Exploring the Low Surface Brightness Galaxies in Abell 194 with Transfer Learning

Outline

01

Introduction to galaxies. What are LSBG and the Importance of LSBGs

02

Introduction to computer vision: Transformers and transfer learning.

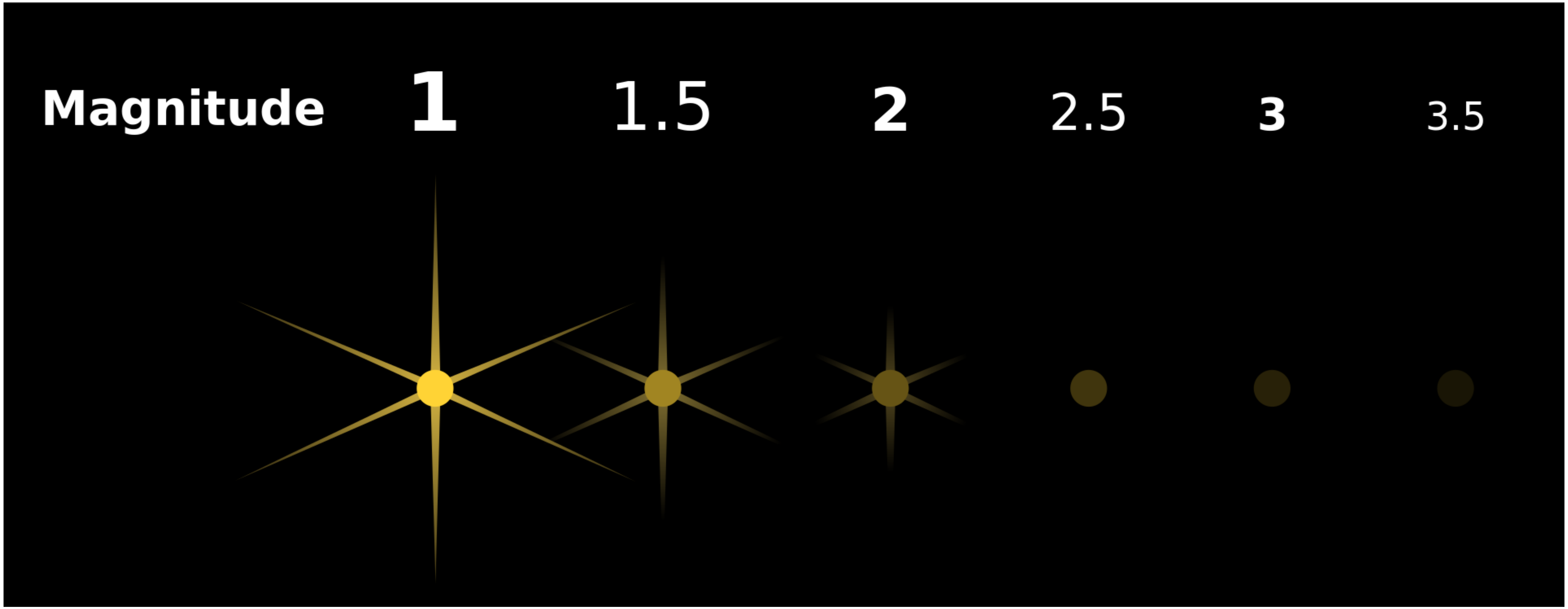
03

Search for LSBGs in Abell 194 cluster and their properties.

Introduction to Astronomy

PART 1

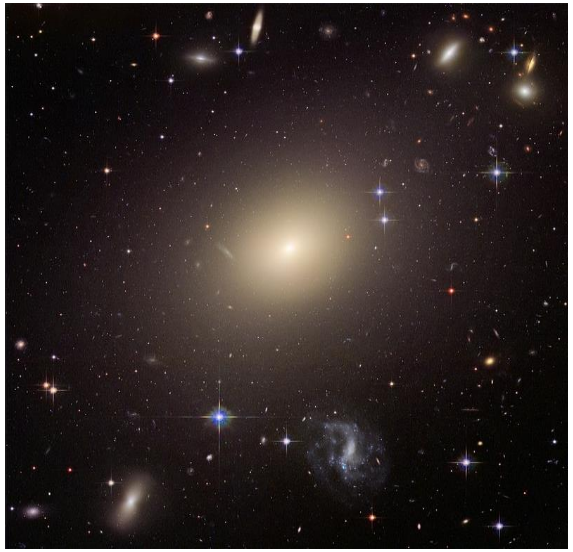
Magnitude



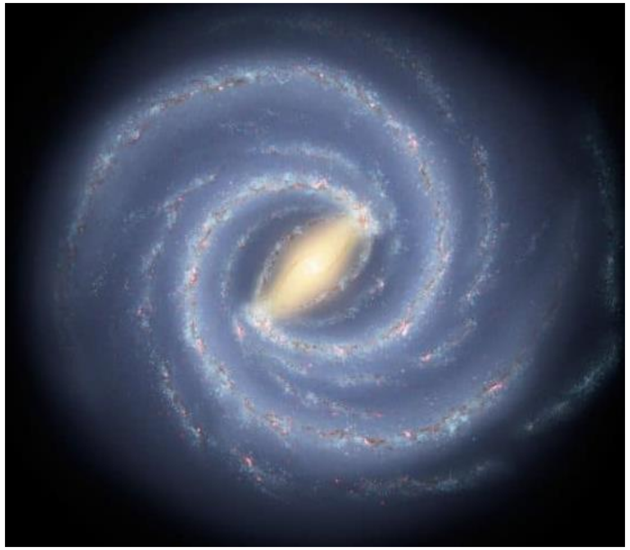
Fainter the object higher the value in magnitude and in surface brightness.

Sérsic Profile of Galaxies

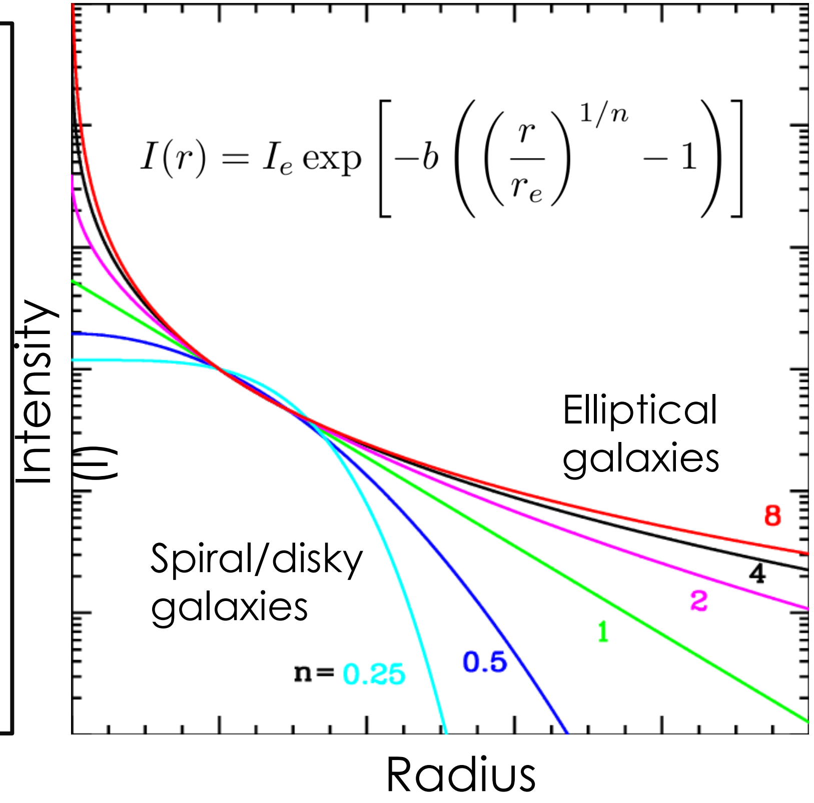
The Sérsic profile is a mathematical function that describes how the surface brightness of a galaxy varies with distance r from its centre. We use **Galfit** package in our work to fit the The Sérsic profile.



n = 4 is a rough approximation of ordinary elliptical galaxies.

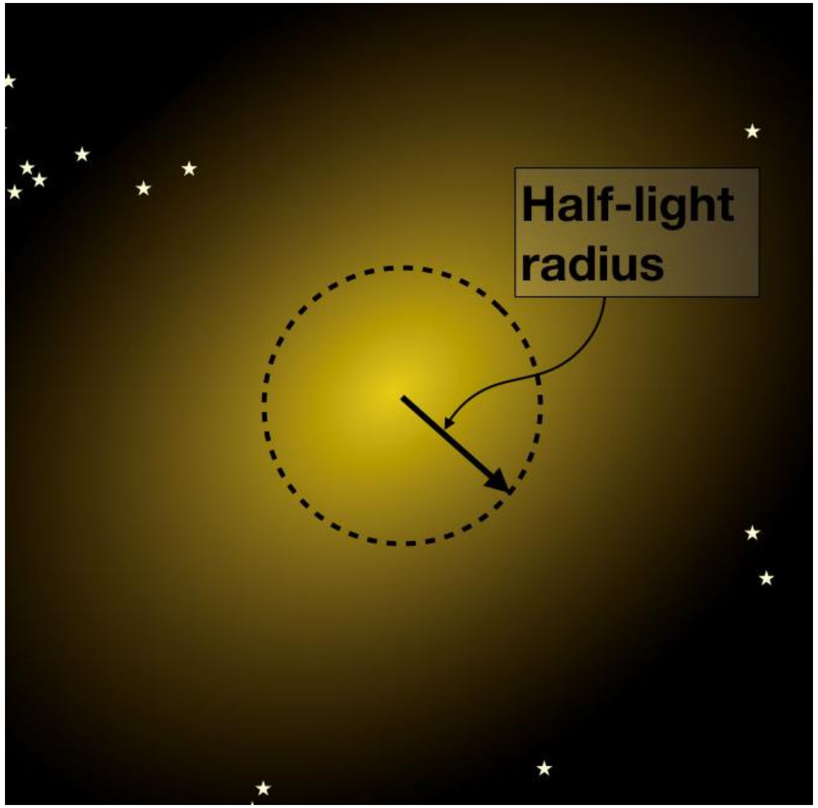


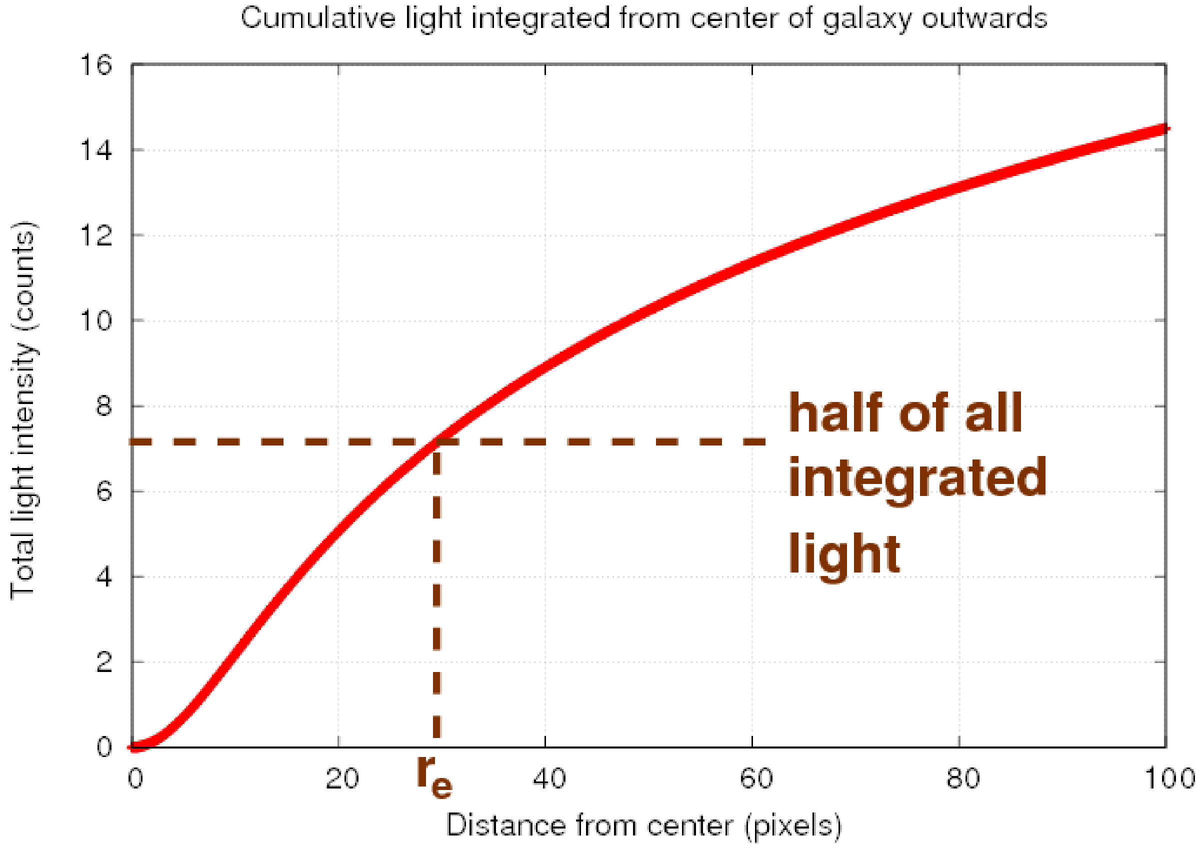
n = 1 is a good approximation of spiral galaxy or disk galaxy.



