DES to HSC: Detecting LSBGs in Abell 194 with Transfer Learning

Hareesh Thuruthipilly,
National Centre for Nuclear Research (NCBJ), Poland.

Collaborators: *Dr. Junais*, Prof. Jin Koda, Prof. **Agnieszka Pollo**, Prof. Masafumi Yagi, **Prof. Katarzyna Małek**

Outline

01

Overview.

02

What are LSBGs and why we need to find them ?

03

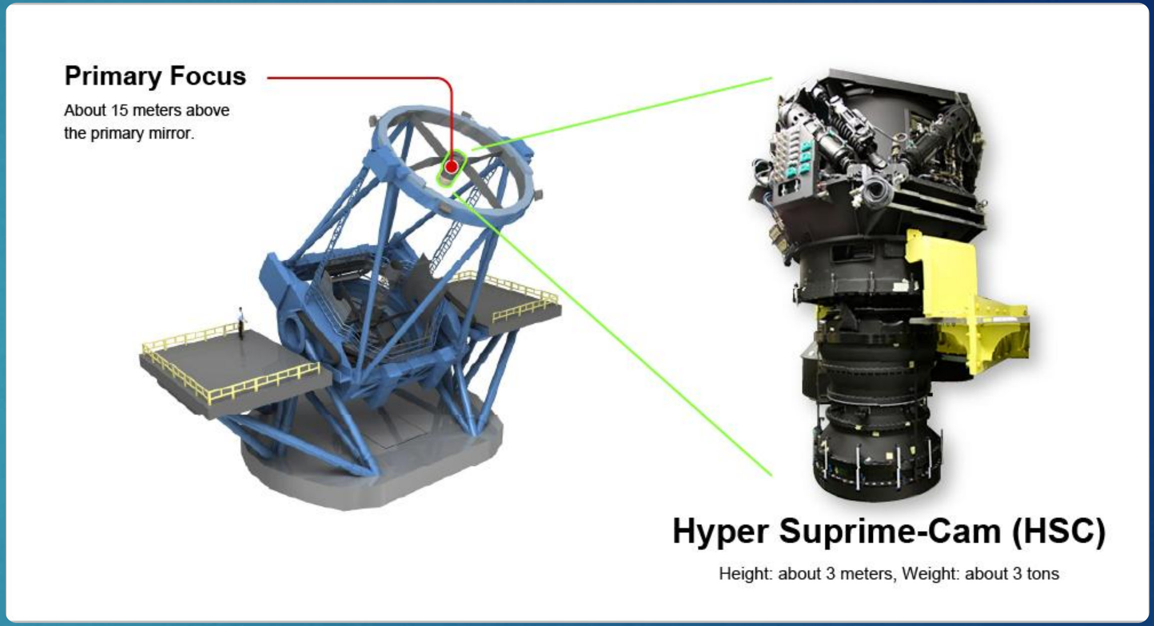
Transformers & Transfer Learning.

04

Search for LSBGs and the properties of the new LSBG sample.

SCAN FOR OUR PAPER!

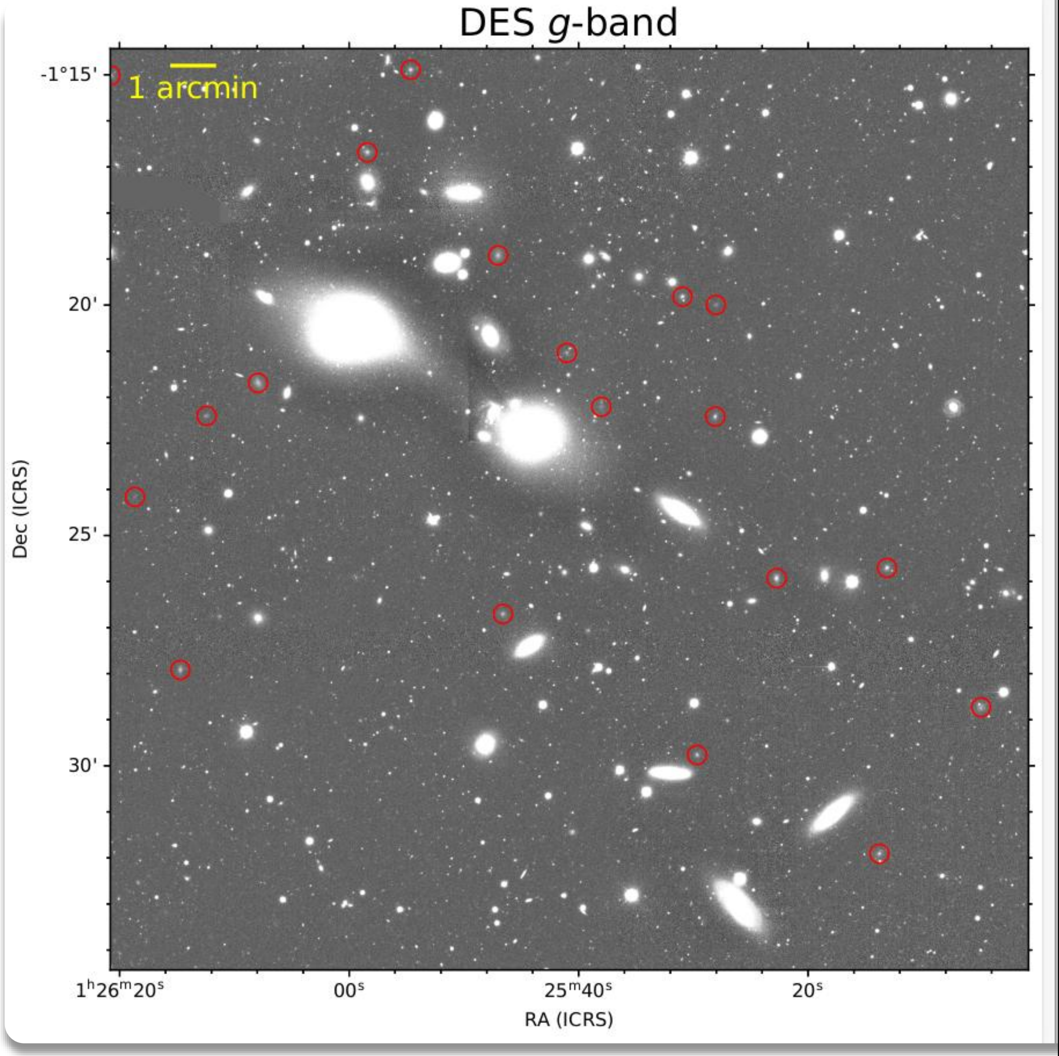
Thuruthipilly H. et al. (in prep.)
Coming Soon!!



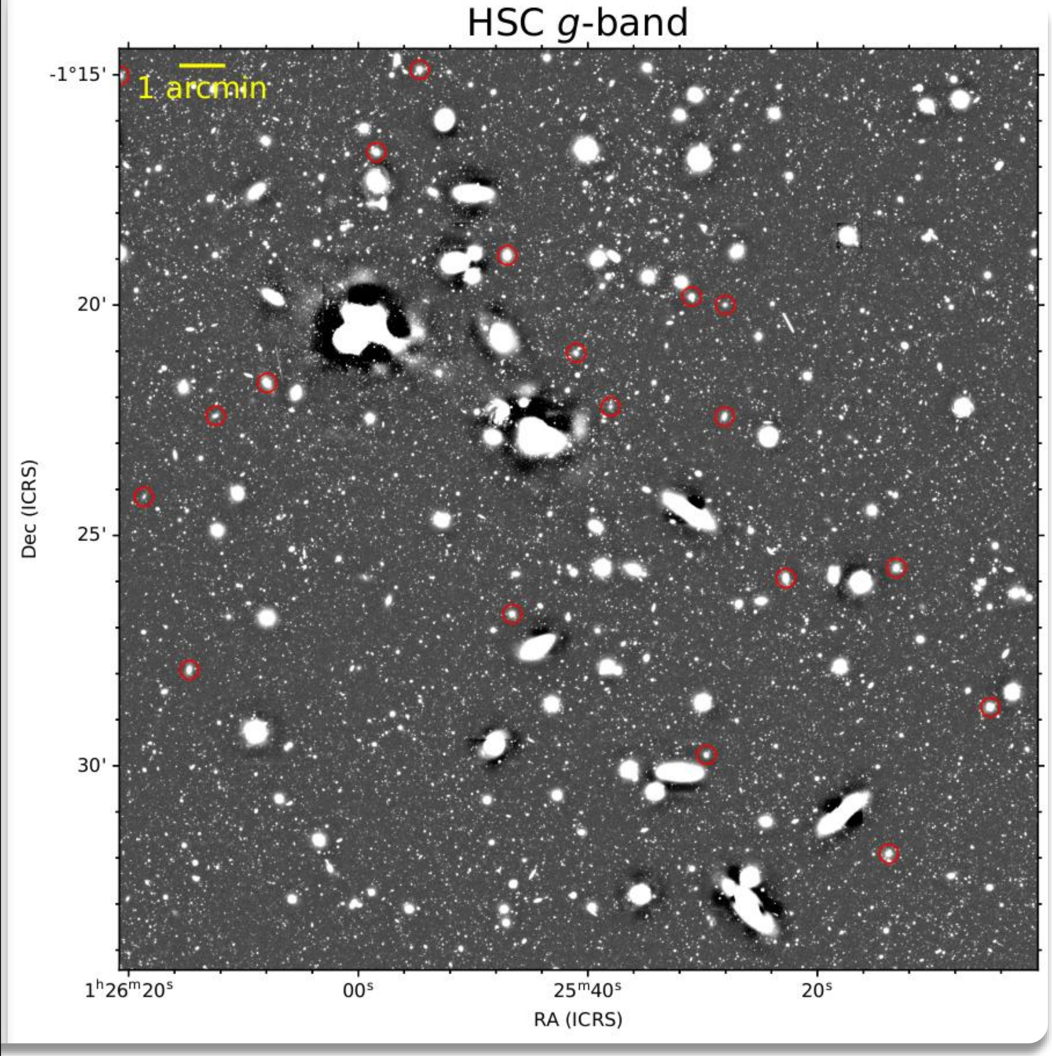
Going from DES to HSC ?

ROAD LINE TO **LSST**

DES vs HSC: Abell 194 Cluster as a Test Case



3σ detection limit = 28.86 mag arcsec^{-2}



3σ detection limit = **30.43** mag arcsec^{-2}

Not from HSC-SSP

10–year **LSST** depth.

LOW SURFACE BRIGHTNESS GALAXIES

What is an LSBG ?

We classify galaxies with $\bar{\mu}(g)$ **> 24.2 mag/arcsec^2** and **r > 2.5" (0.9 kpc)** as LSBGs (Greco+18; Tanoglidis+21)

Examples of LSBGs from Dark Energy Survey (DES) from Thuruthipilly et al. (2024)

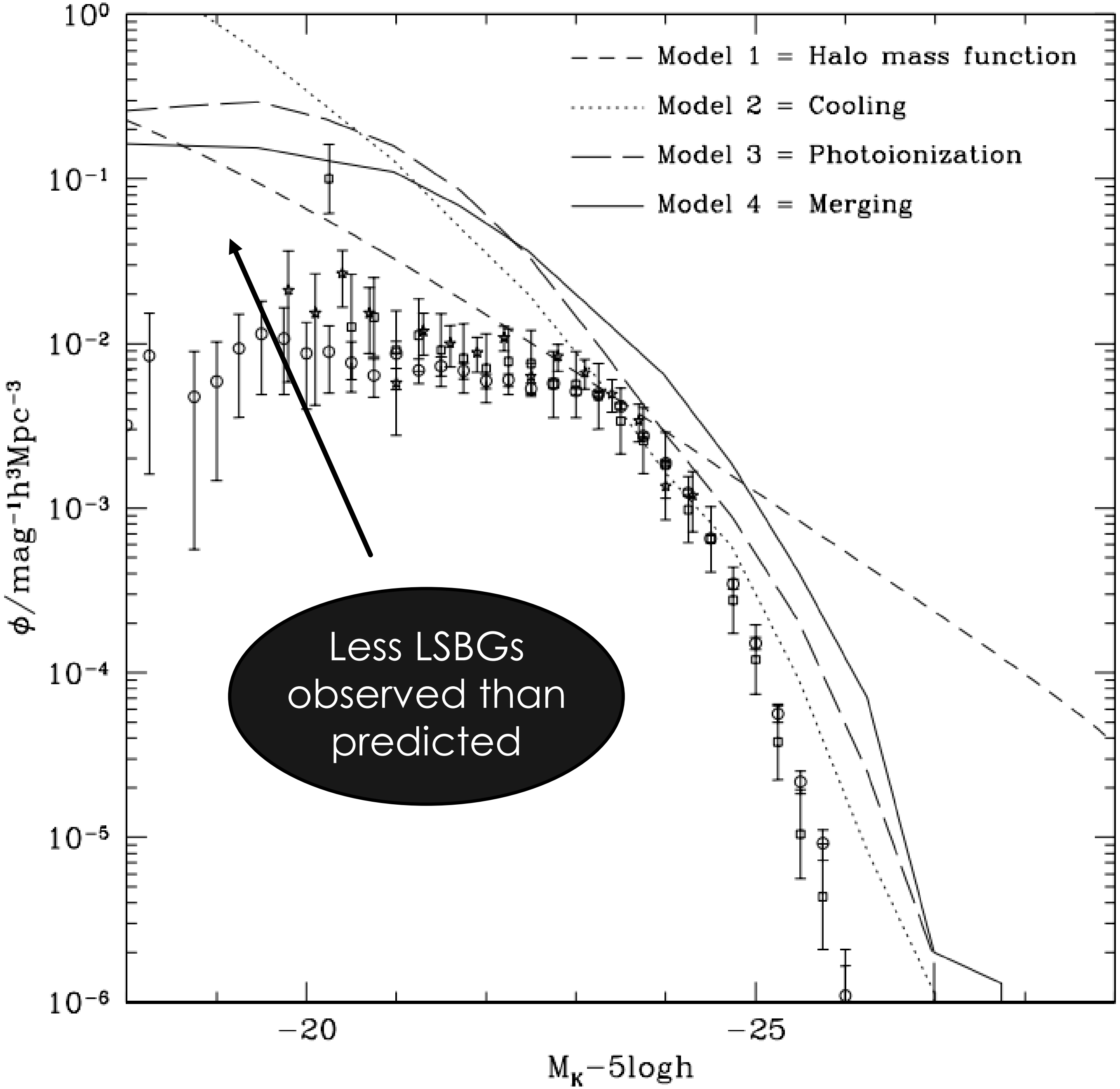
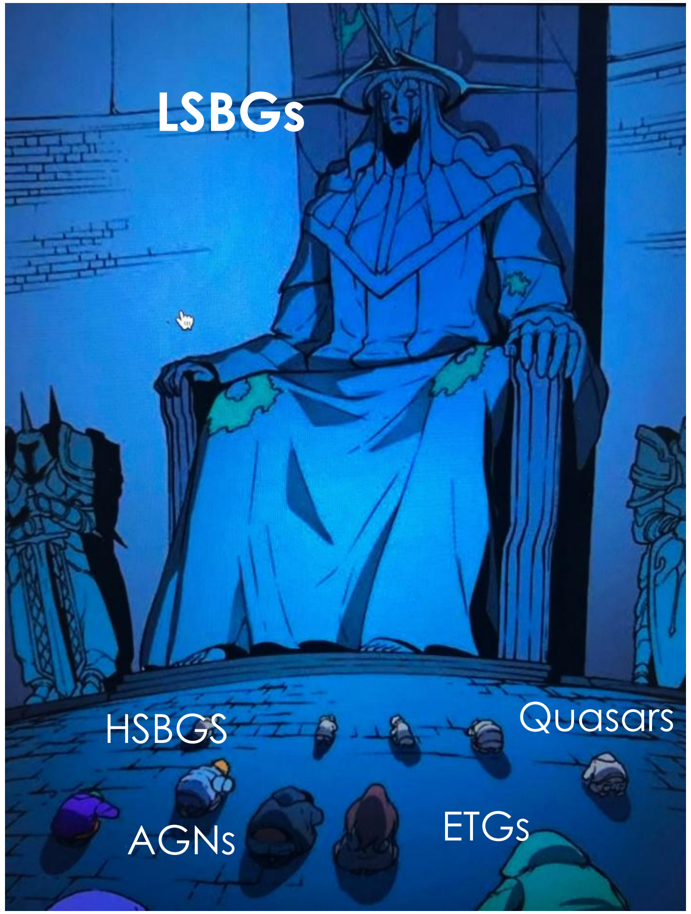


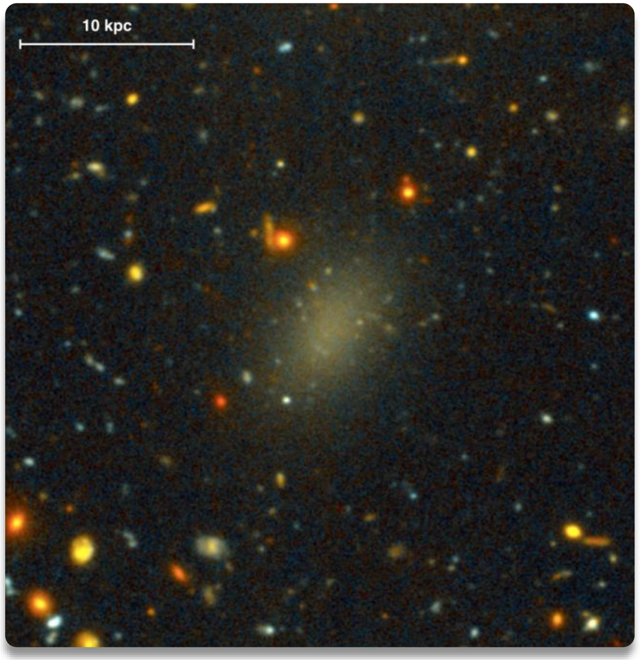
Image taken from A. J. Benson et al. (2003).



