FRONTIERS IN CHEMISTRY
Master's Program

Anes SADAOUI

Internship oral defense

July 1st 2025

Advanced analysis of pitting corrosion using optical and electrochemical techniques enhanced by AI

February 3rd - August 1st

Supervised by Dr. Viacheslav SHKIRSKIY

Key words :
Corrosion, Computer vision, Deep learning, Data analysis , Microscopy

2024-2025

FRONTIERS IN CHEMISTRY

Master's Program

6 months Internship

ITODYS

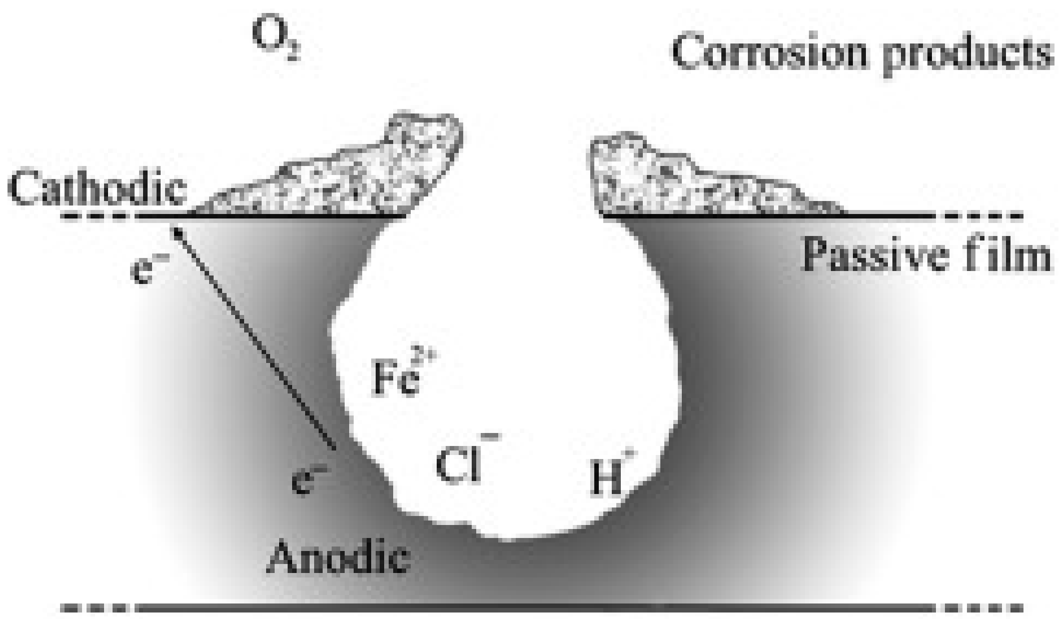
PIXEL


Lavoisier Building - Université Paris Cité

PITTING CORROSION

"Pitting corrosion is characterized by a local formation of pin-sized holes over a small area on the surface of the metal reinforcement"

Corrosion captured on a bridge



Schematic representation of pitting corrosion

Pitting corrosion on steel element

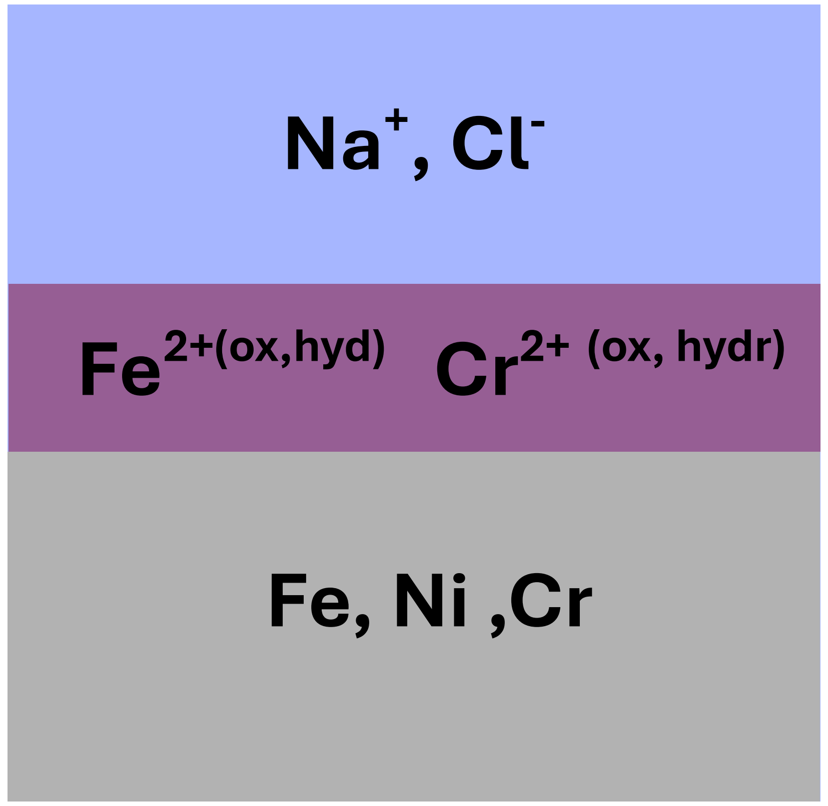
Occurs at random locations → **Unpredictable**

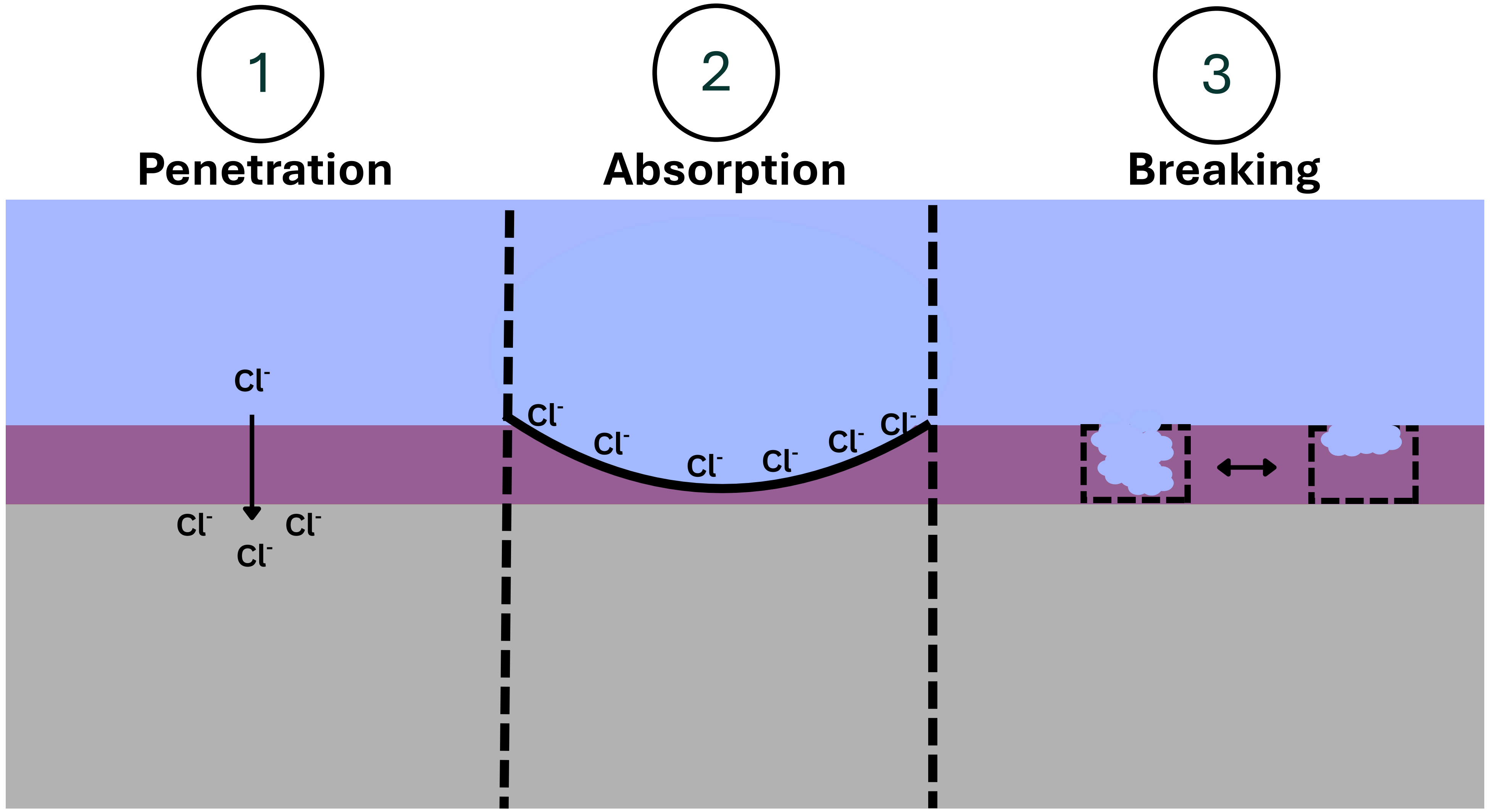
Tiny and covered by dust → **Unnoticeable**

→ **2.5 Trillion $ of loss every year**

Mahmoodian, M. (2018). Introduction. Dans Elsevier eBooks (p. 1-48).

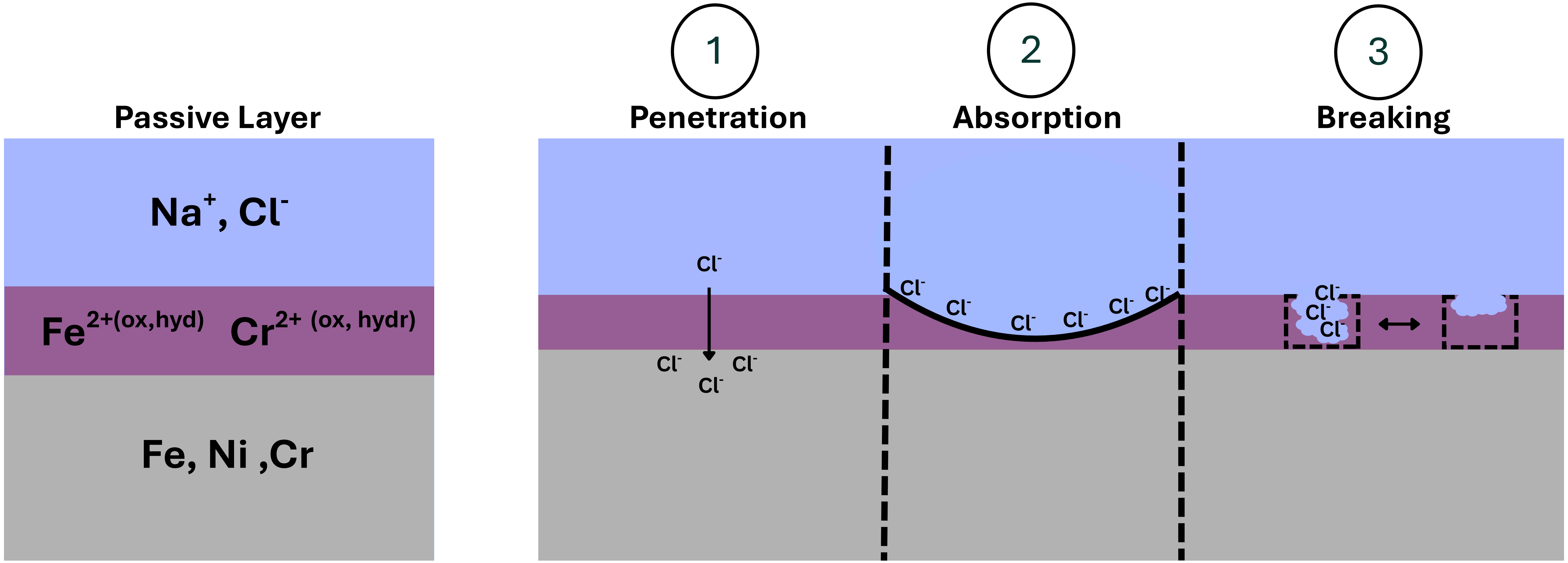
UNDERLYING MECHANISM





Frankel, G. S. (1998). Journal Of The Electrochemical Society, 145(8), 2970a-22970

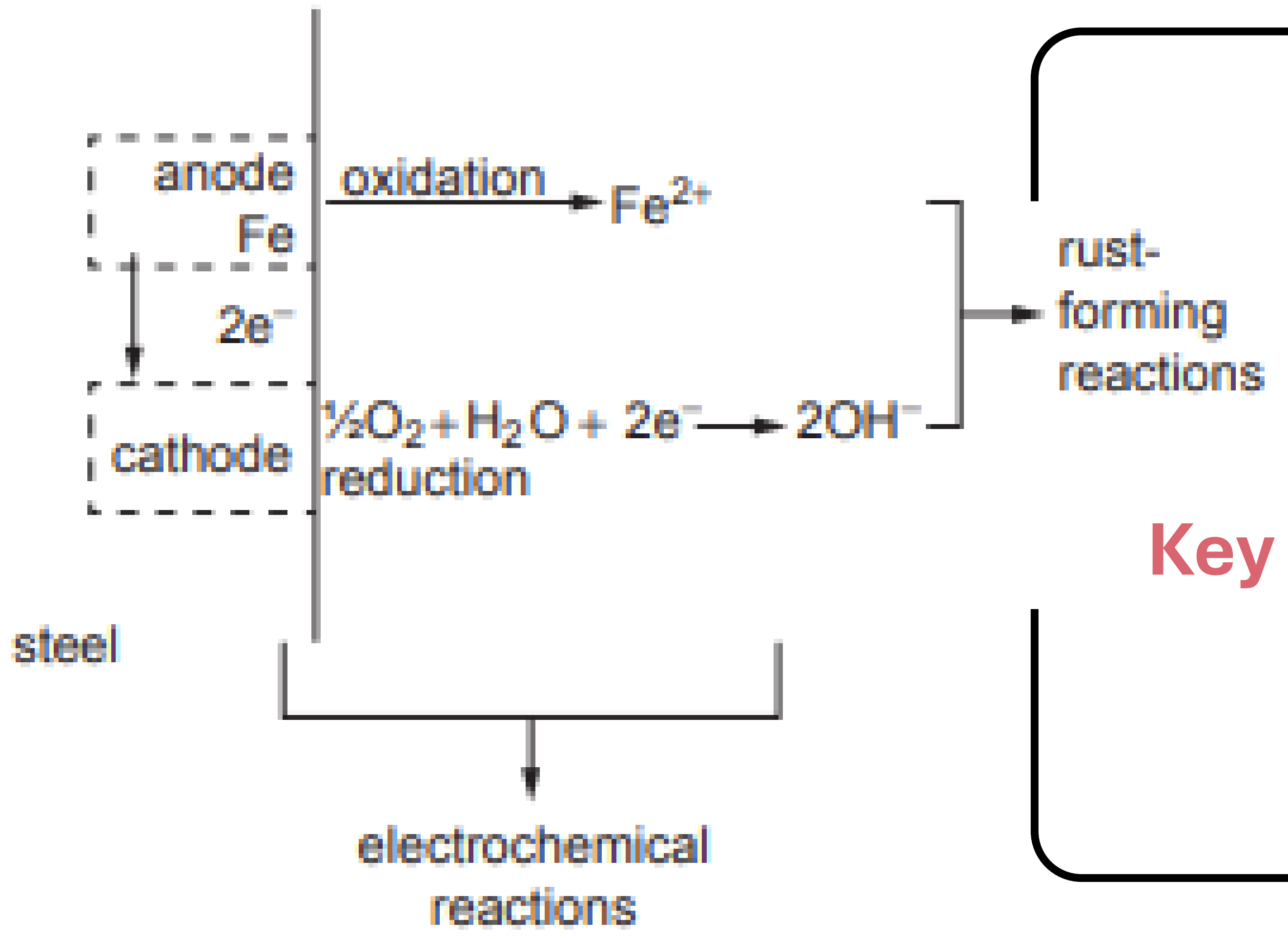
UNDERLYING MECHANISM



Breaking is highly influenced by chloride concentration

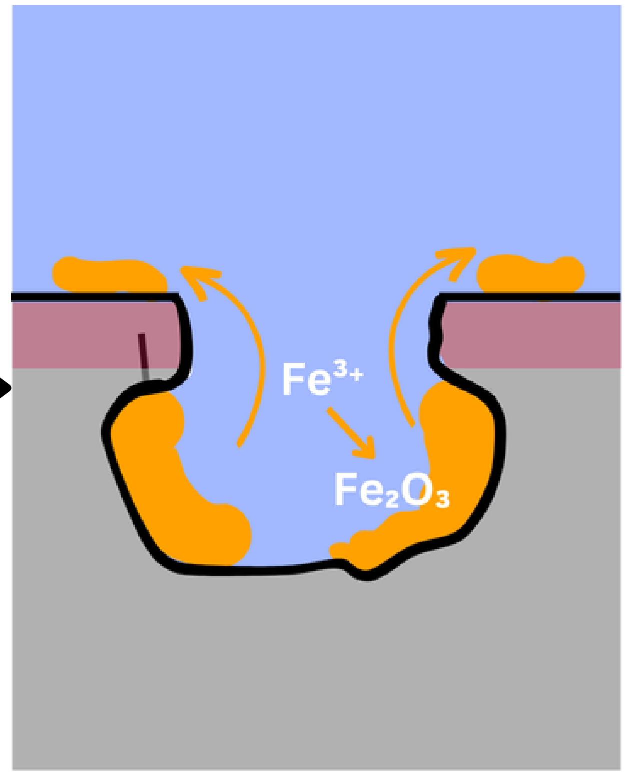
Frankel, G. S. (1998). Journal Of The Electrochemical Society, 145(8), 2970a-22970

UNDERLYING MECHANISM



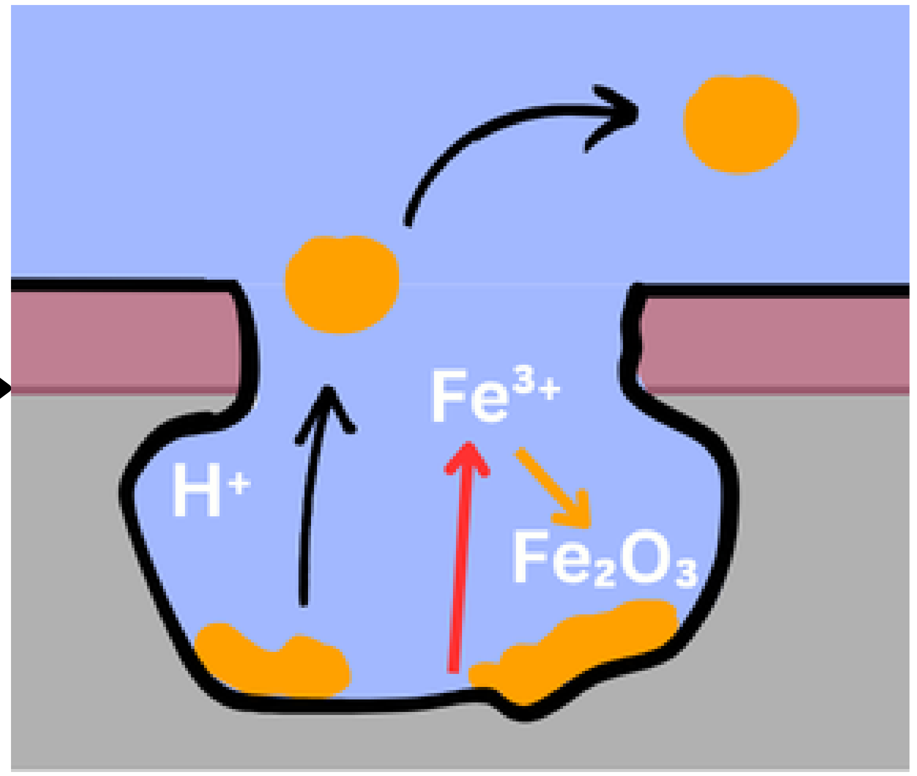
Schematic representation of the electrochemical reactions of steel corrosion.

