

An autoencoder-based approach for image cleaning in IACTs

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Zeuthen, 04-09-2024

Supervisors: Abhay Mehta, Robert Daniel Parsons

HELMHOLTZ



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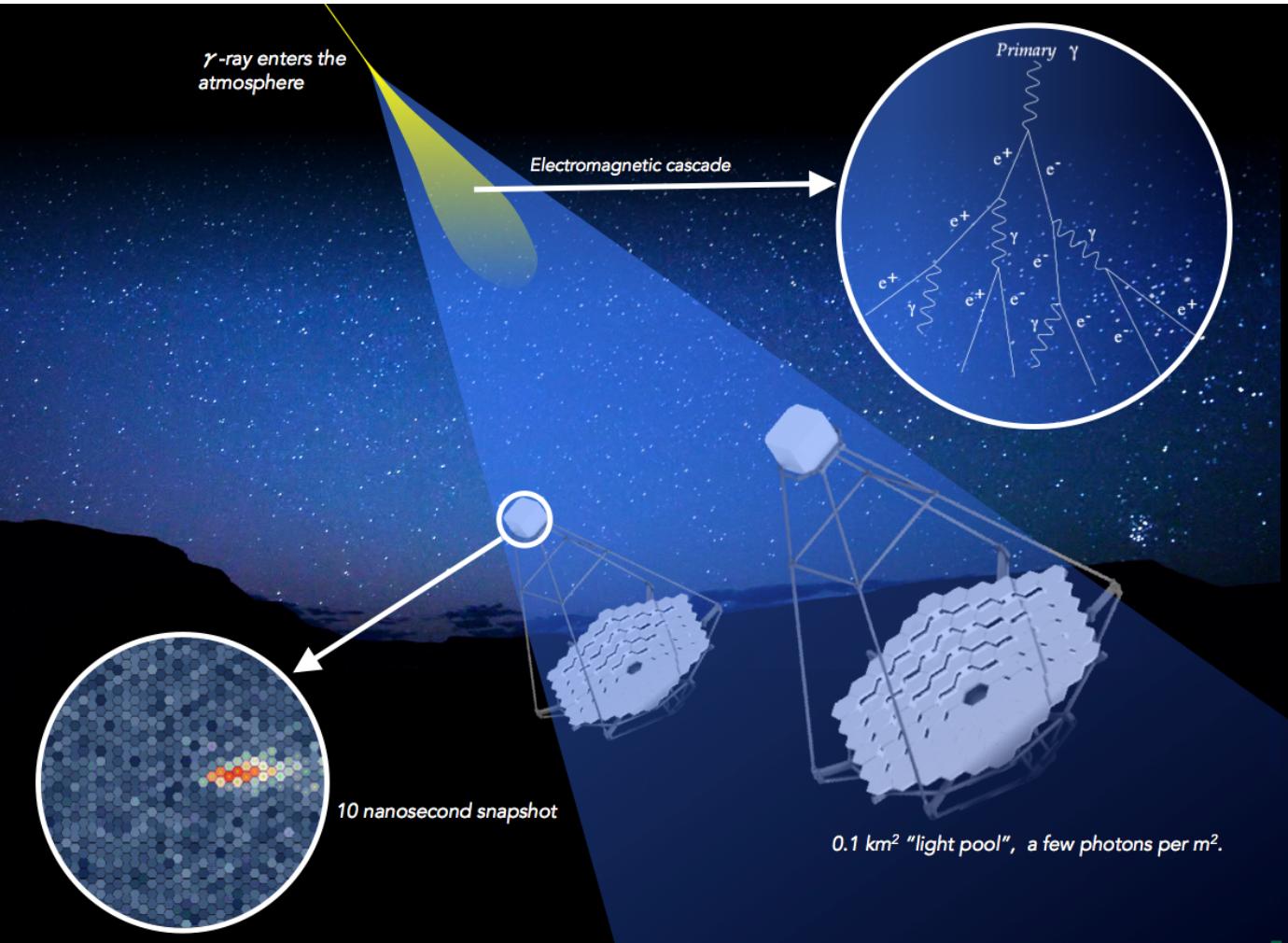
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IACTs and Image Cleaning

IACTs

Imaging Atmospheric Cherenkov Telescopes

- Gamma-ray astronomy
- Electromagnetic shower
- Atmospheric Cherenkov radiation
- Current detectors: H.E.S.S., VERITAS and MAGIC
- Future: CTA



[1]

Image Cleaning

- Noise: NSB and detector
- Cleaning = removing of noise
- Current method: tailcuts

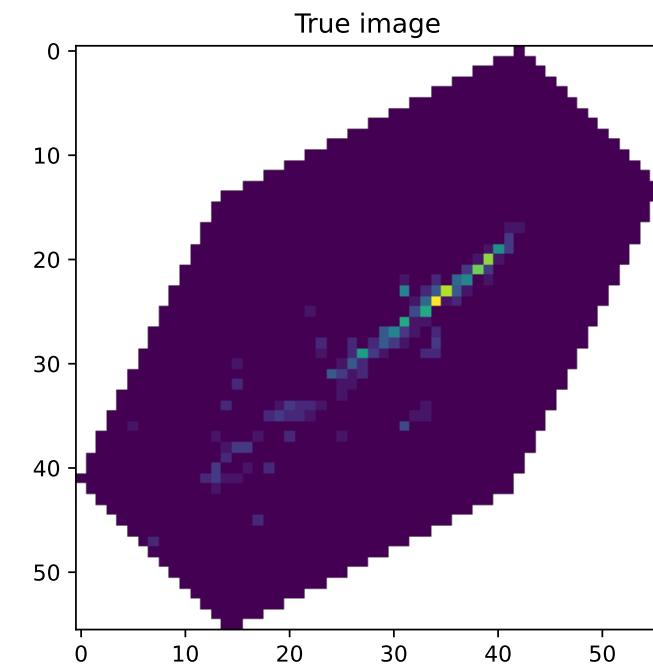
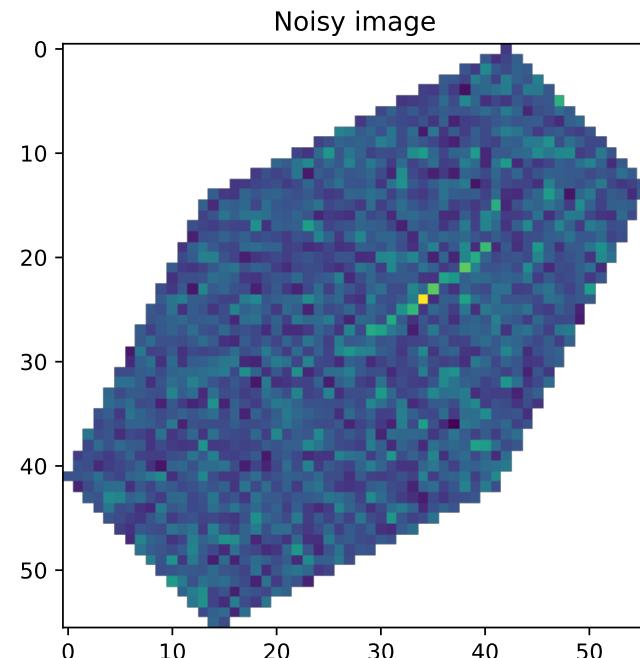
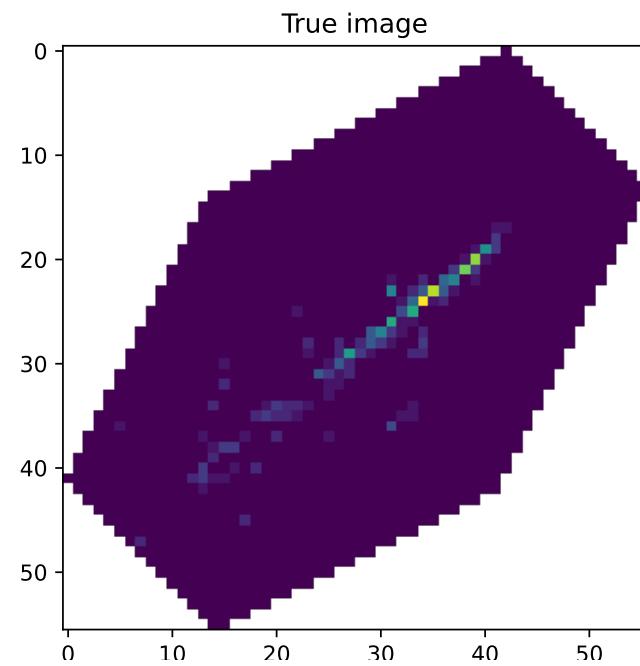
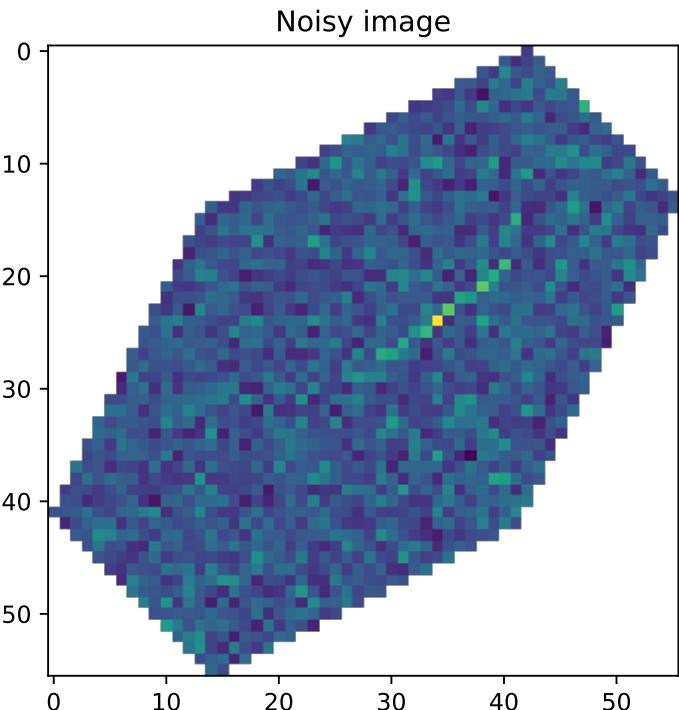


Image Cleaning

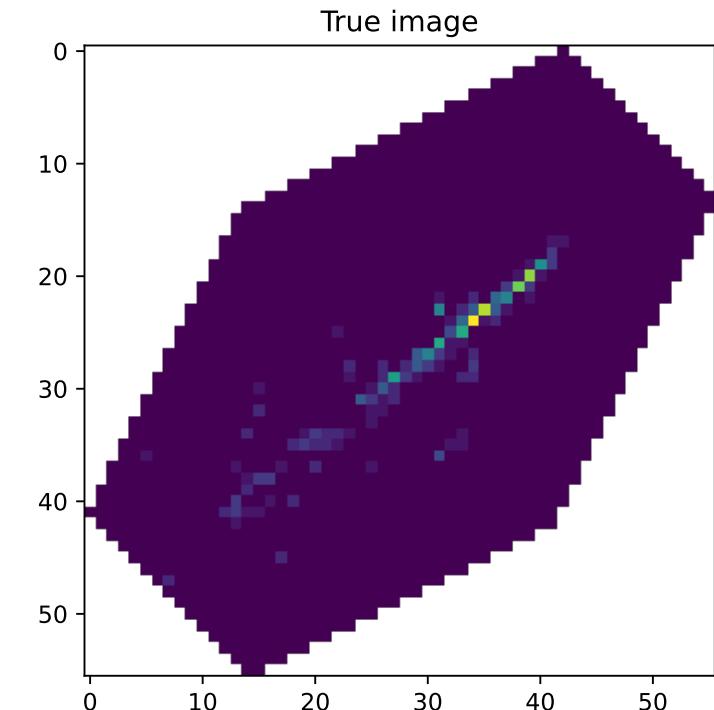
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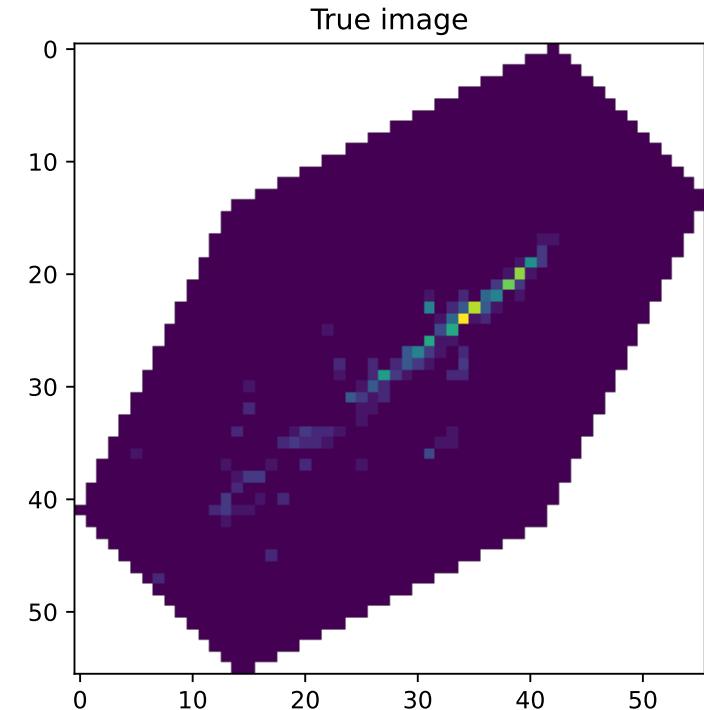
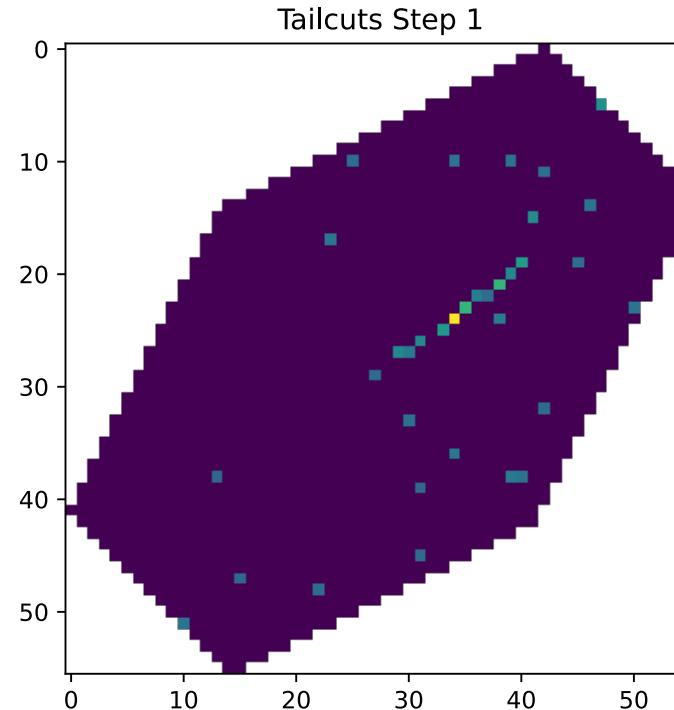
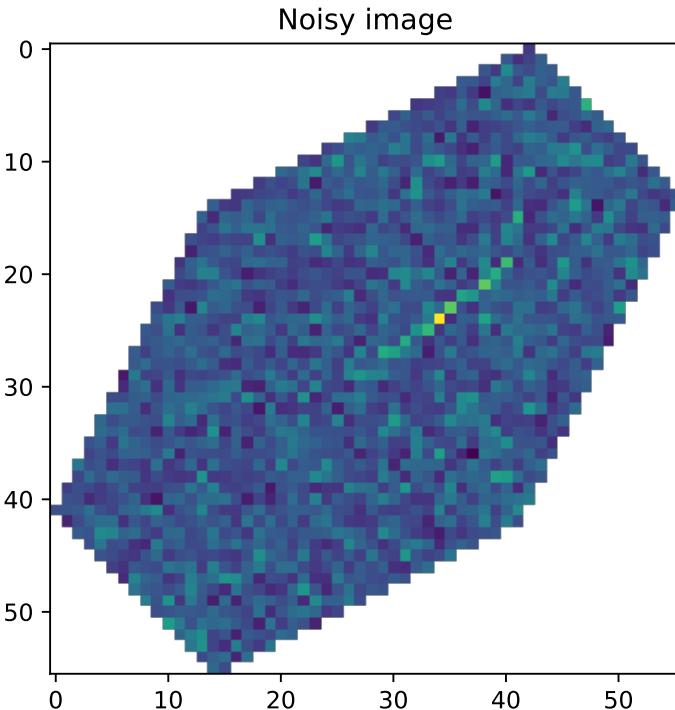
Tailcuts