LSBGs account for up to **50**% of the total population of galaxies.

Ultra-diffuse Galaxies

Ultra-diffuse galaxies (UDGs), are extended LSBGs with **effective radii r > 1.5 kpc** and central surface brightness $\boldsymbol{\mu_0} >$ $\boldsymbol{24.0\ mag\ arsec^{-2}}$(van Dokkum et al. 2015).



DF – 44: Extremely dominated by dark matter.
Image credits :
Teymoor Saifollahi and NASA/HST

NGC 1052-DF2 : Almost void of dark matter.
Image source :
https://www.spacetelescope.org/images/heic1806

Finding LSBGs

Why it is hard to detect LSBGs

Need deep surveys.

Eliminating the sky background.

Separation of **artifacts** from LSBGs.

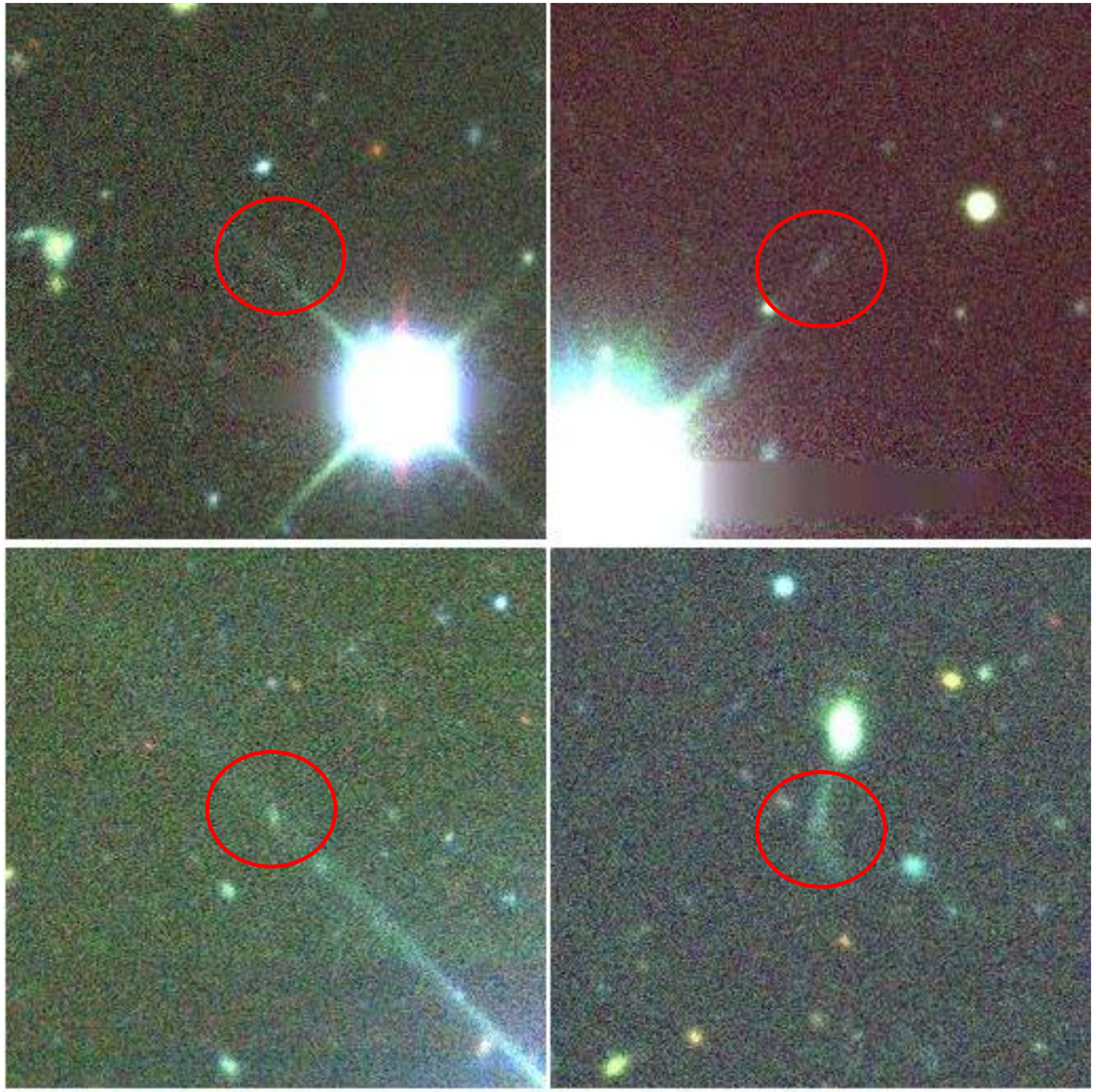
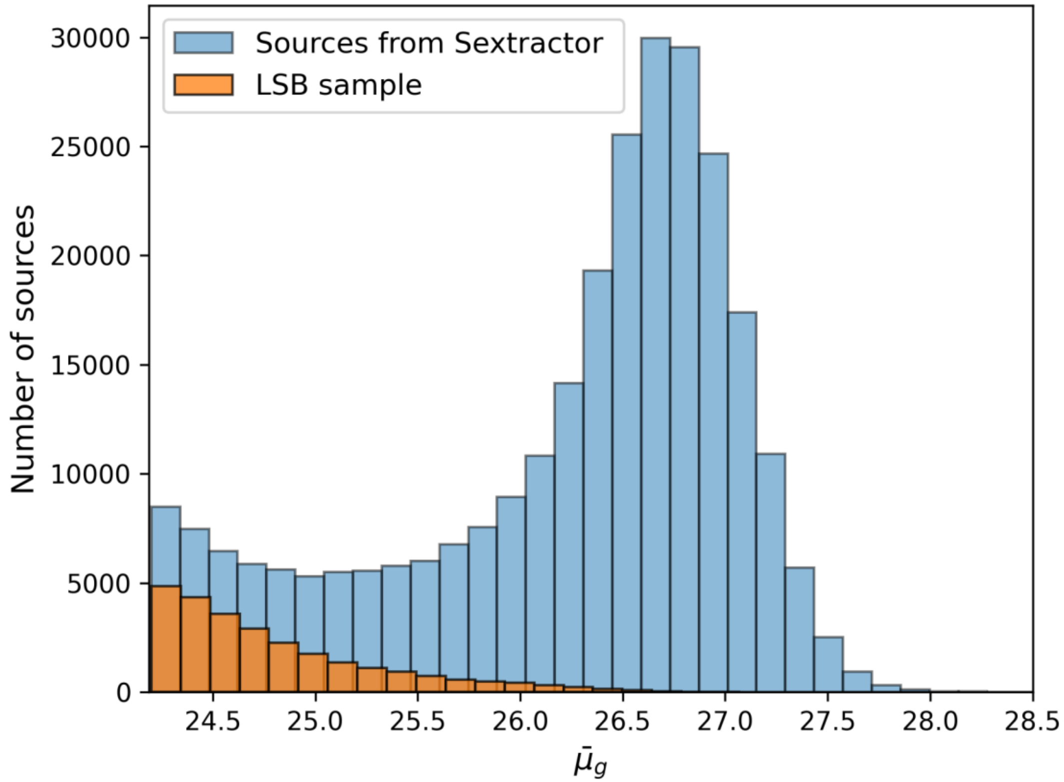
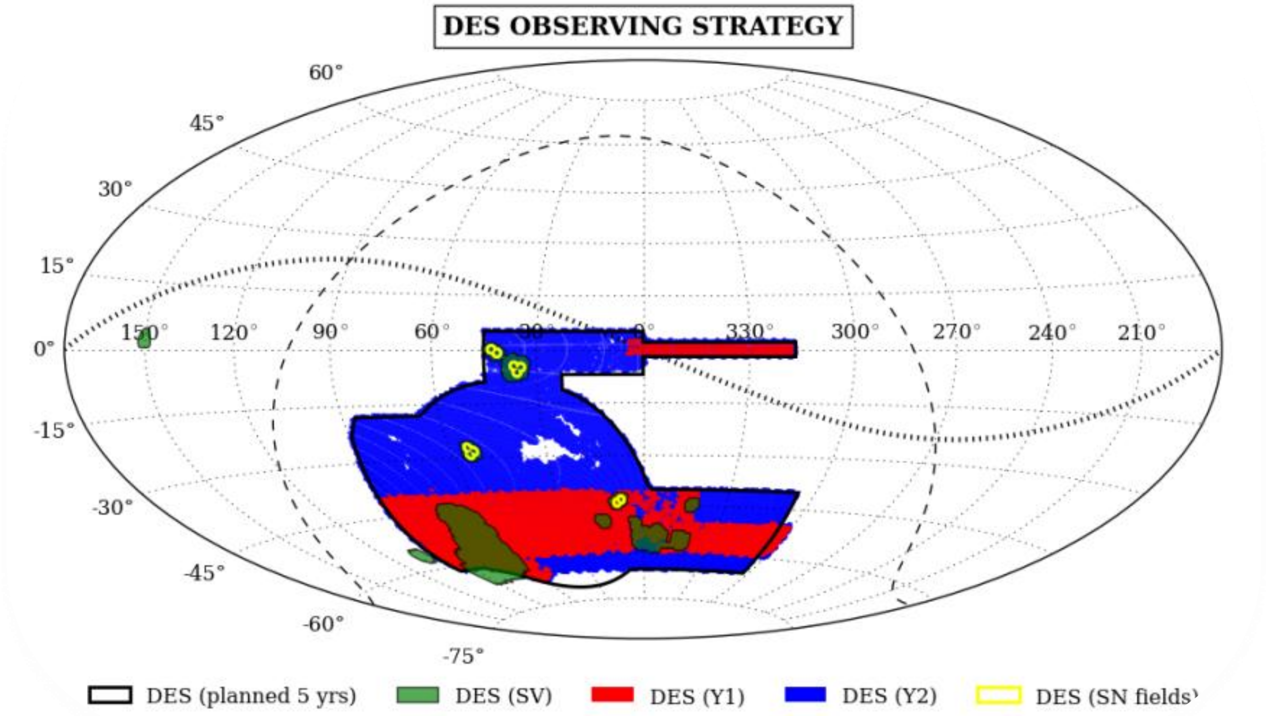


Image taken from Thuruthipilly et al. (2024)

Dark Energy Survey (DES)



Tanoglidis et al. (2021) identified **23,790** LSBGs from DES by visually inspecting **44,979** candidates.



Surveyed around ~ **5000** deg^2 of the sky.

Image taken from J. H. O'Donnell et al (2021)

LSST and EUCLID

The large-scale surveys, such as **LSST** and Euclid are expected to observe **10^5+LSBGs**.

With the current techniques it means **~10^5+artefacts.**

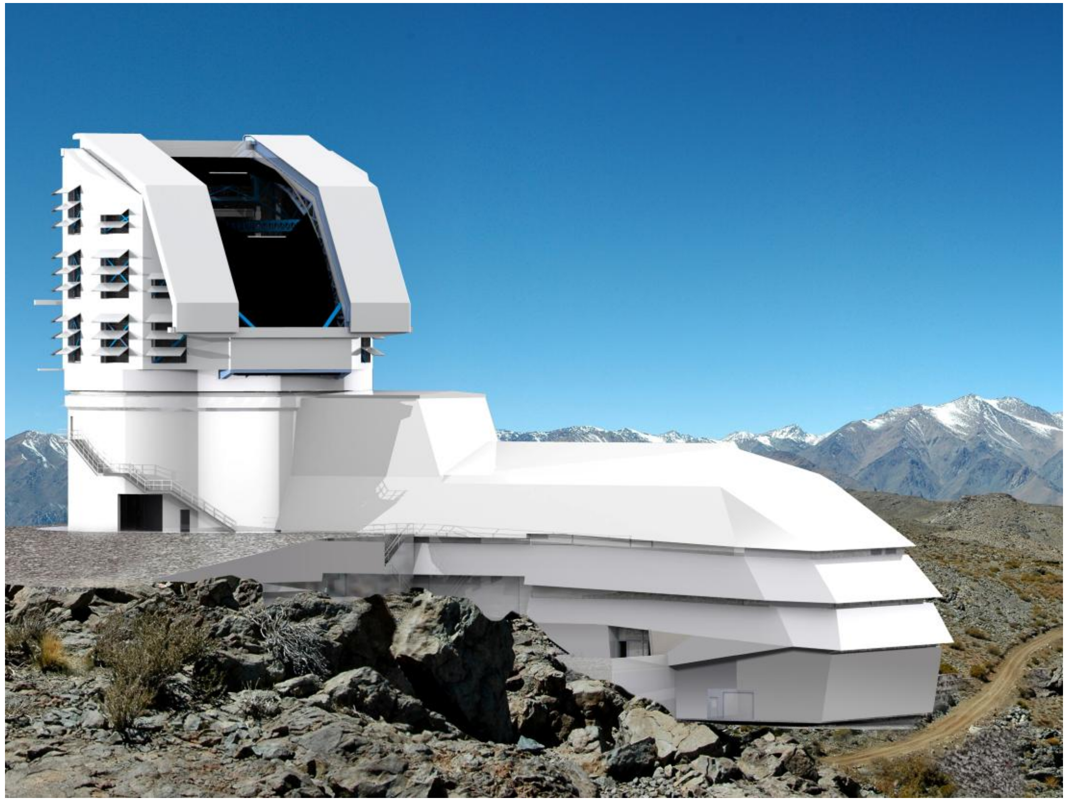
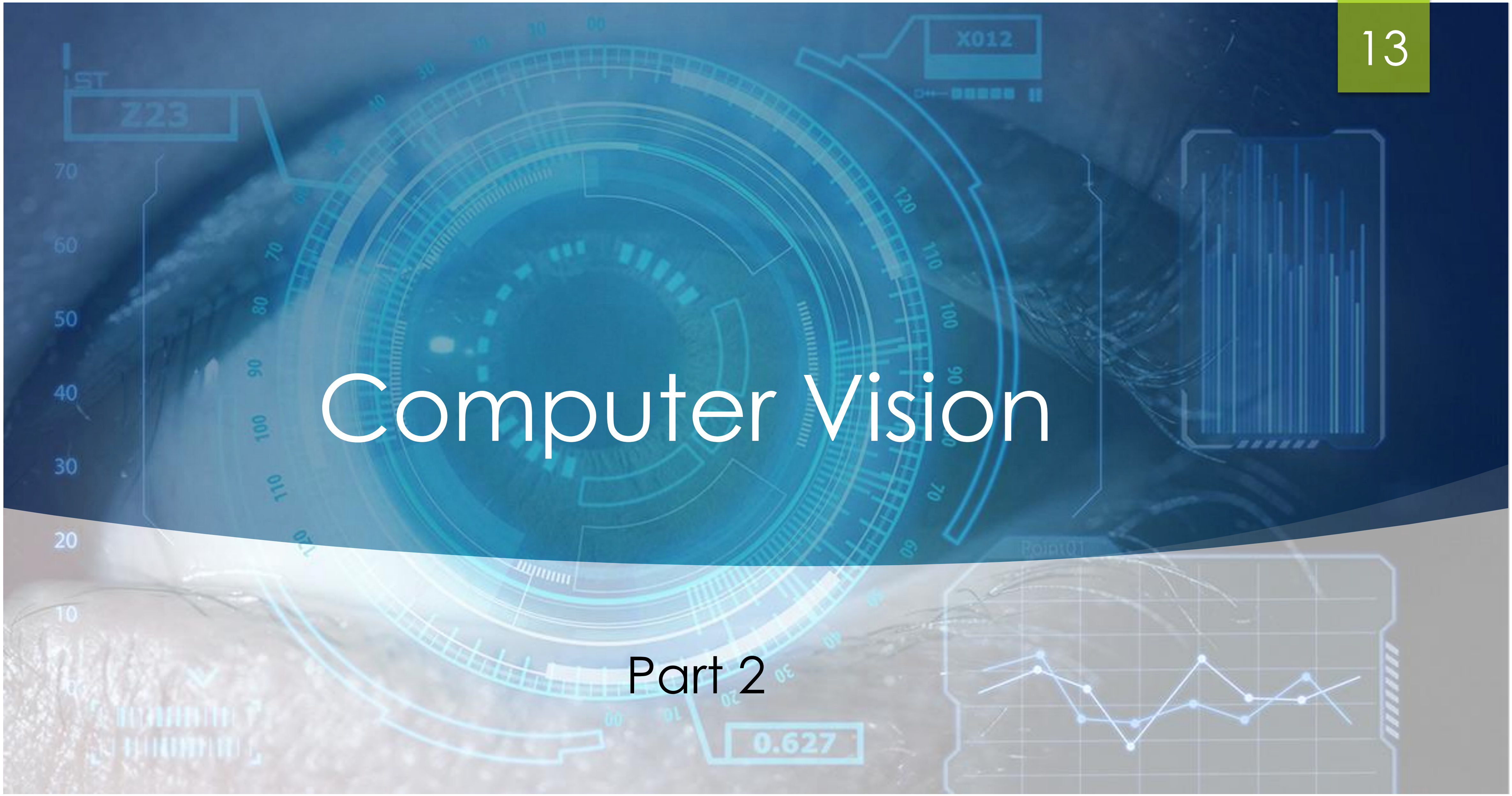