Half-light Radius

The half-light (or 'effective') radius is the radius from within which half of the galaxy light is contained.





Galaxy Cluster

A galaxy cluster, is a structure that consists of hundreds to thousands of galaxies that are bound together by gravity, with typical masses ranging from 10^{14} to 10^{15} solar masses.

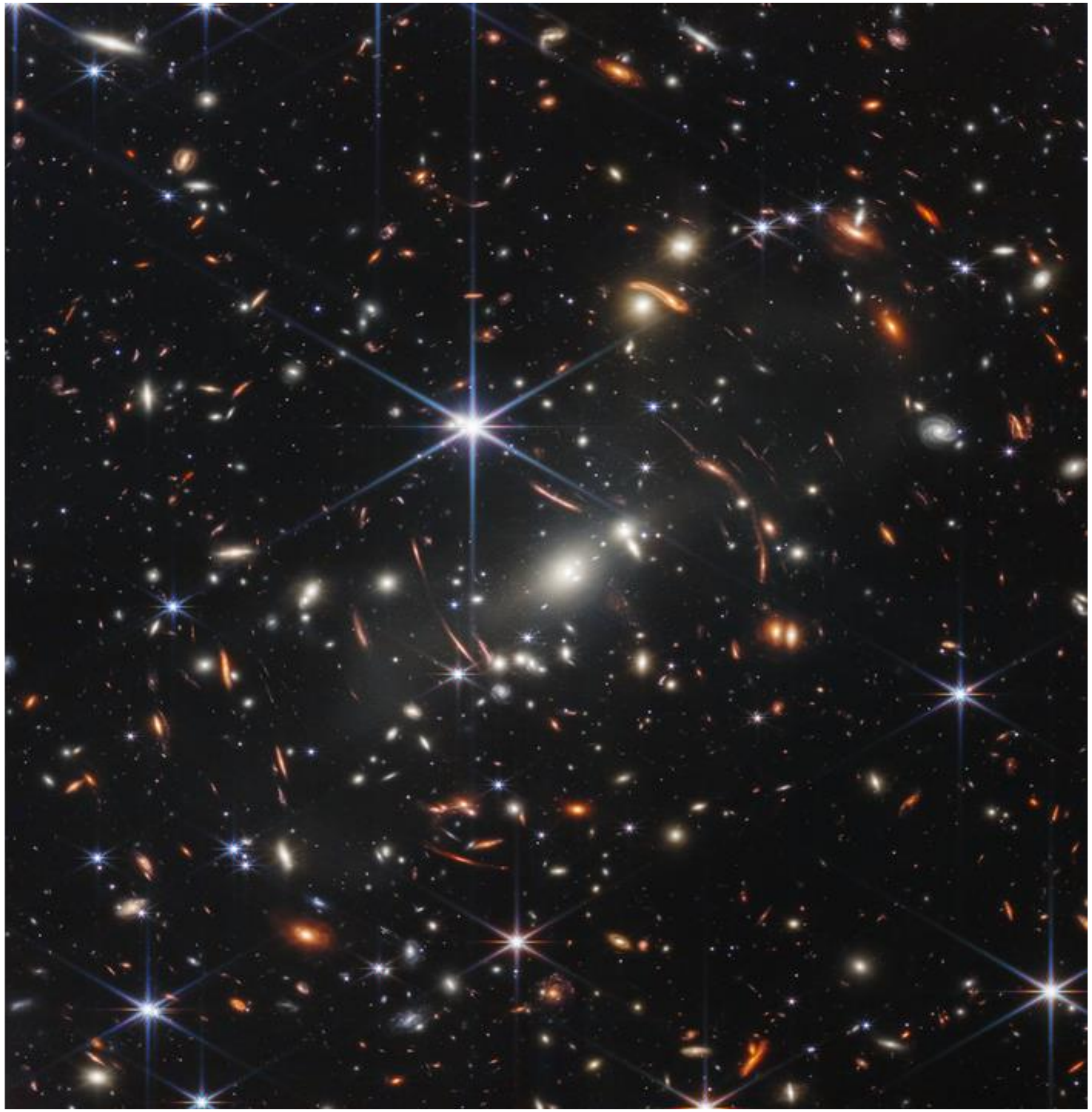
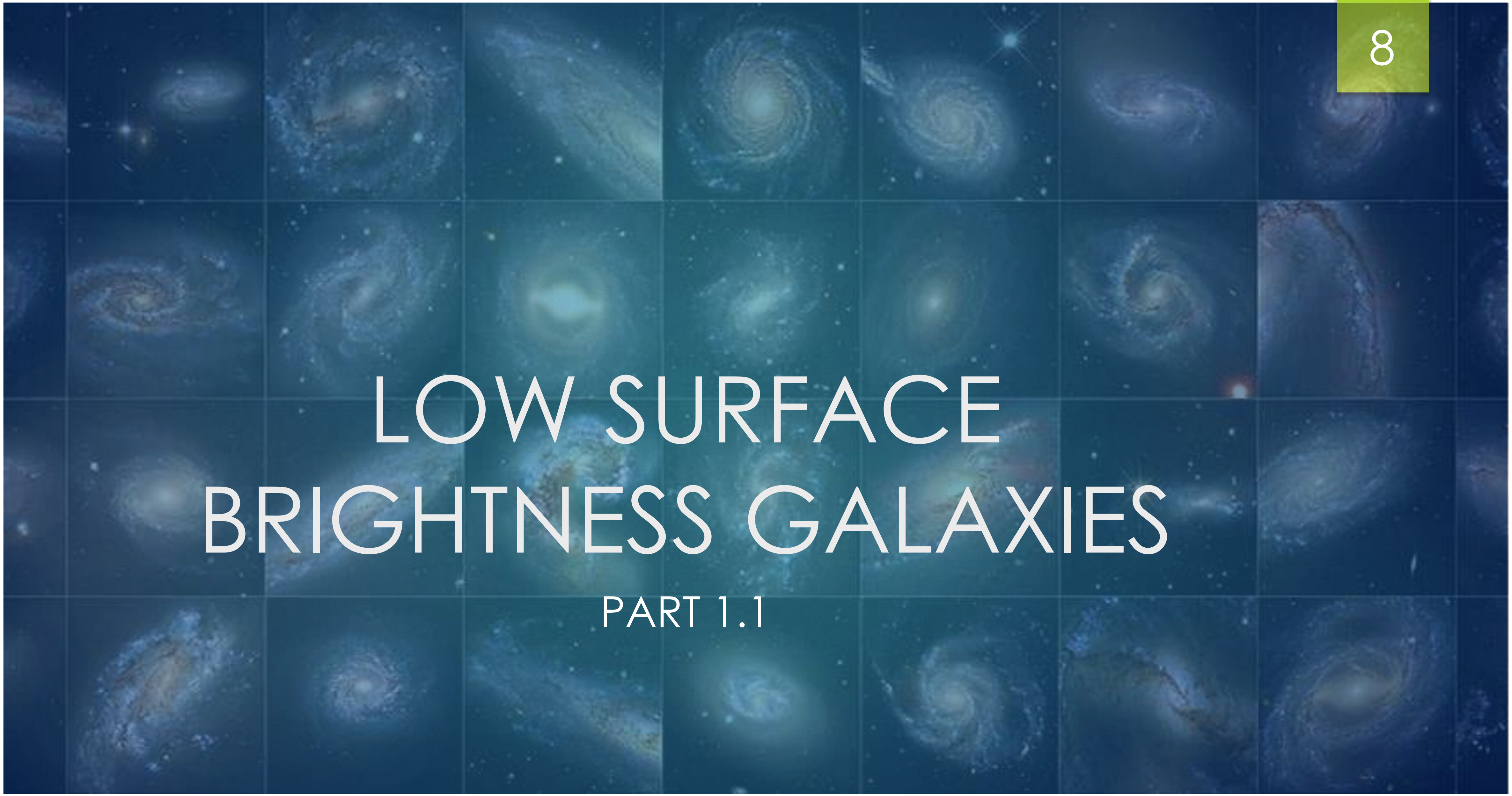


Image of galaxy cluster SMACS 0723 taken with JWST.

Image Credits: https://webbtelescope.org/contents/media/images/2022/038/01G7JGTH21B5GN9VCYAHBXKSD1



LOW SURFACE BRIGHTNESS GALAXIES

PART 1.1

Low-surface brightness galaxies (LSBGs) are galaxies that are fainter than the night sky.

Image of UGC 477 taken by NASA/ESA Hubble Space Telescope. Image taken from: http://www.spacetelescope.org/images/potw1614a/

What is an LSBG ?

In our work we define all the galaxies with **$\mu(g) > 24.2$ mag/arcsec^2 and size 2.5"** as LSBGs.