Cleaning

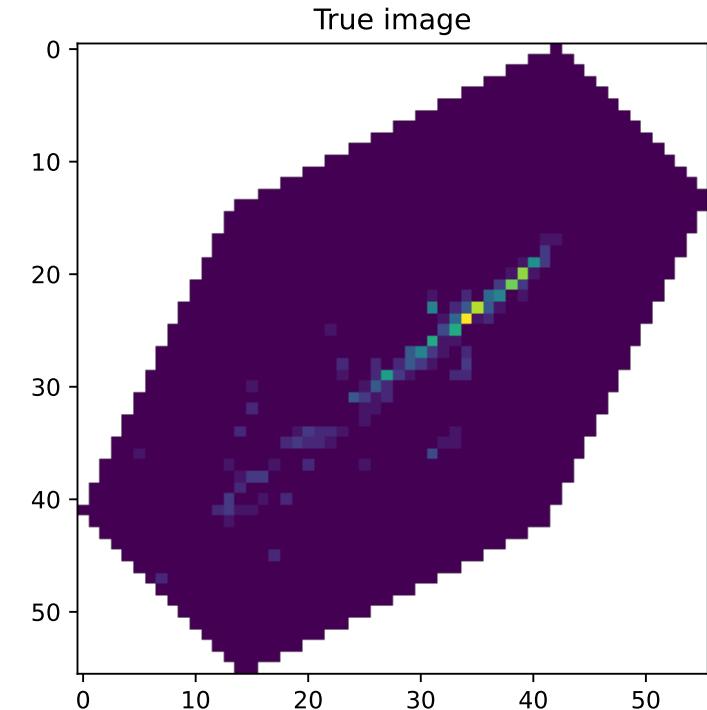
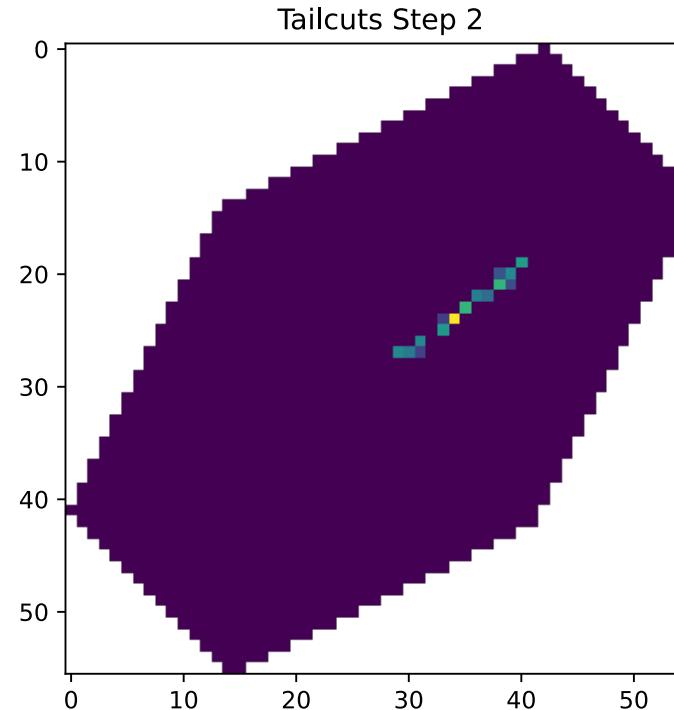
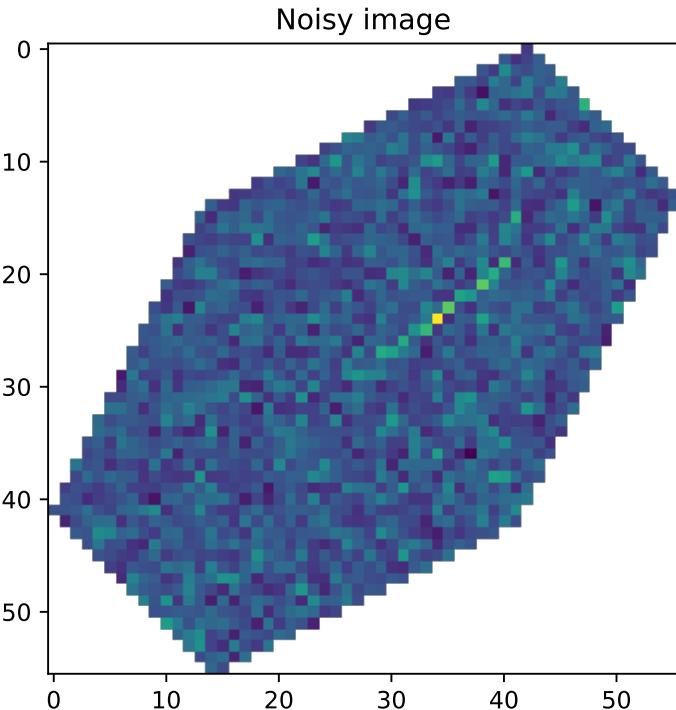


Tailcuts



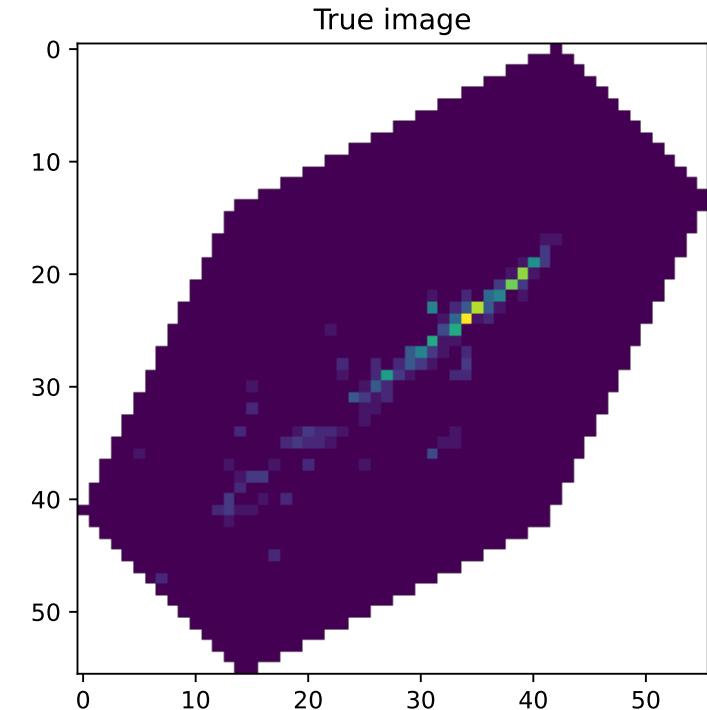
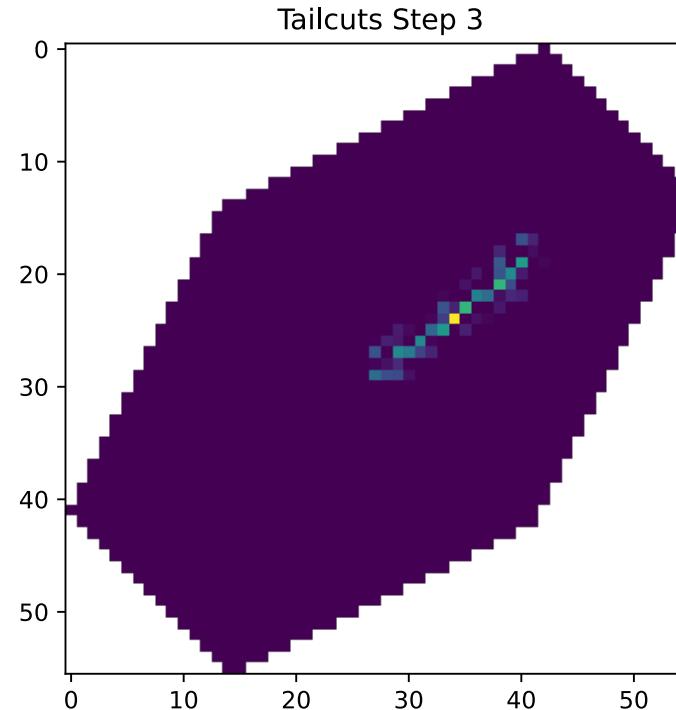
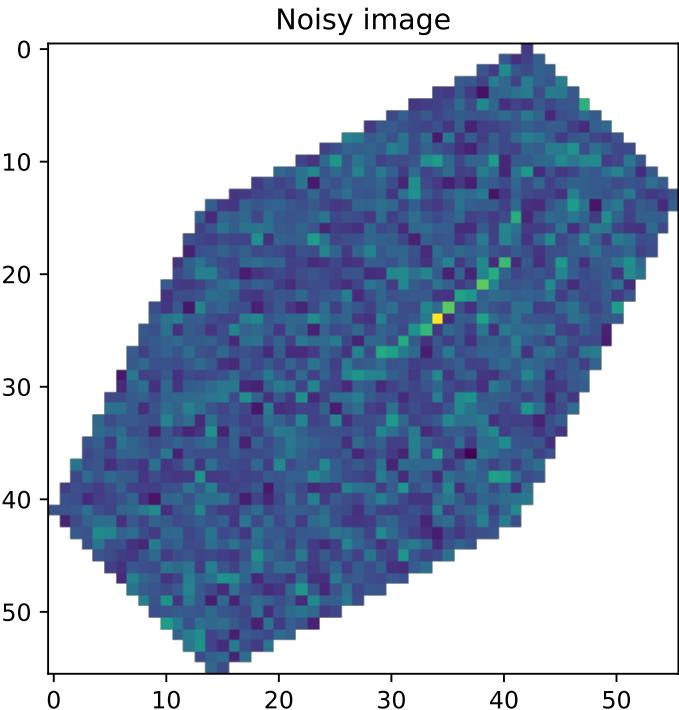
Pixel count > 7

Tailcuts



2 neighbouring pixels > 3.5

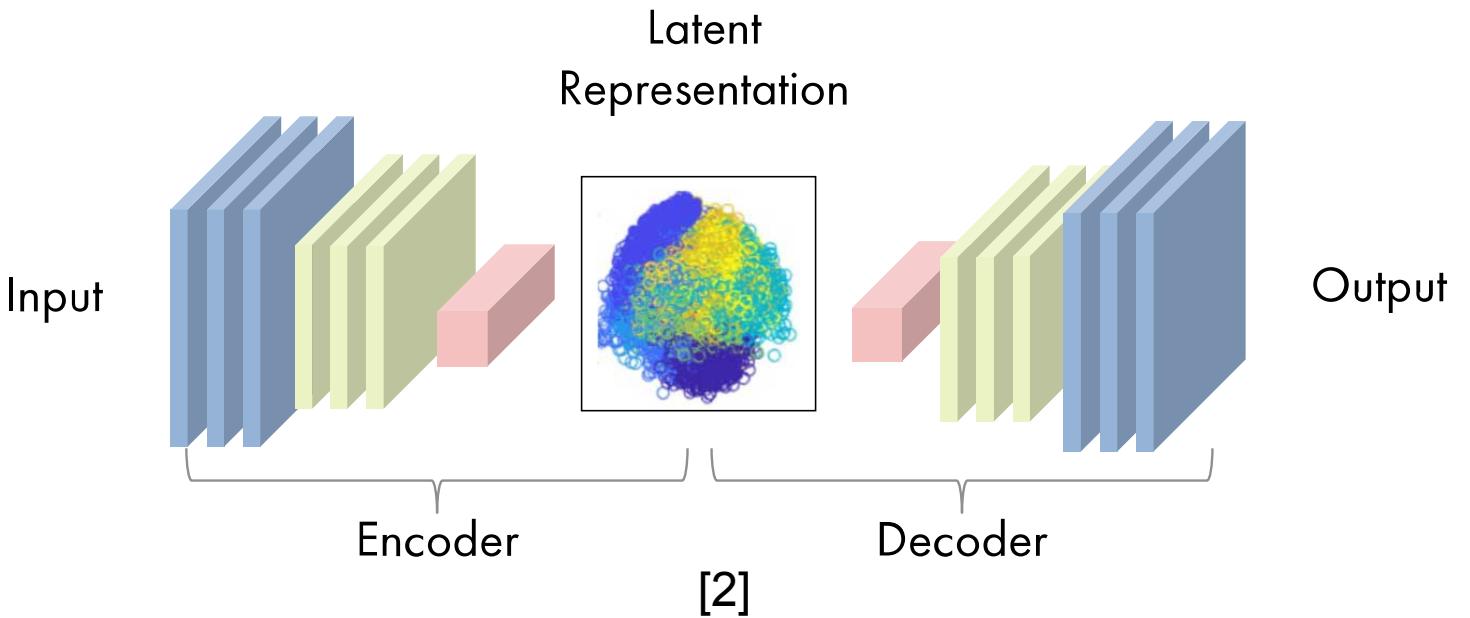
Tailcuts



Dilate with 2 rows

Autoencoders

- Machine learning
- 3 components:
 - Encoder
 - Lower-dimensional (latent) representation
 - Decoder
- Useful for noise reduction
- 2 approaches



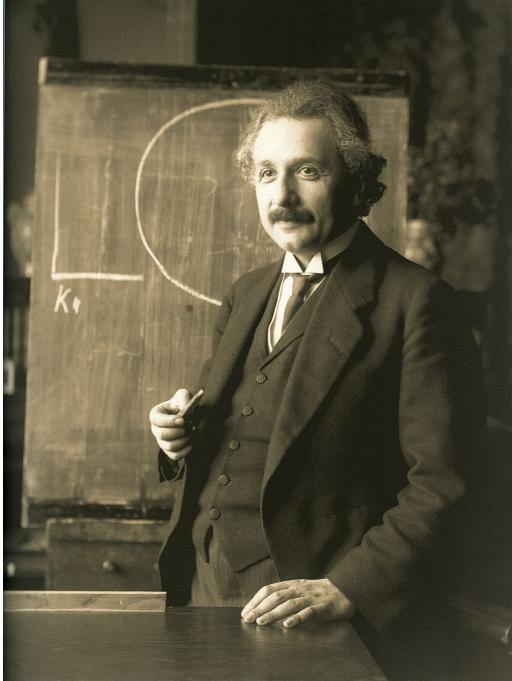
Segmentation-based approach

[3]

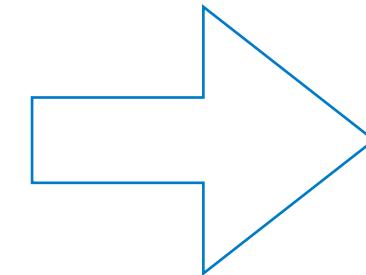
Segmentation

Cutting the signal from background

- Extracting signal from image
- Binary classification problem
- Performance metric:
Intersection-over-Union (IoU)
- Tailcuts: IoU = 0.41

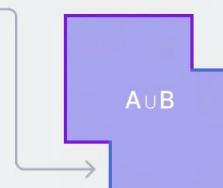
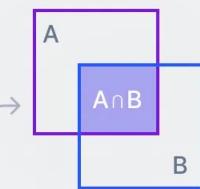


Segmentation



[4]

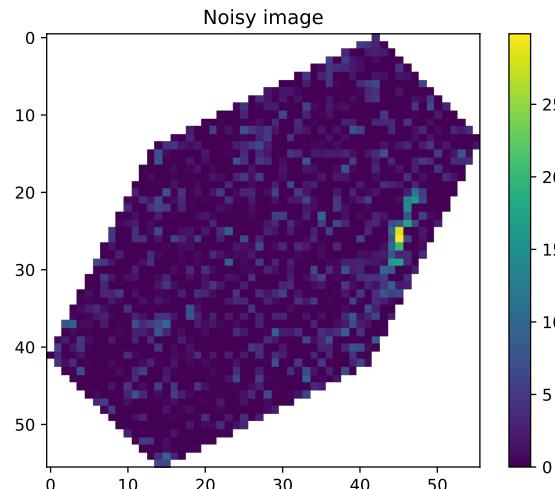
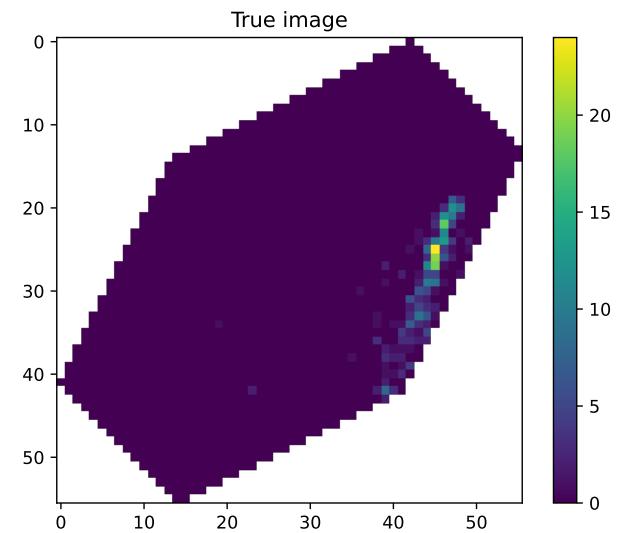
$$IoU = \frac{\text{Area of Overlap}}{\text{Area of Union}}$$



Segmentation Model Construction

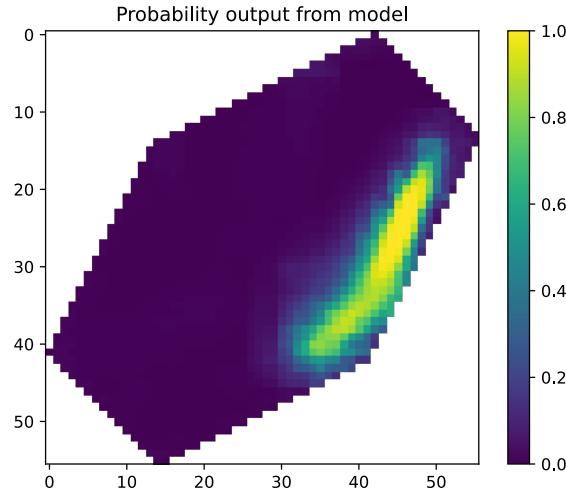
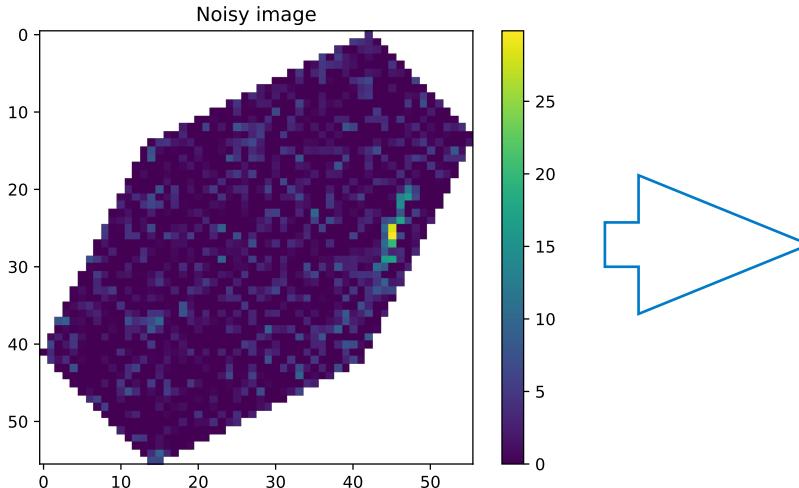
- 6400 image pairs
- Sum of pixels in noisy image > 60
- No normalization of data
- 4 layers: ~100k parameters
- Weighted binary cross-entropy