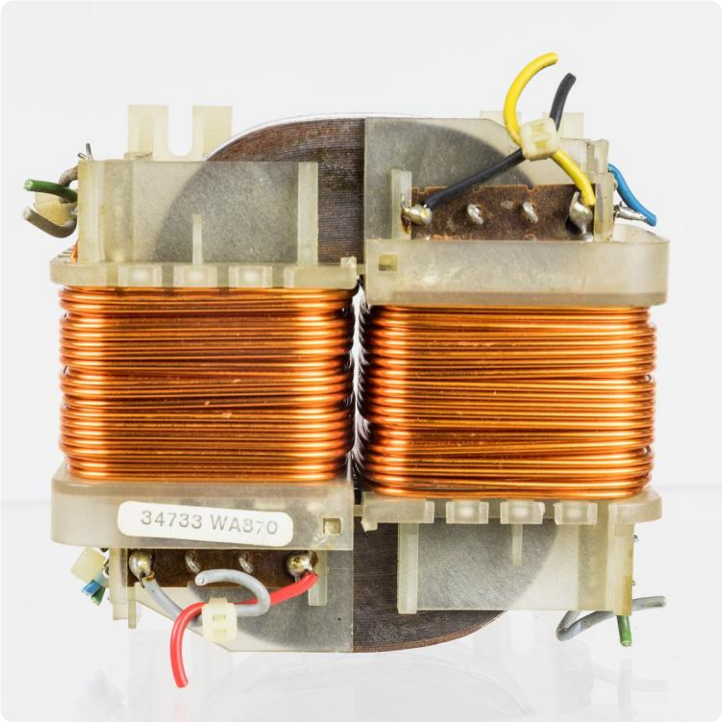
Image taken from https://astronomy.com/news/2017/12/the-lsst-and-big-data-science



Computer Vision

Part 2

Transformer?



Chat Generative Pre-trained **Transformer**

LSBG Detection Transformer (LSBG DETR)

- **CNN** – To extract the Features.
- **Encoder** – To filter the relevant Features of the image.
- **FFN** – To learn the relevant Features.

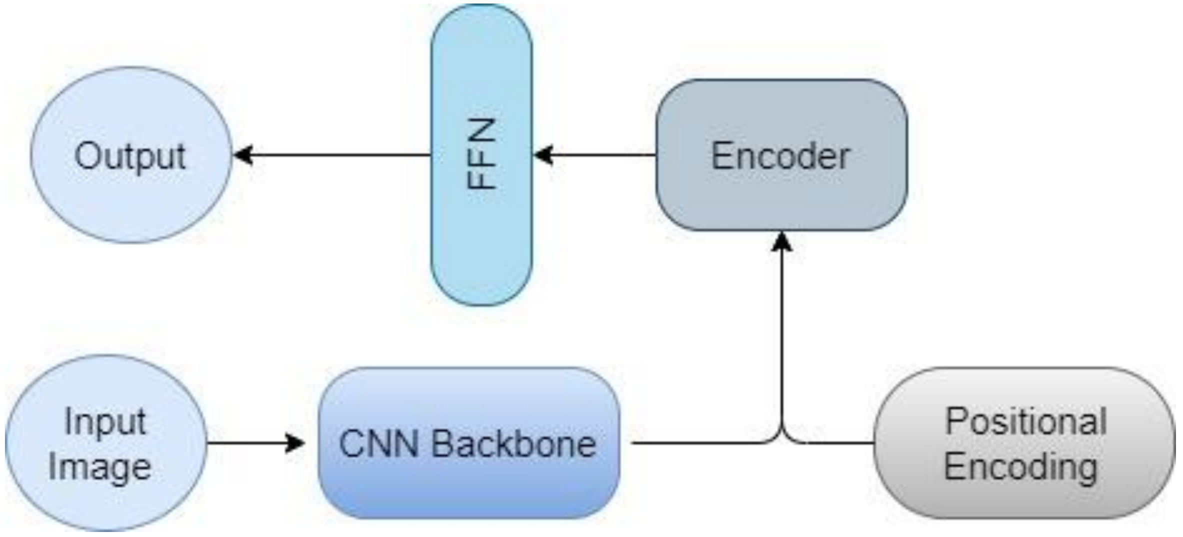


Image taken from Thuruthipilly et al. (2024)

LSBG Vision Transformer

- The Vision Transformer (ViT) divides an image into a grid of patches and feed it to a transformer encoder layer

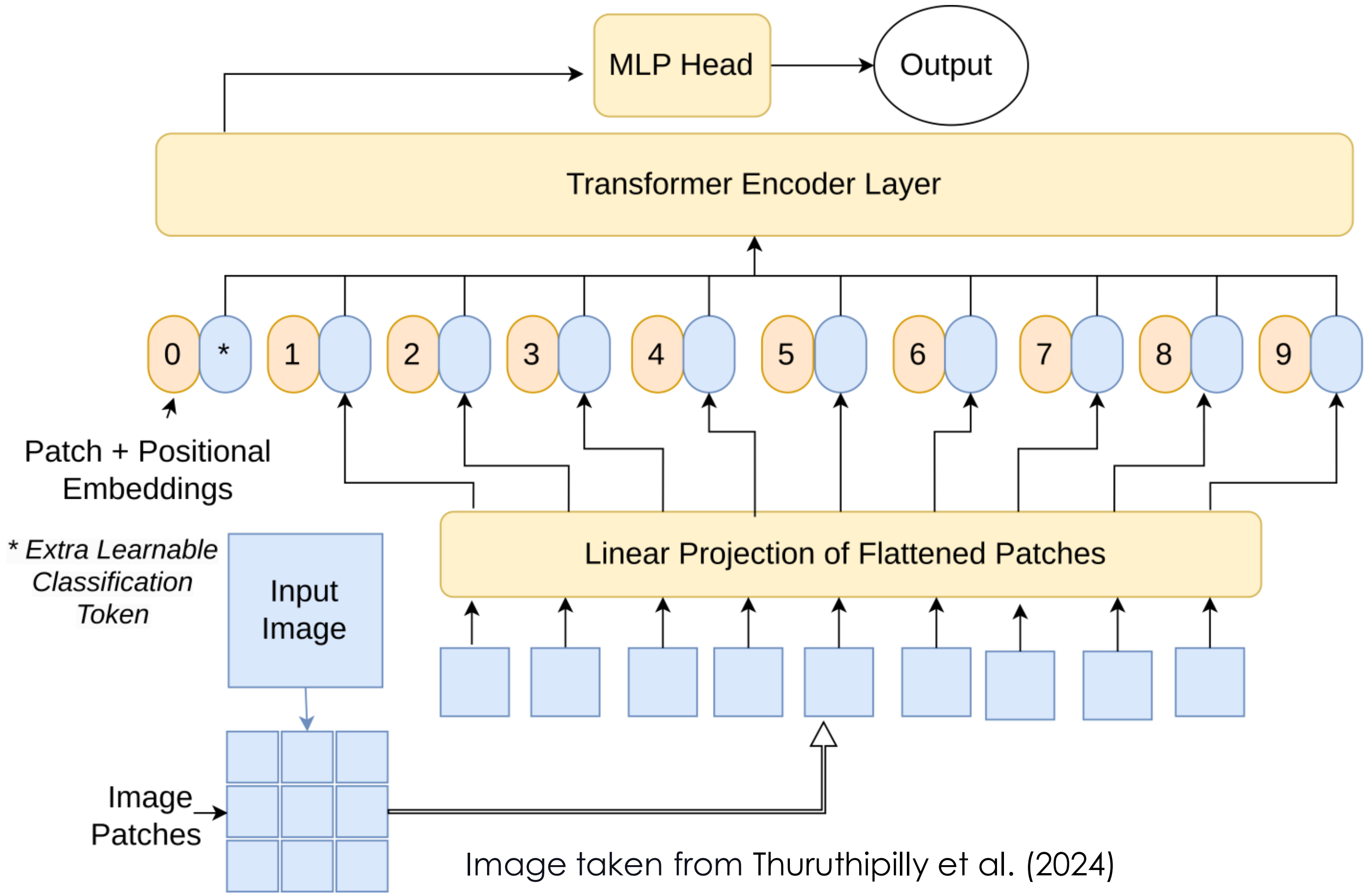
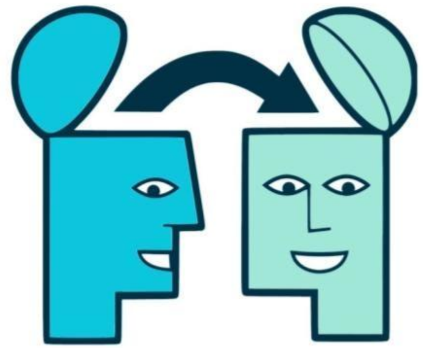
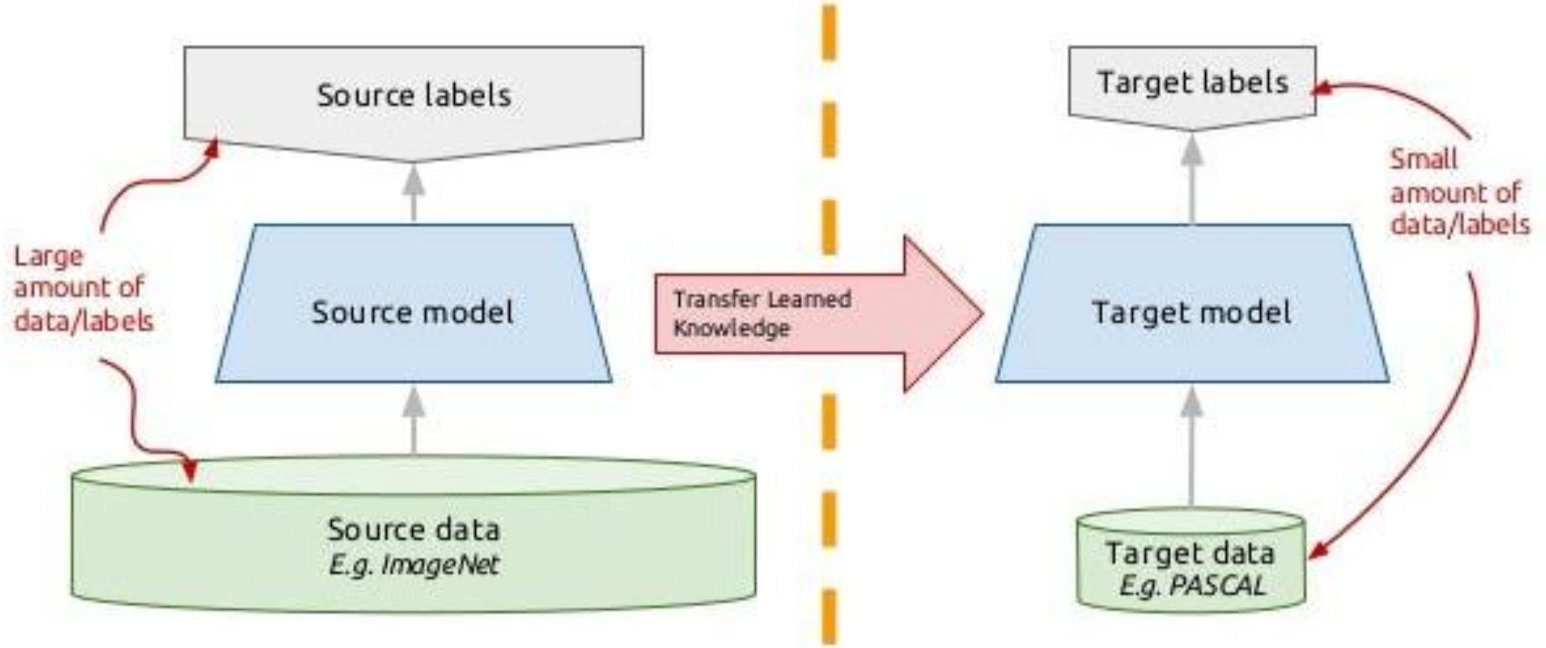


Image taken from Thuruthipilly et al. (2024)

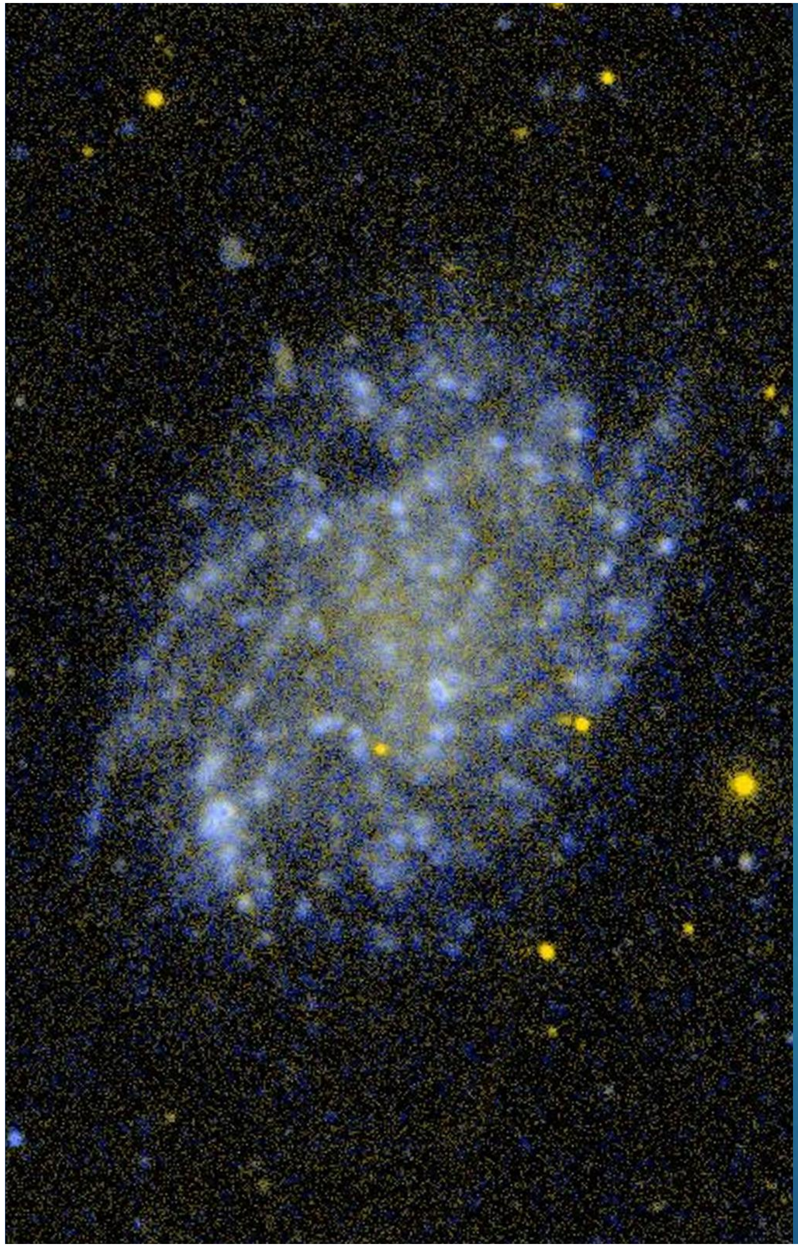
Transfer Learning

Transfer learning: The reuse of a pre-trained model on a new problem.





