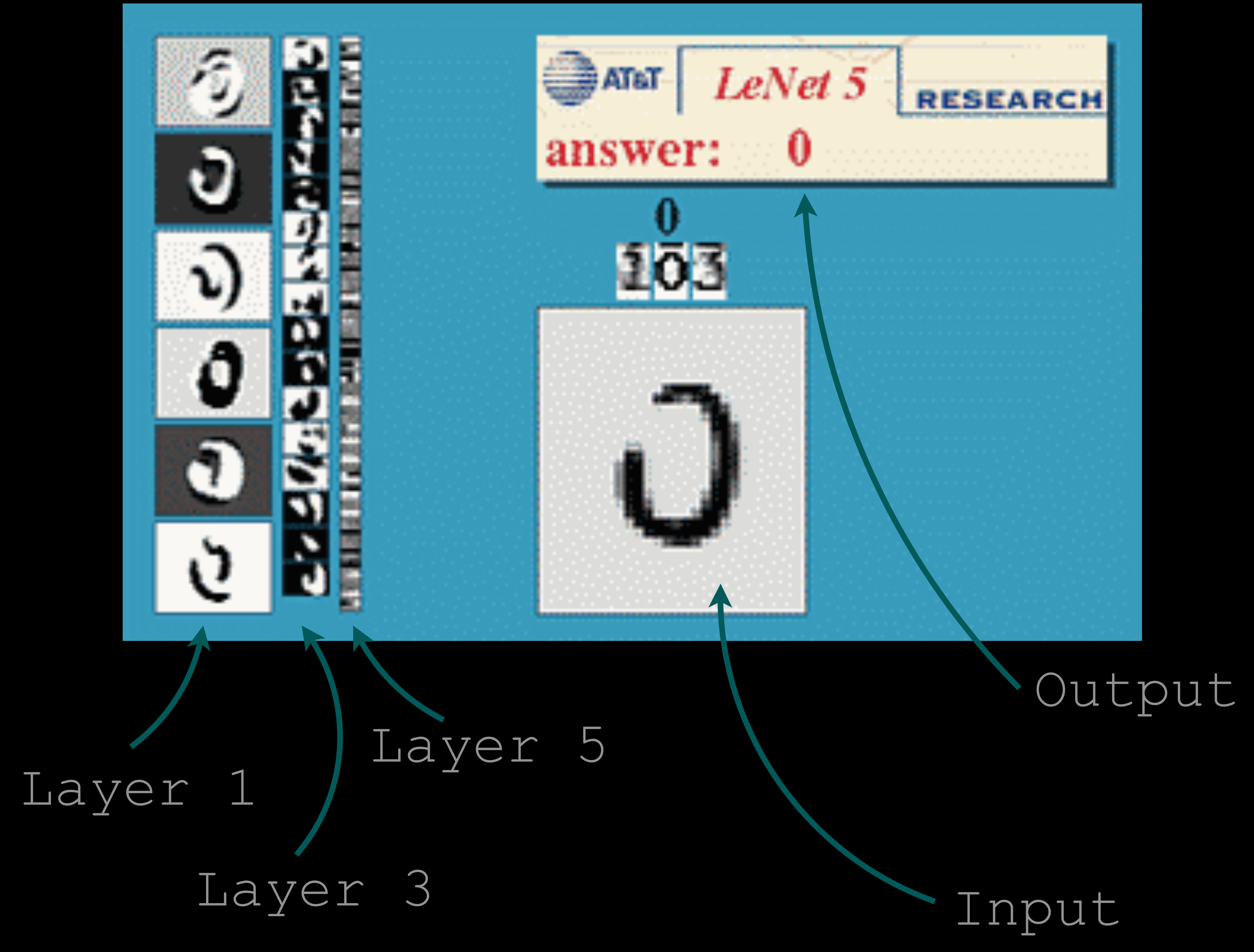
Pushing the limits of Astronomy using AI

Dr Maggie Lieu (University of Nottingham)

@space_mog

Recap.

LeNet-5 (LeCun 1998)



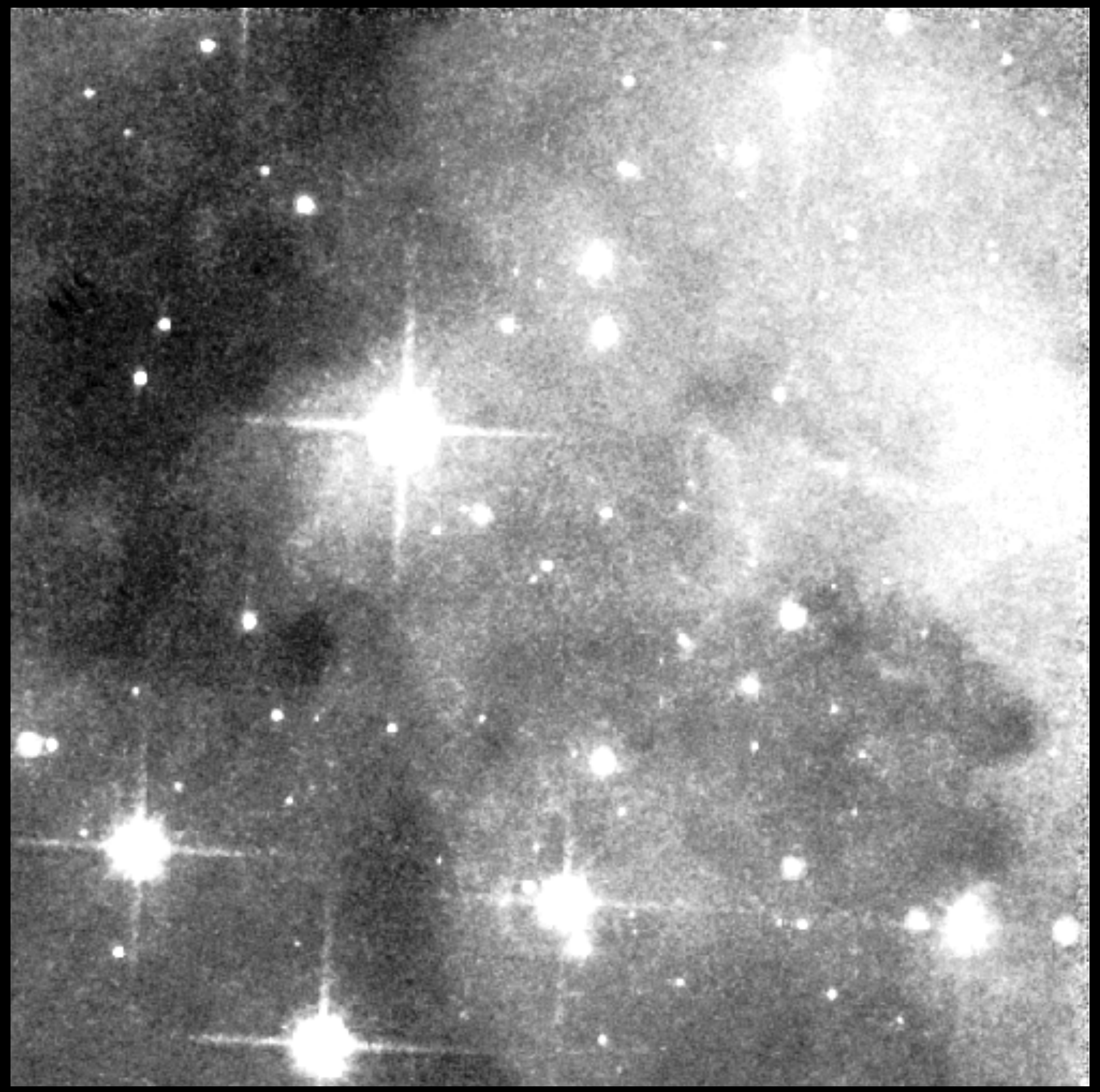
Machine Learning has been revolutionary

Enhancing Hubble

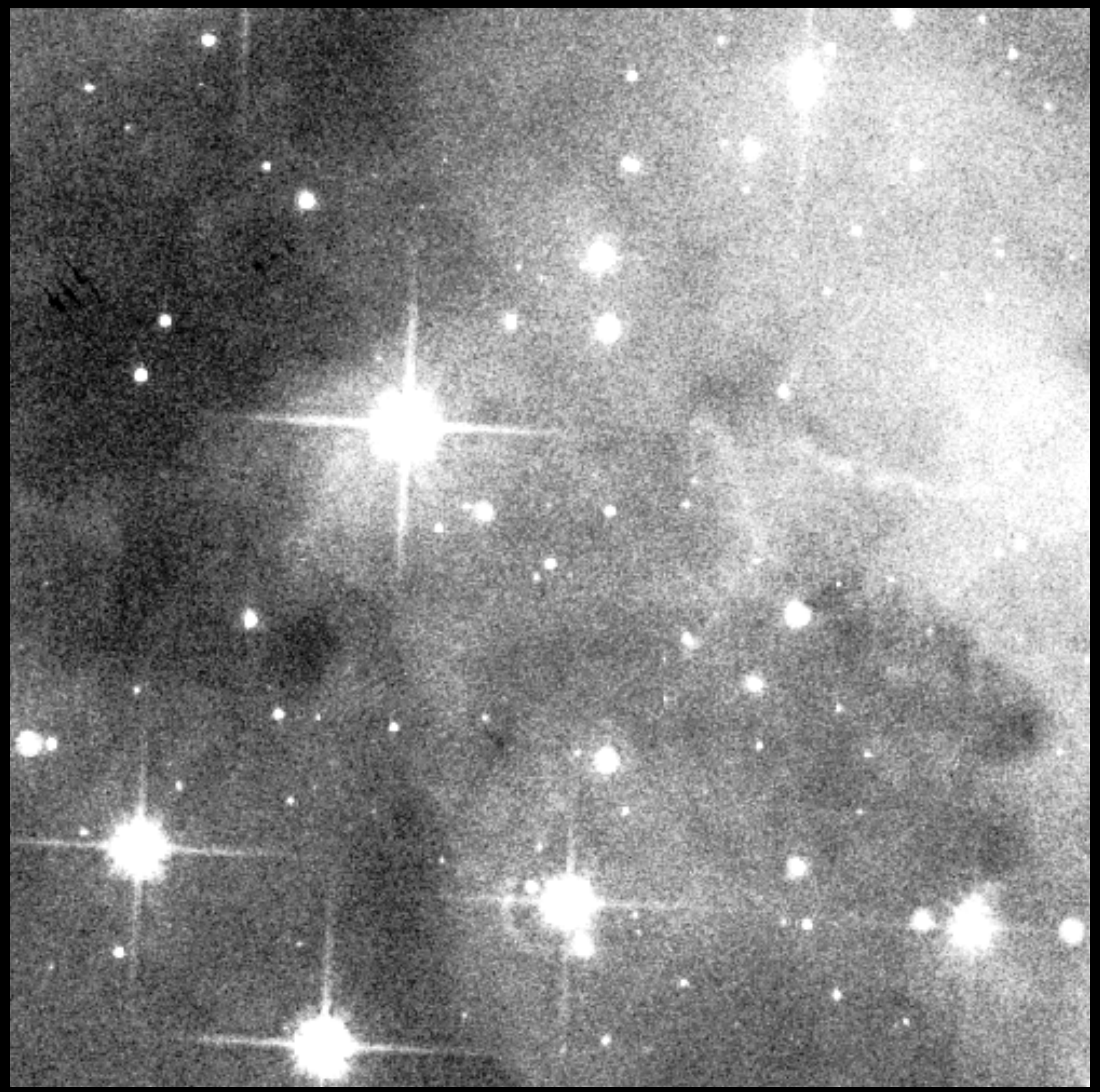
Antonia Vojtekova

Vojtekova+21

SHORT EXP INPUT



AstroUNET-1



LONG EXP TARGET

Enhancing X-ray imaging

Sam Sweere

arXiv:2205.01152

Traditional pipelines (Non ML)