True
image

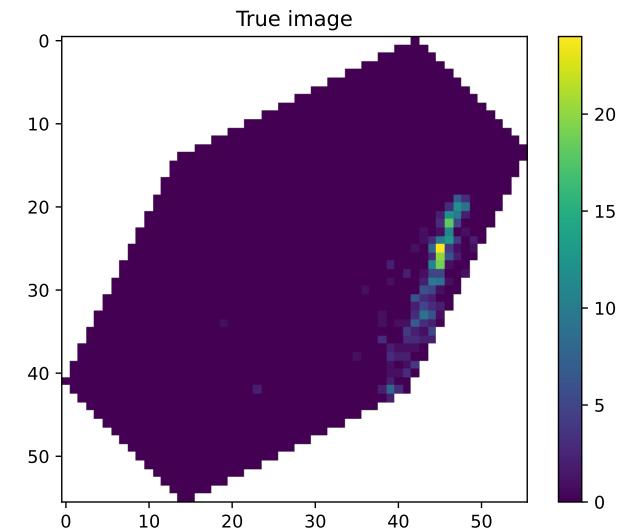


Segmentation Model Construction

- 6400 image pairs
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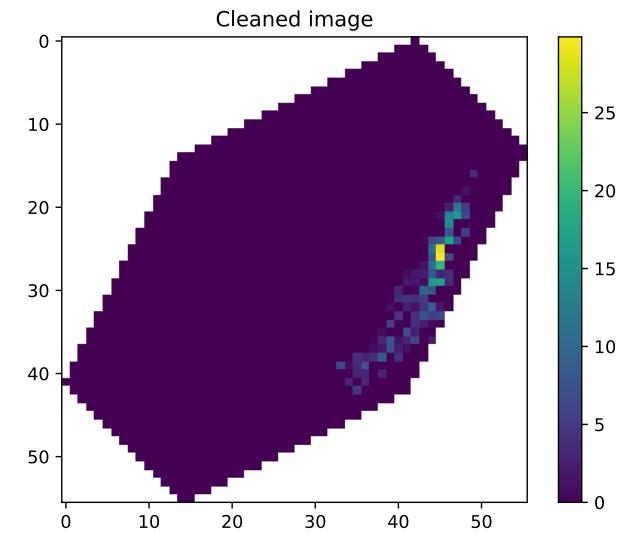
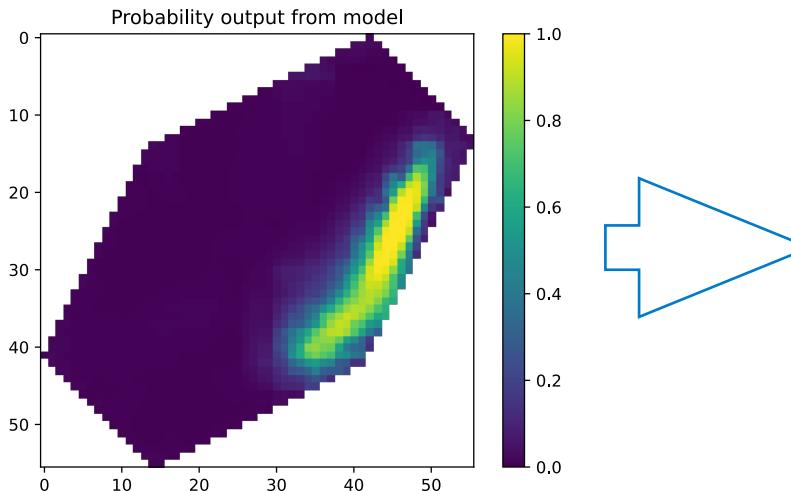
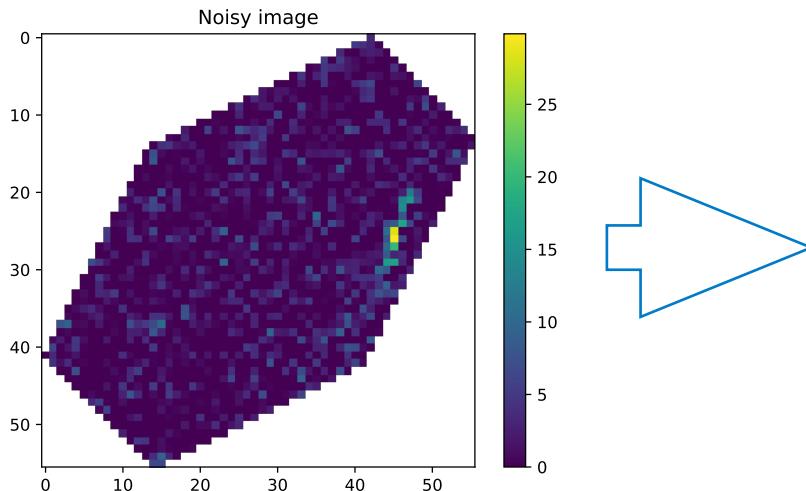
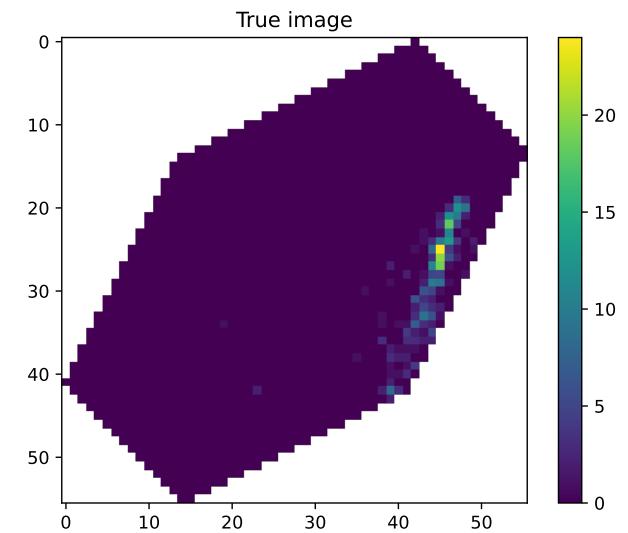
True
image



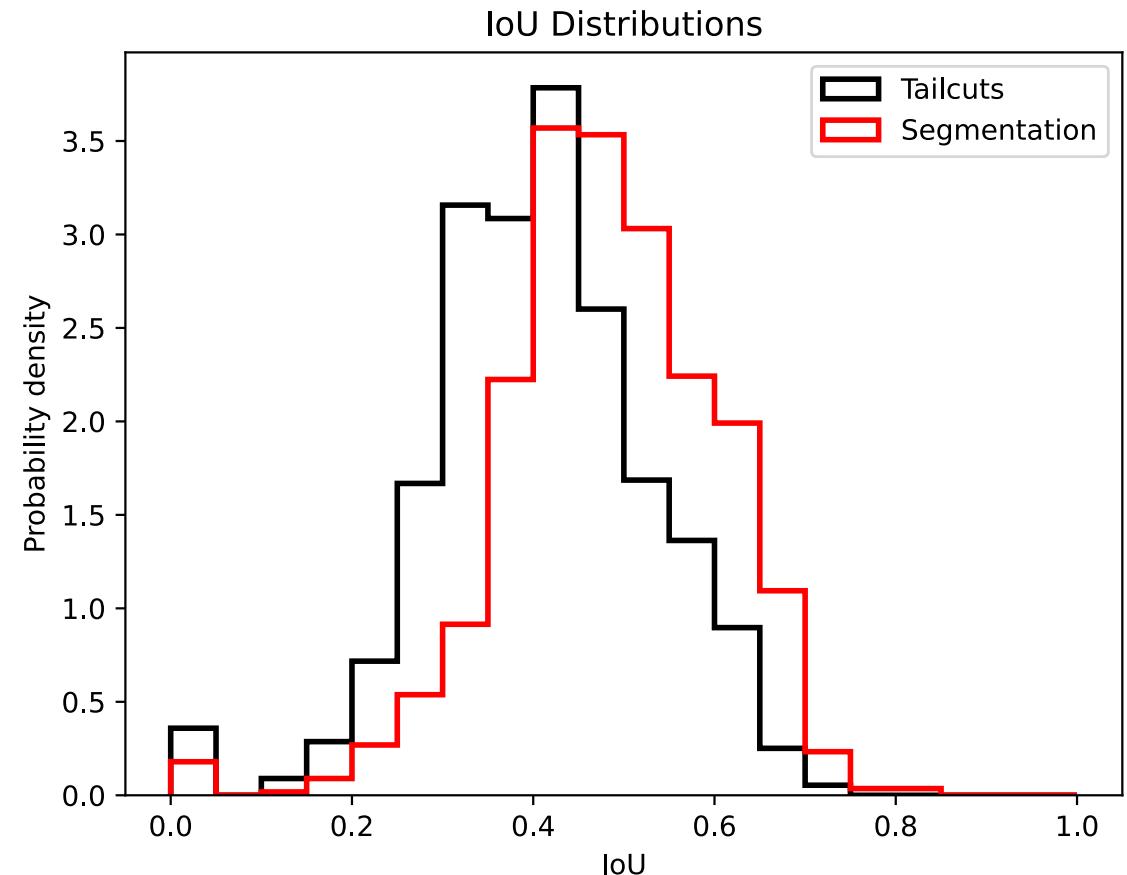
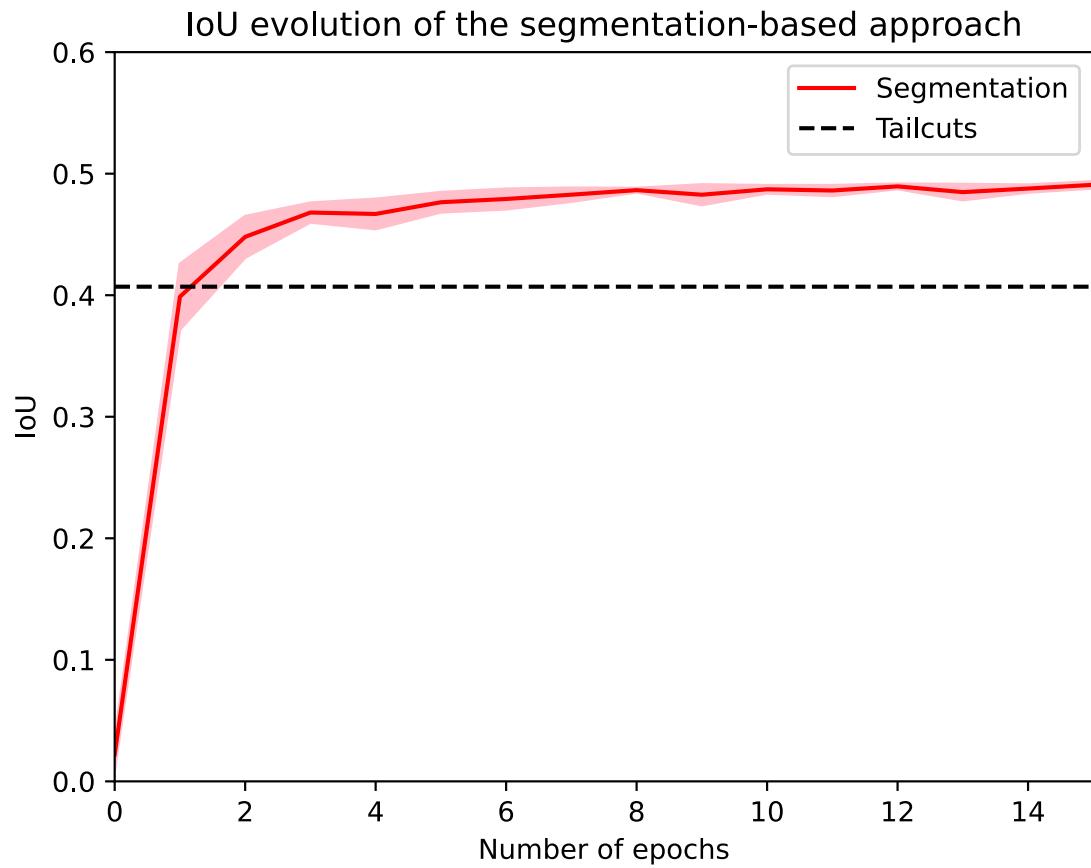
Segmentation Model Construction

- 6400 image pairs
- Sum of pixels in noisy image > 60
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- 4 layers: ~100k parameters
- Weighted binary cross-entropy

True
image



Performance Segmentation Model



Tailcuts: mean IoU = 0.41

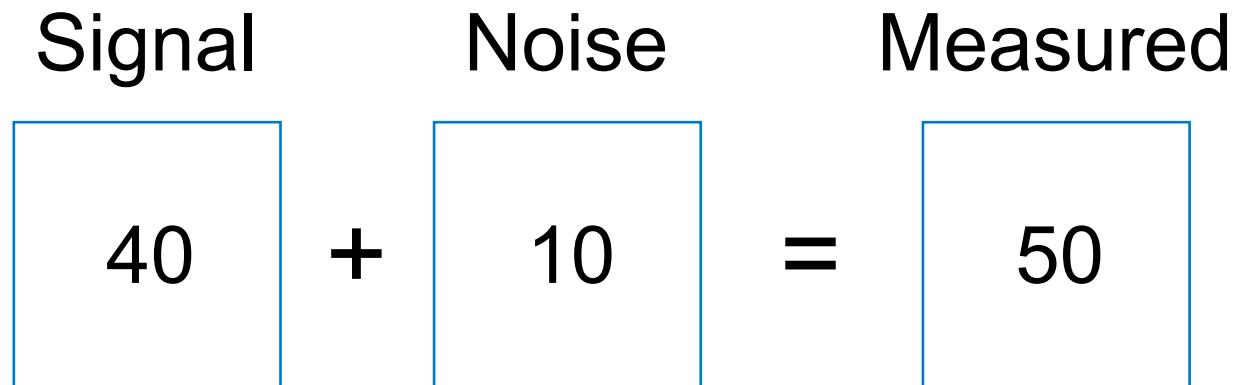
Segmentation: mean IoU = 0.49

Regression-based approach

Regression

- Estimate all pixel counts
- Advantage: remove noise from pixels that also contain signal
- Mean-square error loss function

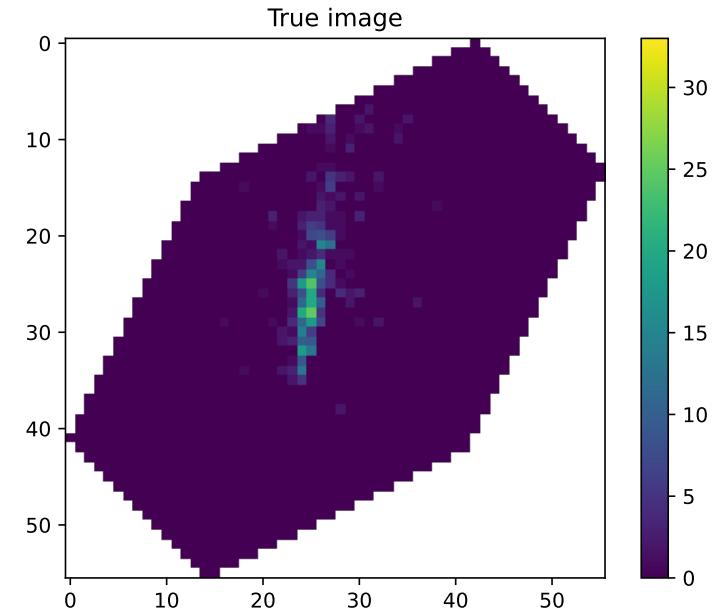
$$\text{MSE} = \frac{1}{N} \sum_{i=1}^N (y_i - \hat{y}_i)^2$$



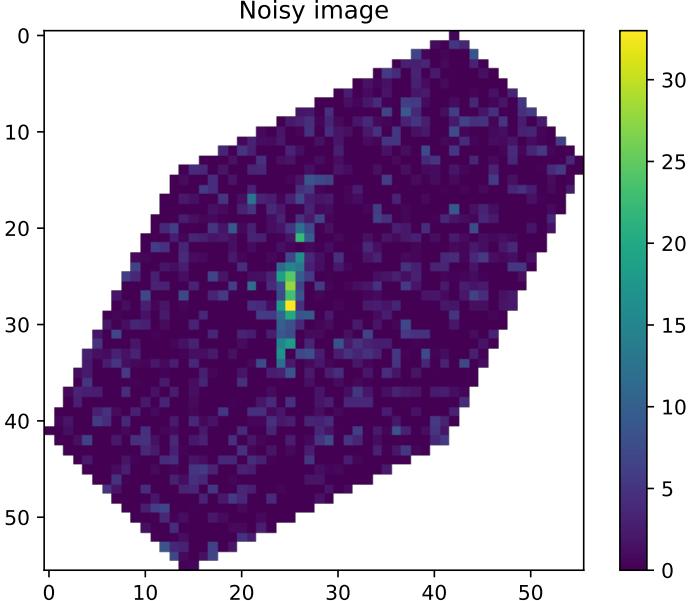
Model Construction

- 6400 image pairs
- Sum of noisy images > 60
- Normalize pixels to range 0 to 1
- 4 layers: ~100k parameters

True
image



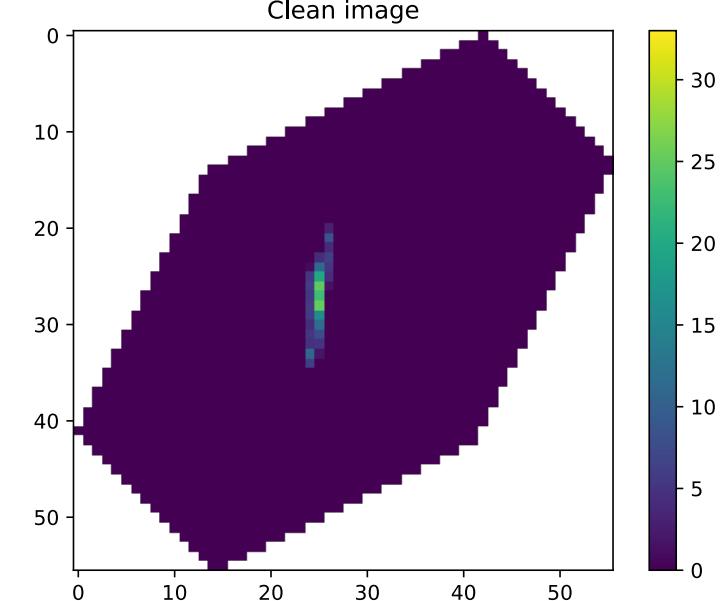
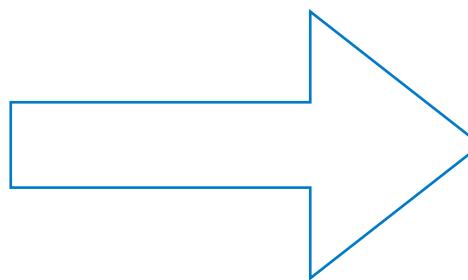
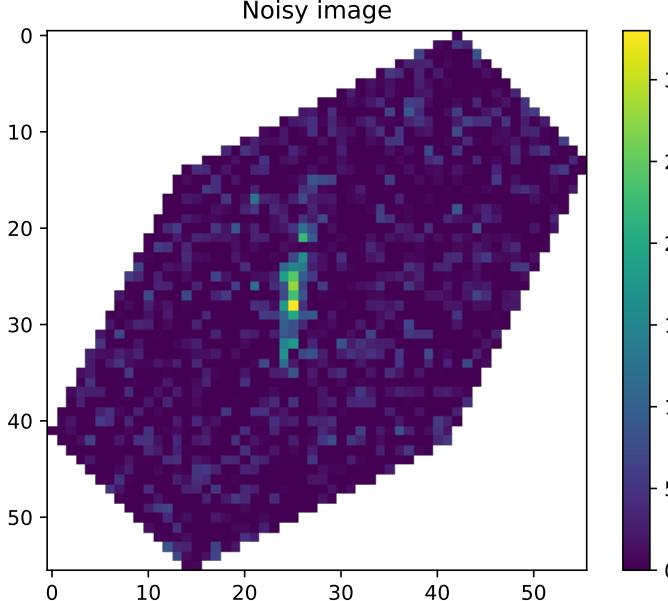
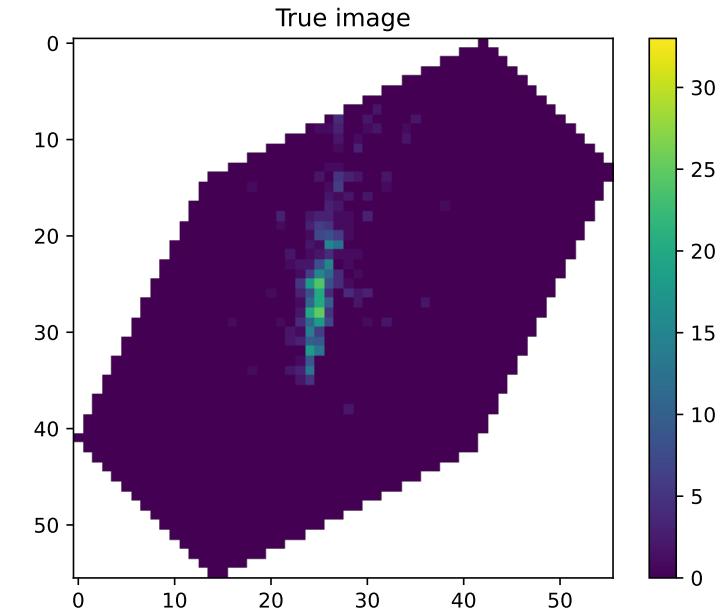
Noisy image



