A presentation on

Radio Halo Detection using Generative Models Assisted Classifiers with MWA Data

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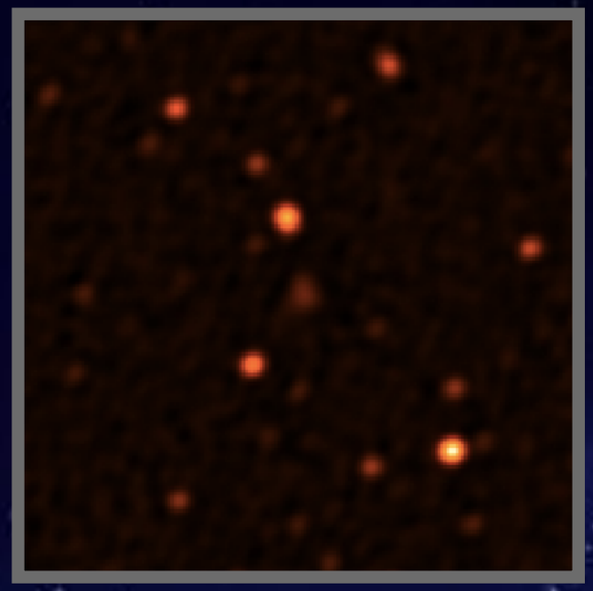
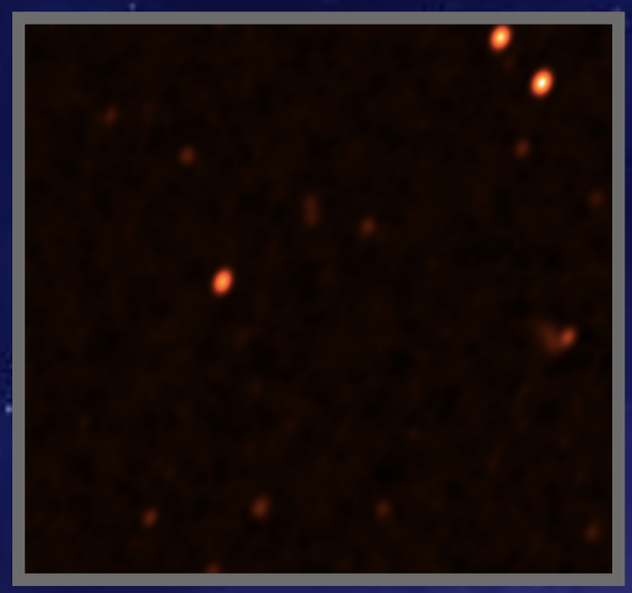
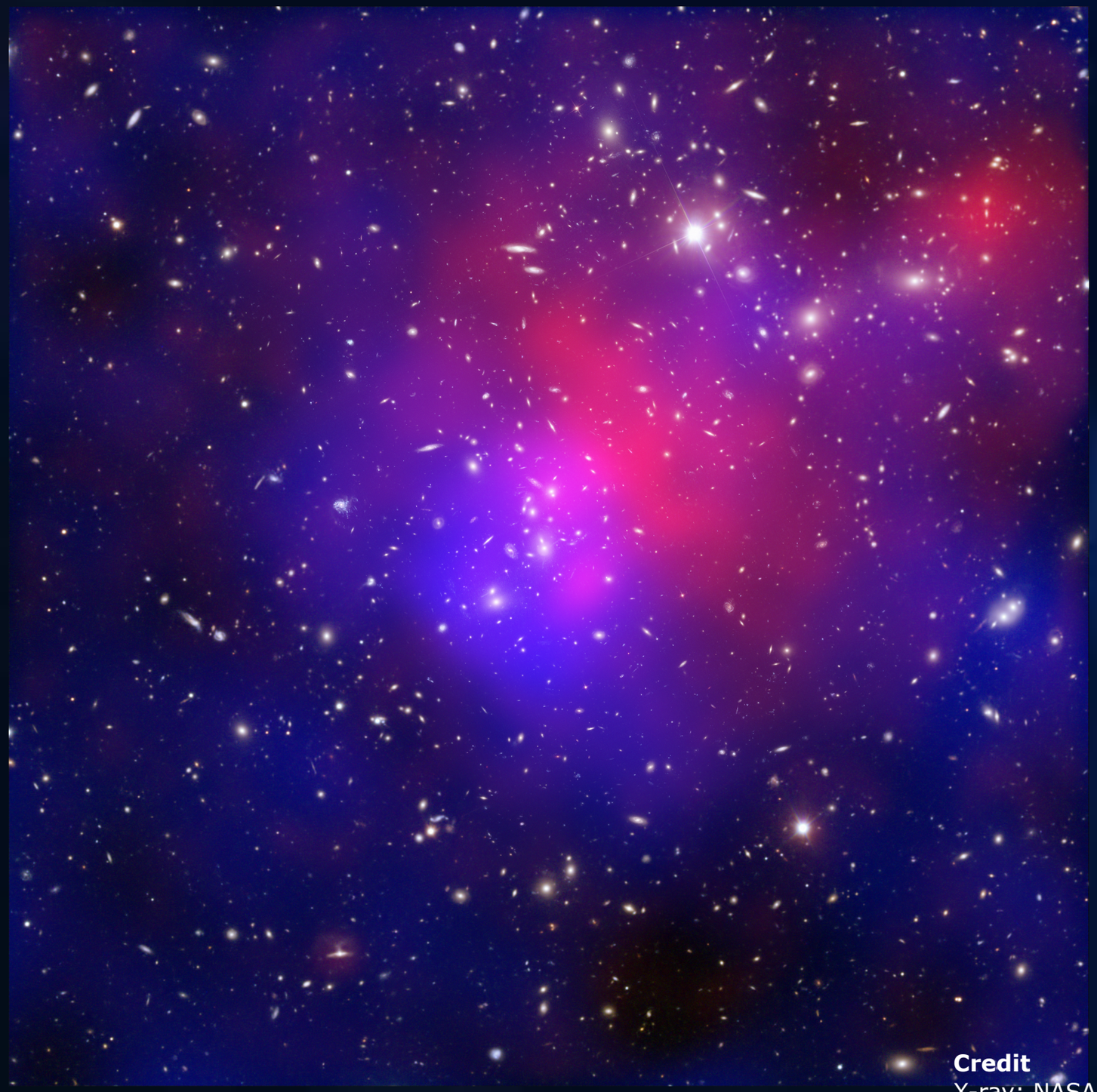




Cosmic Webs

Credit: Millennium Simulation Project

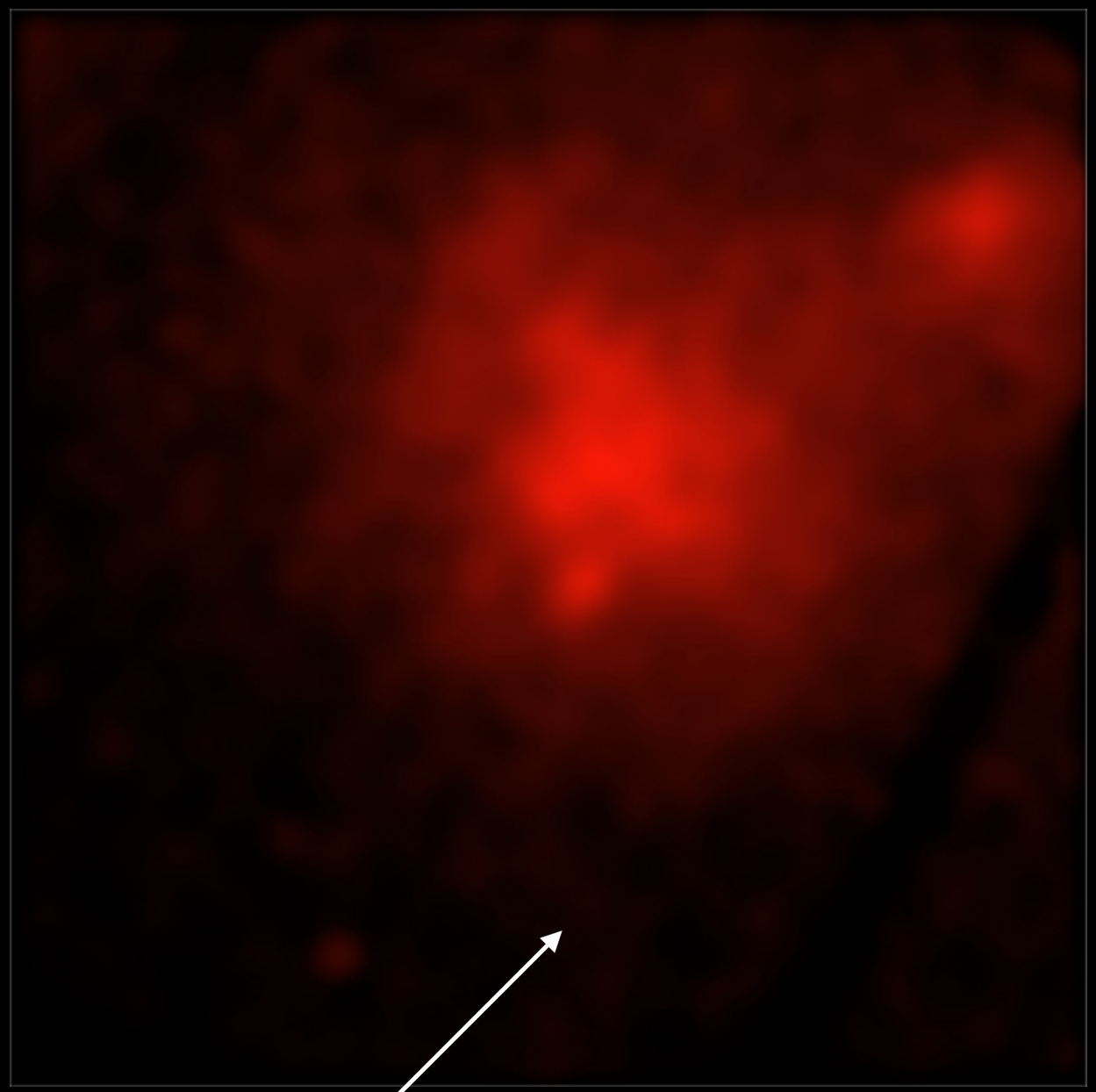
Abell 2744 : Pandora's Cluster



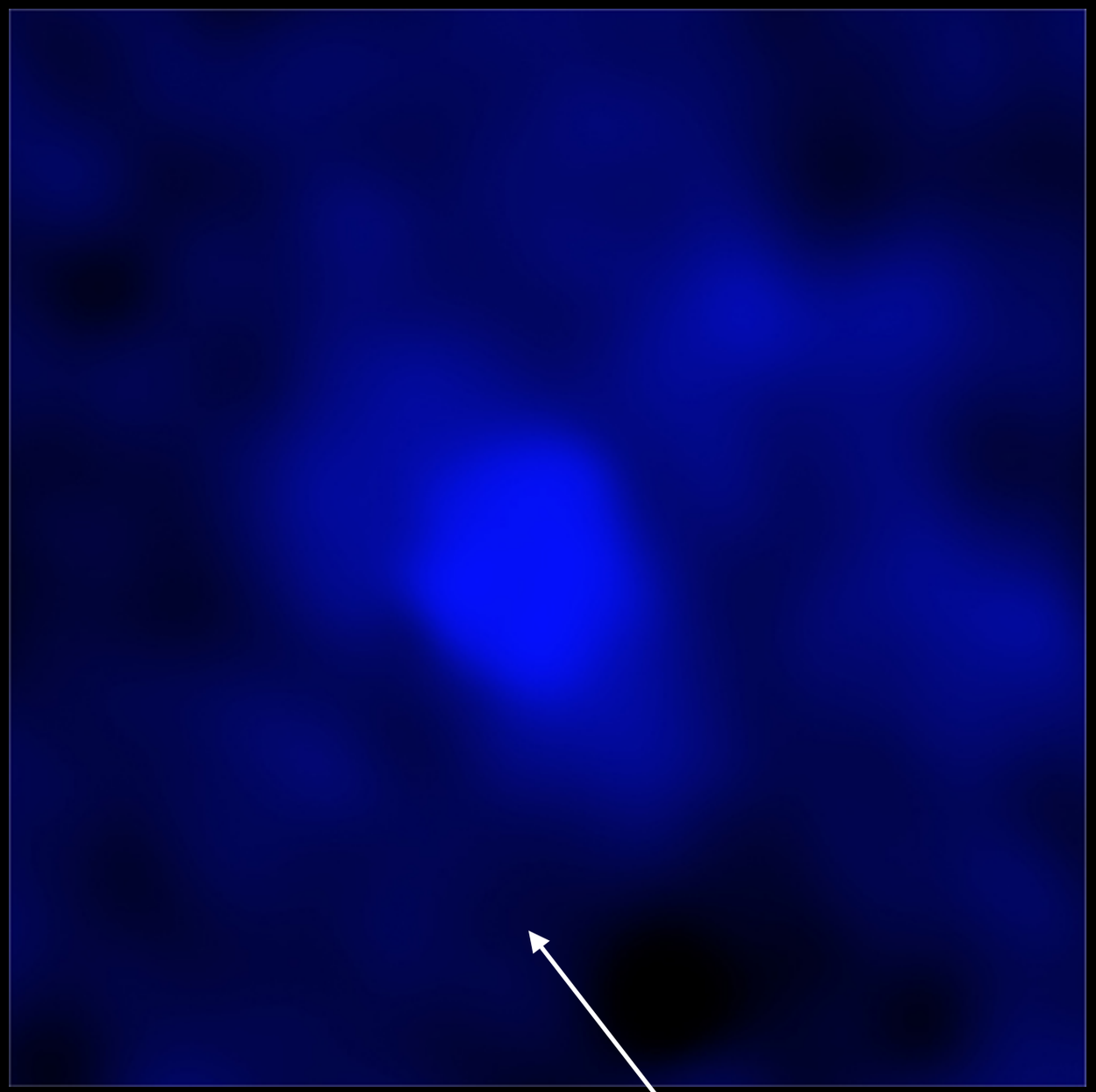
Red : X-Ray
Blue : Lensing

Credit
X-ray: NASA/CXC/ITA/INAF/J.Merten et al,
Lensing: NASA/STScI; NAOJ/Subaru; ESO/VLT,
Optical: NASA/STScI/R.Dupke

X-Ray



LMAP (Lensing)



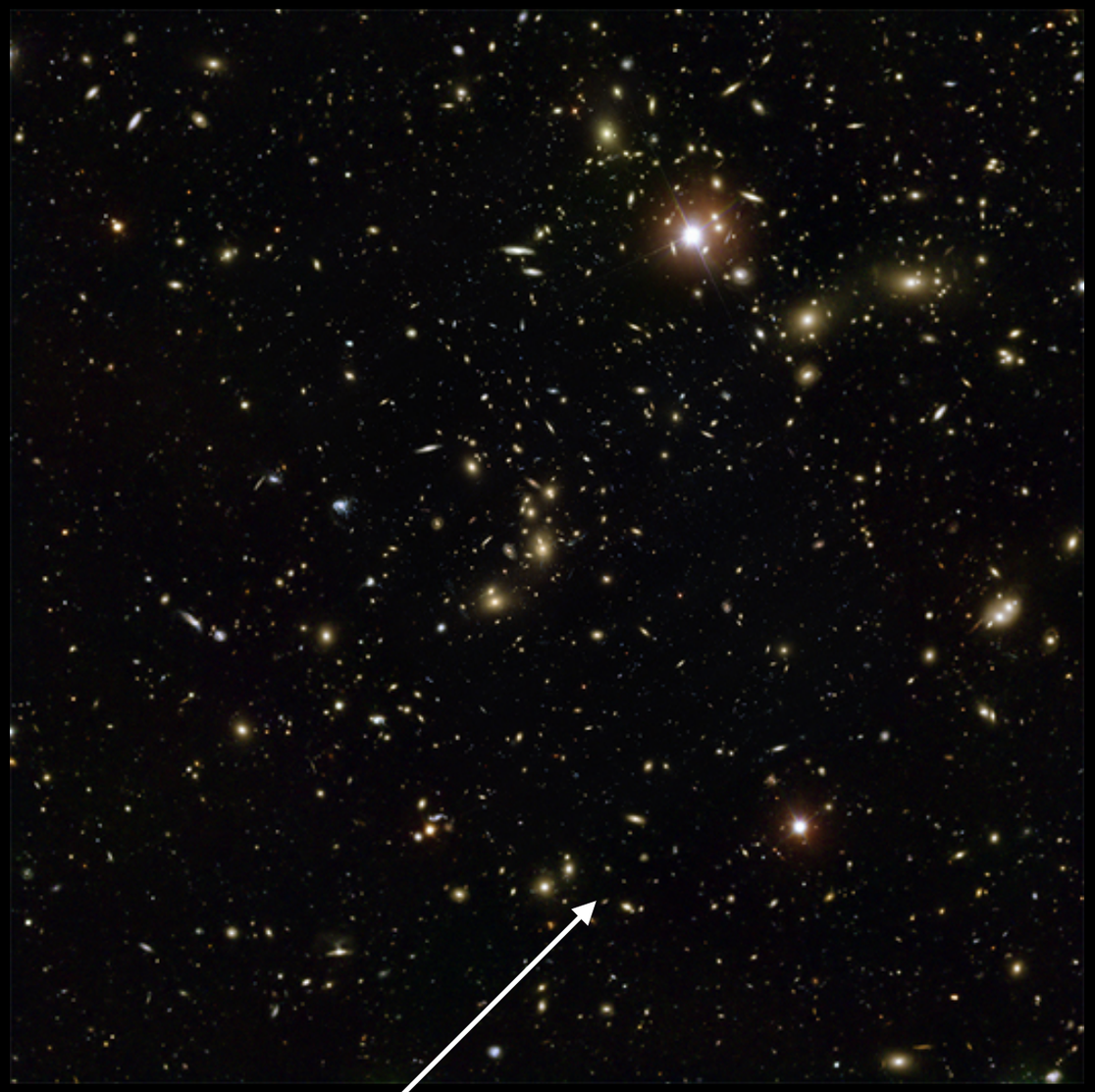
Hot Gas (20 %)