Deposition in the pit



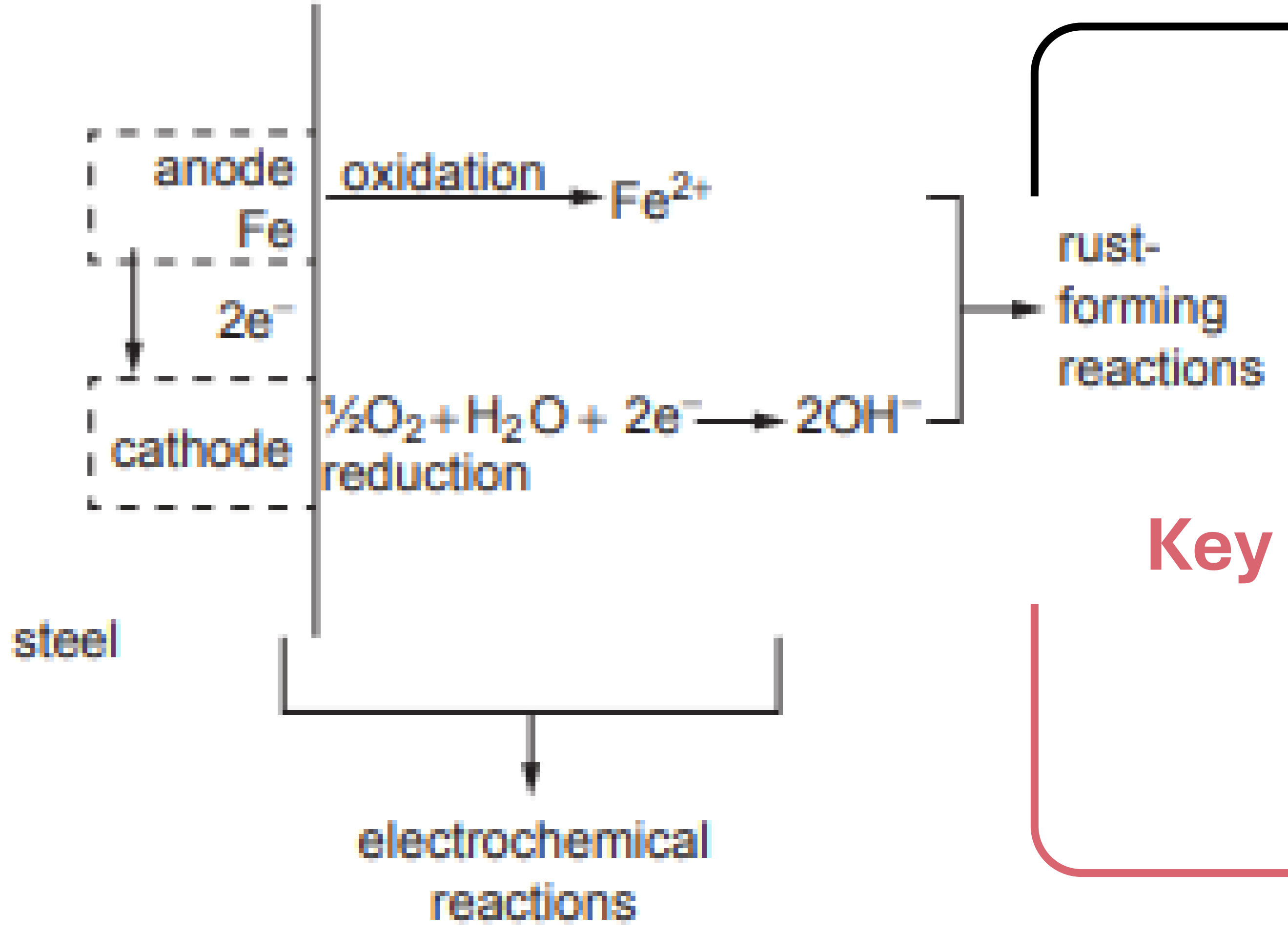
Key parameters to pit growth

Ejection



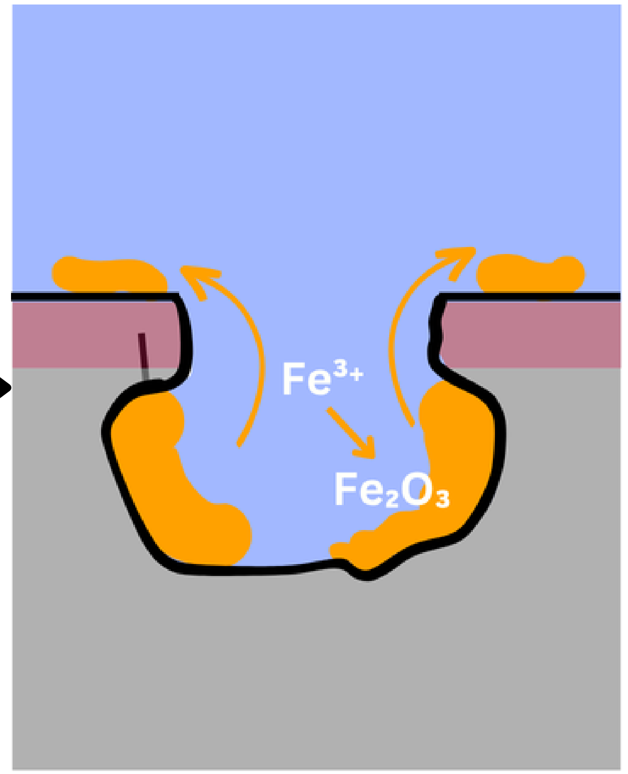
A. Makogon, F. Kanoufi and V. Shkirskiy, Poster presented at scientific meeting, 2023,
Frankel, G. S. (1998). Journal Of The Electrochemical Society, 145(8), 2970a-22970. https://doi.org/10.1149/1.1838748

UNDERLYING MECHANISM



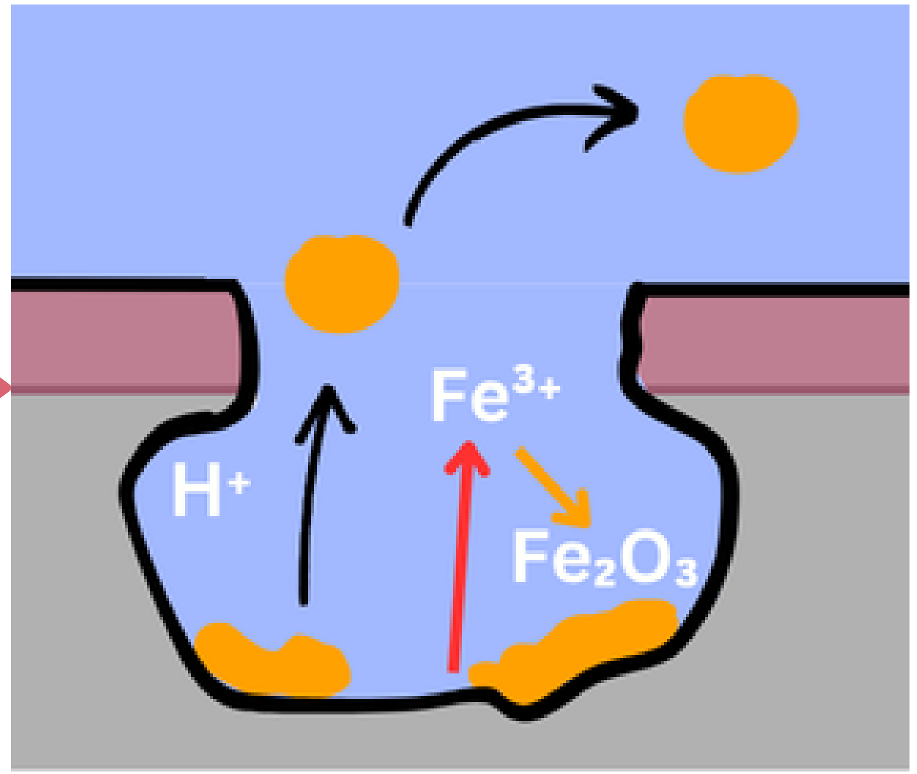
Schematic representation of the electrochemical reactions of steel corrosion.

Deposition in the pit



Key parameters to pit growth

Ejection



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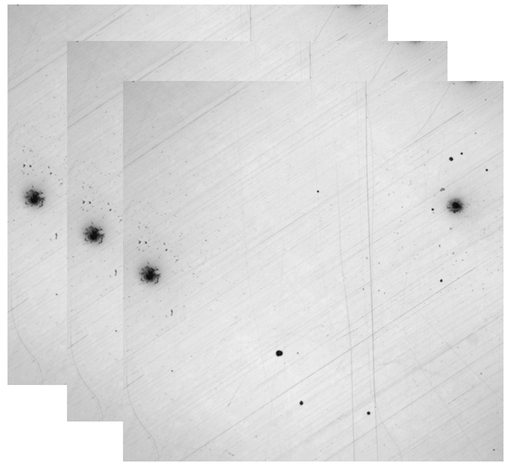
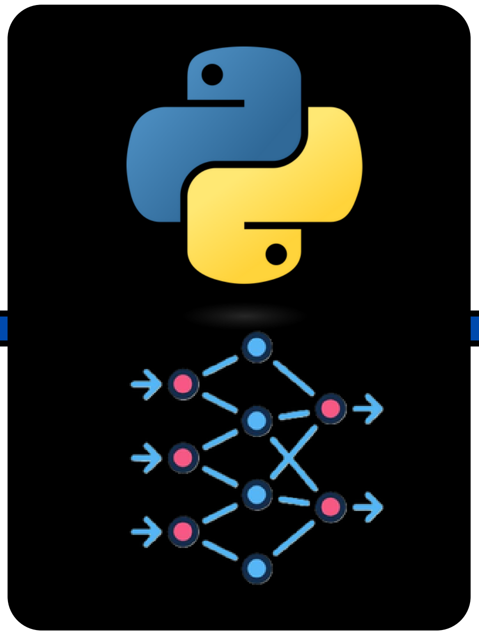
Frankel, G. S. (1998). Journal Of The Electrochemical Society, 145(8), 2970a-22970. https://doi.org/10.1149/1.1838748

PROBLEMATIC

Describing corrosion particle dynamic during ejection using computer vision and Deep learning tools

Work flow





Object detection

- Coordinates
- Velocity
- Size of ejected objects

...

Patterns

DATASET

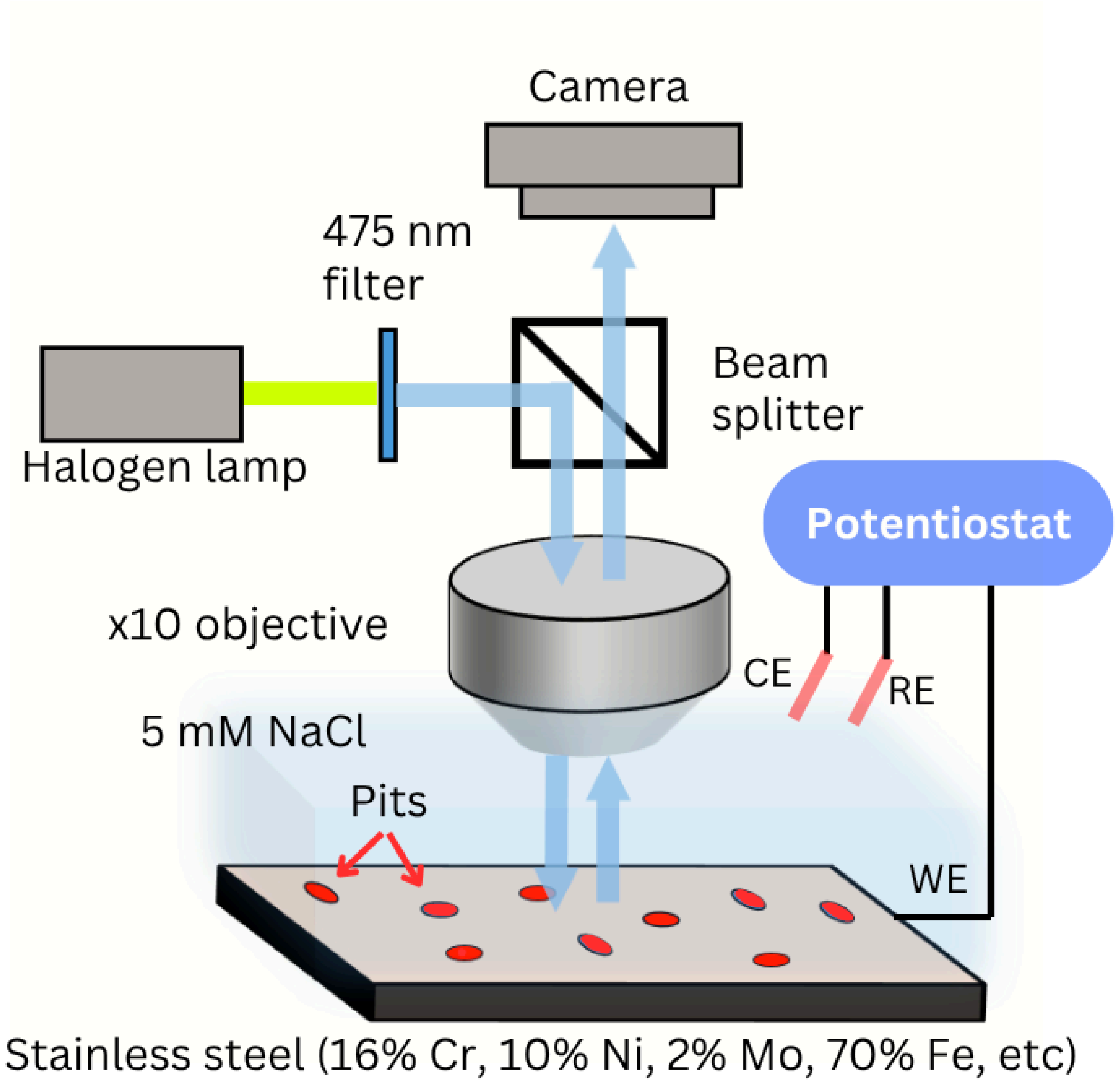
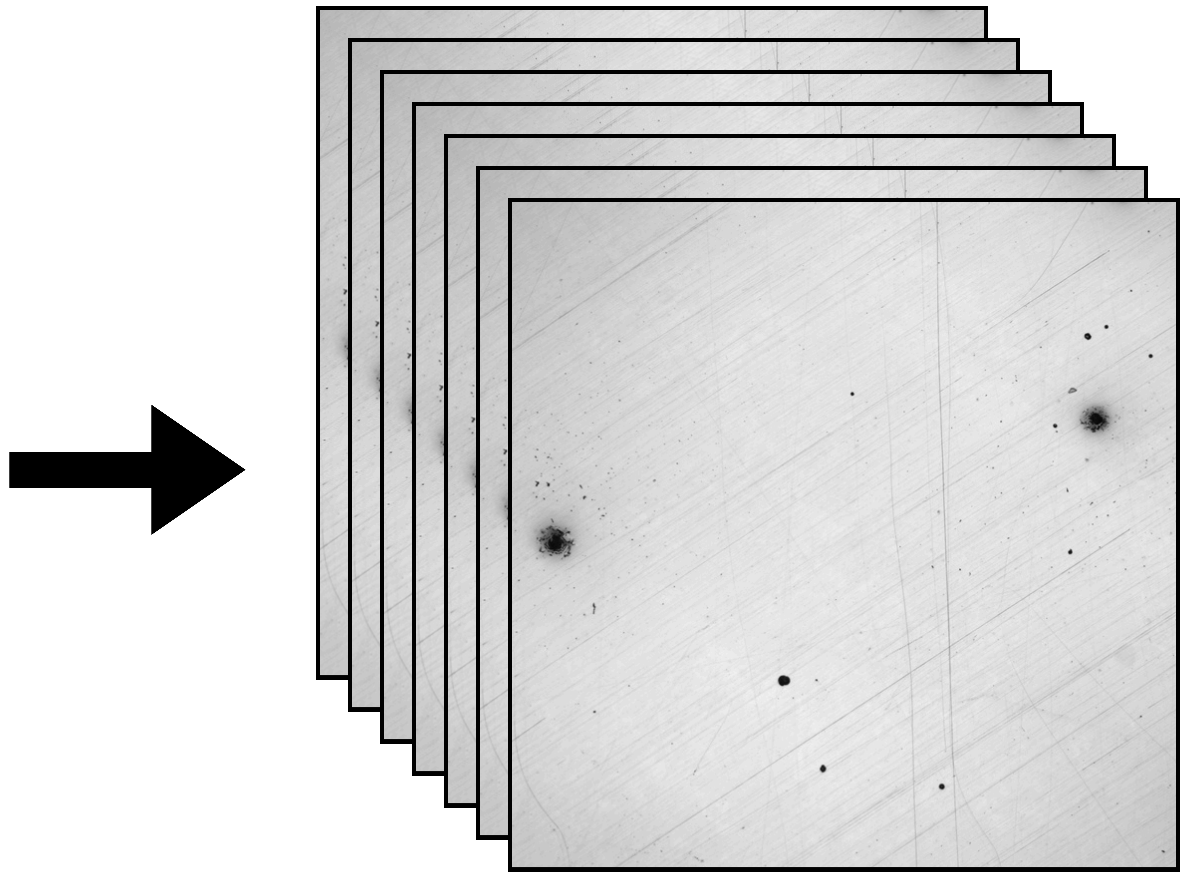


Image acquisition setup scheme



7 videos :