INPUT SHORT EXP | GAUSSIAN BLUR | WAVELET FILTER | LONG EXP

Enhancing X-ray imaging

Sam Sweere
arXiv:2205.01152

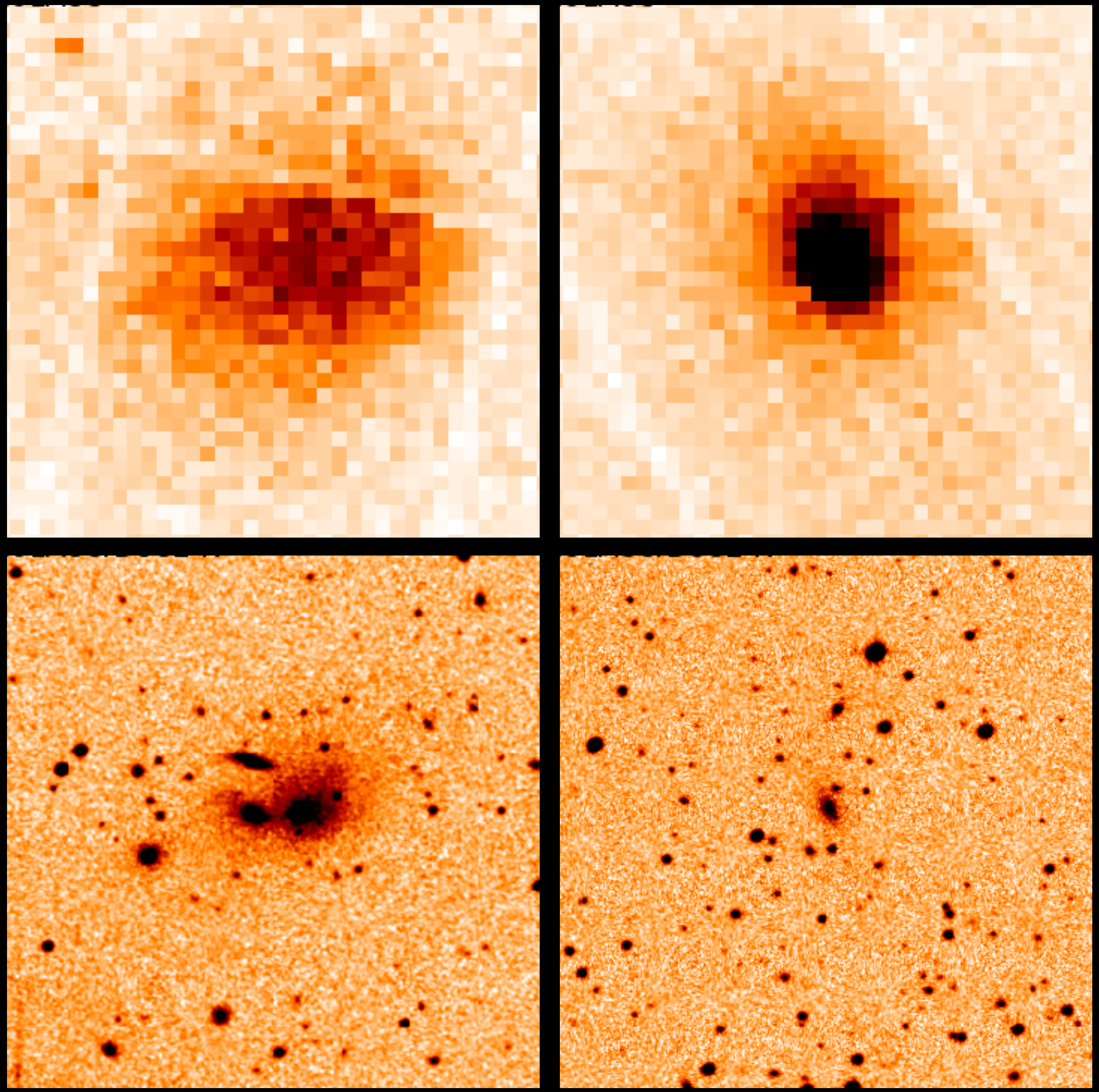
Messier 51

SHORT EXP INPUT | XMM-DeNoise | Wavelet filtered | LONG EXP

Matej
Kosiba

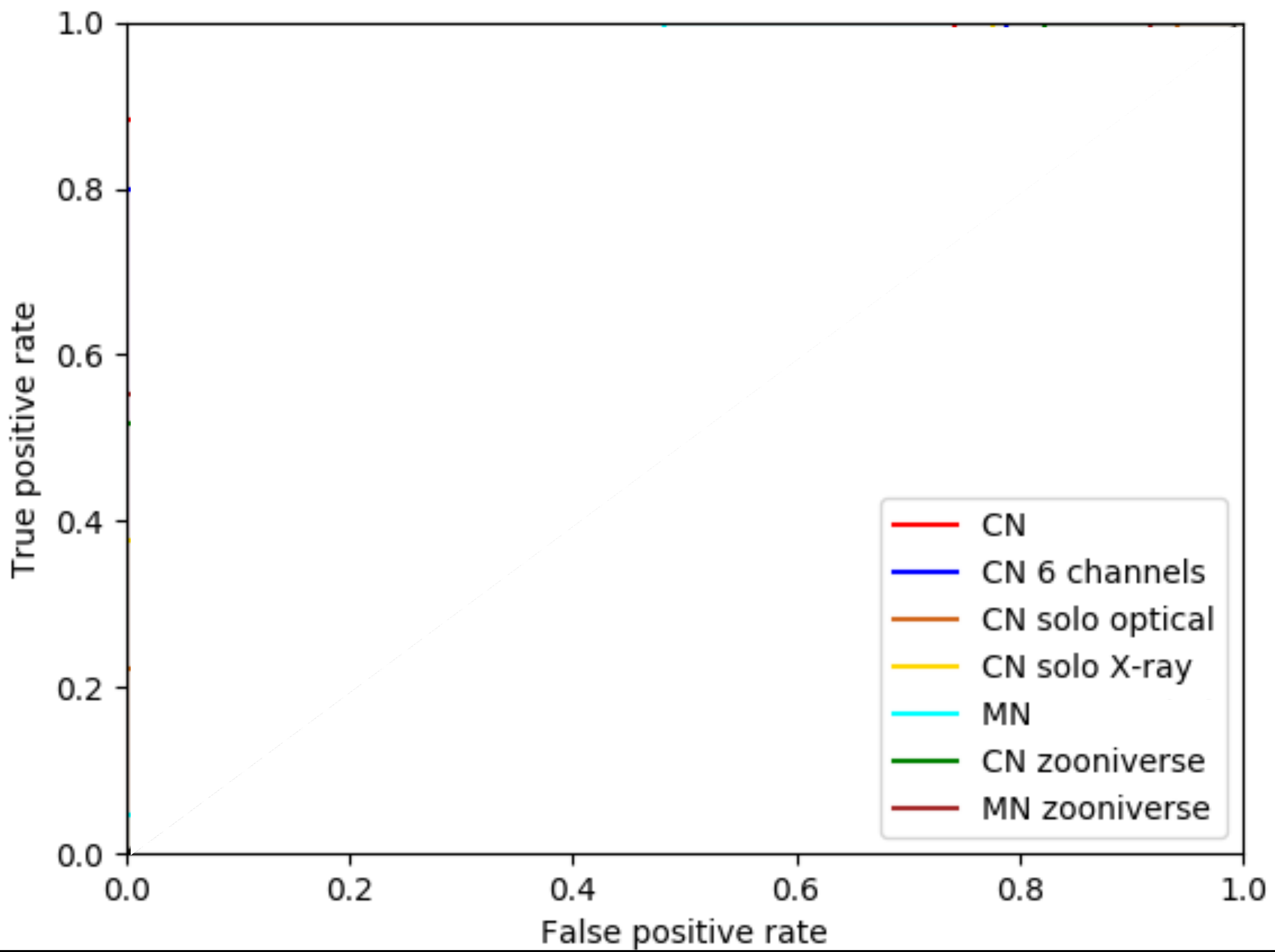
X-RAY

OPTICAL



XCLASS/XMM/SDSS


The Hunt for Galaxy Clusters
ABOUT
CLASSIFY
TALK
COLLECT
Explore the depths of the Universe
with Galaxy clusters
Learn more
Get started



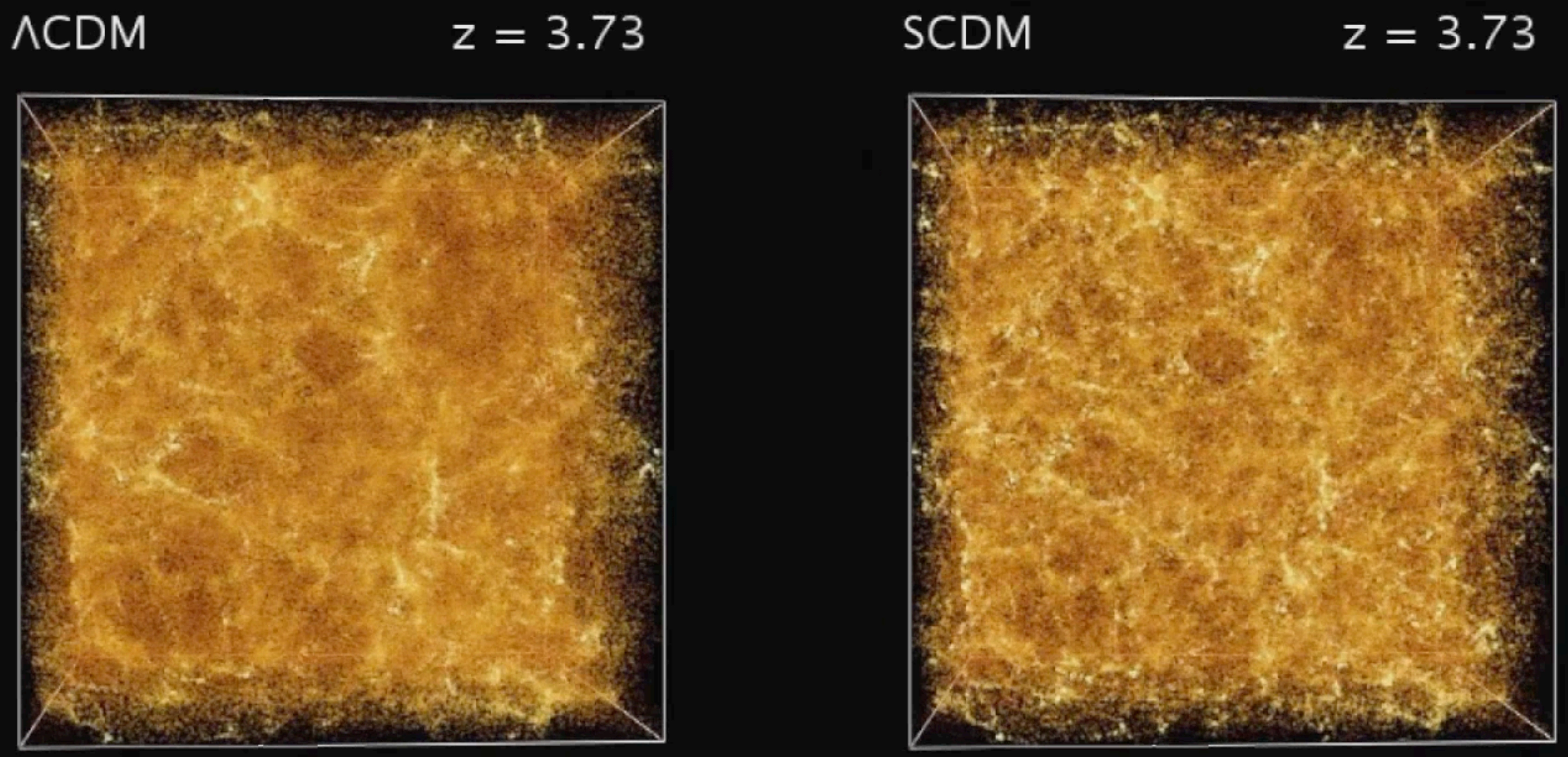
TPR = TP / (TP + FN)

FPR = FP / (FP + TN)