Mostly Dark Matter (75 %)

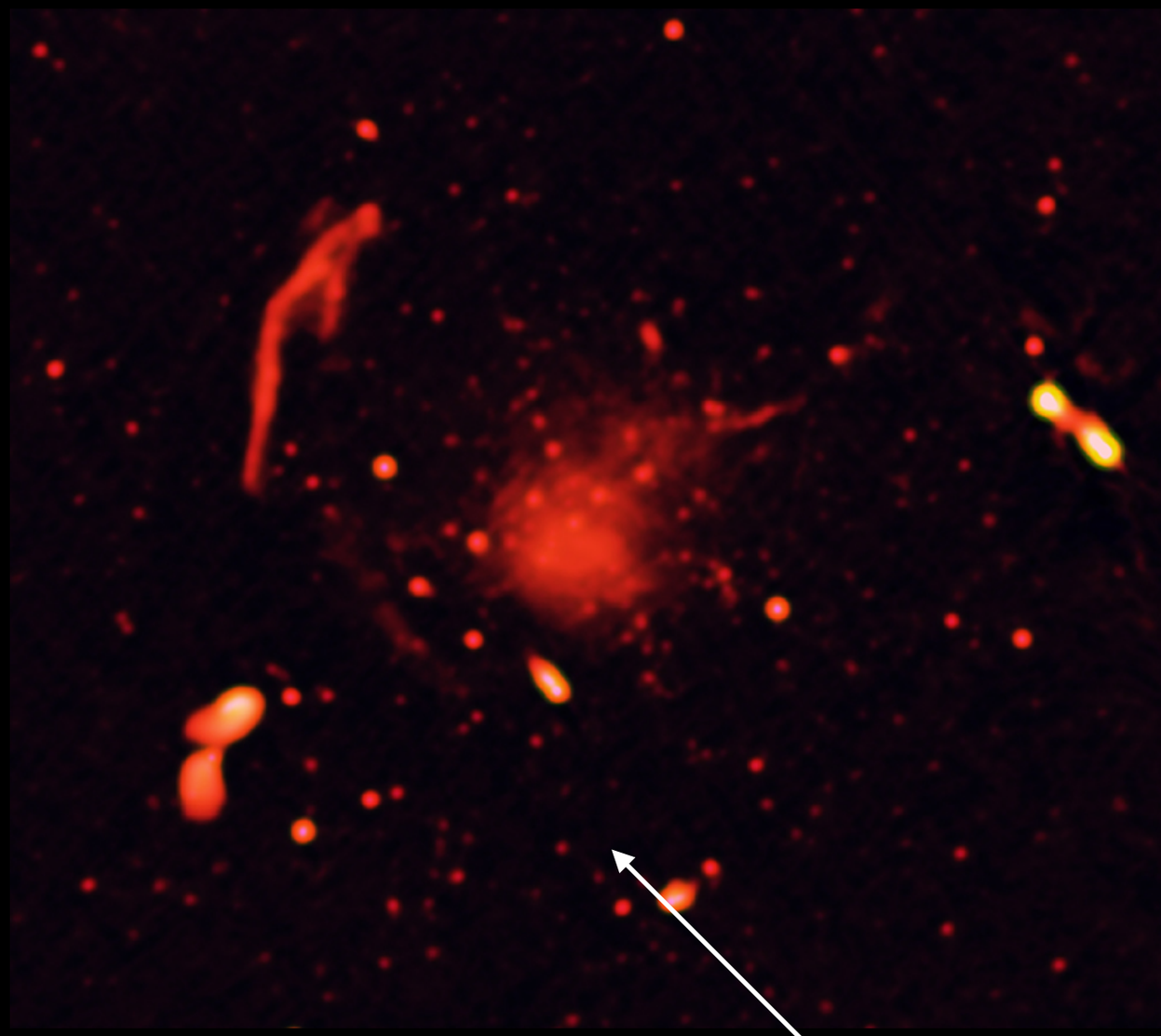
Credit
X-ray: NASA/CXC/ITA/INAF/J.Merten et al

Credit
Lensing: NASA/STScI; NAOJ/Subaru; ESO/VLT

Optical



Radio



Constituent Galaxies

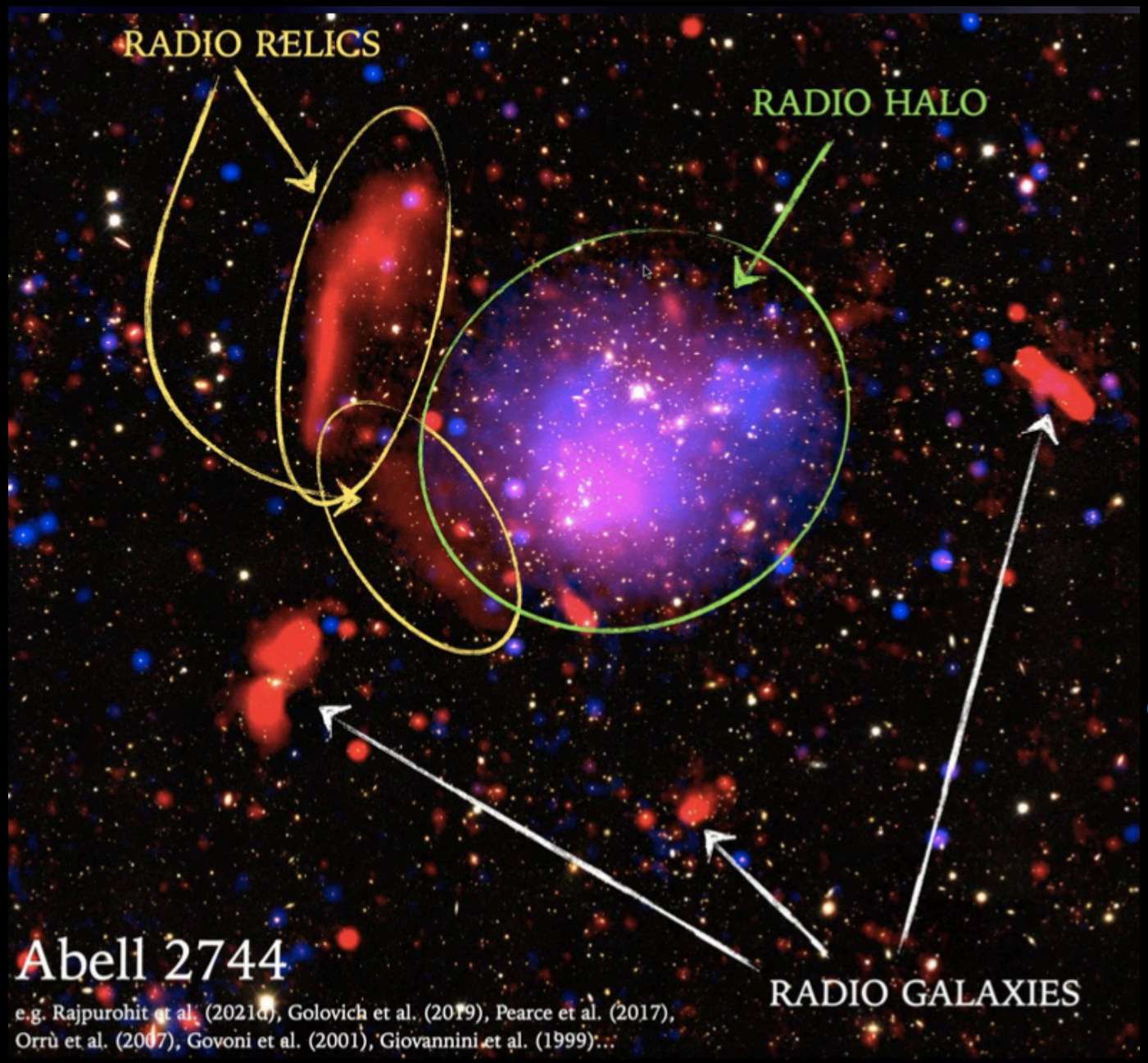
Radio Sources

Credit
Optical: NASA/STScI/R.Dupke

Credit
Radio: Pearce et al., NRAO/AUI/NSF

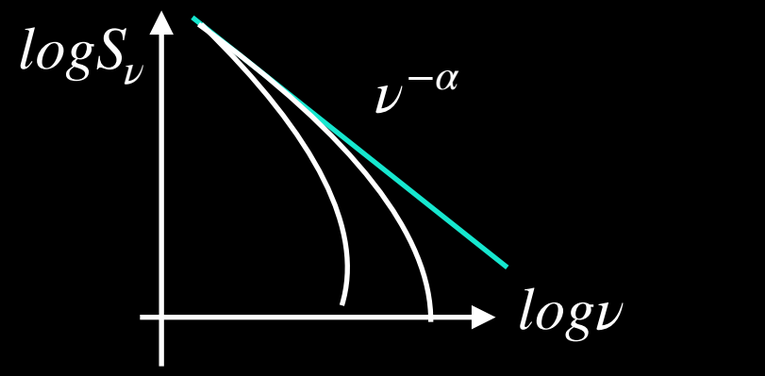
Motivation for the Work

01 Diffuse Extended Emission Detection



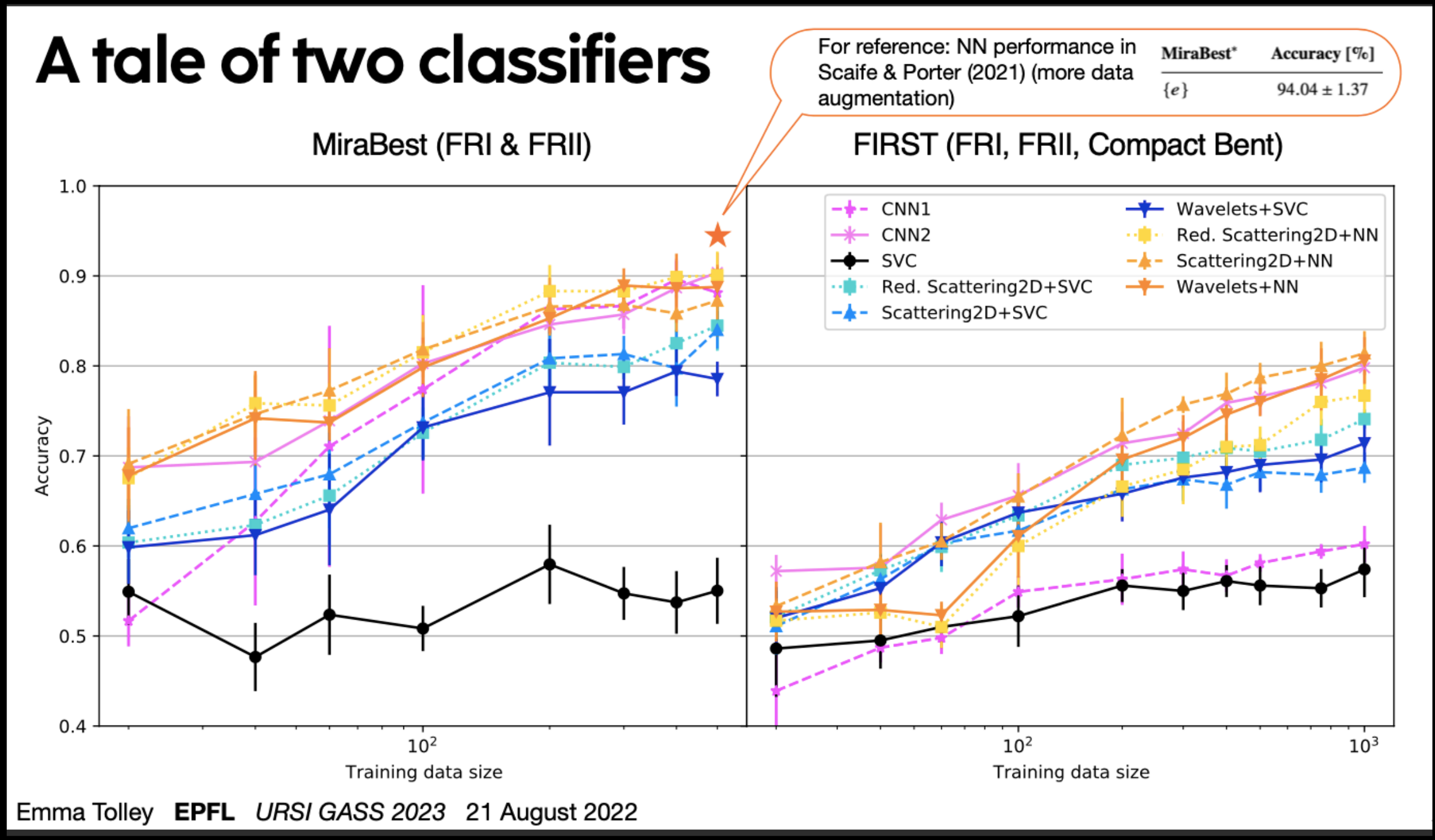
Red : Radio ; Blue : X-Ray

Synchrotron emission!



- **Large-Scale Magnetic Fields**
- **Merging State of Clusters**

02 Rise of Machine Learning in Radio Astronomy

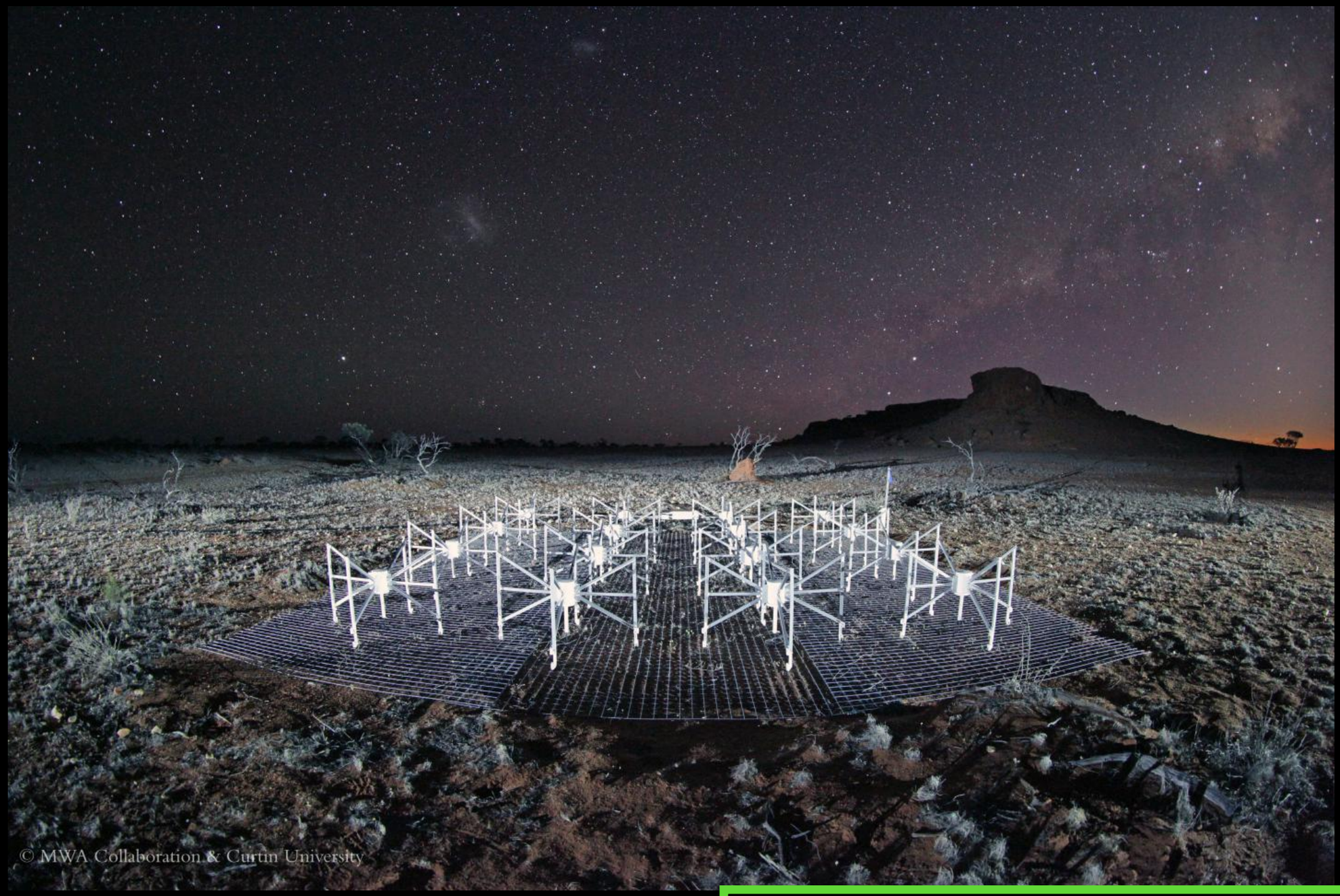


Why MWA?