Examples of LSBGs from Dark Energy Survey (DES)

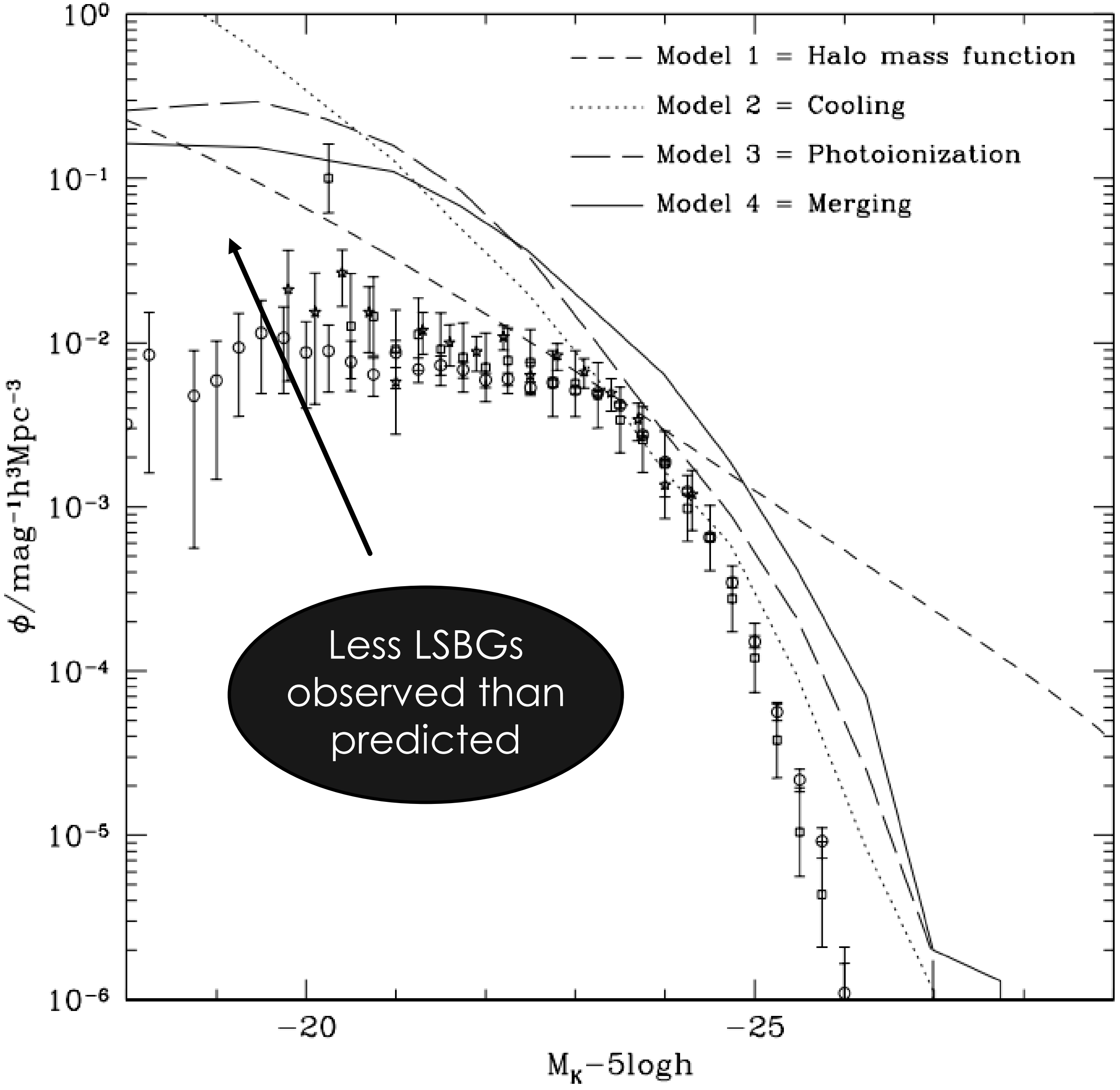
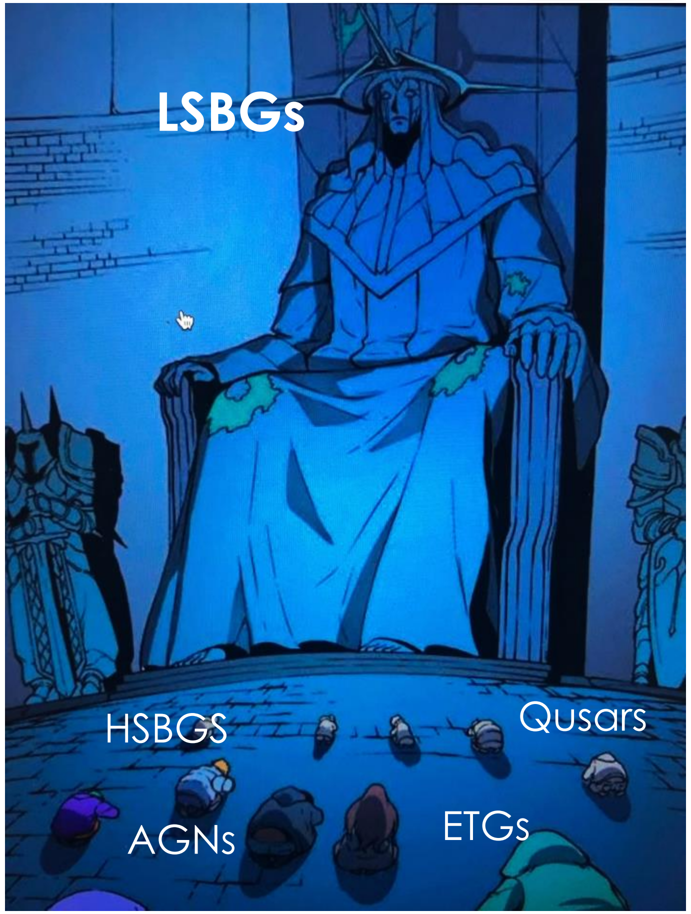


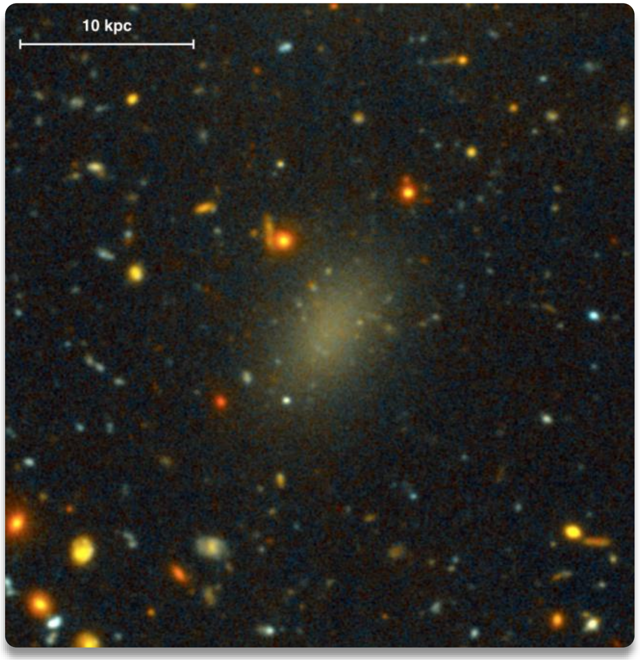
Image taken from A. J. Benson et al. (2003).



Low surface brightness galaxies may account for up to **50%** of the total population of galaxies.

Ultra-diffuse Galaxies

- Ultra diffuse galaxy (UDG), are extended LSBGs with effective radii r > 1.5 kpc and central surface brightness $\mu_0\,(g) < 24.0\, mag\ arsec^{-2}$.
- This class of LSBGs includes both extremes of dark matter content and are in contradiction with the standard λCDM paradigm of cosmology.



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

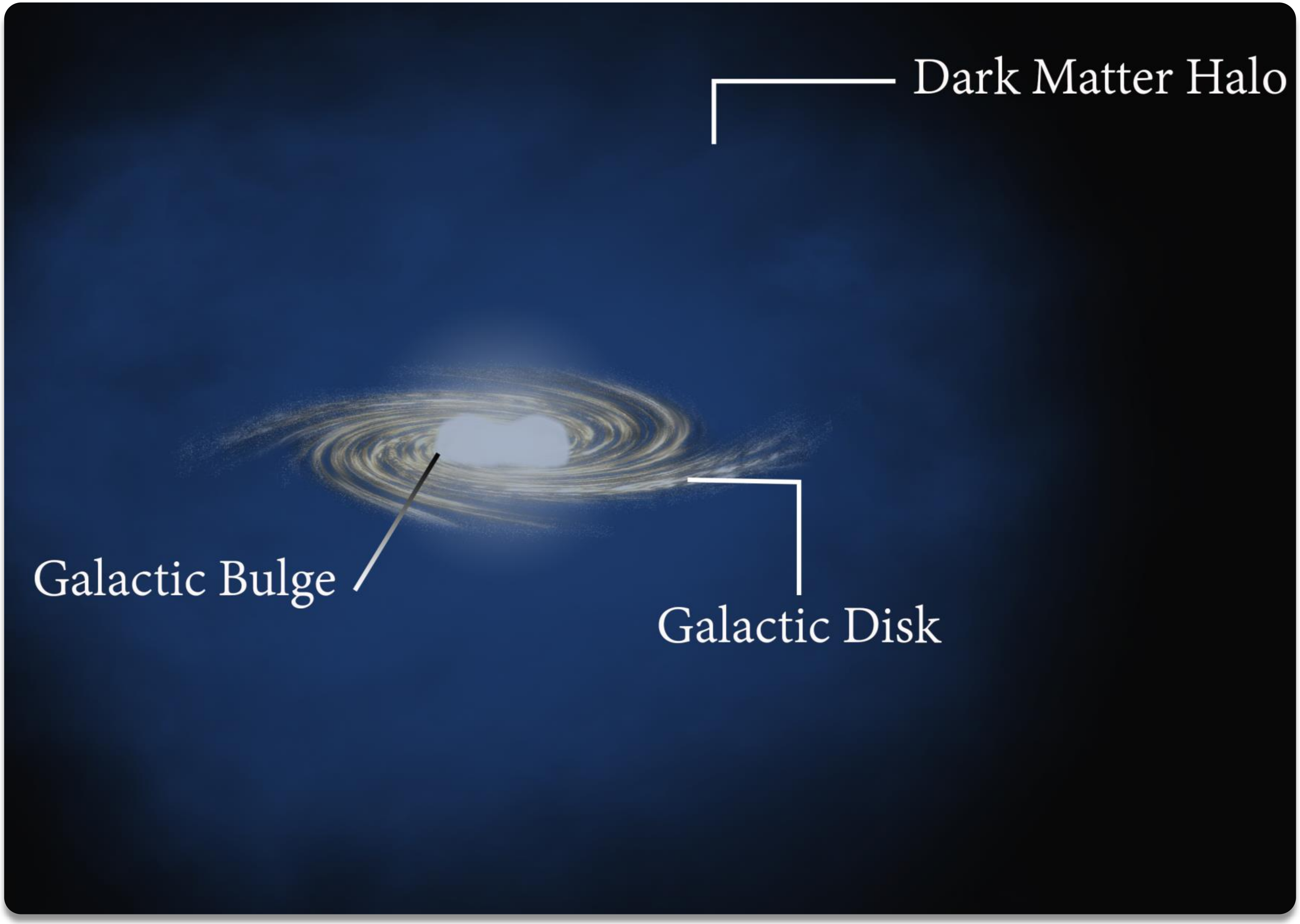


Image Credit: L Jaramillo and O Macias, Virginia Tech

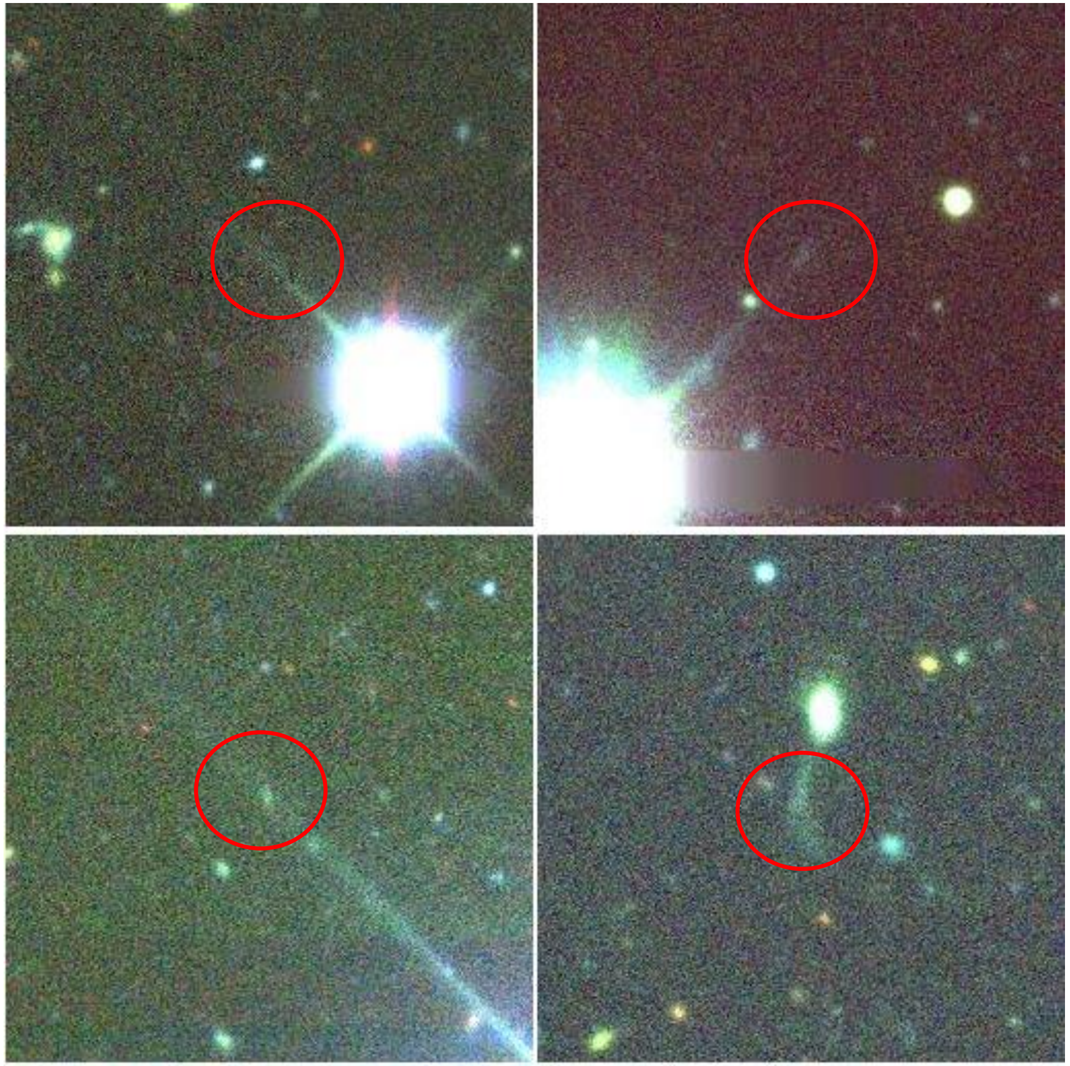
LSBGs provides a robust platform to test different dark matter models and cosmological evolution scenarios.