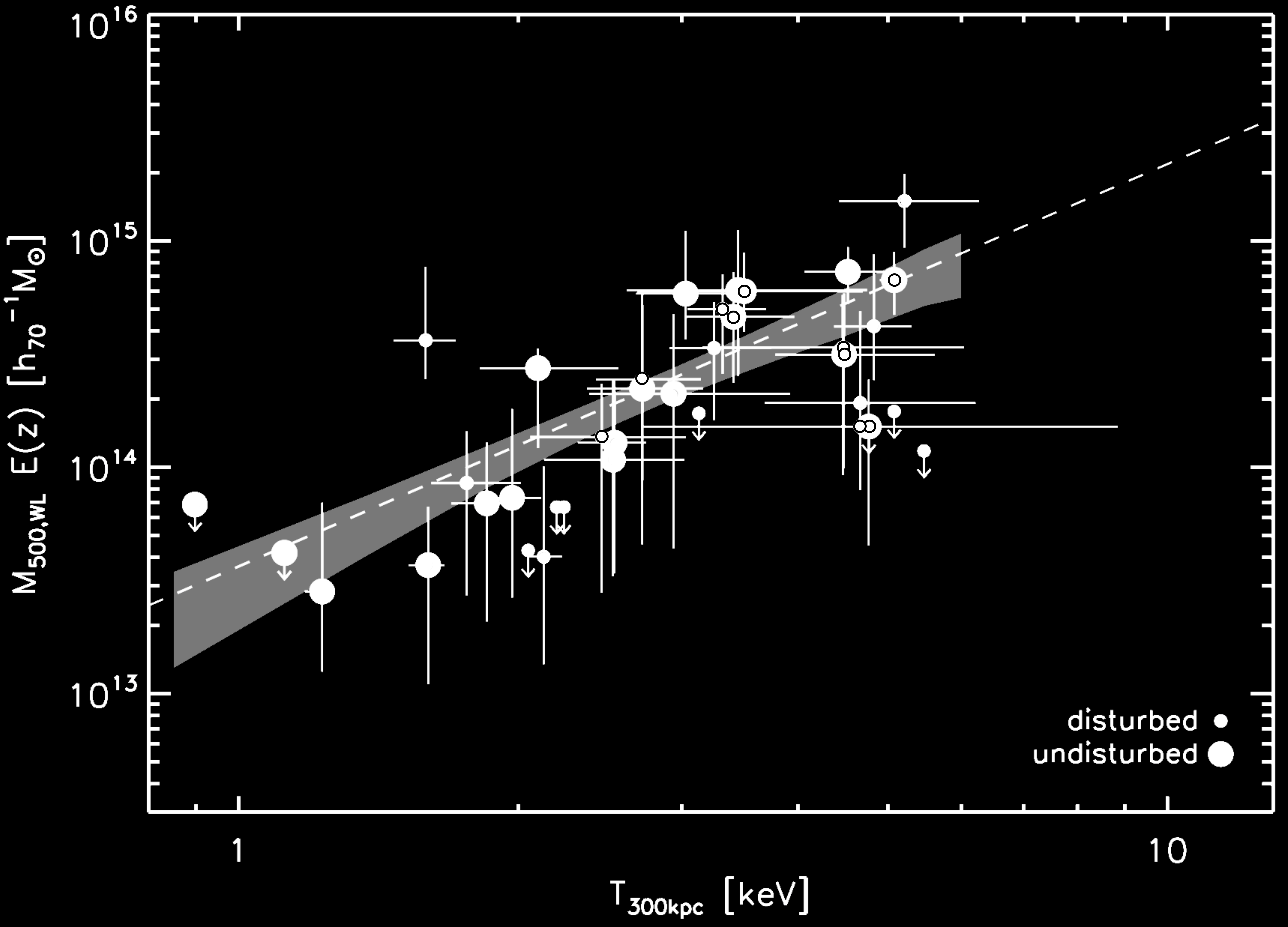
Kosiba+20

THE LARGEST GRAVITATIONALLY BOUND OBJECTS

Dolag

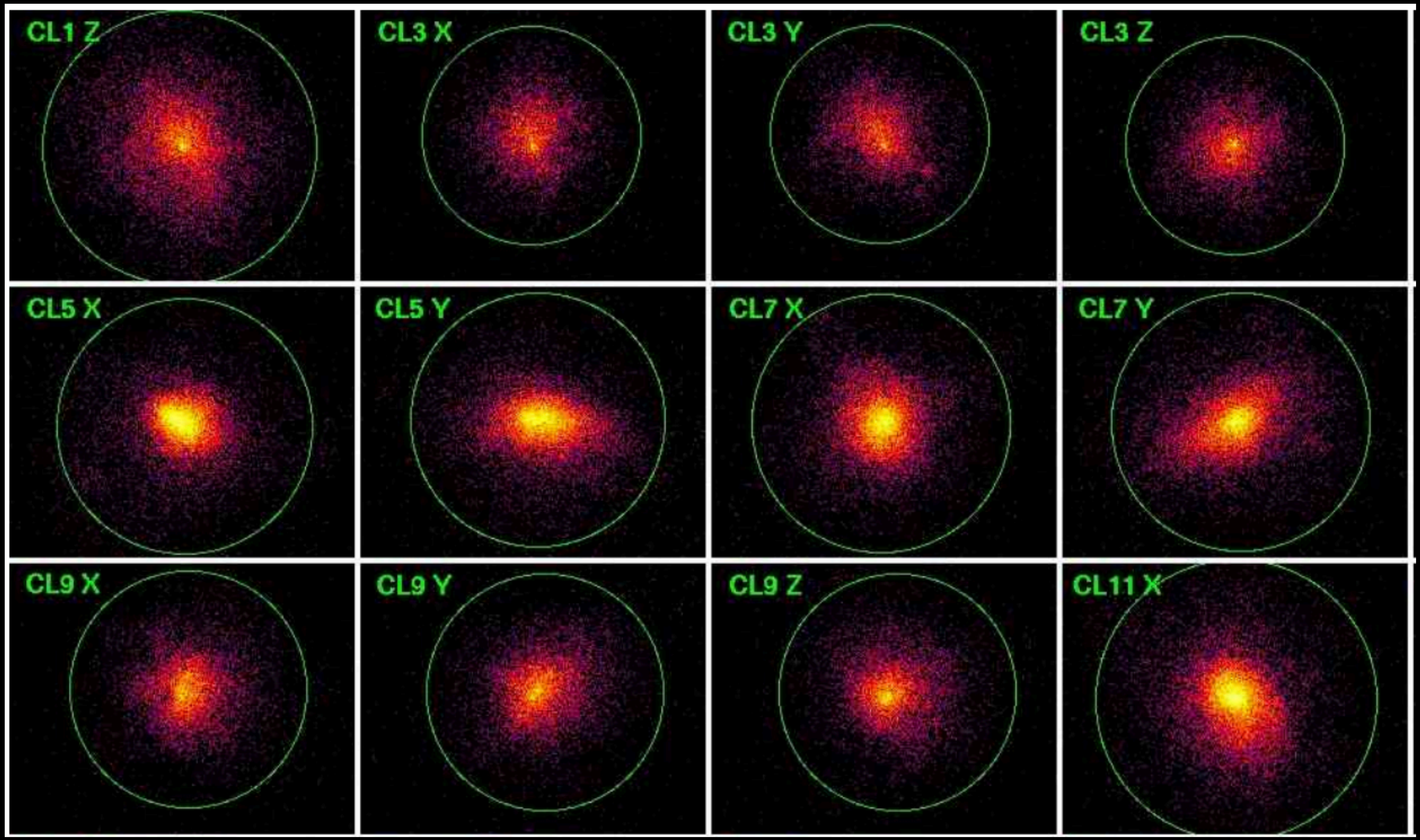


J. Hartlap



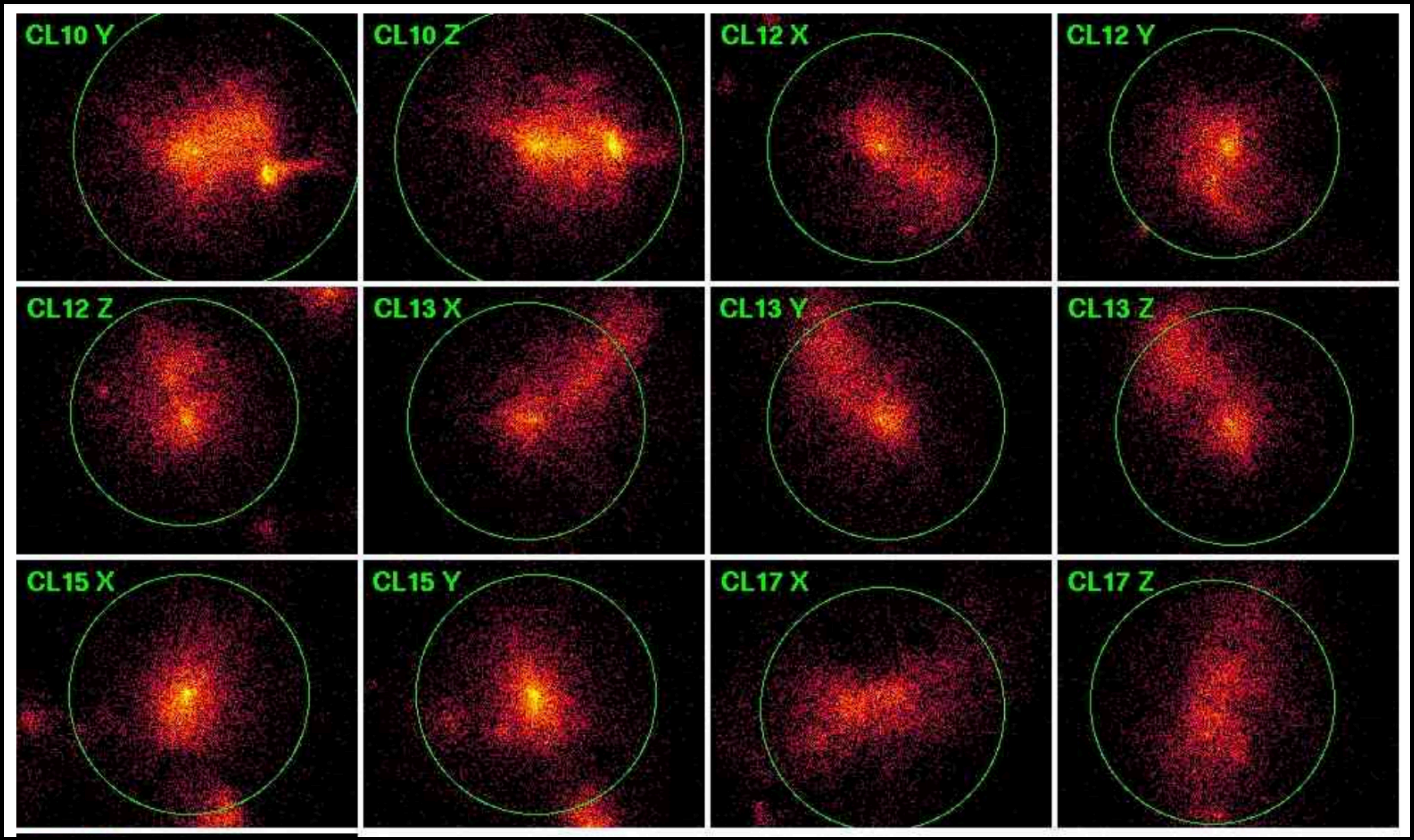
10^16
10^15
10^14
10^13
M500,WL E(z) [h70^-1 M☉]
1
10
T300kpc [keV]
disturbed
undisturbed

Lieu+16



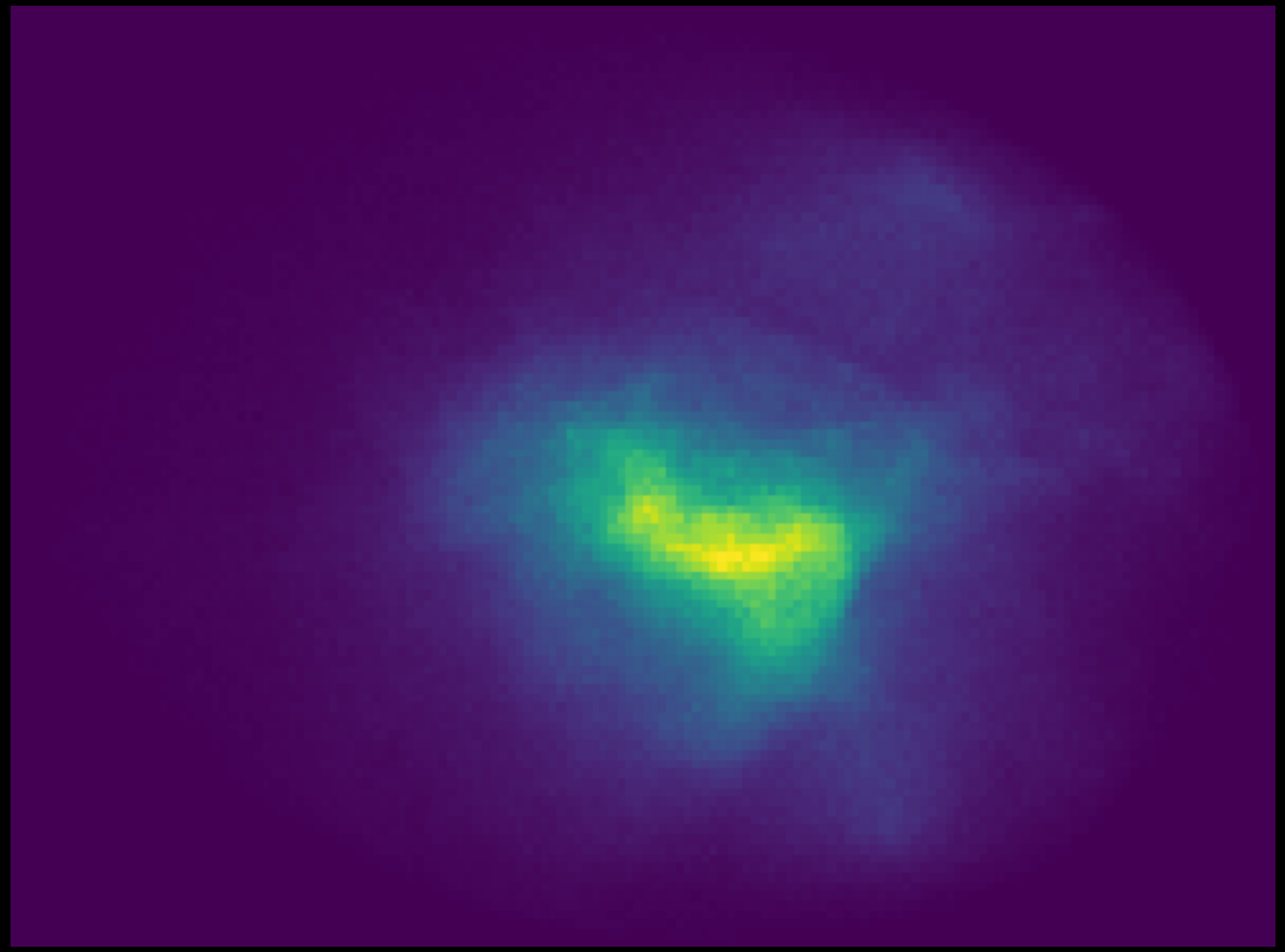
Relaxed

RASIA+2012

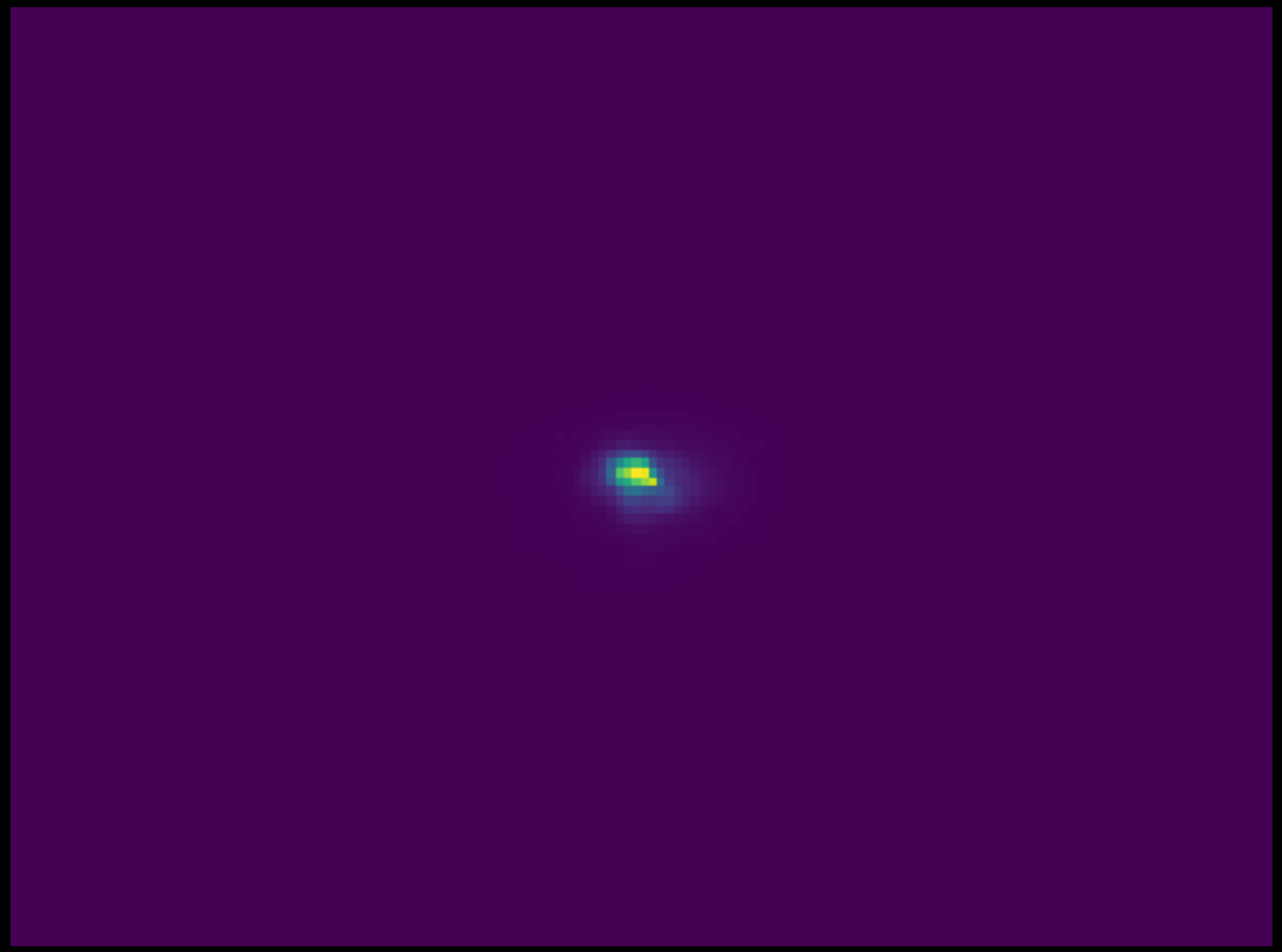


Disturbed

RASIA+2012



19.53 Gyr



0.62 Gyr

Cooling time

$$t_{cool} = \frac{3}{2}\frac{(n_e + n_i)k_B T}{n_e n_i \Lambda(T, Z)}$$

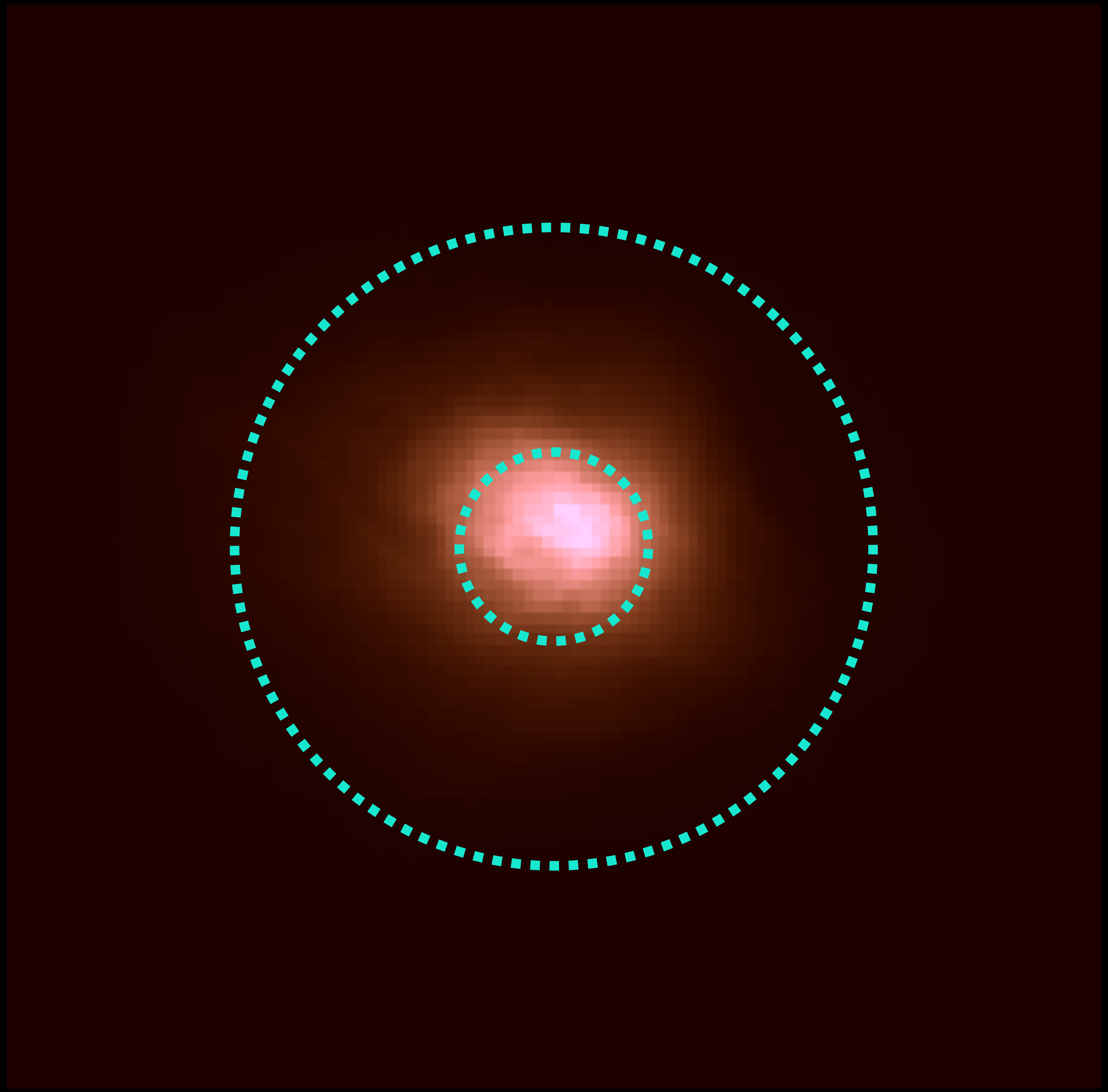
How to measure morphology?