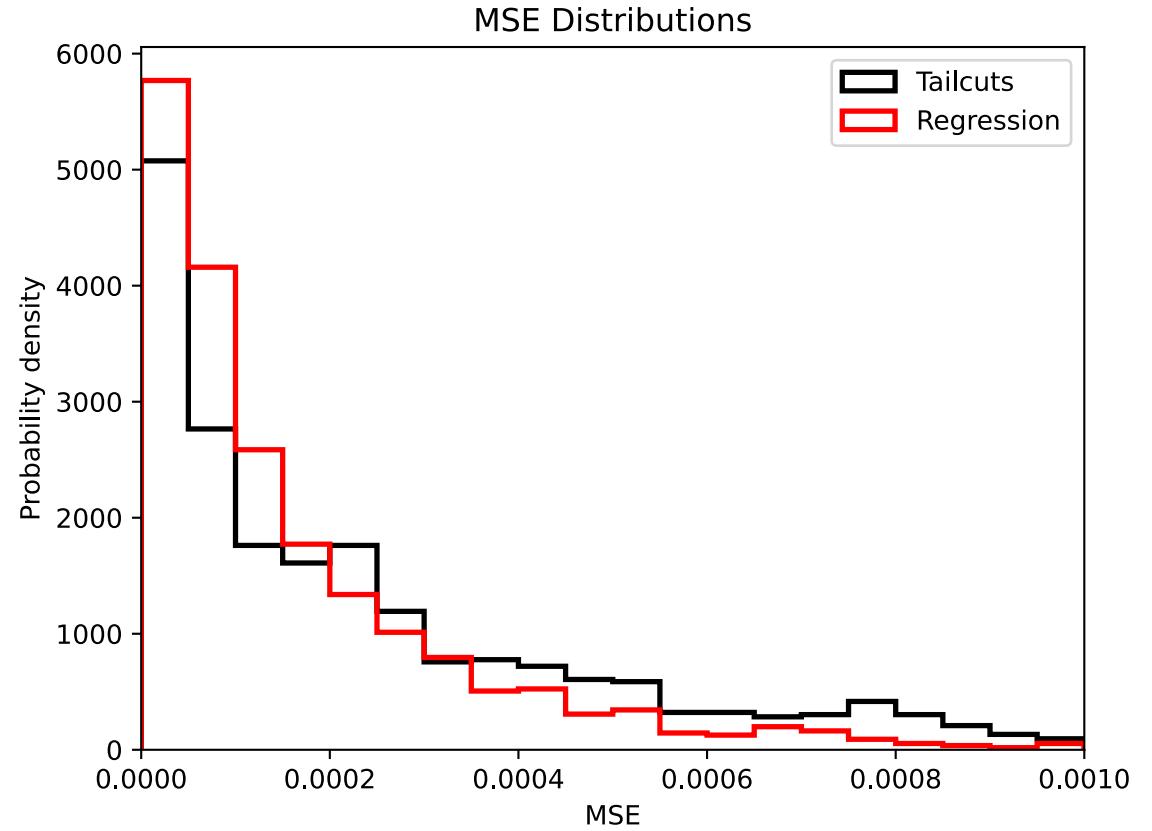
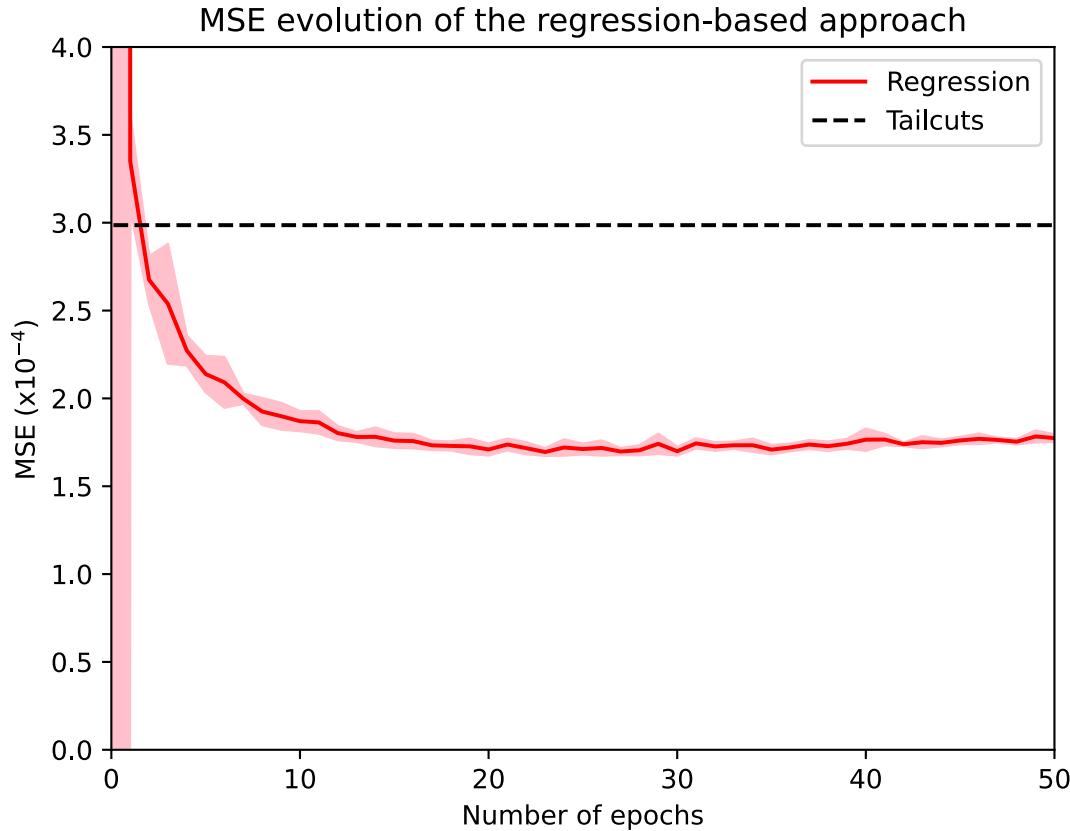
Model Construction

- 6400 image pairs
- Sum of noisy images > 60
- Normalize pixels to range 0 to 1
- 4 layers: ~100k parameters

True
image



Performance Regression Model



Tailcuts: MSE = 0.00030
Regression: MSE = 0.00016

Comparison and further Reconstruction

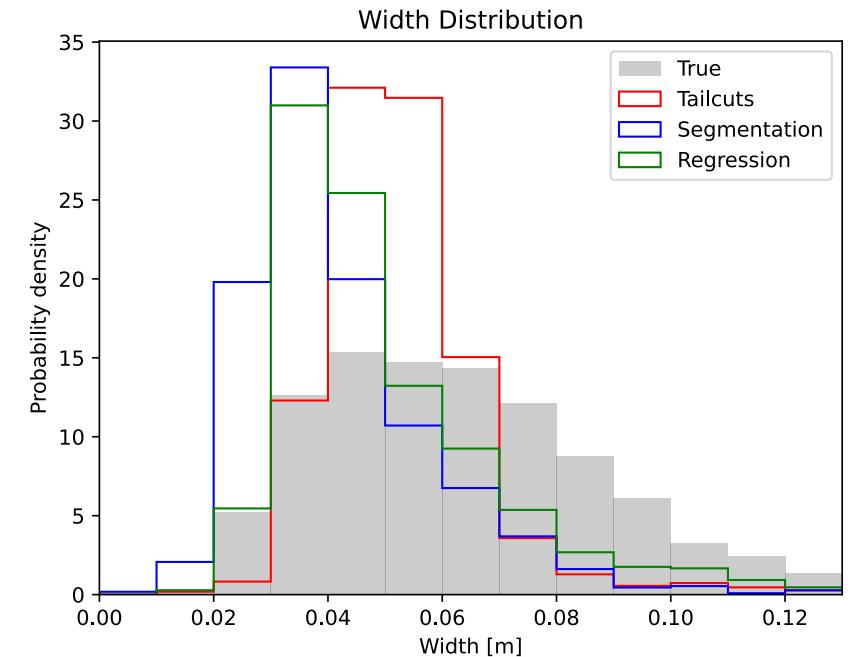
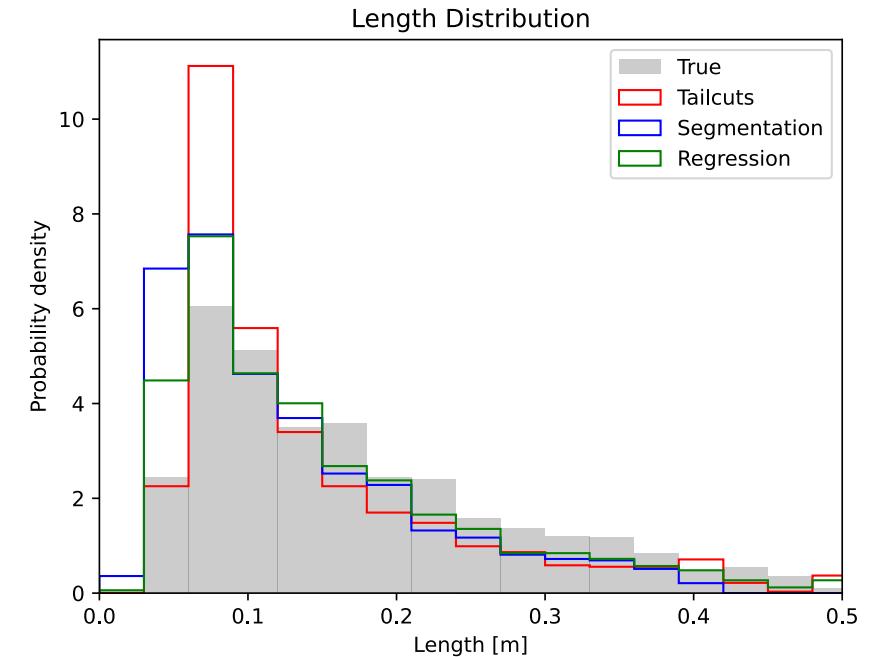
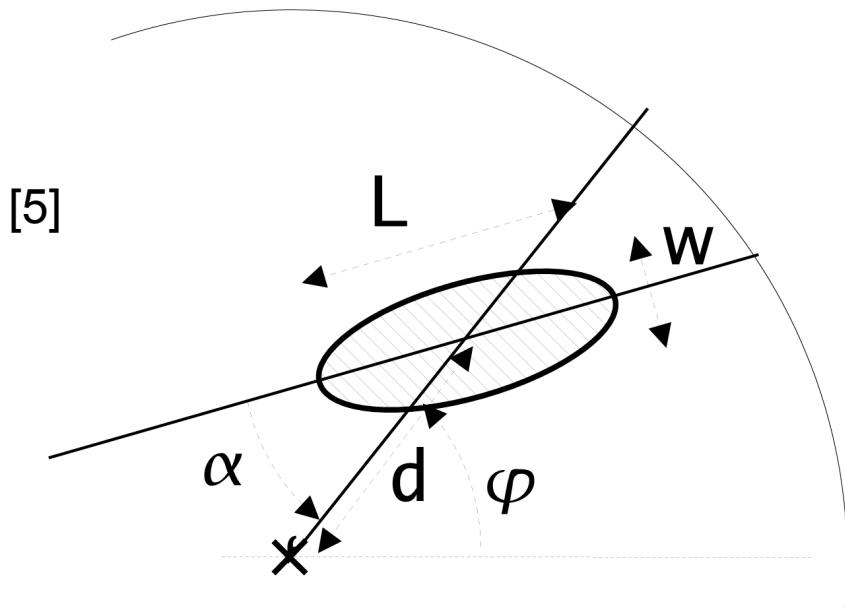
Comparison of Different Approaches

- Segmentation: most signal included
- Regression: counts most realistic
- Both improvement upon tailcuts

	IoU	MSE ($\times 10^{-4}$)
Tailcuts	0.41	2.99
Segmentation	0.49	2.62
Regression	0.46	1.63

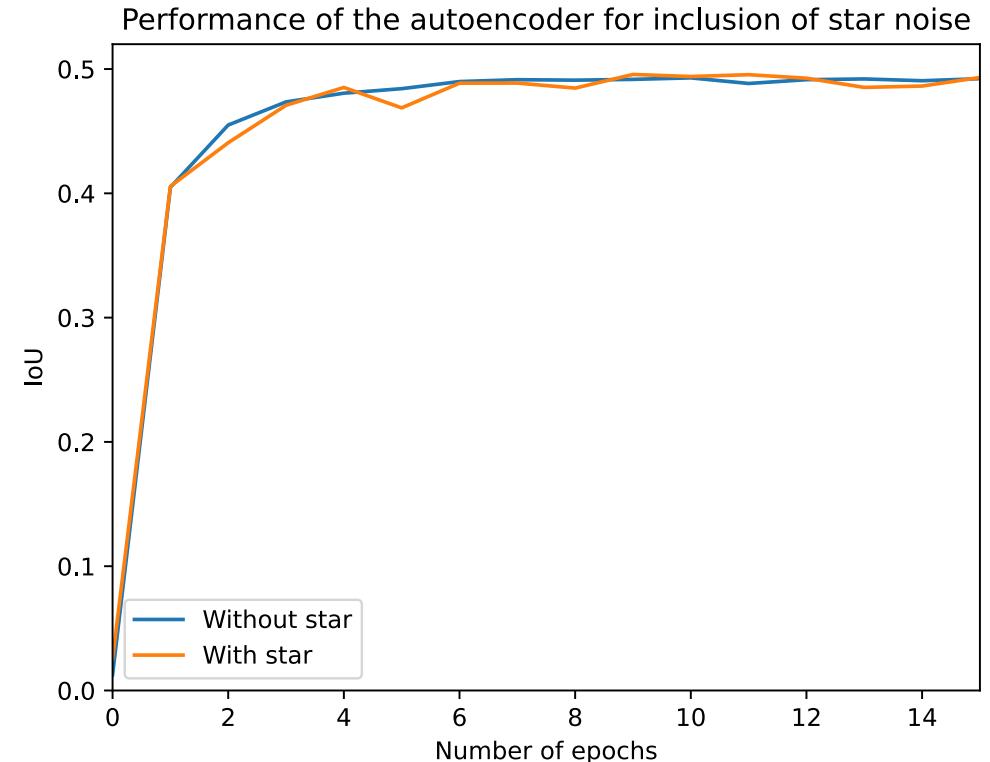
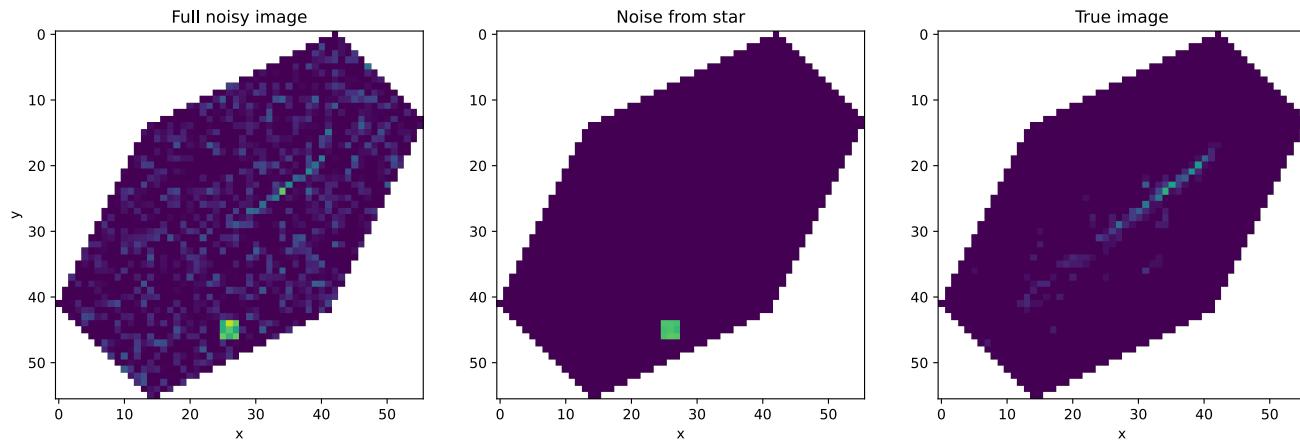
Hillas Parameters

- Next step in reconstruction
- Parameters describing topological information of signal



Future

- Test gamma-ray/proton seperation
- Test number of measured gamma rays
- Apply to real data
- Noise from stars