Images taken from https://www.linkedin.com/pulse/ai-atlas-3-transfer-learning-rudina-seseri



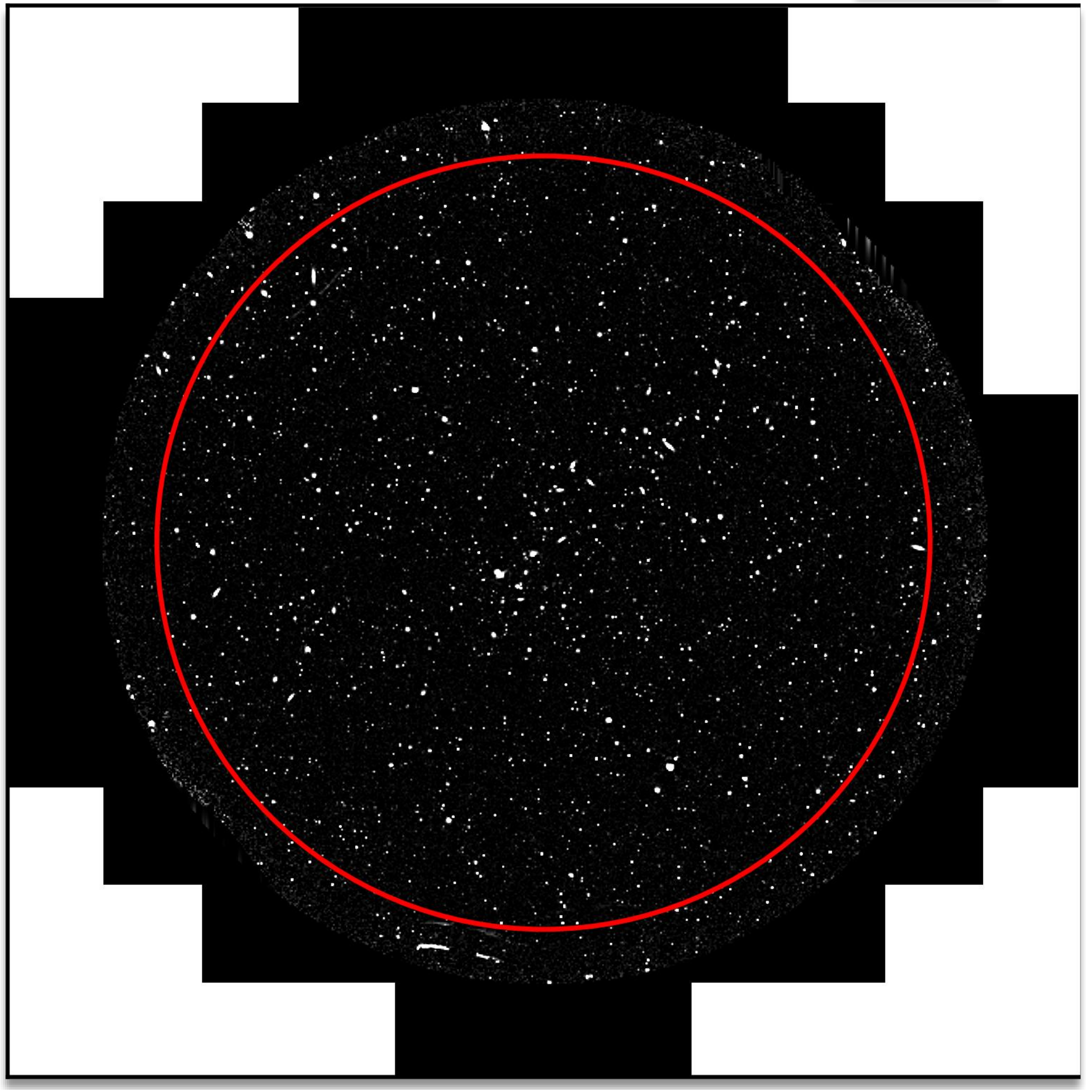
Search for LSBGs

PART 3

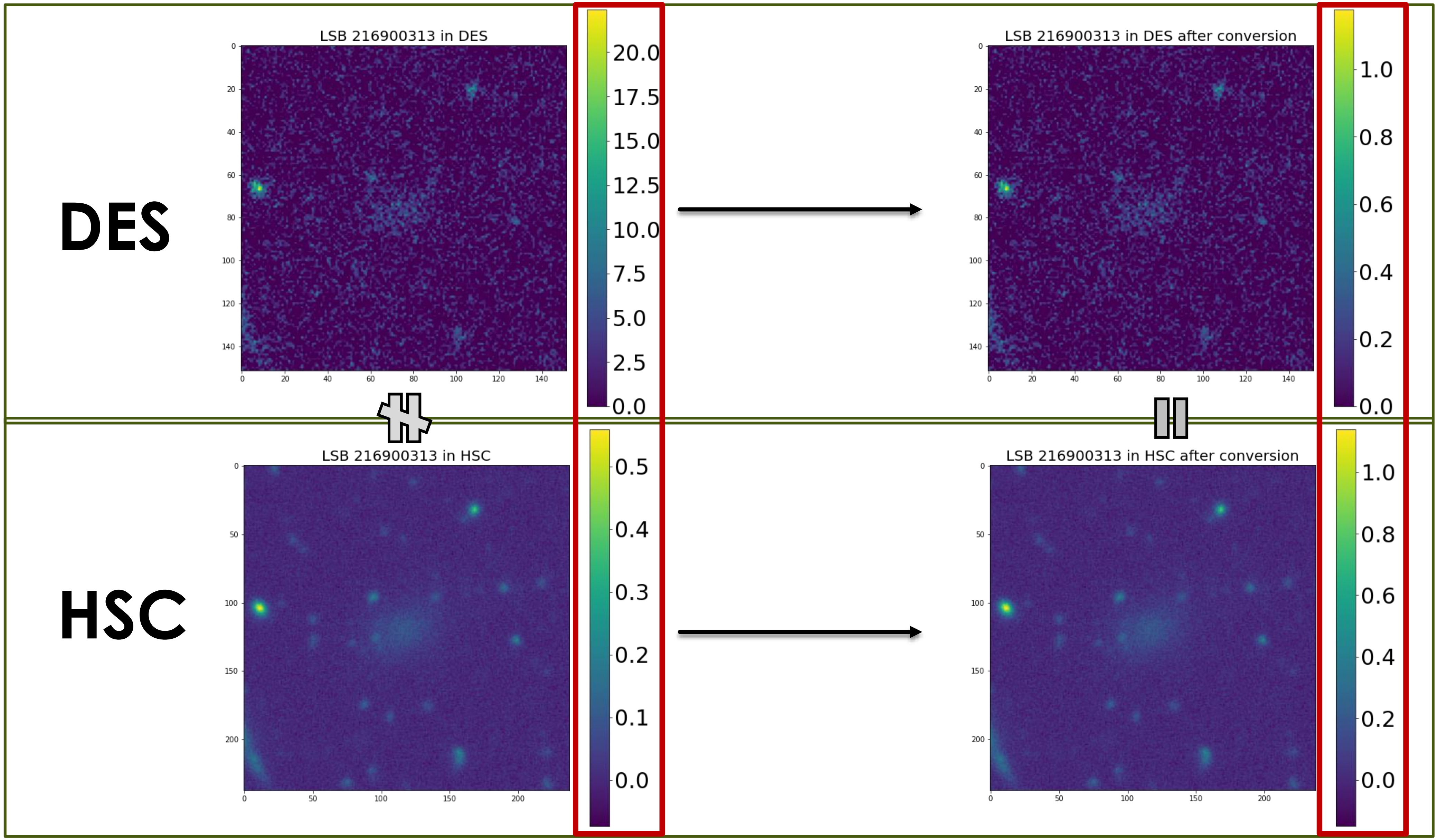
Image taken from
http://www.wikisky.org/?object=NGC+45&img_source=GALEX

Abell 194 Cluster

- DES covers Abell 194 cluster.
- We made deep observations of the Abell 194 cluster in *g* and *r*-bands.
- **94** known LSBGs, insufficient for ML training.



Coverage of the Abell 194 Cluster observed with HSC. The red circle shows the virial radius of the cluster (~1Mpc).



Convert the raw data to a physical unit (micro jansky arcsec^{-2}) to make the average pixel values in the image data similar for both surveys.

Performance in **DES**

Model name	Accuracy (%)	TPR	FPR	AUROC
LSBG VISION 1	95.58	0.96	0.05	0.9908
LSBG VISION 2	95.48	0.96	0.05	0.9906
LSBG VISION 3	95.58	0.97	0.06	0.9906
LSBG VISION 4	95.14	0.96	0.05	0.9895
LSBG VISION Ensemble	**95.62**	**0.96**	**0.05**	**0.9911**
LSBG DETR 1	95.68	0.96	0.04	0.9893
LSBG DETR 2	95.36	0.95	0.04	0.9887
LSBG DETR 3	95.48	0.96	0.05	0.9891
LSBG DETR 4	95.54	0.97	0.06	0.9904
LSBG DETR Ensemble	**95.62**	**0.96**	**0.05**	**0.9903**

$$TPR = \frac{N_{True\ positives}}{N_{True\ positives} + N_{False\ Negatives}}$$

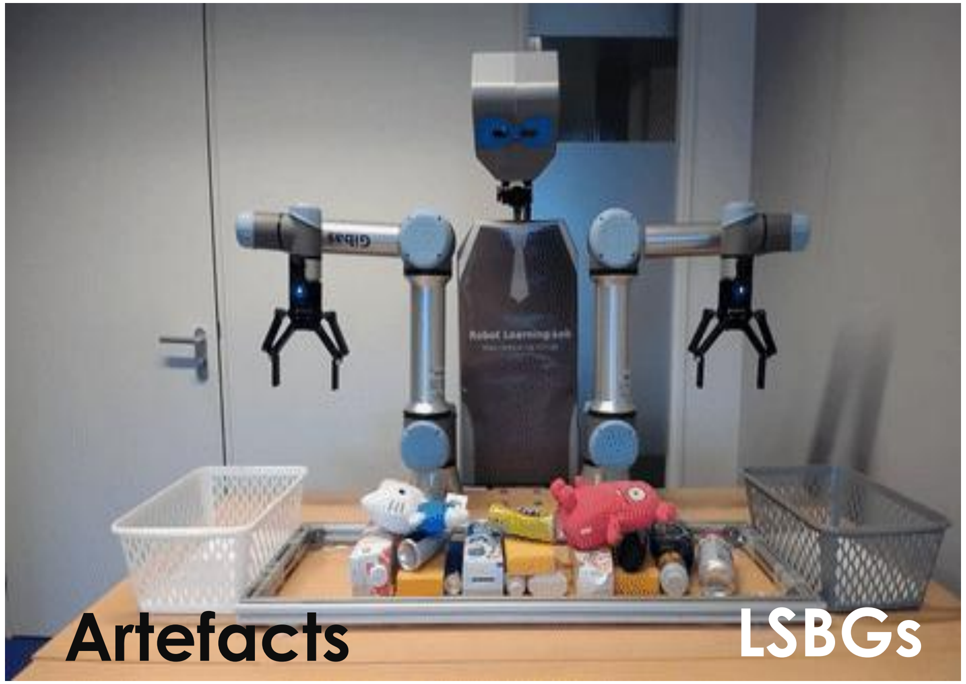
$$FPR = \frac{N_{False\ positives}}{N_{False\ Positives} + N_{True\ Negaitves}}$$

For a perfect classifier AUROC = **1**, TPR = **1** and FPR = **0.**

LSBGs in A194 – Simplified Pipeline

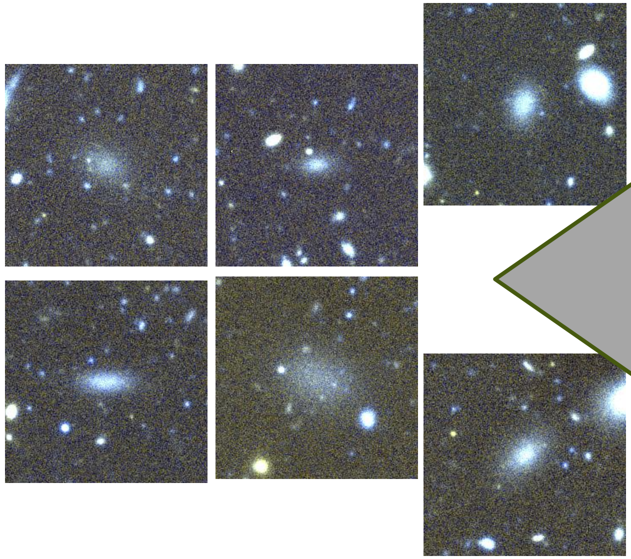
991 faint objects from Sextractor

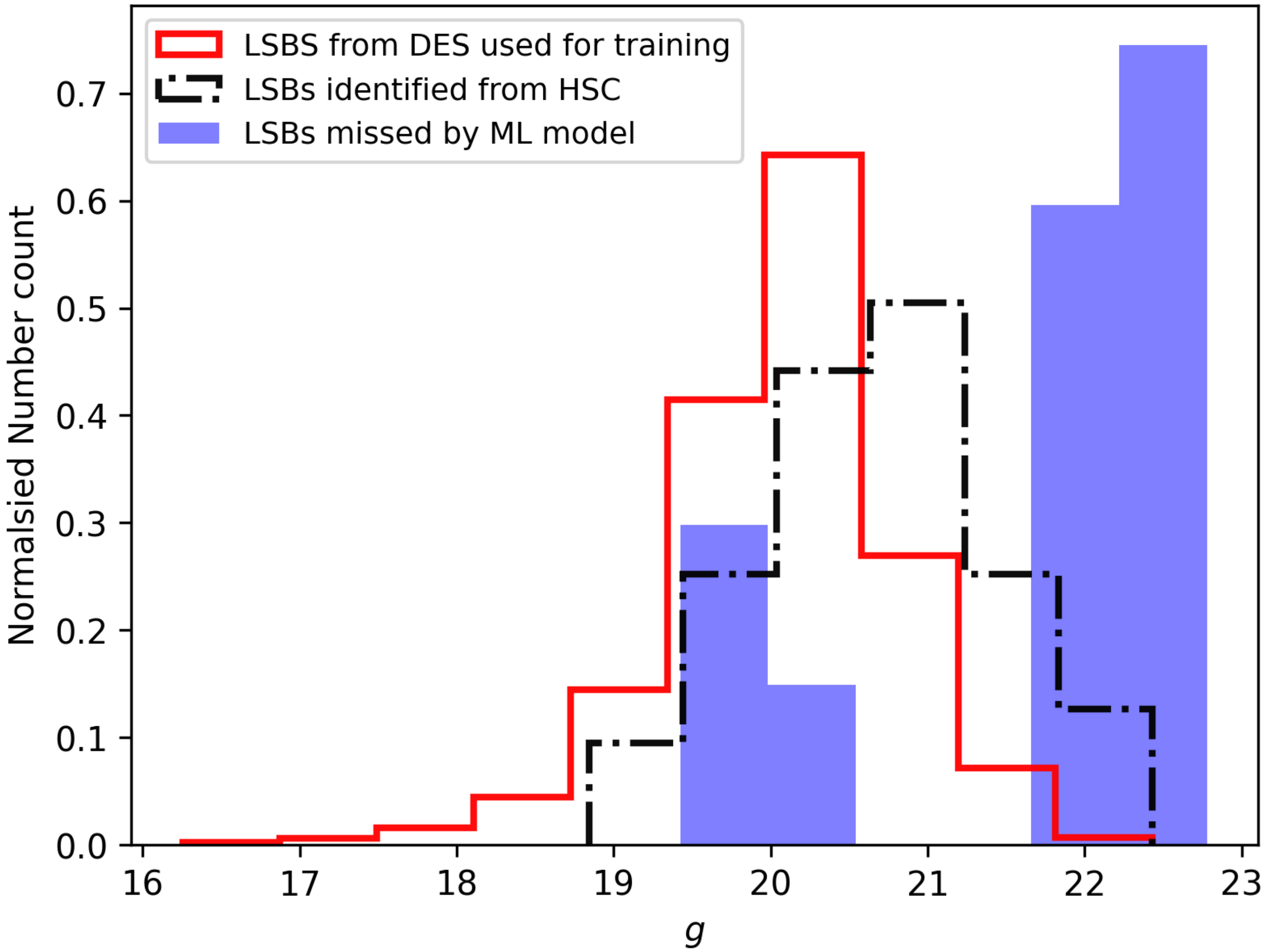
ML models



Sérsic profile fitting & visual inspection = **159** LSBGs.