MeerKAT

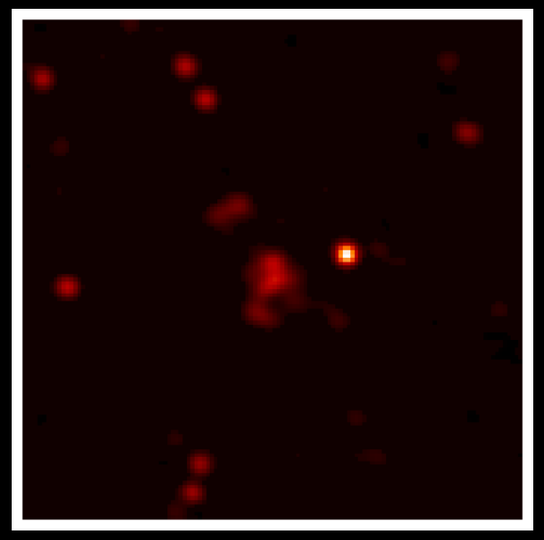
- **Larger baselines**
- **No blending of point sources**

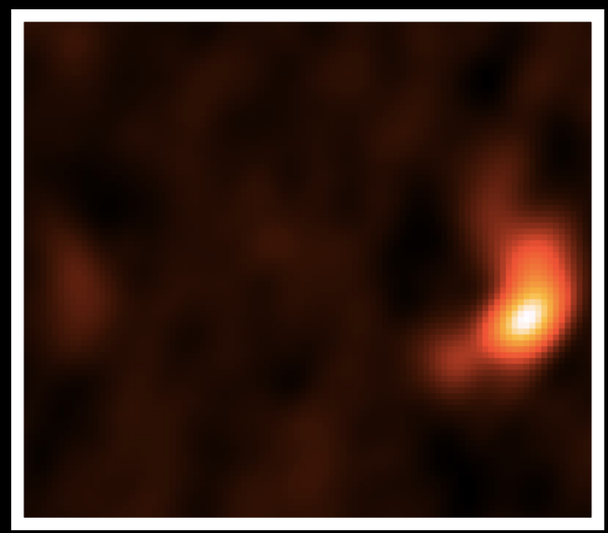
MWA



- **Difficult to deal with due to poor resolution and blending !**

Simplified Classification





DIFFUSE SOURCES

HALOS

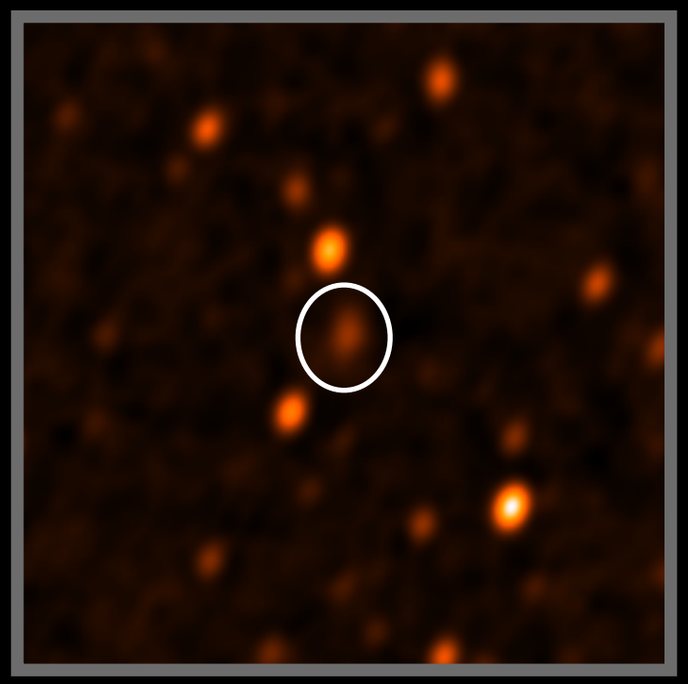
NON-HALOS

- centrally located
- mostly unpolarized
- no optical counterparts
- origin: (probably) from merger-driven turbulent (re)-acceleration mechanisms

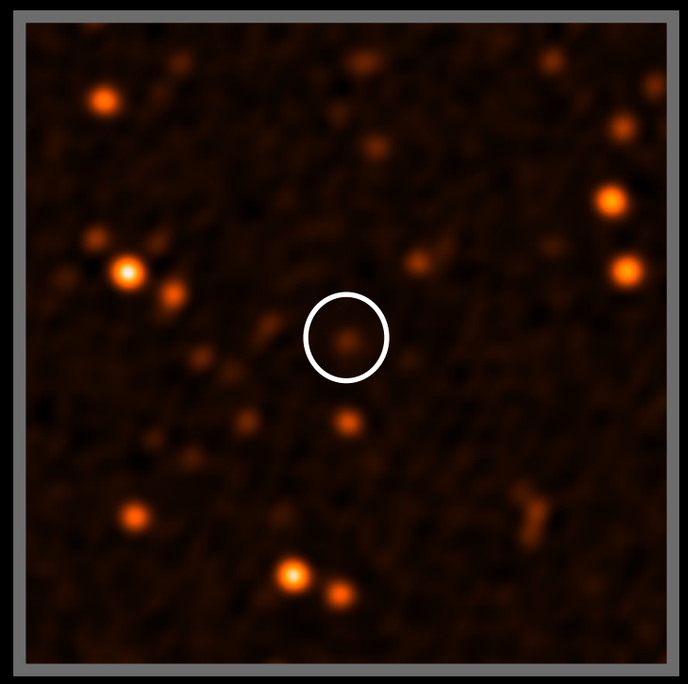
- Anything other than halo

Example

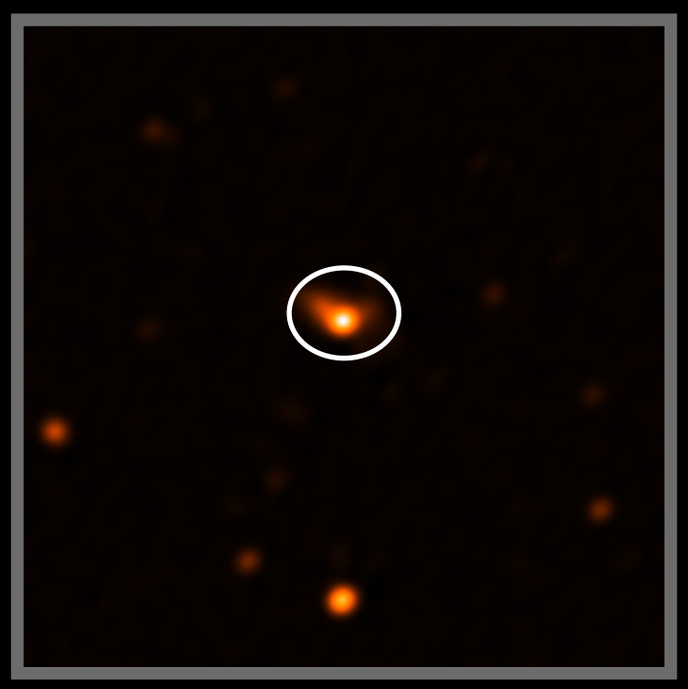
Halo



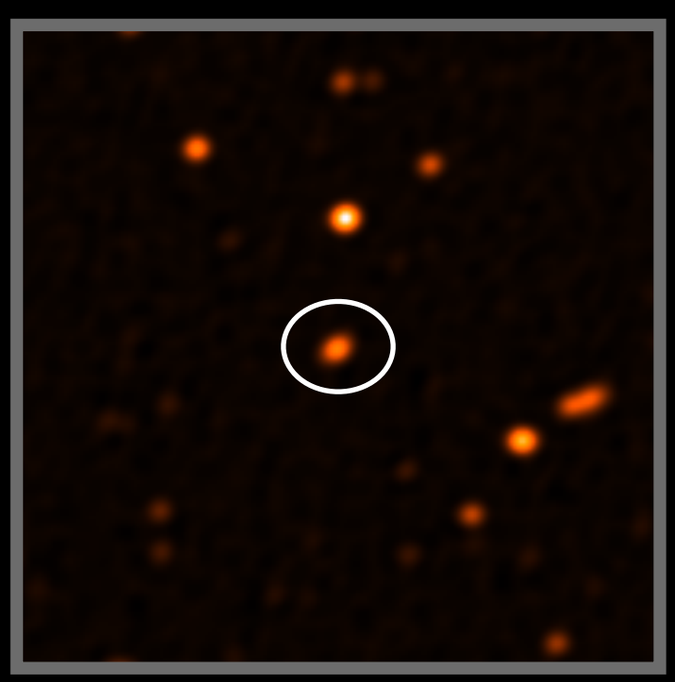
Candidate Halo



Minihalo



Candidate Minihalo



Data Collection

10 Halos (H)

10 Candidate Halos (cH)

3 (Candidate) Minihalos (cmH)

Pre-Processing

01 **3σ Clipping**: Image [Image< mean (Image) + 3σ] = 0

02 **Making relevant sized cut-outs from the clipped image**

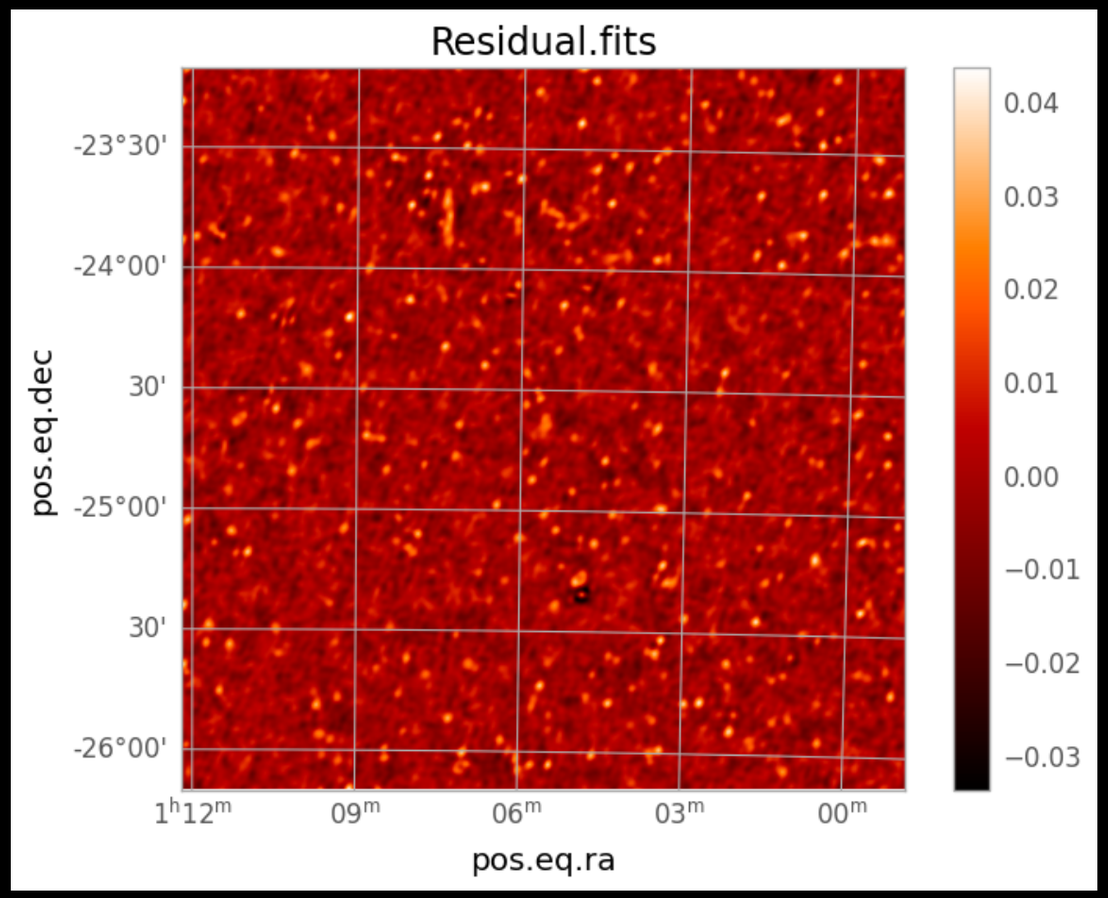
03 **Log Normalization of cut-outs**

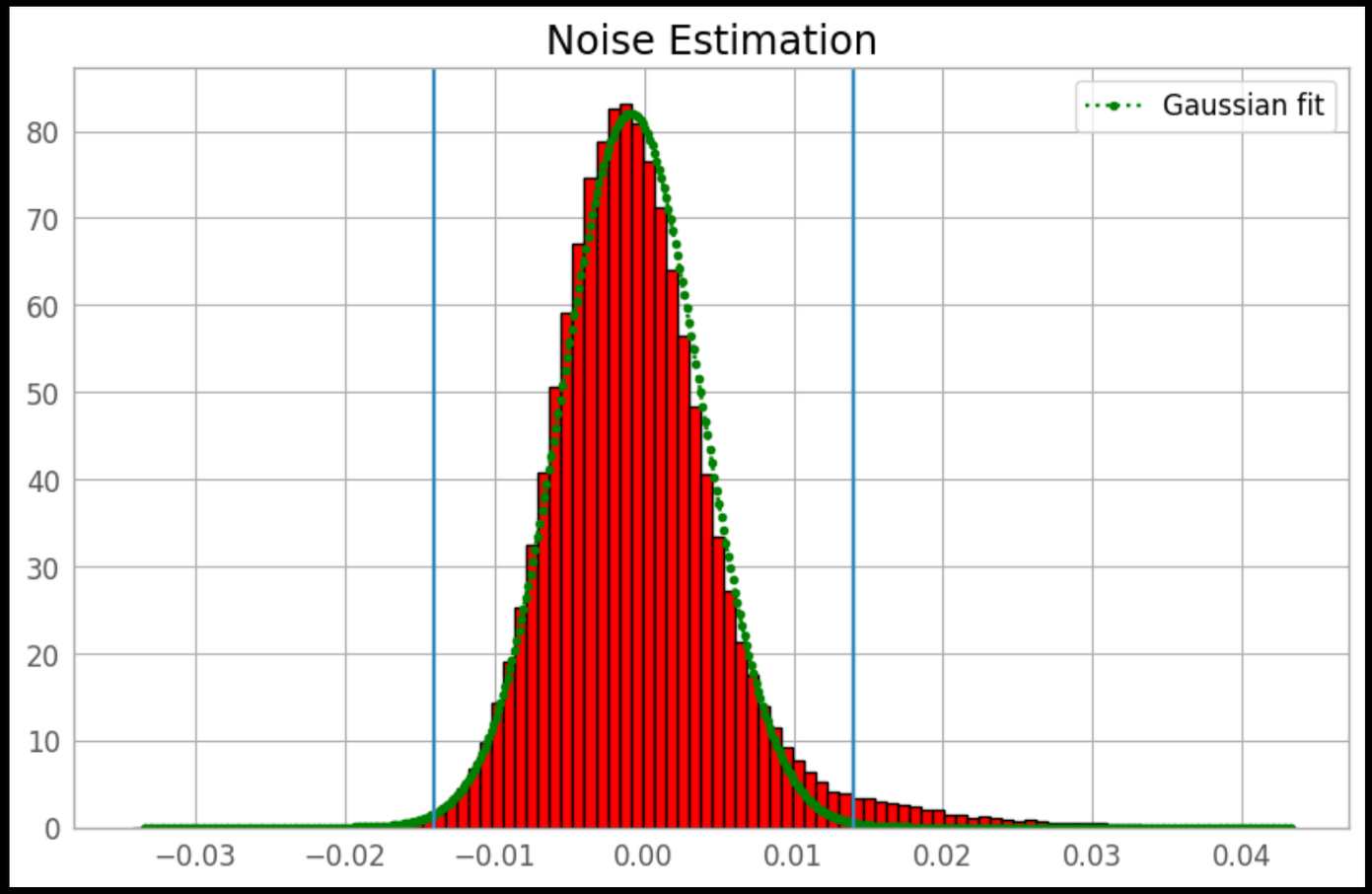
04 **Min-Max Normalization for Classifier**

Noise Estimation I

01 Non-GLEAM Images : Residual Files Available

Good Noise Estimate!

