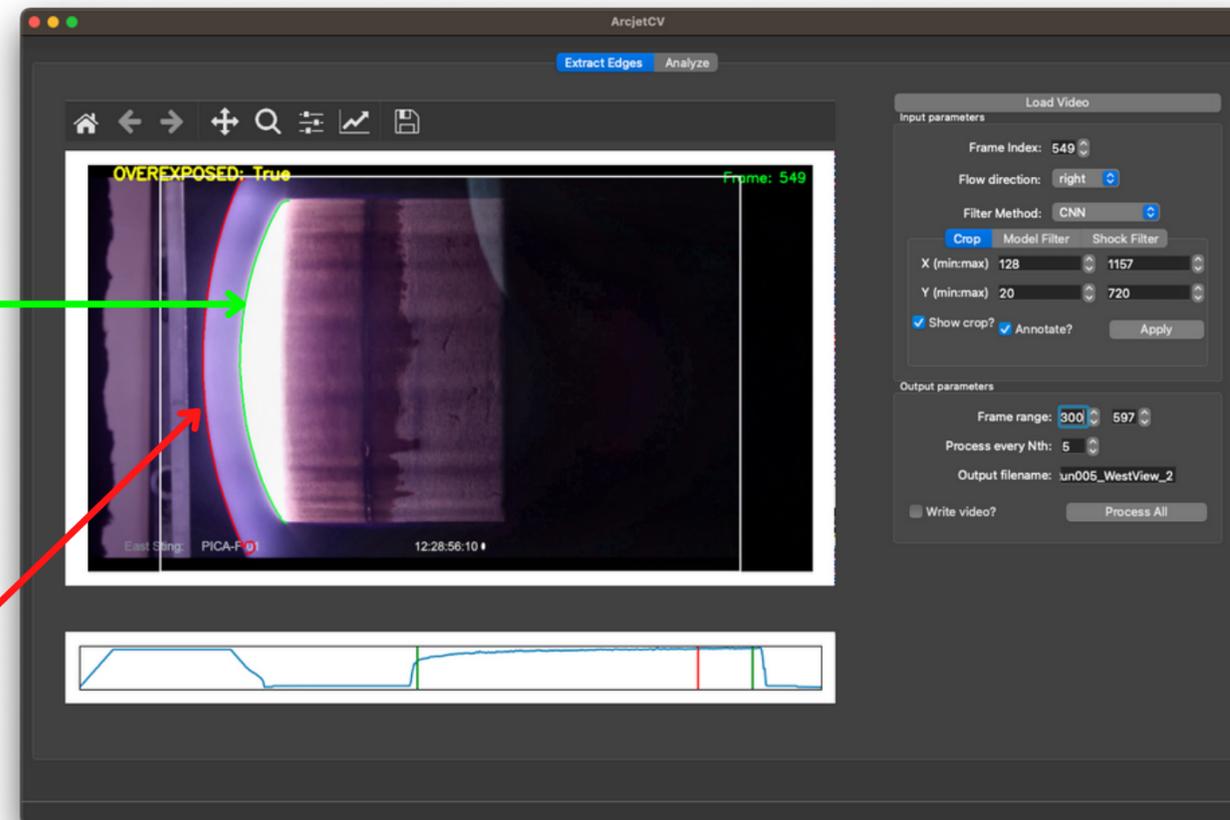
# Introduction

## Solution: arcjetCV

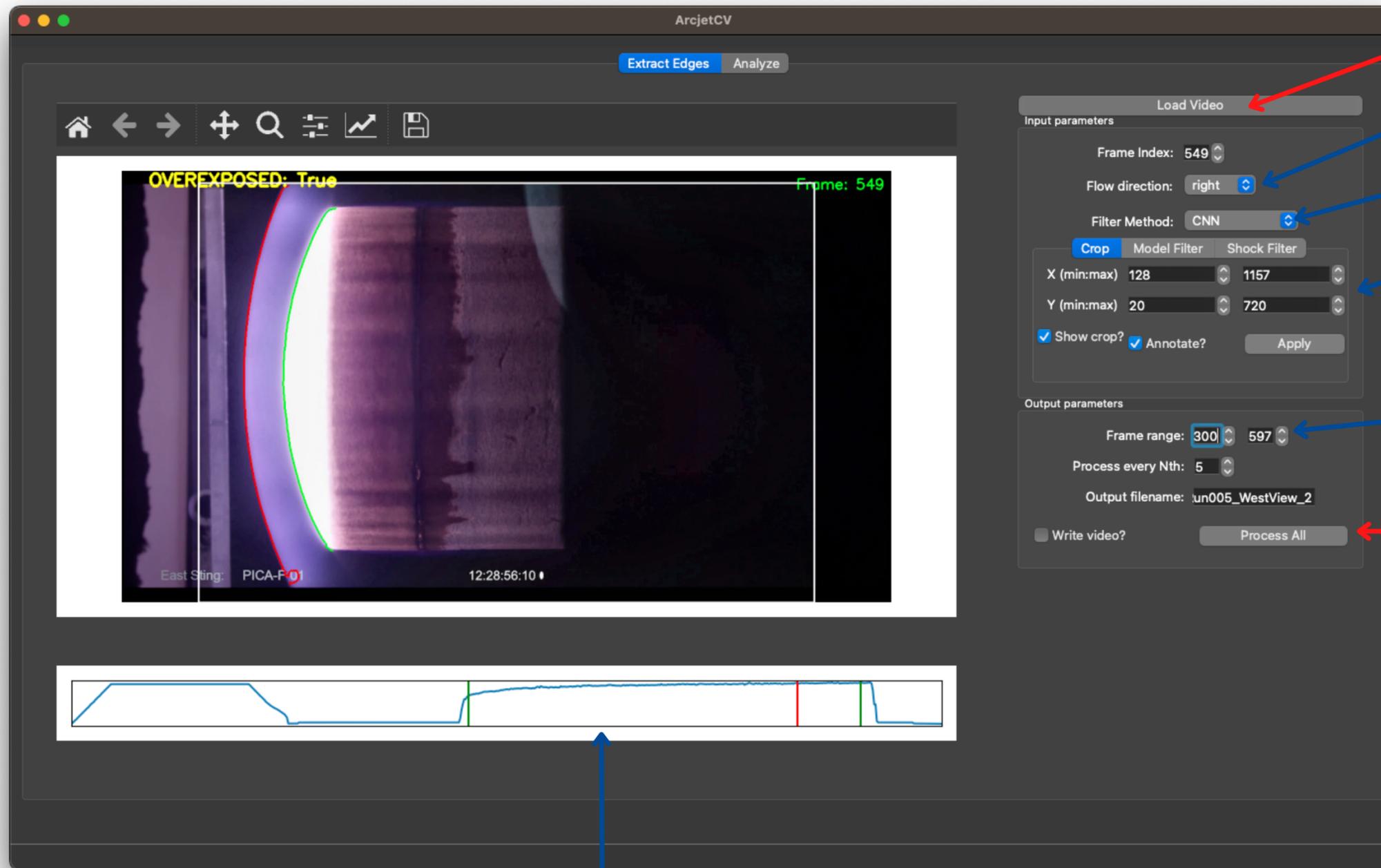
- Computer vision & machine learning automate software.
- Graphical user interface enables anyone to process video.
- Result:
  - New time-resolved recession tracking for all samples.
  - 2D and 3D verification and validation for coupled aerothermal, material codes.