74 New LSBGs

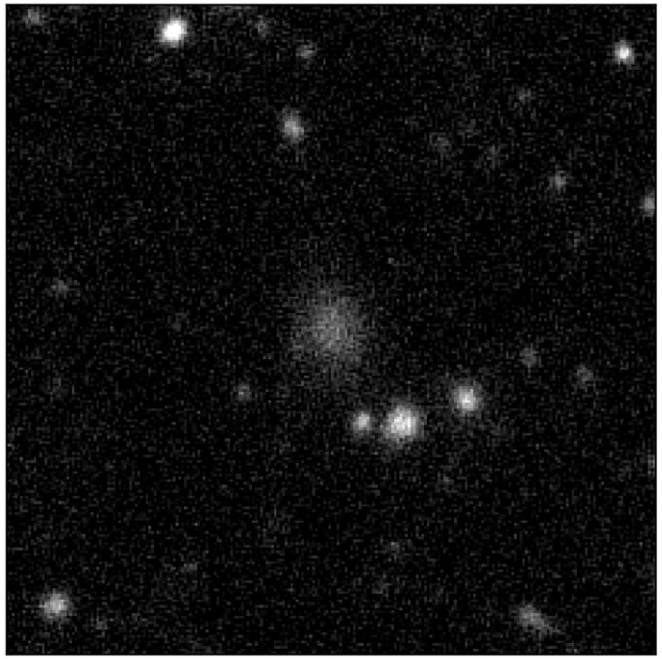
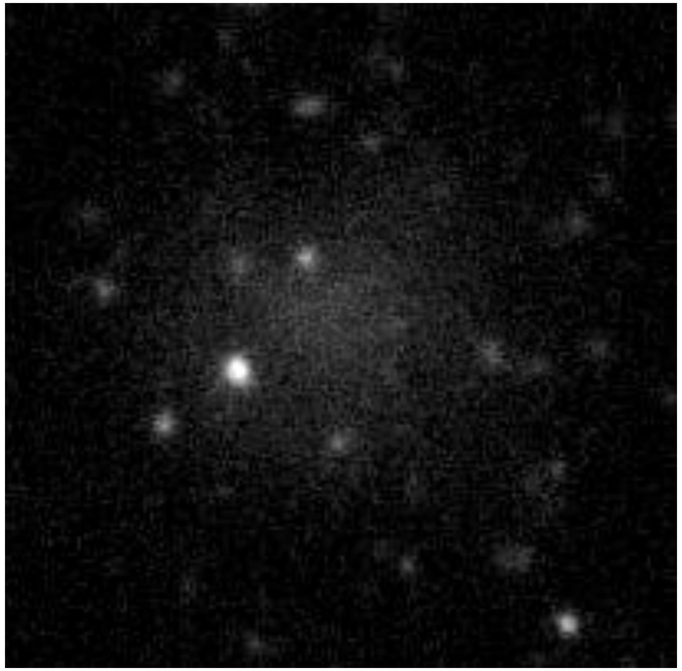




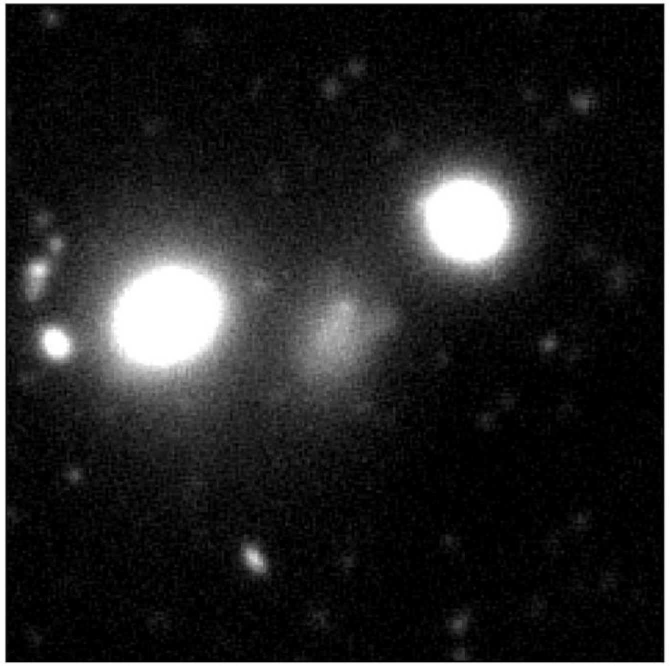
Missing LSBGs !!

We missed **12 LSBGs** which were found with **visual inspection** and Galfit.

Why ?

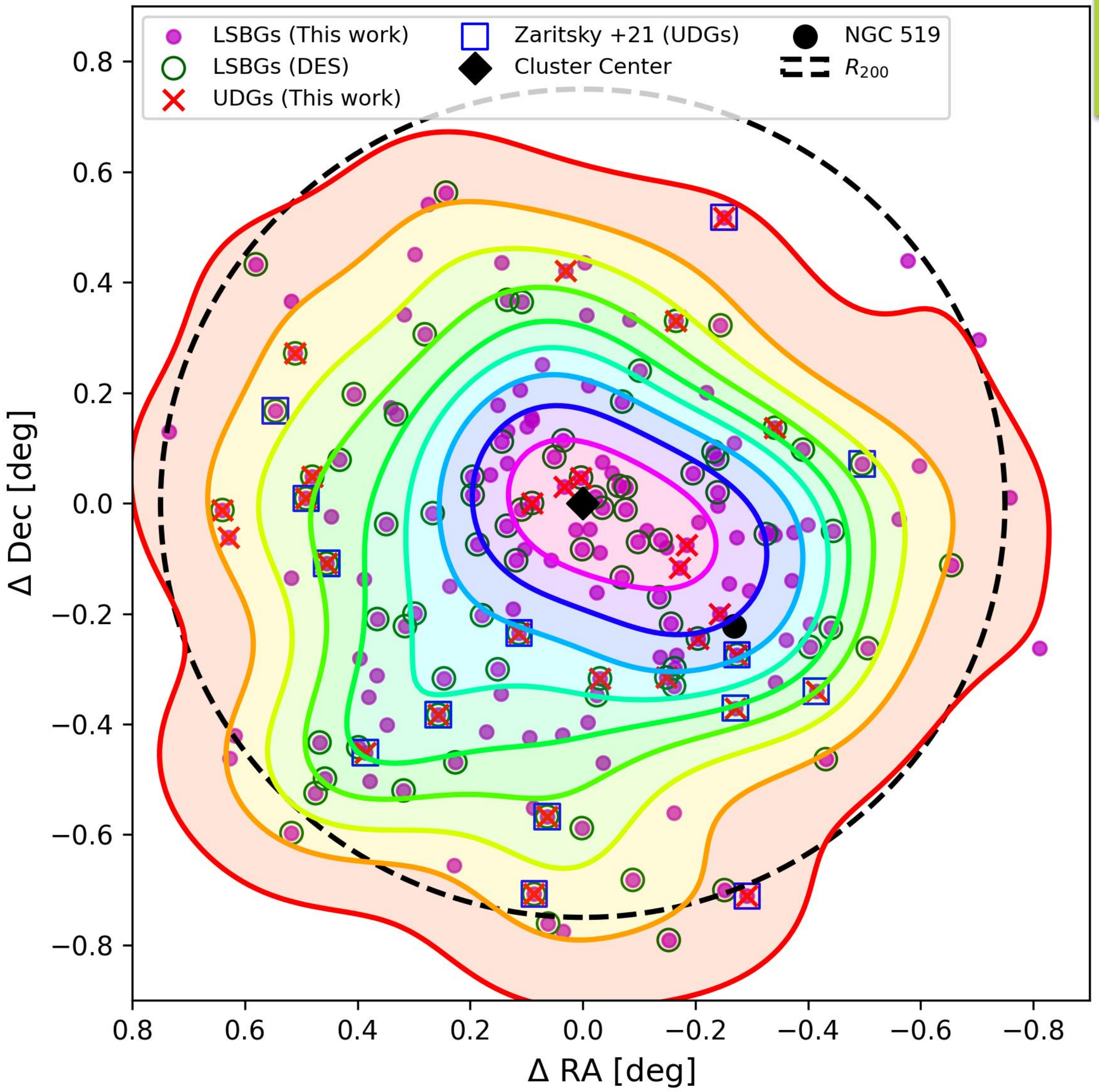
Vey faint (g~22) and representative sample was not present in the training set.



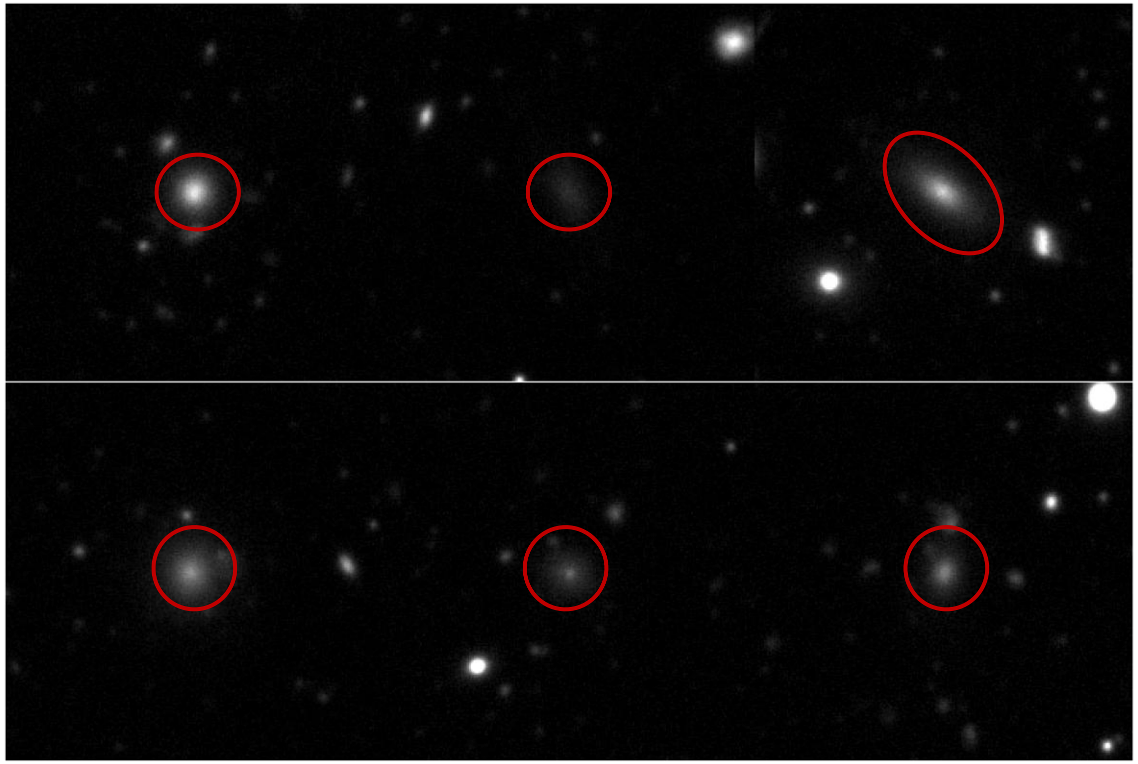
Presence of a bright object near the center.

LSBGs & UDGs

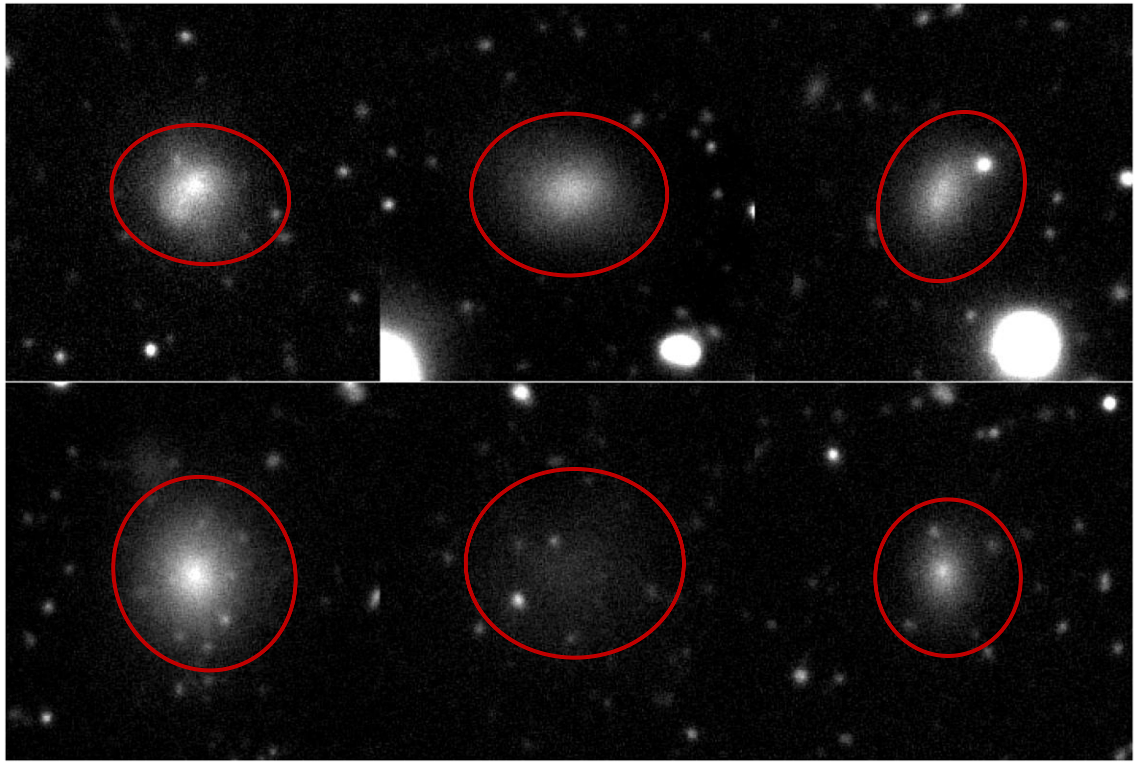
- **171** LSBGs and **28** UDGs
- **93%** recovery rate **without fine tuning.**



Examples of LSBGs and UDGs



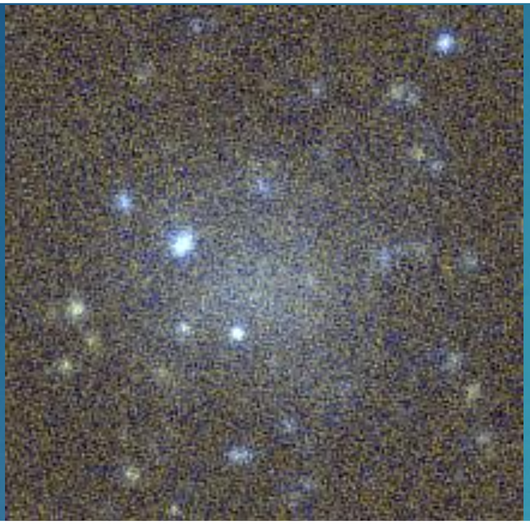
LSBGs (non-UDGs)