Why it is hard to detect LSBGs : Artefacts

Surveys not deep enough.

Eliminating the sky background to detect the LSBGs.

Faint, compact objects blended in the diffuse light from nearby bright stars or giant elliptical galaxies.



Dark Energy Survey

Surveyed around ~ 5000 deg^2 of the sky.

Tanoglidis et al. (2021) identified **23,790** LSBGs from DES with a success rate of ~**50** %.

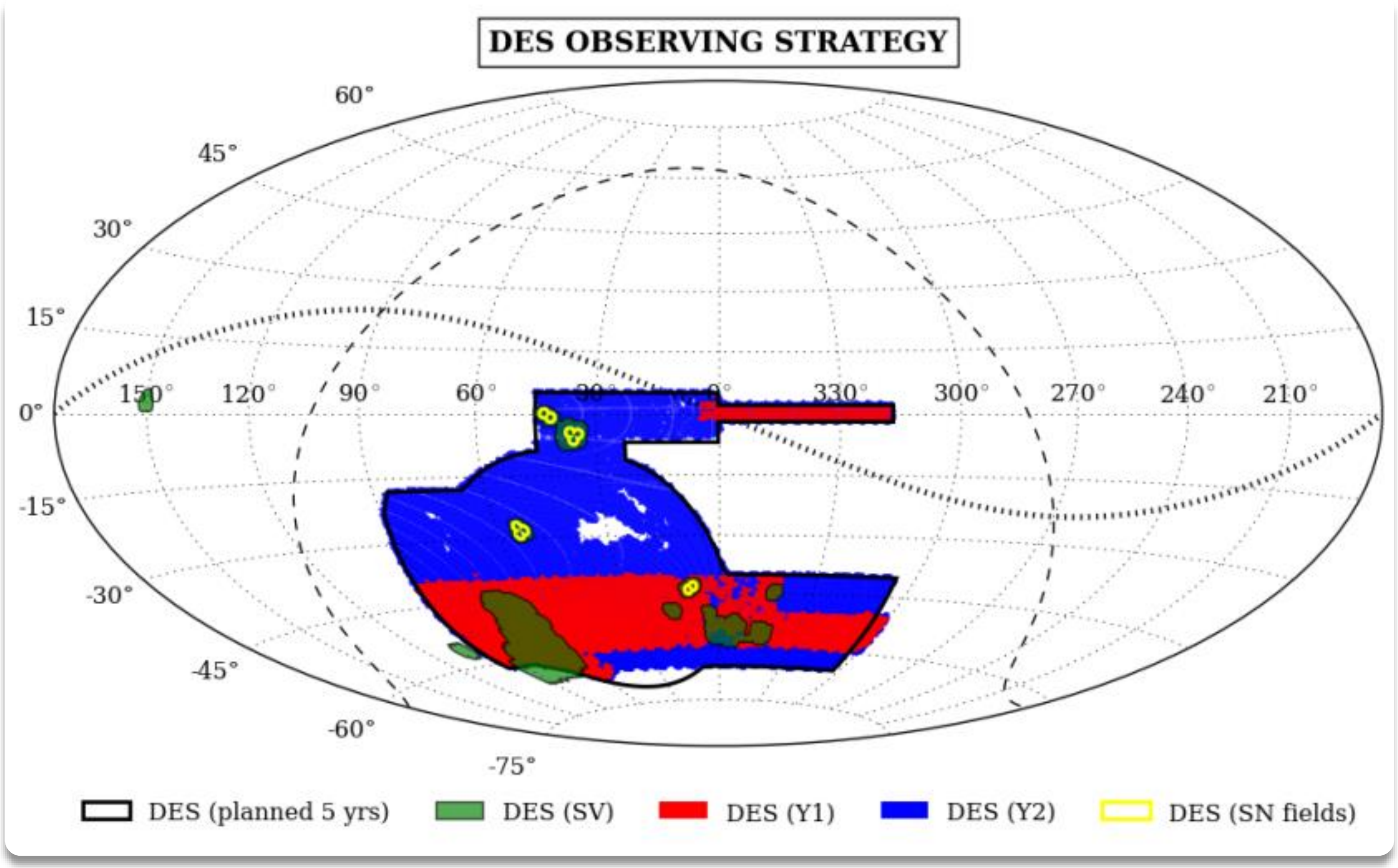


Image taken from J. H. O'Donnell et al (2021)

LSST and EUCLID

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

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

NCBJ is also an active member of the LSST collaboration.

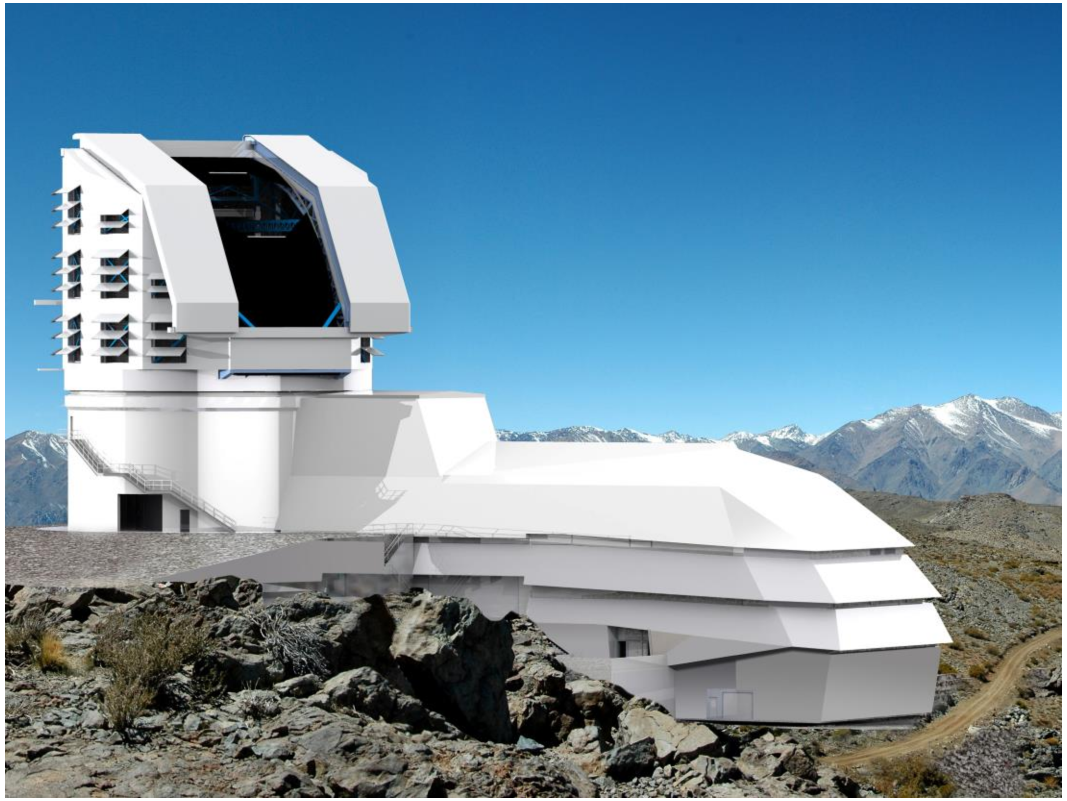
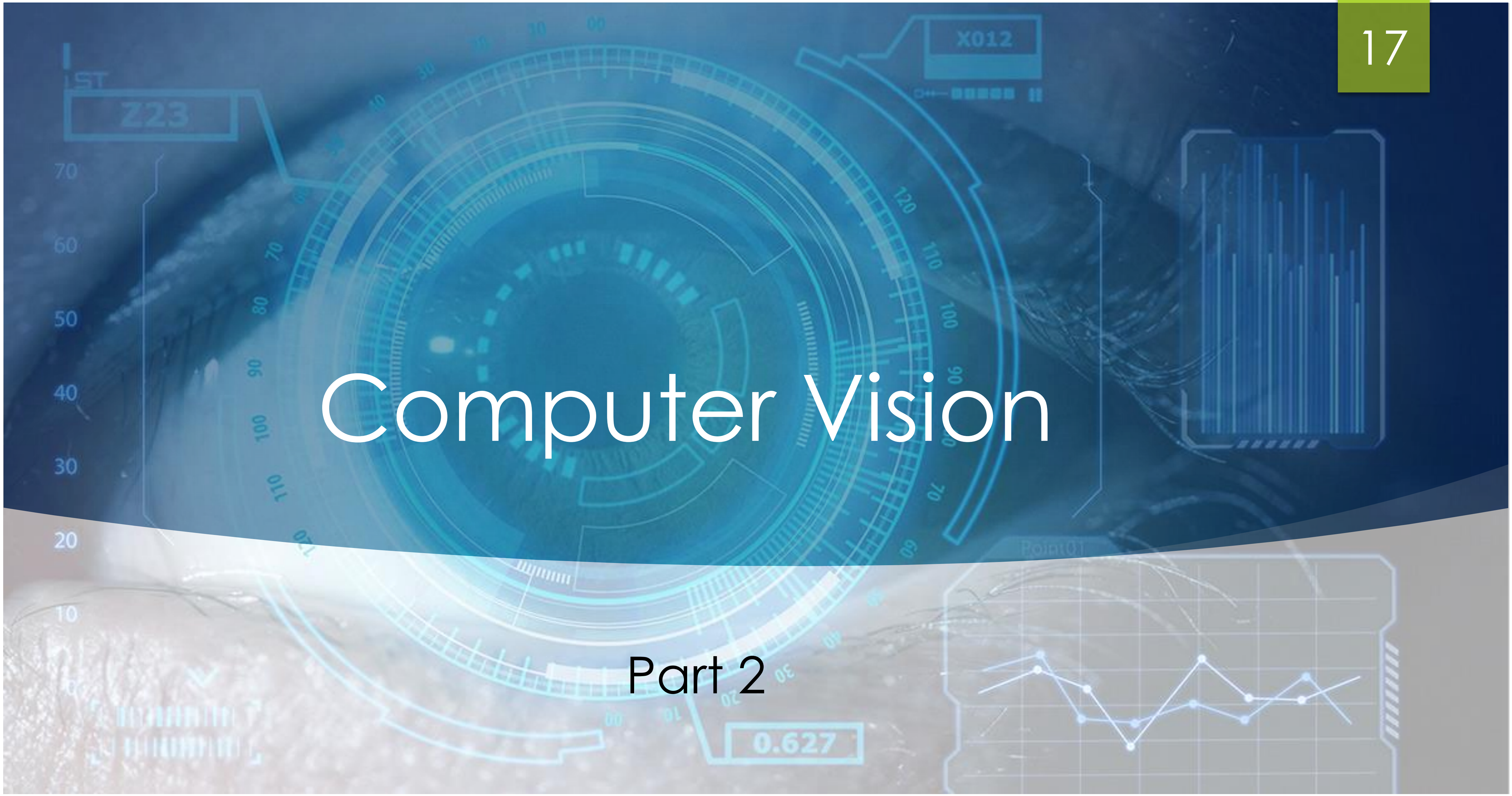