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

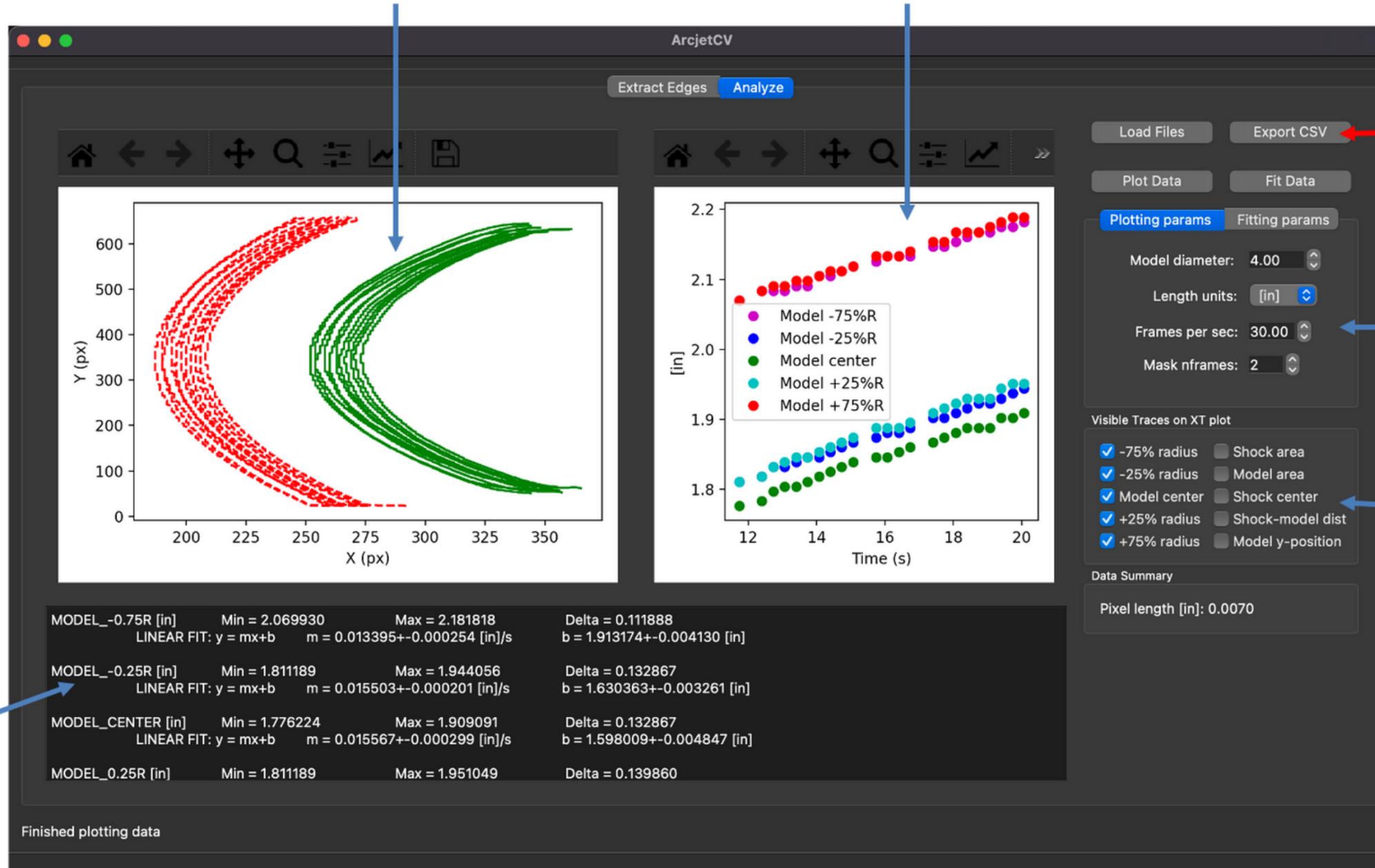
2. Process all frames

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



3. Export

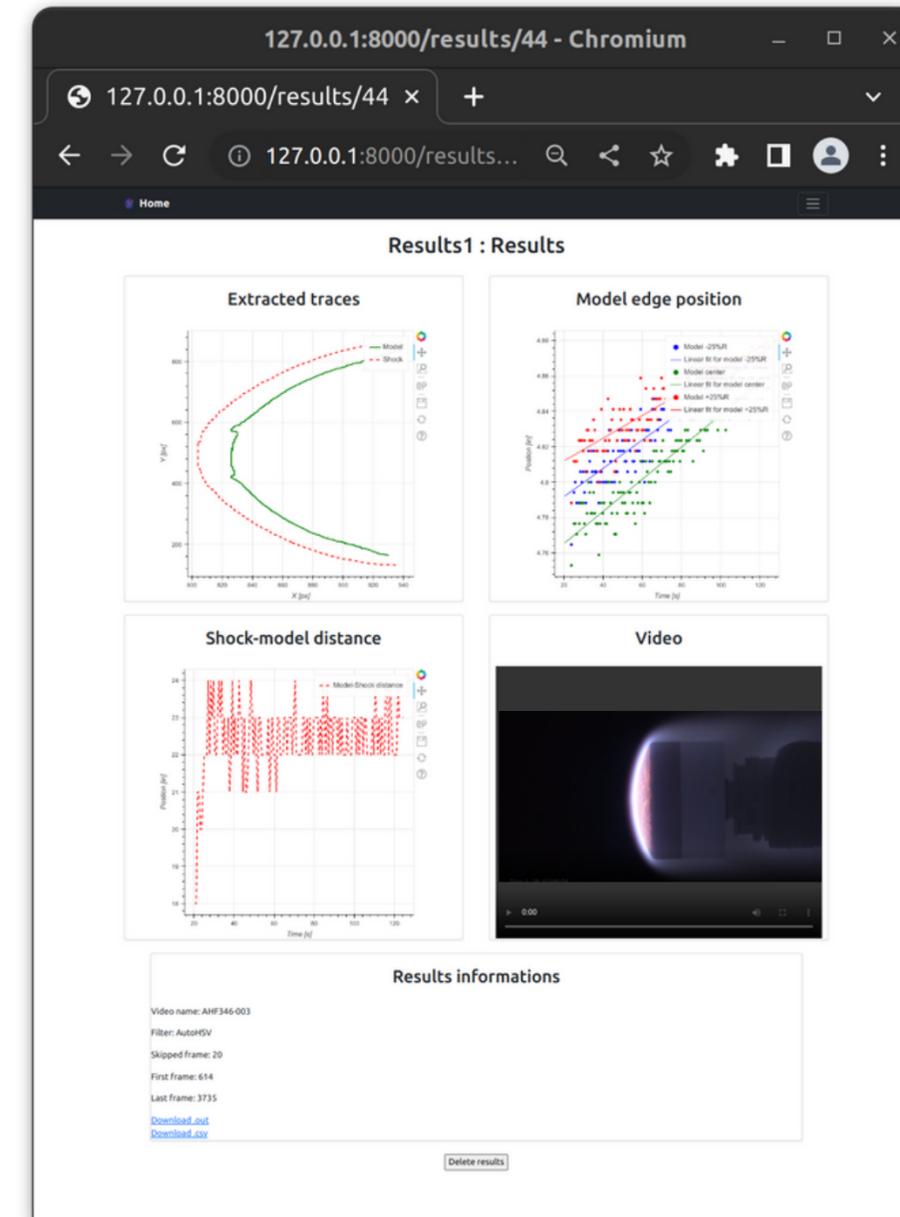
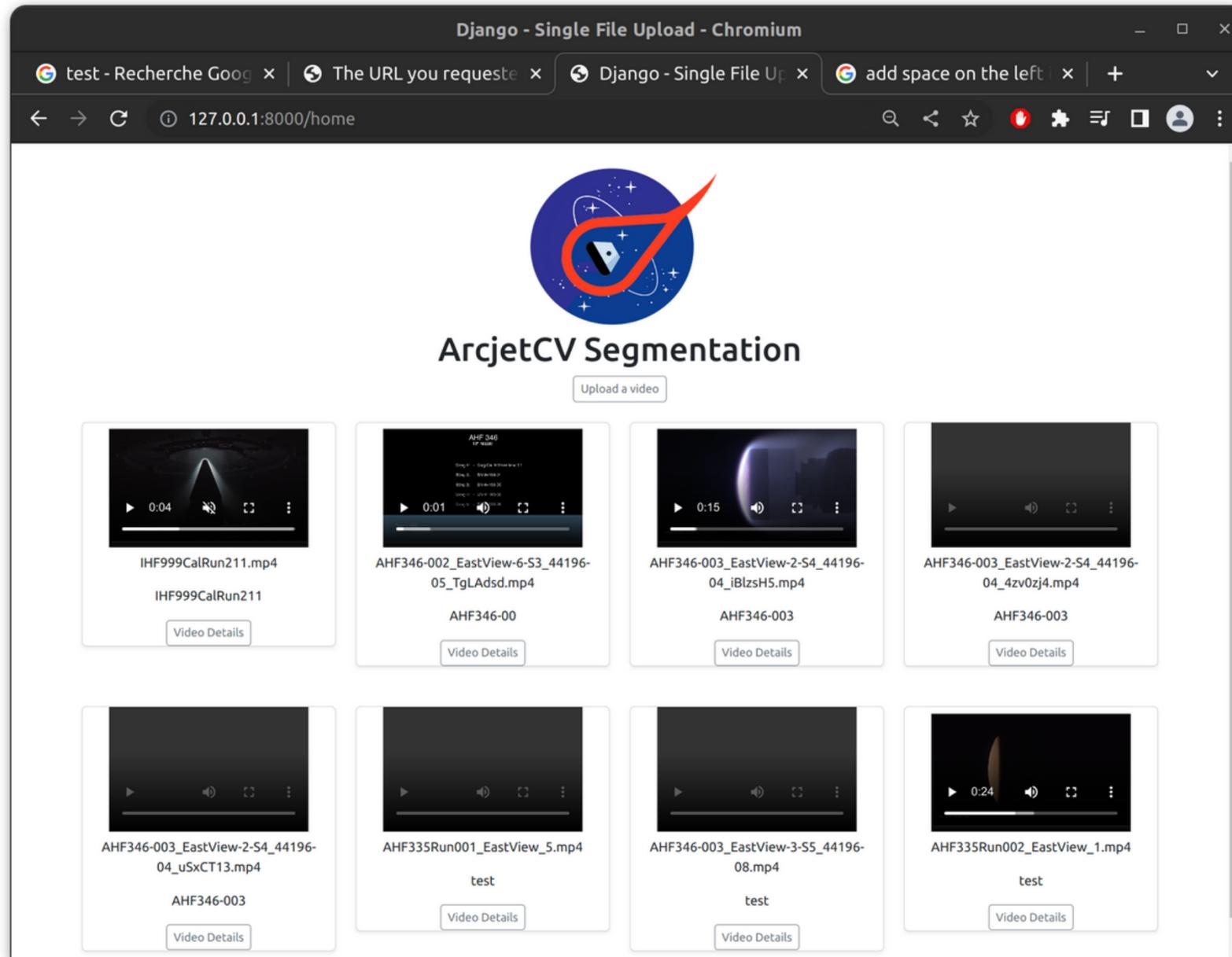
Parameters