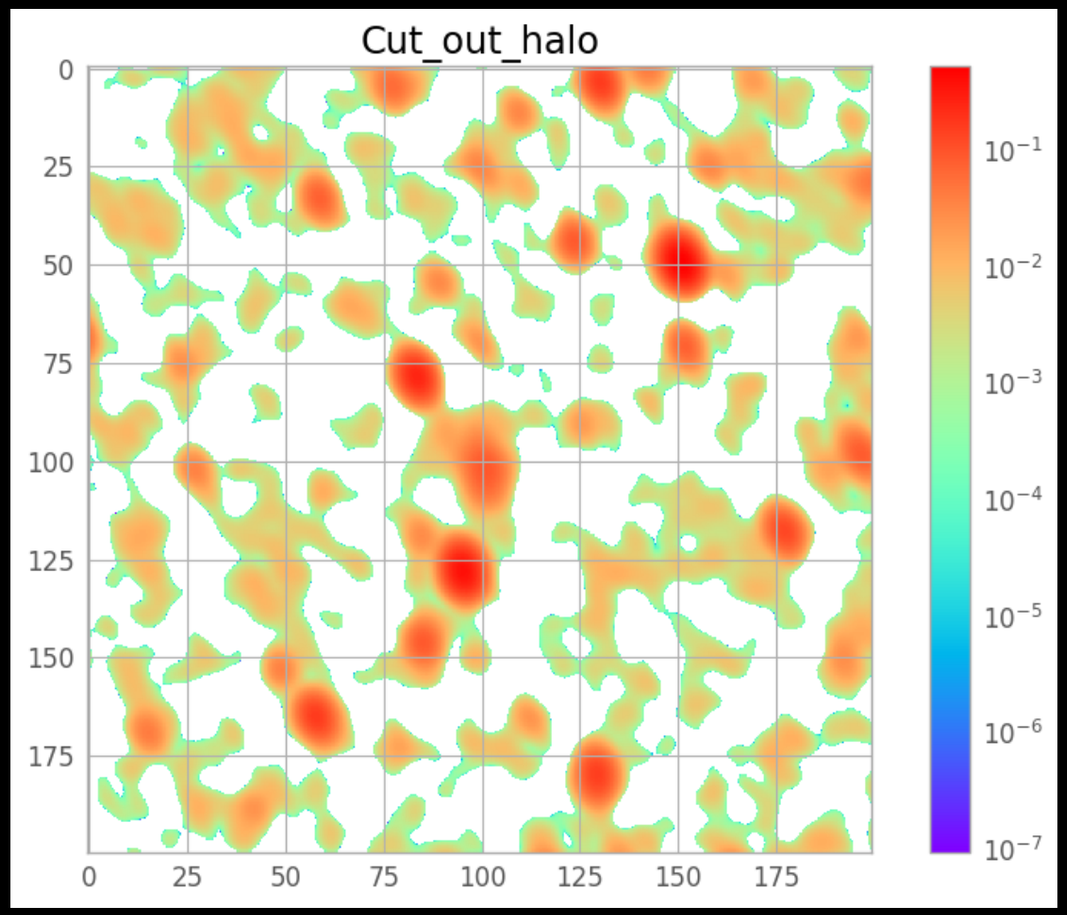


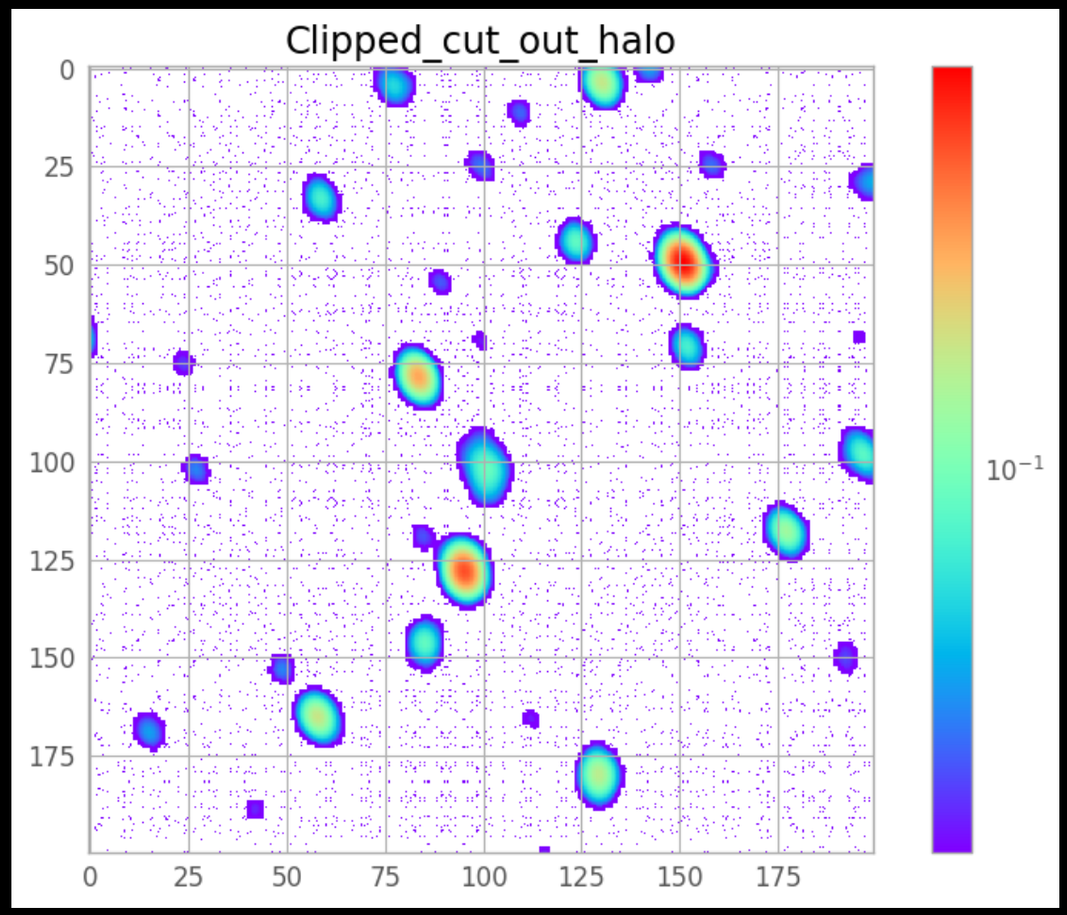


Residual File and Fitting Example

Noise Estimation I

02 Non-GLEAM Images : Clipped Image Example





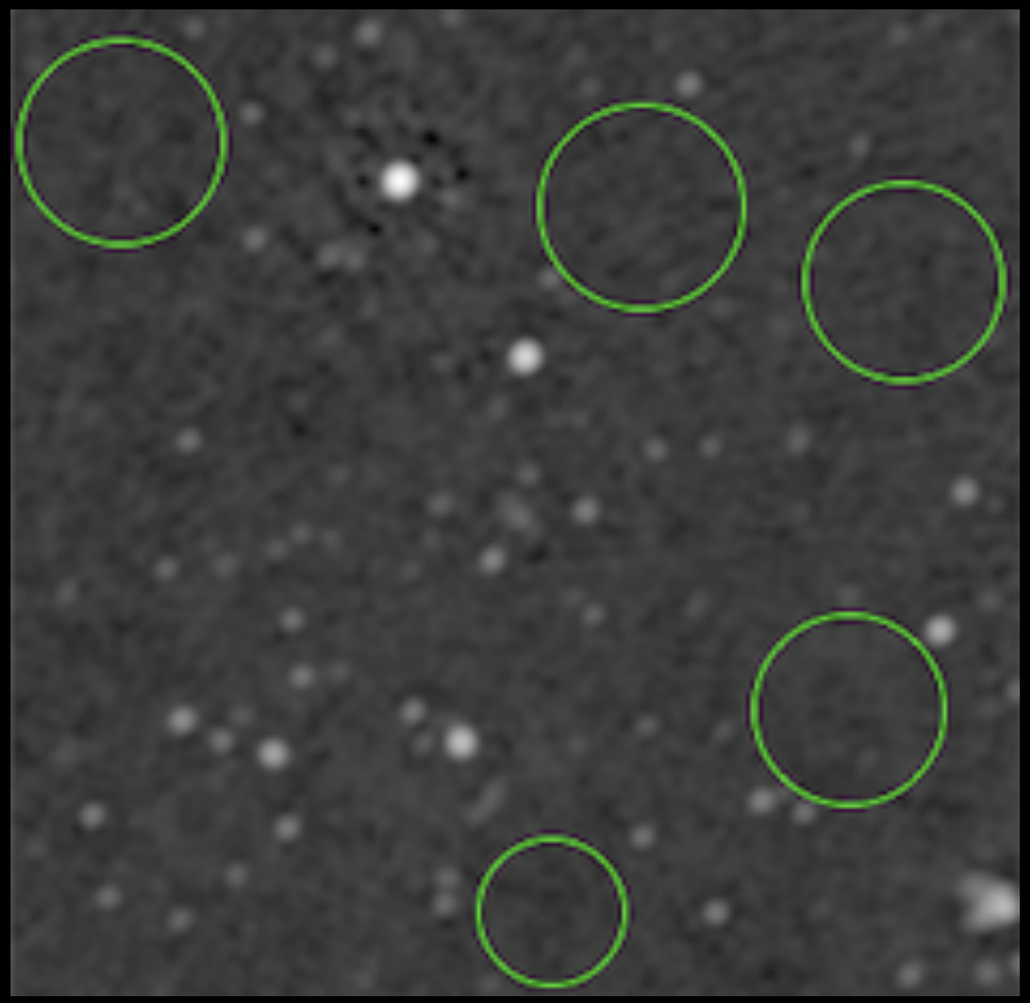
Log-Normalized Plots

Noise Estimation II

01 **GLEAM Images : Residual Files NOT Available**

MANUAL NOISE ESTIMATION

5 Special Patches



σ Estimate with ds9!

Image Augmentation

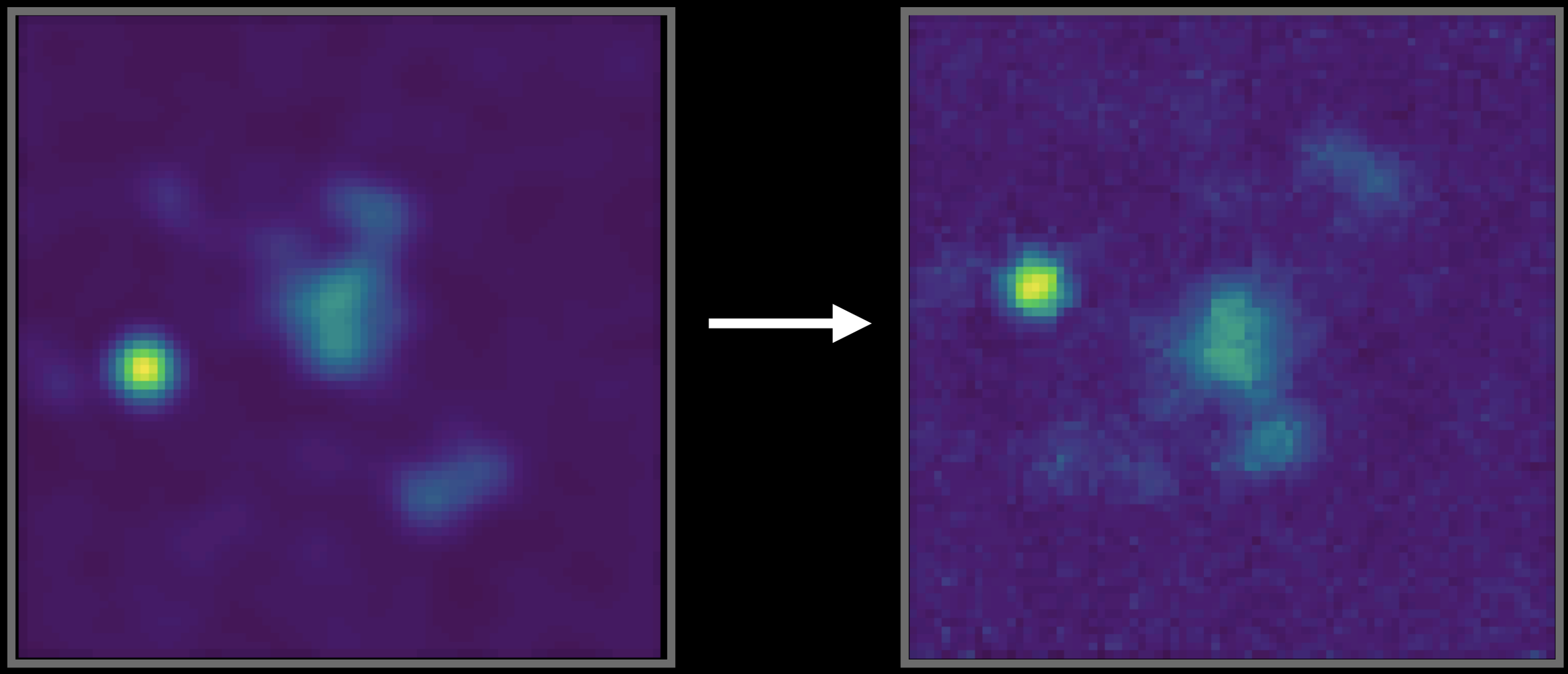
01 **Rotation about centre through multiple of 45 degrees in the range [0,360º] : 8 of them**

02 **2 Flips (up-down, left-right)**

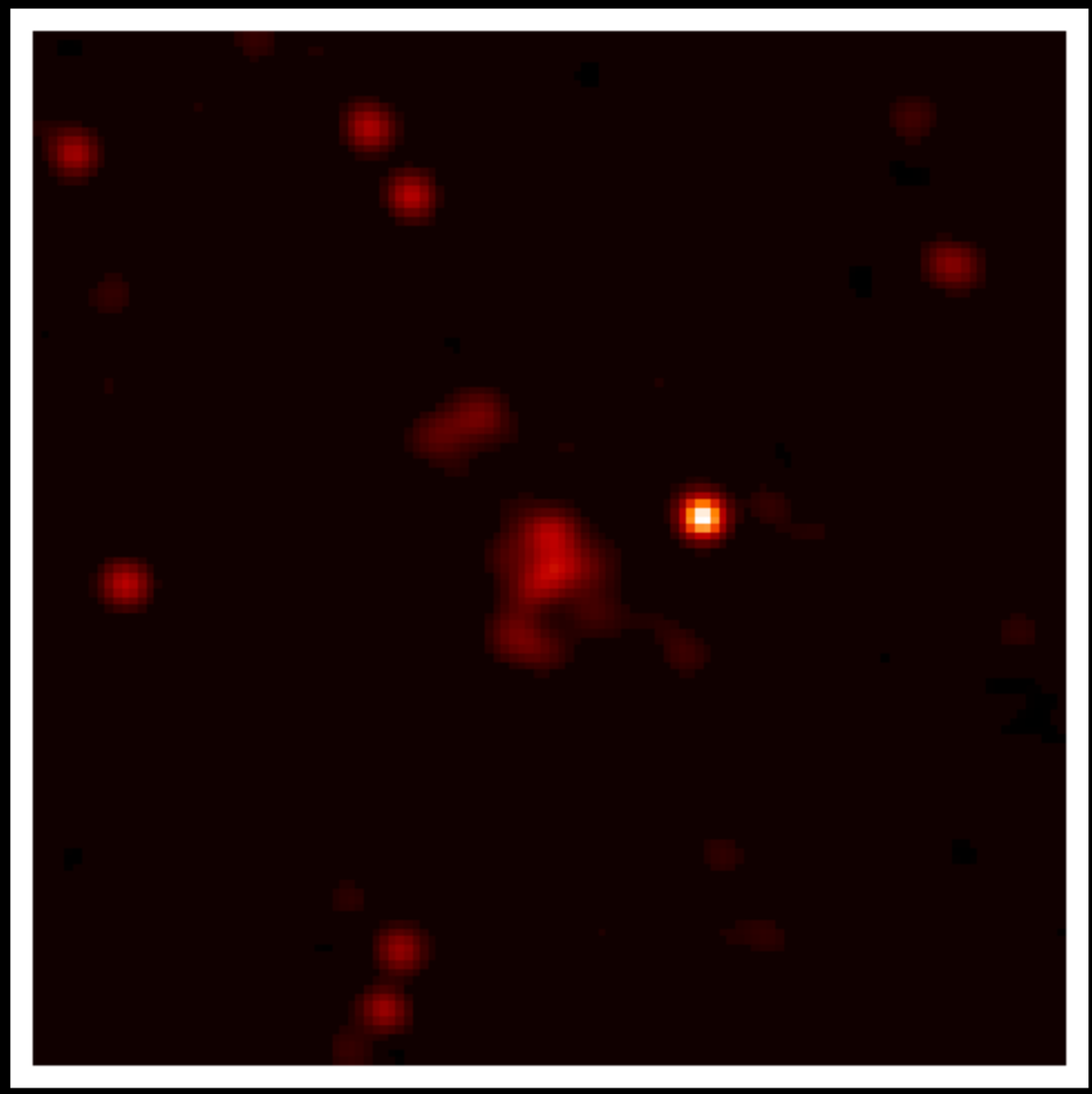
03 **Pixel Scaling with a random coefficient chosen from the range [0.9,1.3]; 10 of them**

04 **Size scaling: Standard cutout for classifier 64 by 64**

Halo Image Generation



01 Conditional Diffusion Model

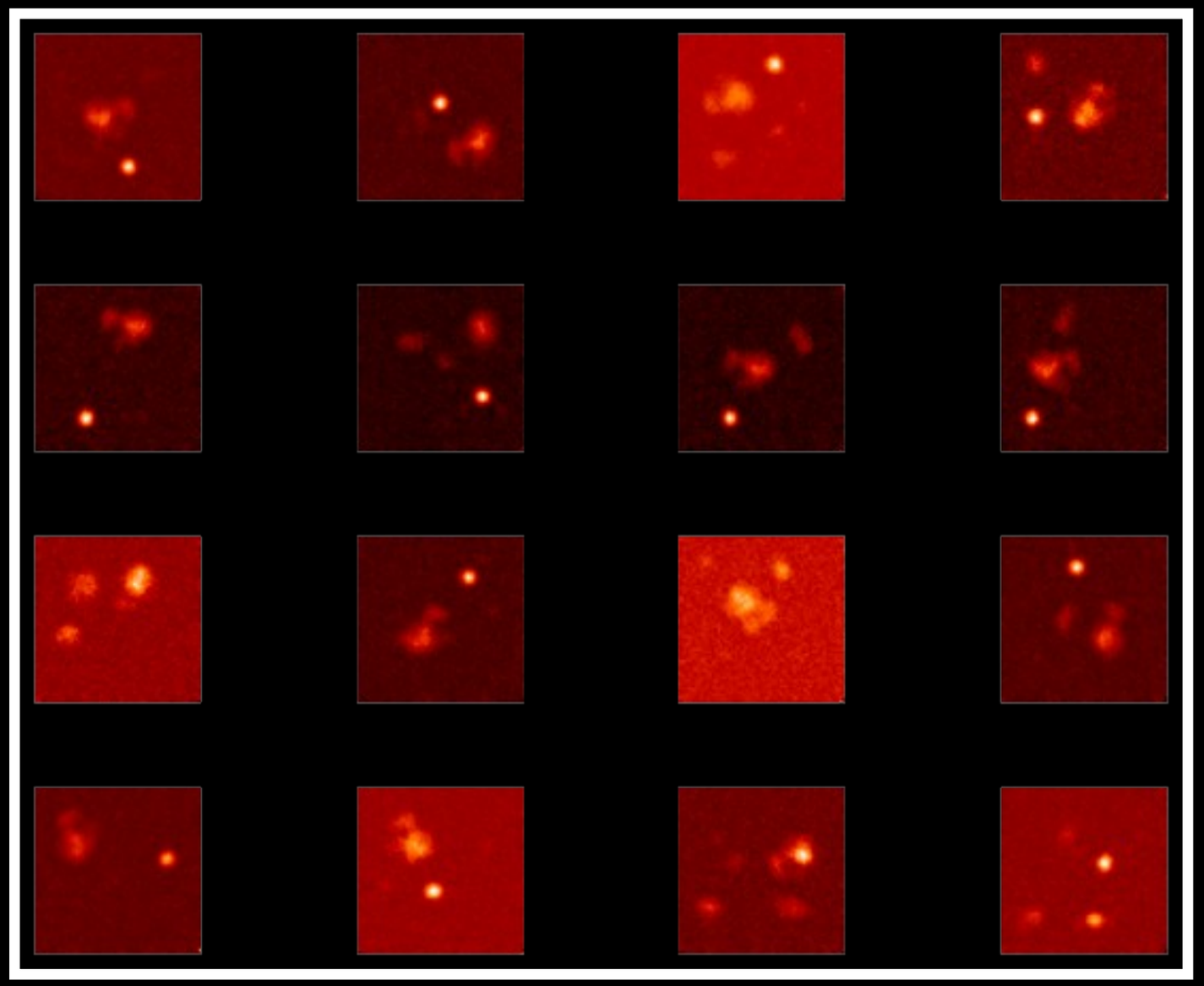


REAL IMAGE

Generated Samples

Looking ‘Realistic’!