Image taken from https://astronomy.com/news/2017/12/the-lsst-and-big-data-science



Computer Vision

Part 2

Current Trend in Computer Vision

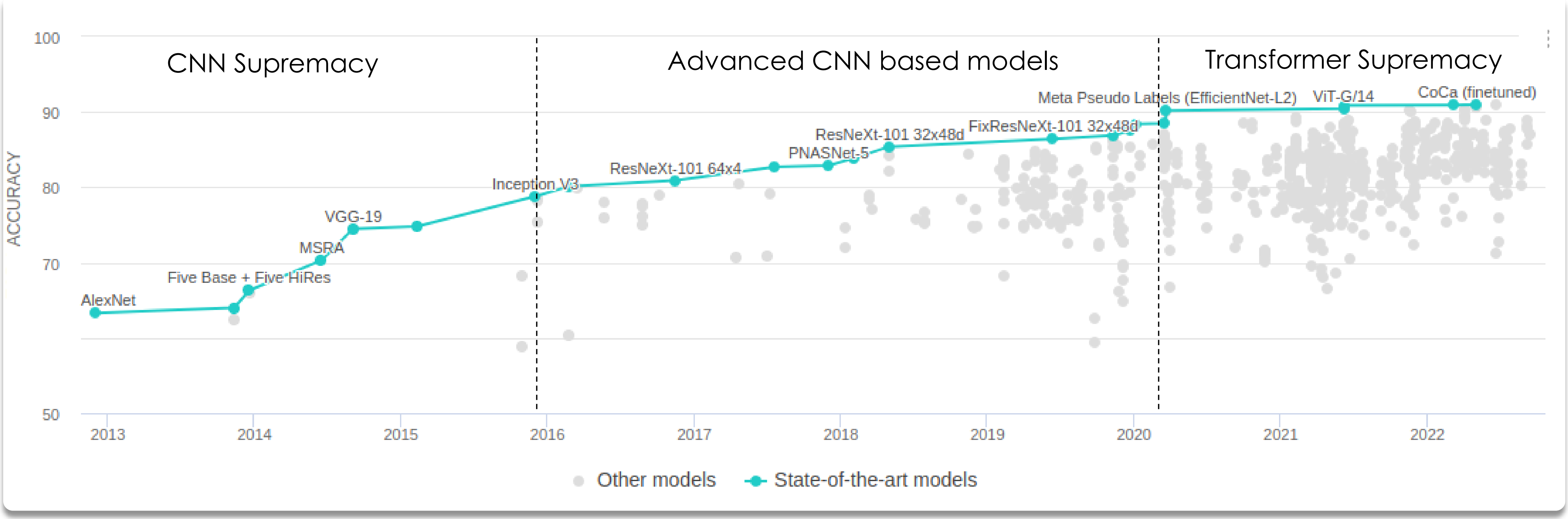


Image taken from https://paperswithcode.com/sota/image-classification-on-imagenet

LSBG Detection Transformer (LSBG DETR)

We can assume that the Encoder model works in 3 phases.

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

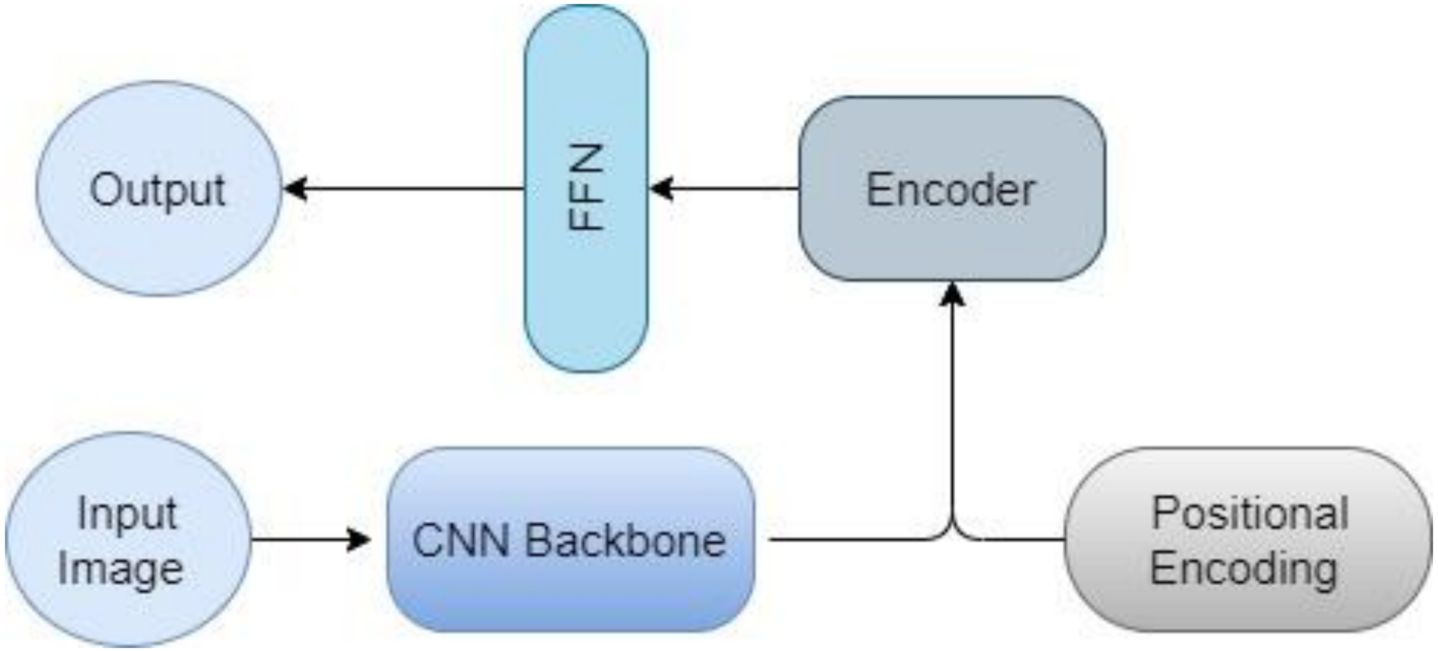


Image taken from Thuruthipilly et al. (2022)

LSBG Vision Transformer

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

- Flattened patches are processed through multiple transformer layers, and make predictions.

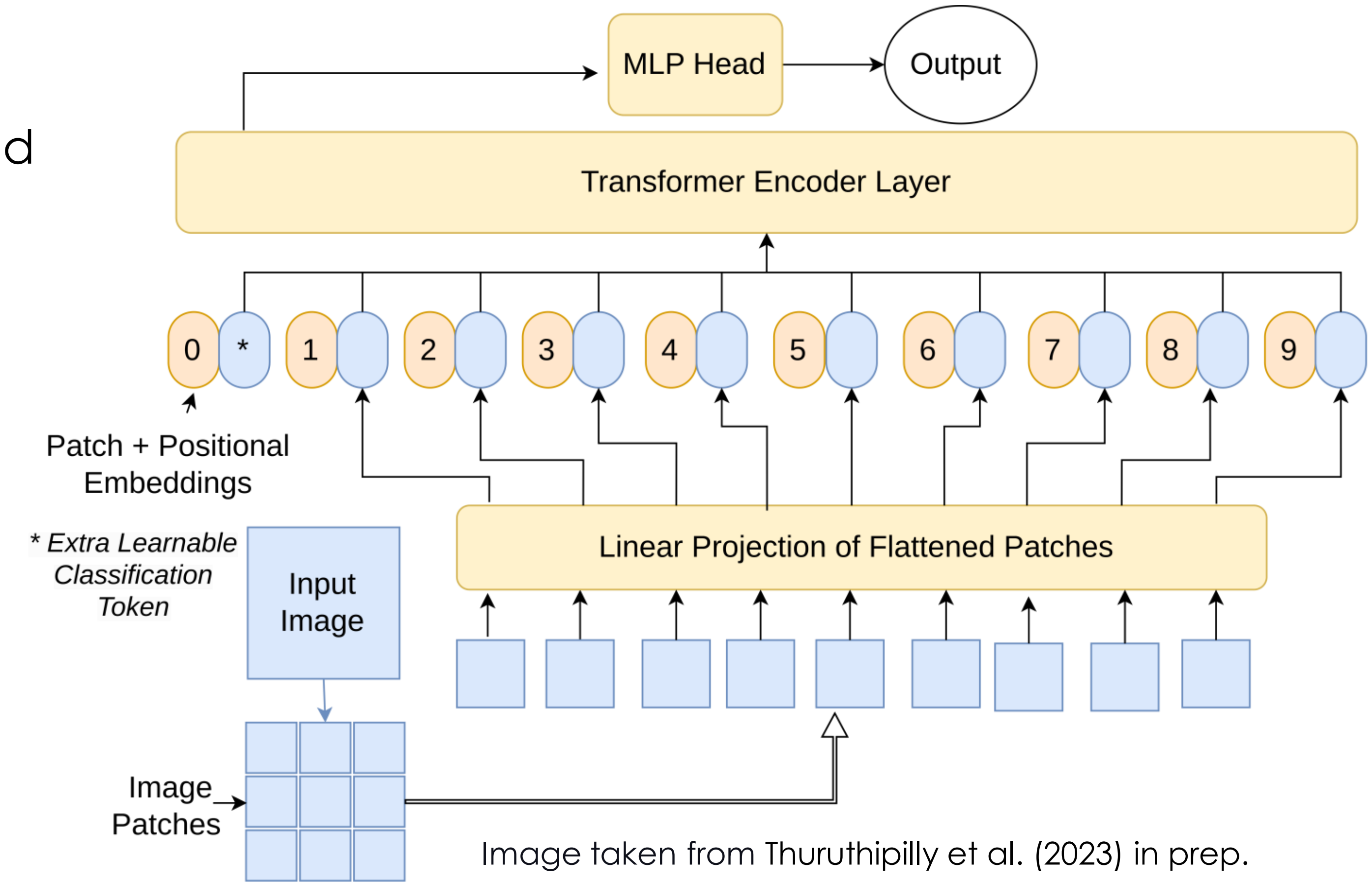
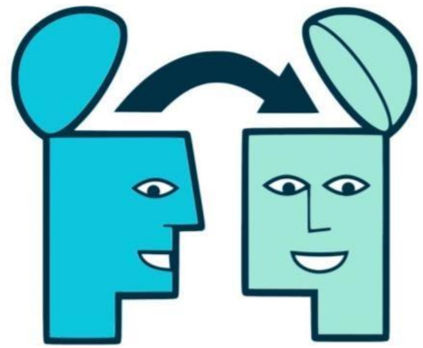
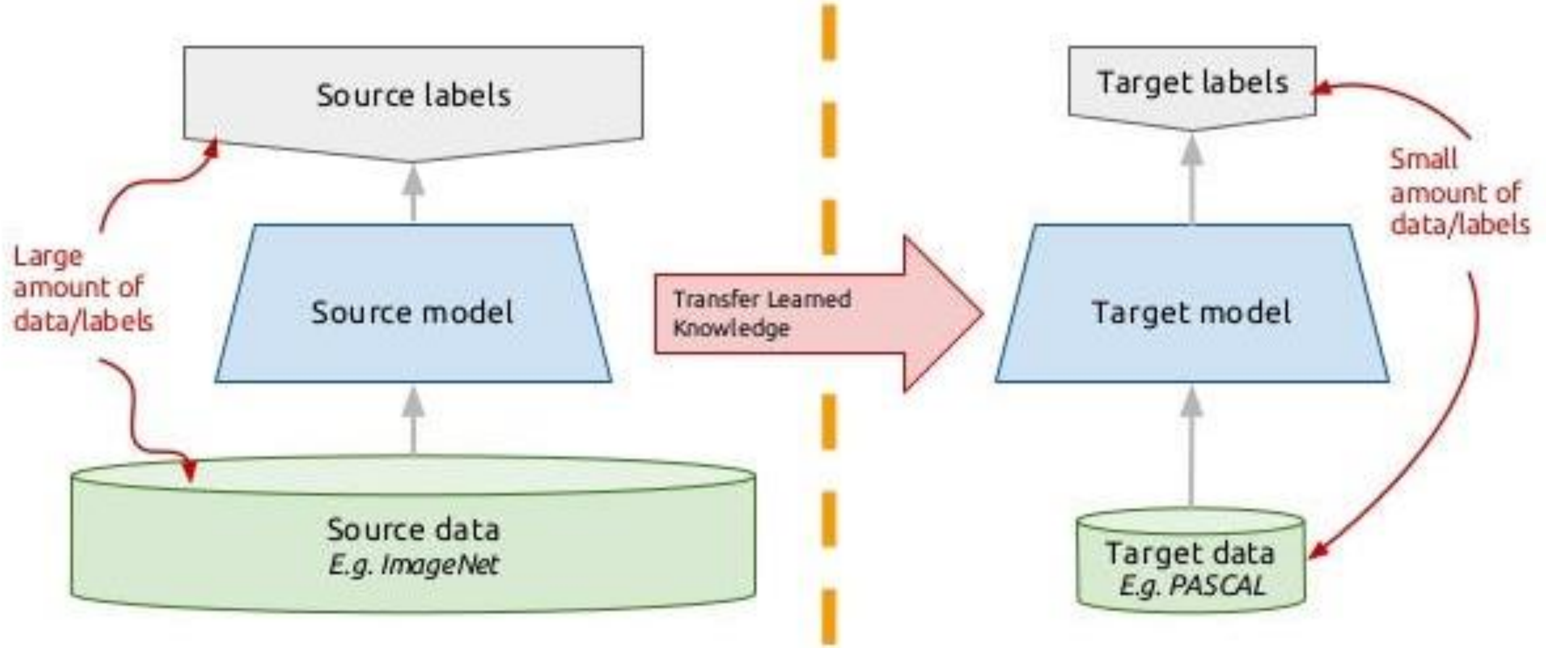