Plot options

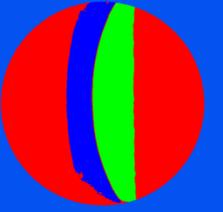
Linear Fits

# Web Browser Interface

Setup arcjetCV on a secure local server



# CNN Theory



CNNs are neural networks designed to recognize patterns in images.

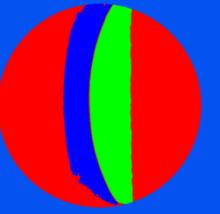
- Typically trained on manually labeled images.
- Robust performance compared to other methods.

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

- material sample
- shock
- background

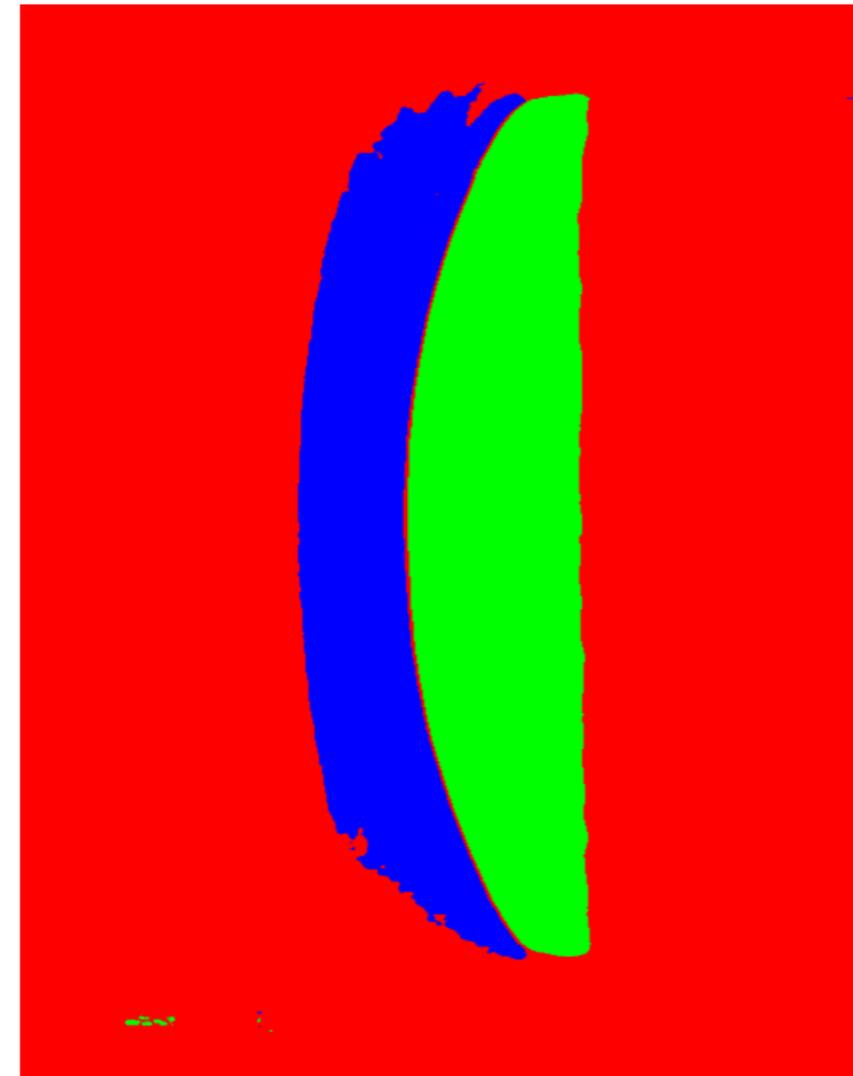
This segmentation is then passed through simple image processing methods to extract the leading edge of the sample.

# CNN Results



Input frame

→  
Convolutional  
Neural Network



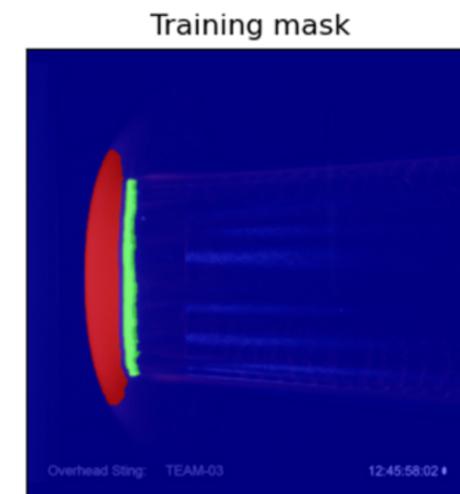
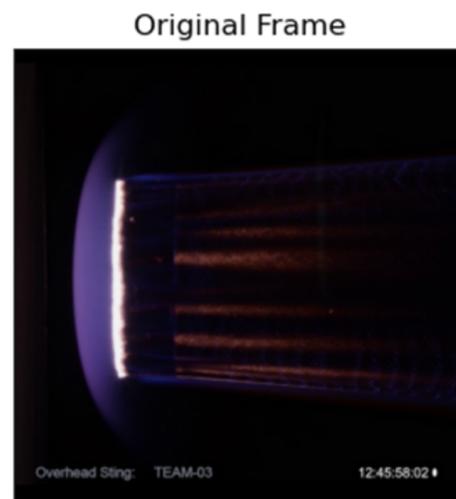
Output frame

Shock  
Sample  
Background

# CNN Training

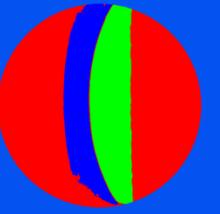
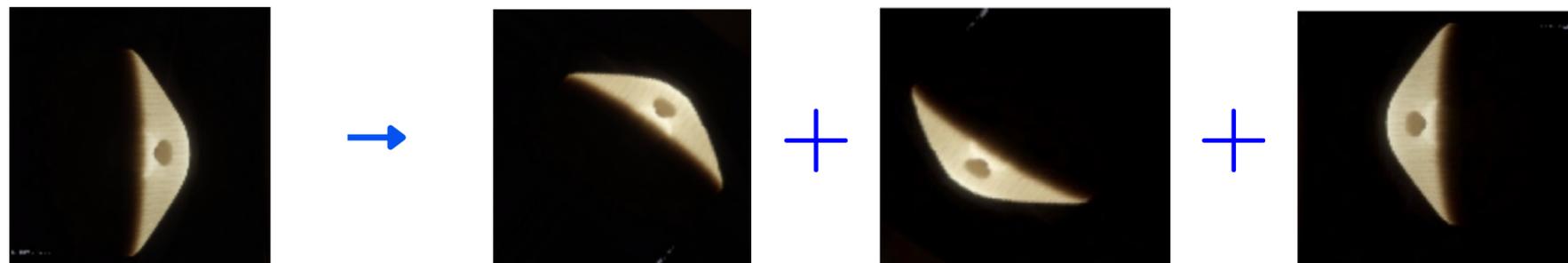
Data labelling

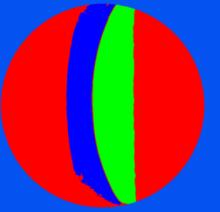
Label by hand with assistance



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

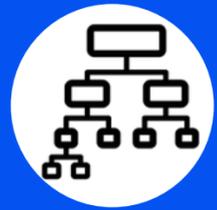
**F1 score:**

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

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.