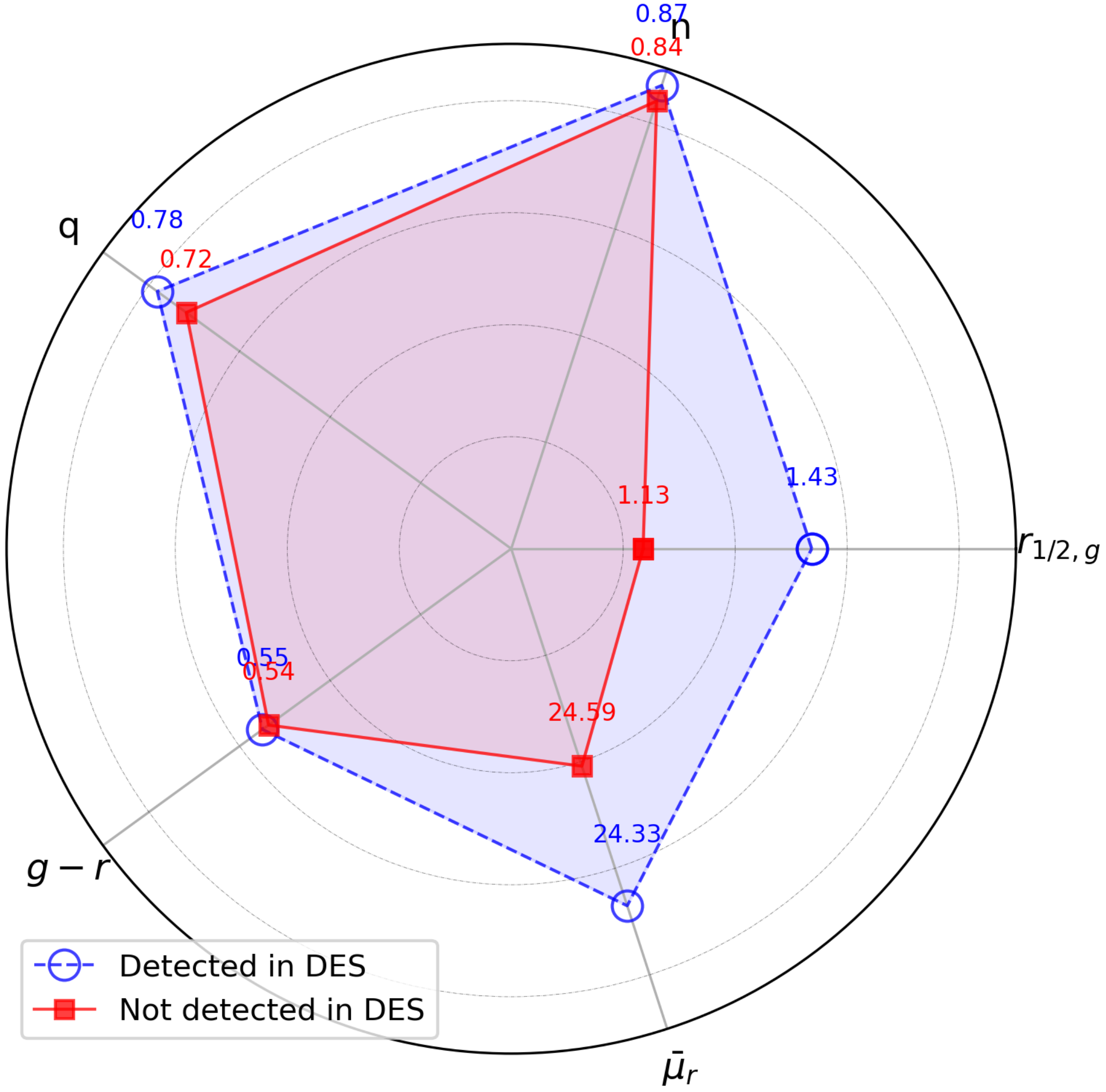
UDGs

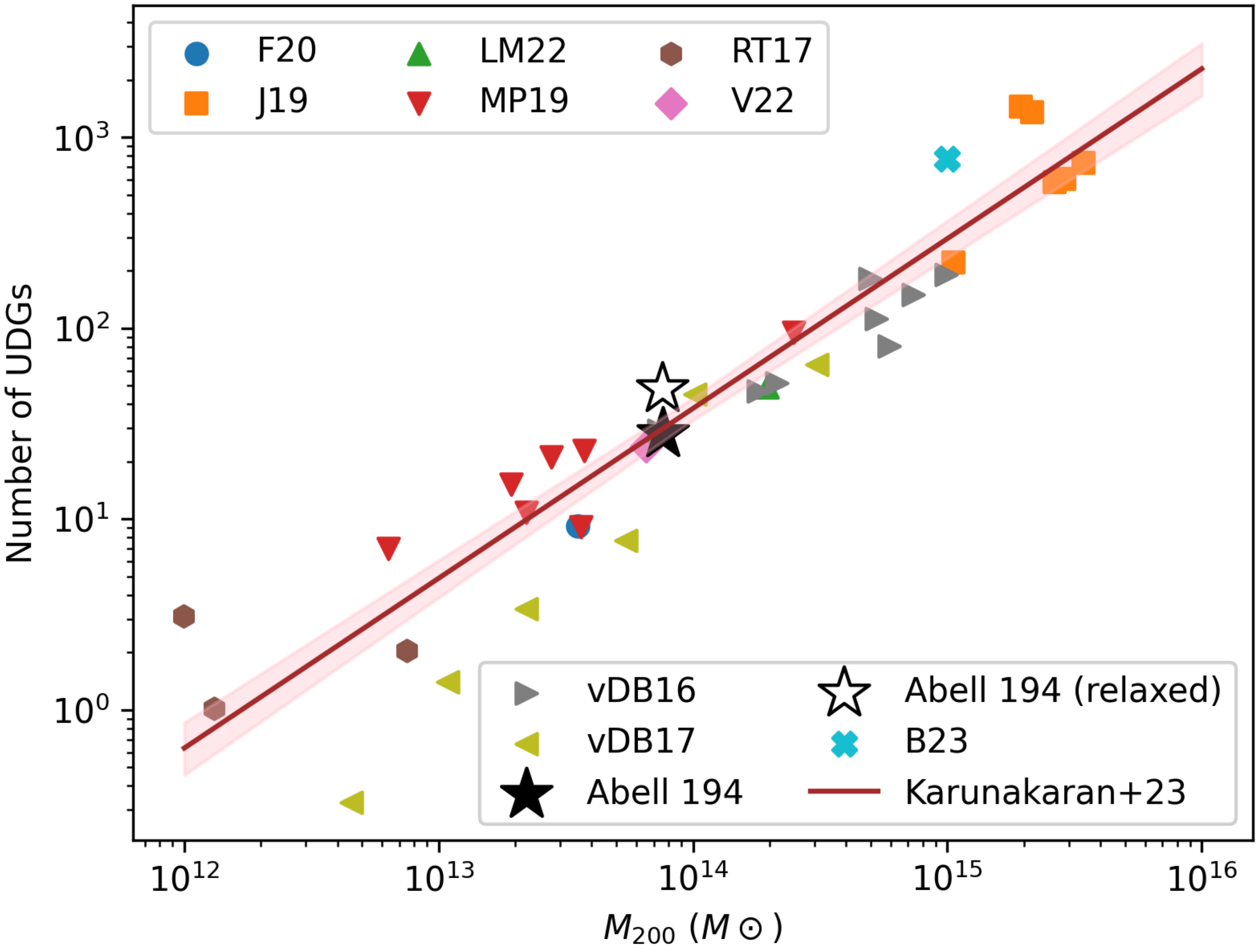
LSBGs in DES vs HSC

LSBG detected in HSC.



Same LSBG in DES.



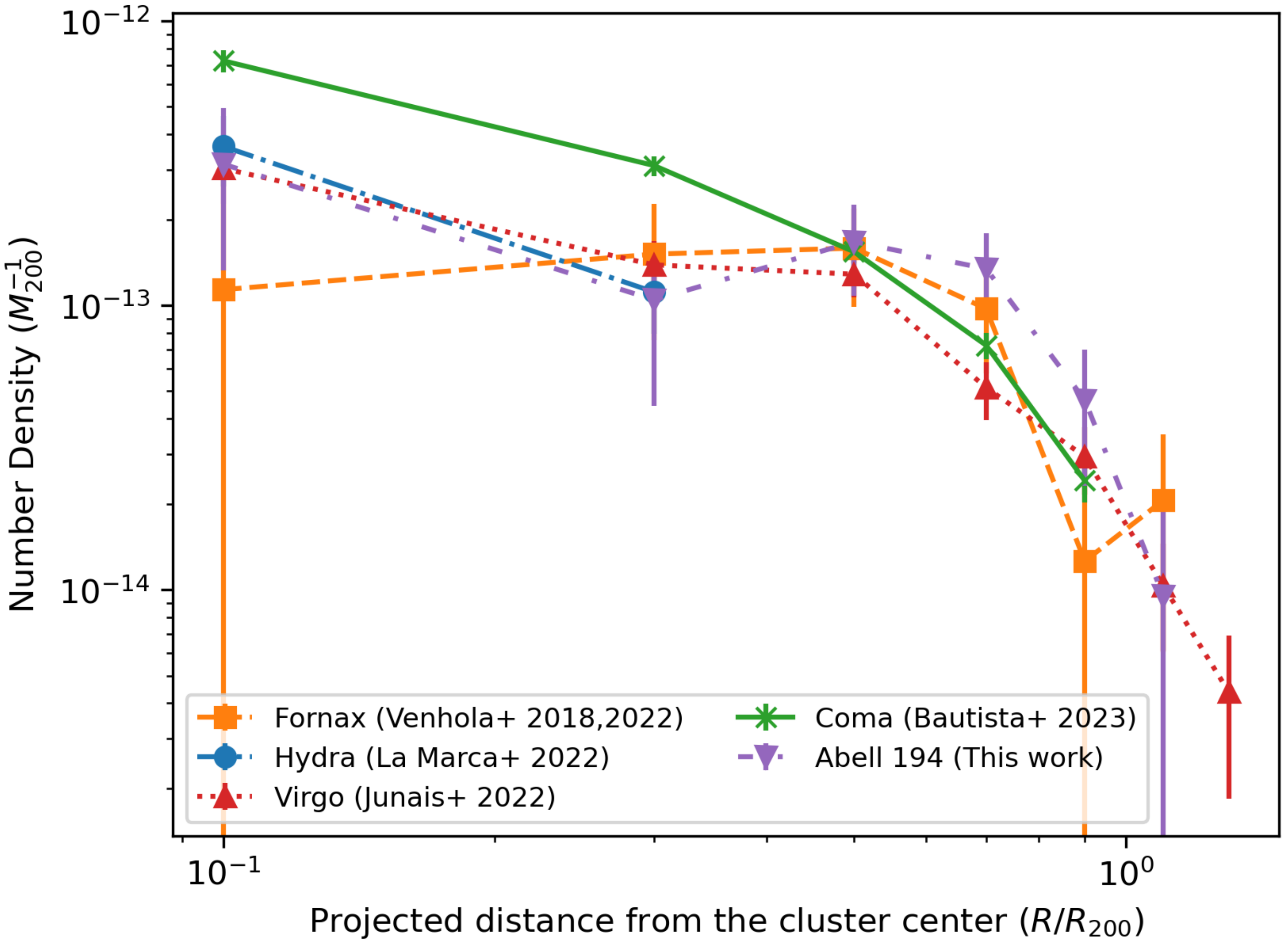


Abell 194 **relaxed** UDG sample is based on the mean surface brightness rather than the central surface brightness in *g*-band.

Scaling Relation of UDGs

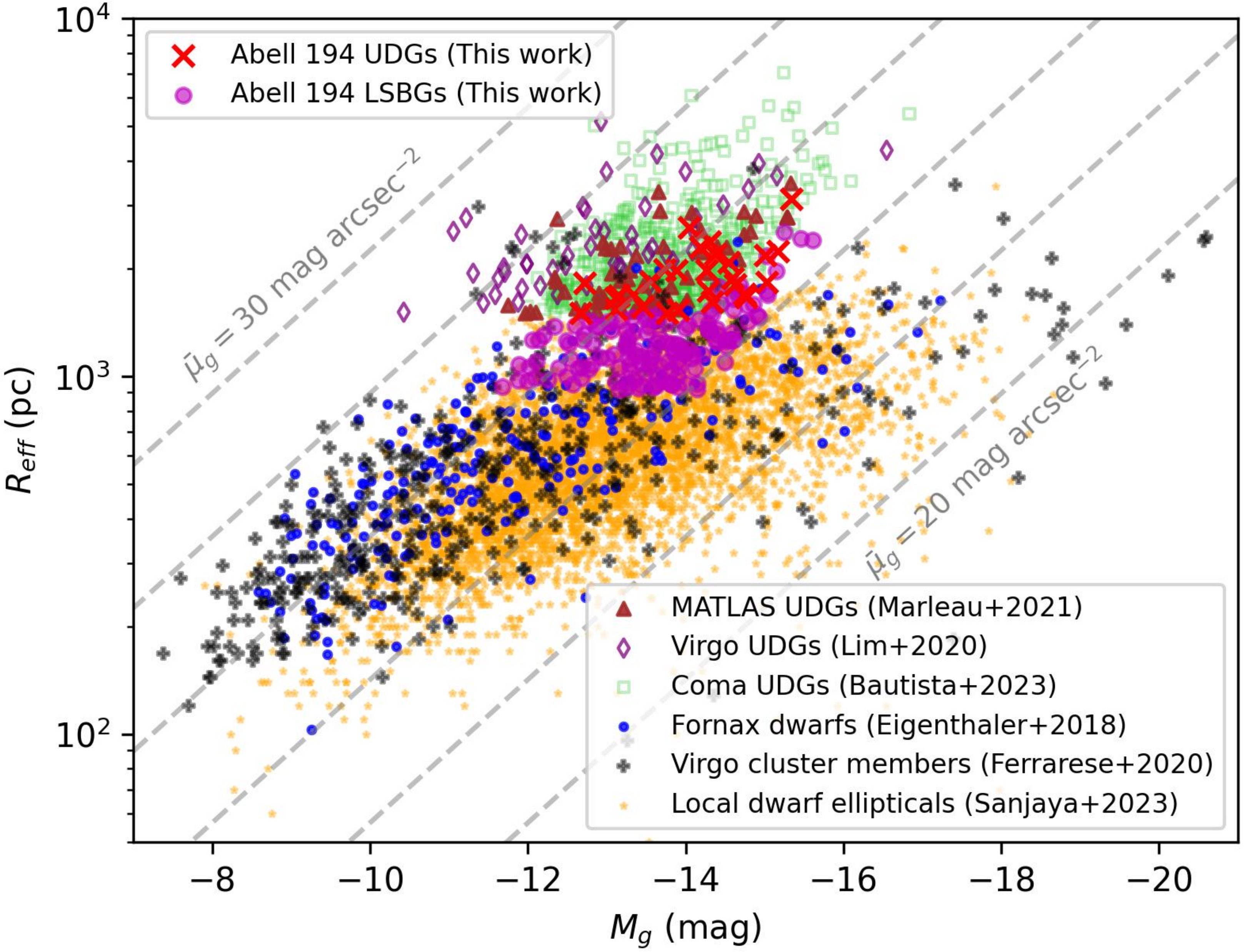
UDG number is proportional to the mass of the host cluster/group.

UDG Surface Number Density

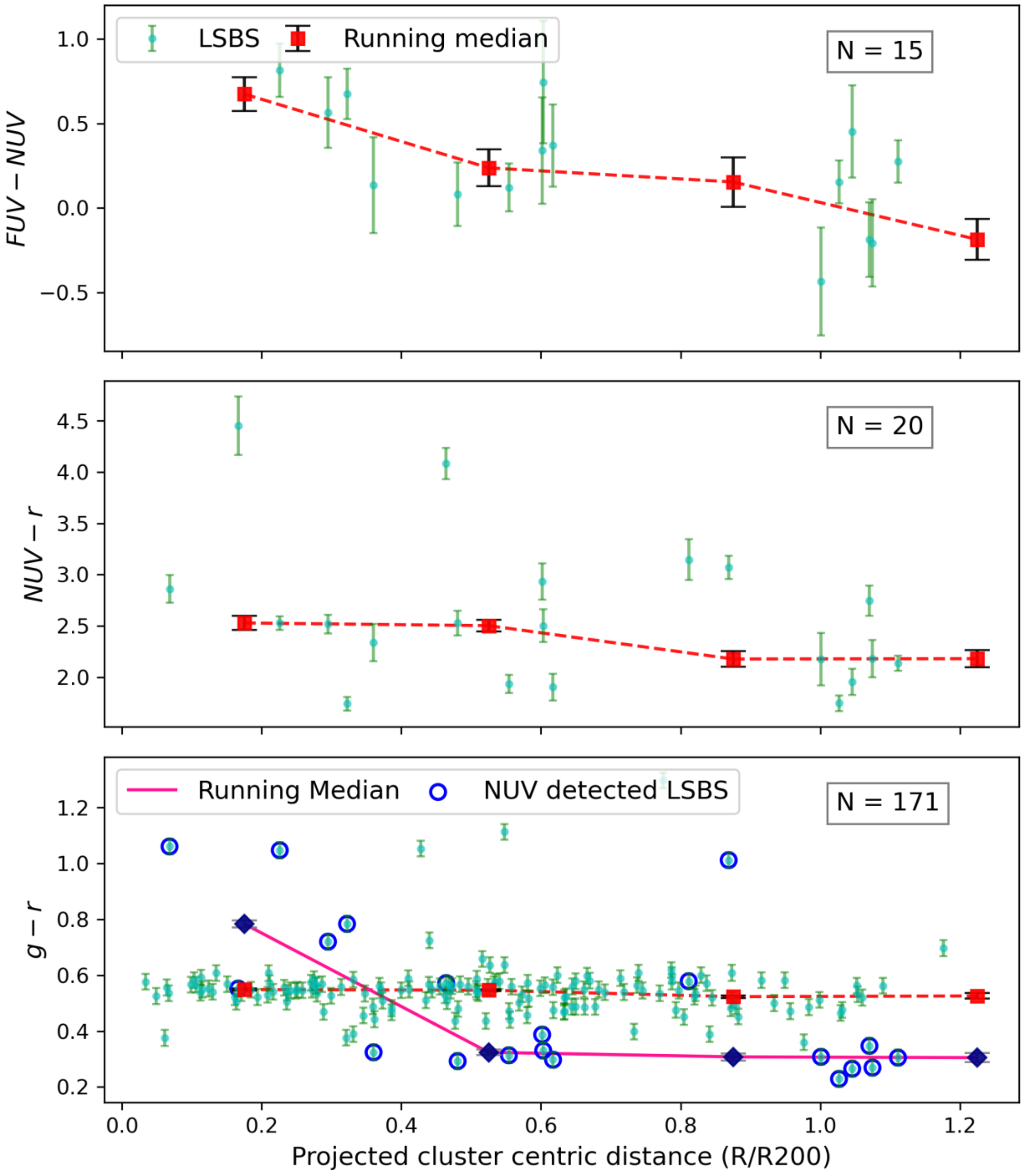


UDG number density is normalized by their cluster mass for comparison.