Santos+2008:

$$CSB_{Santos} = \frac{\Sigma(r < 40kpc)}{\Sigma(r < 400kpc)}$$

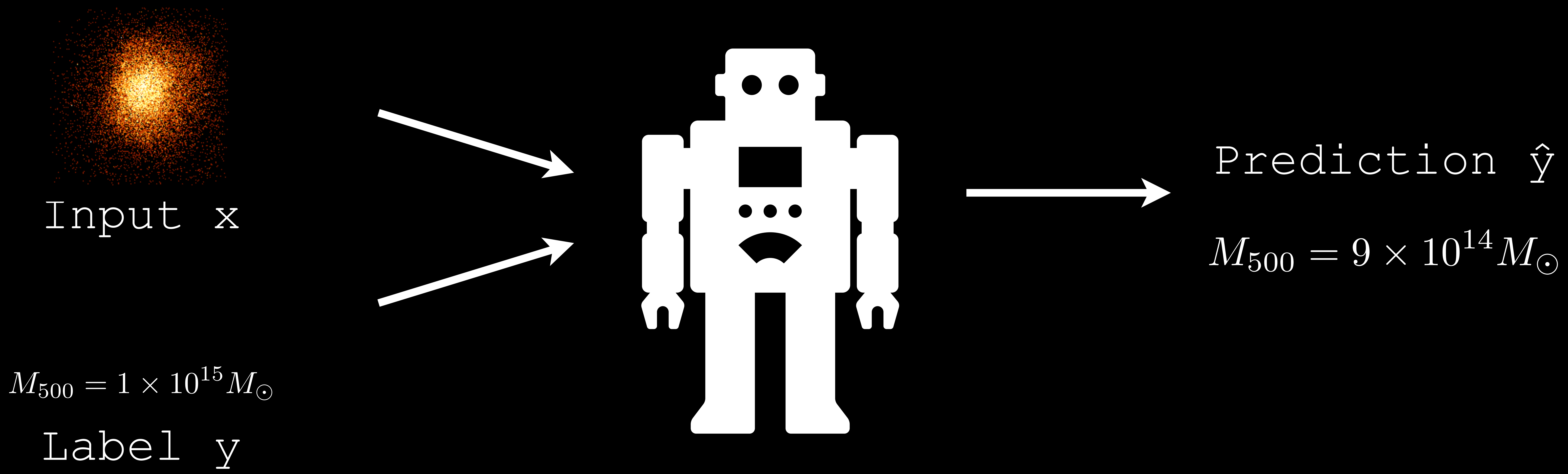
Maughan+2012:

$$CSB_{Maughan} = \frac{\Sigma(r < 0.15 r_{500})}{\Sigma(r < r_{500})}$$

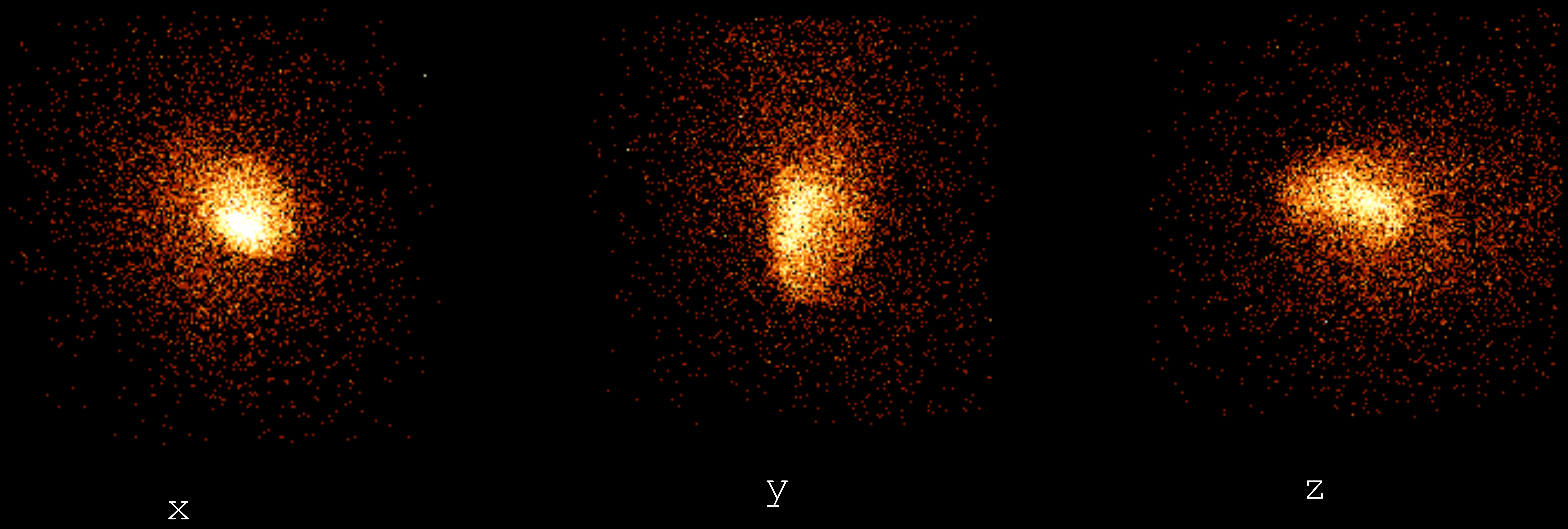


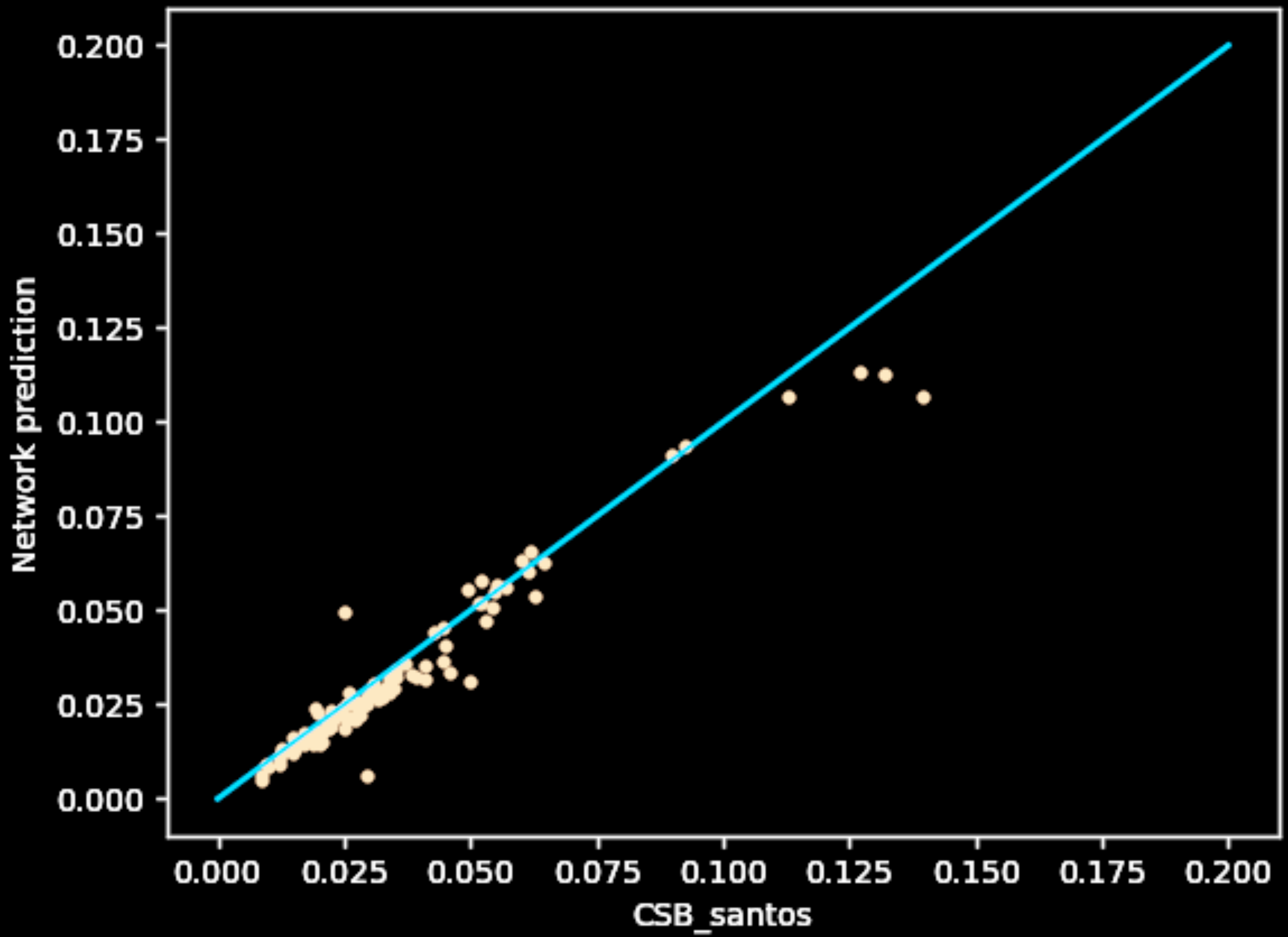
Others: centroid shift, hardness ratio, etc. (see Rasia+12, Ghirardini+21)

Supervised learning



Illustris TNG300 simulations





Santos+2008:

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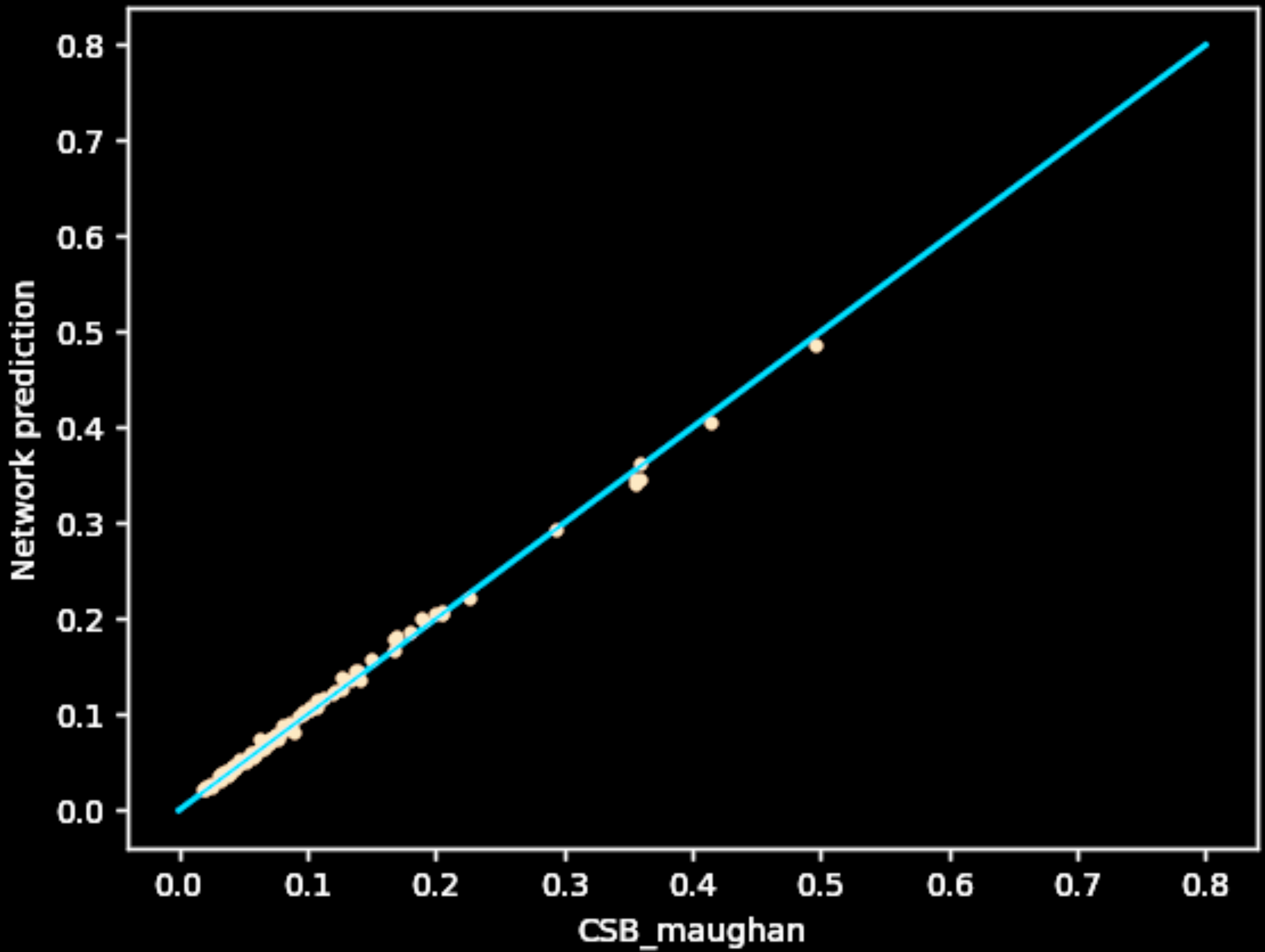
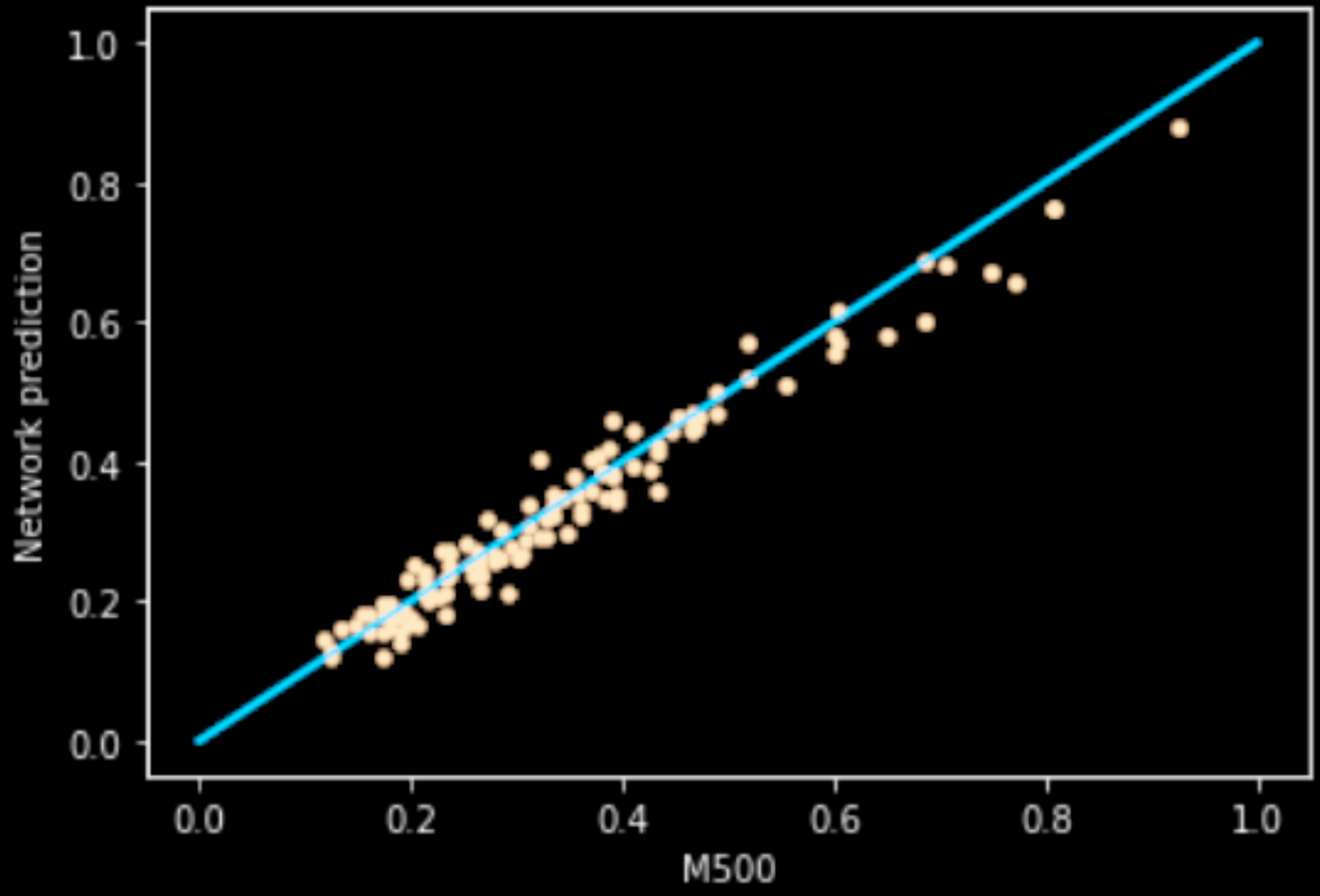
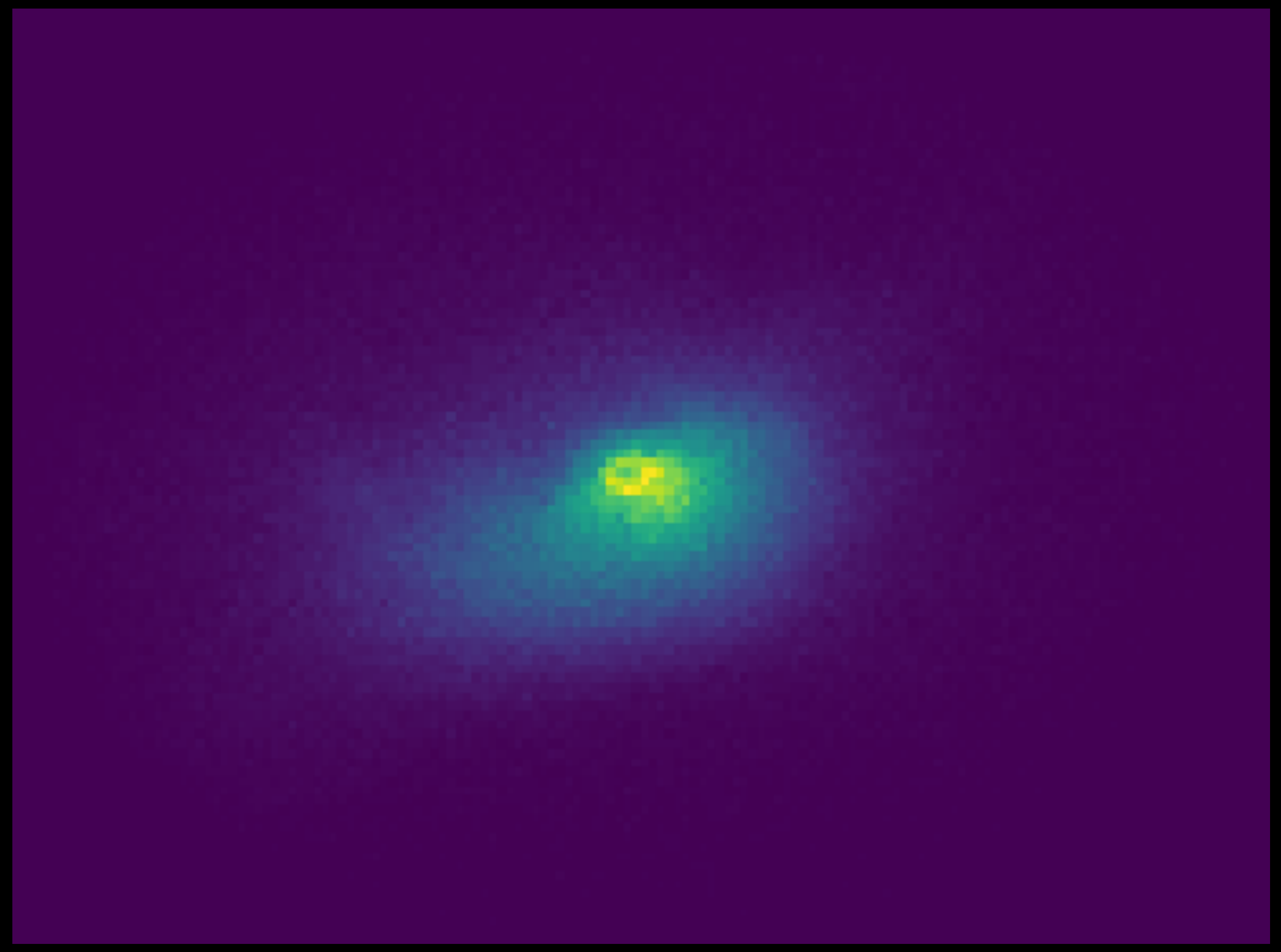
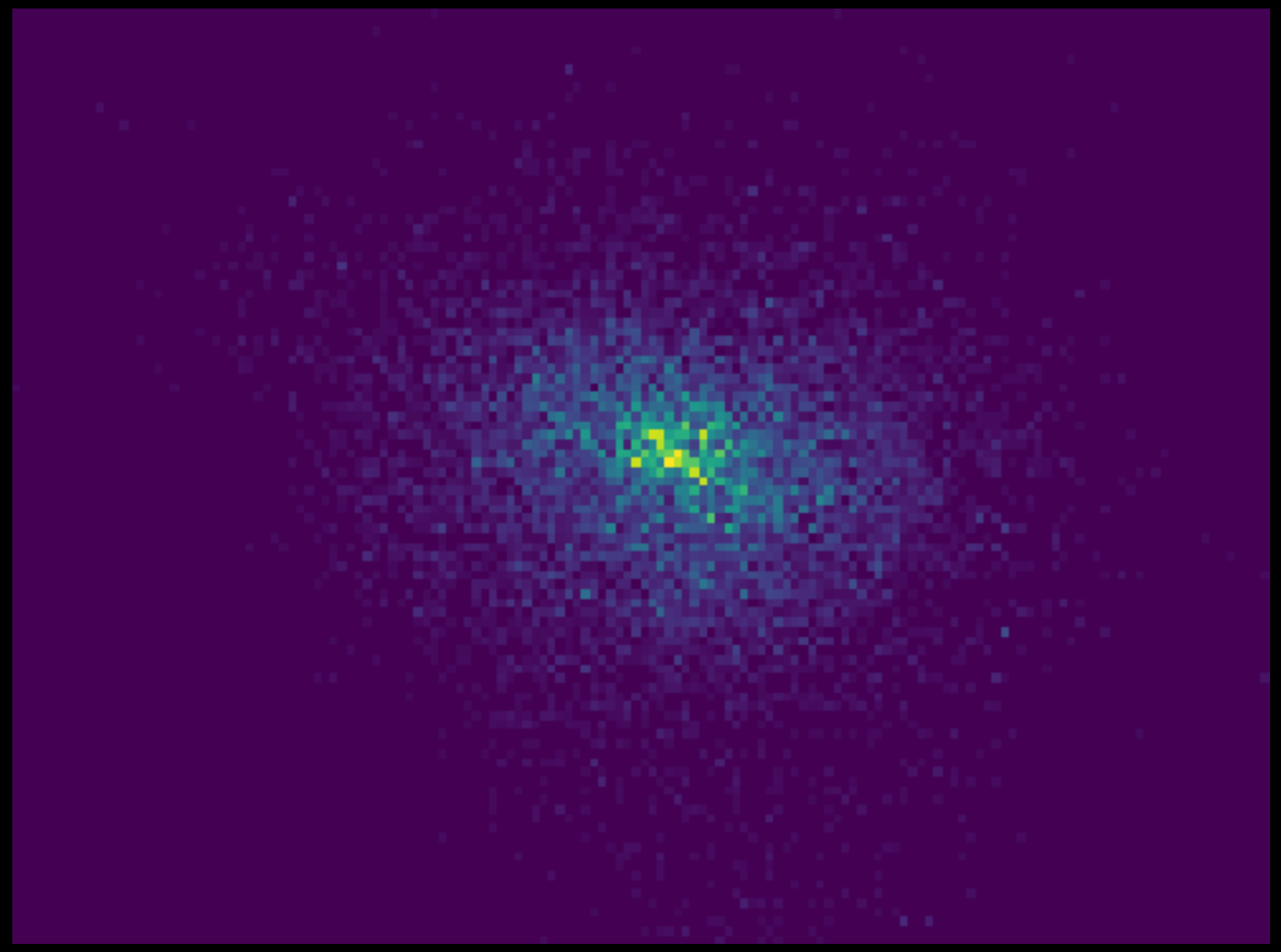