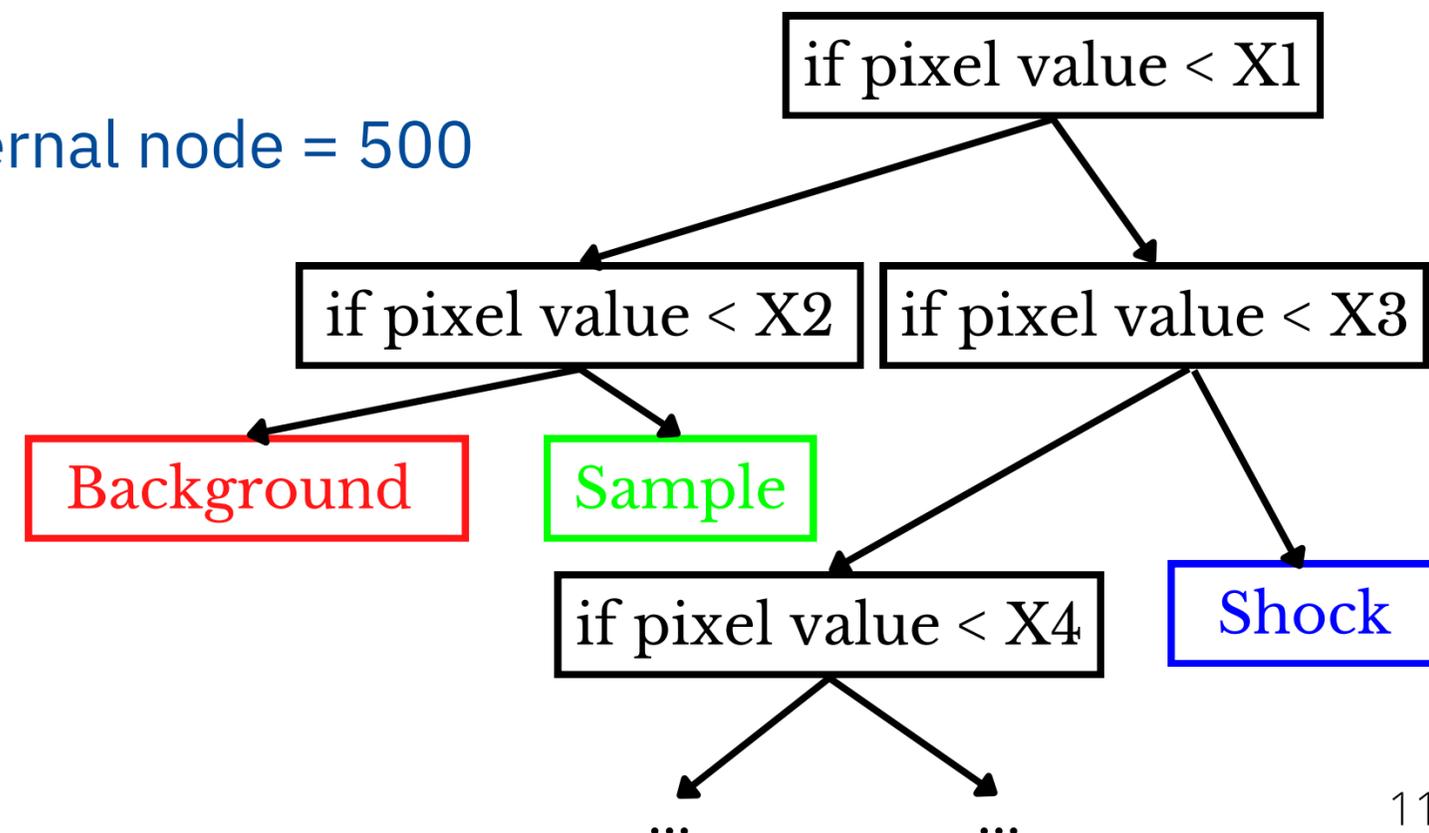
Accuracy: 0.93573

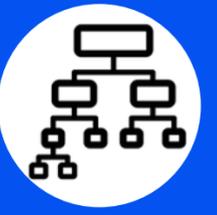
## Parameters selected:

- 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



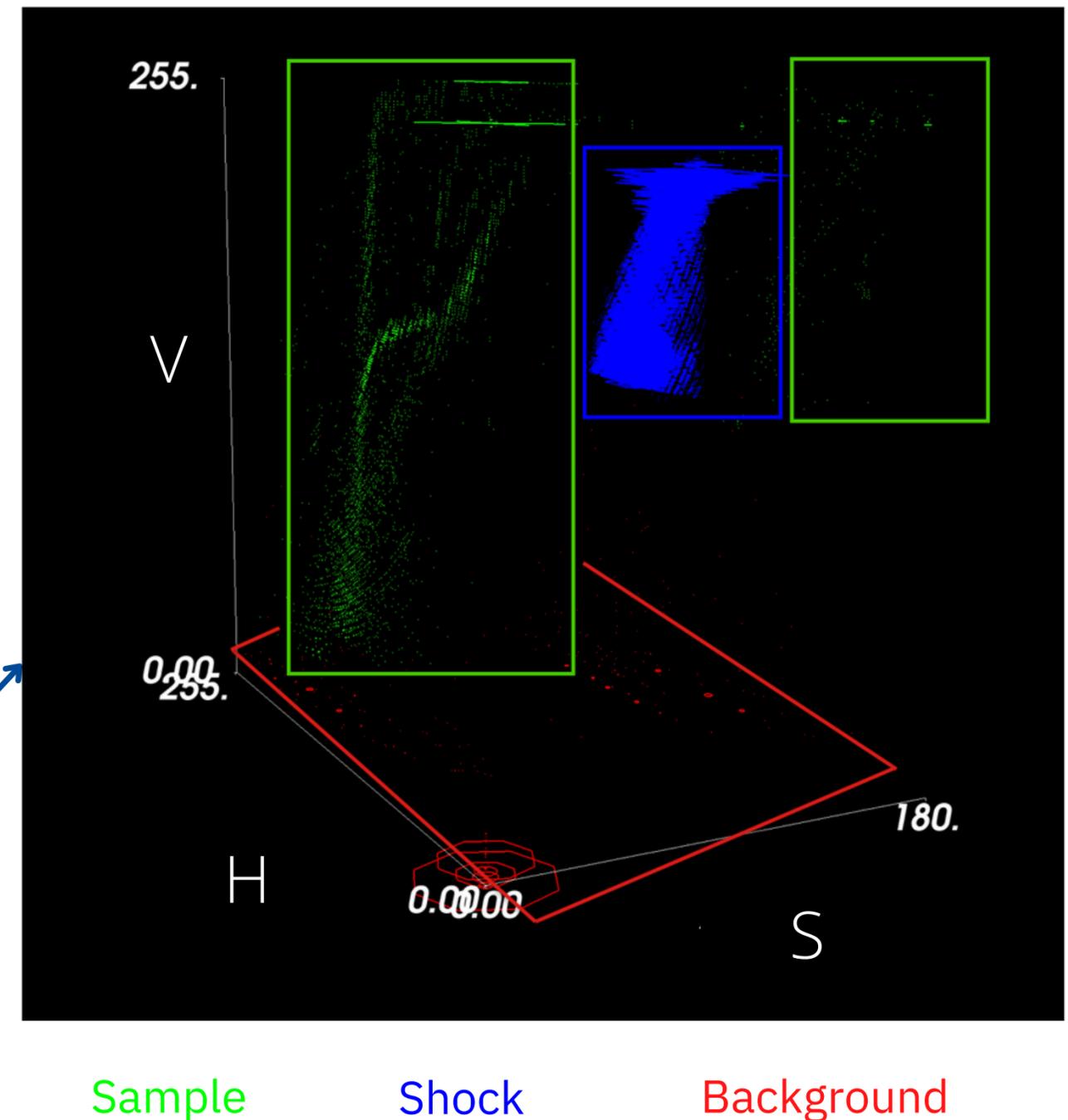


# Decision Tree Results

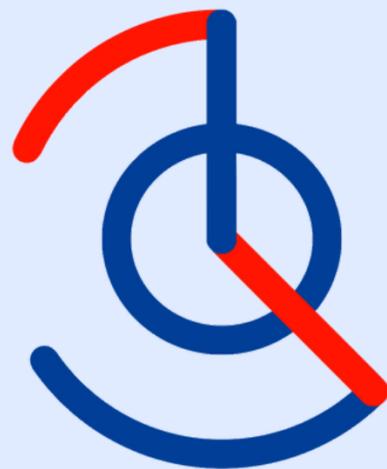
## Why a decision tree ?