[NaCl]:
5mM, 10mM (x2) , 30 mM (x2), 50 mM, 100 mM

Size = 2248x2252 pixels

1 pixel = 480x480 nm

Rate = 15 Hz

Makogon, A., & SHKIRSKIY, S. (2025). Zenodo

IMAGE PROCESSING AND TRACKING

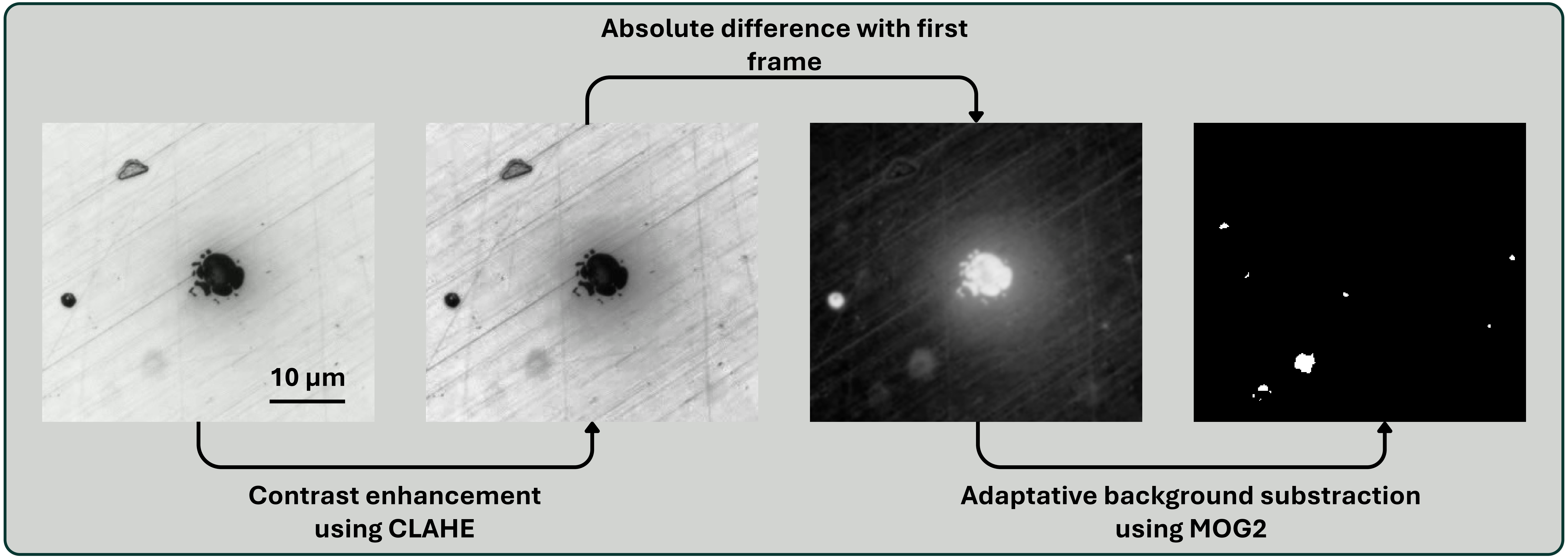
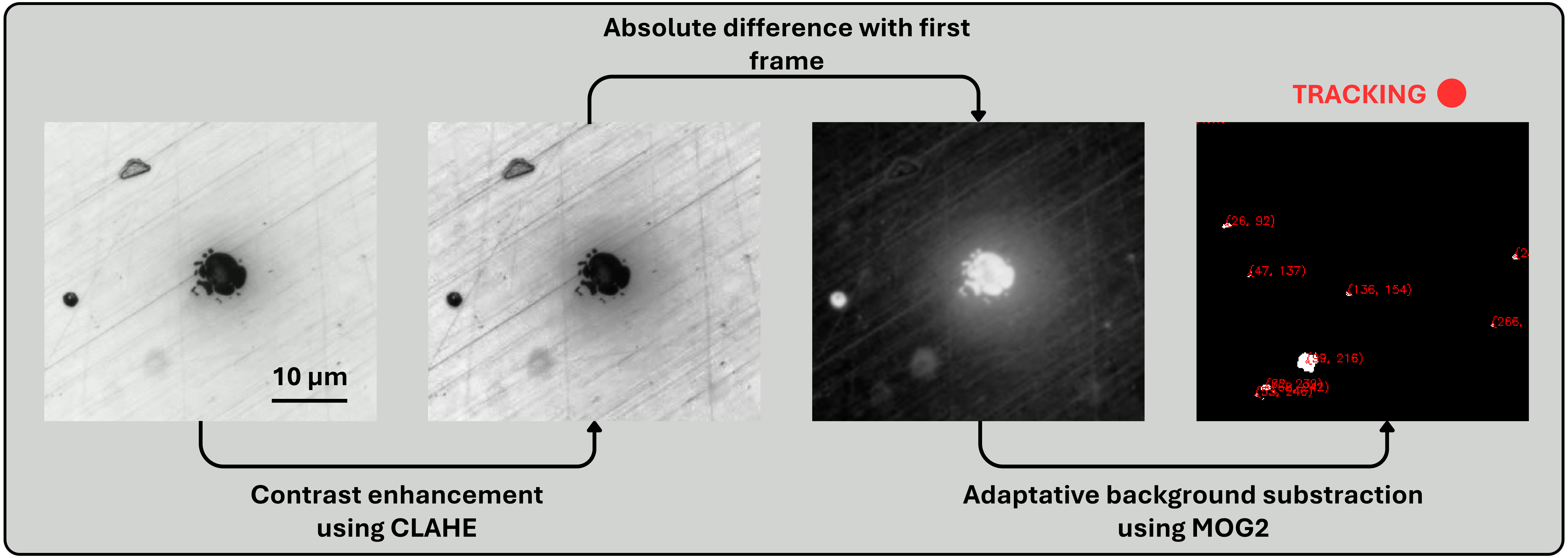
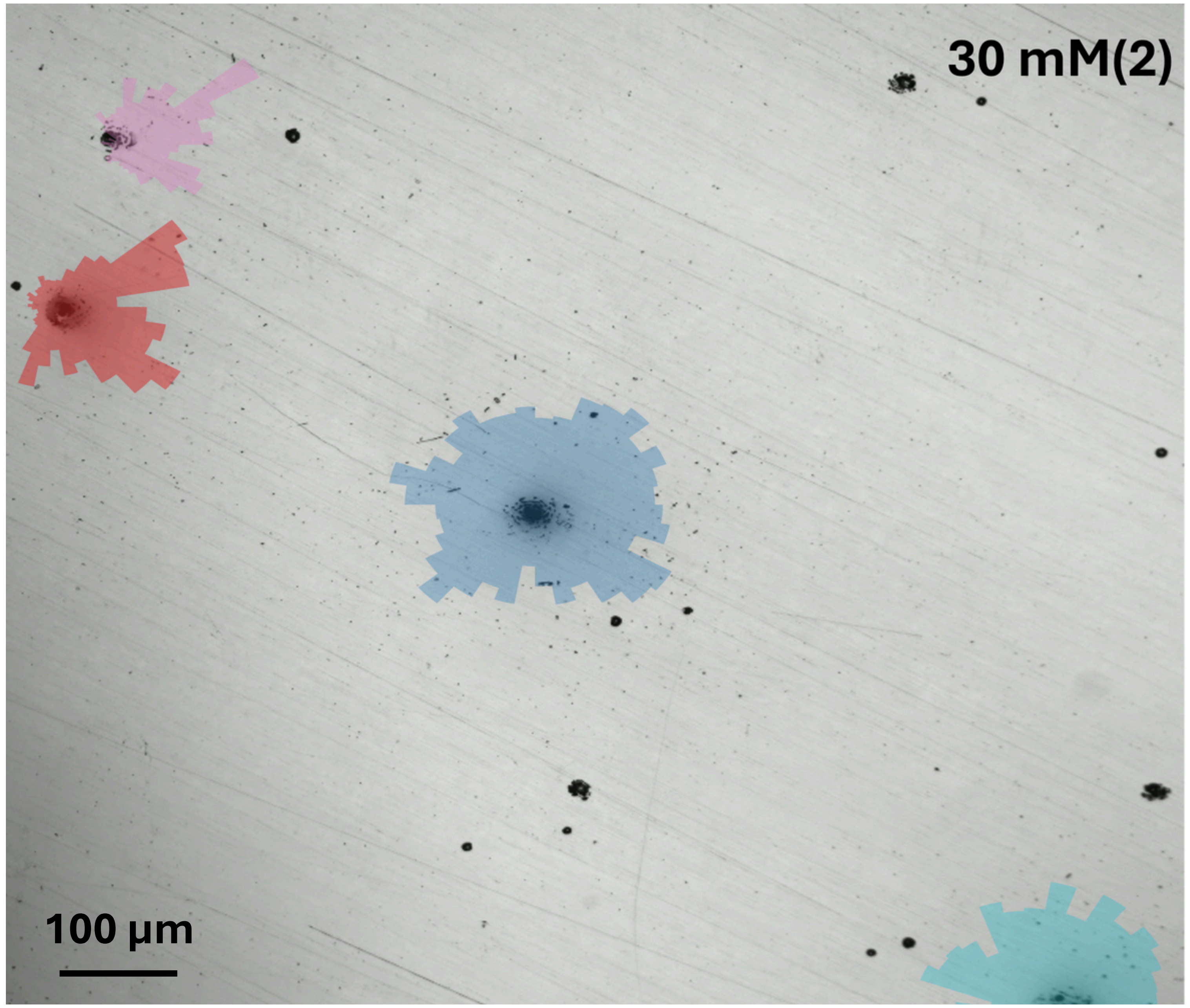
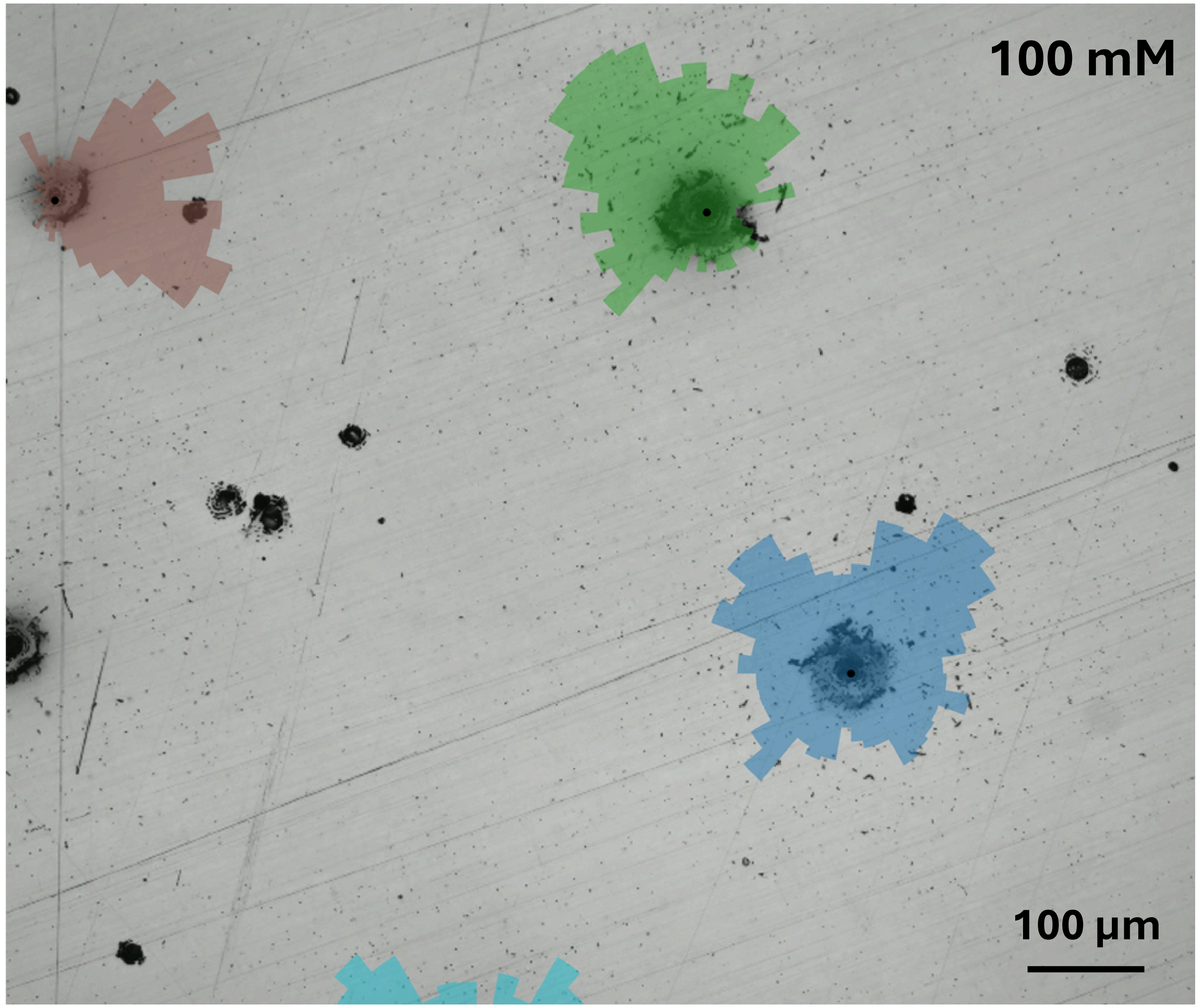


IMAGE PROCESSING AND TRACKING



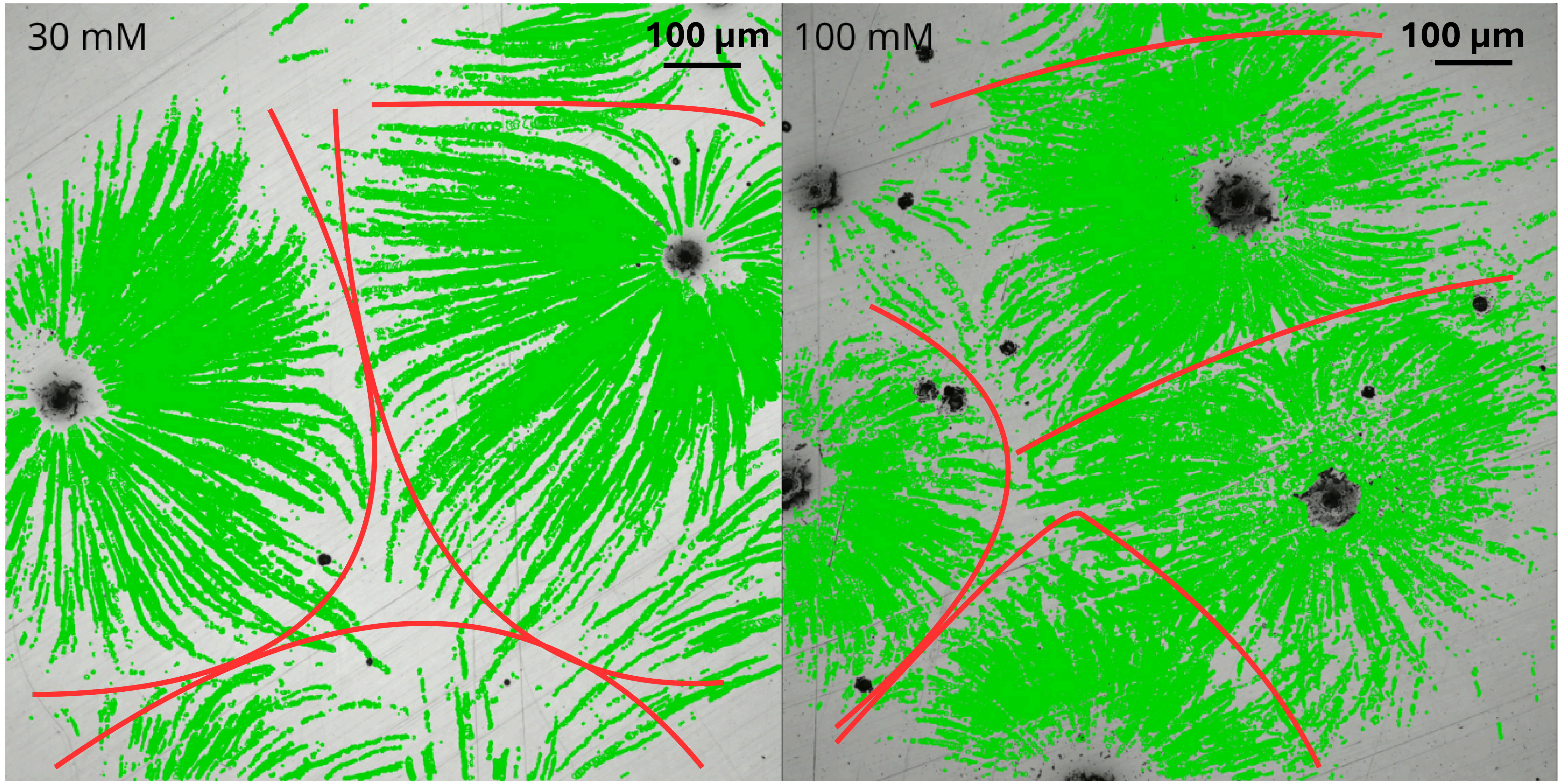
ANGLE OF EJECTION





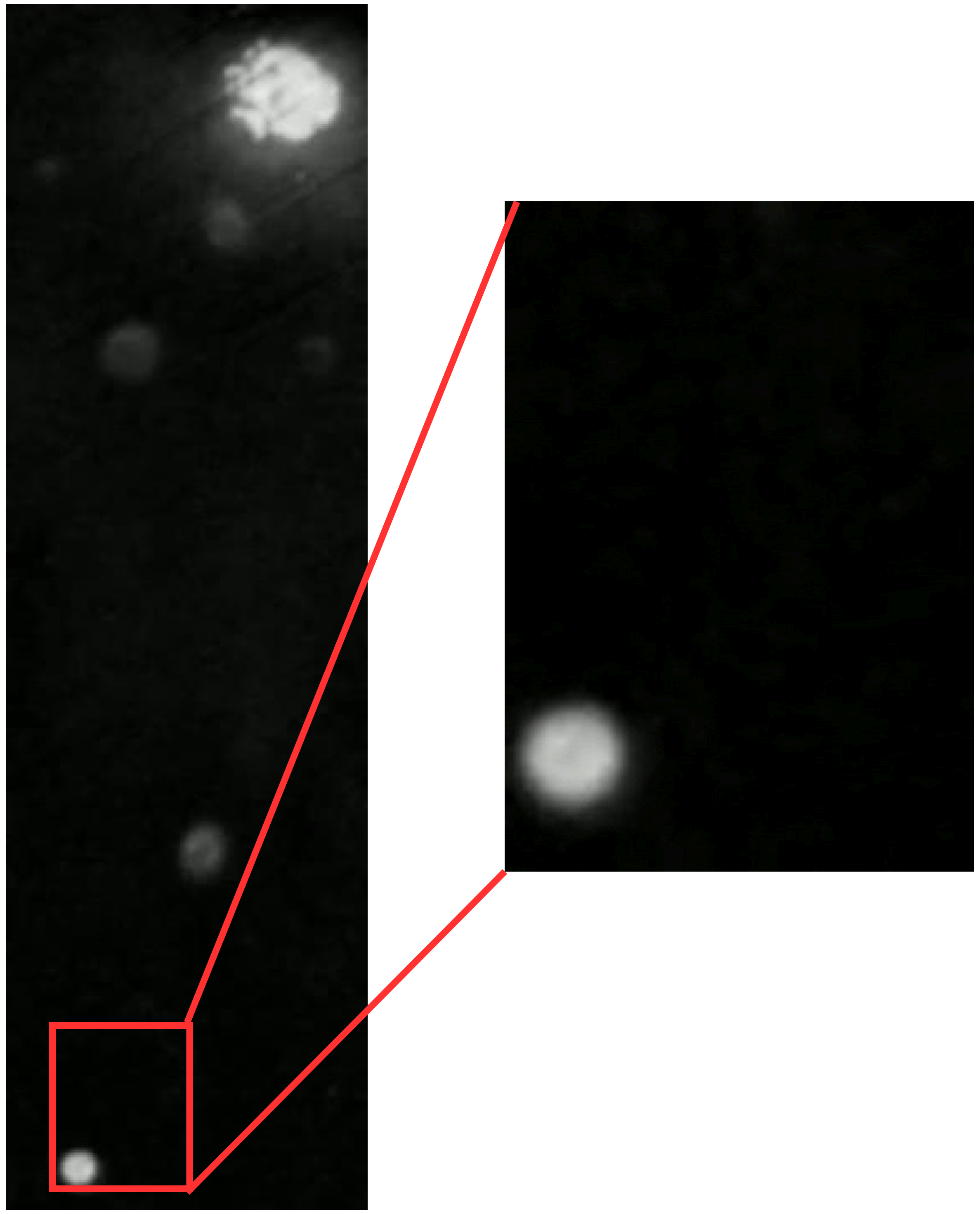
- No clear correlation between angle of ejection and relative position of neighboring pits
- Internal driving force