UDGs vs Dwarf Galaxies



Color as a function of Projected Cluster-Centric distance



- Visible trends in FUV and NUV colors detected with GALEX.
- LSBGs near the cluster center tend to be redder than LSBGs in the outskirts which is more prominent in **UV colors** than in optical color.

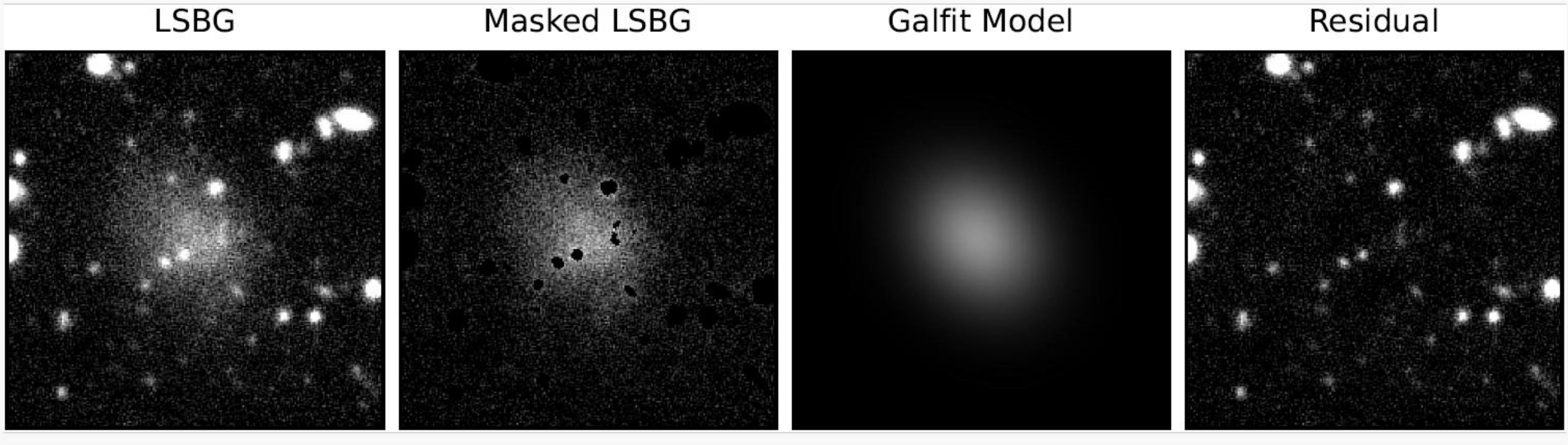
Summary

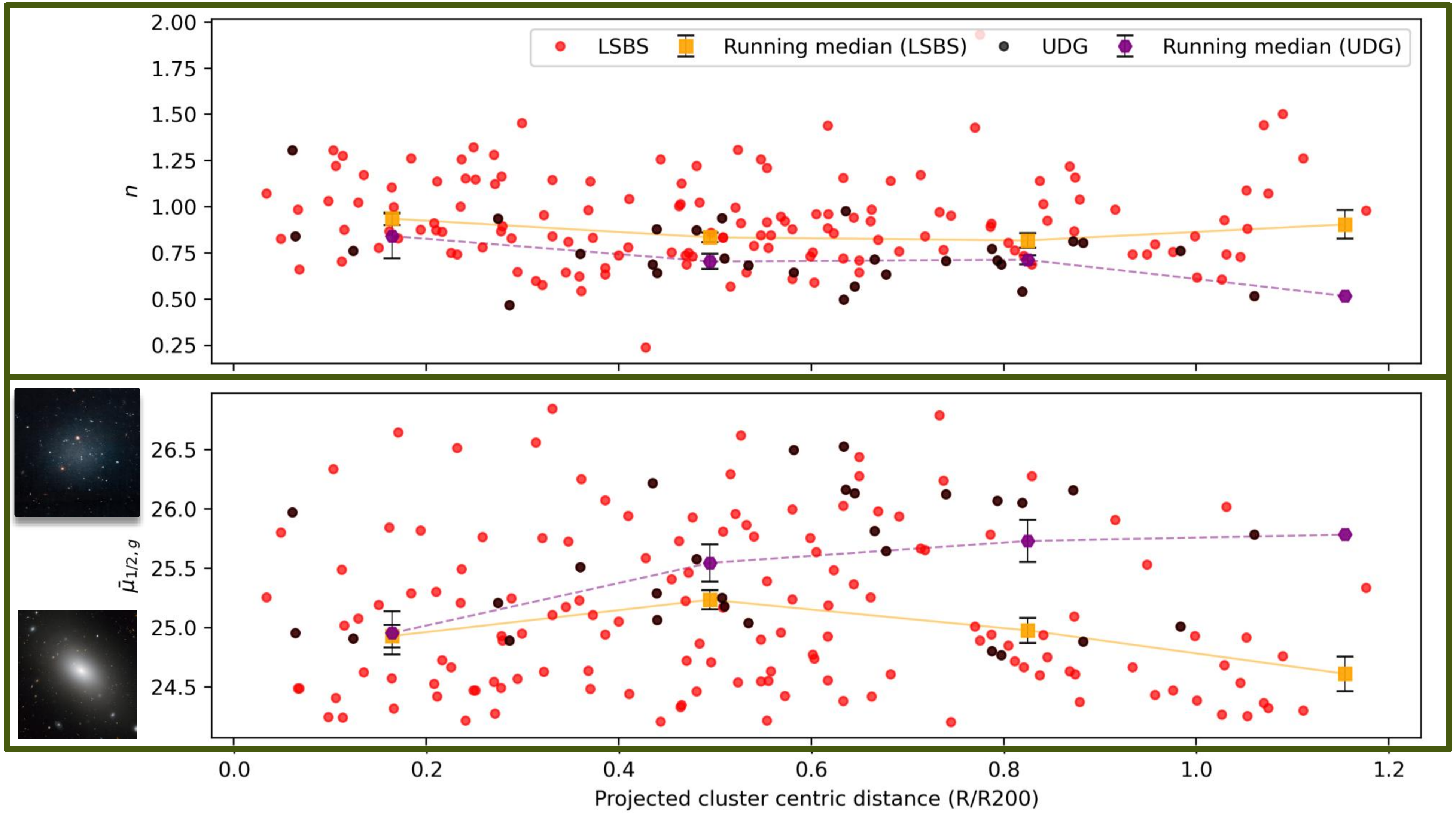
- We successfully implemented **transfer learning** which could applied to LSST.
- Transformers trained on DES data identify **93%** of LSBGs in the Abell 194 cluster from HSC data **without fine-tuning**.
- Future work: How much we can extrapolate (Deeper data, different PSF etc.)

- **171** LSBGs and **28** UDGs found in Abell 194, doubling known counts.
- New LSBGs are smaller and fainter. LSBGs near the cluster center are redder in UV color than those in the outskirts.
- UDG abundance scale with cluster mass and they might be an extension of dwarf galaxies.

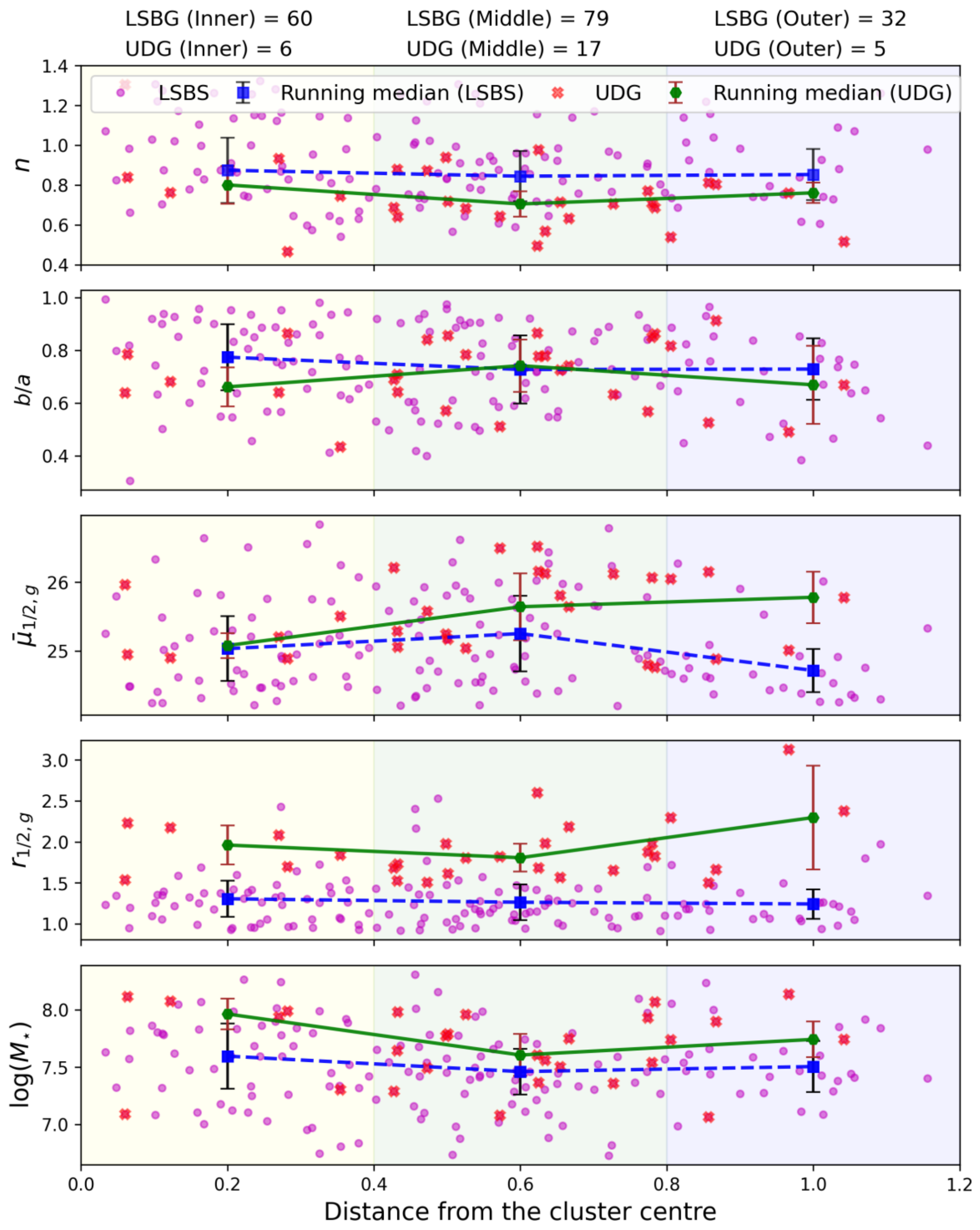

Thank You
QUESTIONS ?

Improved Masks!





Morphological Properties as a function of Projected Cluster-Centric distance



Morphological Properties as a function of Projected Cluster-Centric distance

Current Trend in Computer Vision

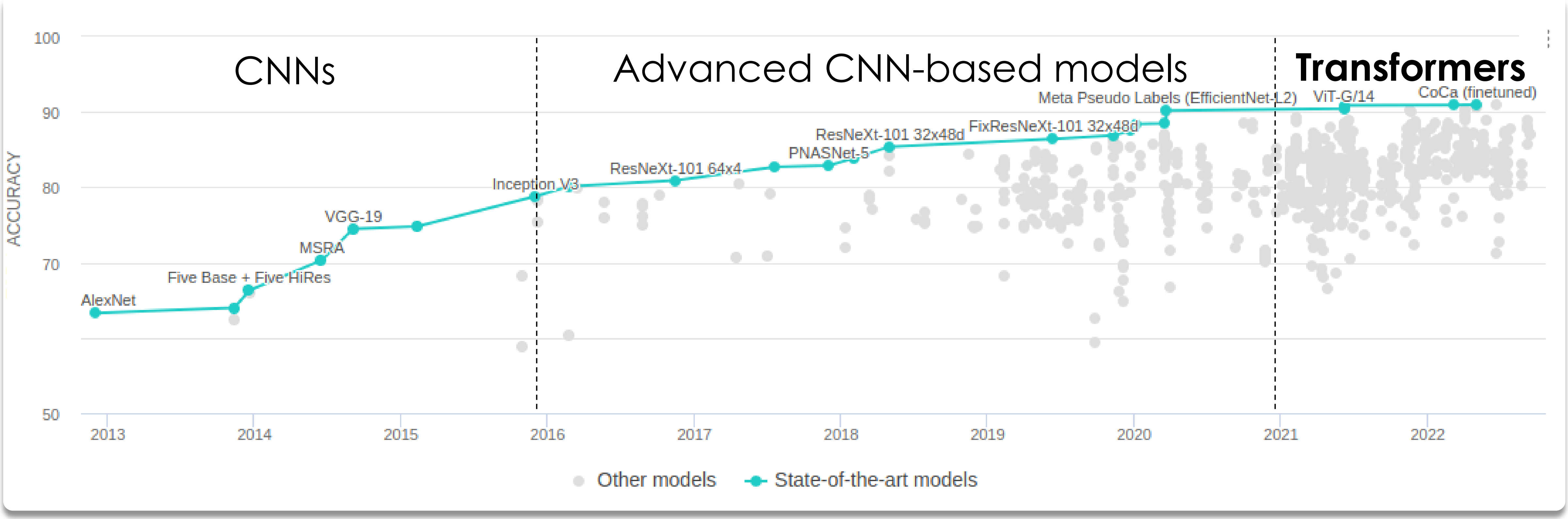
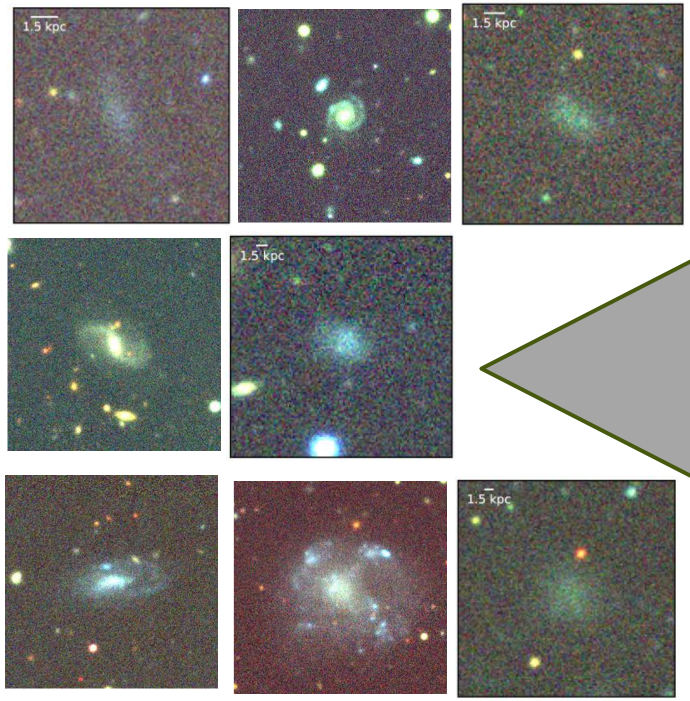


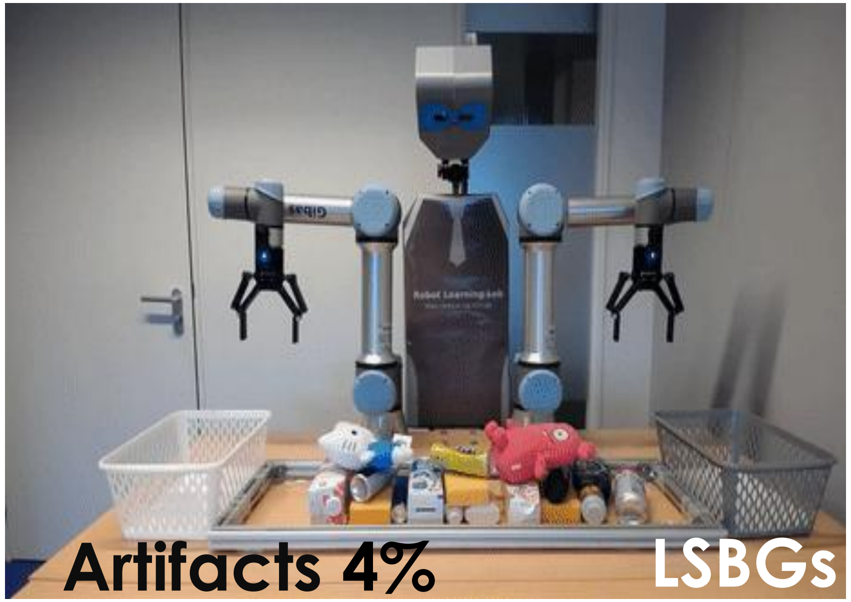
Image taken from https://paperswithcode.com/sota/image-classification-on-imagenet

LSBGs from DES DR1

419,782 faint objects selected from DES DR1



ML models applied to all the objects.