MASS



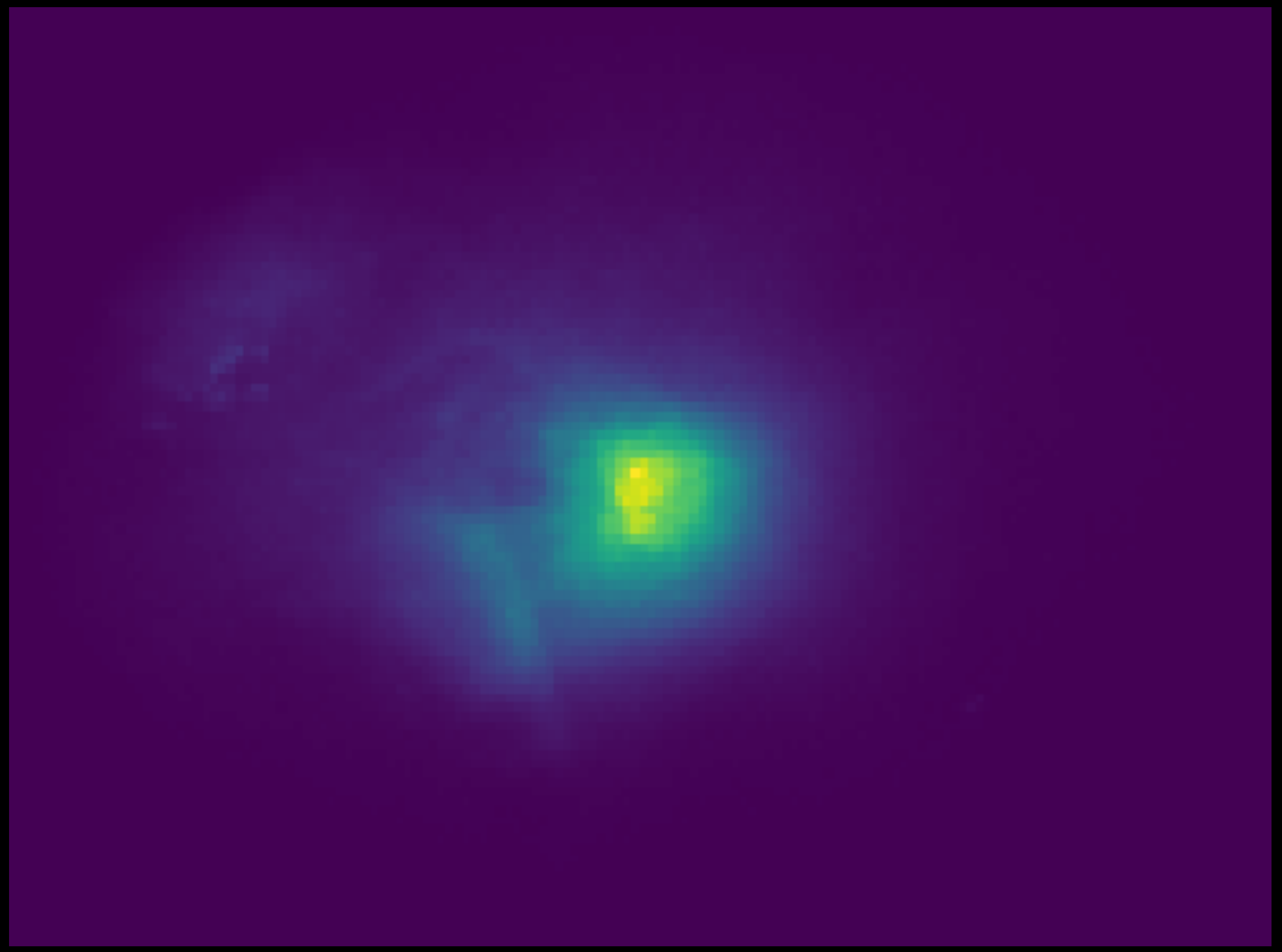


1.94x10^{15}M$_\odot$

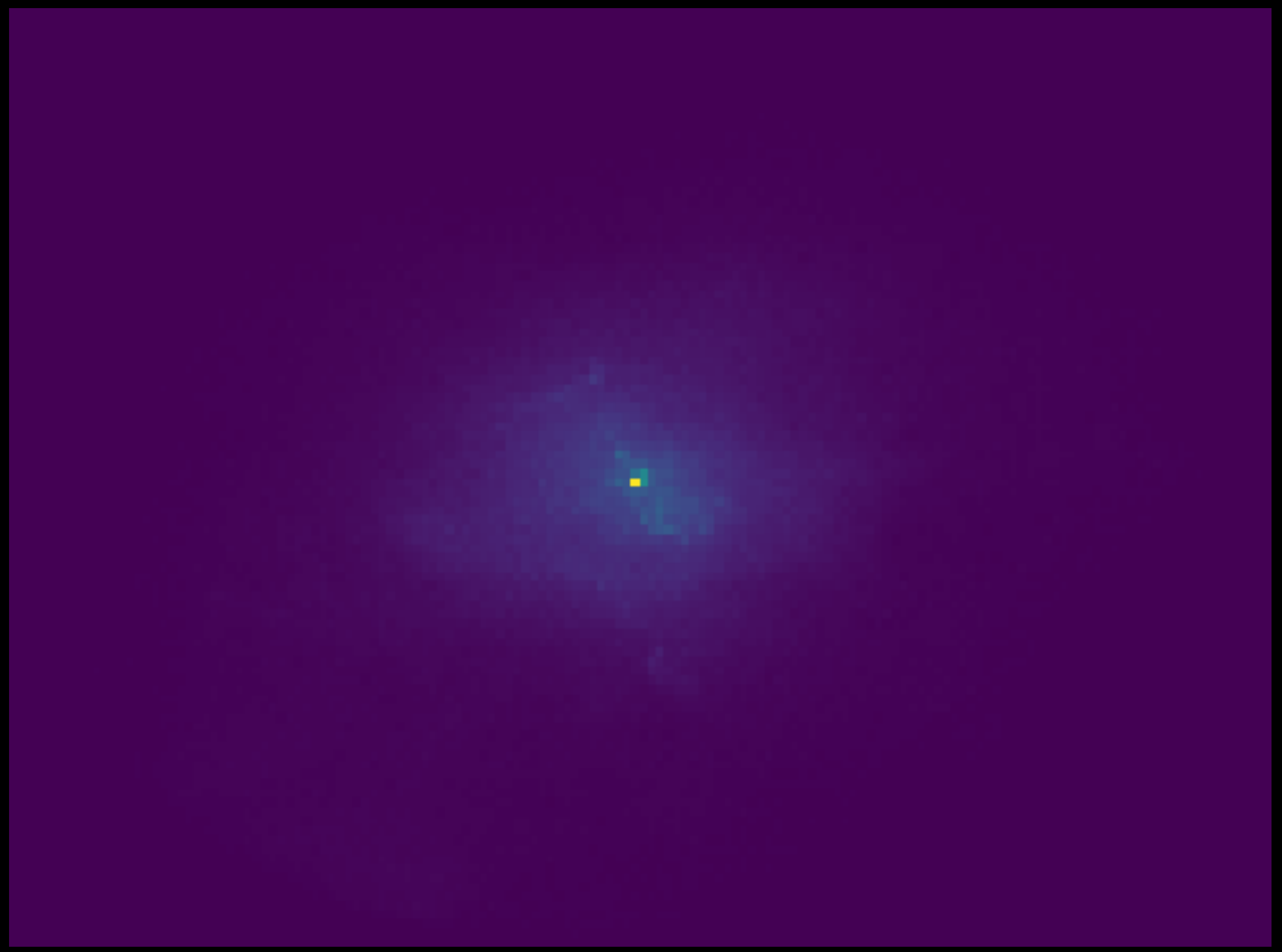


7.2x10^{13}M$_\odot$

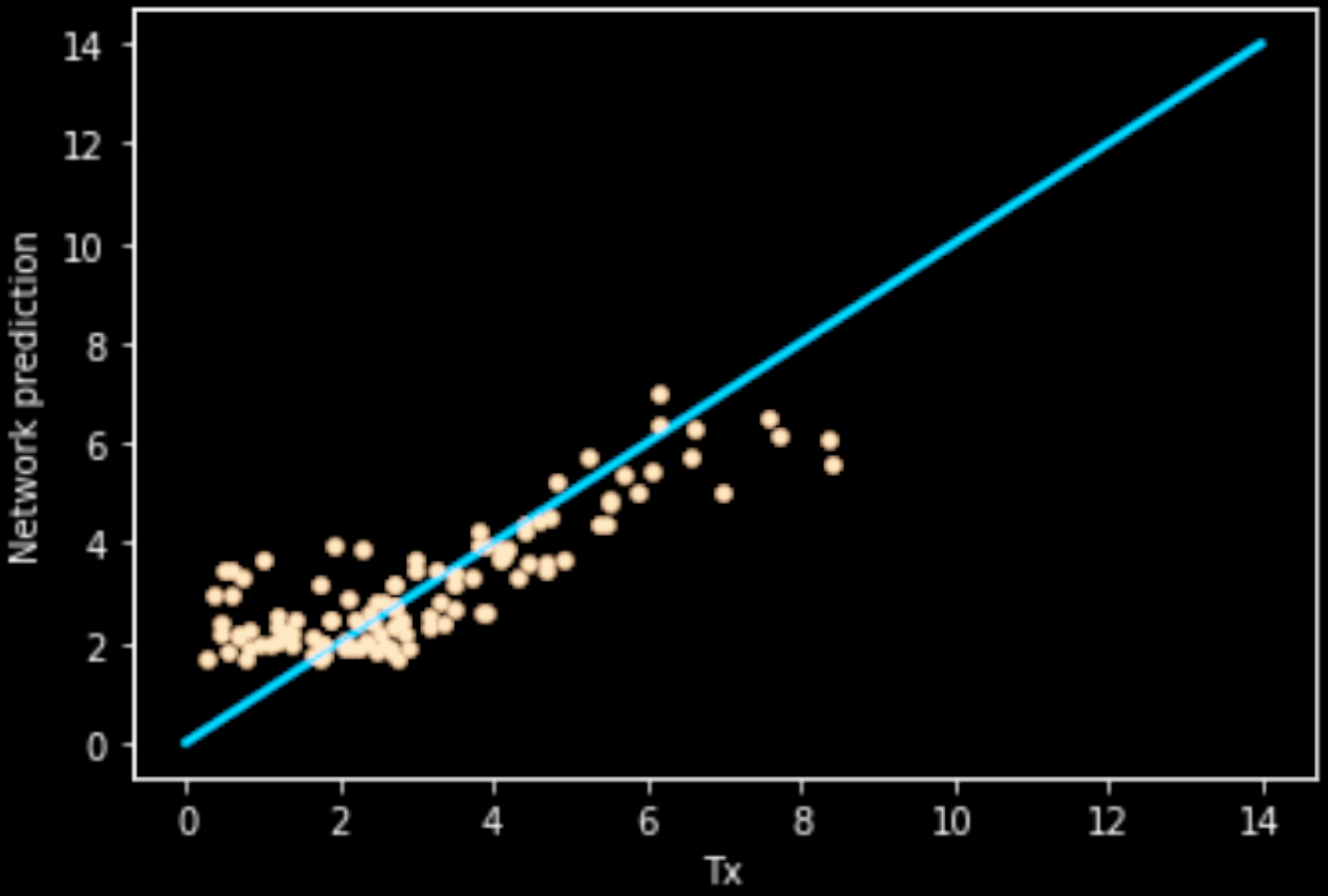
Temperature



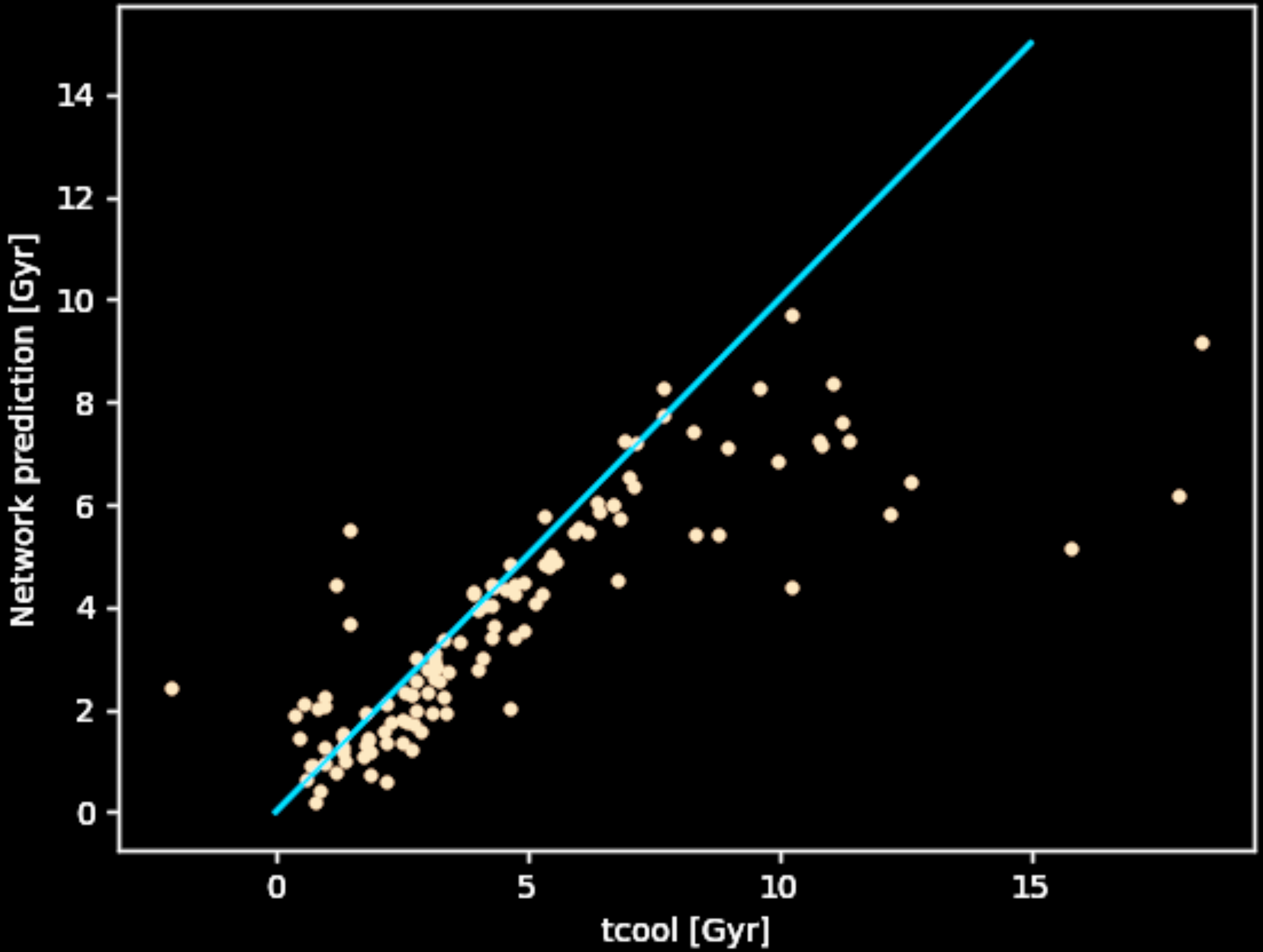
7.91keV



0.01keV



Cooling time