| 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**





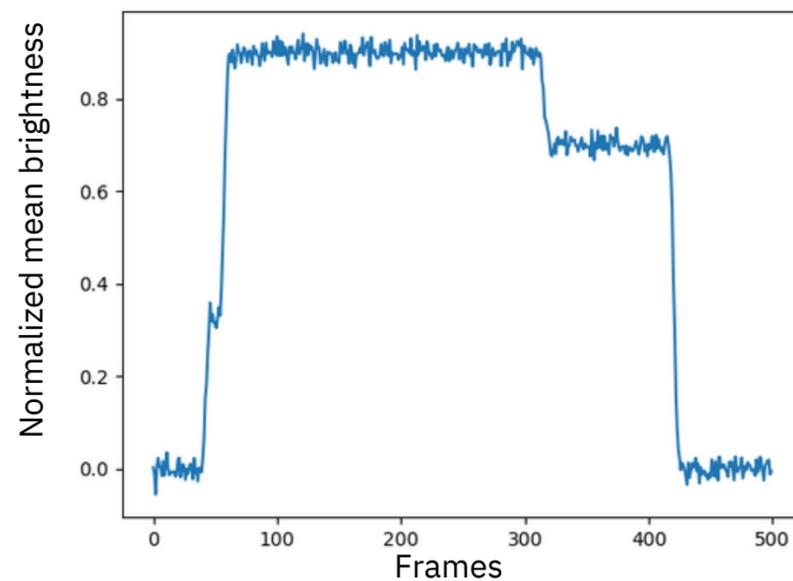
# Time Segmentation

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

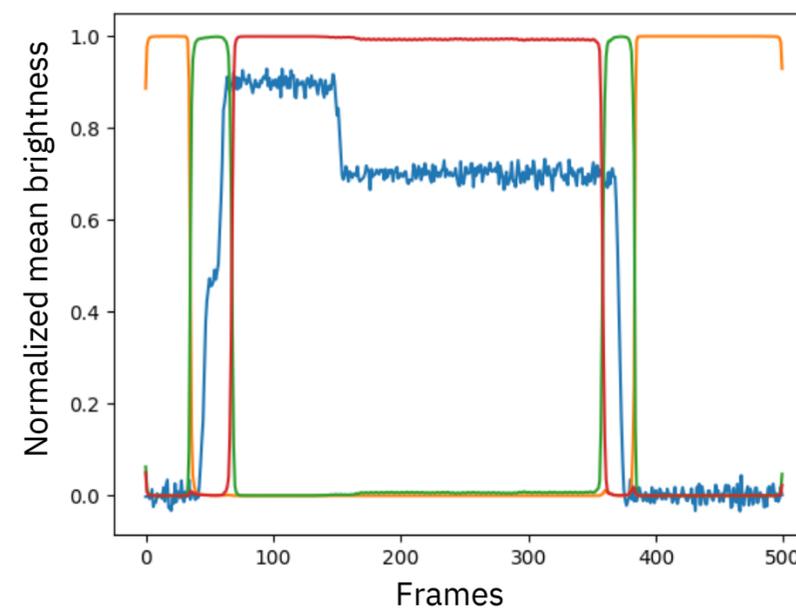
## Training

**Problem:** Not enough data for the training.

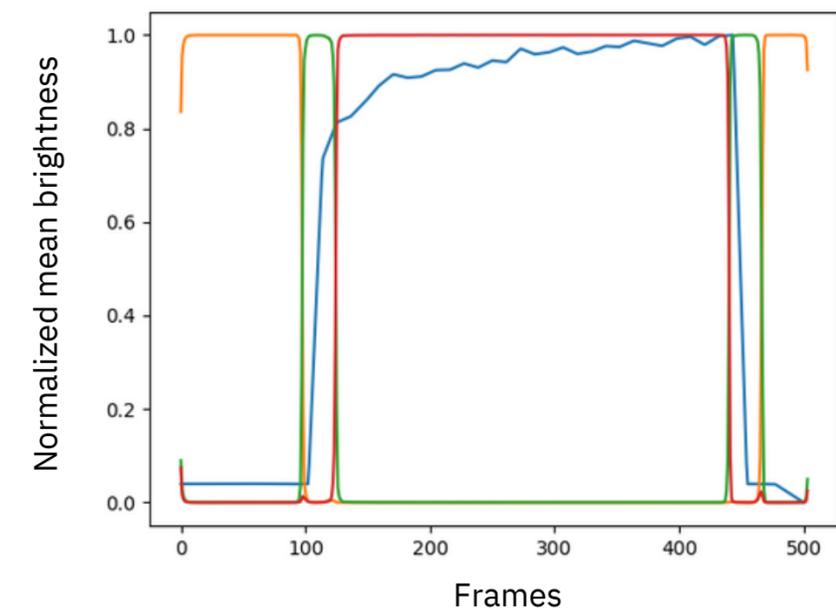
→ **Solution:** Create artificial data.



Artificial signal



Training data segmentation



Signal prediction

Sample in the frame

No sample

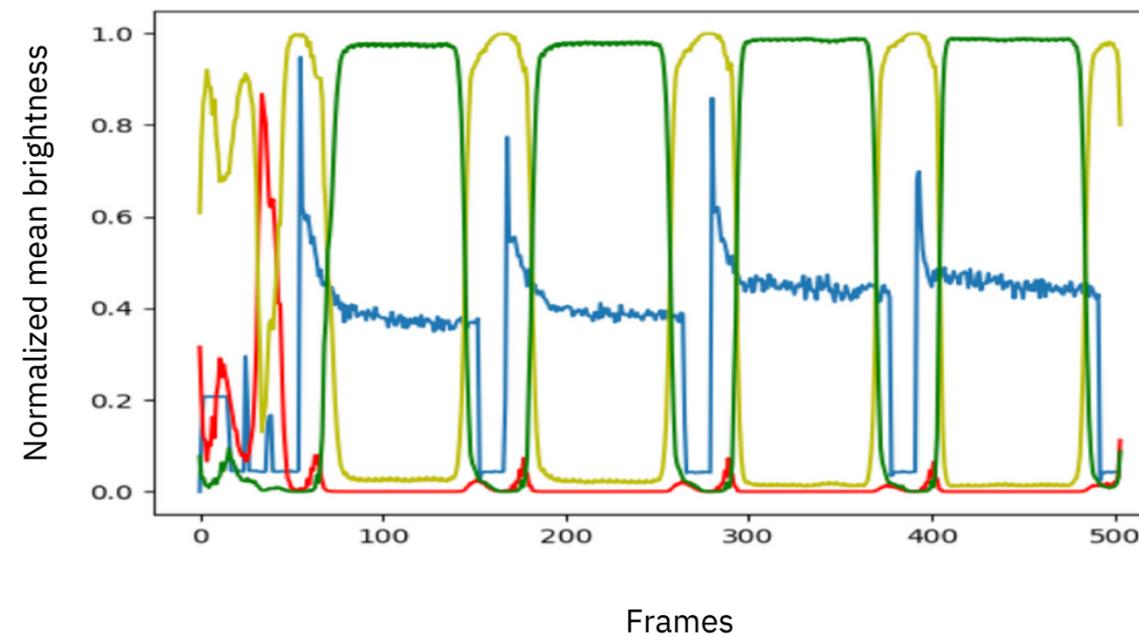
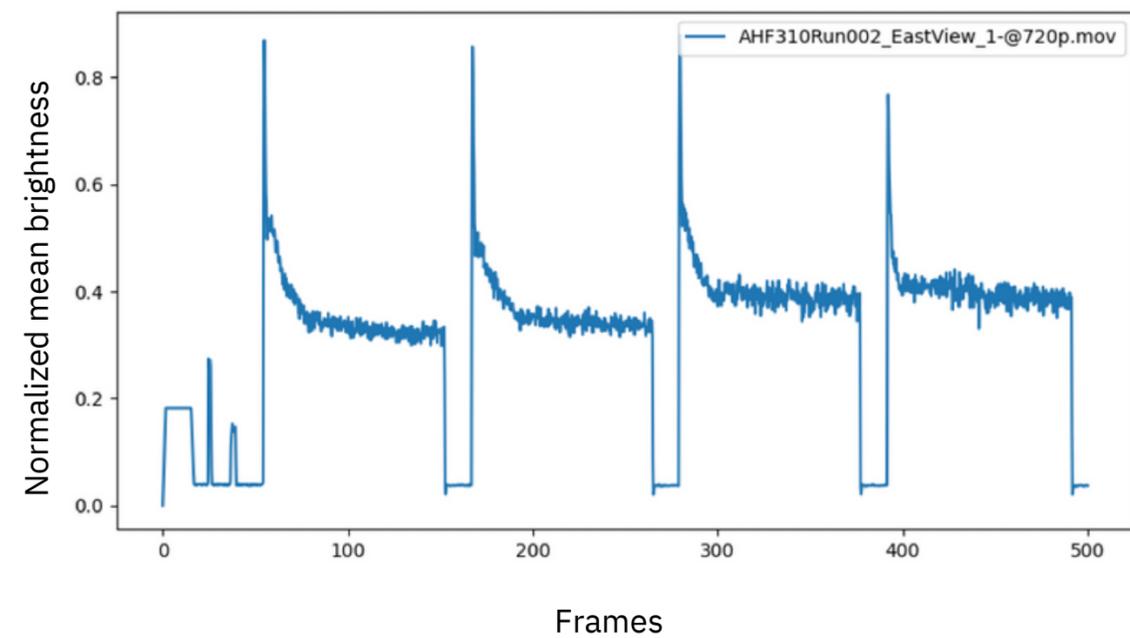
Transitional area