Thank you

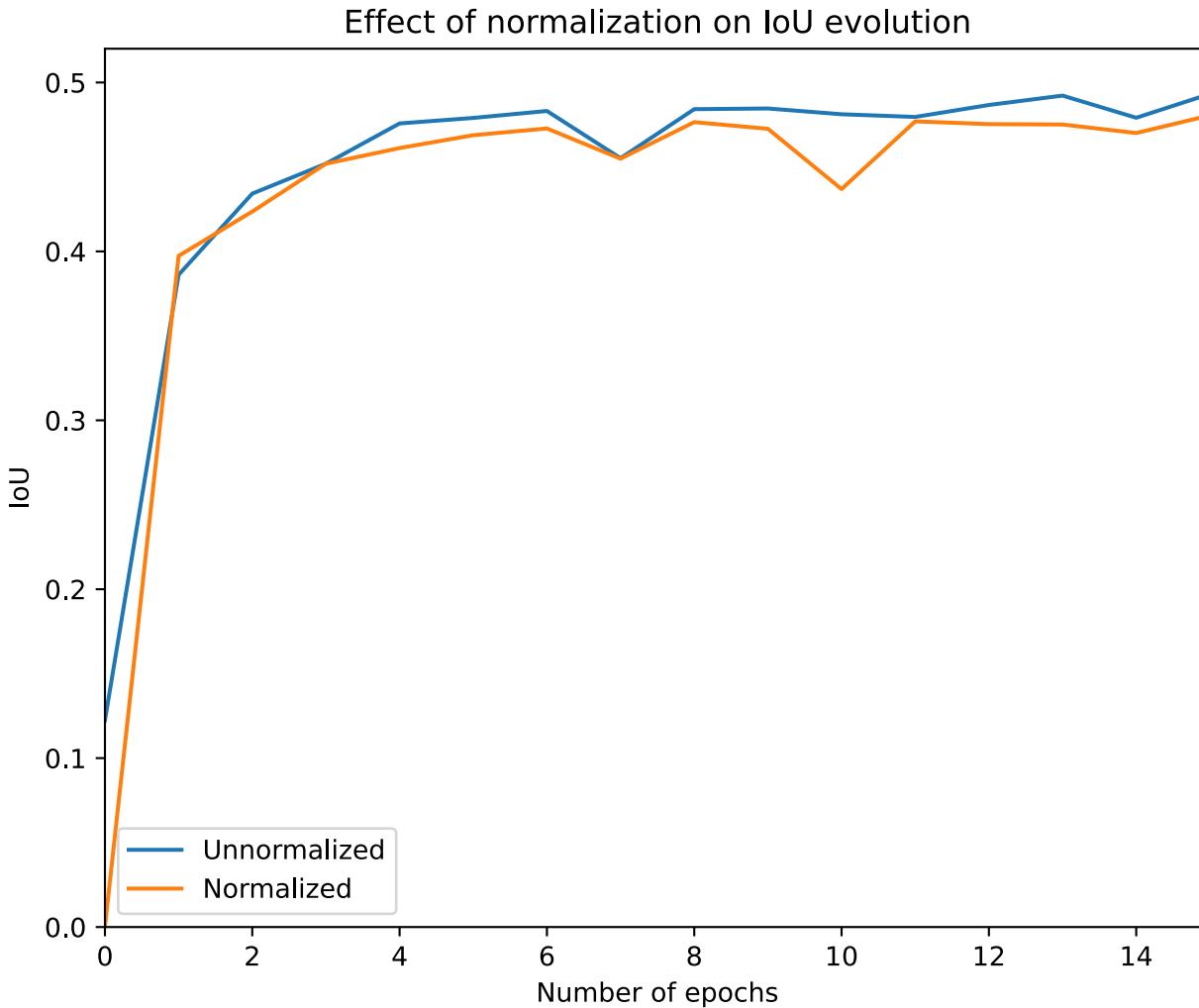


Sources

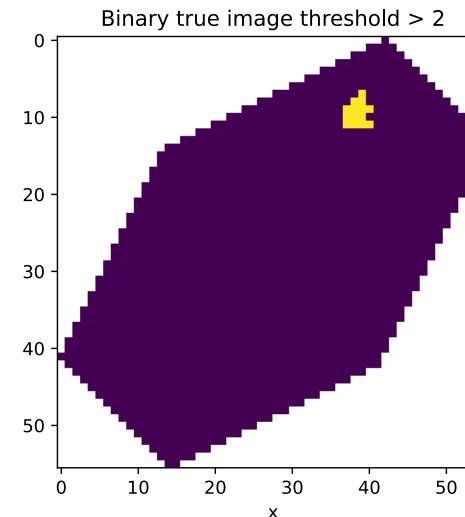
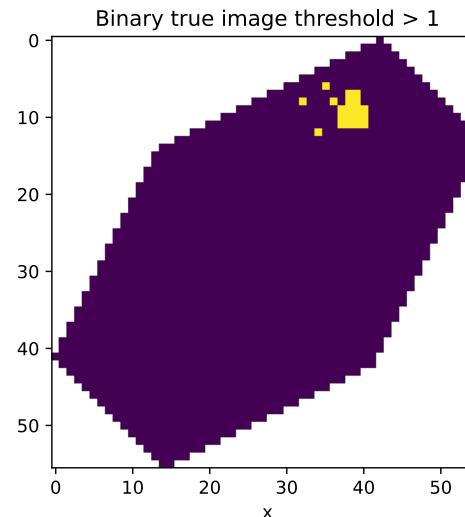
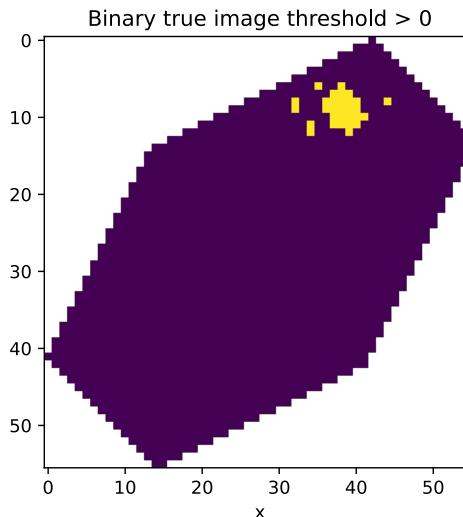
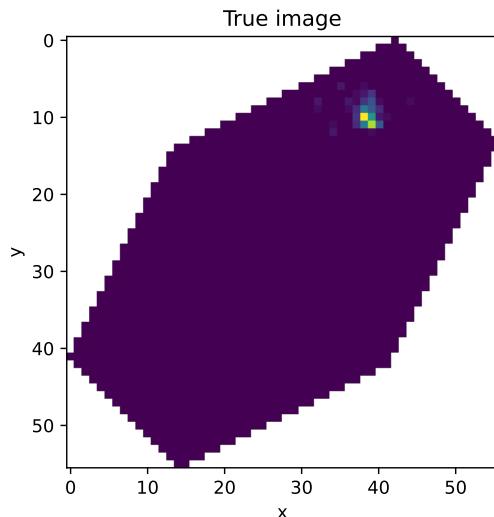
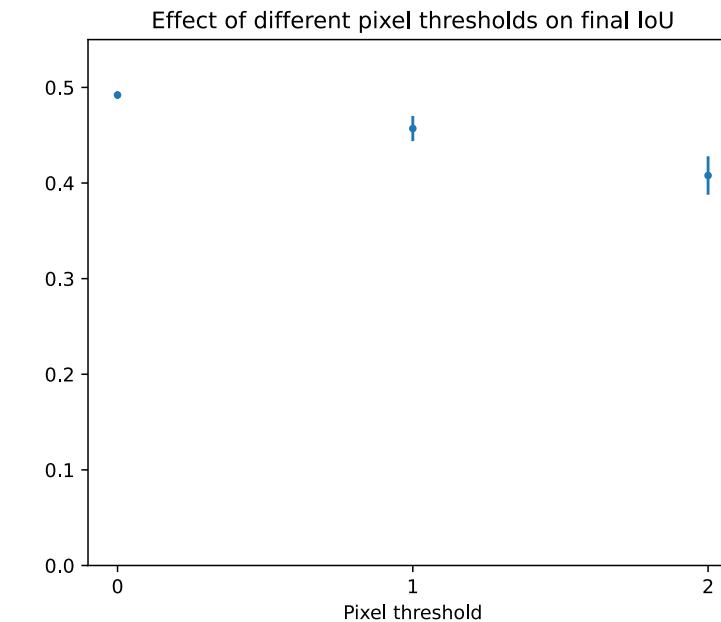
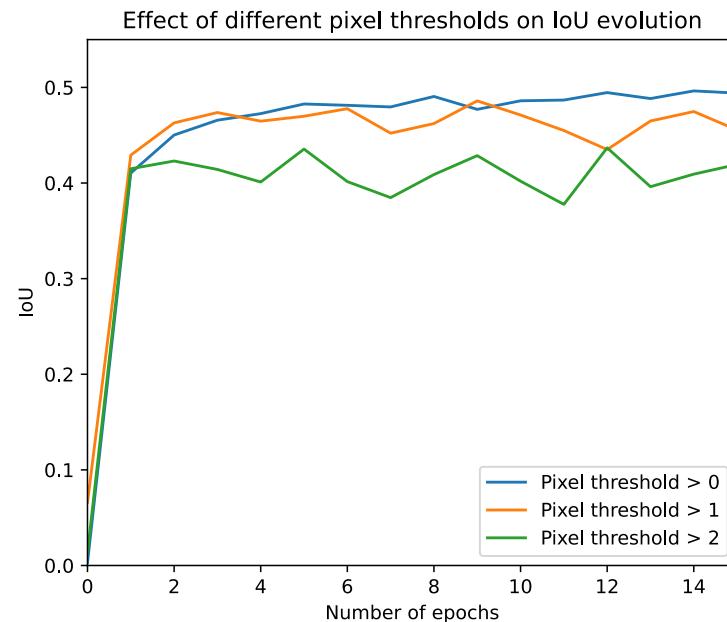
1. R. White (MPIK) / K. Bernlohr (MPIK) / DESY <https://www.iac.es/en/projects/iactec-large-telescopes-cherenkov-telescope-array-observatory-ctao>
2. <https://de.mathworks.com/discovery/autoencoder.html>
3. Ferdinand Schmutzler <https://web.archive.org/web/20071026151415/http://www.anzenbergergallery.com/en/article/134.html>
4. <https://pyimagesearch.com/2016/11/07/intersection-over-union-iou-for-object-detection/>
5. Mathieu De Naurois. Analysis methods for atmospheric cerenkov telescopes. arXiv preprint astro-ph/0607247, 2006.

Backup slides

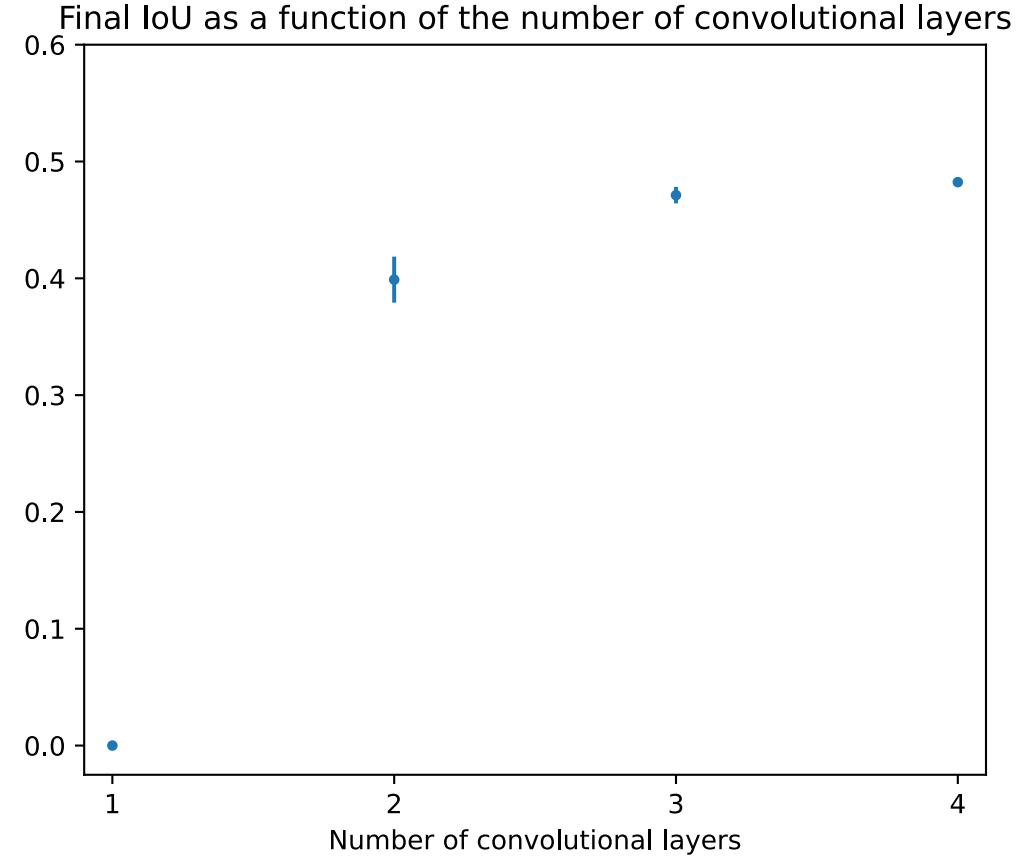
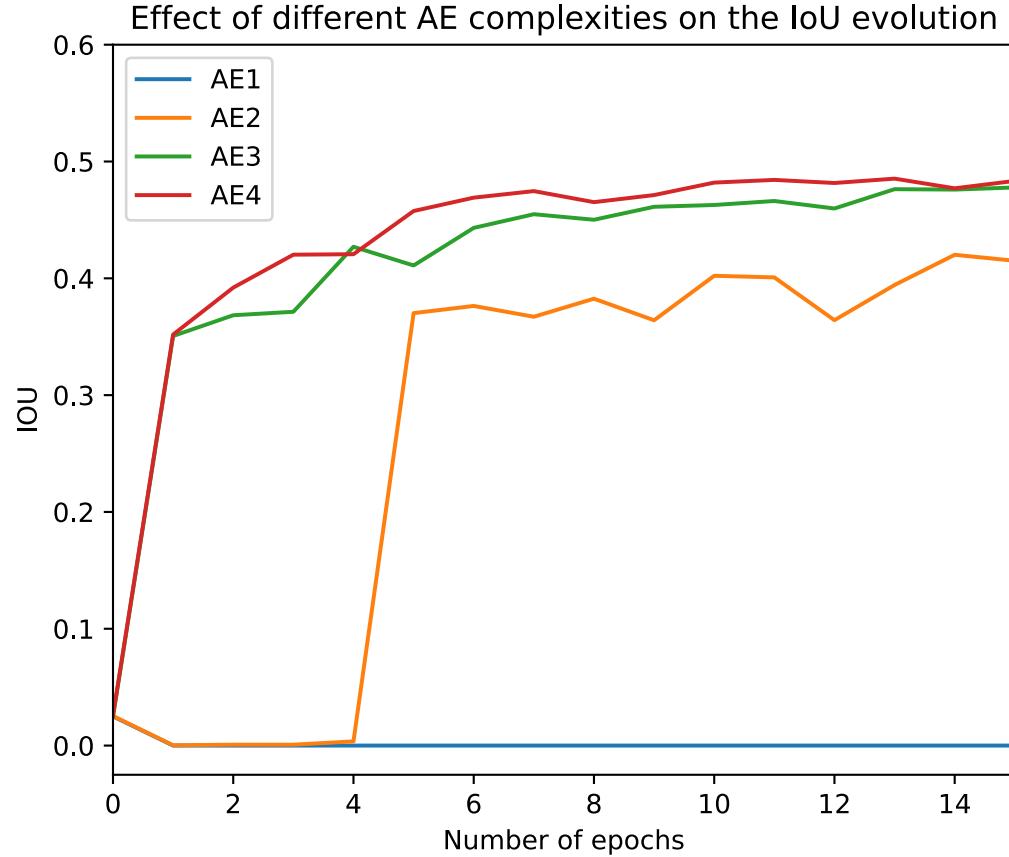
Segmentation - data preprocessing - normalization



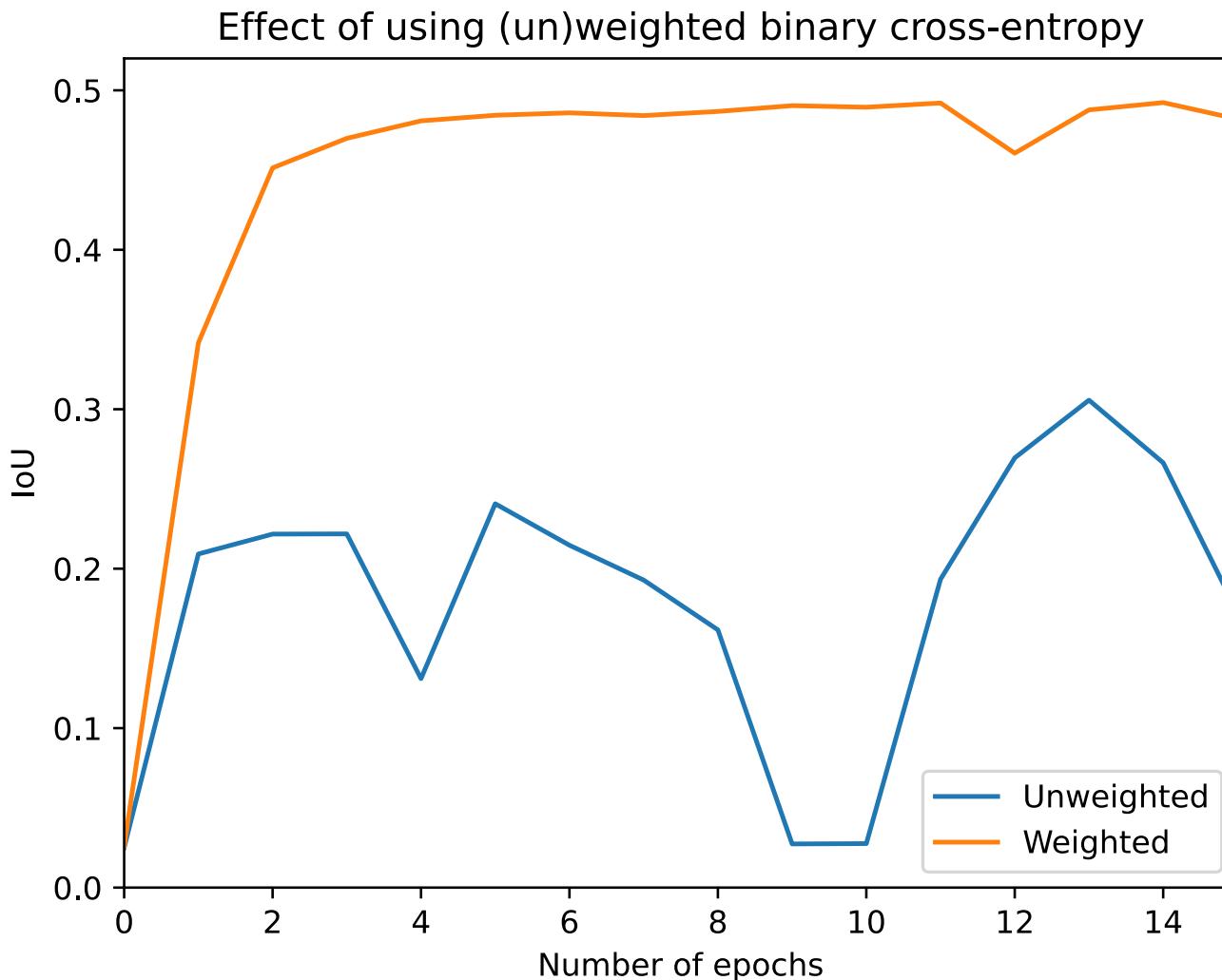
Segmentation - data preprocessing - pixel thresholds