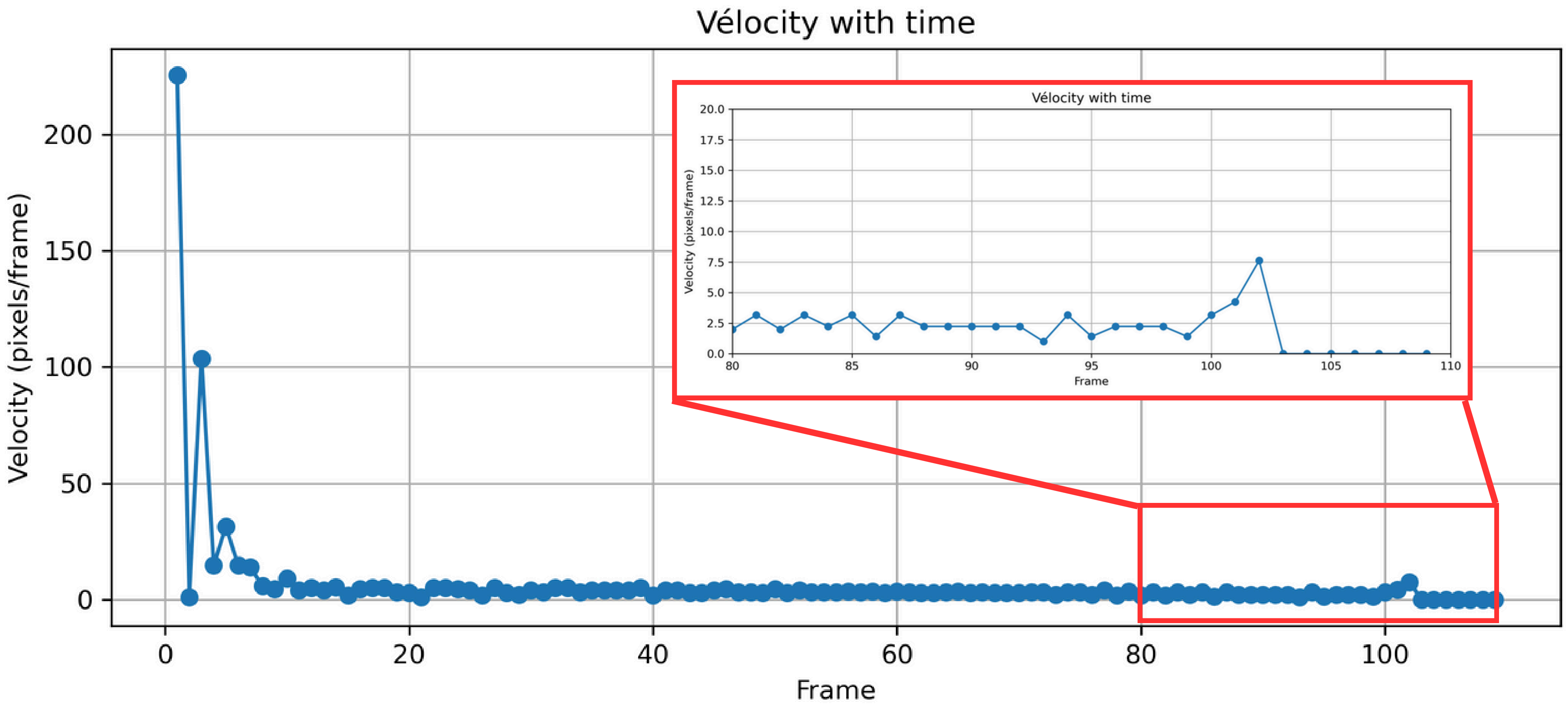
GENERAL FLUX BEHAVIOR



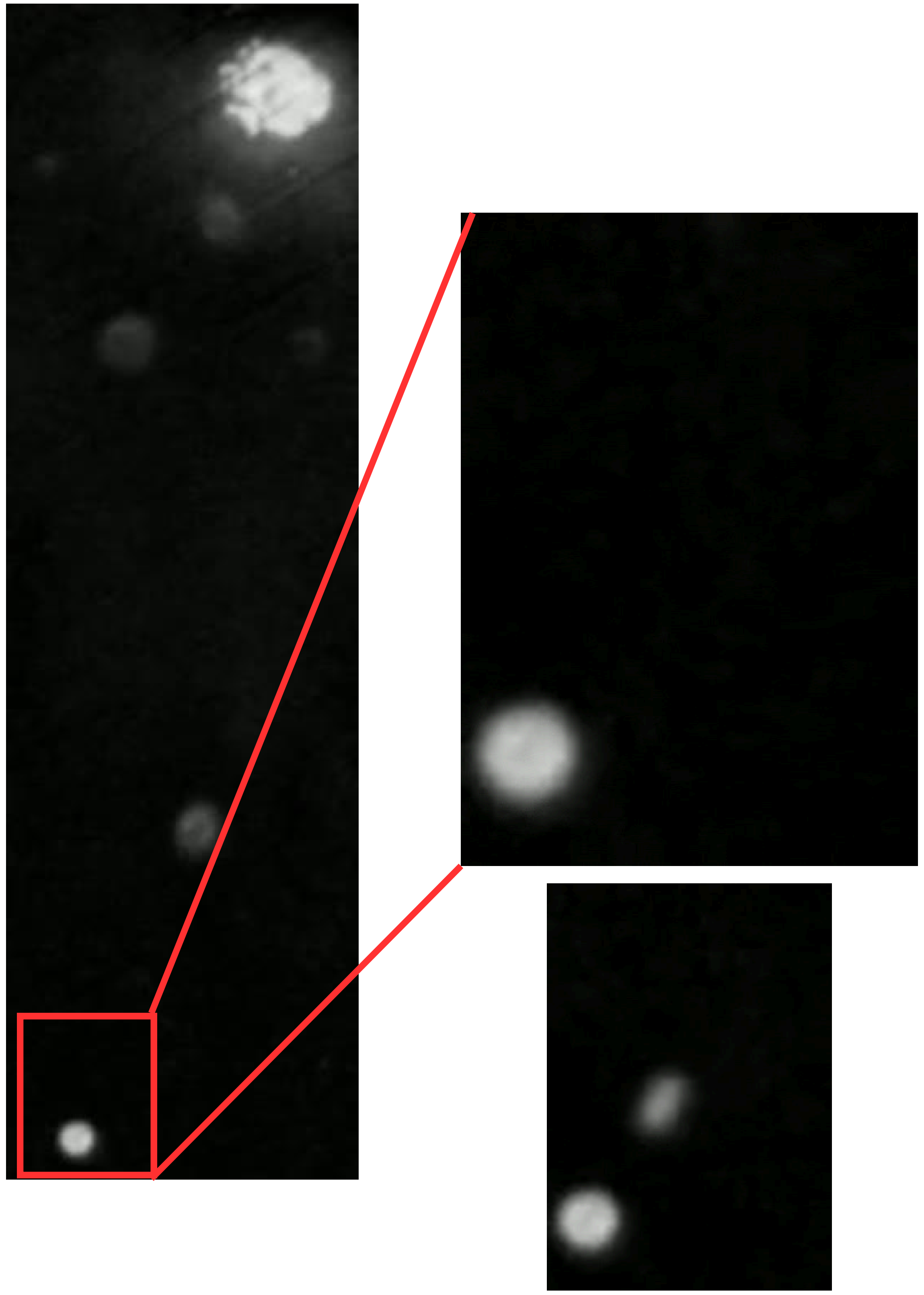
- Multiple flux domain interacting each others
- Ejection direction influenced by neighboring flux

OUTLIER

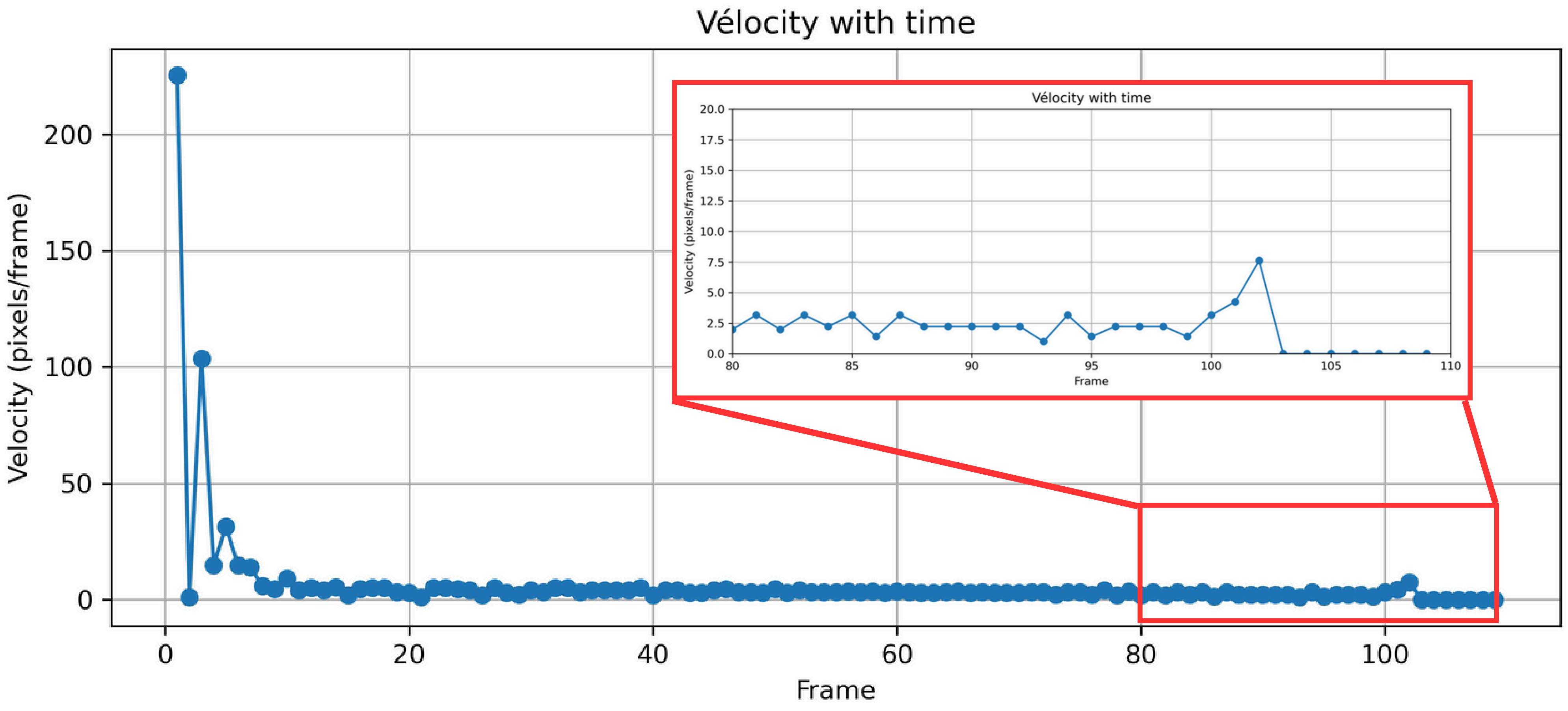



Vélocity with time
Velocity (pixels/frame)
Frame
0
50
100
150
200
0
20
40
60
80
100
Vélocity with time
Velocity (pixels/frame)
Frame
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
80
85
90
95
100
105
110