Image taken from Thuruthipilly et al. (2023) in prep.

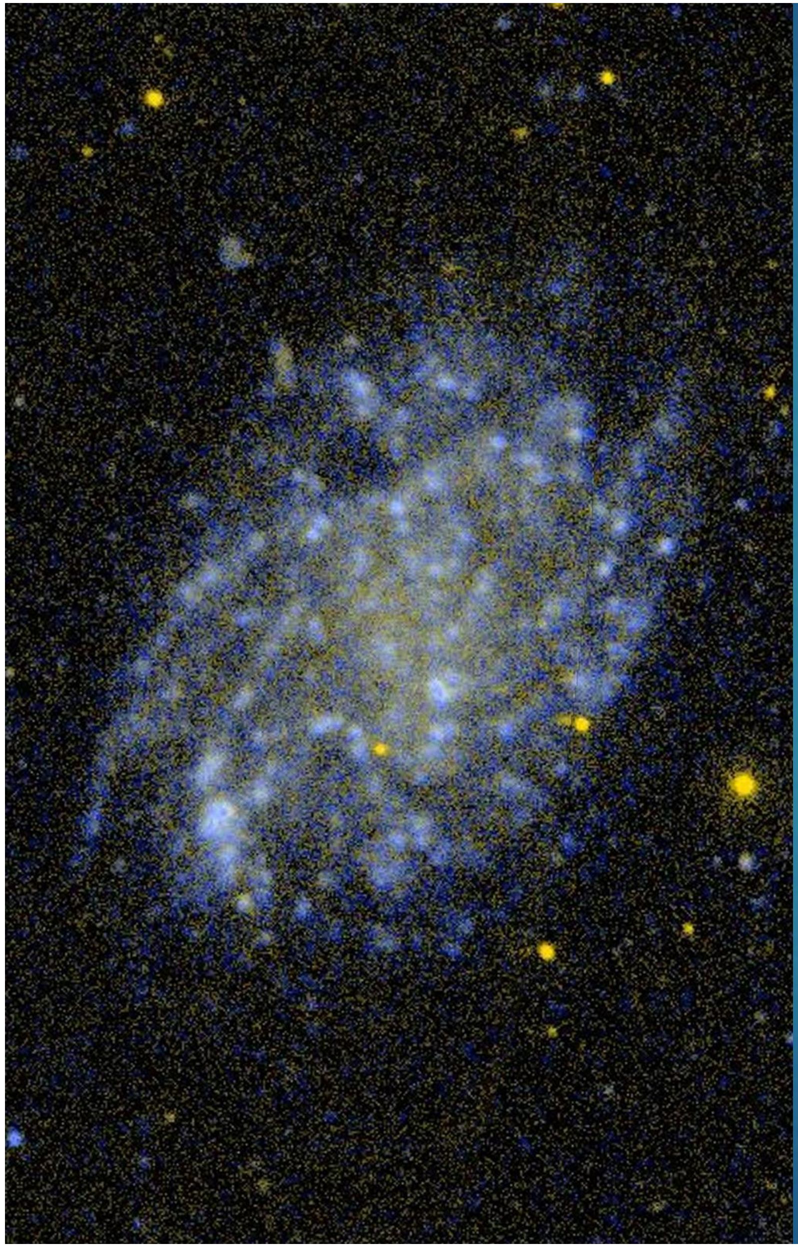
Transfer Learning

The reuse of a pre-trained model on a new problem is known as transfer learning in machine learning.





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



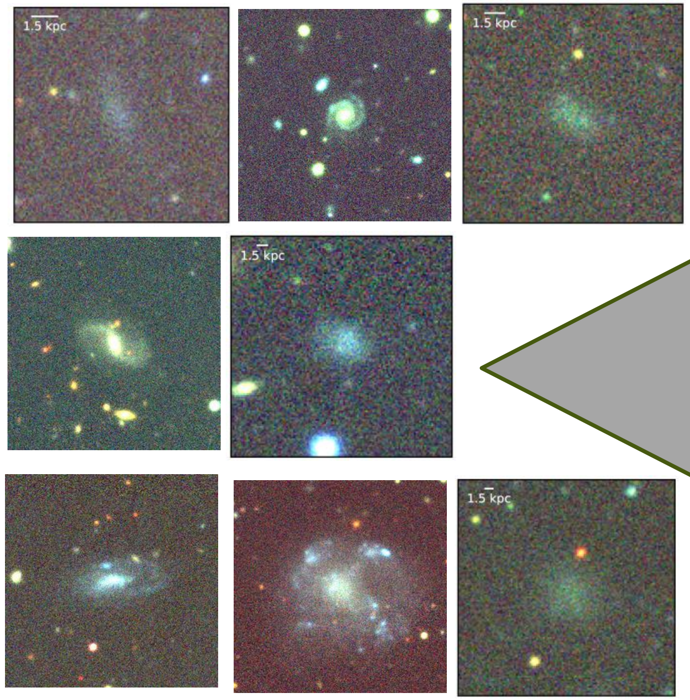
Search for LSBGs

PART 3

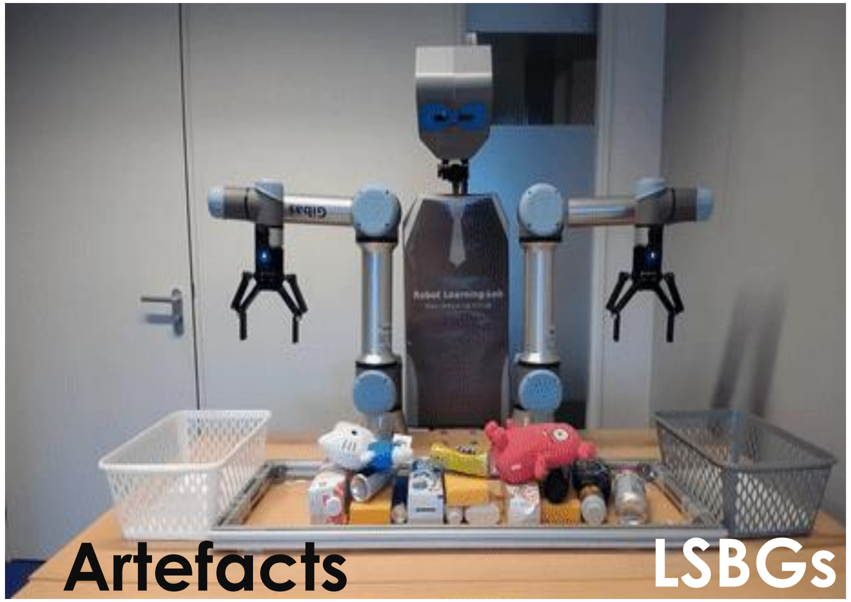
Image taken from
http://www.wikisky.org/?object=NGC+45&img_source=GALEX

LSBGs from DES DR1

419,782 faint objects selected from DES DR1

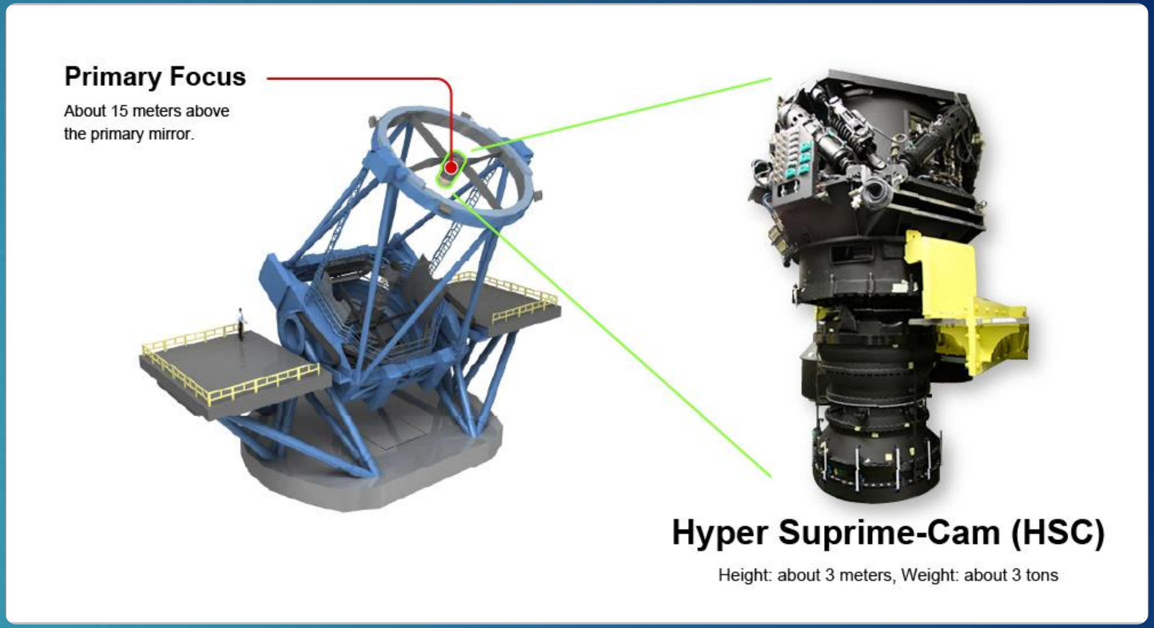


ML models applied to all the objects.