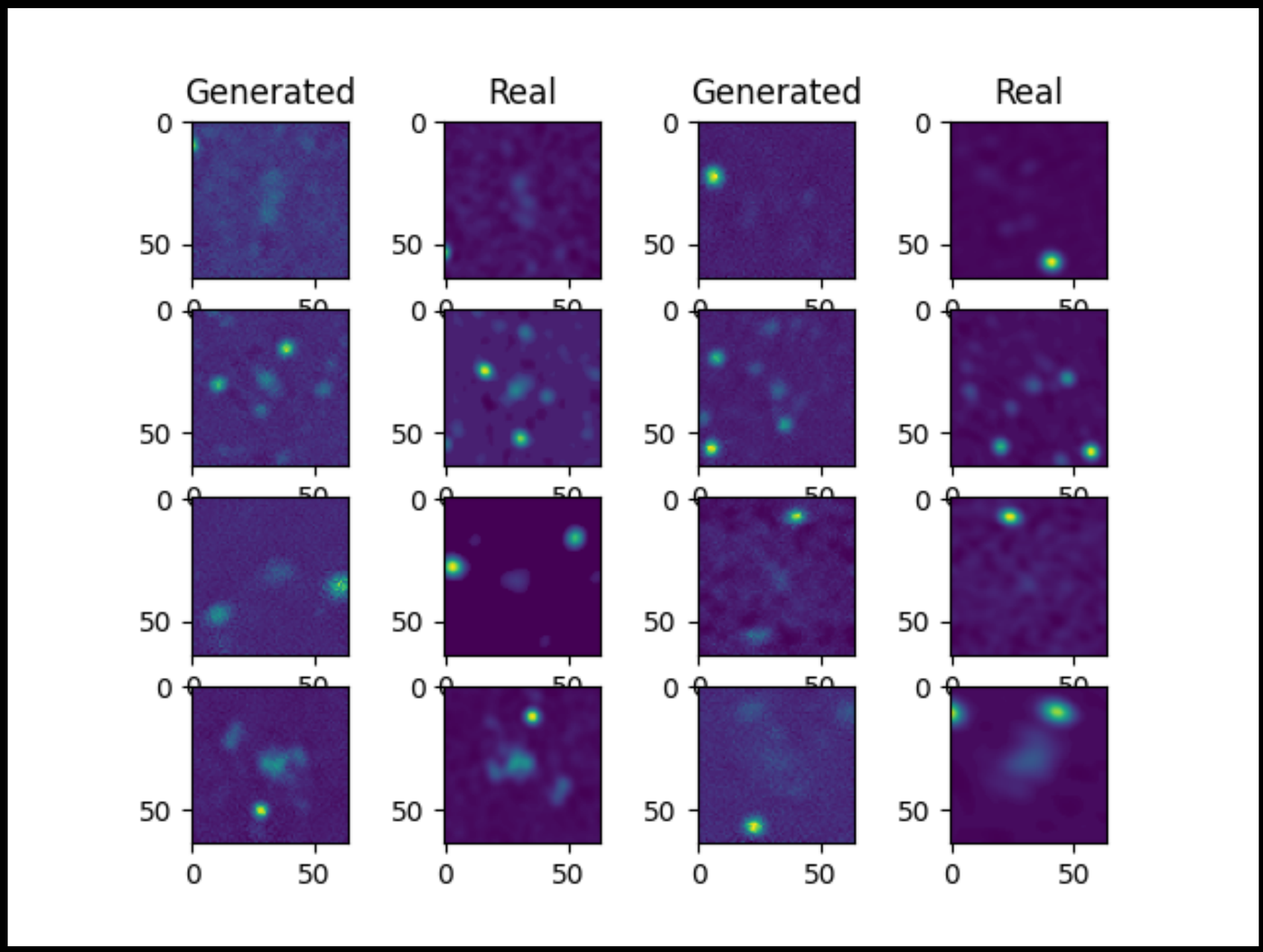
REAL



Halo Image Generation

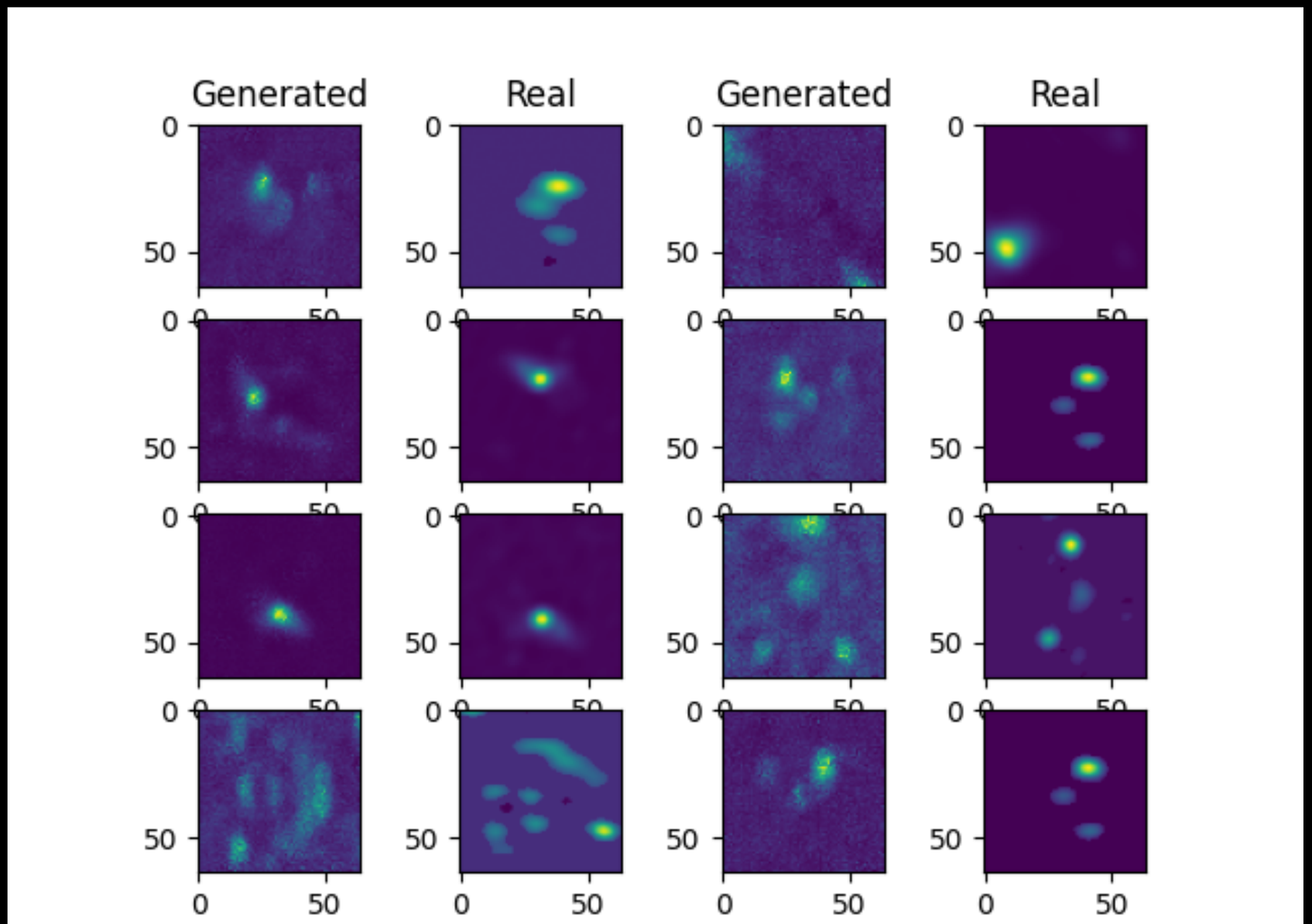
02 Conditional Wasserstein GAN (cWGAN)

Better than our diffusion!



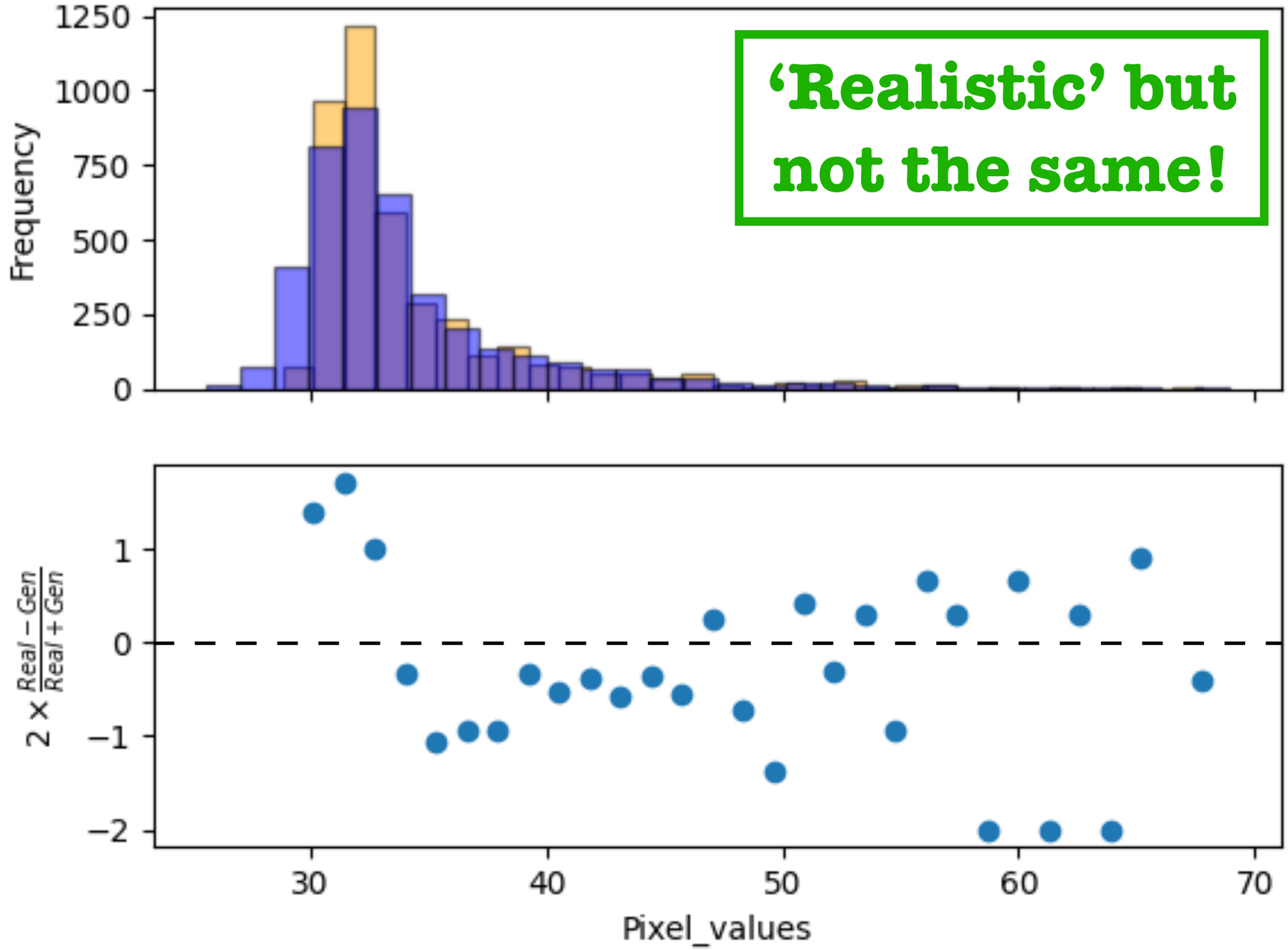
cWGAN (on H,cH,mH)

Works for samples of varied classes!



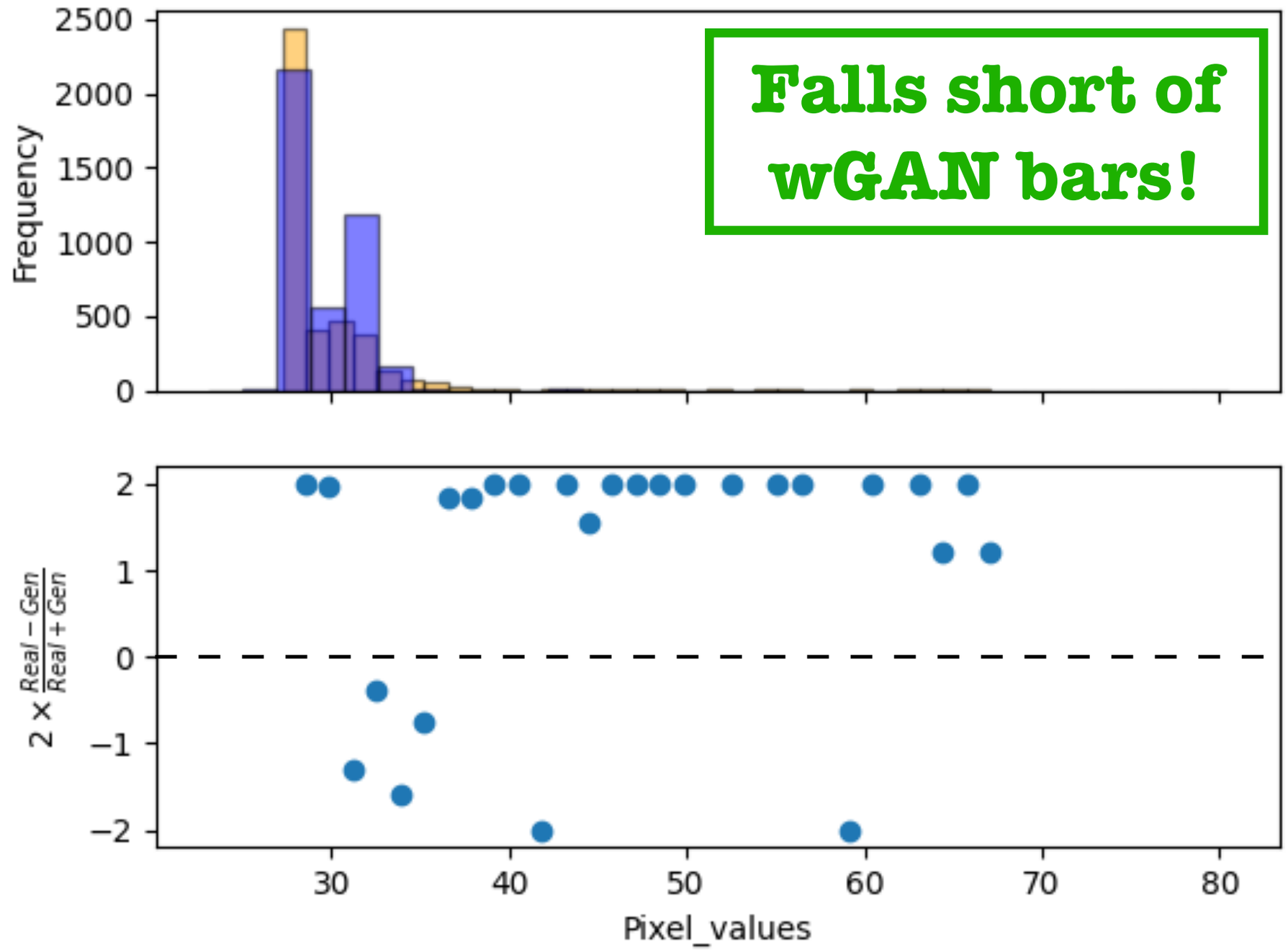
Test of Image Quality

01 GANs

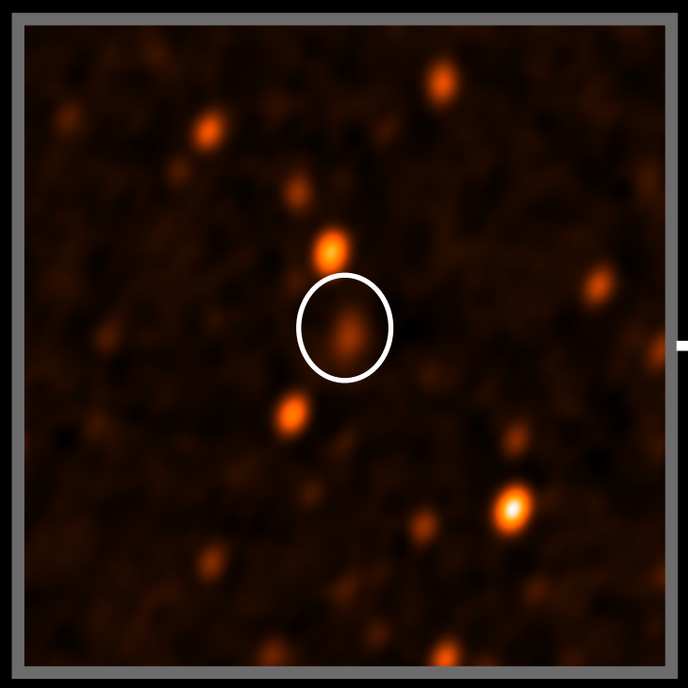

1250
1000
750
500
250
0
Frequency
‘Realistic’ but not the same!
1
0
−1
−2
$2 \times \frac{Real - Gen}{Real + Gen}$
30
40
50
60
70
Pixel_values