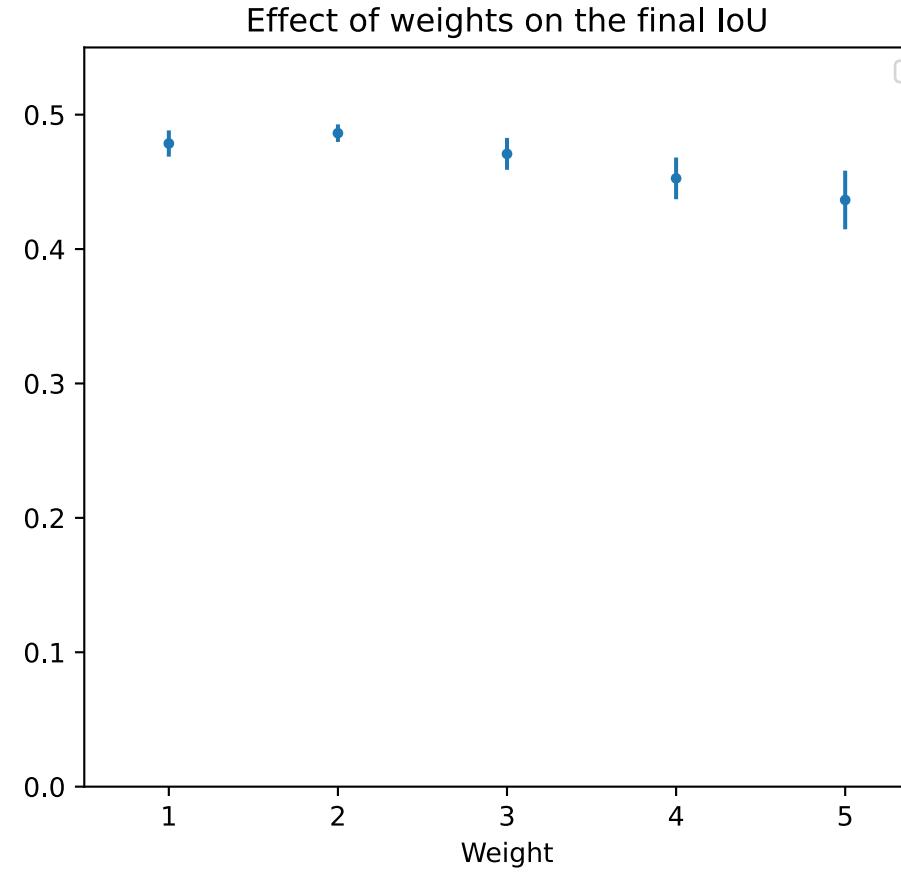
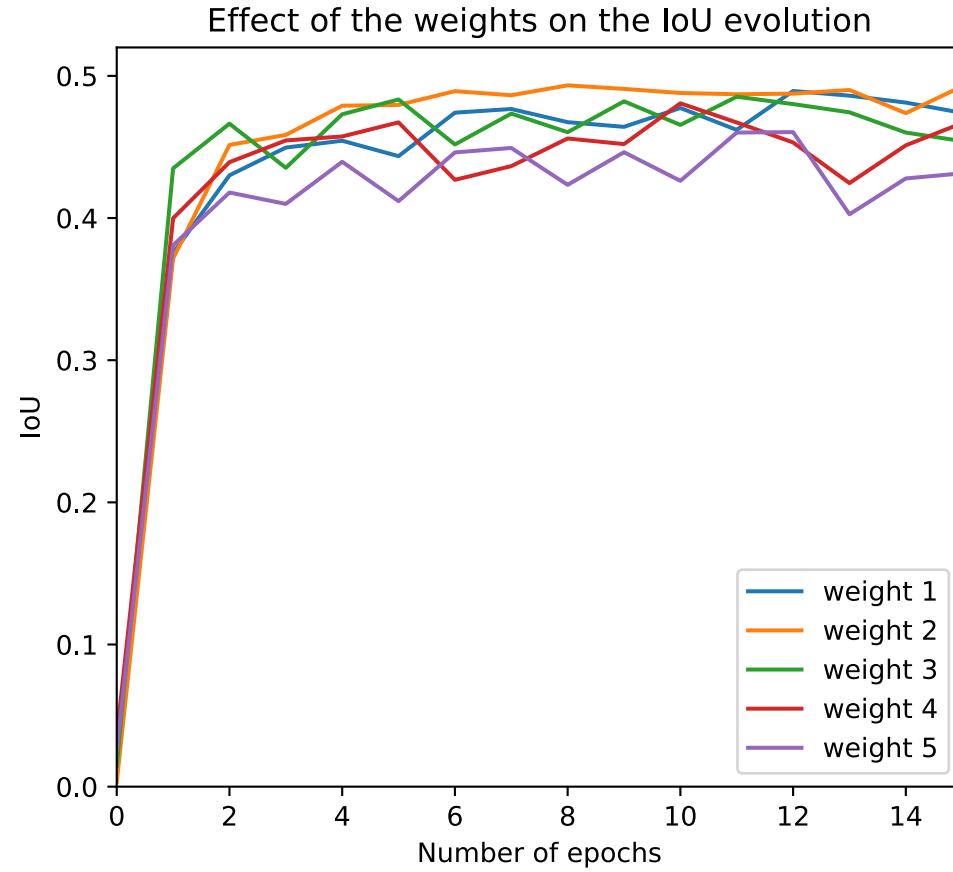
Segmentation - model development - complexity



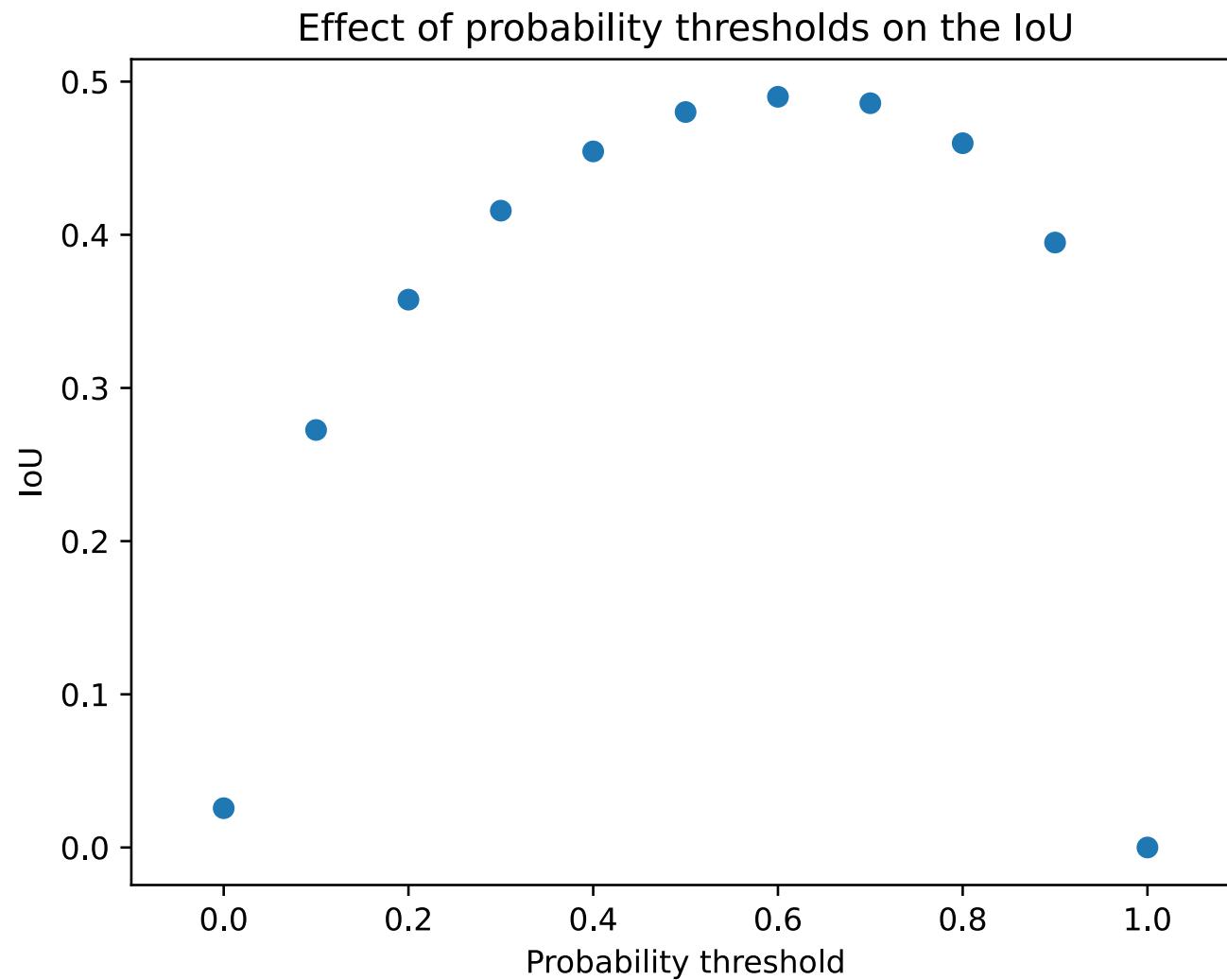
Segmentation - model development - weights (I)



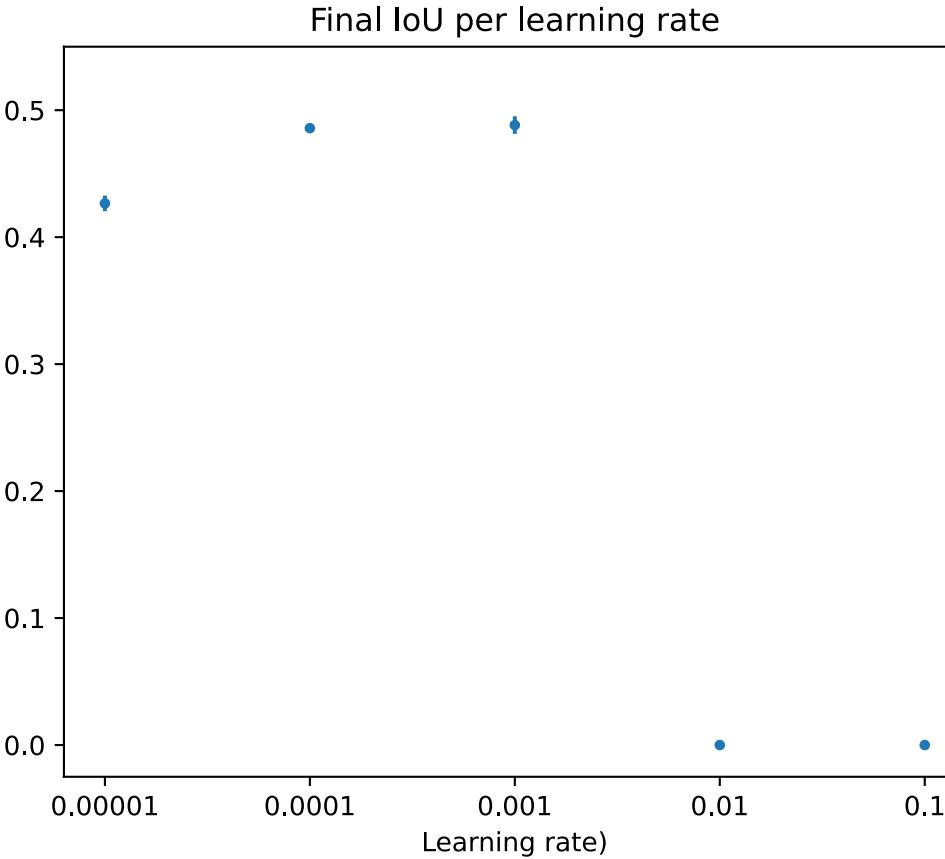
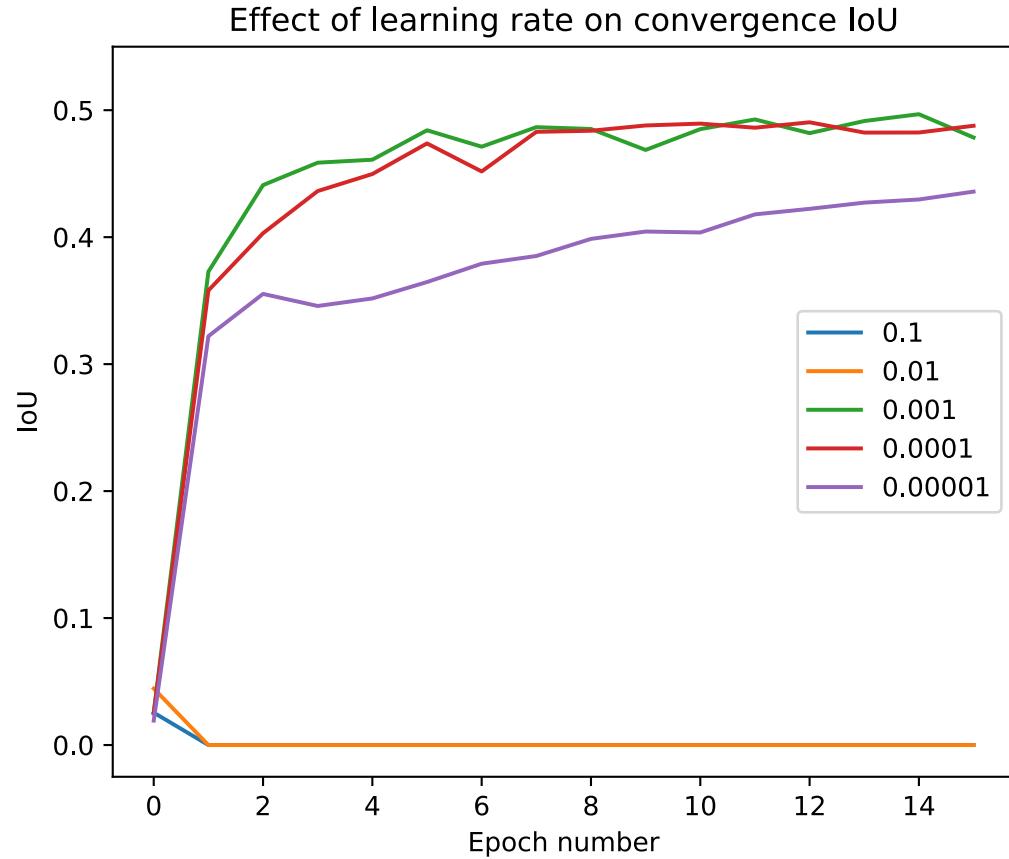
Segmentation - model development - weights (II)



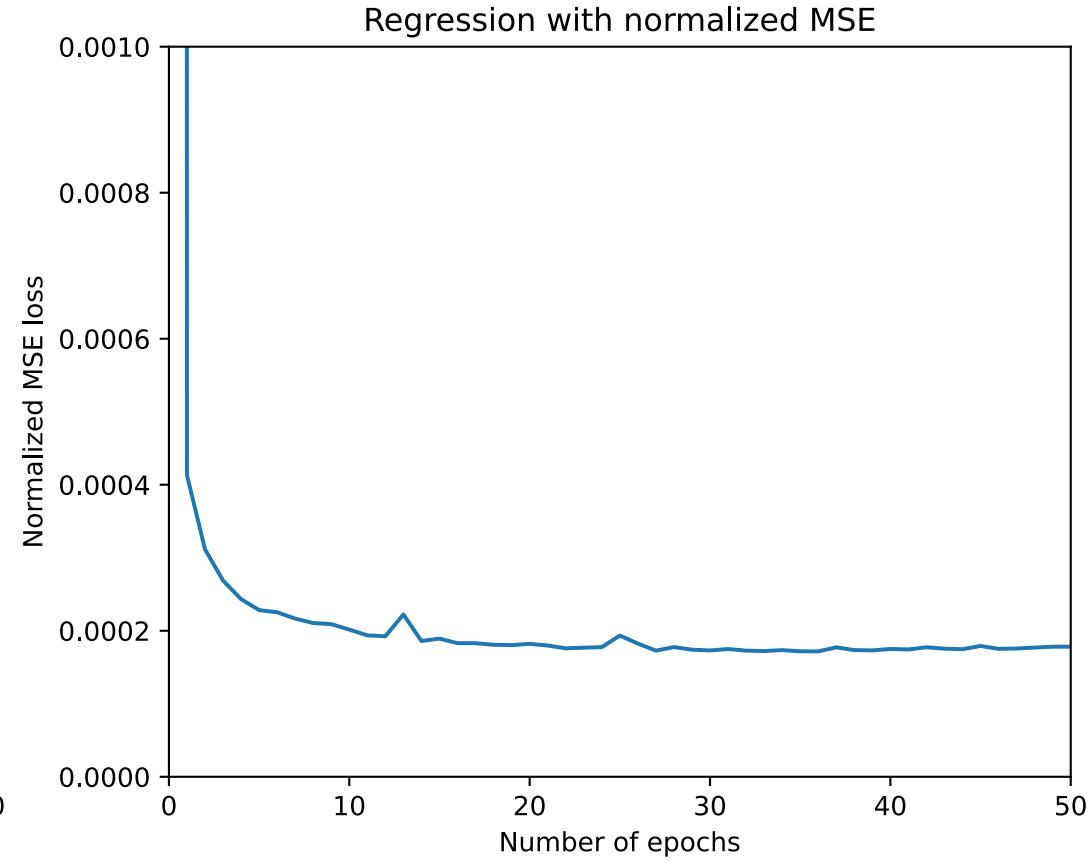
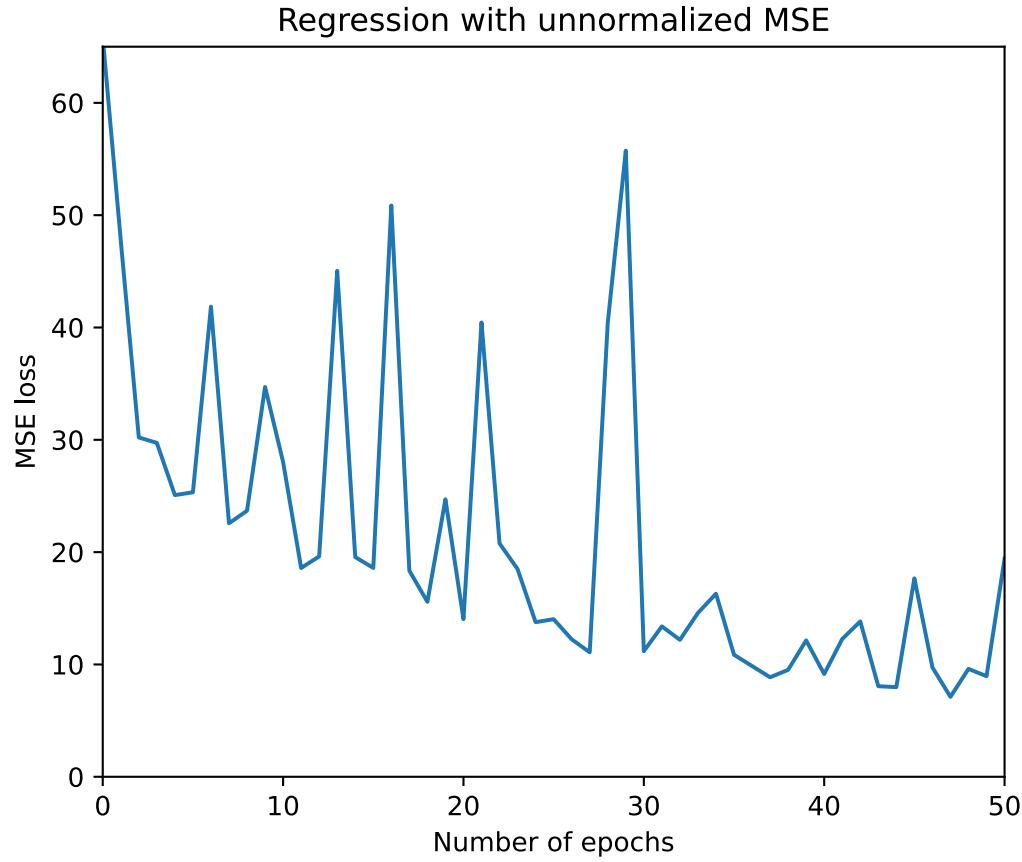
Segmentation - model development - probability thresholds