OUTLIERS

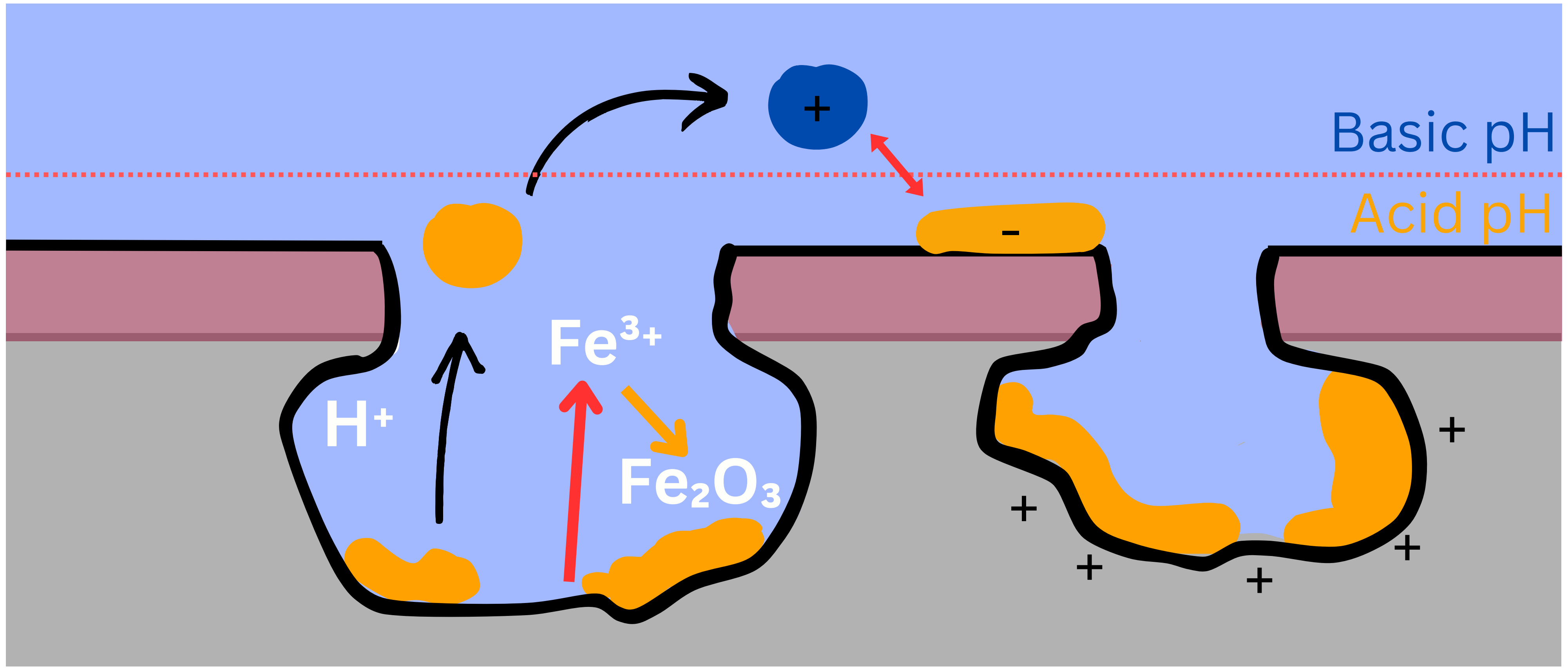


SNAPPING



- Increase of the velocity close to the pit
- Possible particle/pit interactions

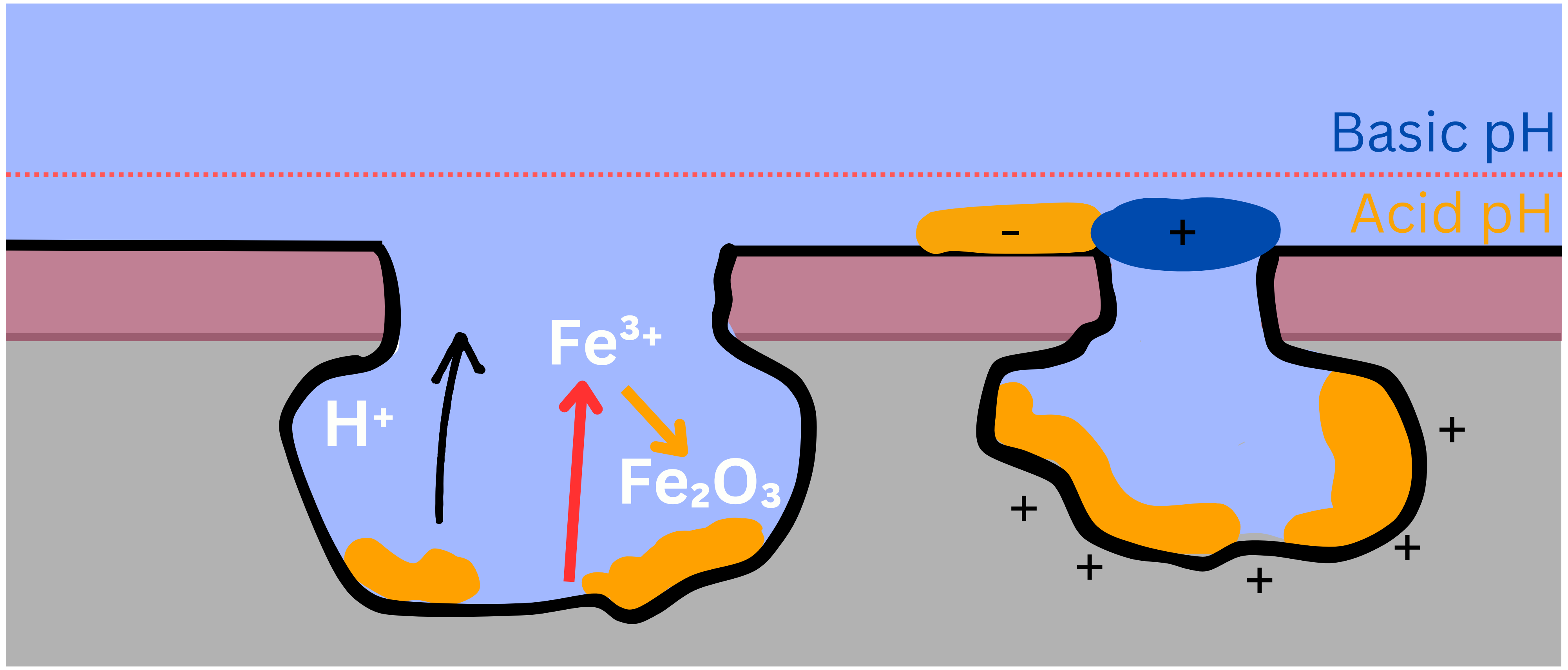
OUTLIER



Schematic representation of possible electrostatic interactions

Difference of pH = difference of charge

OUTLIER

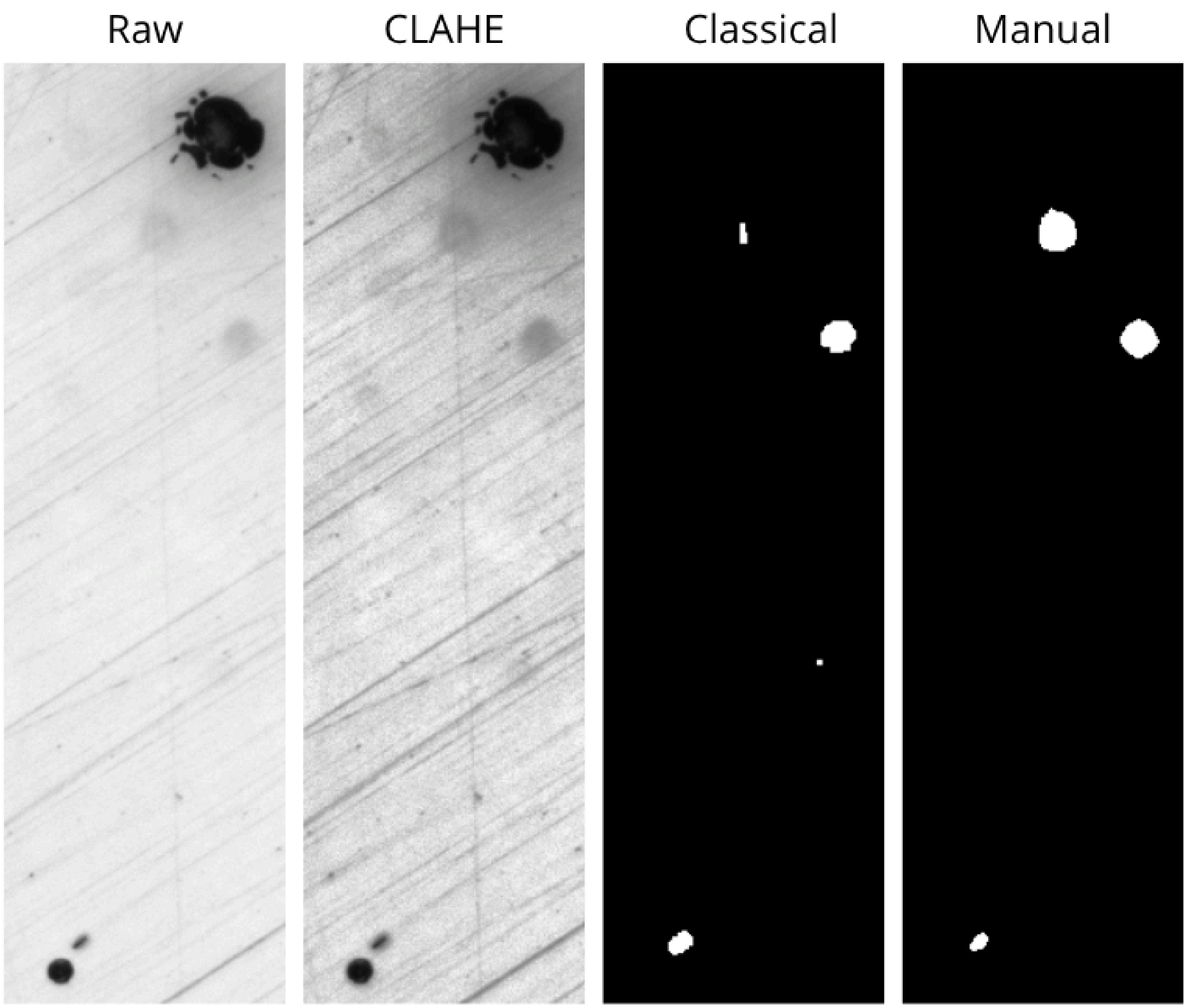


Schematic representation of passivation from ejected particles

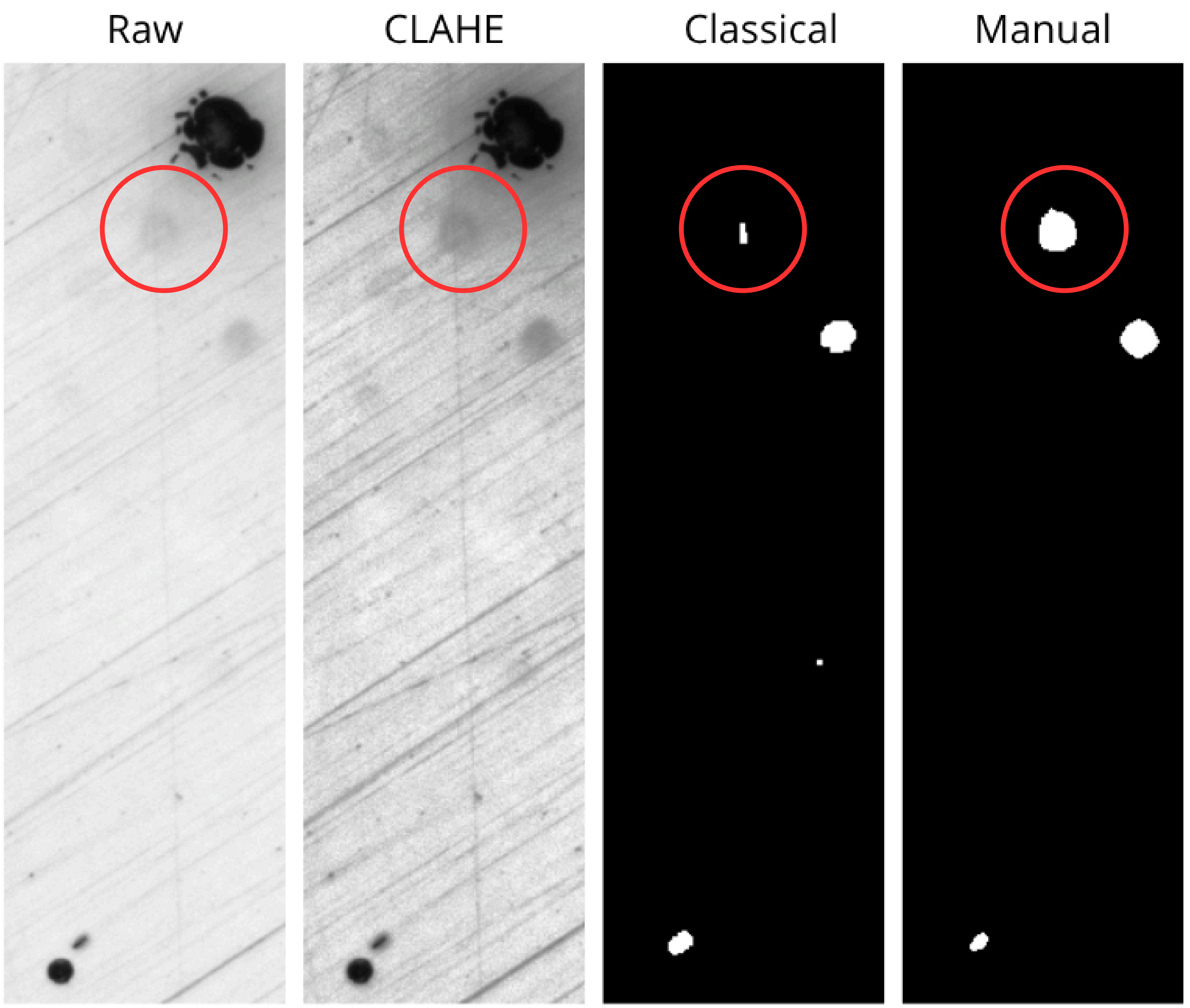
Possible passivation from ejected particles

Frankel, G. S. (1998). Journal Of The Electrochemical Society, 145(8), 2970a-22970. https://doi.org/10.1149/1.1838748

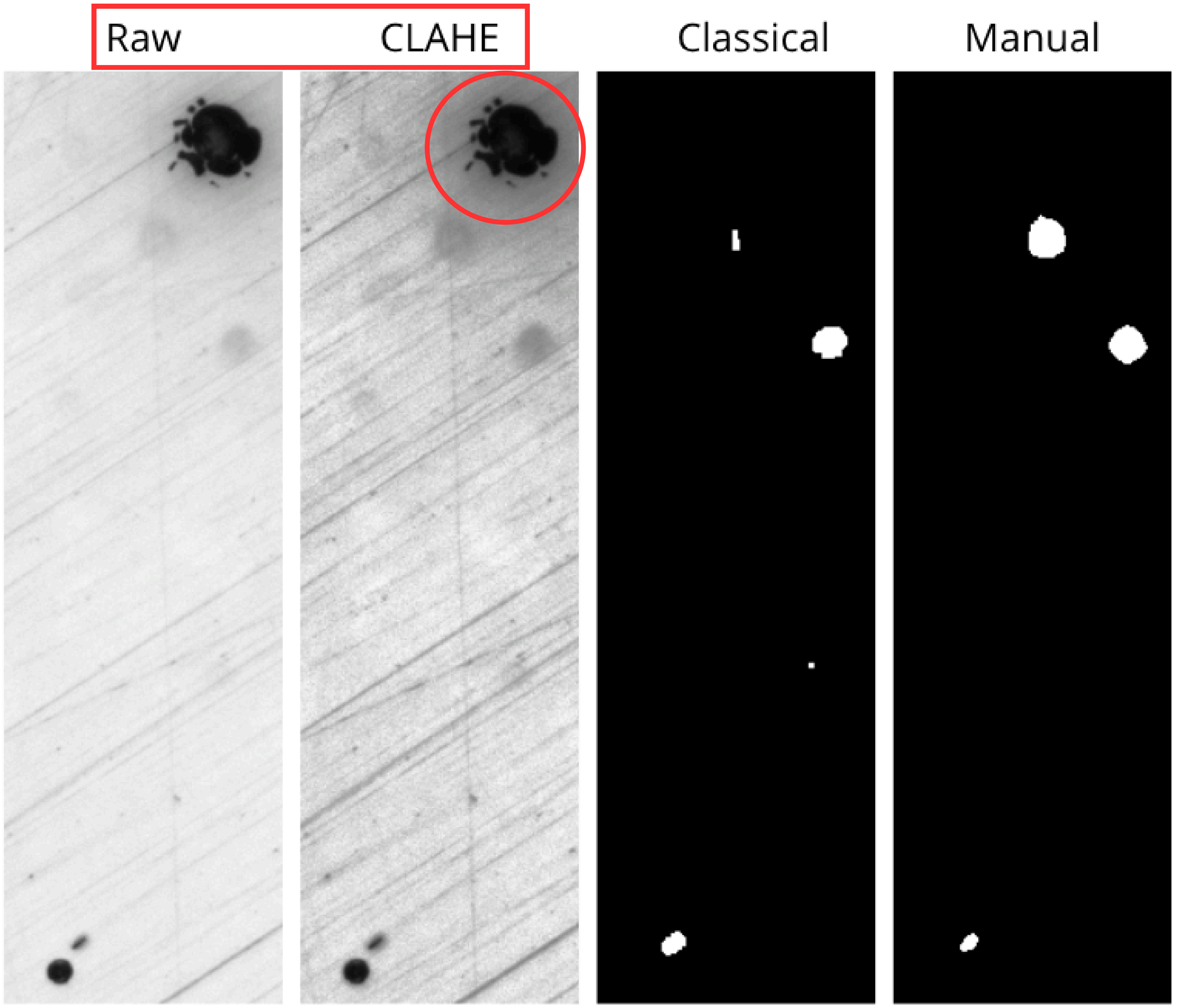
DETECTION LIMITATIONS



DETECTION LIMITATIONS

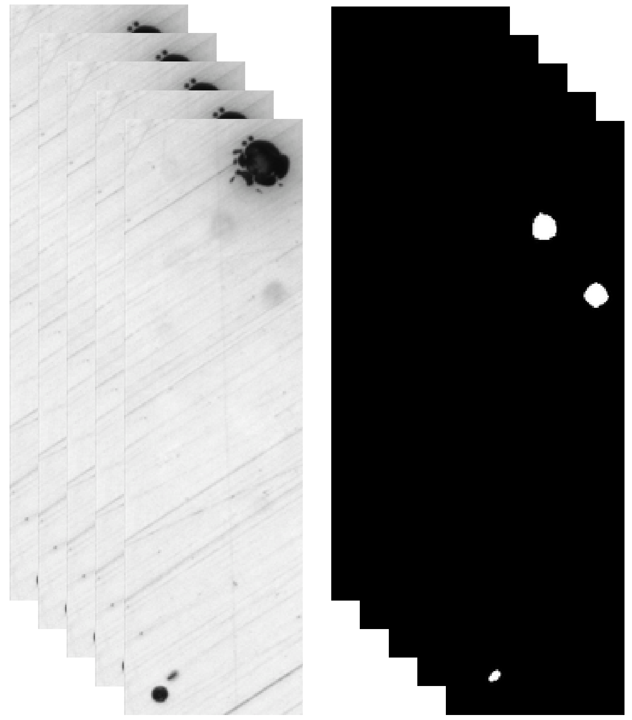


DETECTION LIMITATIONS

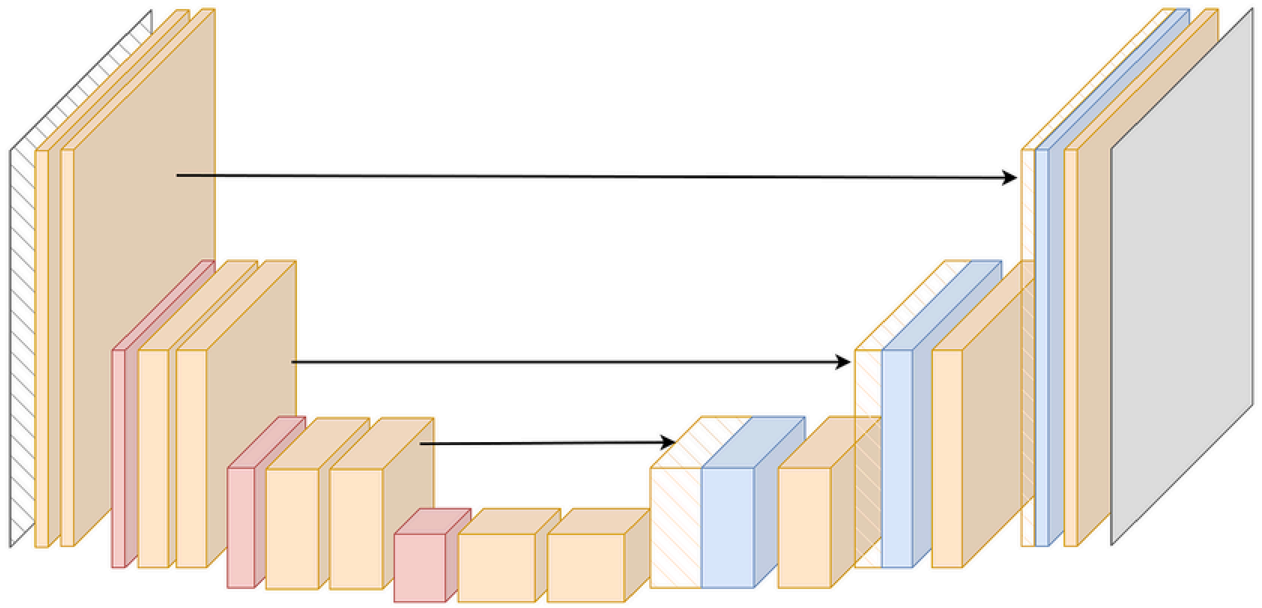


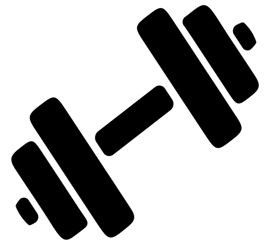
Increase of contrast generate loss of information

DEEP LEARNING APPROACH



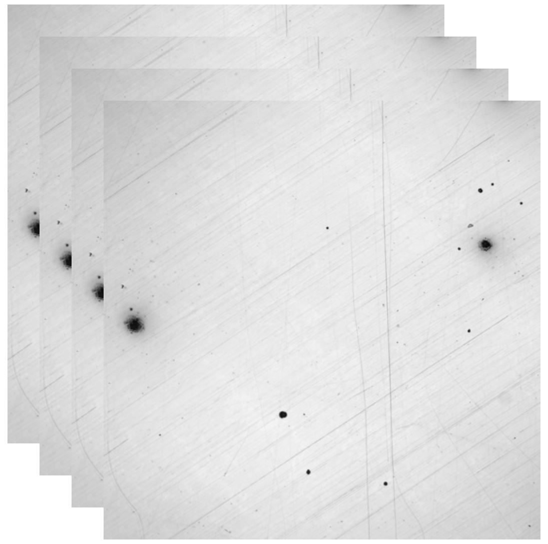
U-Net





Weights

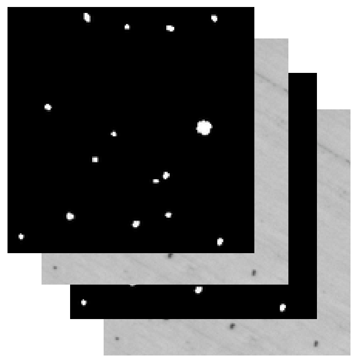
Dataset



8 images (30mM, 50mM)