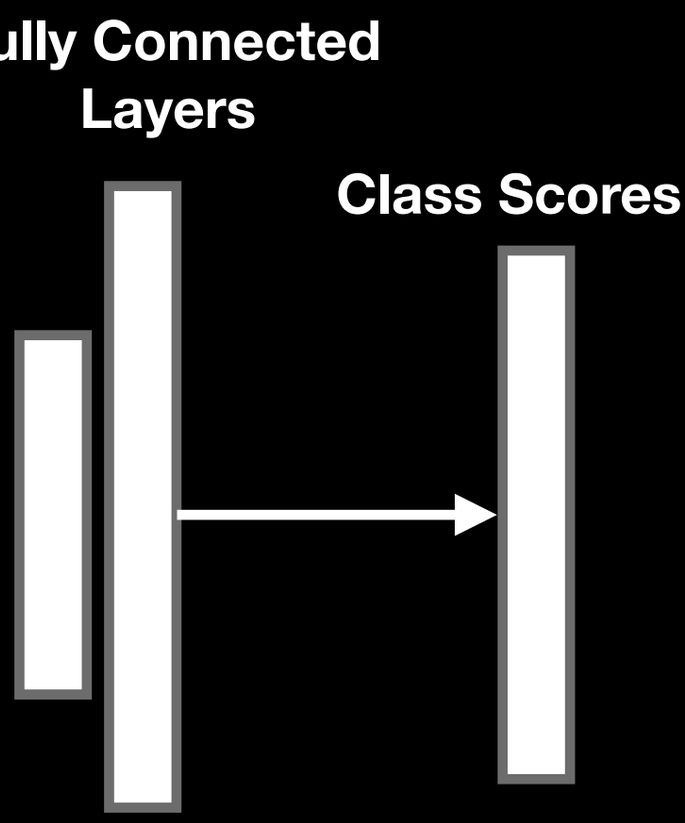
02

Diffusion



Classifier





Feature extractor

Classifier

Training & Test Data

23 Sources (H, cH, mH, cmH)

18 Sources for Training Set

5 Sources for Test Set

Augmentation

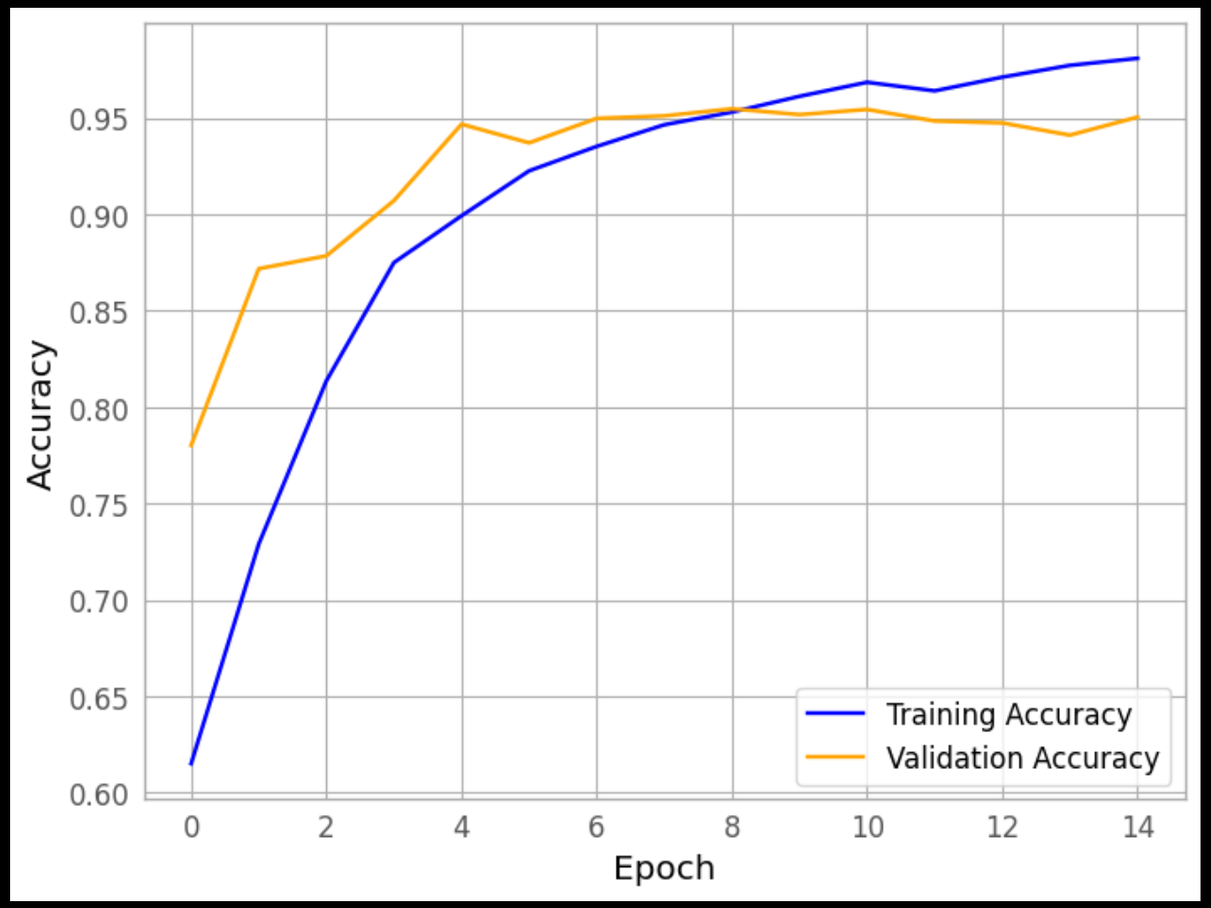
~16000 images

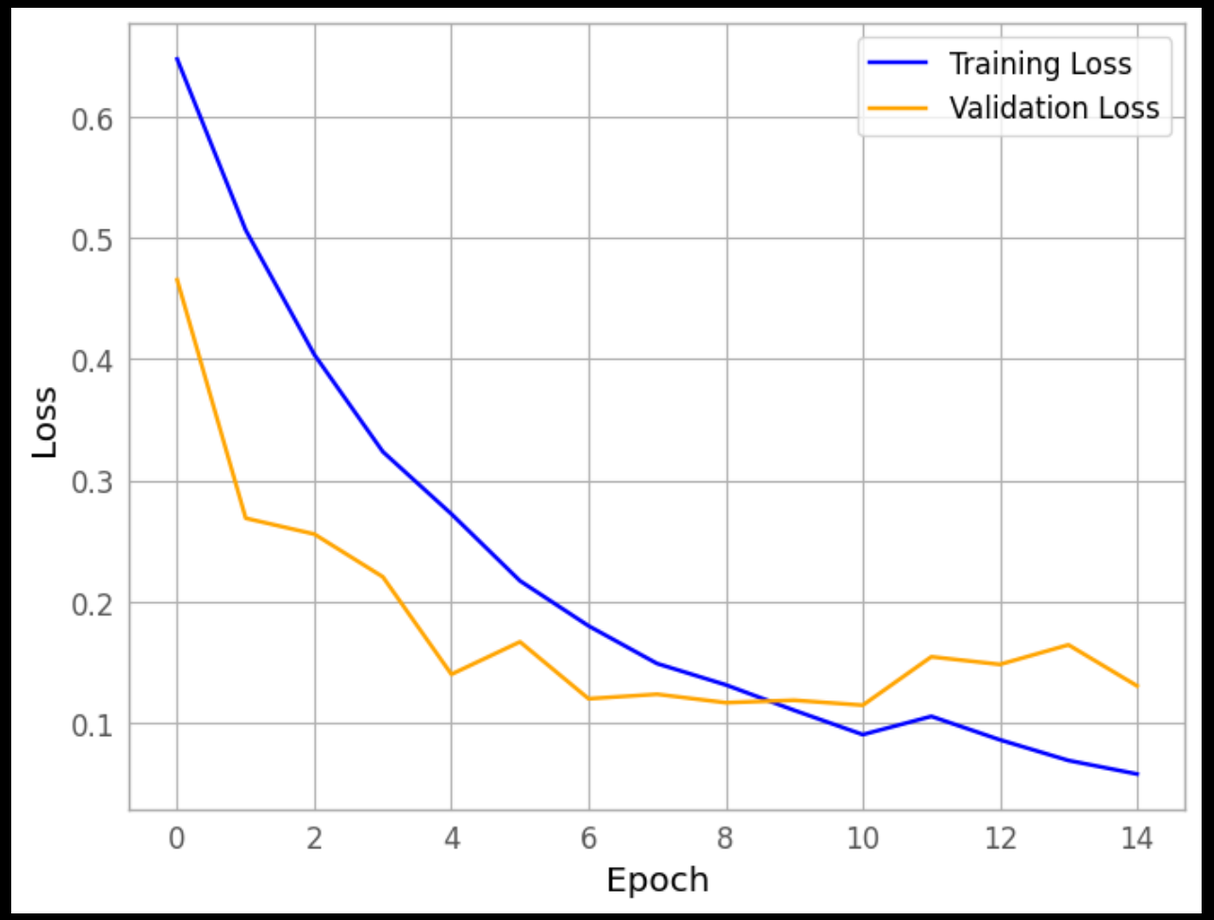
~3000 images

Classifiers

01 **Simple CNN (LeCun et. al. 1998) - 0.05M parameters**

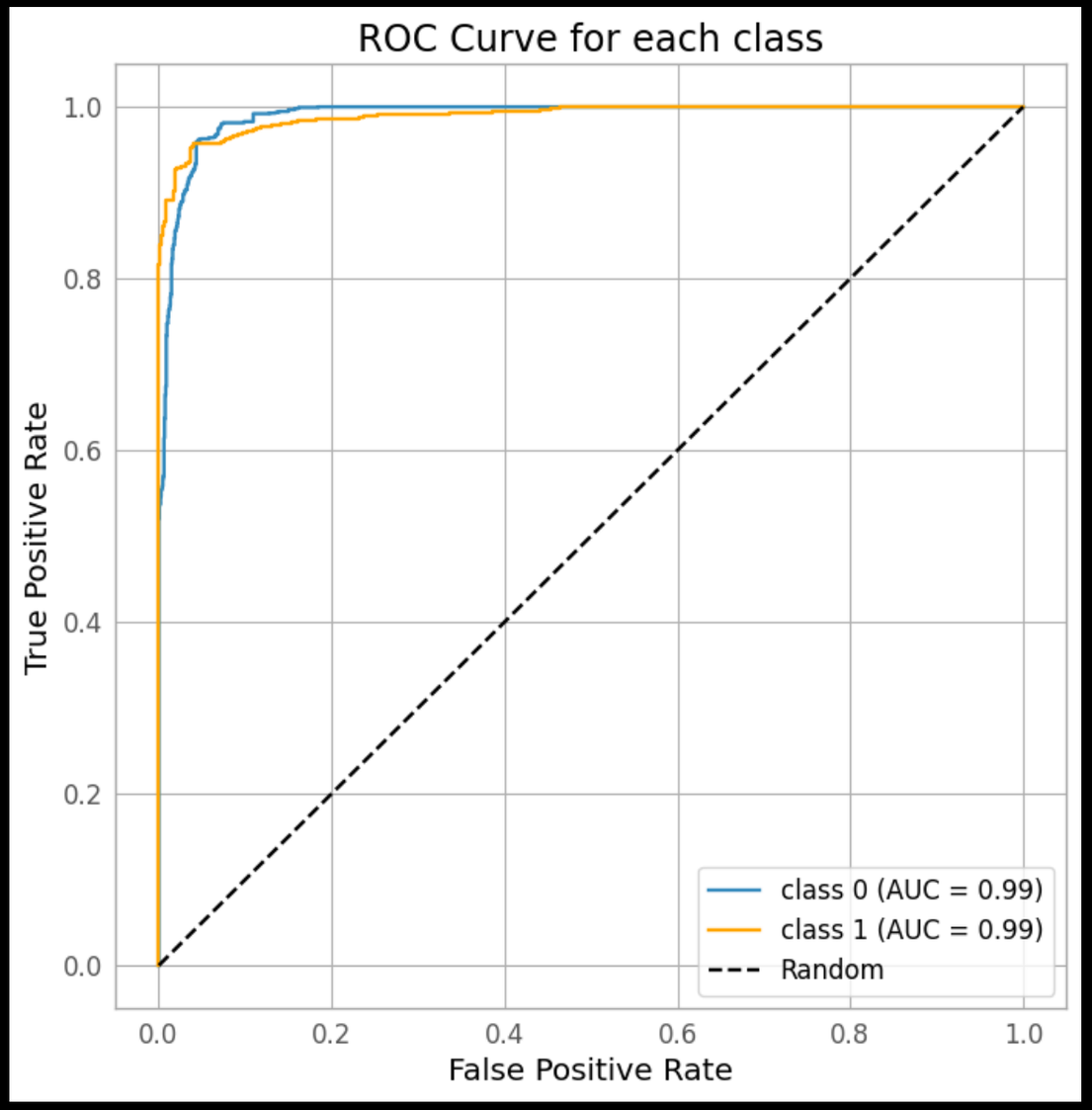
(VGG 16 ~ 100M parameters)

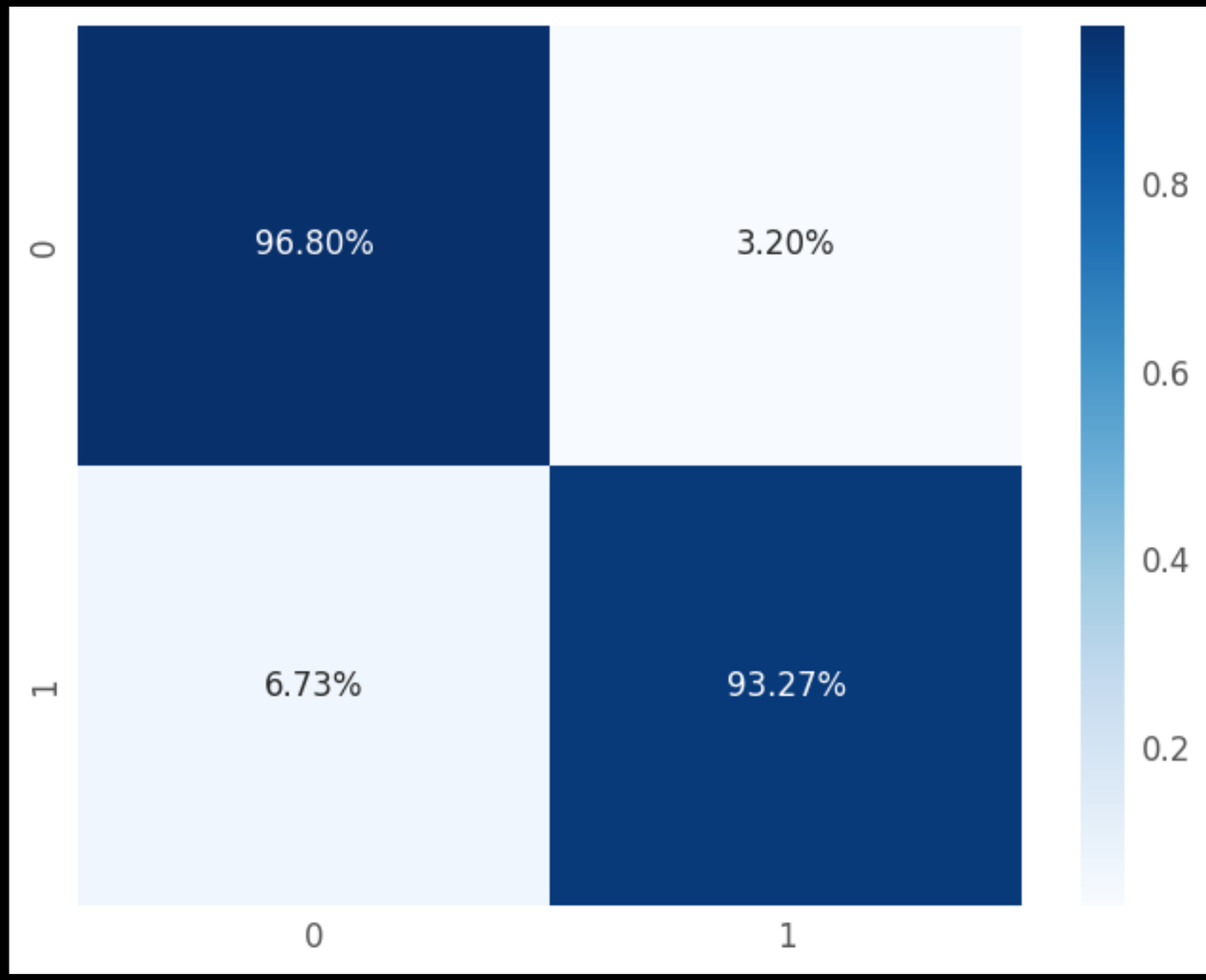




Both loss and accuracy begin to saturate!