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

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



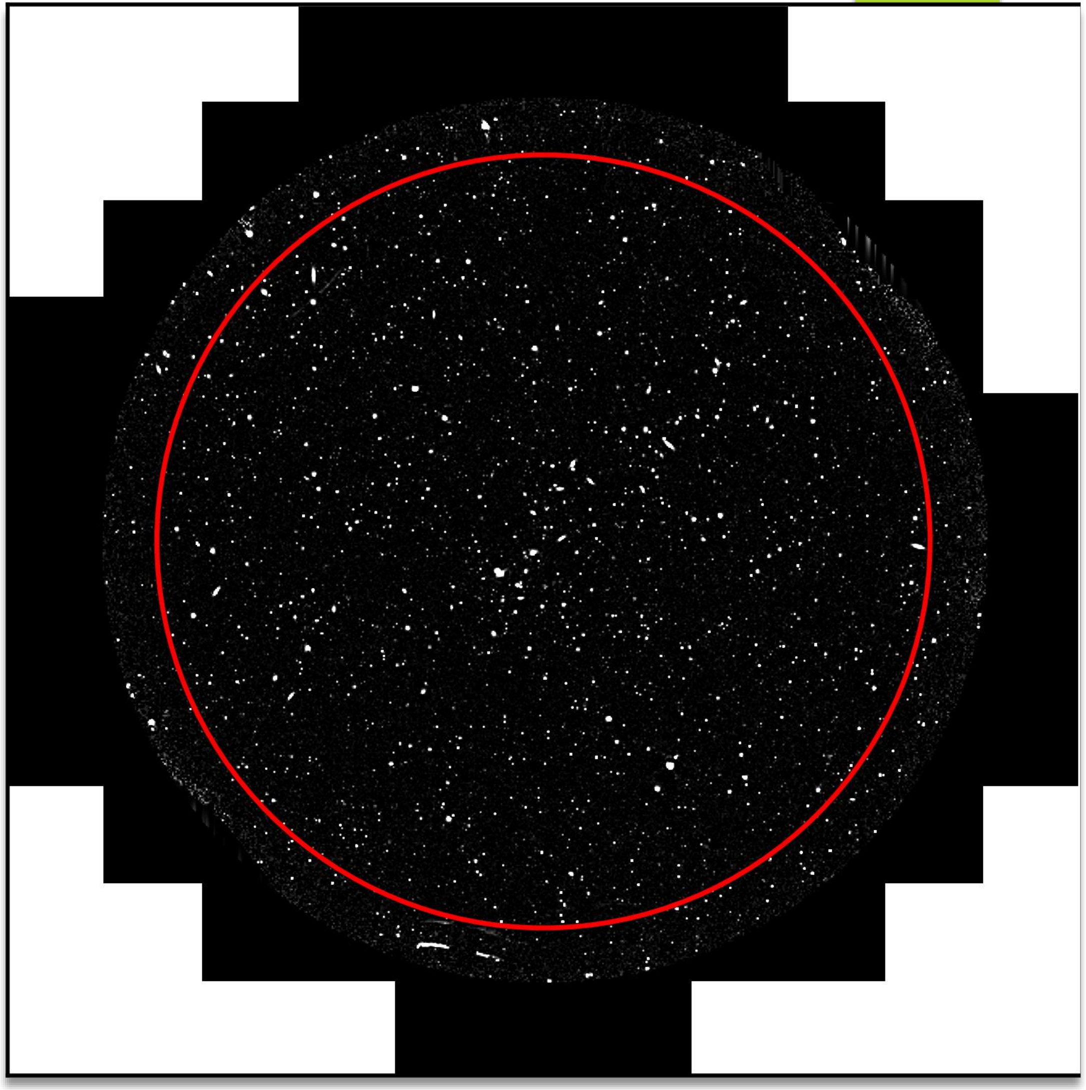
Going from DES to HSC ?

ROAD LINE TO LSST

Abell 194 Cluster

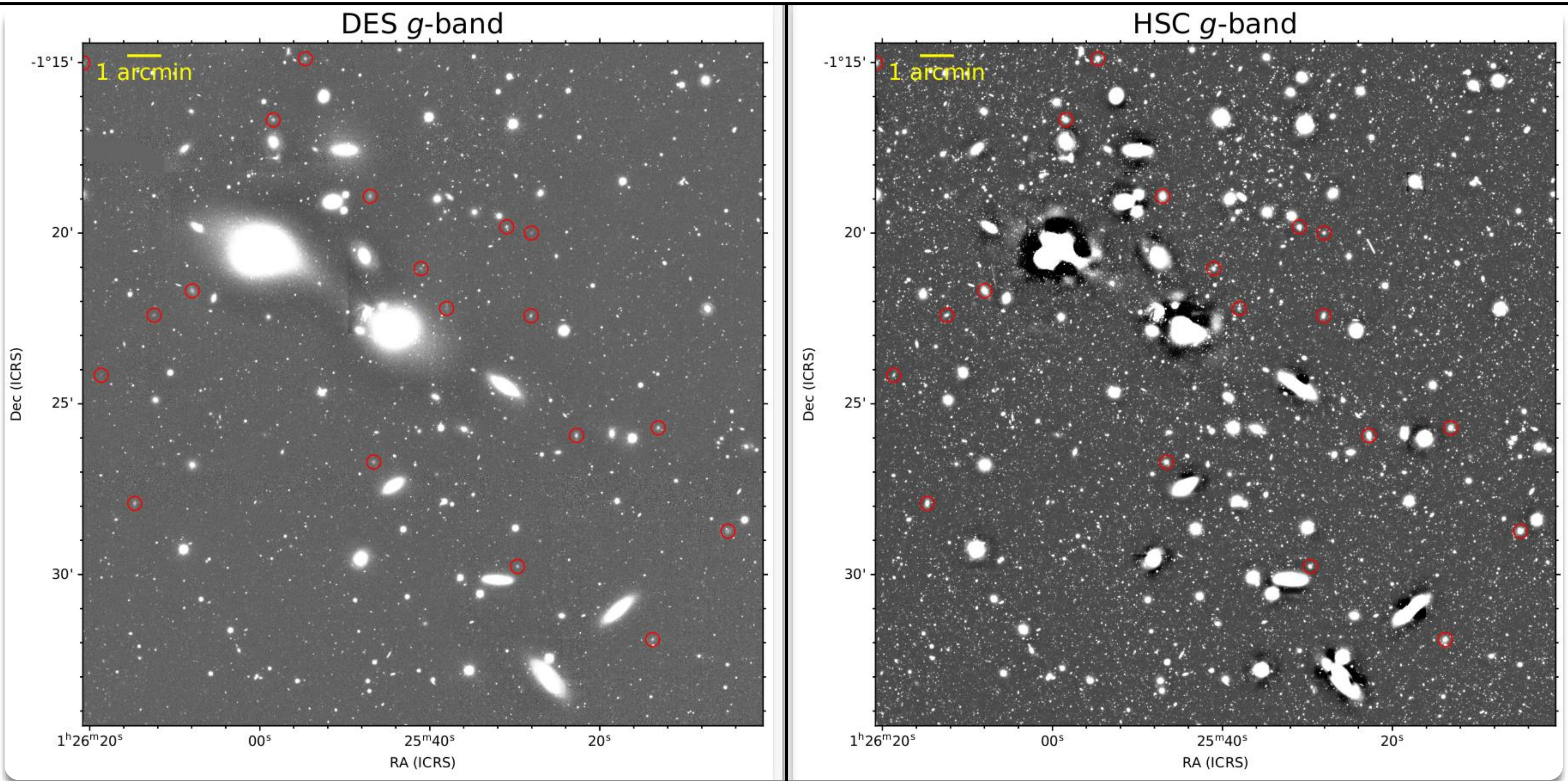
- Abell 194 is covered by DES and the data of Abell 194 observed with HSC in *g* and *r* is available to us.

- Known LSBGs and artefacts in the field of A194 is less than **150** which is not enough to train a ML model.



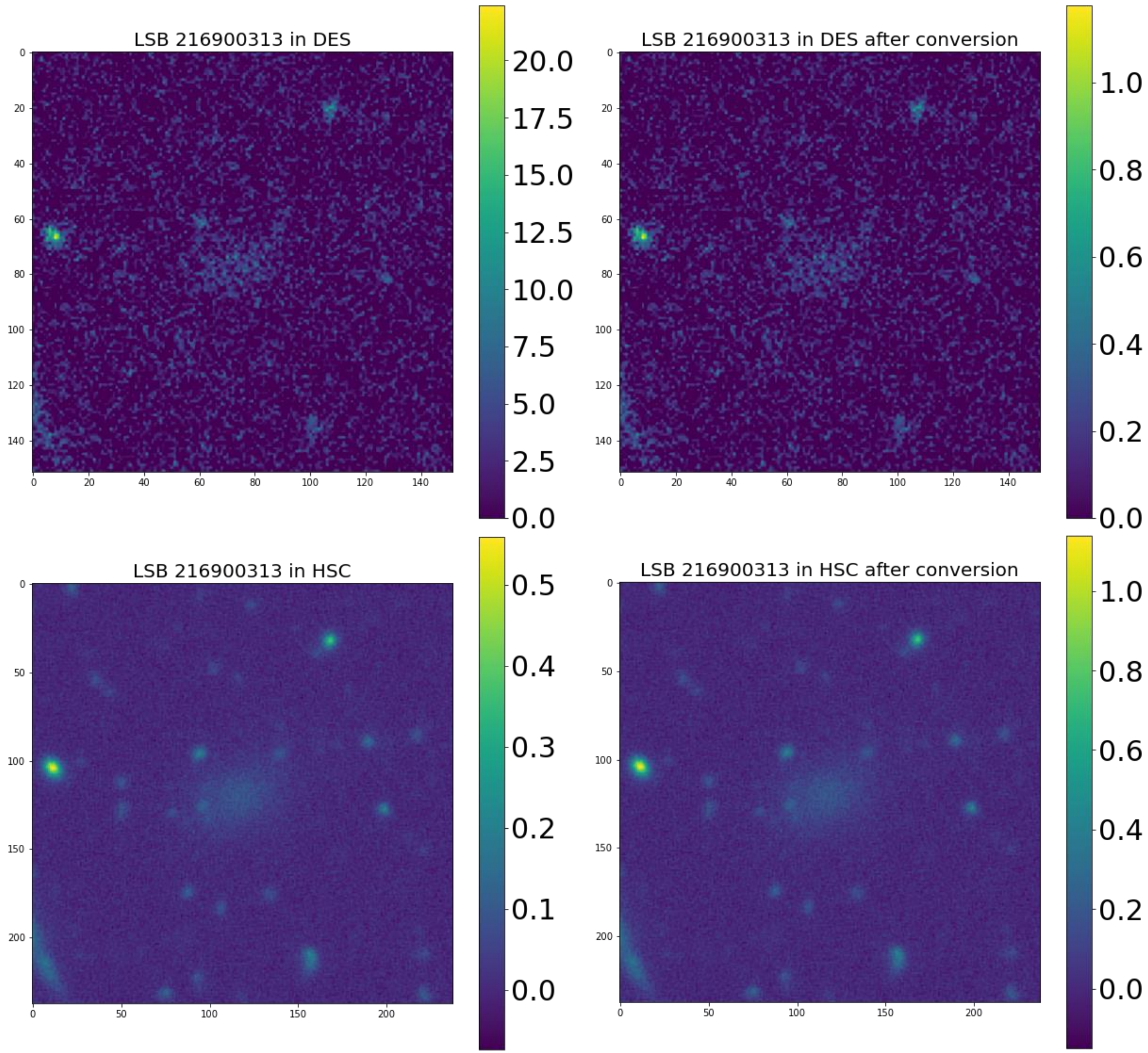
Coverage of the Abell 194 Cluster by HSC. The red circle shows the virial radius of the the cluster (~1Mpc).

Surface Brightness Depth Limit; HSC vs DES



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

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



Convert the raw data to a physical unit (Micro jansky per arcsec^2) make the data equivalent for both the surveys.

The trained model can recognise the general features more easily.

The flux per unit area match after conversion for both surveys.