2248x2252 pixels

Slicing



100 manually annotated images

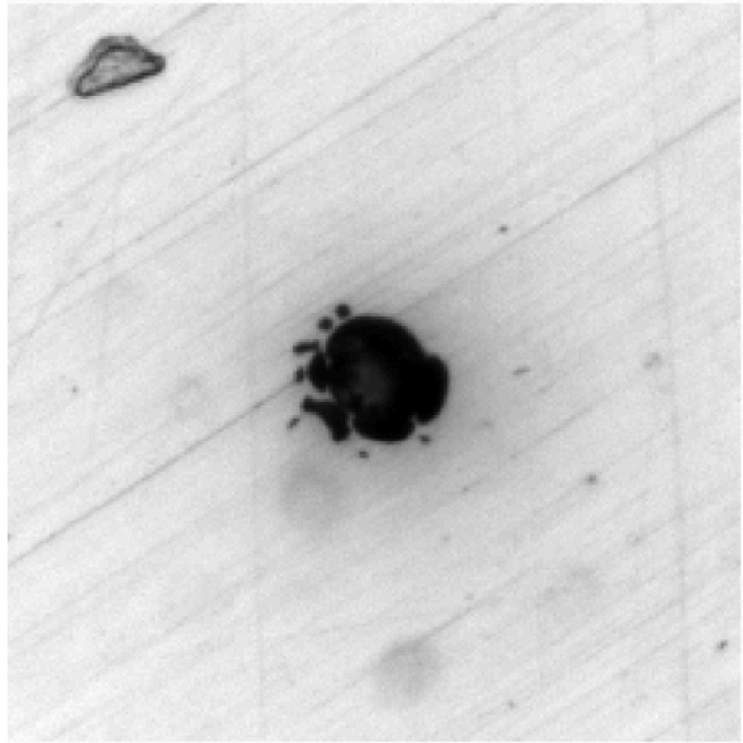
200x200 pixels

Meta SAM 2

Segments.ai

MODEL COMPARISON

RAW

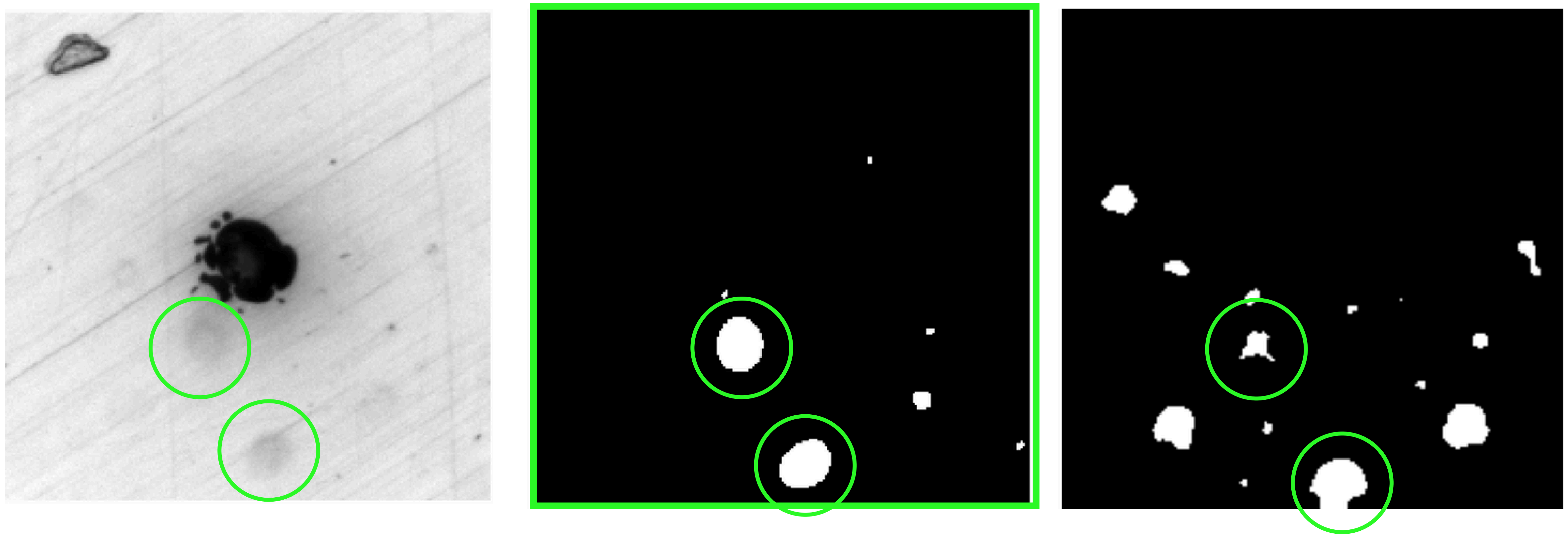


U-NET

CANNY EDGES

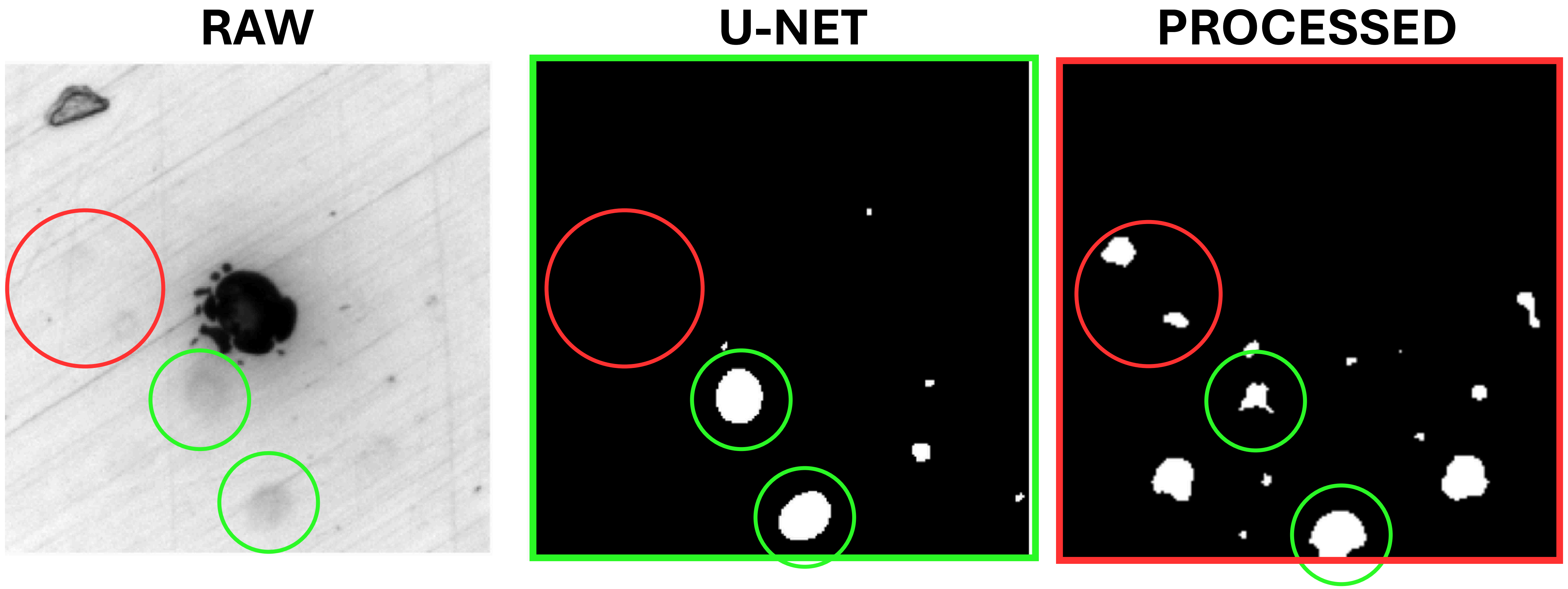
MODEL COMPARISON

RAW U-NET PROCESSED



Accurate prediction of particle shape

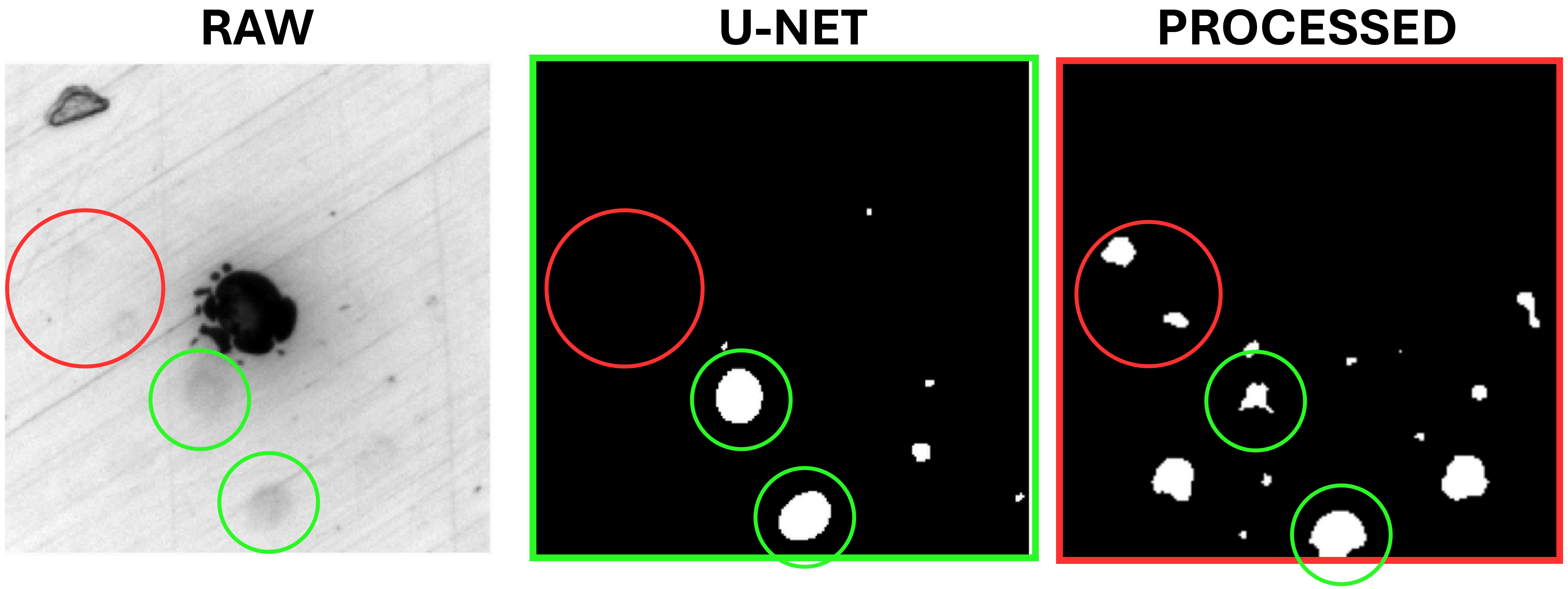
MODEL COMPARISON



Accurate prediction of particle shape

Missed particles

MODEL COMPARISON

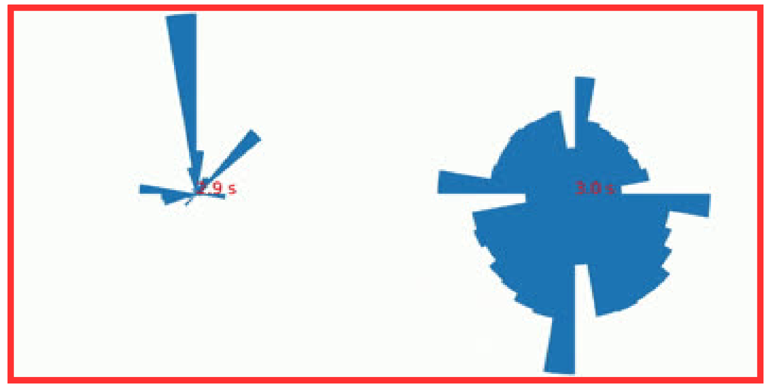


Accurate prediction of particle shape

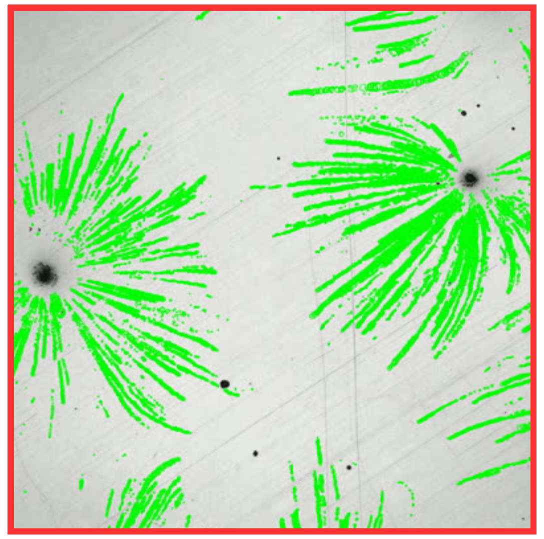
Missed particles

Room for improvement

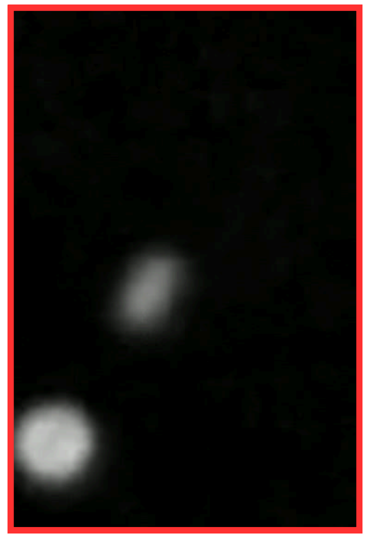
Corrosion products dynamic



Ejection
vs
propagation



Flux domain



Snapping behavioir

Leveraging data analysis and artificial intelligence to drive scientific discovery

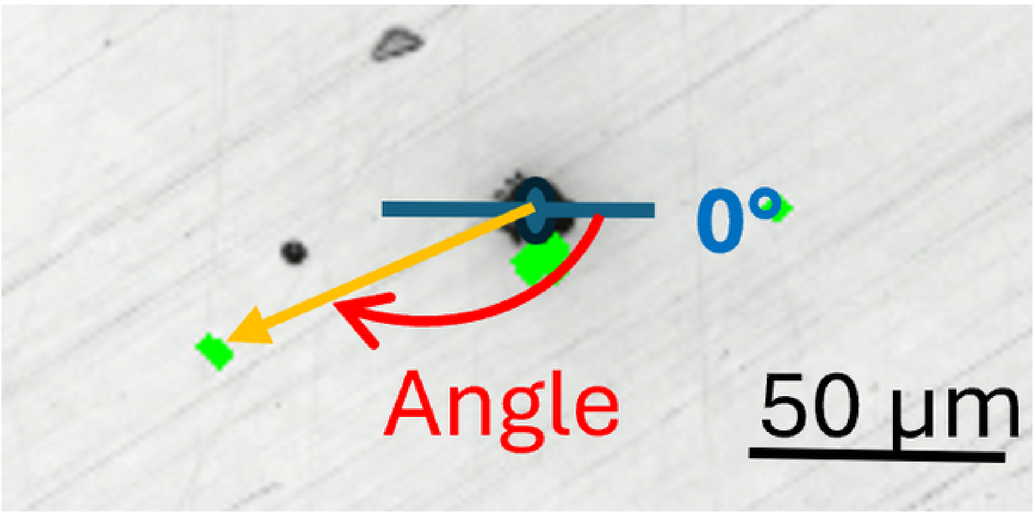
Perspectives

Further chemical analysis

- Chemical composition of corrosion product — Raman spectroscopy
- Passive layer chemical composition — XPS
- Probing pH inside pits