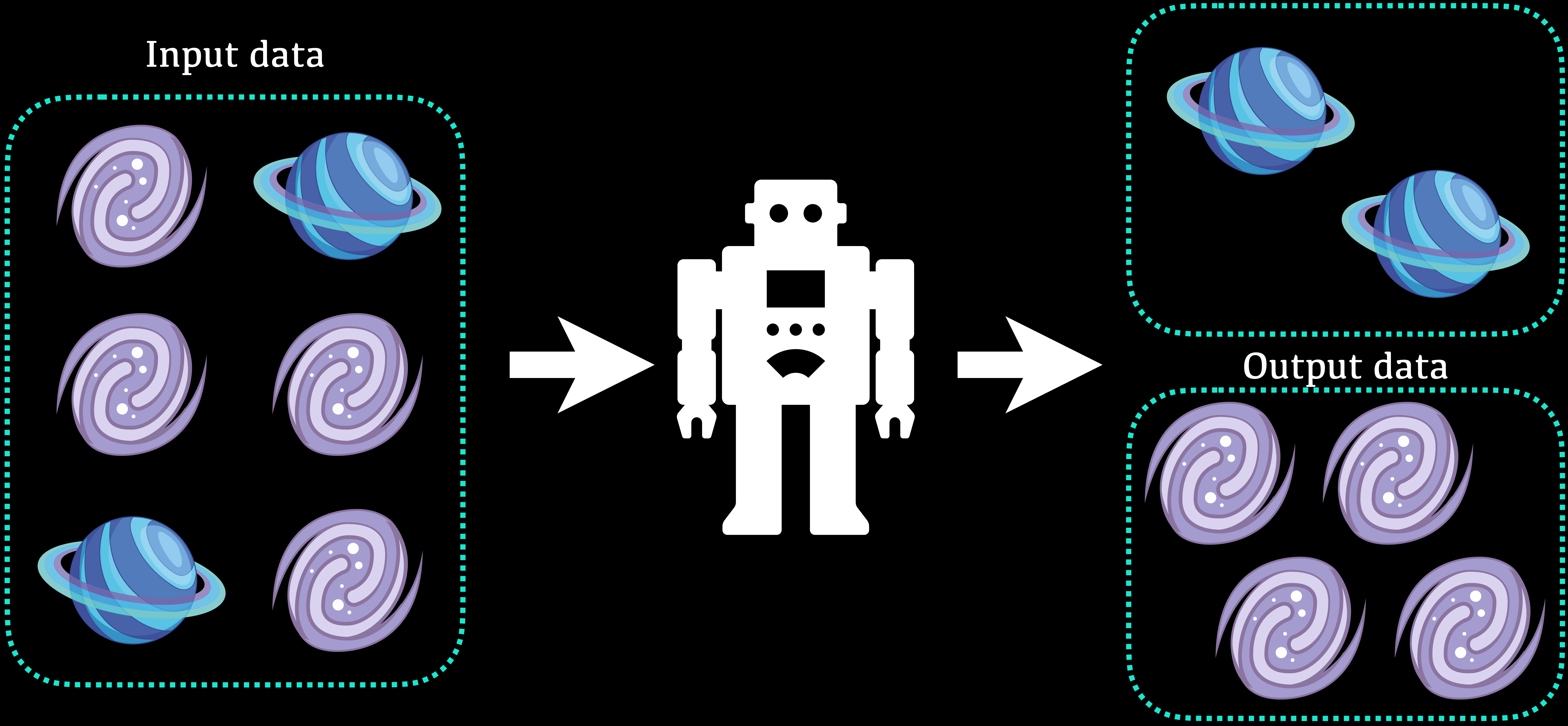


Supervised learning is easy

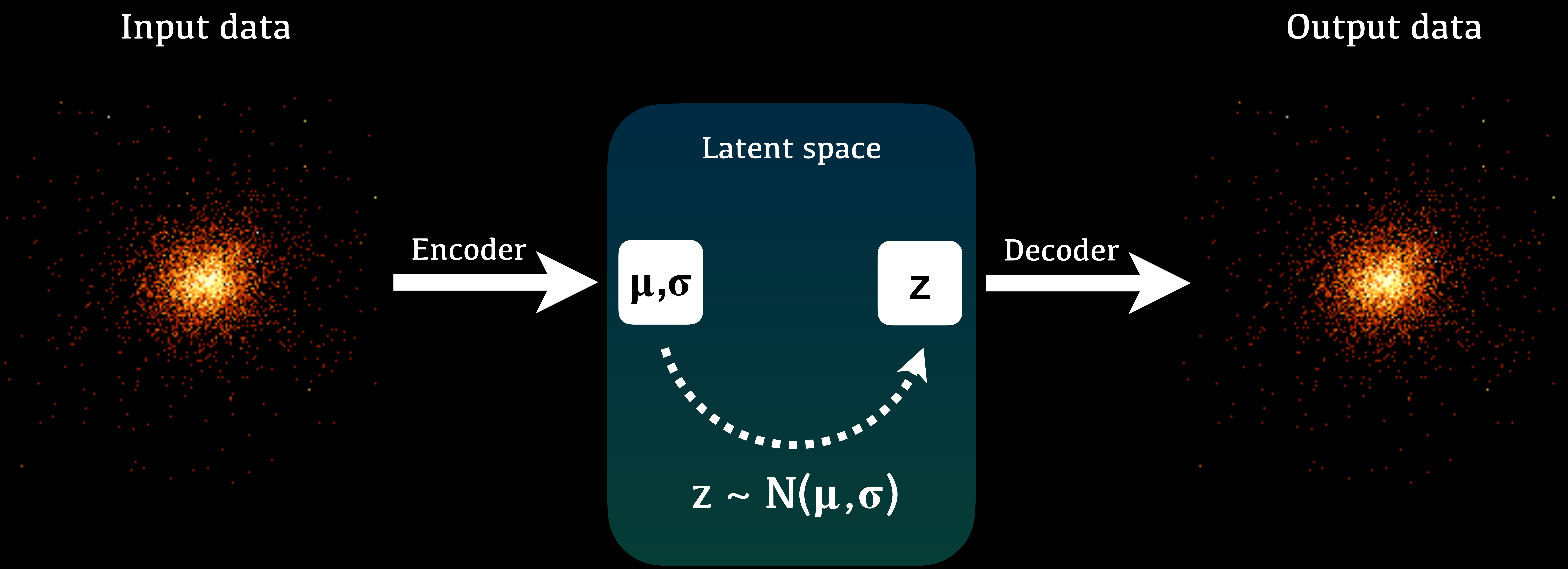
Science goals

- A **data-driven**, **unbiased**, **interpretable** model to describe clusters

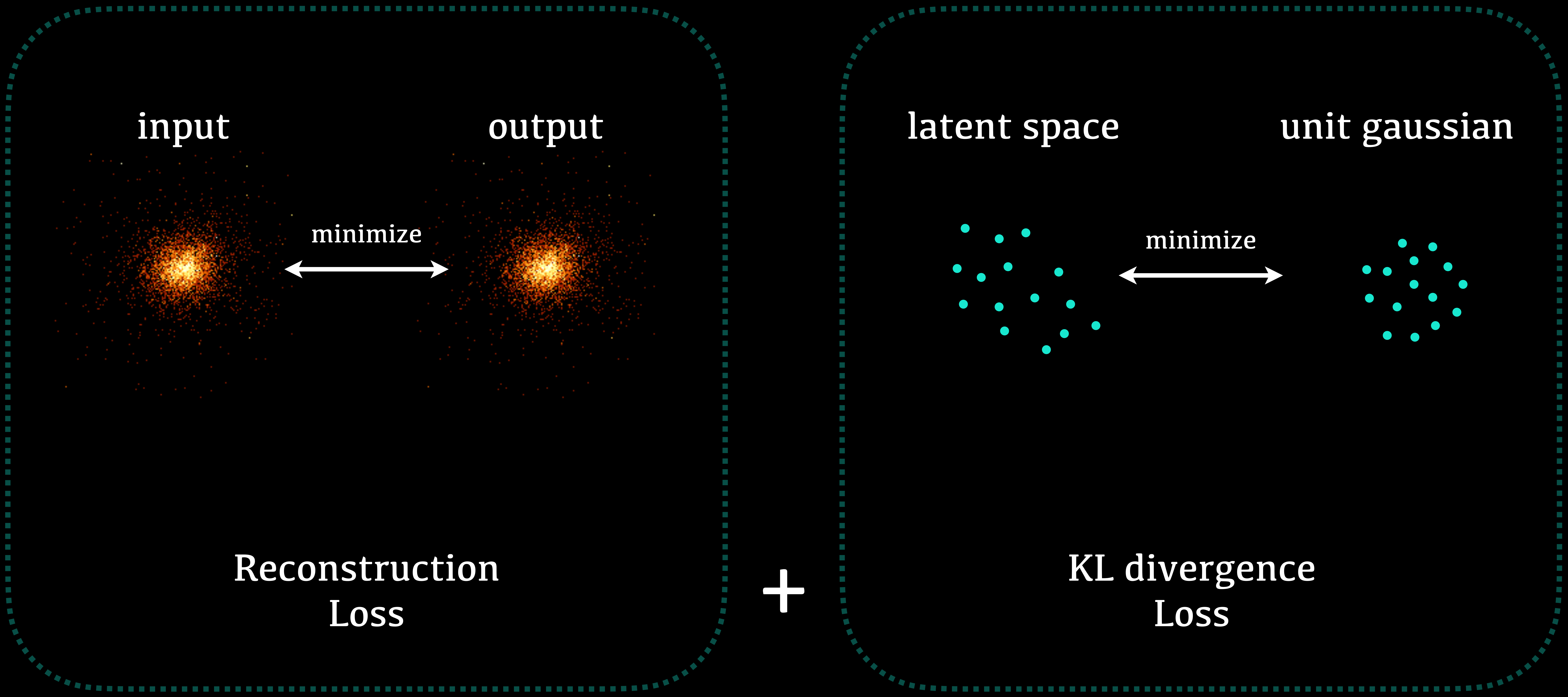
Unsupervised learning



Variational Autoencoder (VAE)