After Sérsic profile fitting & visual inspection **4083** new LSBGs.

Paper available at: 10.1051/0004-6361/20234764, Thuruthipilly, H., A&A (2024).

Transformers and Self-Attention

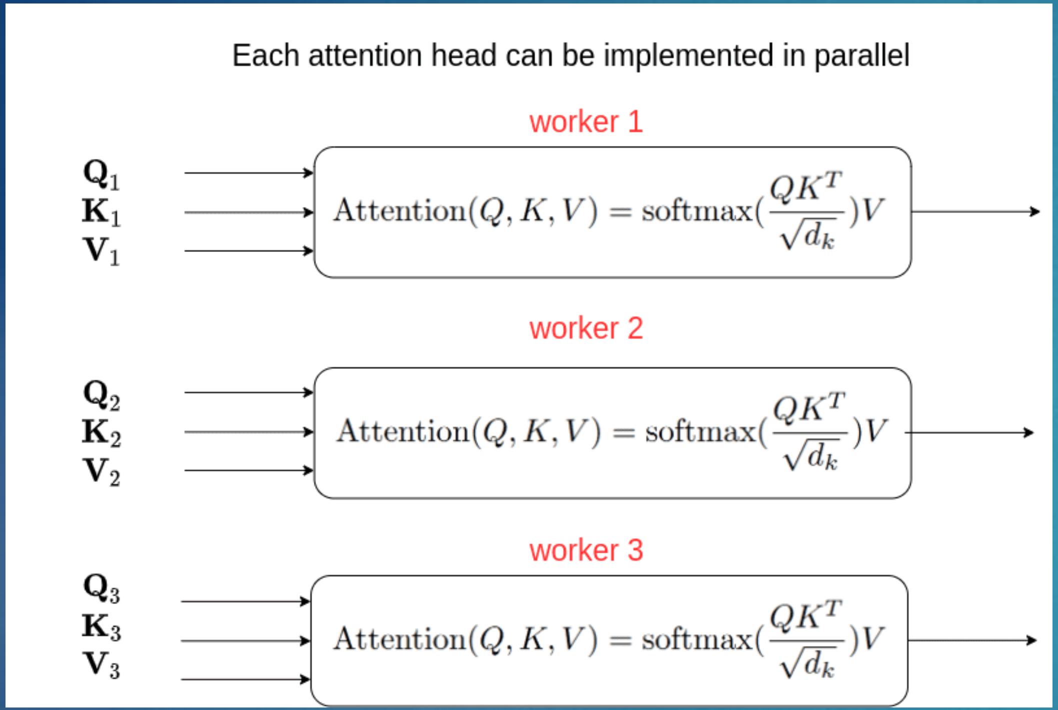
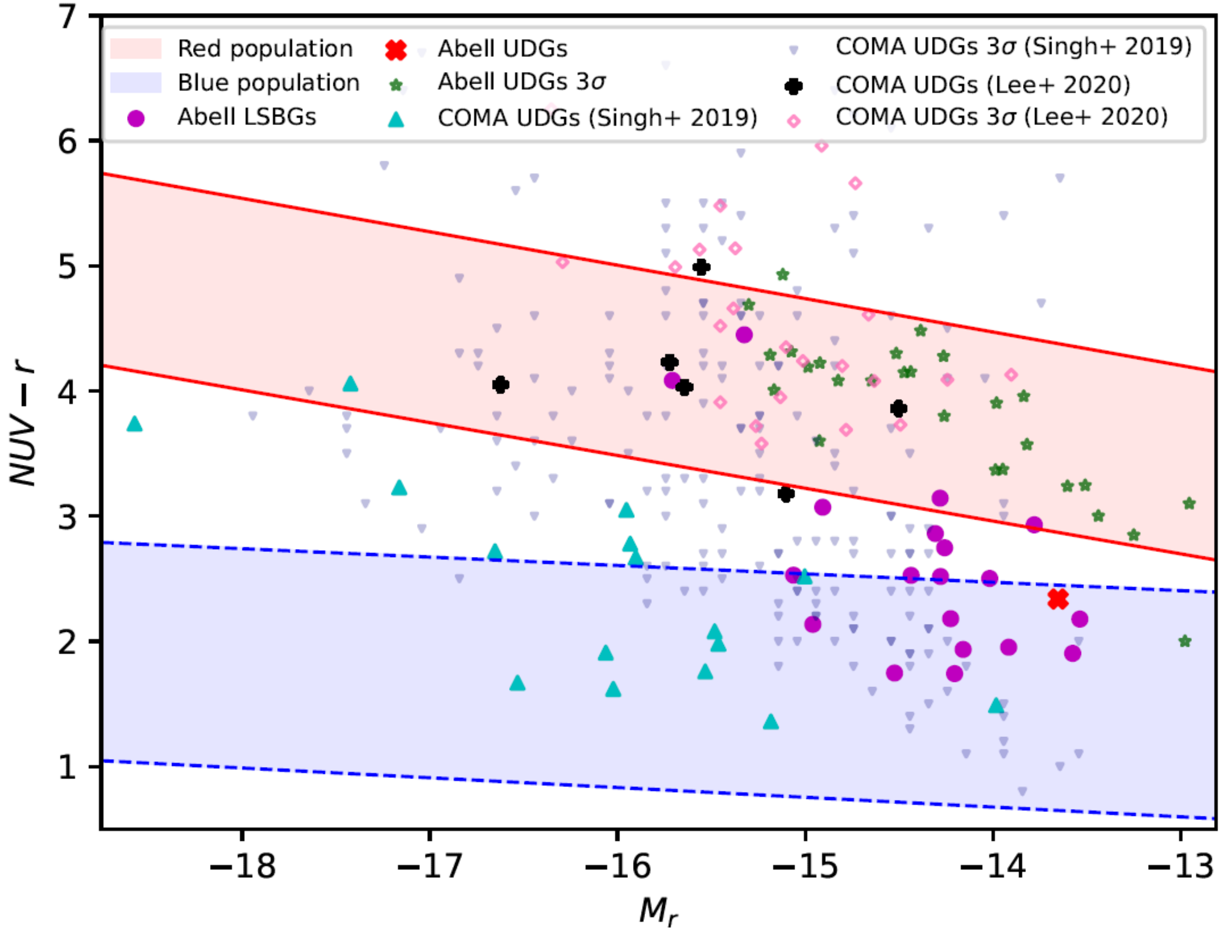
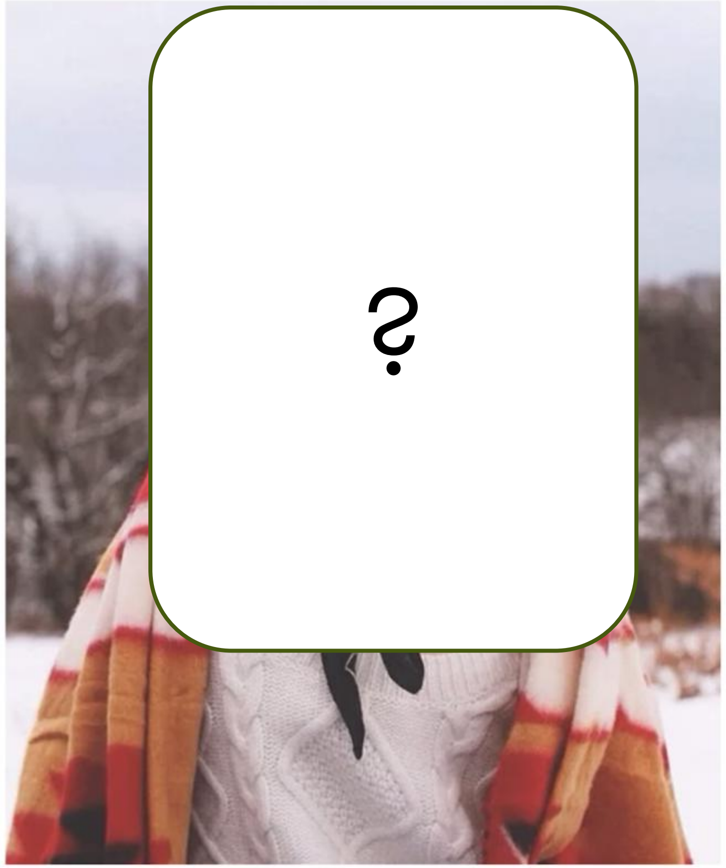


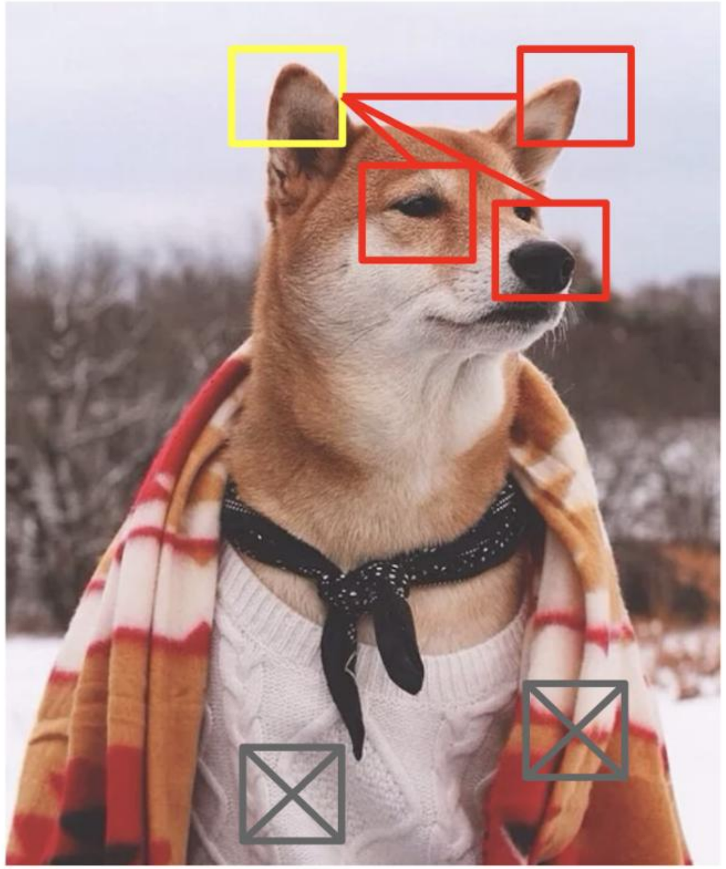
IMAGE CREDITS :HTTPS://THEAISUMMER.COM/SELF-ATTENTION

Color-Magnitude Diagram



Attention in Action





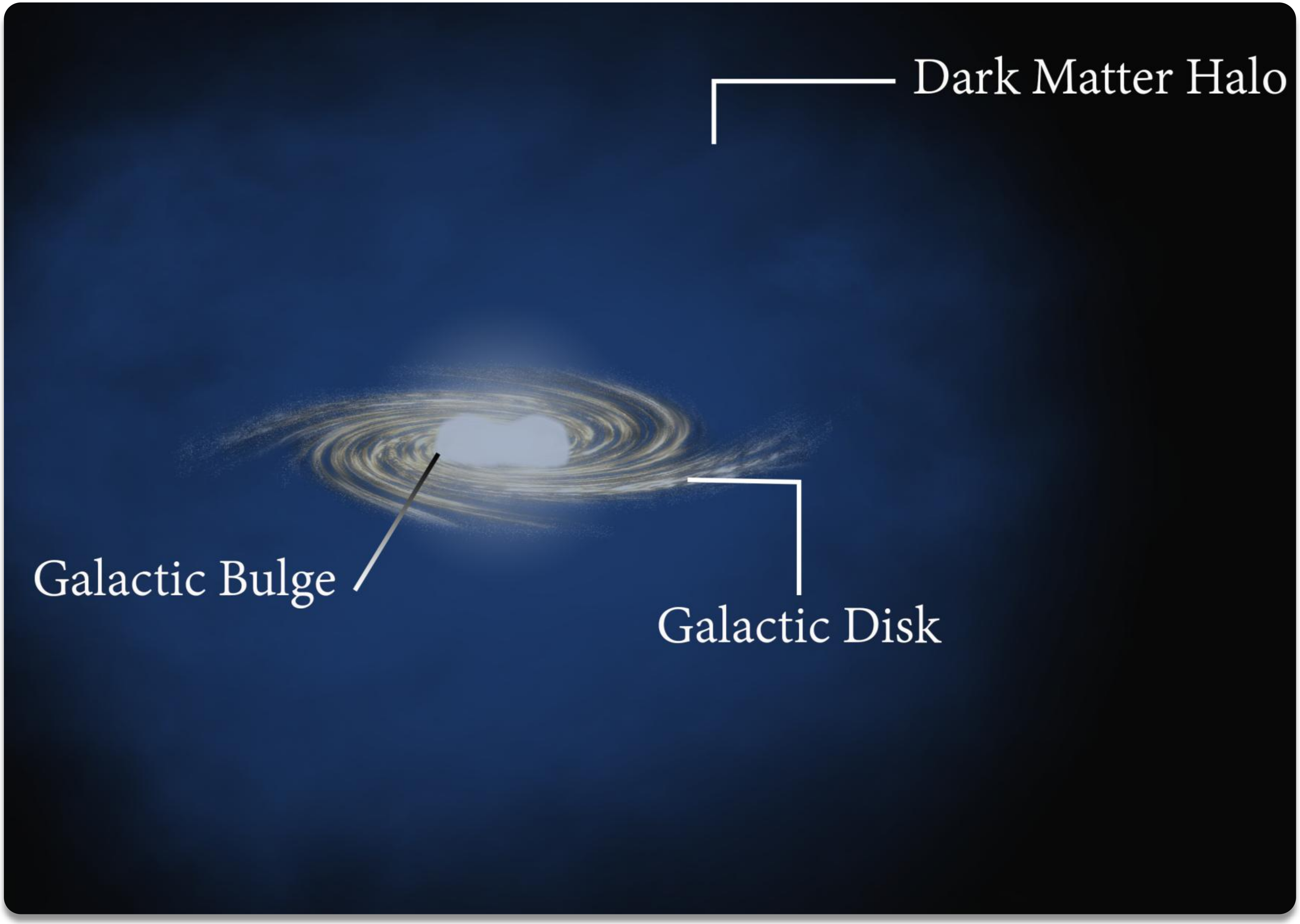


Image Credit: L Jaramillo and O Macias, Virginia Tech

LSBGs provides a robust platform to test different dark matter models and cosmological evolution scenarios.