# 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.



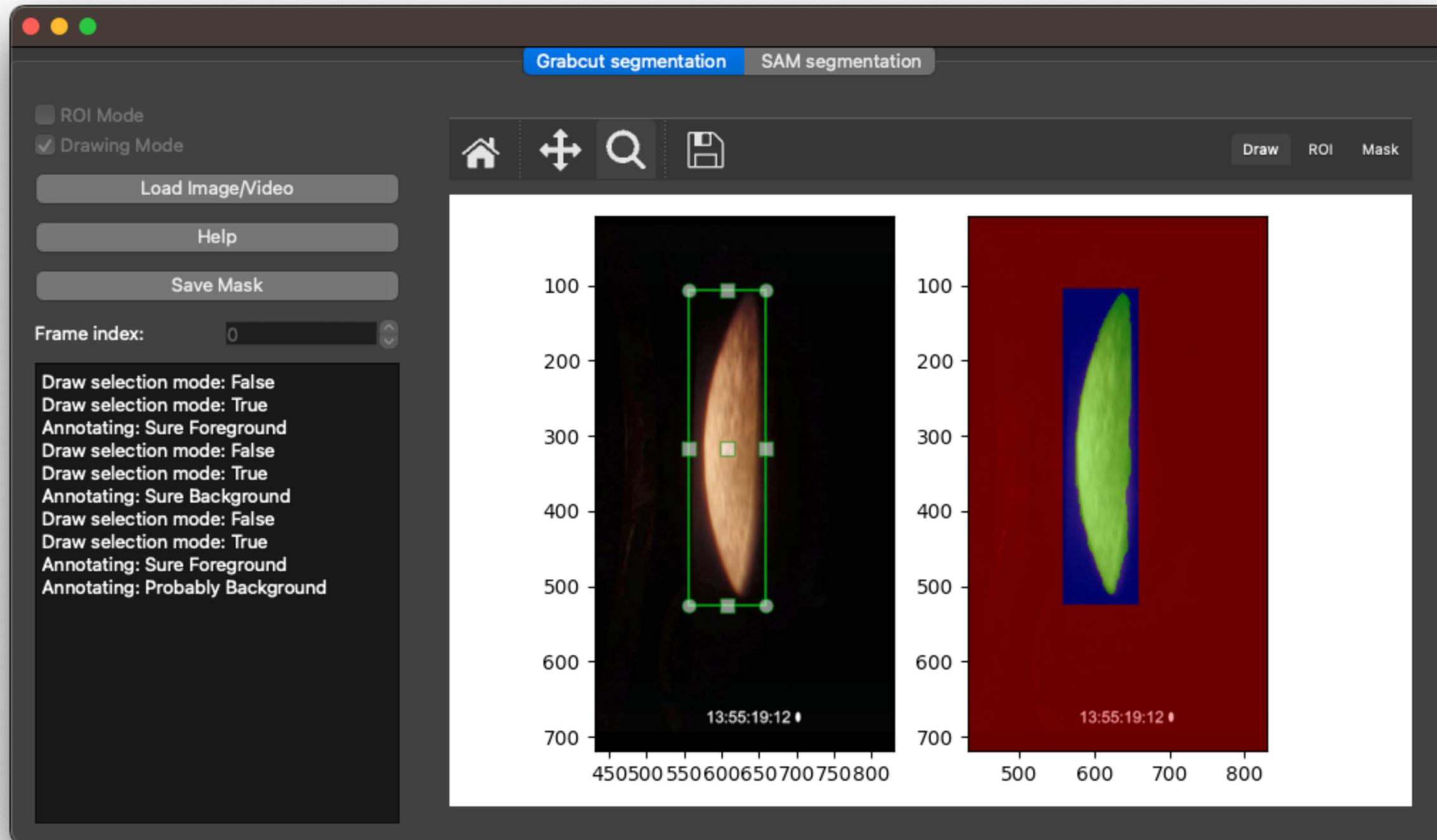
Highest fidelity segmentation for specific frames.



Create new datasets to create new ML models.

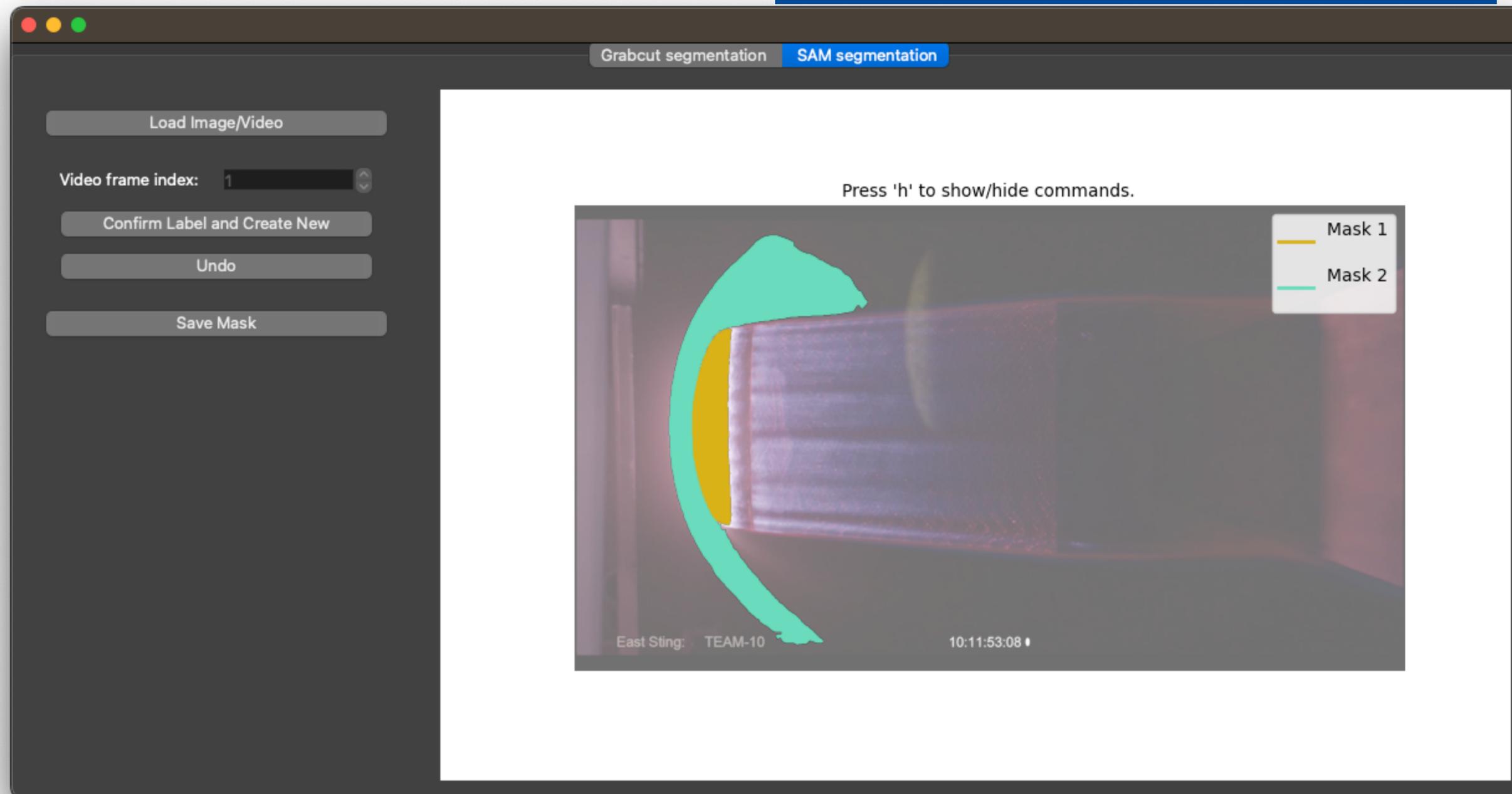
# GrabCut

Segmentation through iterative graph cuts using color probability.