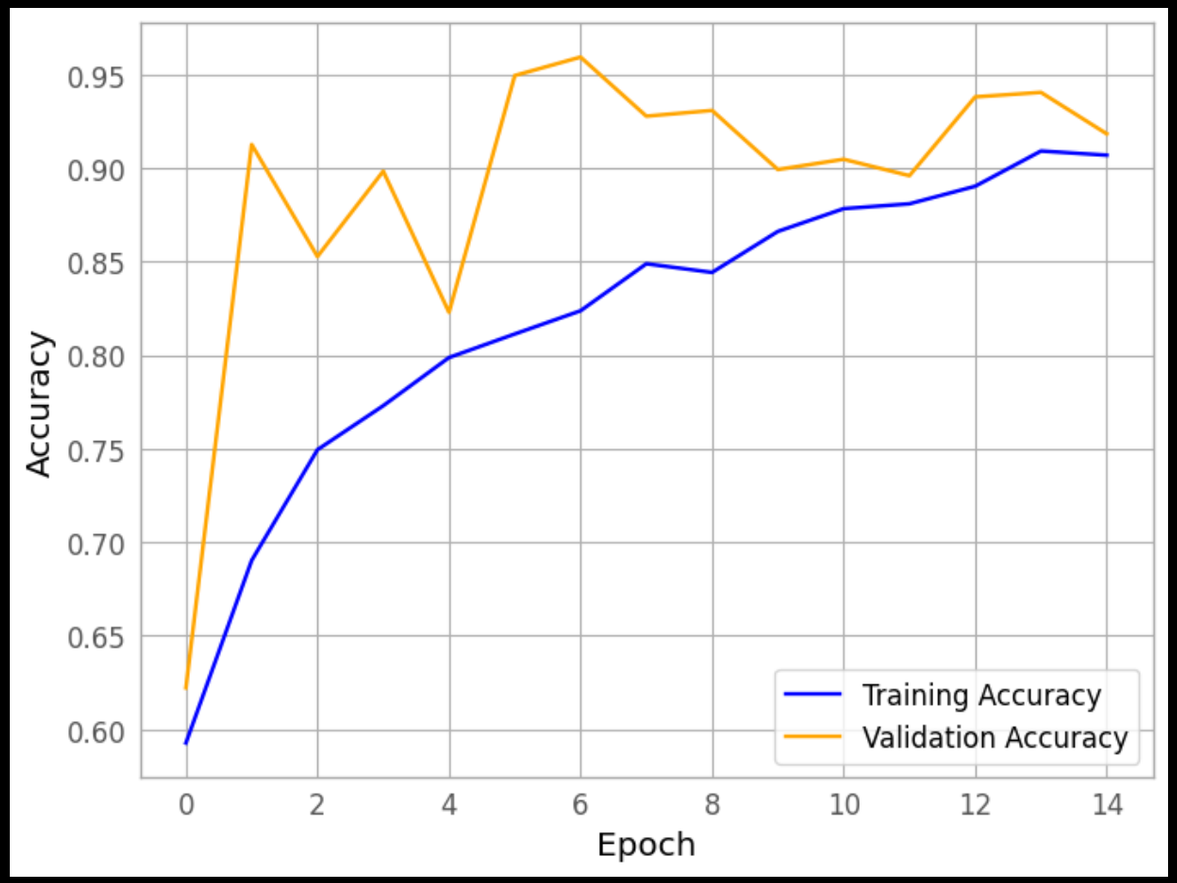
ROC, Confusion Matrix

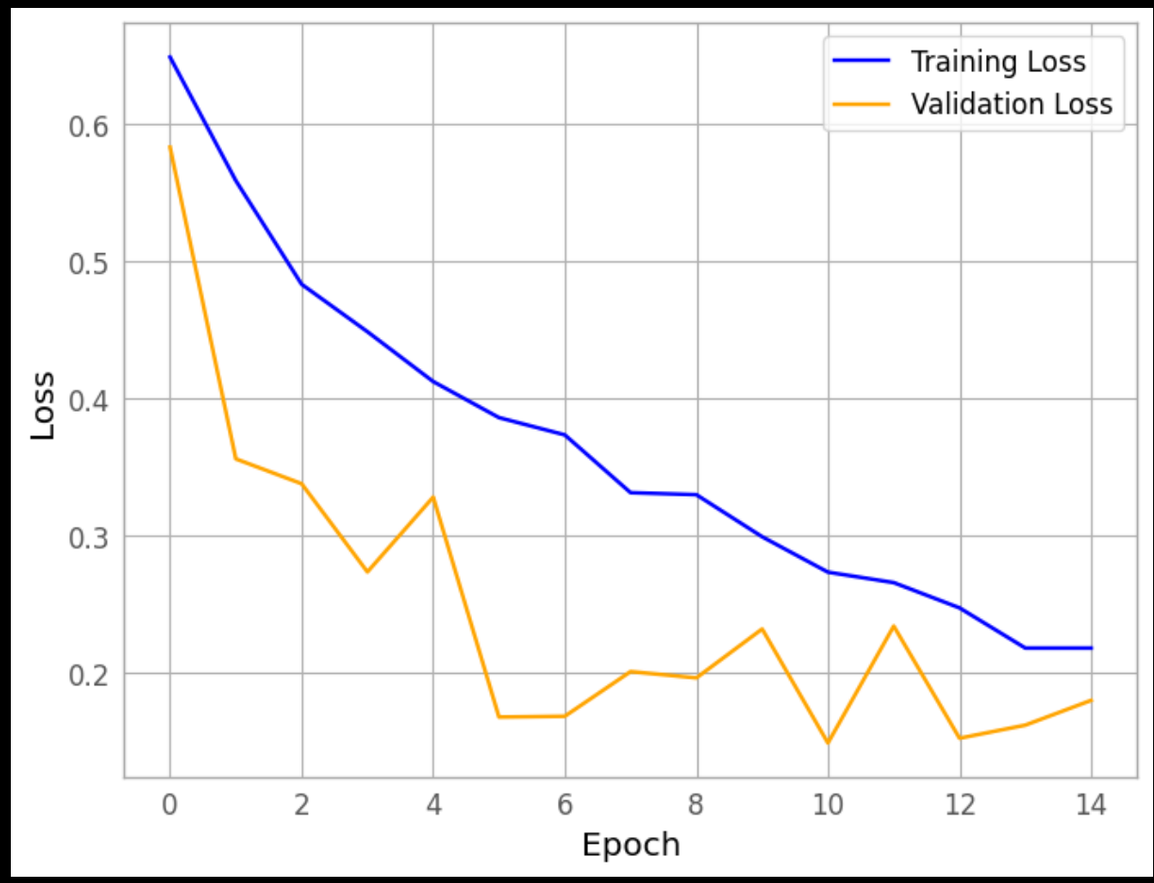




Does a pretty good job with 0.05M parameters!

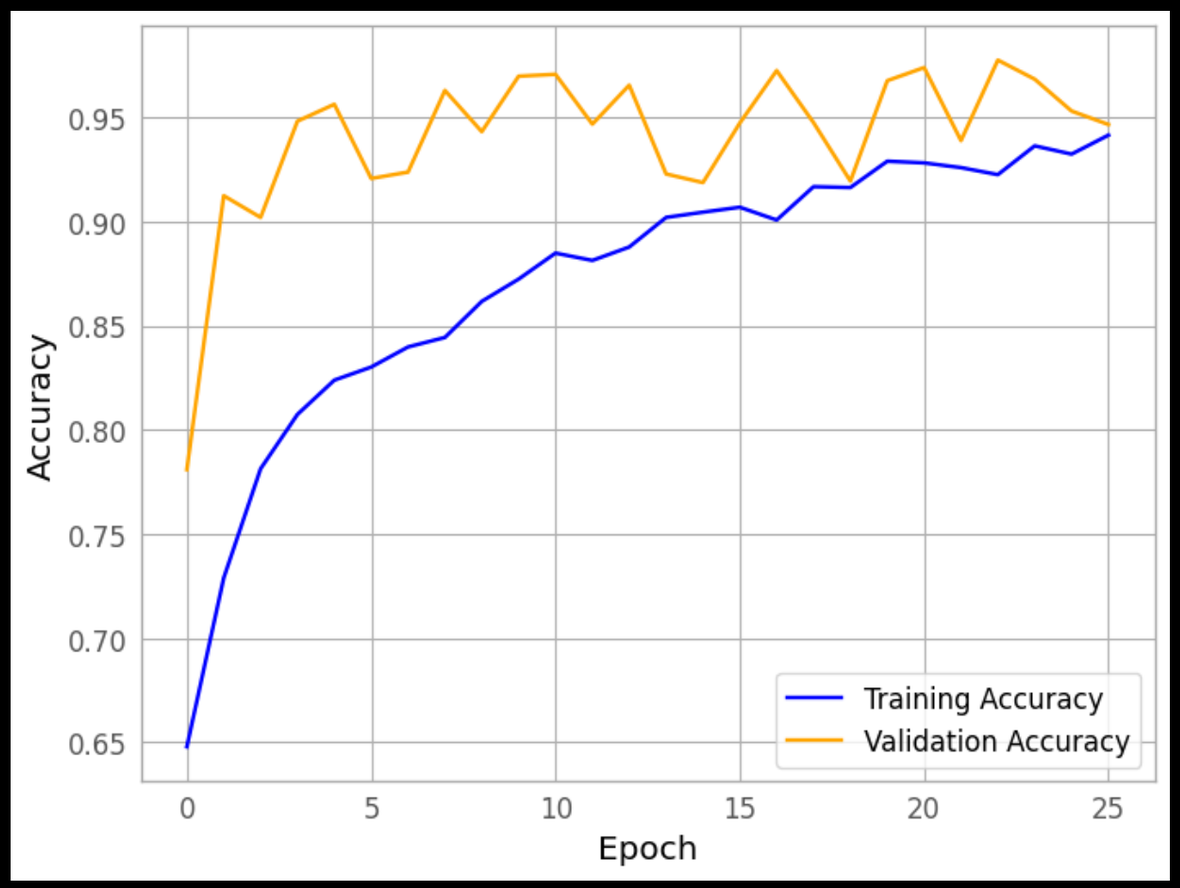
02 Fully-Connected Network for Classification

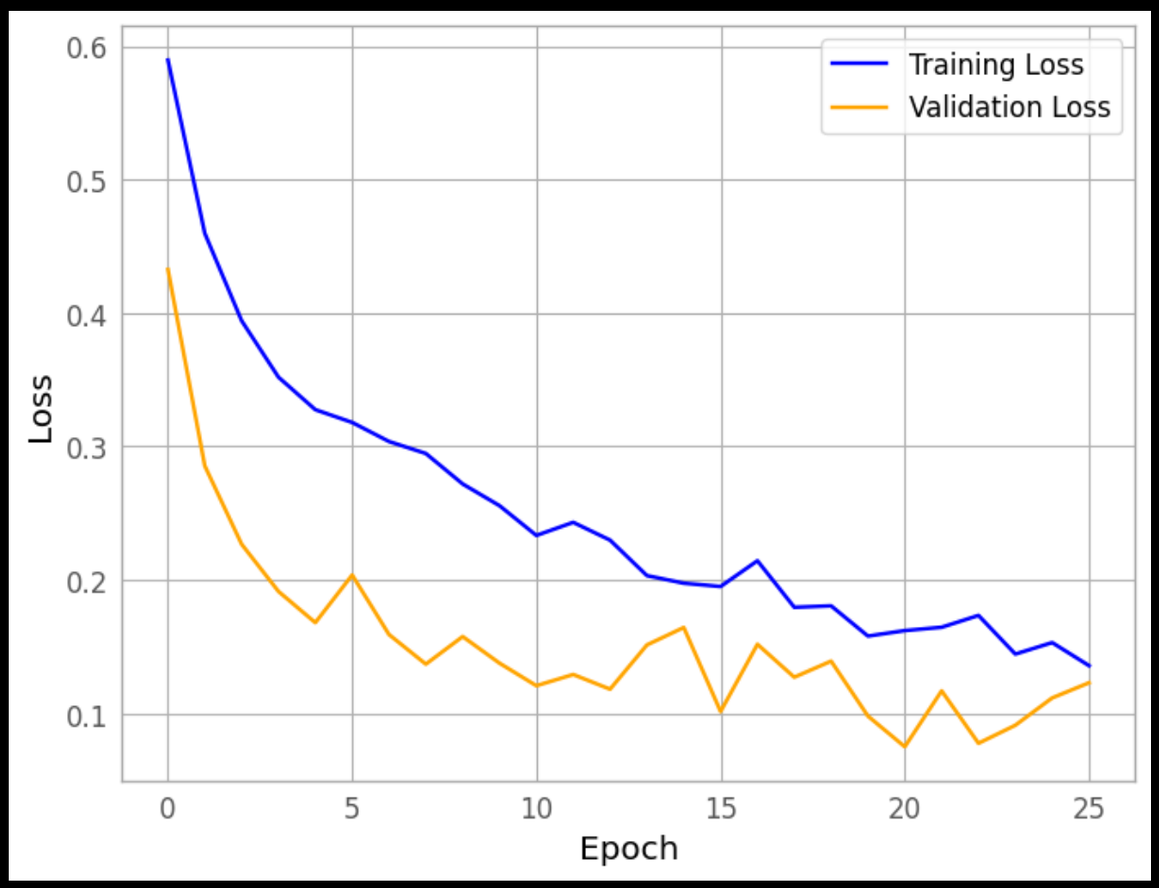




Not Bad (Around 90% validation accuracy)!

03 GAN Aided Classifier





Indeed improves the base dense network performance!

04 Different Classifiers and Corresponding results

	Precision	Recall	Specificity	F1-Score
Simple CNN	0.97	0.93	0.97	0.95
Multi-Headed Attention CNN	1.0	0.93	1.0	0.96
Fully Connected	0.89	0.94	0.89	0.92
GAN Aided Classifier	0.96	0.95	0.95	0.95

Work in Progress!
(Still to apply on MeerKAT)

01 **Comparisons for classifiers with classical and wGAN augmentation (separately) (also with Diffusion)**

02 **Comparison between different classifier models with k-fold Cross-validation**

03 **Stable Diffusion for Halo Image Generation**

04 **Radio Halo Detection directly from u-v plane with the use of shapelets**

THANK YOU!

Question?