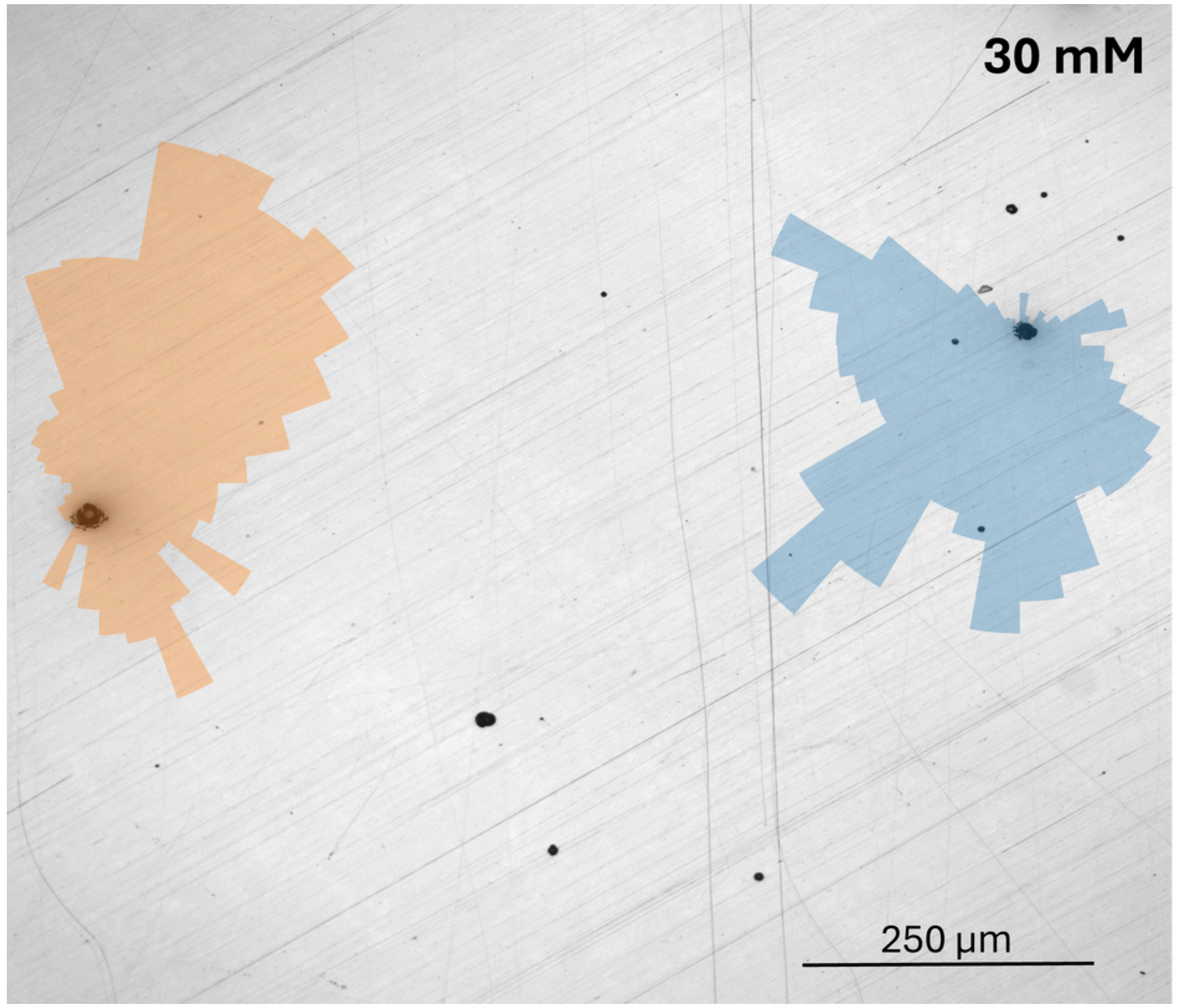
ANGLE OF EJECTION

Methodology



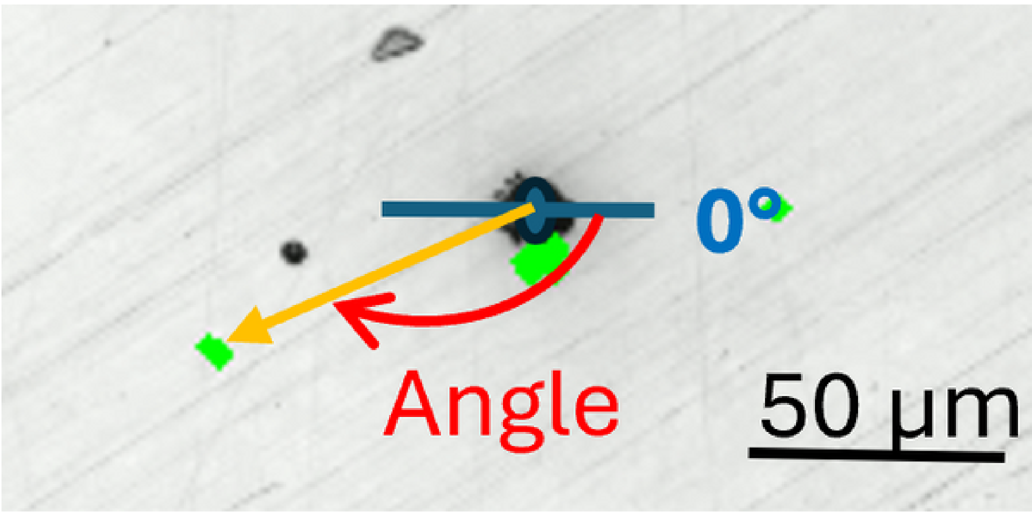
Frame N
(x1, y1), (x2, y2) …
θ1, θ2 …

Results



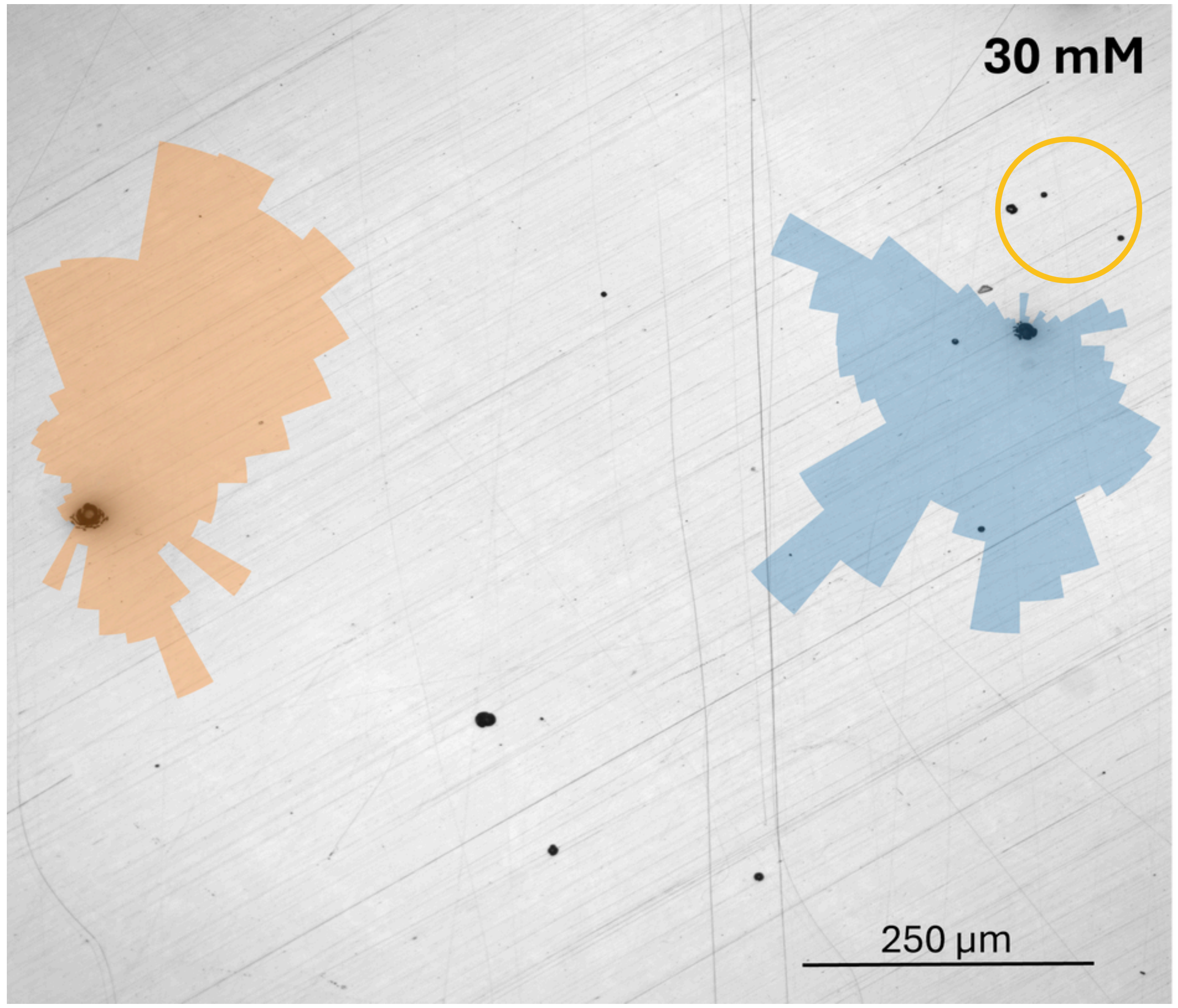
ANGLE OF EJECTION

Methodology



Frame N
(x1, y1), (x2, y2) …
θ1, θ2 …

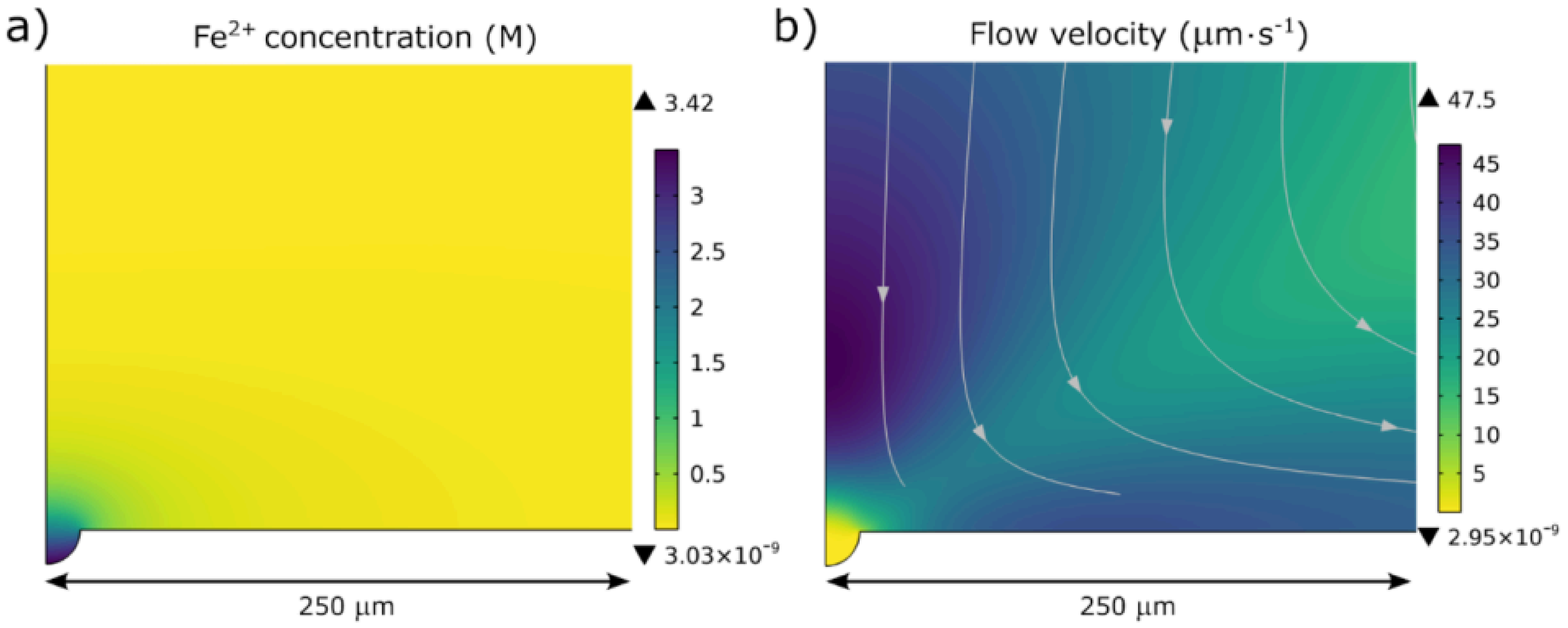
Results



Hypothesis 1 : "Neighboring pit influence ejection ?"

GENERAL FLUX BEHAVIOR

Mauzeroll et. al



“Hydrodynamic flux initiated by density grandient”

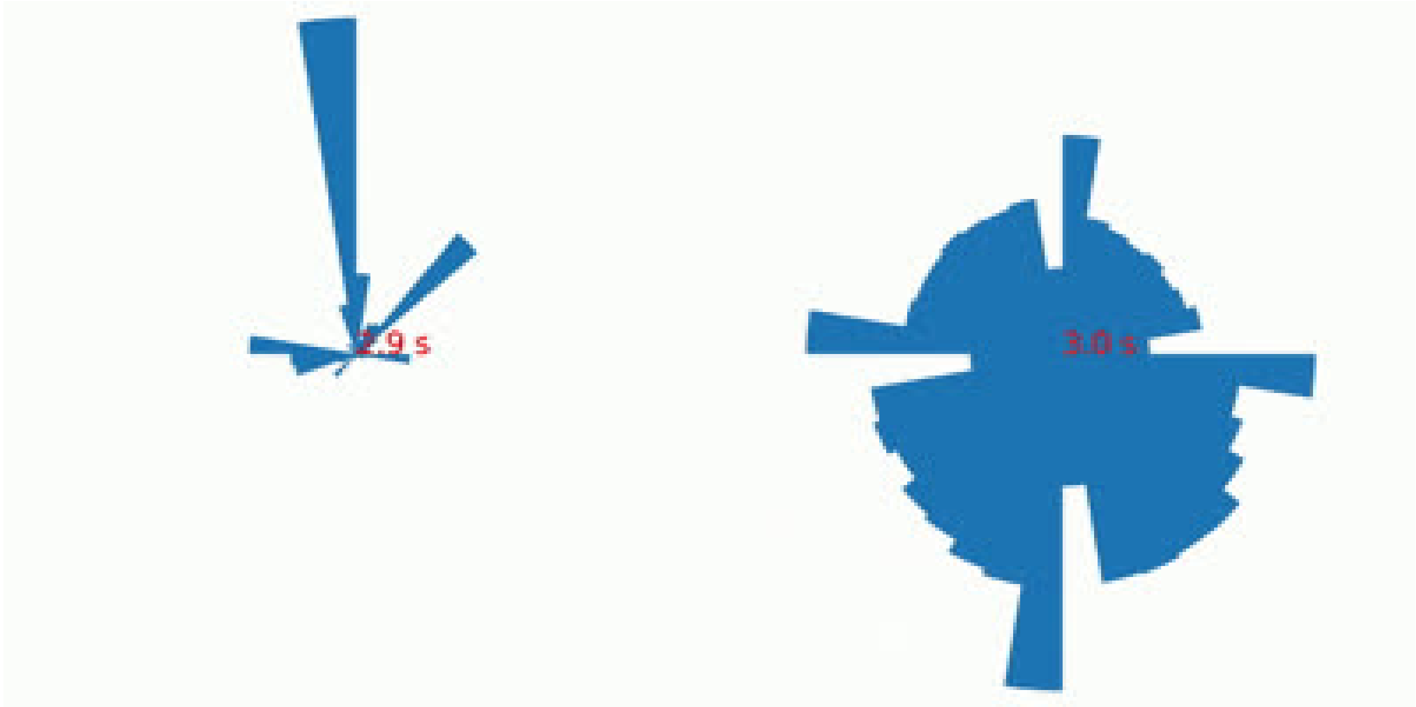
“Downward and lateral flux to the pit”

Mauzeroll, J. (2024). Observation of Natural, Corrosion Science, 241, 112518

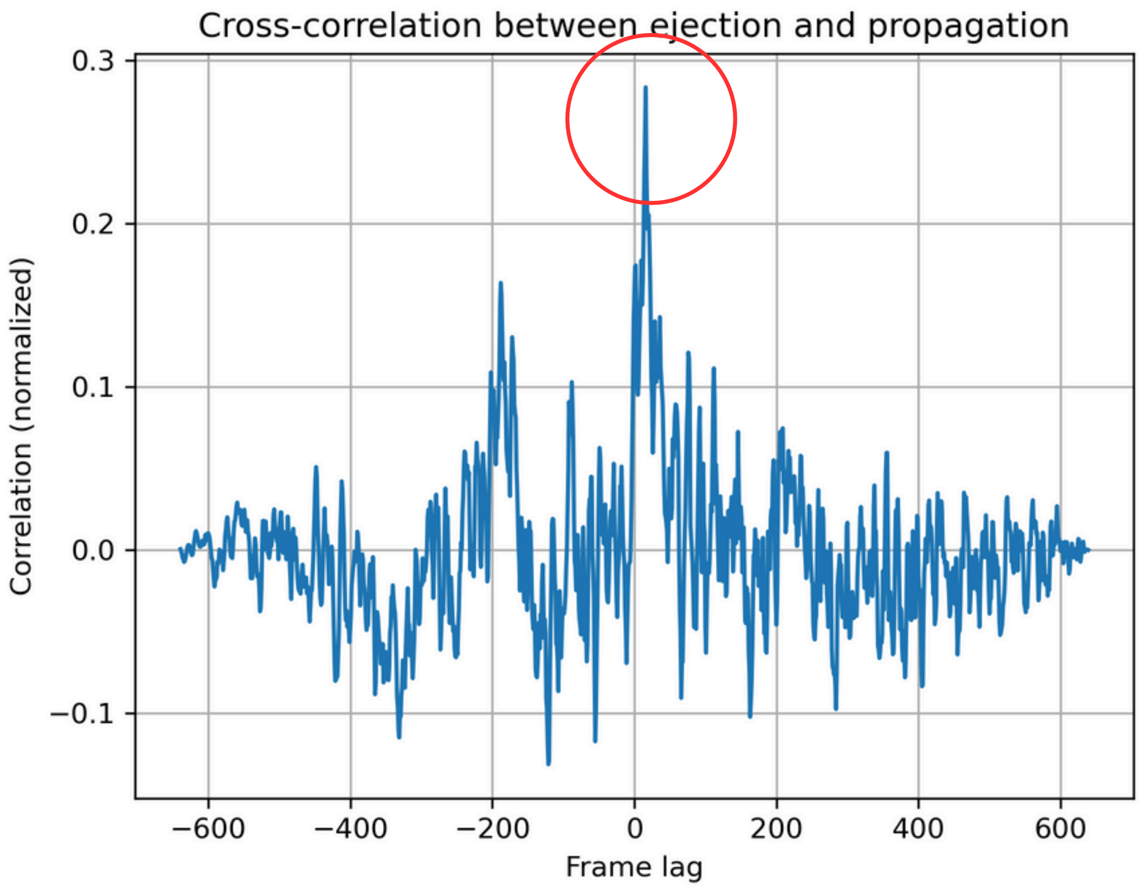
PROPRAGATION VS EJECTION

Hypothesis 2 : “Ejection is influenced by structural parameters of the pit”

Frame N
(x1, y1), (x2, y2) …
θ1, θ2 …



Ejection **Propagation**

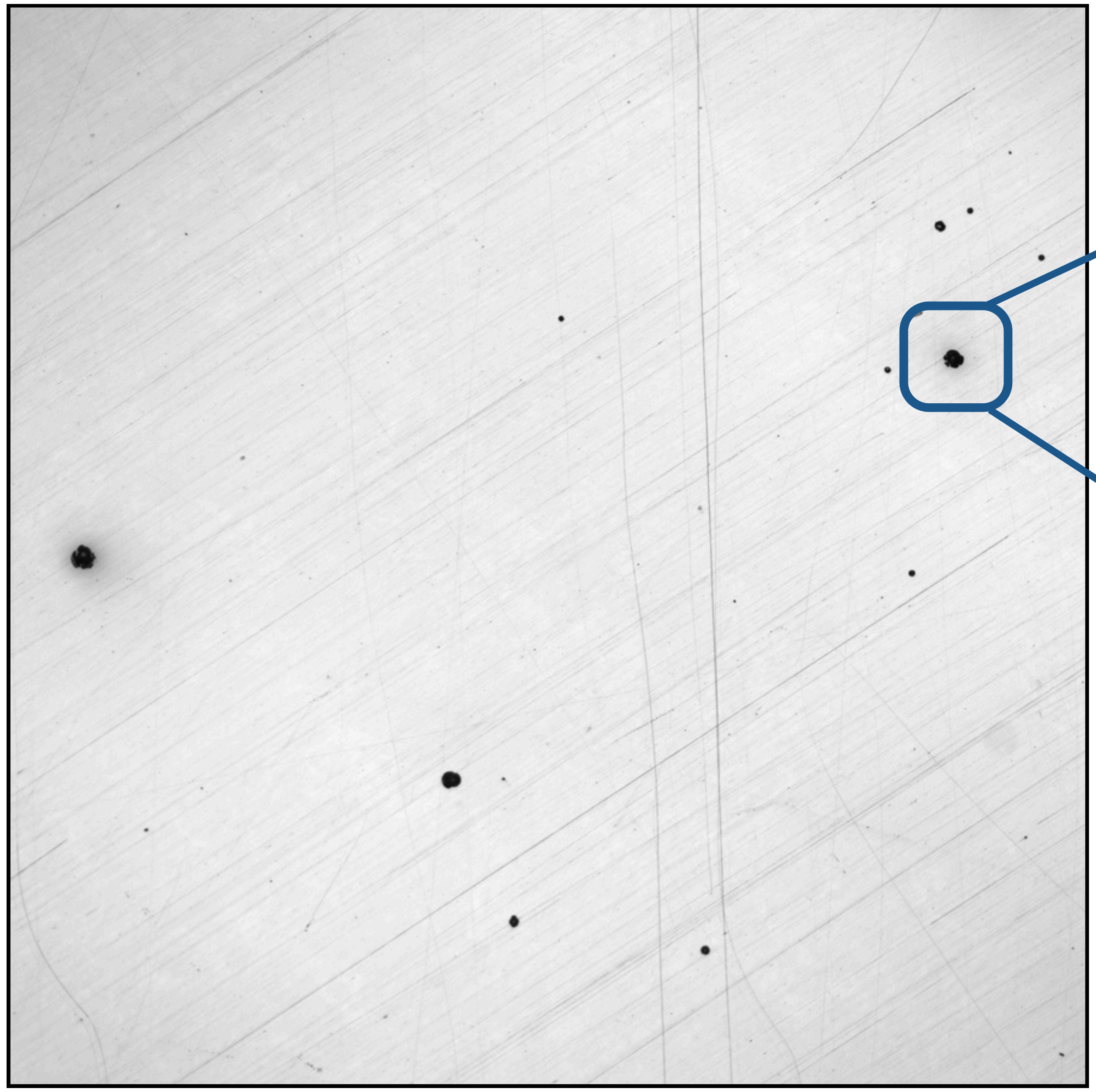


Ejection of particles could be influenced by pit propagation

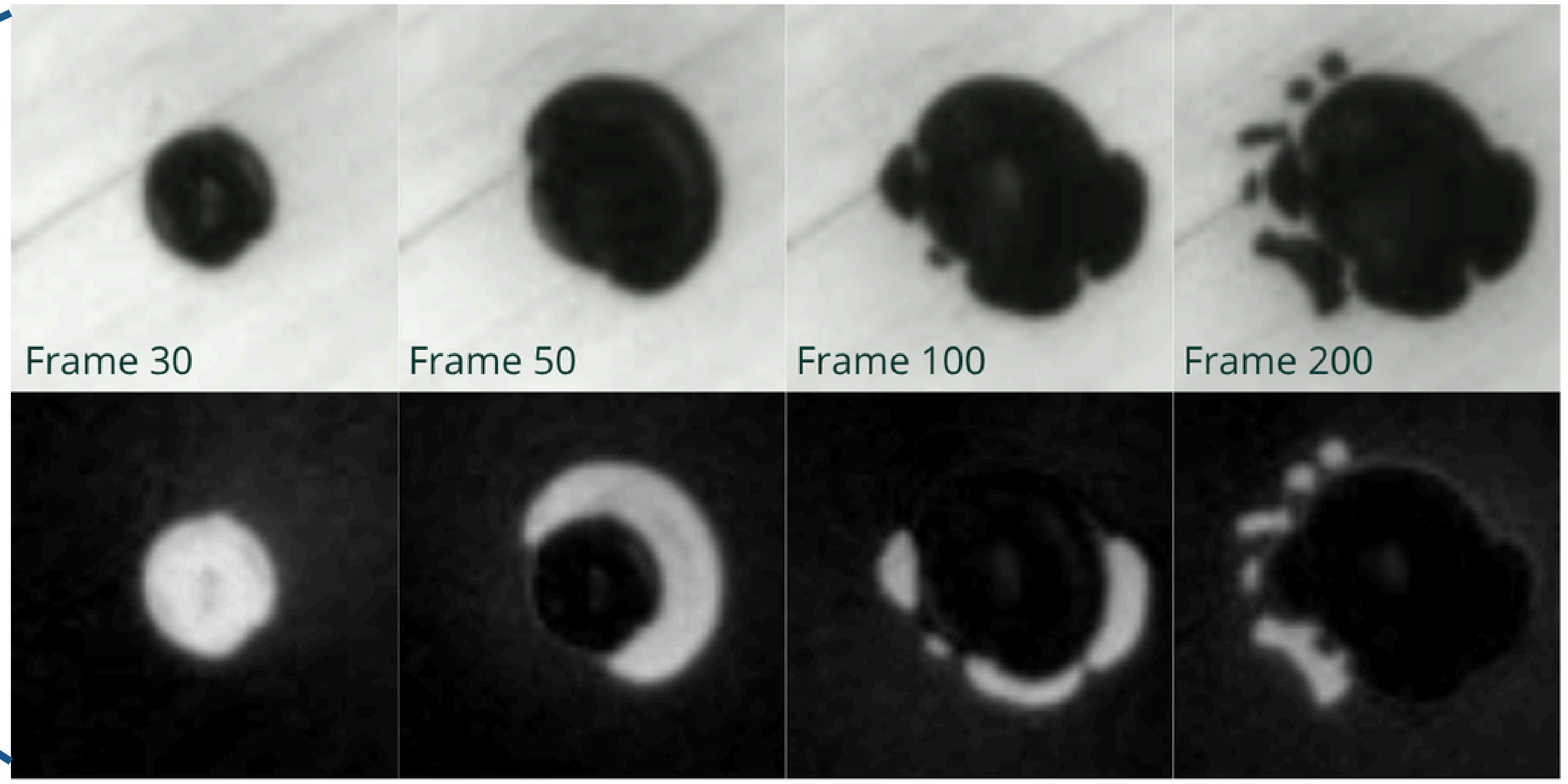
Relatively low correlation probably linked to insufficient detection

PROPRAGATION ANGLE

Hypothesis 2 : “Ejection is influenced by structural parameters of the pit”