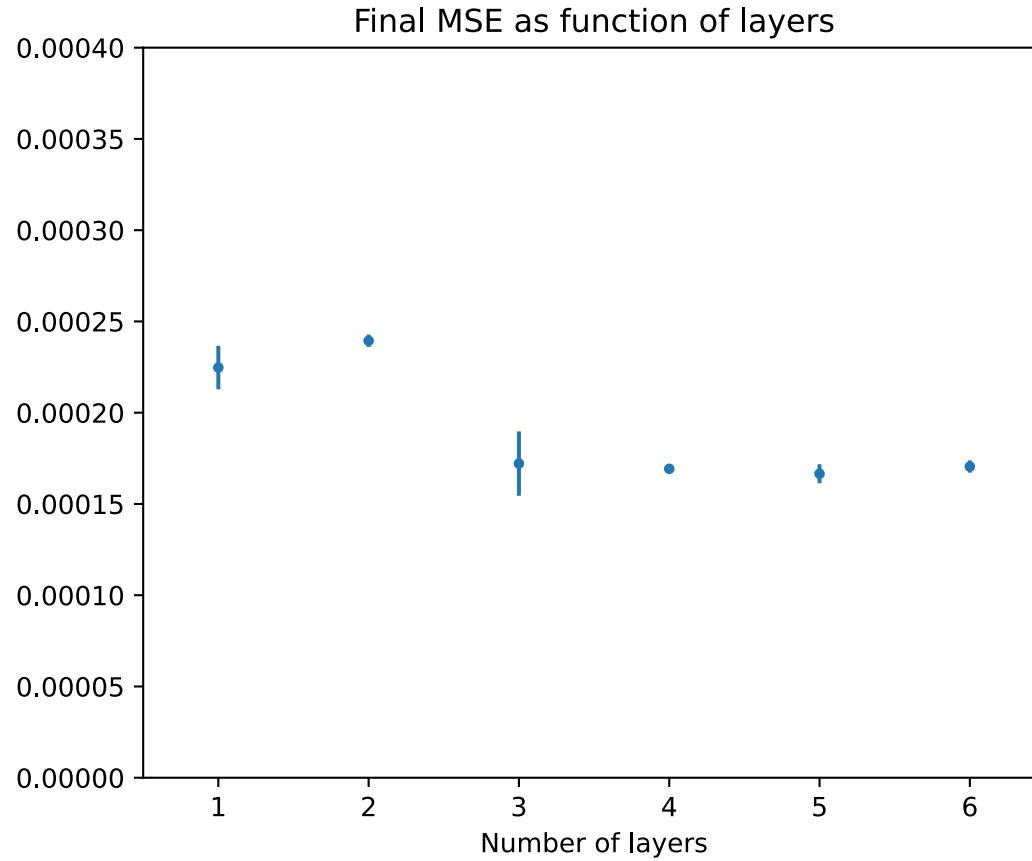
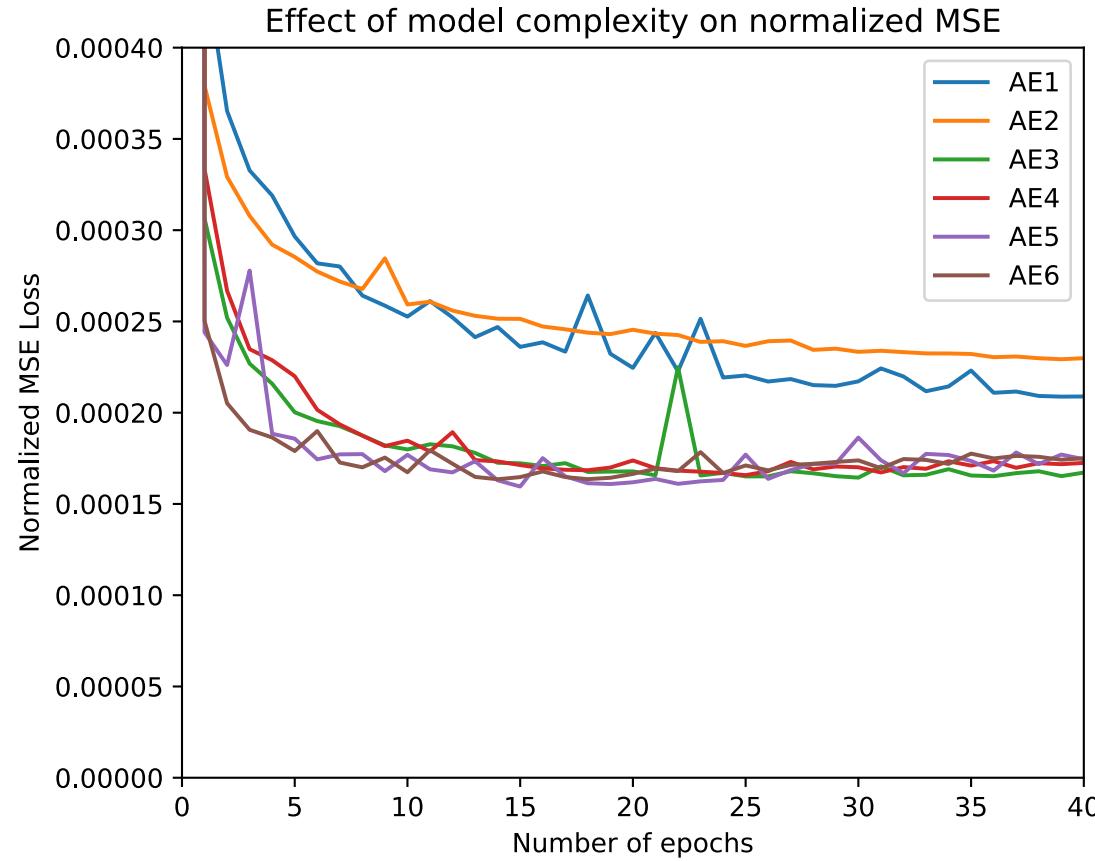
Segmentation - model development - learning rates



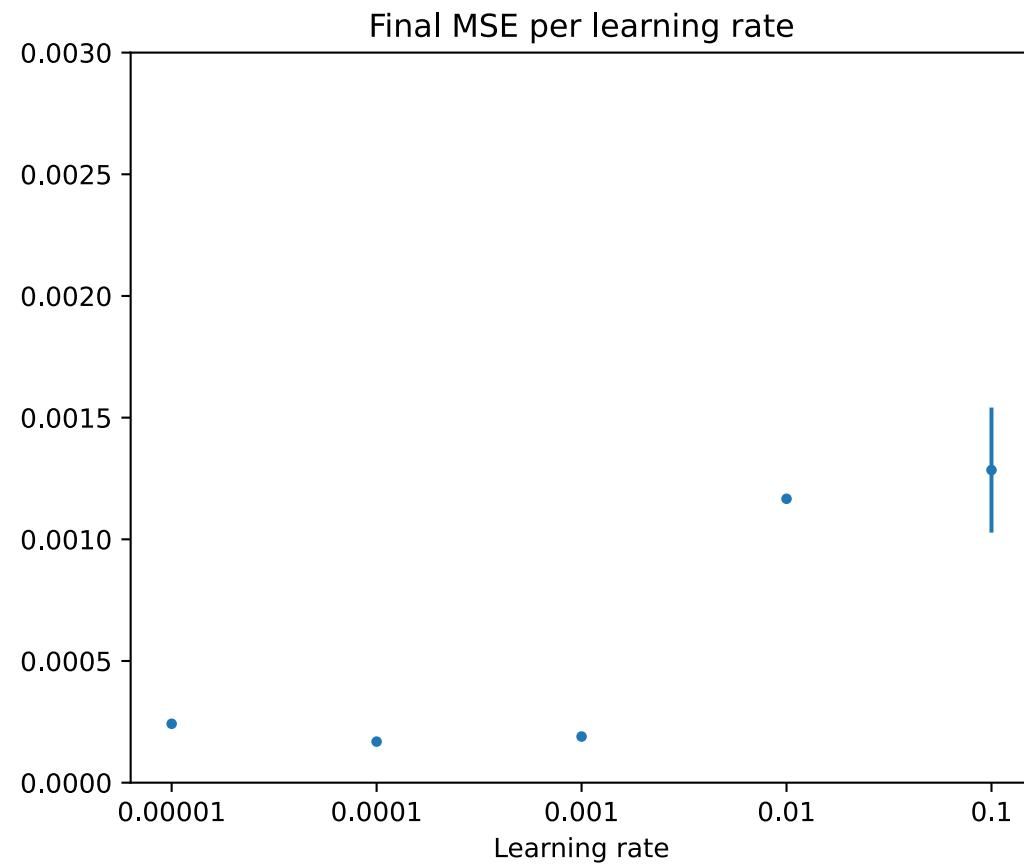
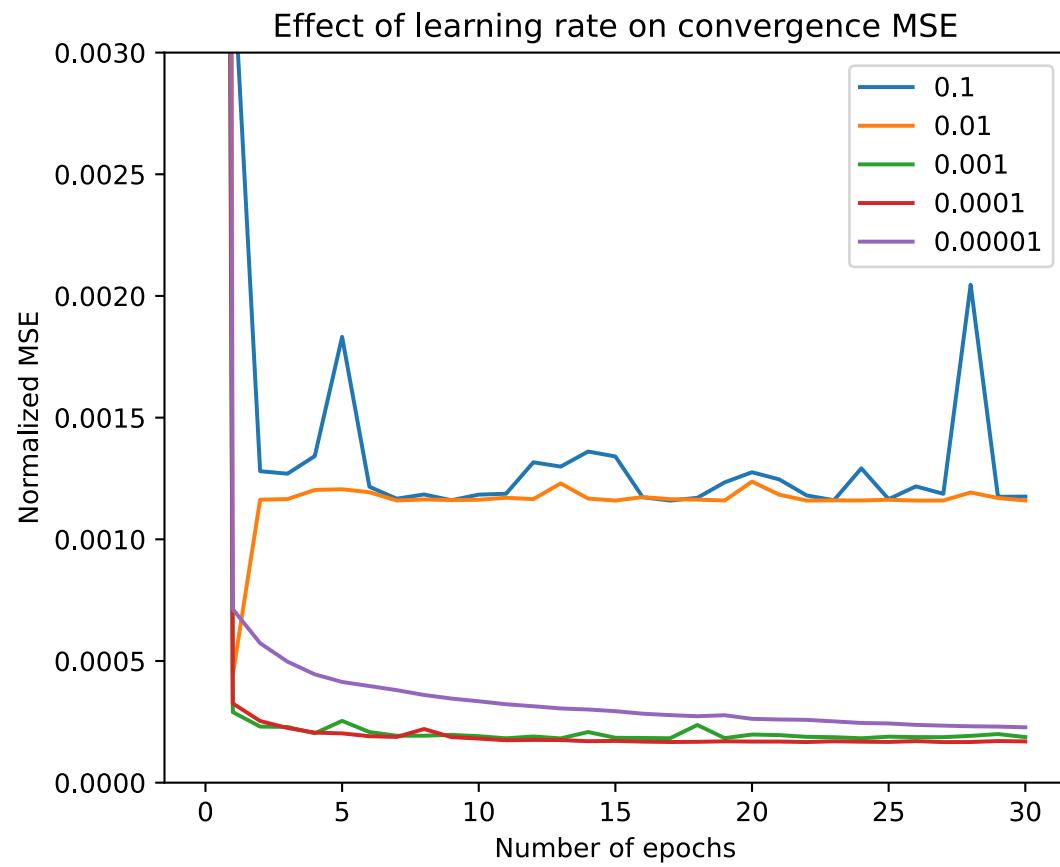
Regression - data preprocessing - normalization



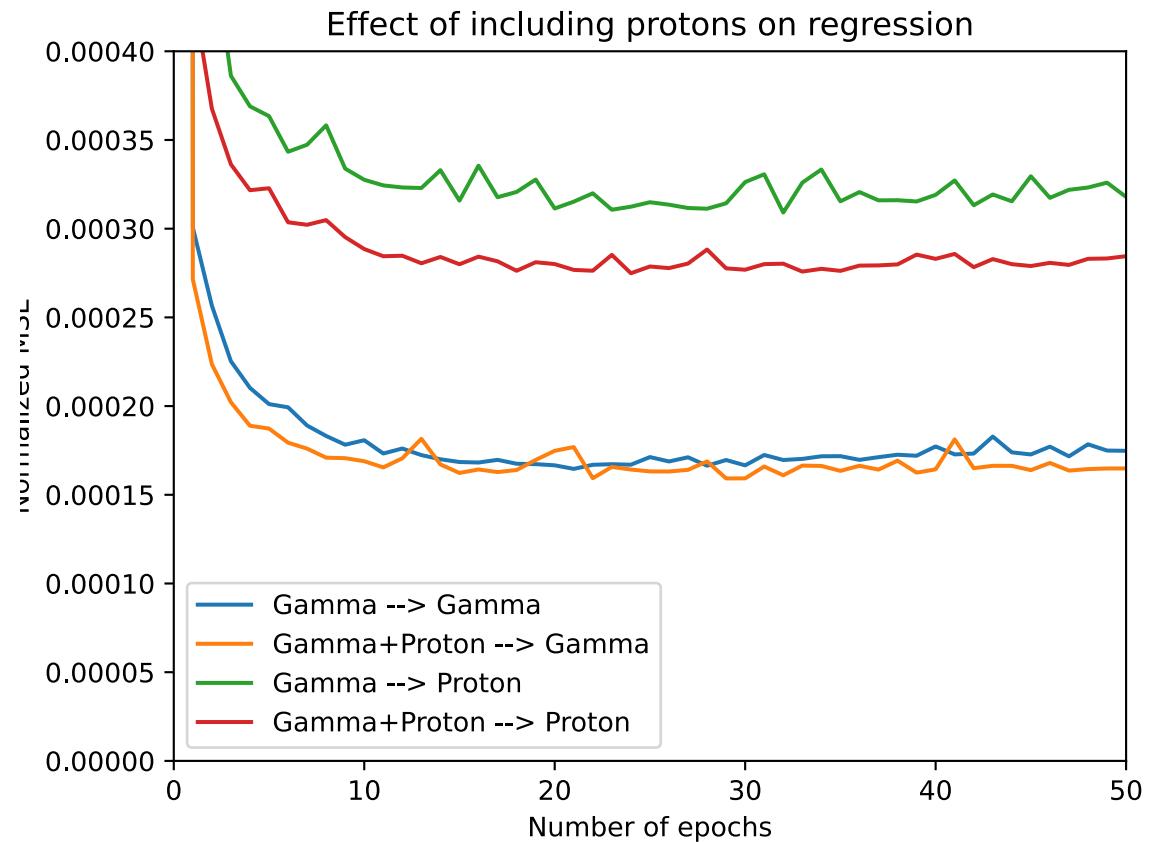
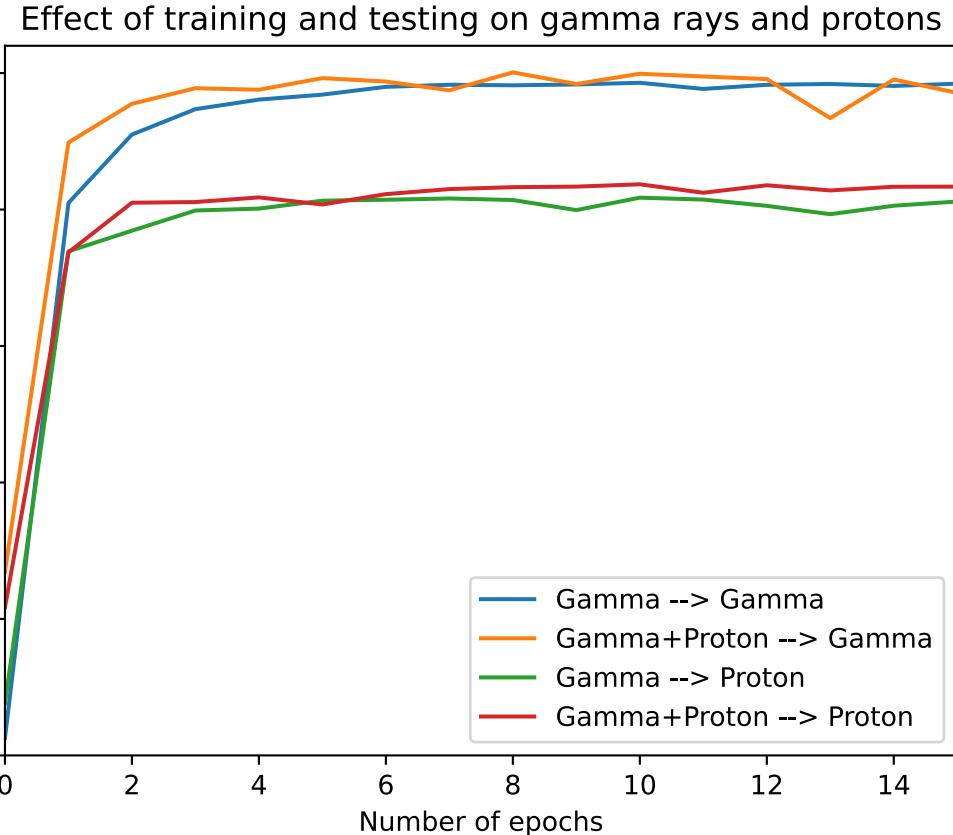
Regression - model development - complexity