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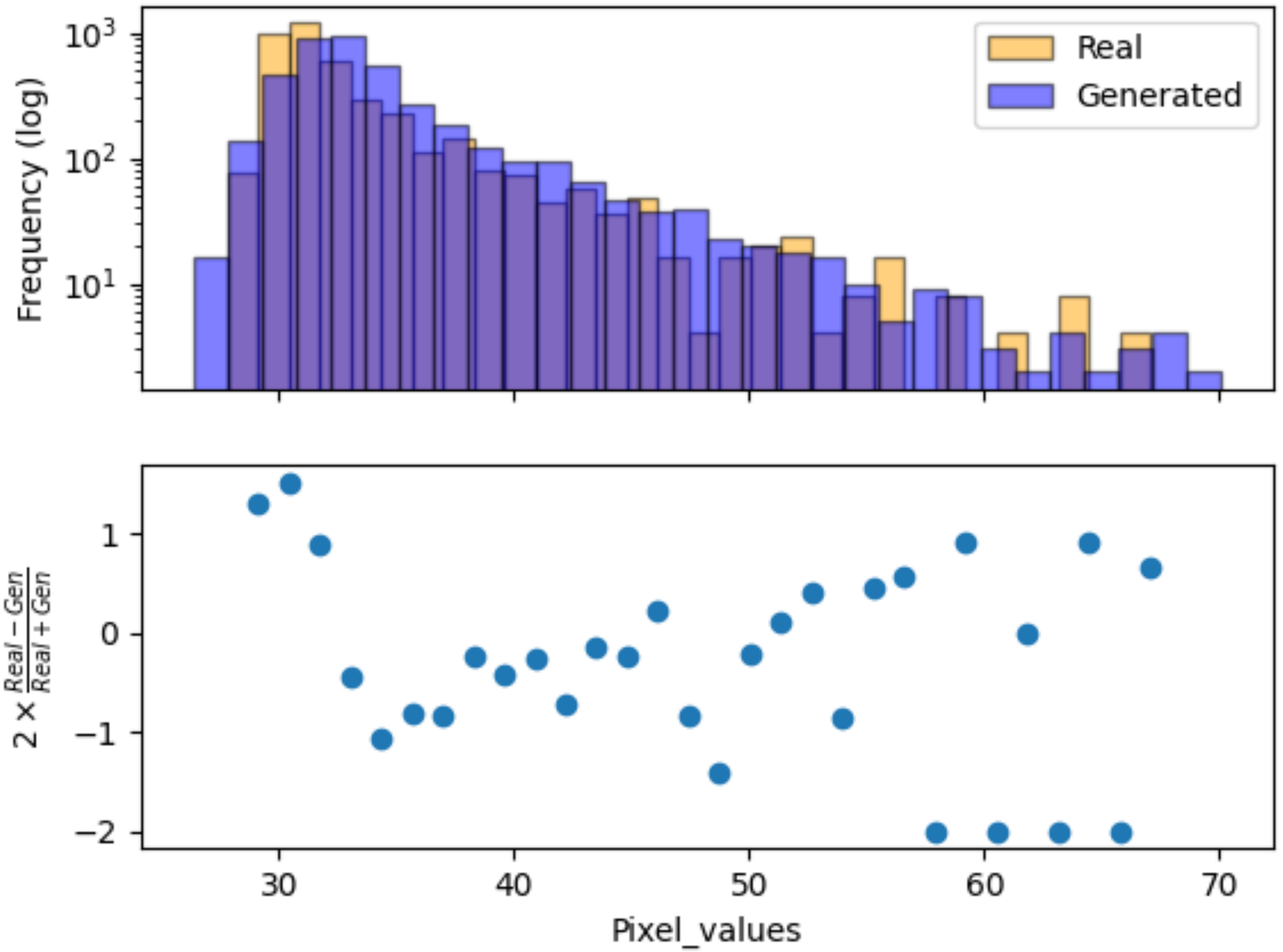
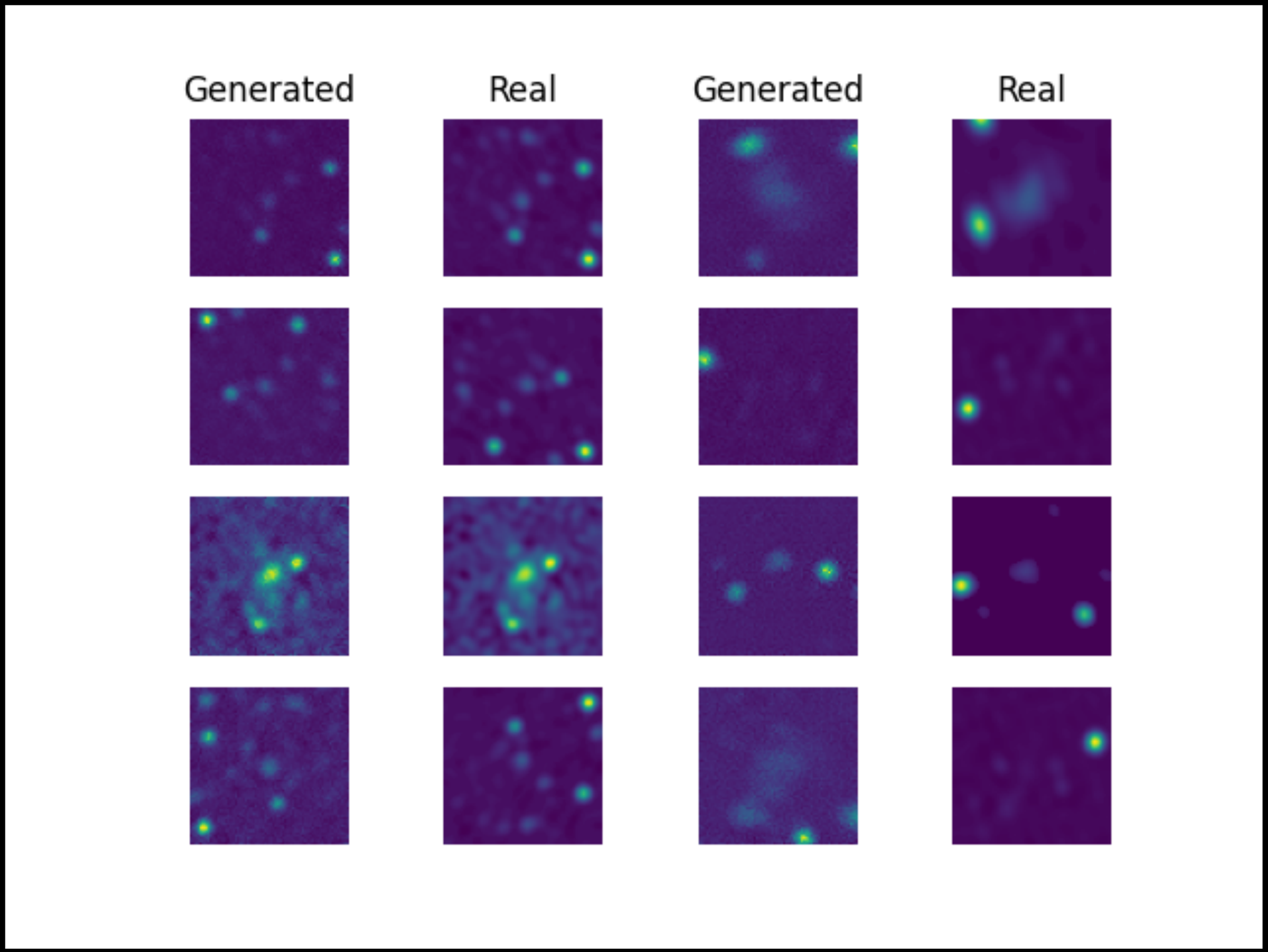
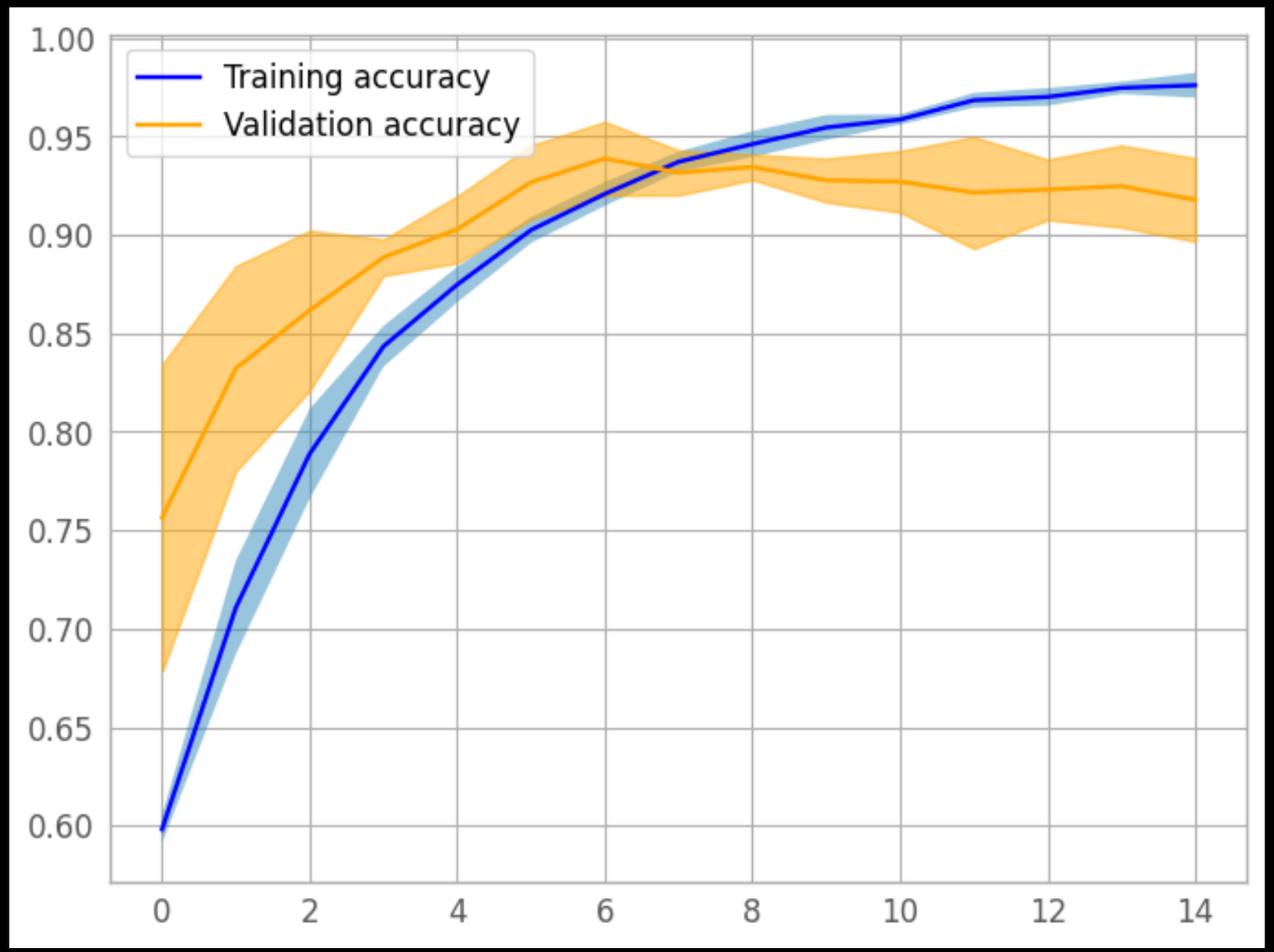
Backup Slides


Frequency (log)
10^3
10^2
10^1
Real
Generated
$2 \times \frac{Real - Gen}{Real + Gen}$
1
0
−1
−2
30
40
50
60
70
Pixel_values


Generated
Real
Generated
Real

Five Training Runs

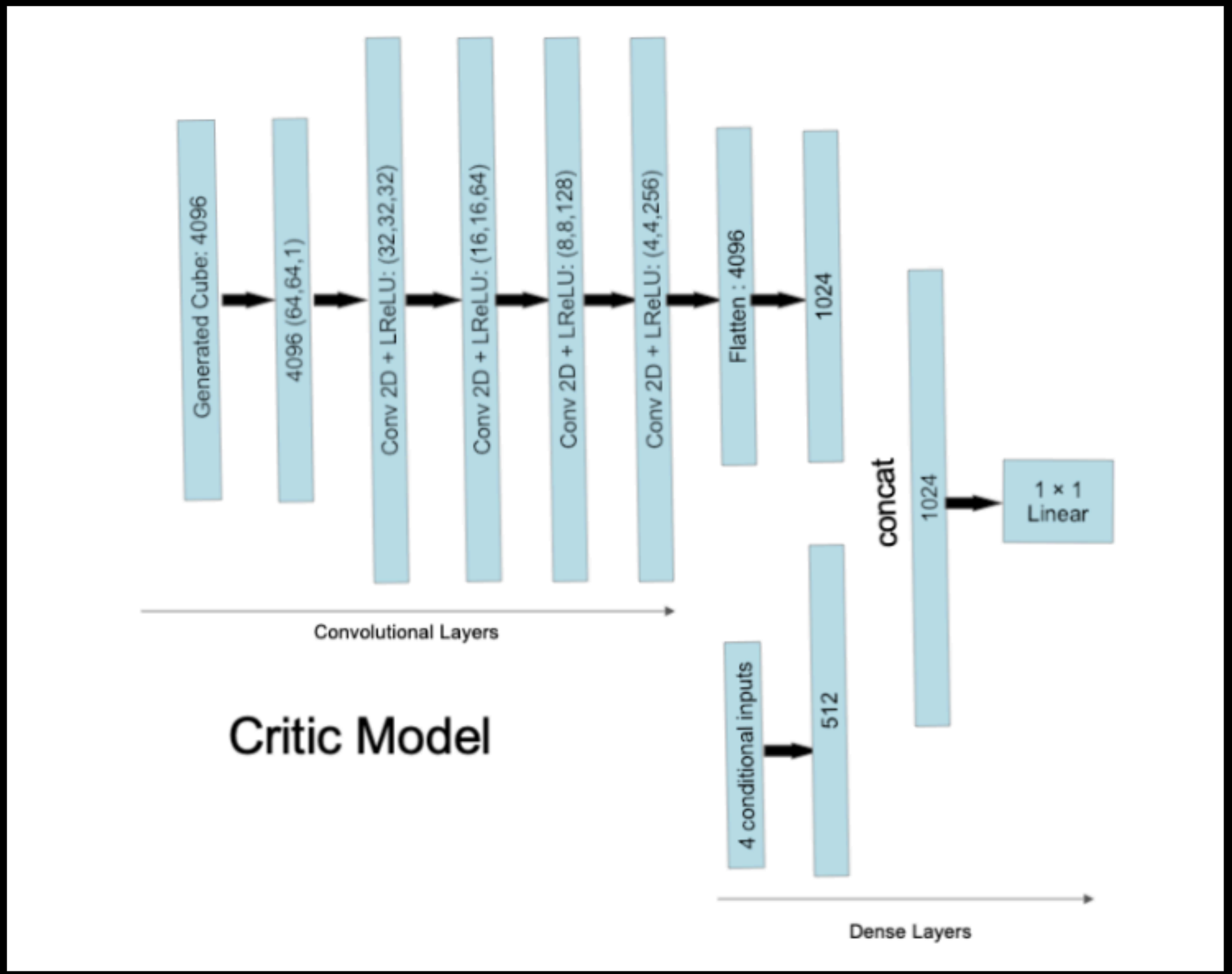


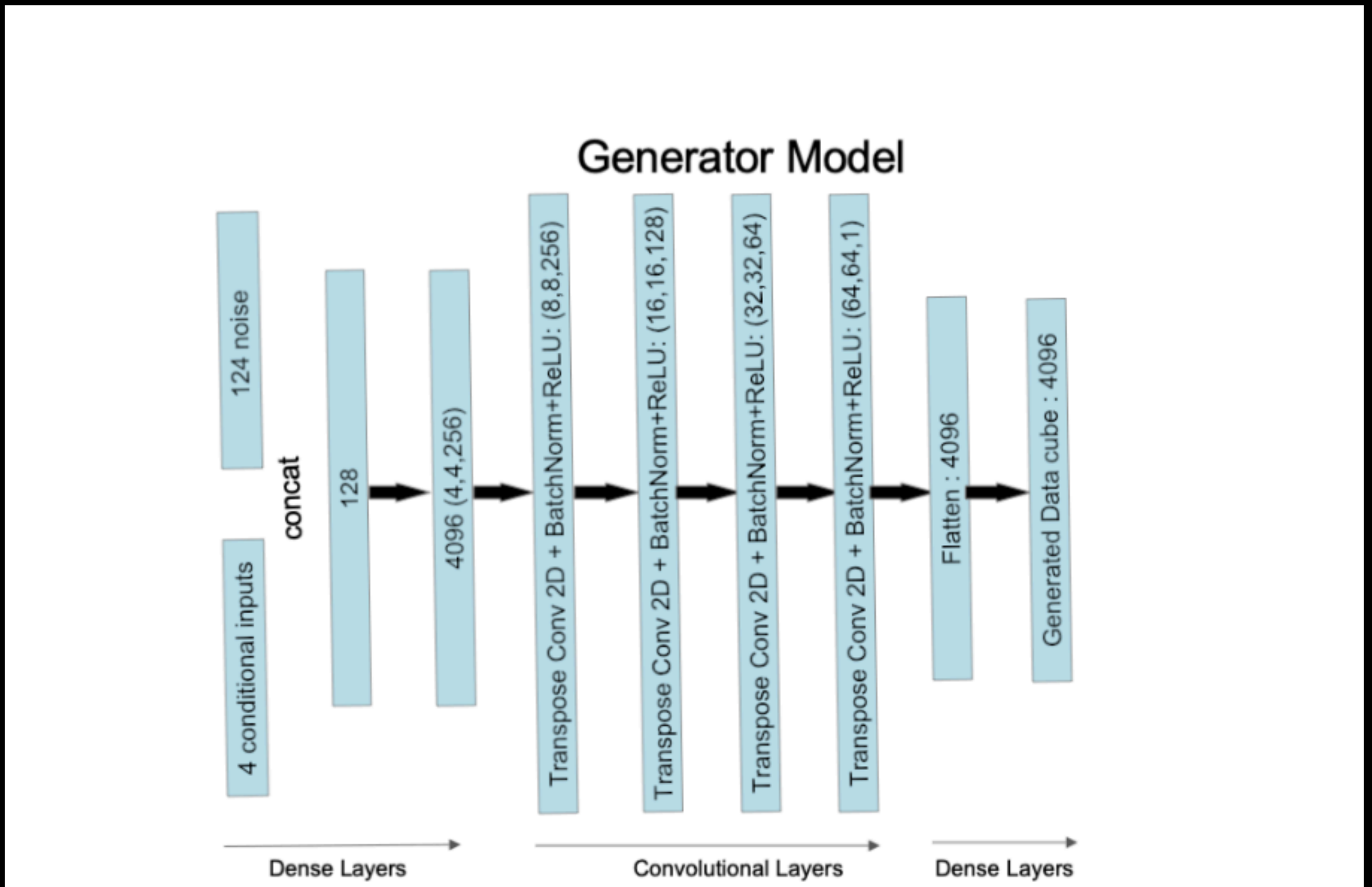
Data Collection I

S.N.	Galaxy Cluster	Classification	Source of Data Collection	Classification Paper		
1	Abell 0141	H	https://dmc.datacentral.org.au/dataset/mwa-askap-atca-and-chandra-images-of-abell-141-and-abell-3404	https://arxiv.org/abs/2103.08282		
2	Abell 3404	H	,,	https://arxiv.org/abs/2103.08282		
3	Abell S1121	H	GLEAM Survey (https://skyview.gsfc.nasa.gov/current/cgi/query.pl)	https://arxiv.org/abs/1707.03517		
4	Abell S1063	H	GLEAM Survey	https://arxiv.org/abs/1707.03517		
5	MACS J2243.4-0935	H	GLEAM Survey	https://arxiv.org/abs/1707.03517		
6	Abell 2163	H	GLEAM Survey	https://arxiv.org/pdf/1701.06742		
7	Abell 2254	H	GLEAM Survey	https://arxiv.org/pdf/1701.06742		
8	Abell 2744	H	GLEAM Survey	https://arxiv.org/pdf/1701.06742		
9	plck G287.0+32.9	H	GLEAM Survey	https://arxiv.org/pdf/1701.06742		
10	rxc j1314.4-2515	H	GLEAM Survey	https://arxiv.org/pdf/1701.06742		

Data Collection II

11	Abell 2680	cH	https://dmc.datacentral.org.au/dataset/data-for-an-mwa-2-survey-of-diffuse-radio-emission-in-galaxy-clusters	https://arxiv.org/abs/1707.03517		
12	Abell 2693	cH	”	”		
13	Abell 2811	cH (or mH)	”	”		
14	Abell 3186	cH	”	”		
15	Abell 3399	cH	”	”		
16	PSZ1 G287.95-32.98	cH	”	”		
17	Abell 2496	cH	GLEAM Survey	”		
18	Abell 2721	cH	GLEAM Survey	”		
19	Abell S0084	cH	GLEAM Survey	”		
20	GMBCG J357.91841-08.97978	cH	GLEAM Survey	”		
21	Abell 0122	cmH	https://dmc.datacentral.org.au/dataset/data-for-an-mwa-2-survey-of-diffuse-radio-emission-in-galaxy-clusters	”		
22	MCXC J0145.2-6033	cmH	”	”		
23	rxc j01377.2-0912	mH	”	”		


Generated Cube: 4096
4096 (64,64,1)
Conv 2D + LReLU: (32,32,32)
Conv 2D + LReLU: (16,16,64)
Conv 2D + LReLU: (8,8,128)
Conv 2D + LReLU: (4,4,256)
Flatten : 4096
1024
Convolutional Layers
concat
1024
1 × 1
Linear
4 conditional inputs
512
Dense Layers
Critic Model


Generator Model
124 noise
concat
4 conditional inputs
128
4096 (4,4,256)
Transpose Conv 2D + BatchNorm+ReLU: (8,8,256)
Transpose Conv 2D + BatchNorm+ReLU: (16,16,128)
Transpose Conv 2D + BatchNorm+ReLU: (32,32,64)
Transpose Conv 2D + BatchNorm+ReLU: (64,64,1)
Flatten : 4096
Generated Data cube : 4096
Dense Layers
Convolutional Layers
Dense Layers