30 mM sample during corrosion at frame 109



Pits propagation

Subtract each frame by the previous one

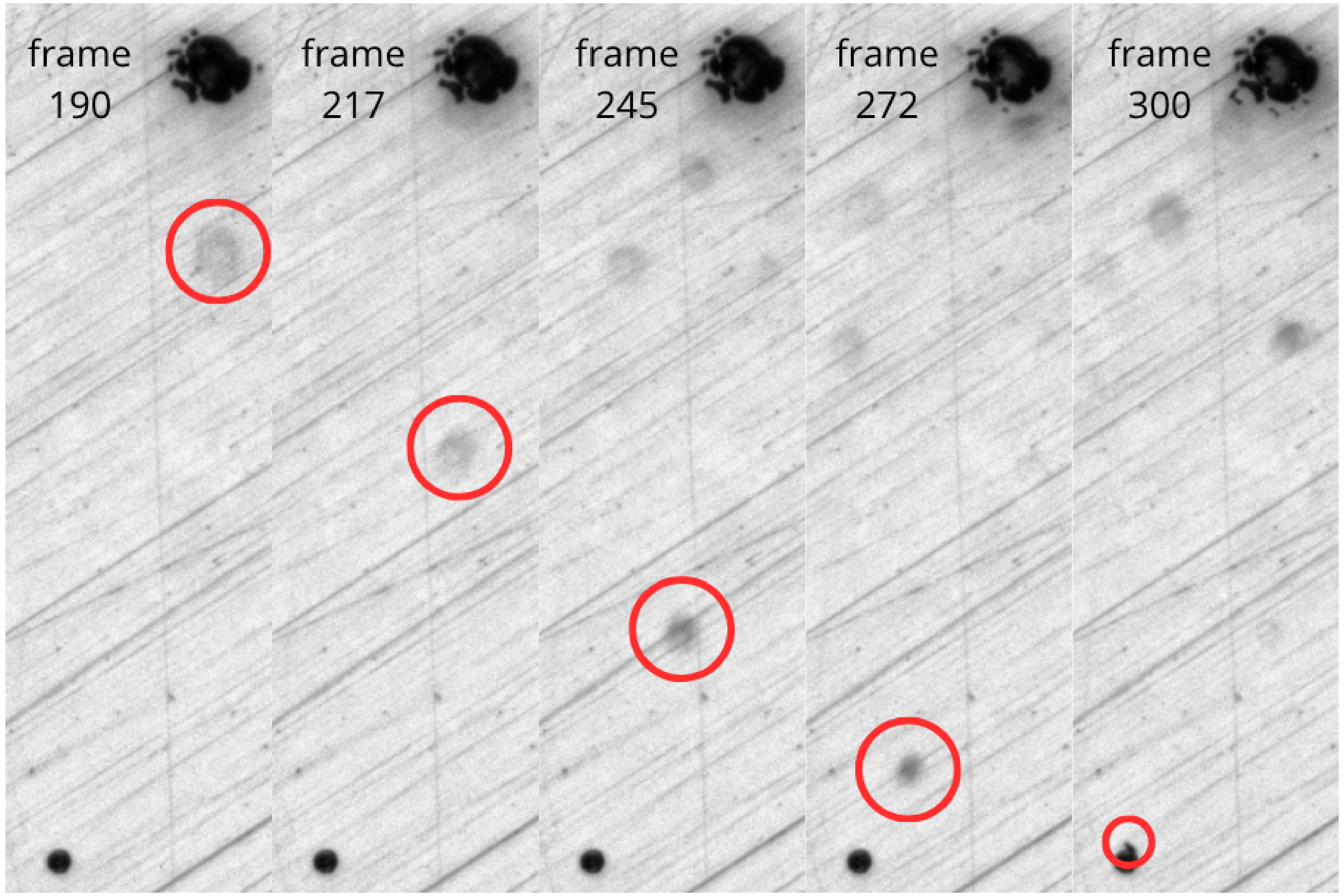
↓

New pixels

↓

Propagation quantification

Parabolic trajectory



Tracking of a single particle (red circle)

↗ **INTENSITY** ↗ **SHARPNESS**

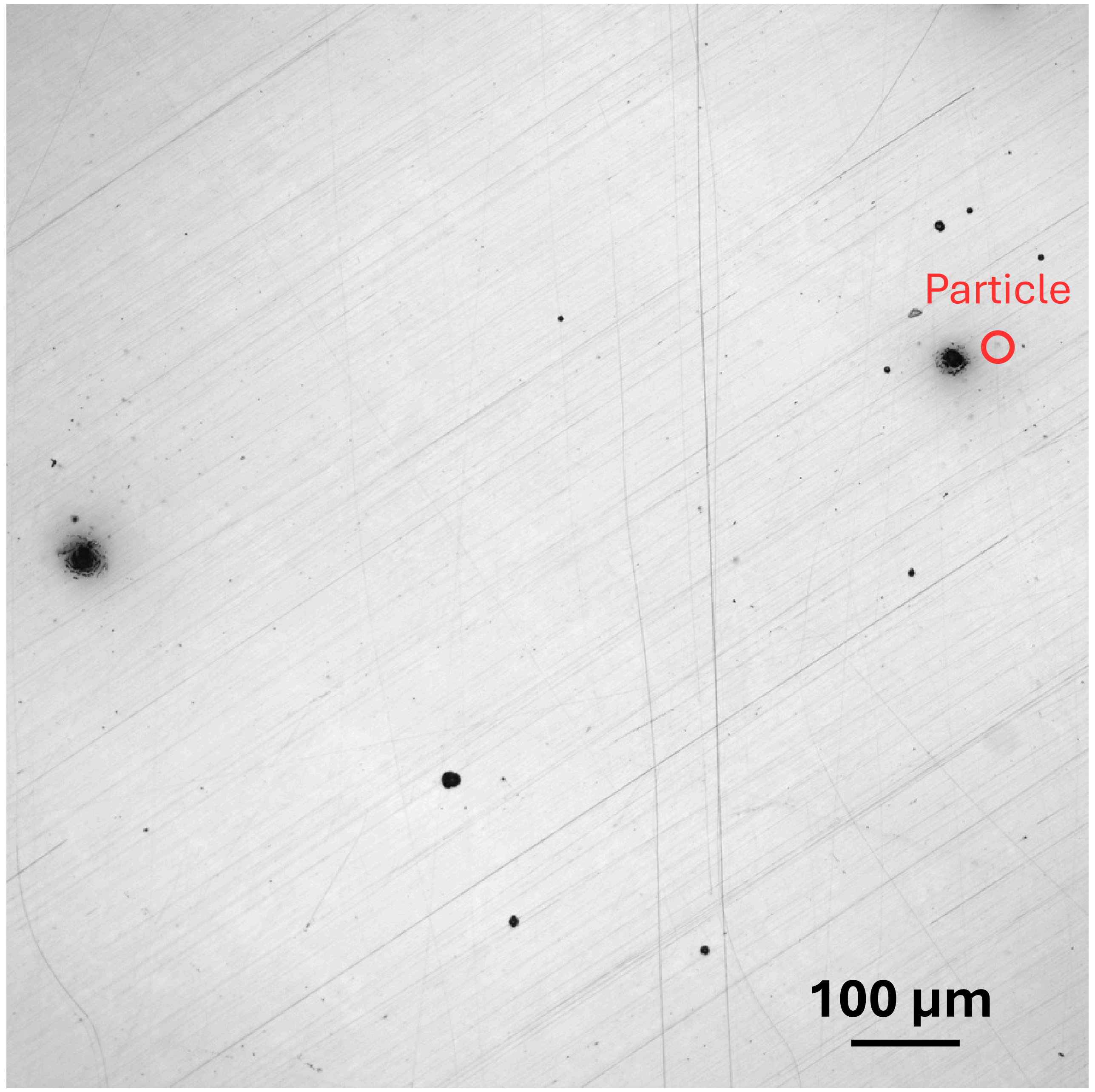
↓

Out of focus

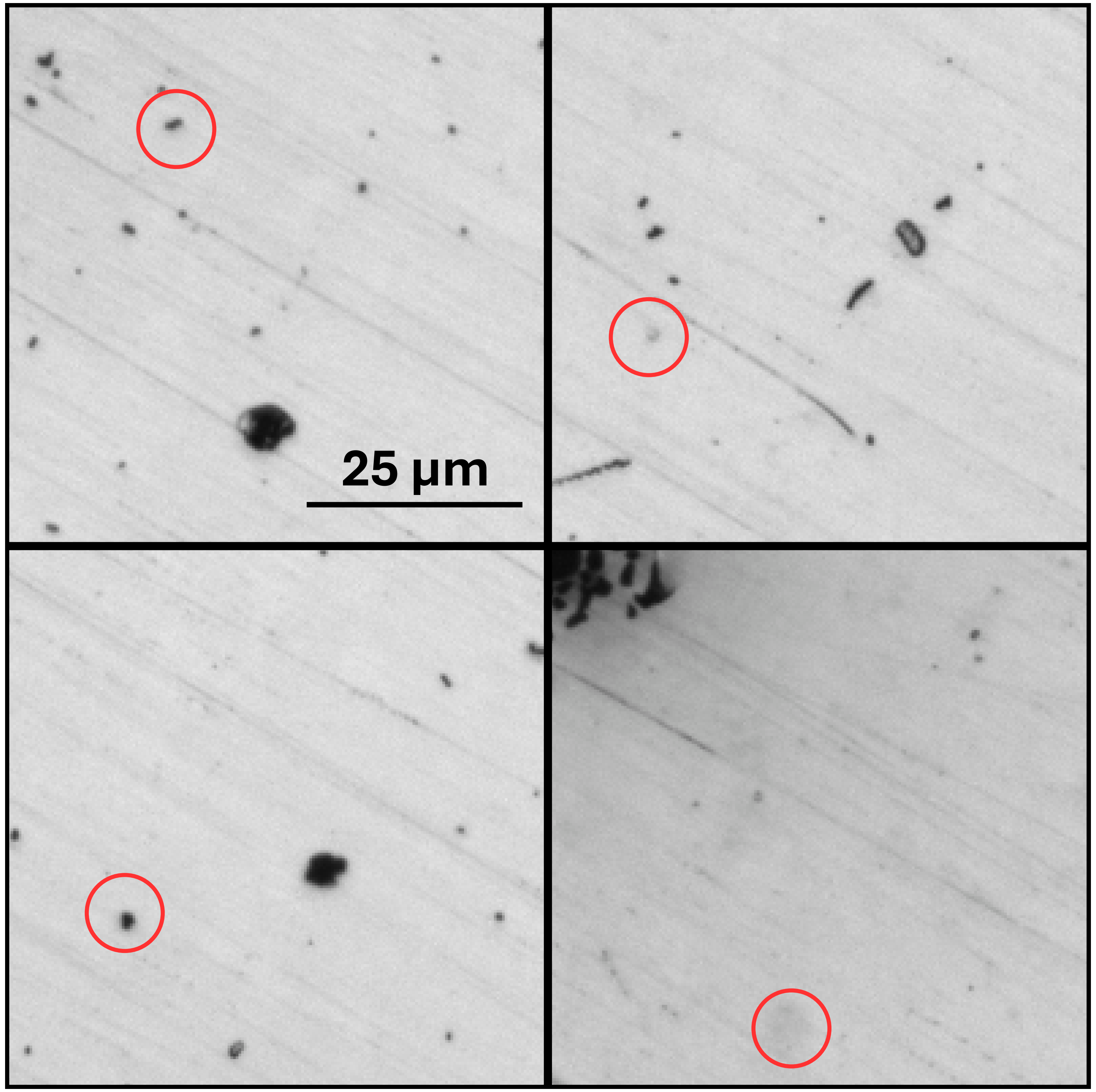
↓

Vertical movement

IMBALANCE PROBLEM

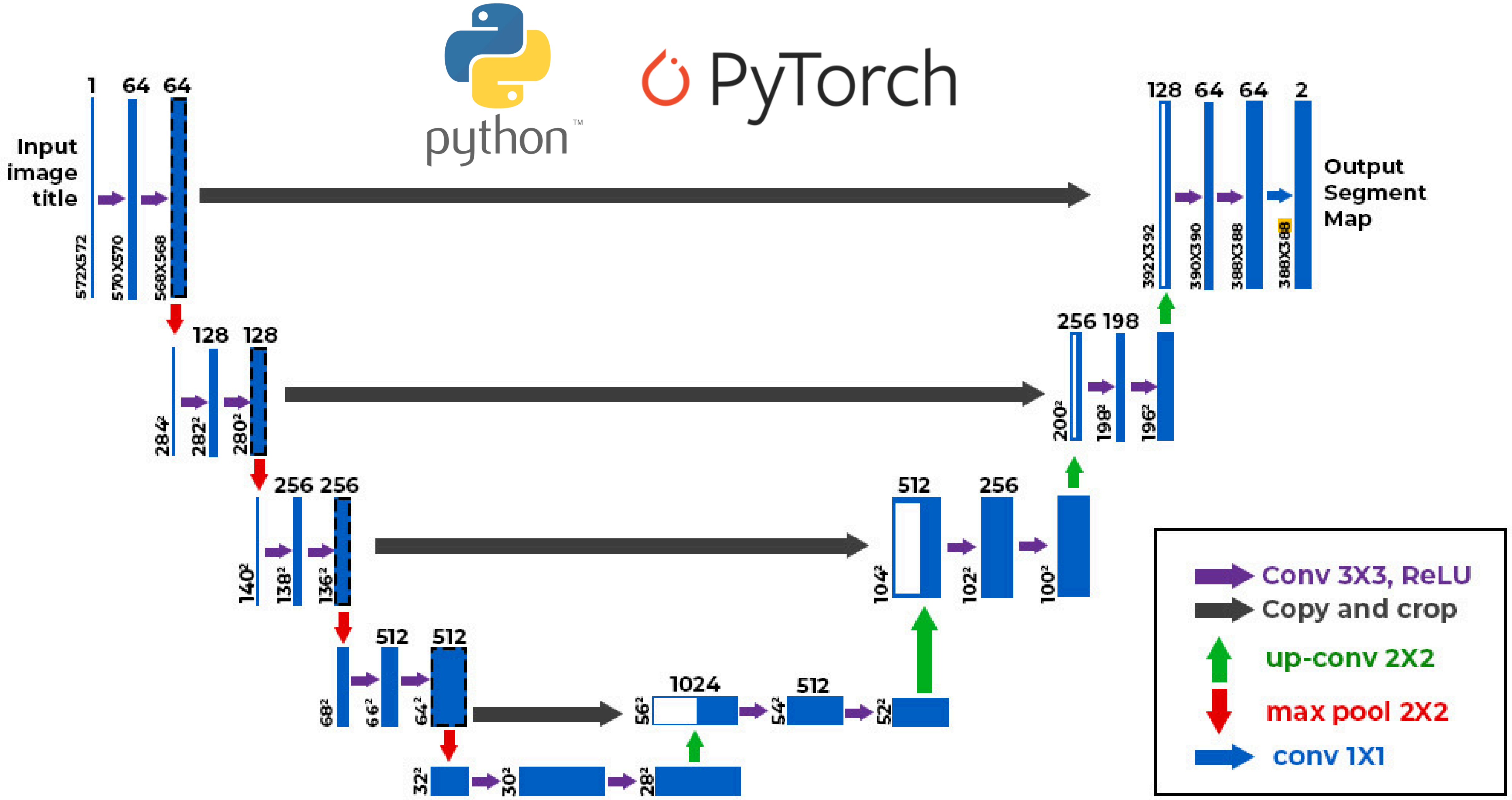


Mostly negative signal
at 2248x2252 pixels



200x200 pixels

UNET



ENCODER

→ **Extract features and context**

DECODER

→ **Reconstruct the mask**

MODEL PERFORMANCE

Parameters

- Number of epochs
- Learning rate

Metrics

TP : True positives FP : False positives TN : True negatives FN : False negatives

$$Precision = \frac{TP}{TP + FP}$$: Ability to accurately detect the object

$$Accuracy = \frac{TP + TN}{TP + FN + FP + TN}$$: Ability to distinguish the object from the background

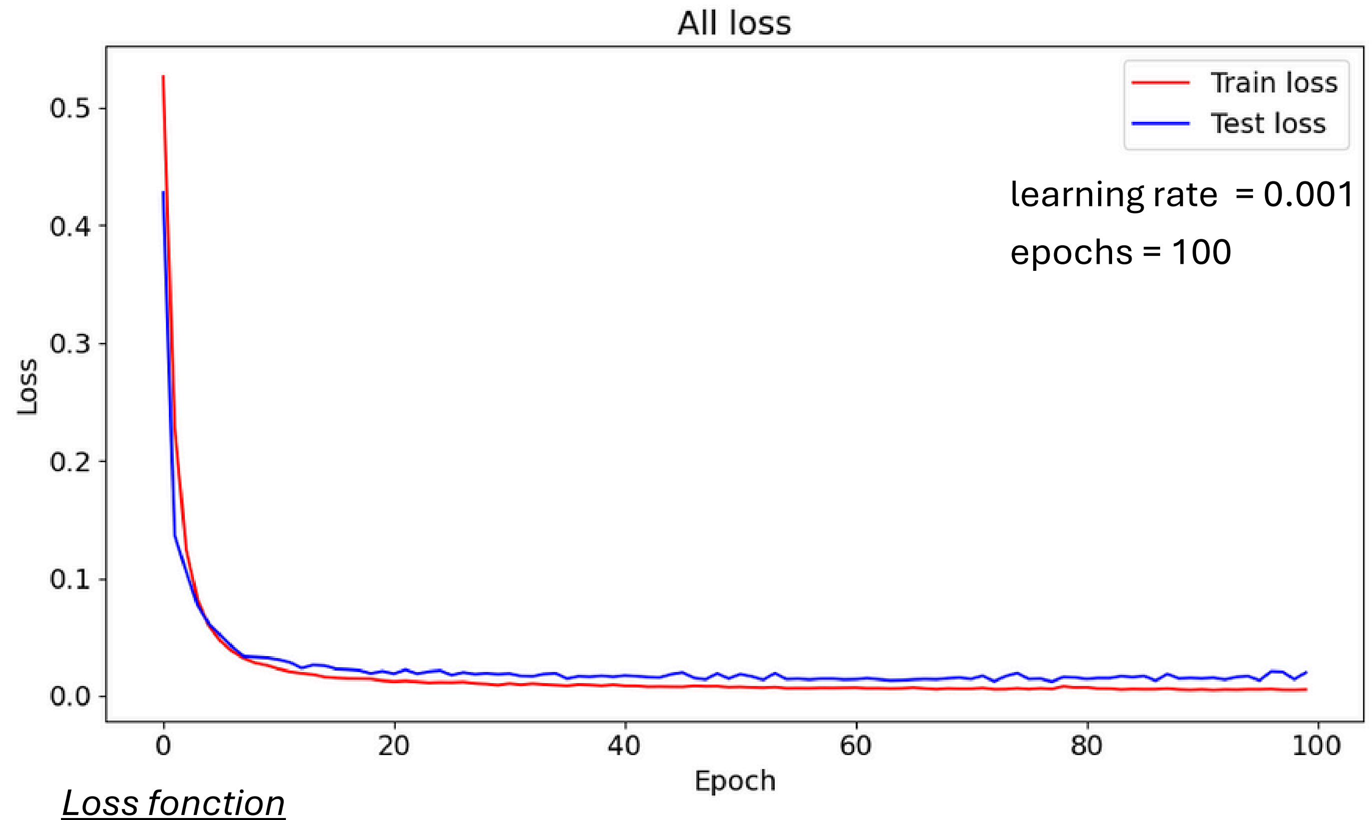
$$Recall = \frac{TP}{TP + FN}$$: Ability to accurately detect the object entirely

$$F1\,Score = 2 \times \frac{pecision \times recall}{precisio + recall}$$: Ability to distinguish the object from the background and entirely detecting it

MODEL PERFORMANCE

	EPOCHS					LEARNING RATE				
	15	30	50	70	100	0.0005	0.001	0.005	0.01	0.1
F1 SCORE	0,37	0,18	0,7	0,73	0,75	0,7	0,74	0,54	0,39	0,58
ACCURACY	0,2	0,99	0,99	1,0	1,0	1.0	1.0	1.0	0.99	0.99
RECALL	0,1	0,1	0,6	0,61	0,7	0,63	0.70	0.40	0,26	0,64
PRECISION	0,8	0,77	0,78	0,82	0,80	0,79	0,79	0,84	0,79	0,54

Results of model bench marking



Loss fonction