# autoSAM

Segmentation using the Segment Anything Model (SAM) of META



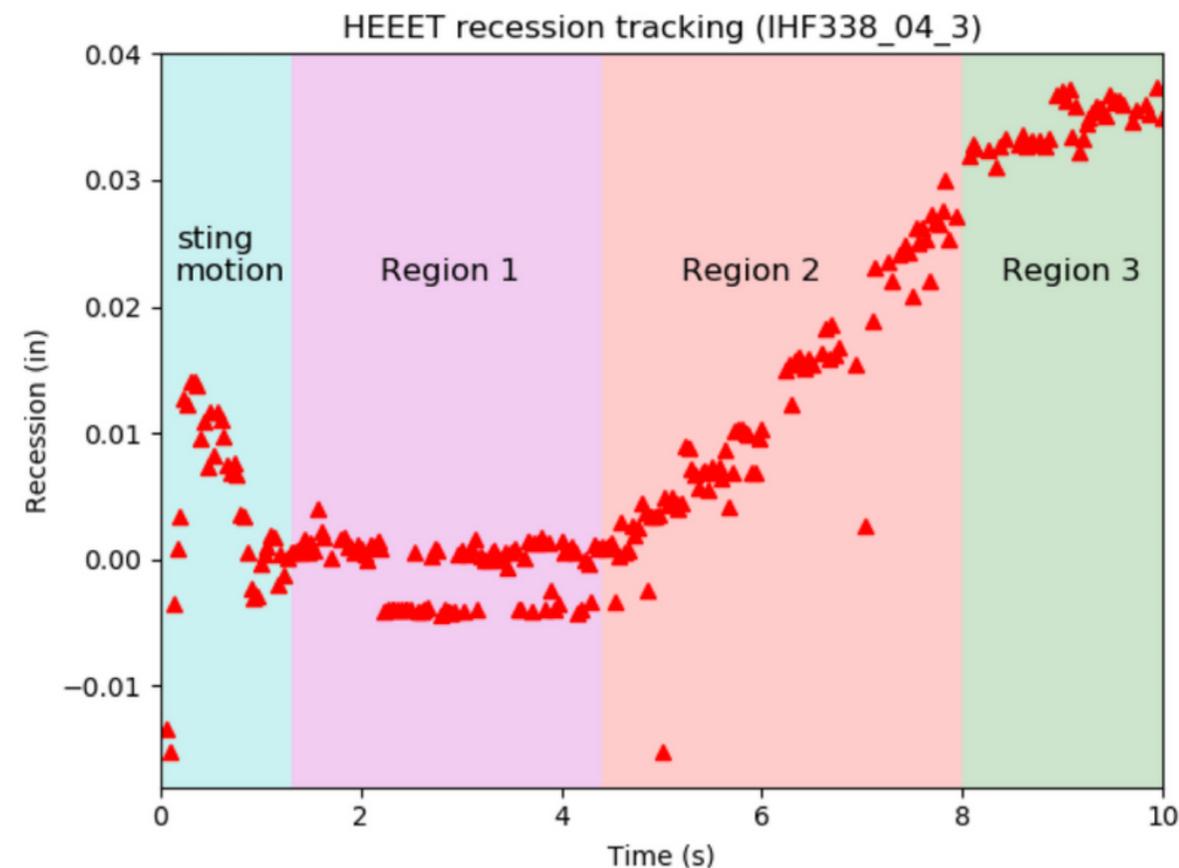
Based on the Segment Anything GUI co developed with Federico Semeraro.

# 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

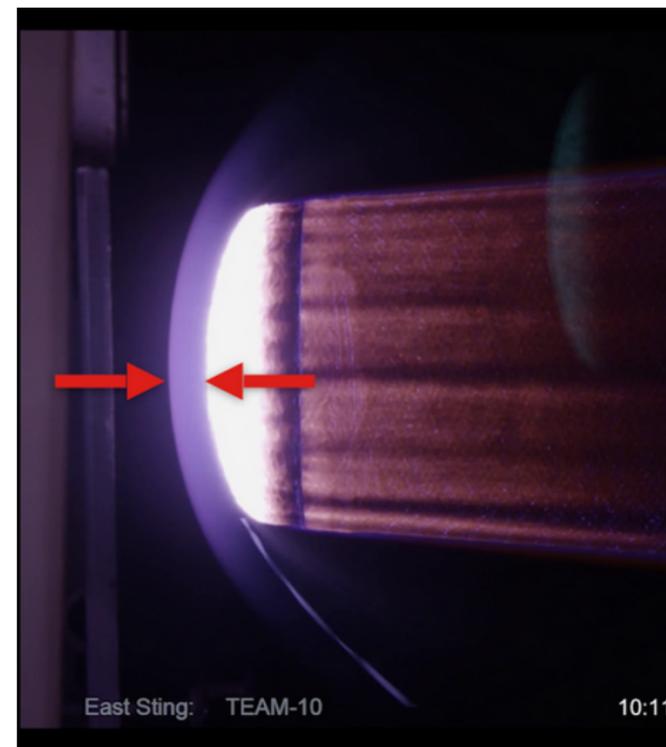
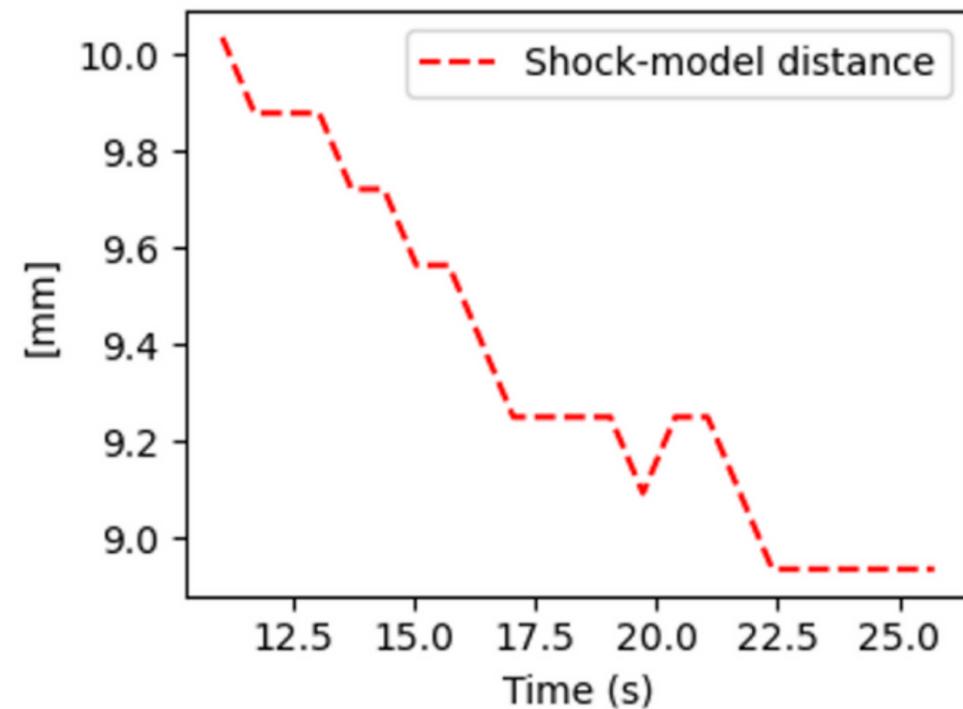