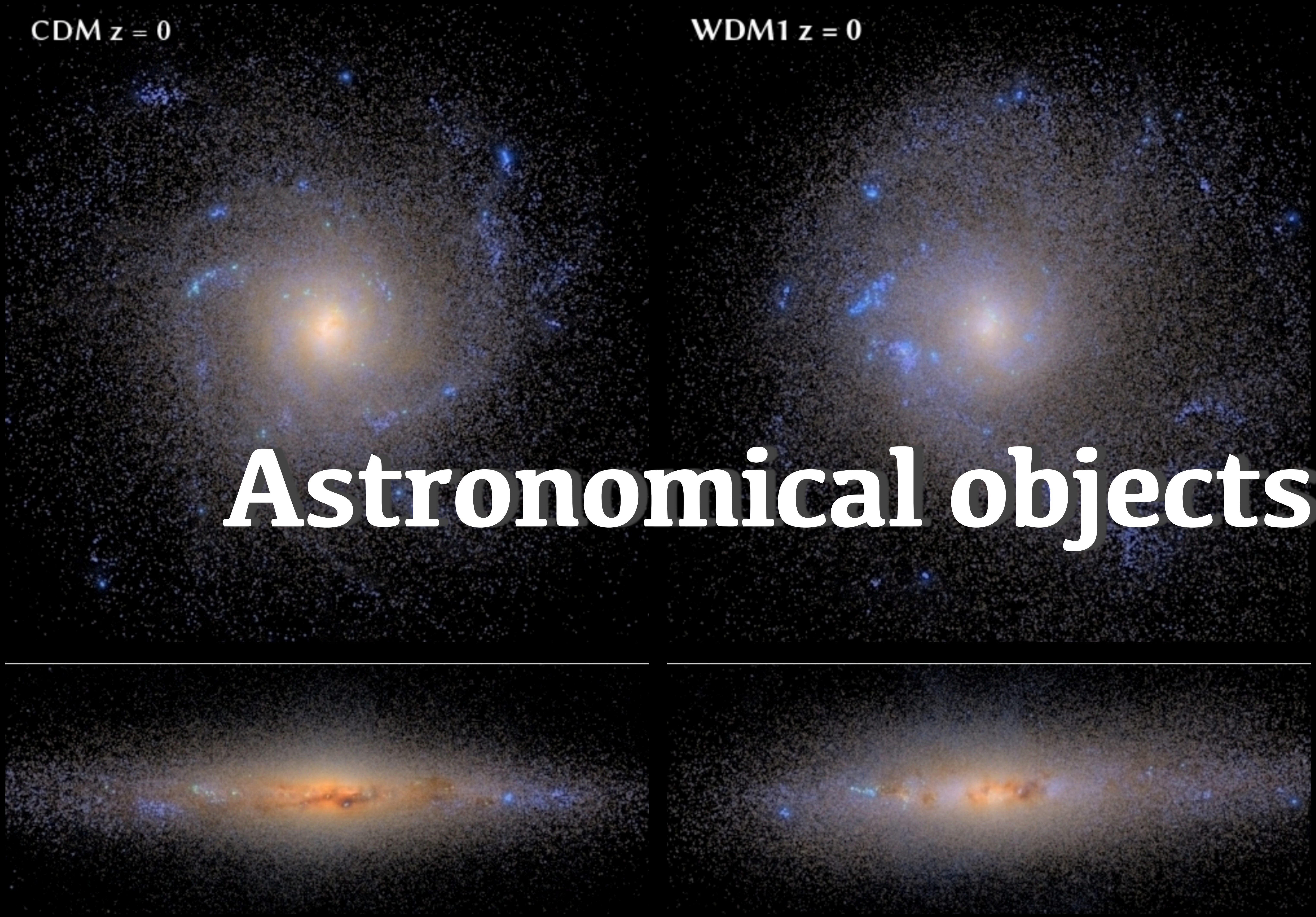


Loss

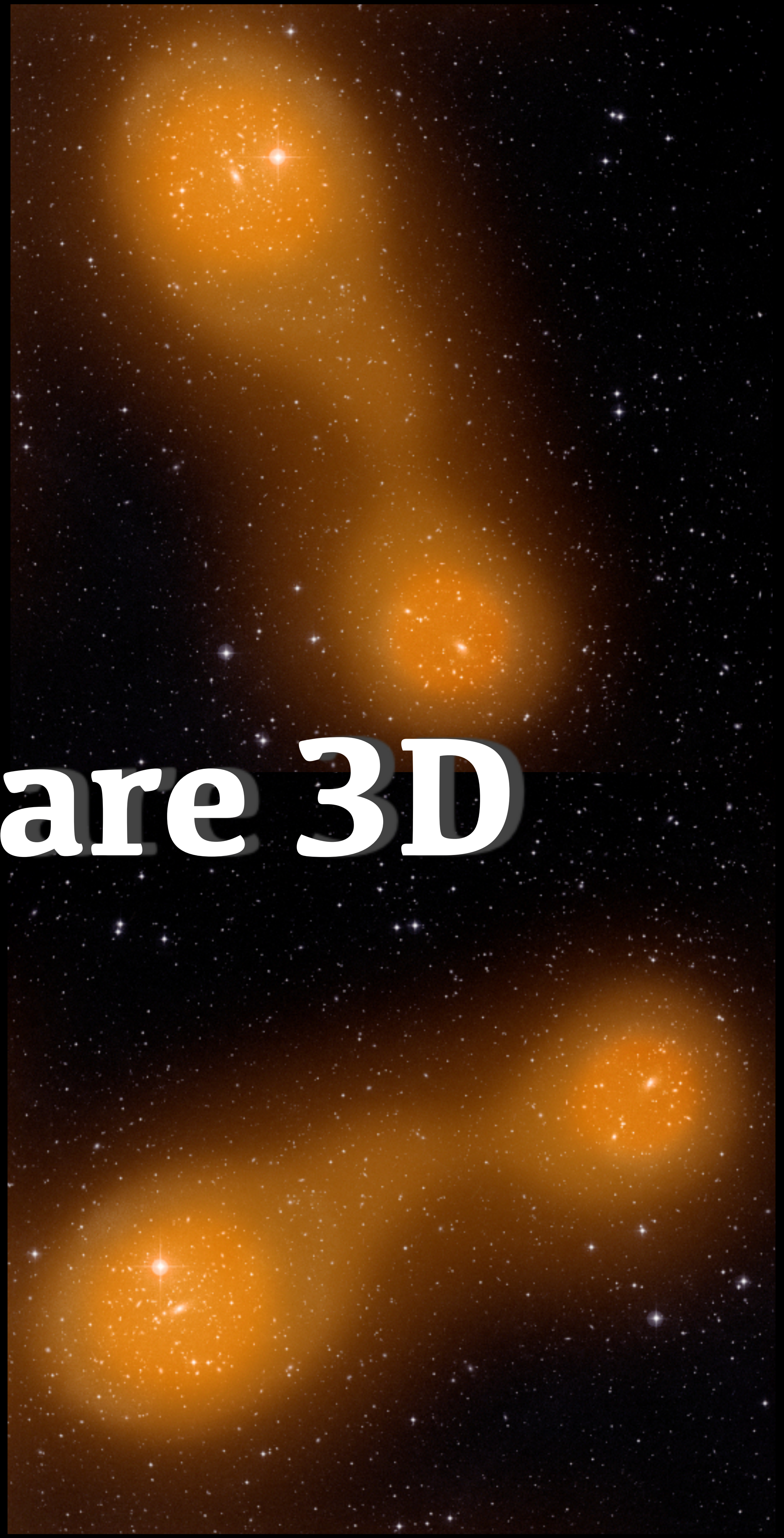


input
output
minimize
Reconstruction Loss
+
latent space
unit gaussian
minimize
KL divergence Loss

Astronomical objects are 3D



HERPICH+2013

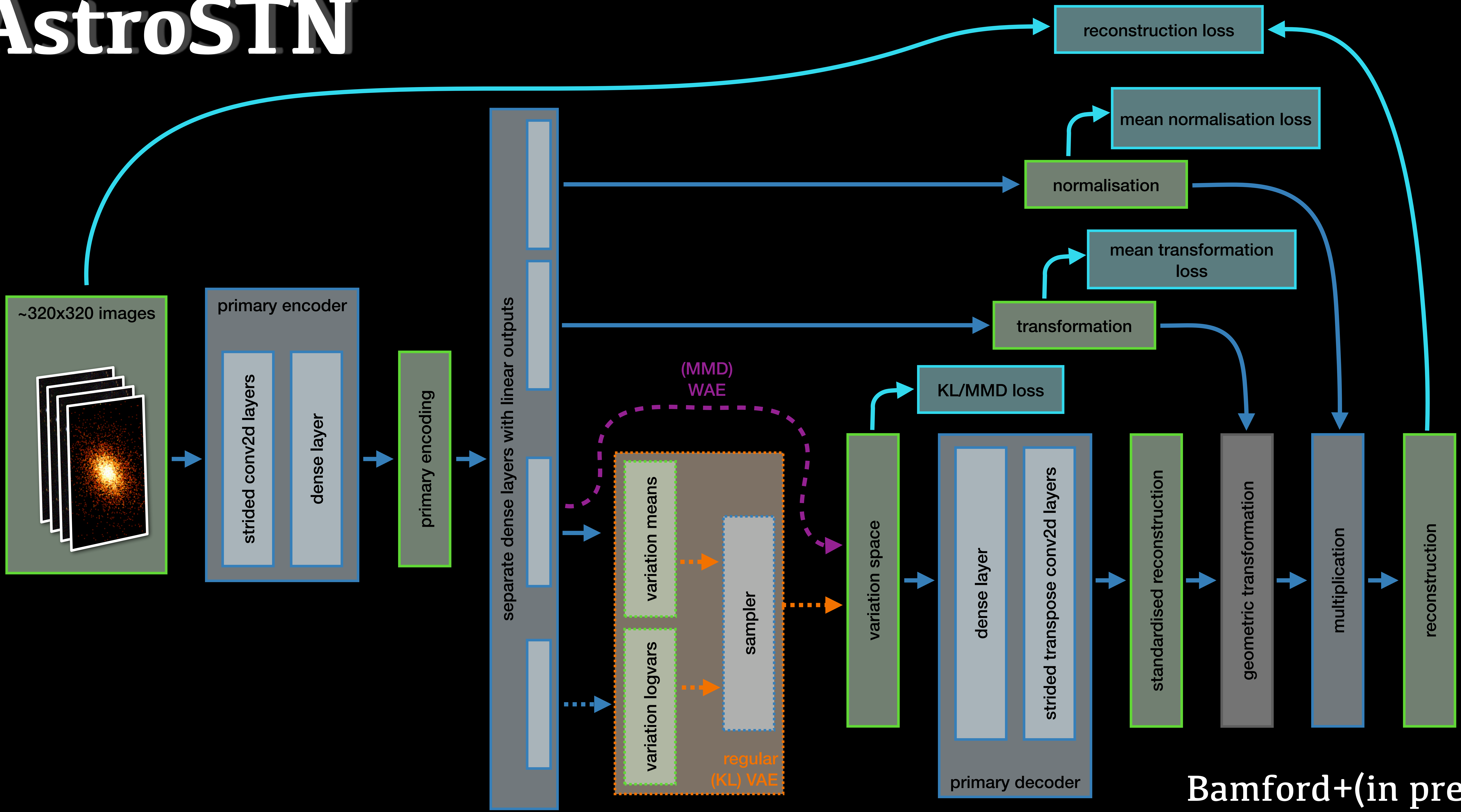


ESA/Planck Colab./STScI

STN transformer

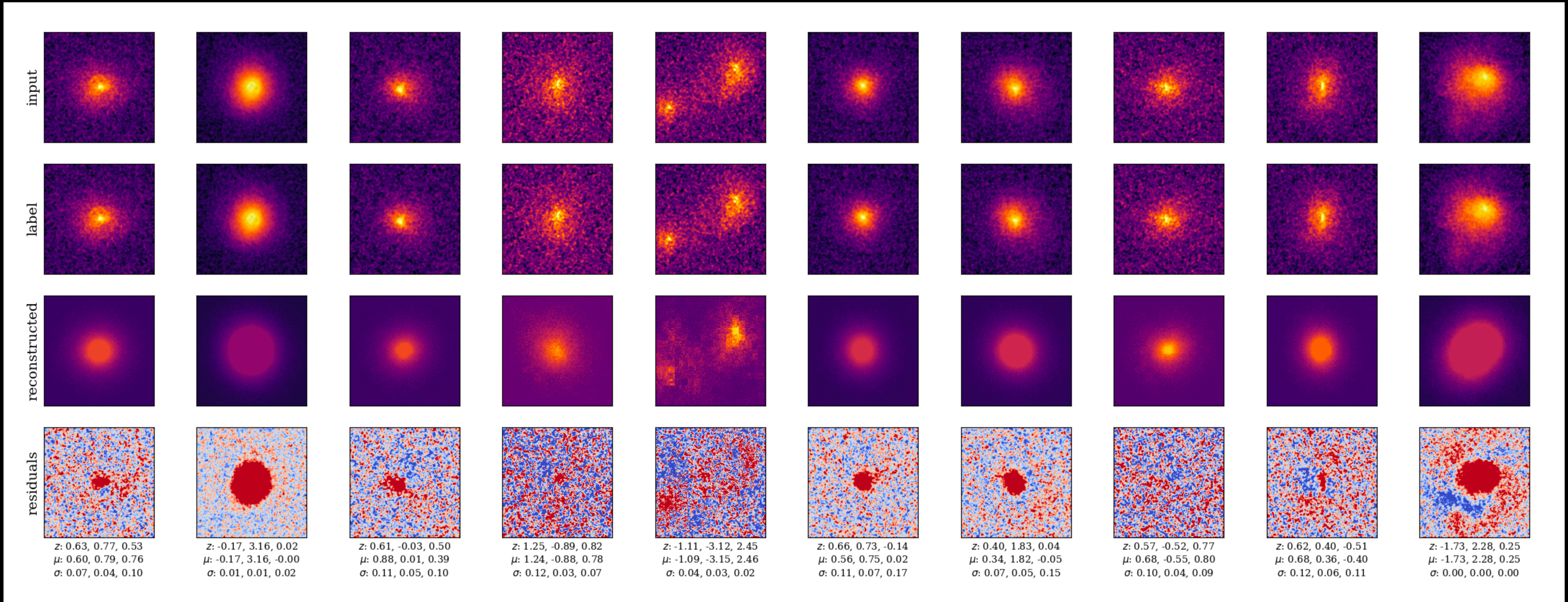
θ = (x scale, y scale, rotation, dx, dy)

AstroSTN

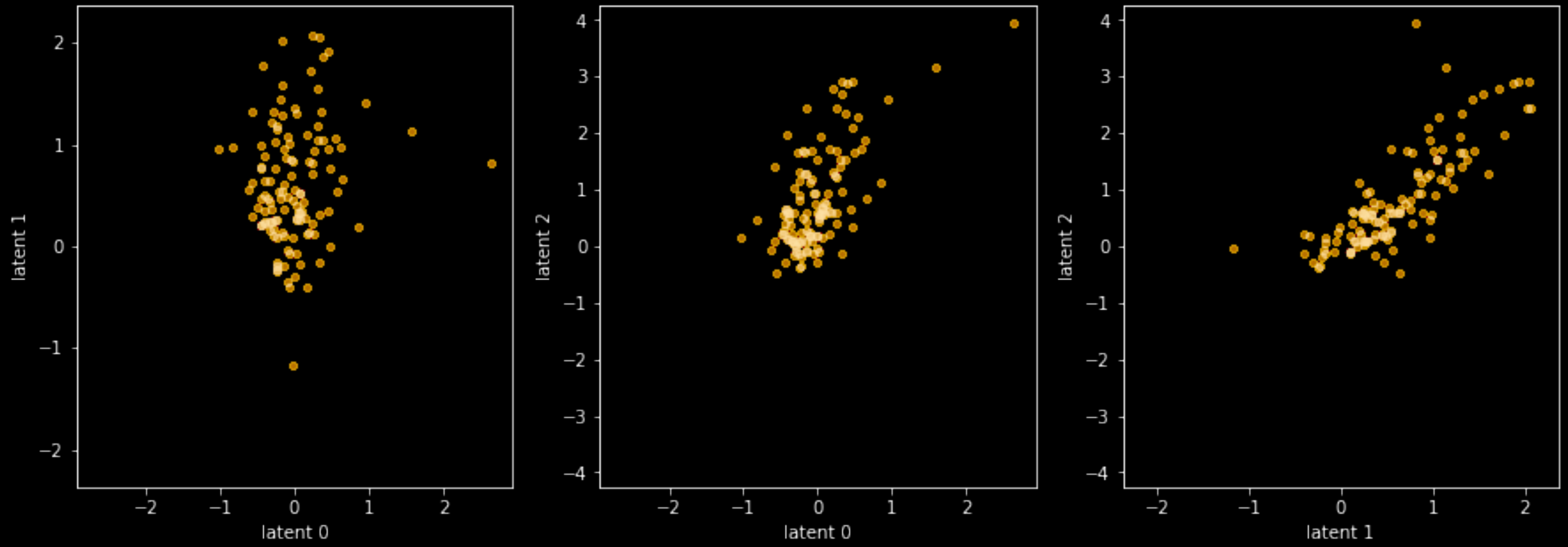


Bamford+(in prep.)