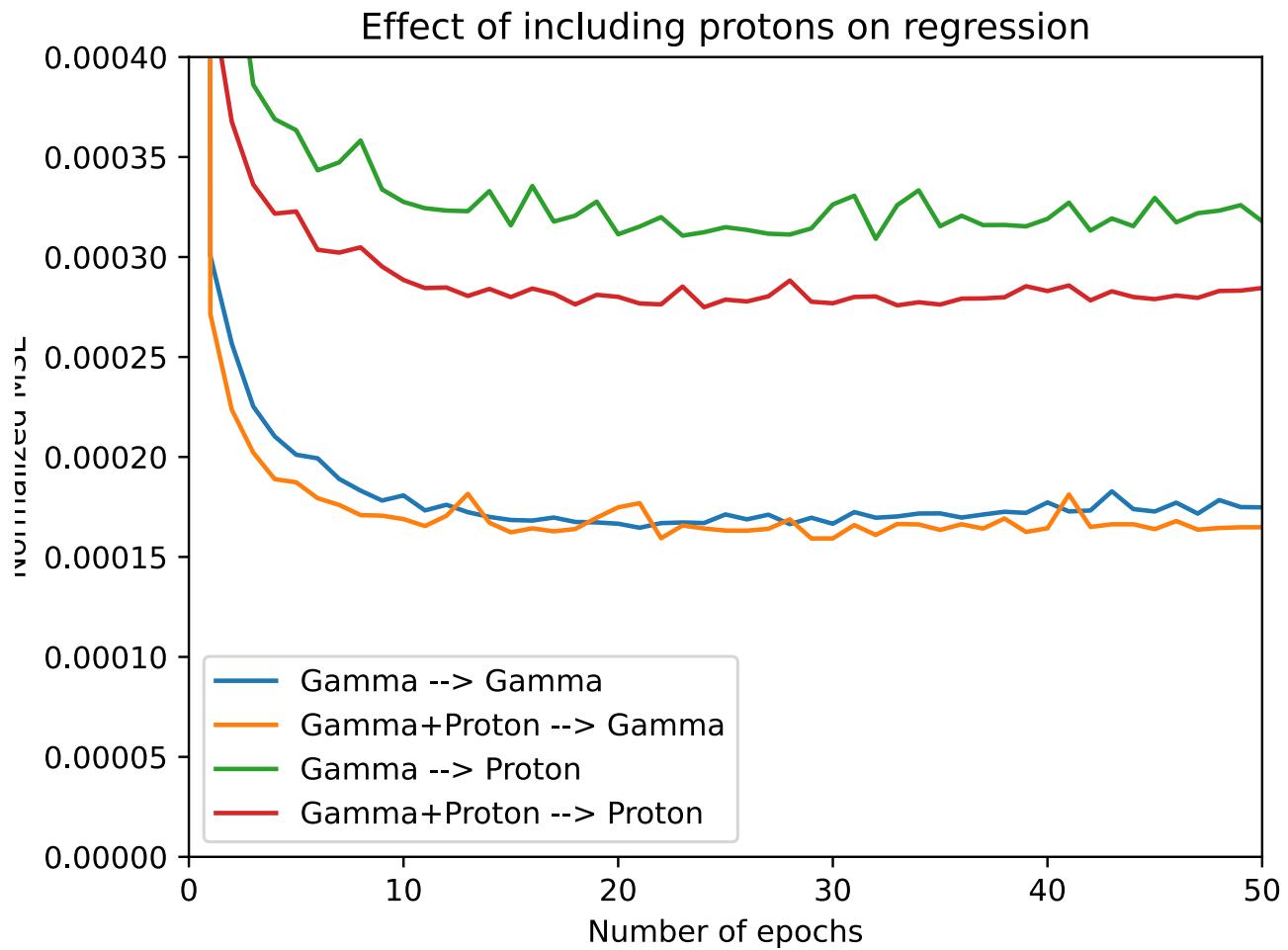
Regression - model development - learning rates



Testing on protons - segmentation

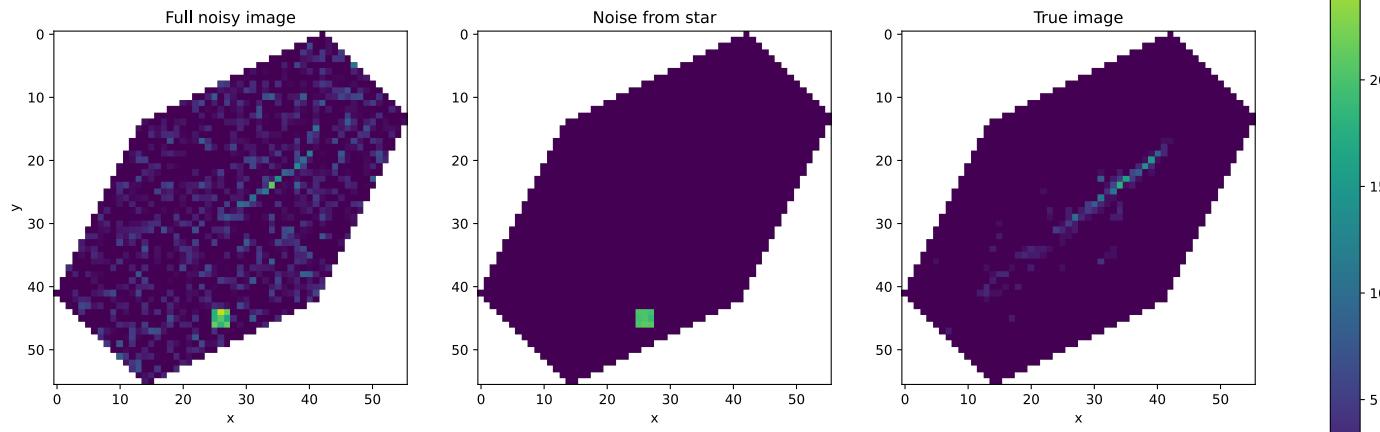
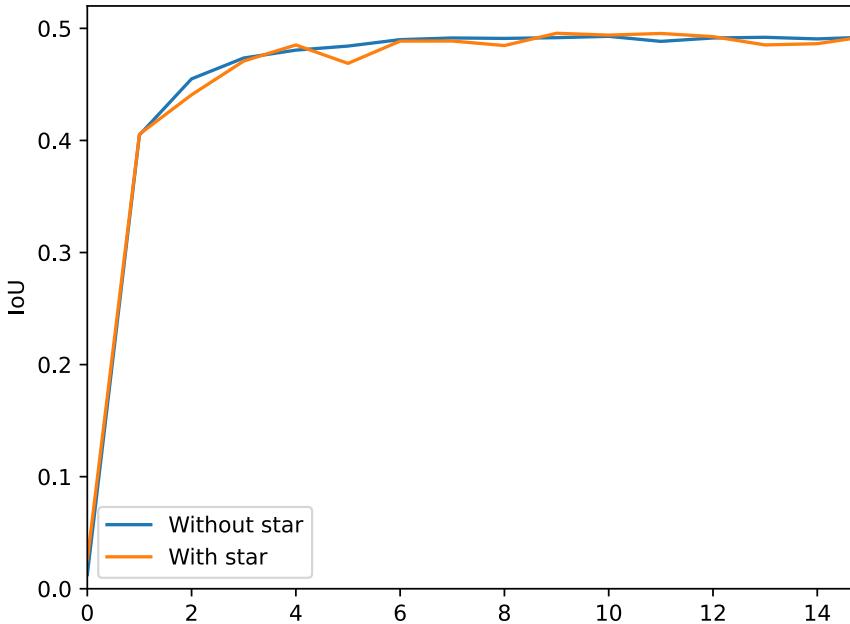


Testing on protons - regression

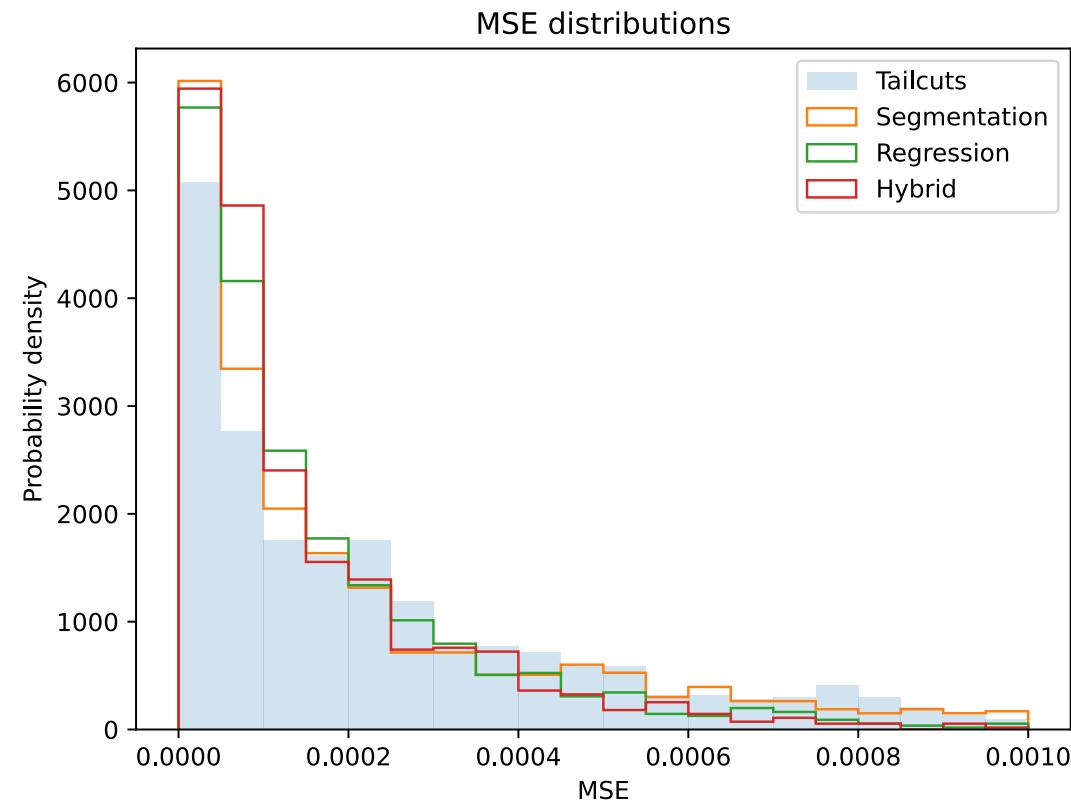
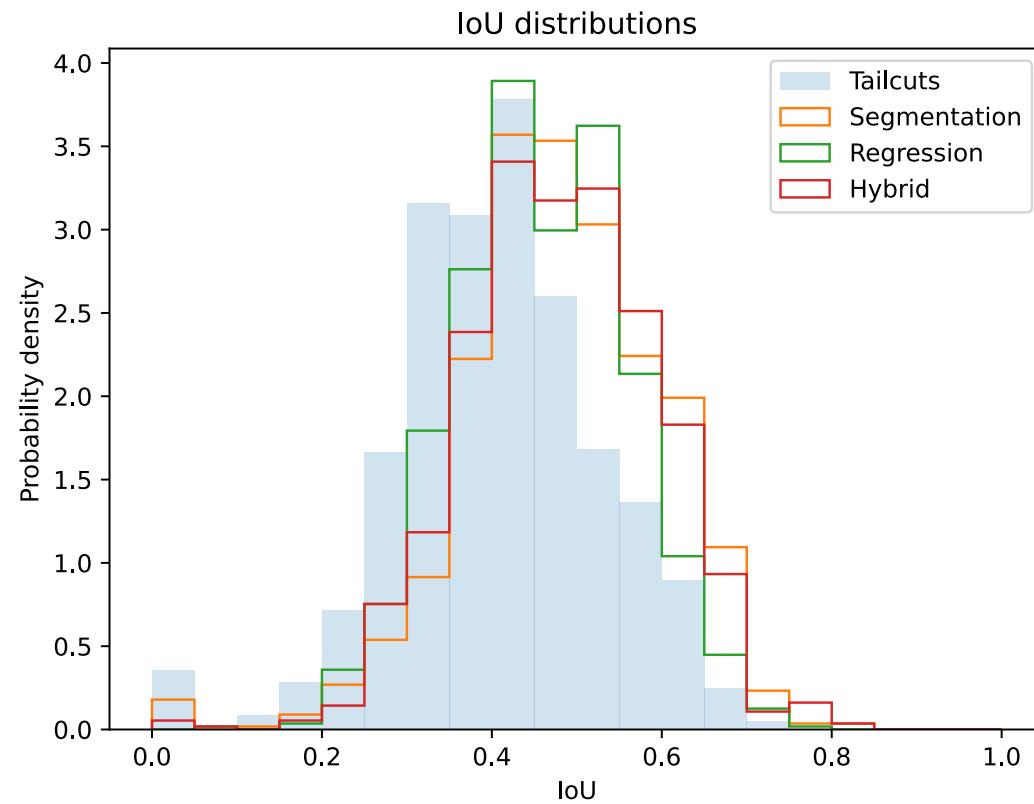


Star noise

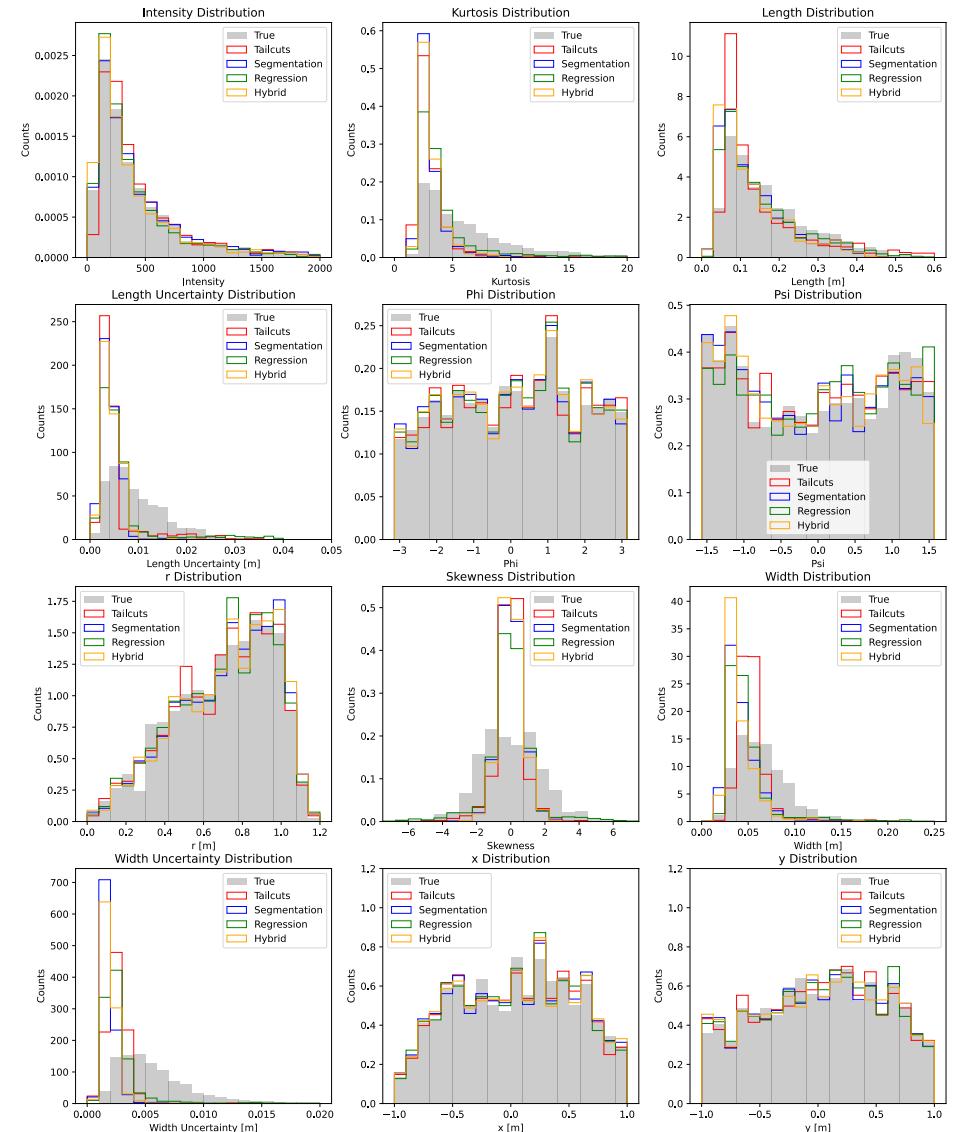
Performance of the autoencoder for inclusion of star noise



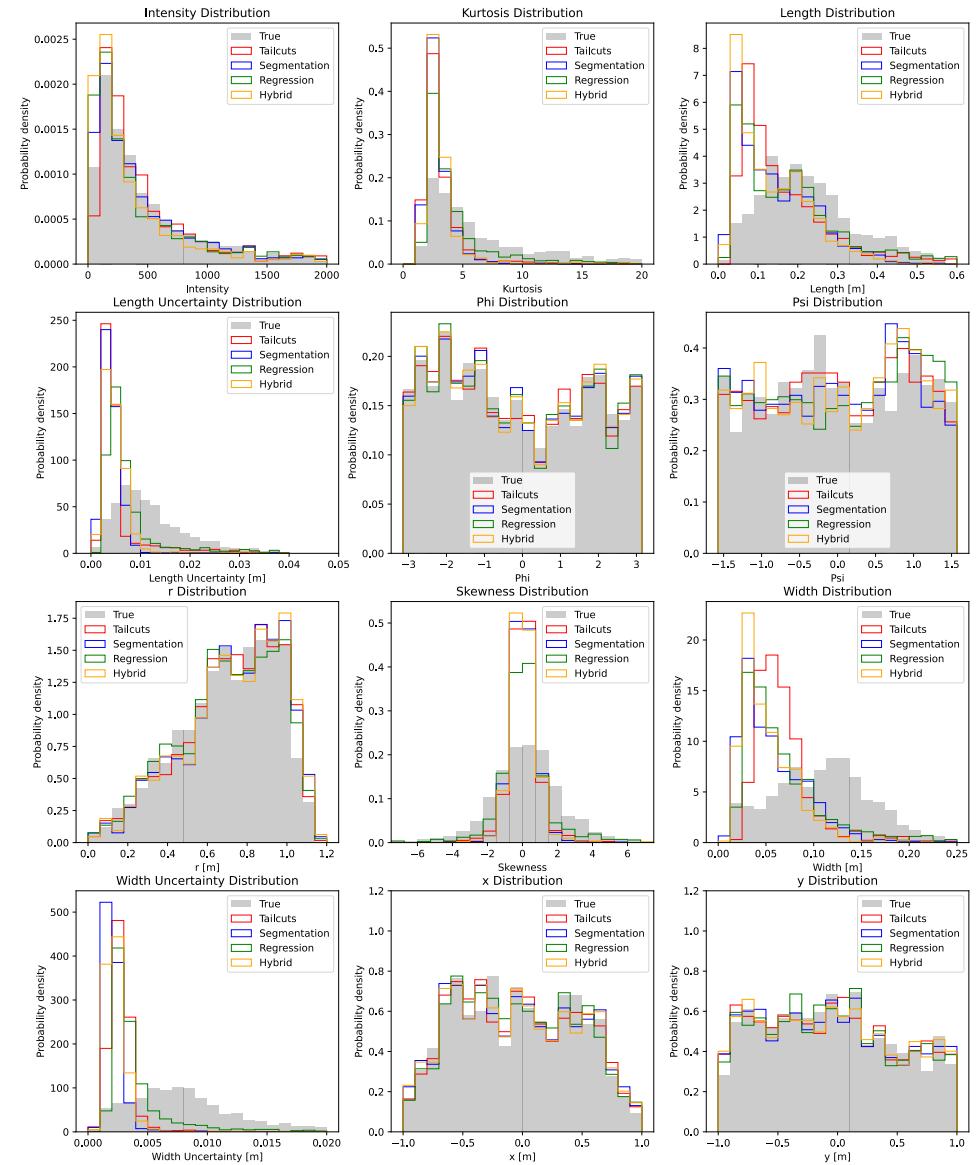
Comparison



Hillas - Gamma rays



Hillas - Protons



Gamma/Proton Separation