**NEW PHENOMENON! NOT POSSIBLE TO OBSERVE WITHOUT ARCJETCV**

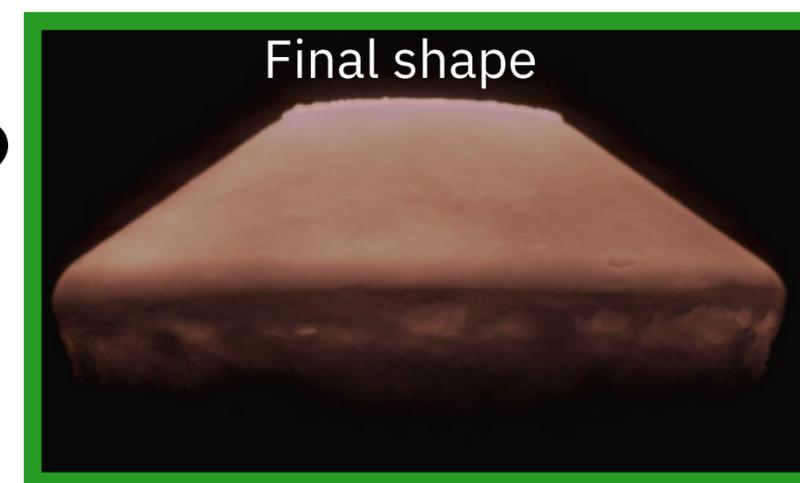
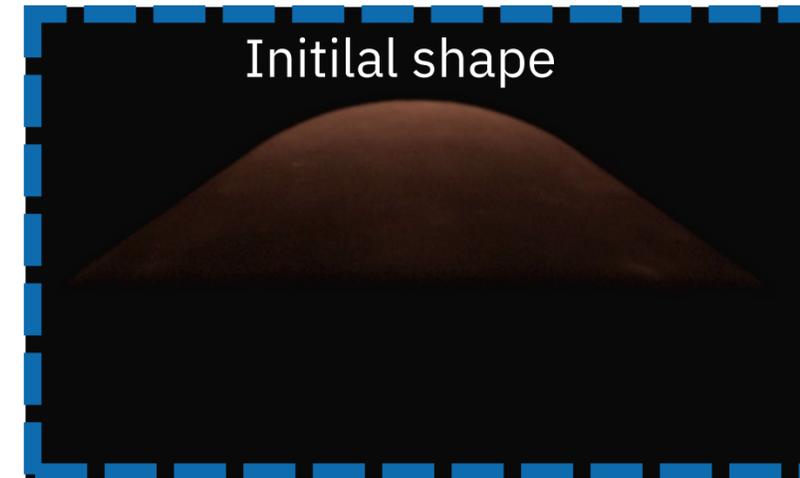
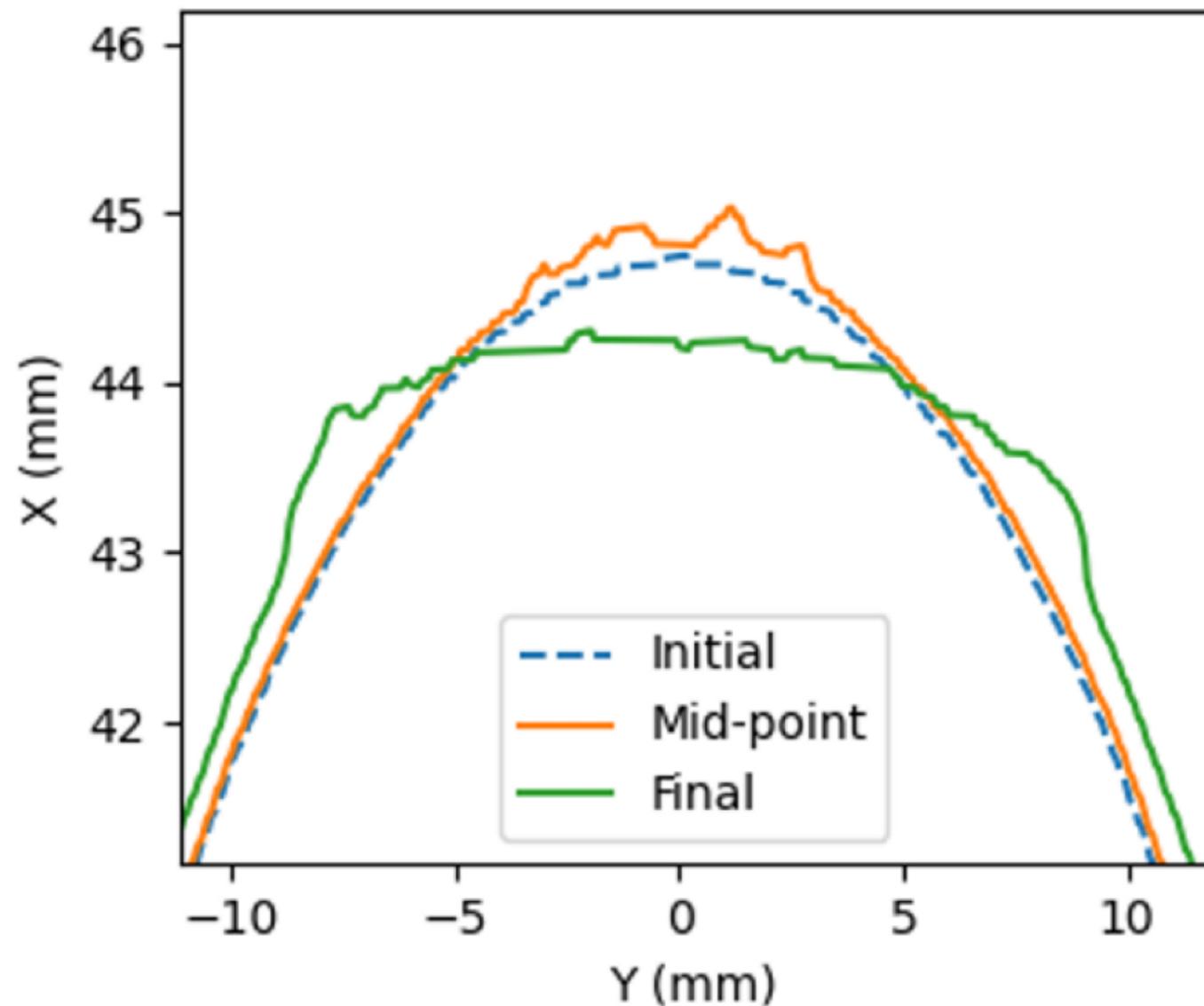
# Shock standoff

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

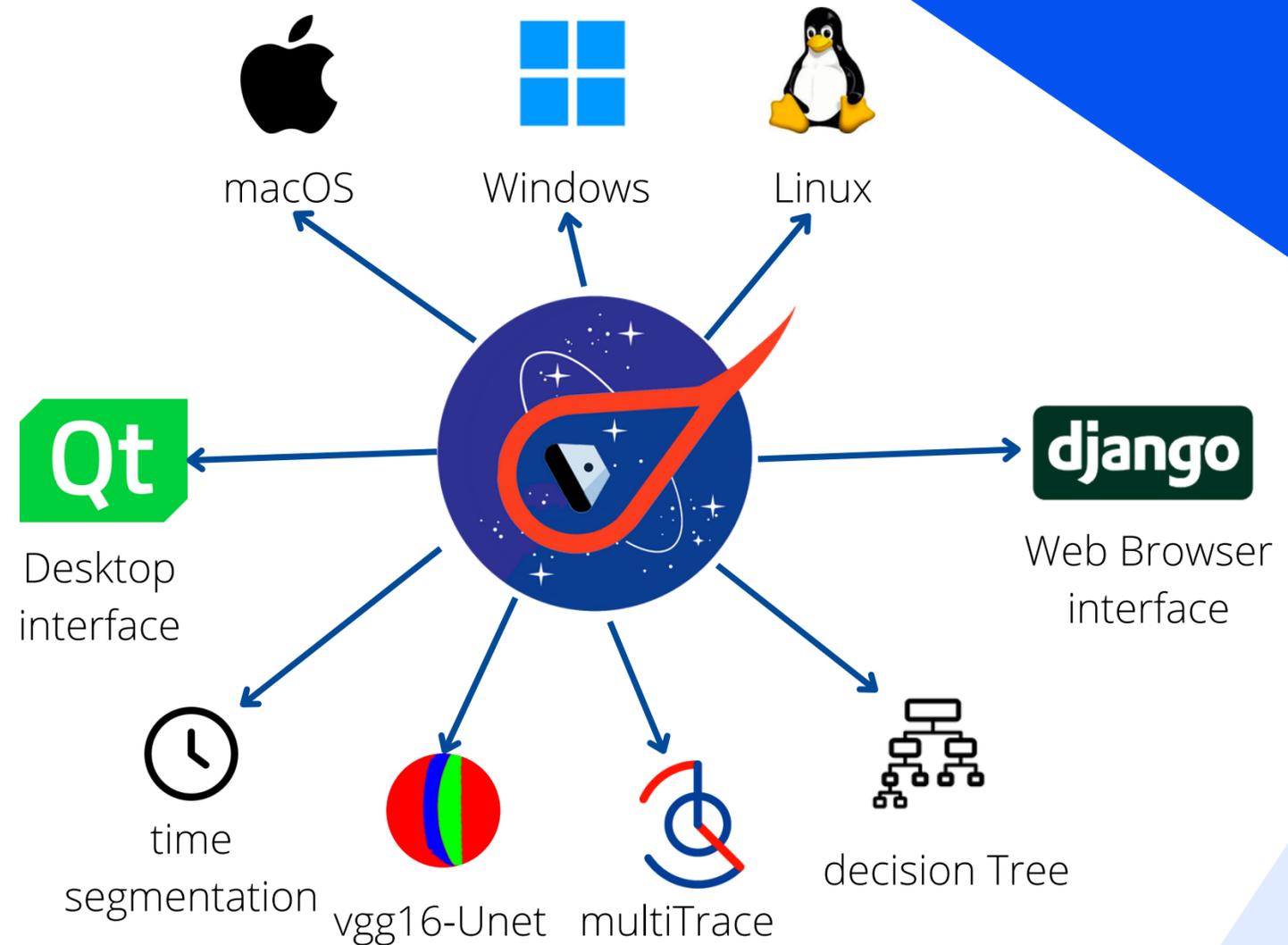
2 interfaces

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**