(Preliminary) Results

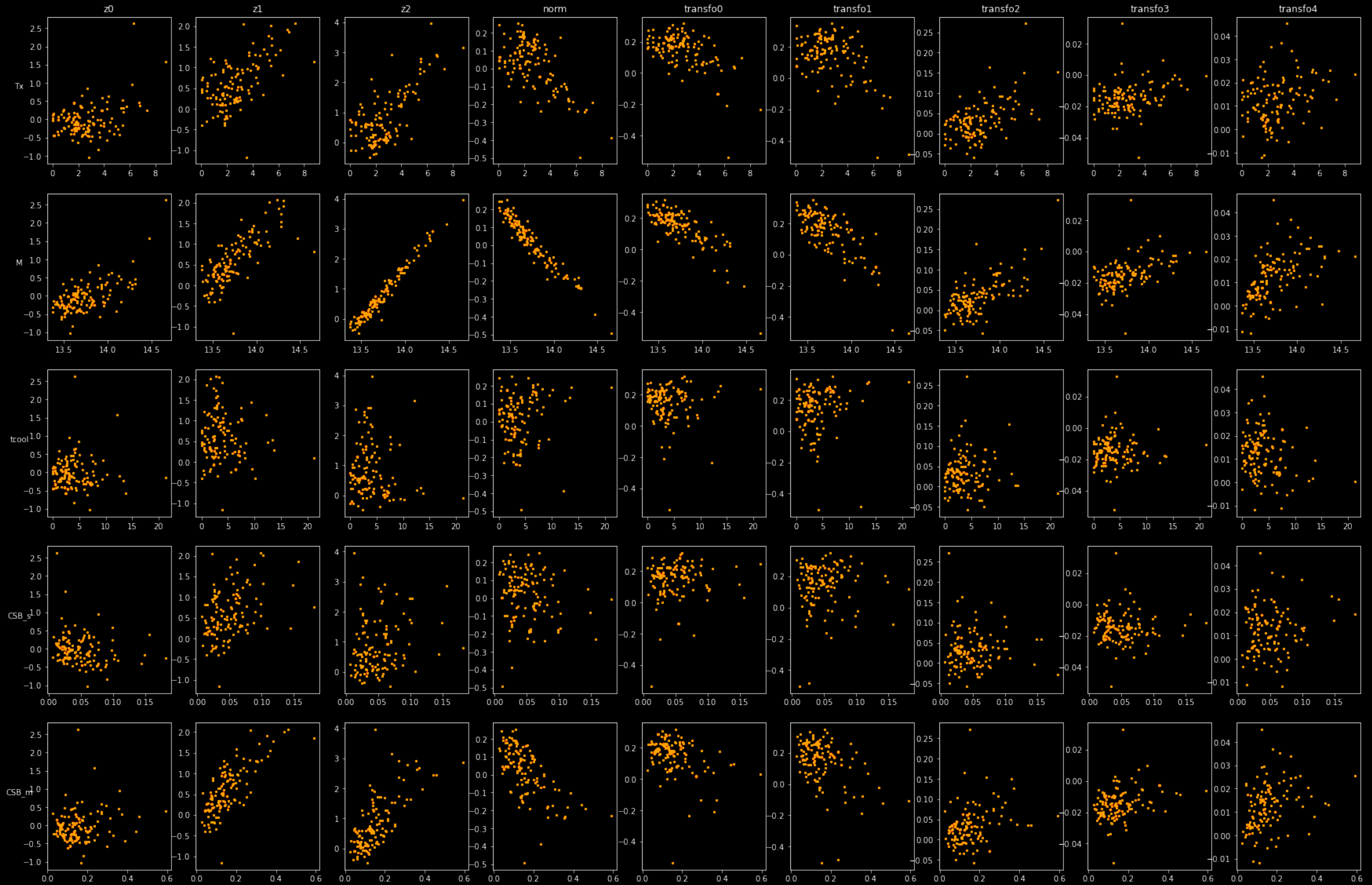


The Latent space



Visualising latent space

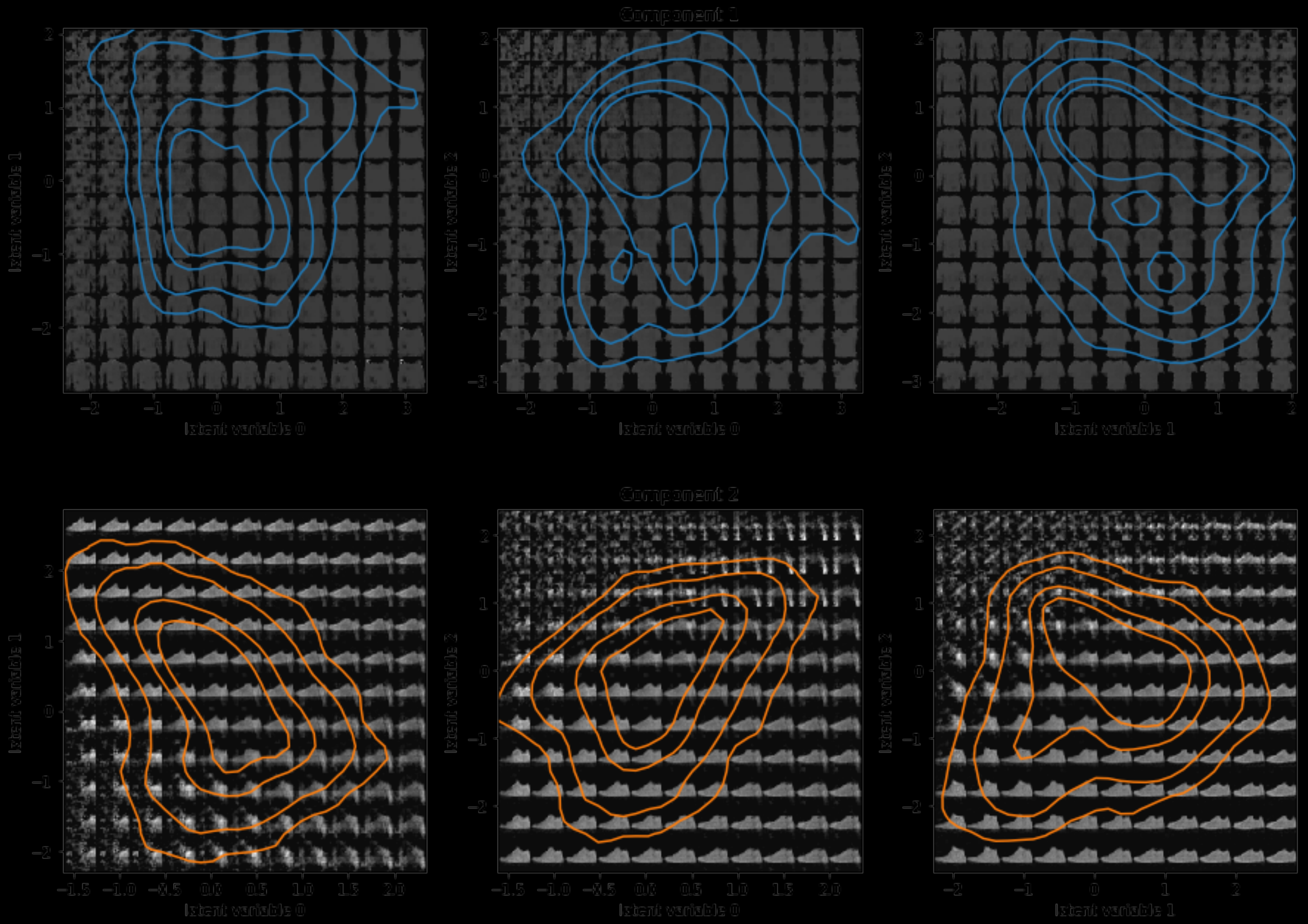
Correlations

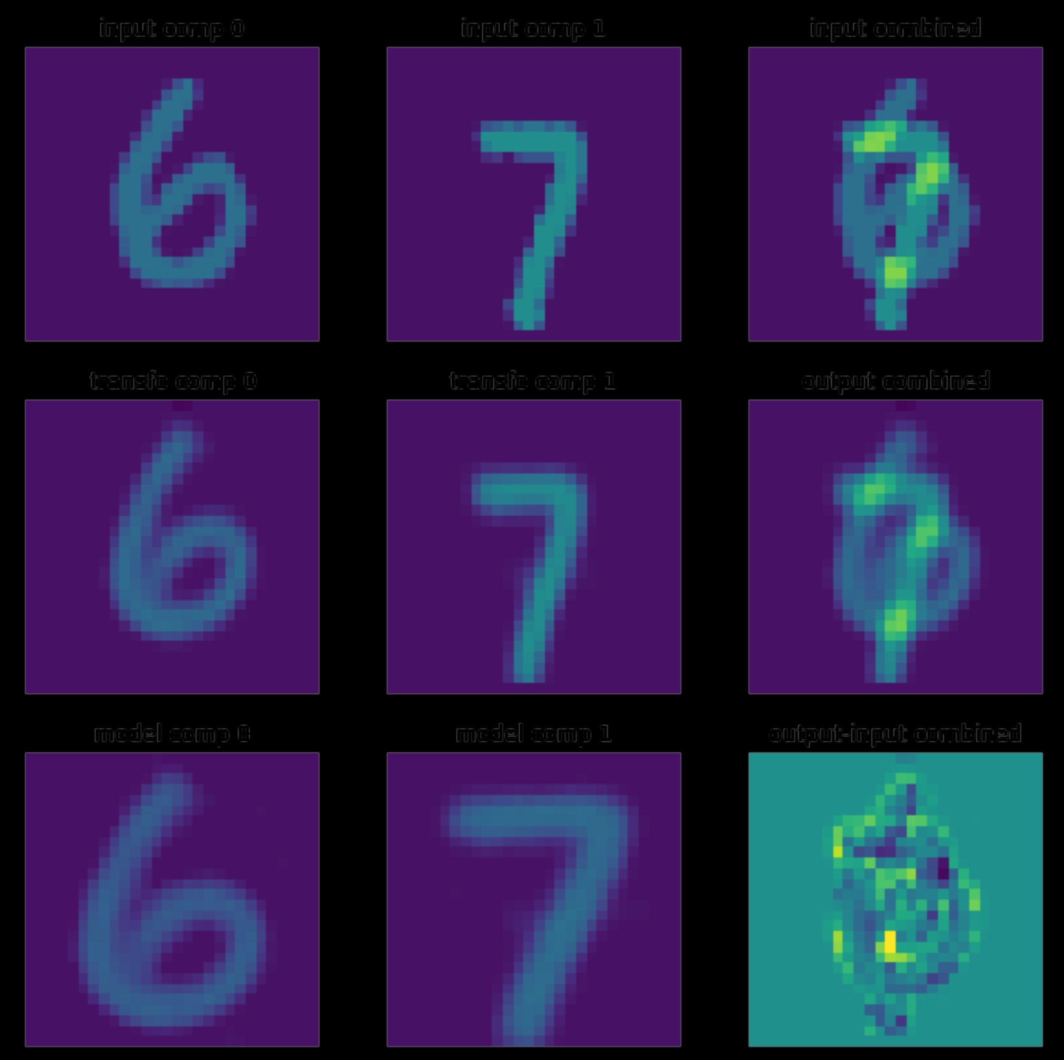


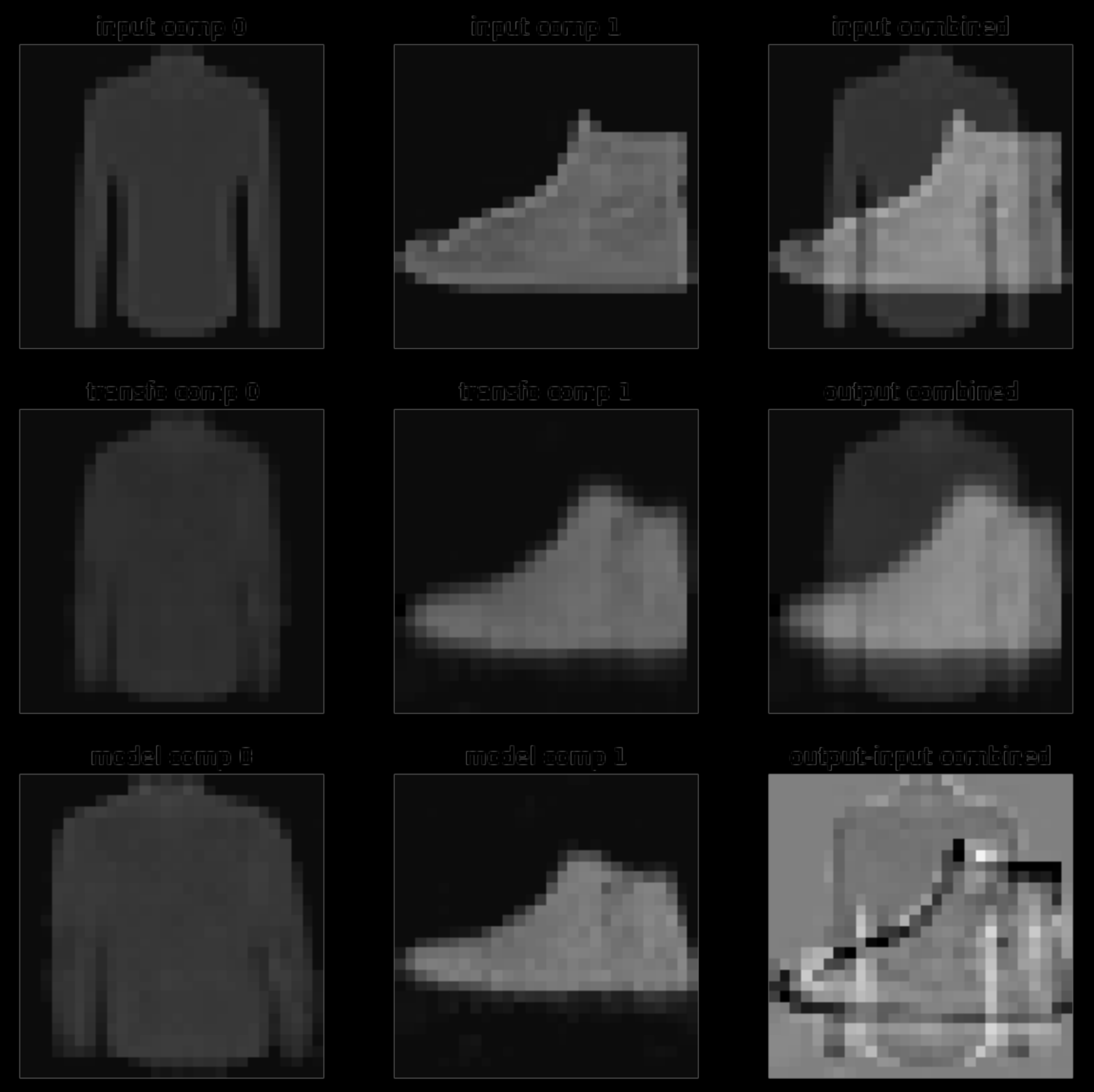
Take home message

- **Supervised learning** is **easy**
- Supervised learning **only as good as the training data** quality
- **Unsupervised learning** for **exploratory data analysis**
- **Spatial transformer networks** remove **expendible** features

Bonus slide







Bamford+(in prep.)

Questions?