Performance Comparison of ML Models

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**

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

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

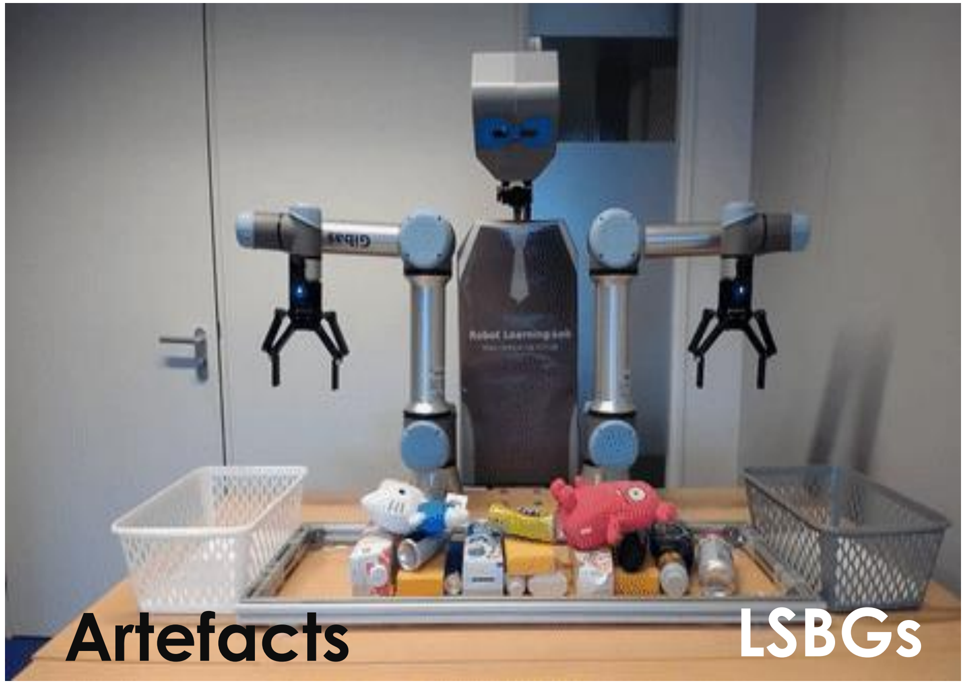
For a perfect classifier TPR = **1** and FPR = **0.**

Area under the receiver operating characteristic curve (AUROC) assesses the overall ability of a classifier to distinguish between classes. For a perfect classifier AUROC = **1.**

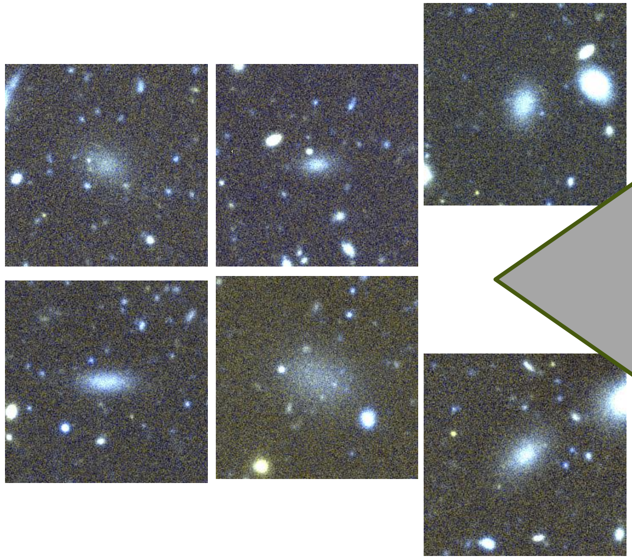
LSBGs in A194 – Simplified Pipeline

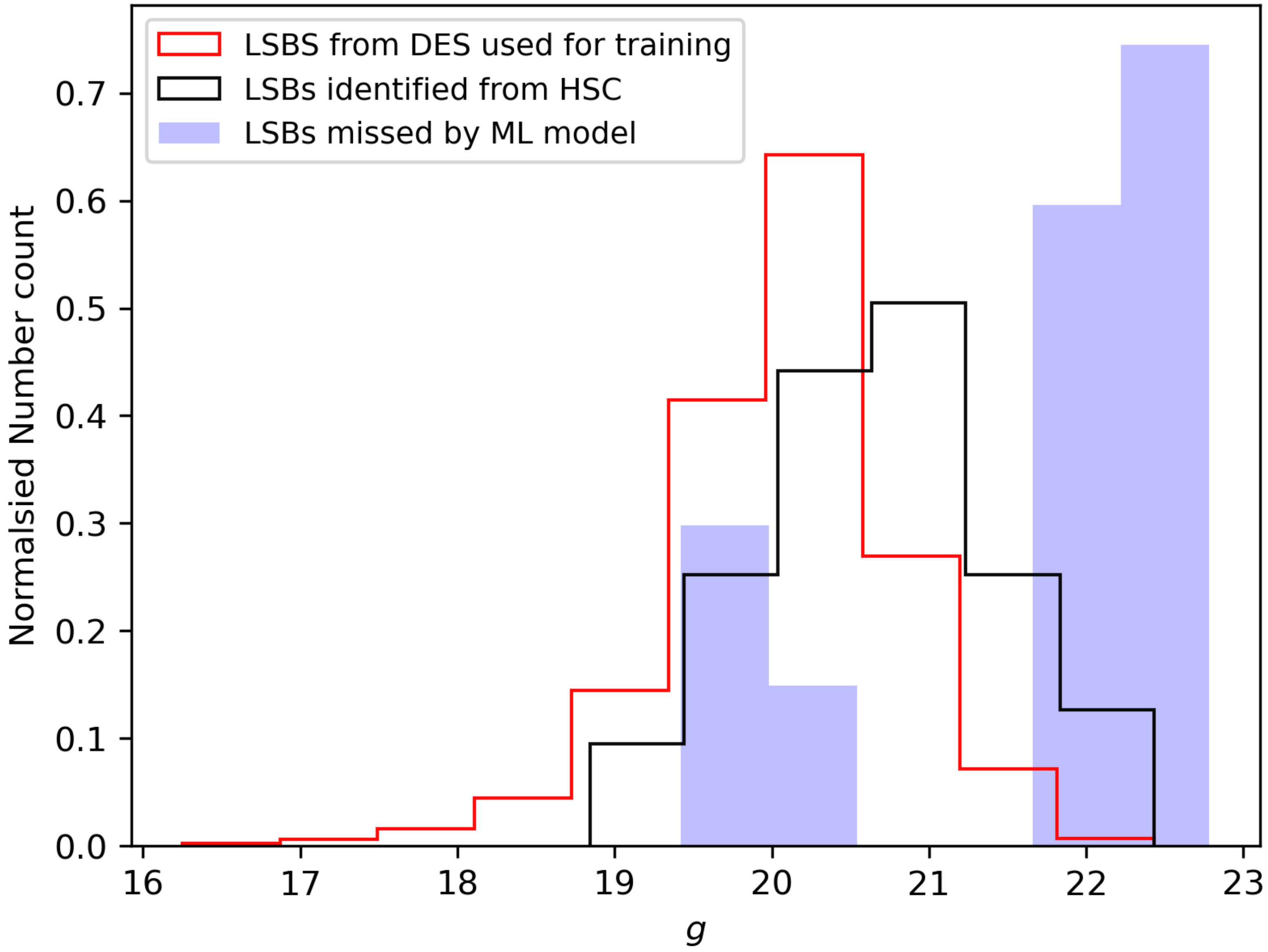
991 faint objects selected with Sextractor

ML models applied to all the objects.



After Sersic profile fitting & visual inspection **159** new LSBGs.

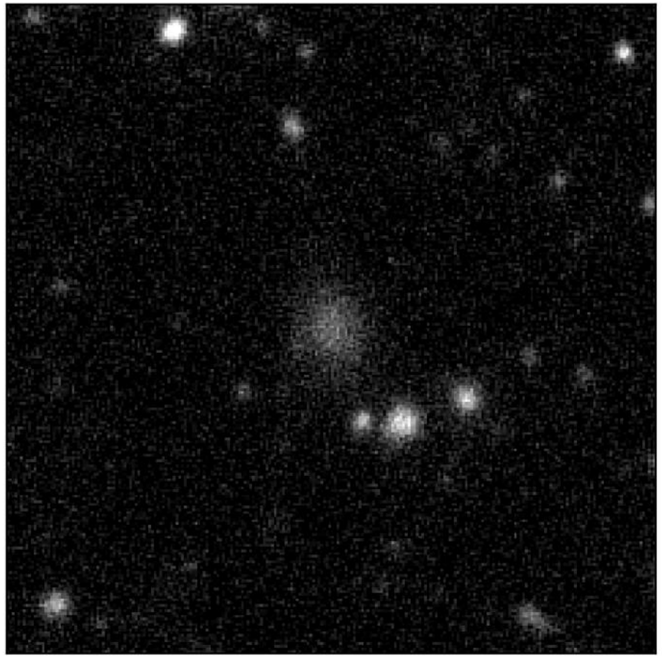


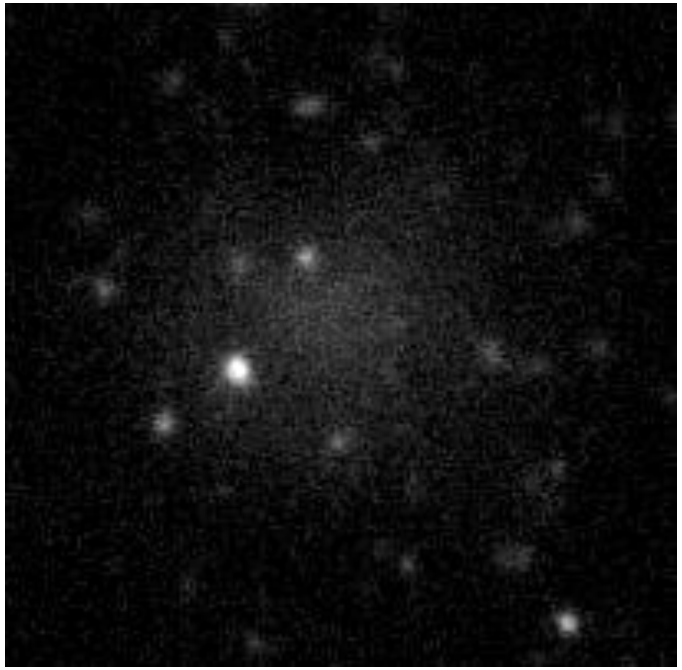


Missing Galaxies !!

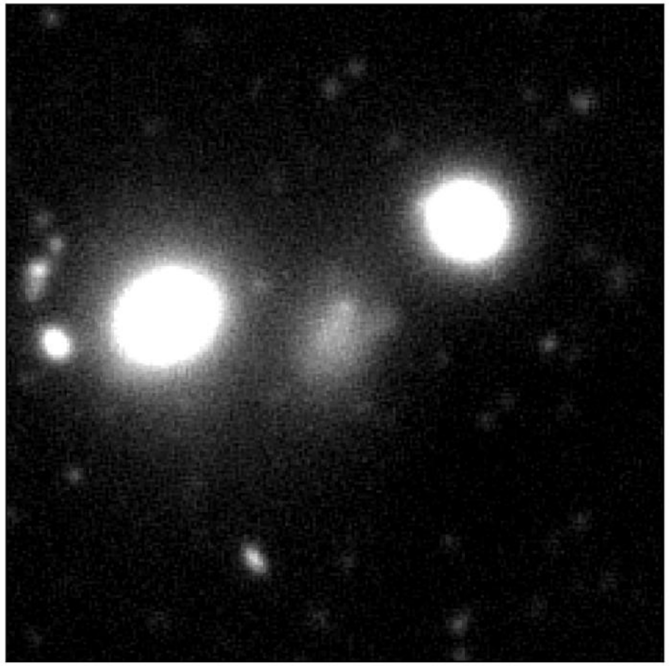
We missed**12** LSBGs which were found with visual inspection and Galfit

Why ?





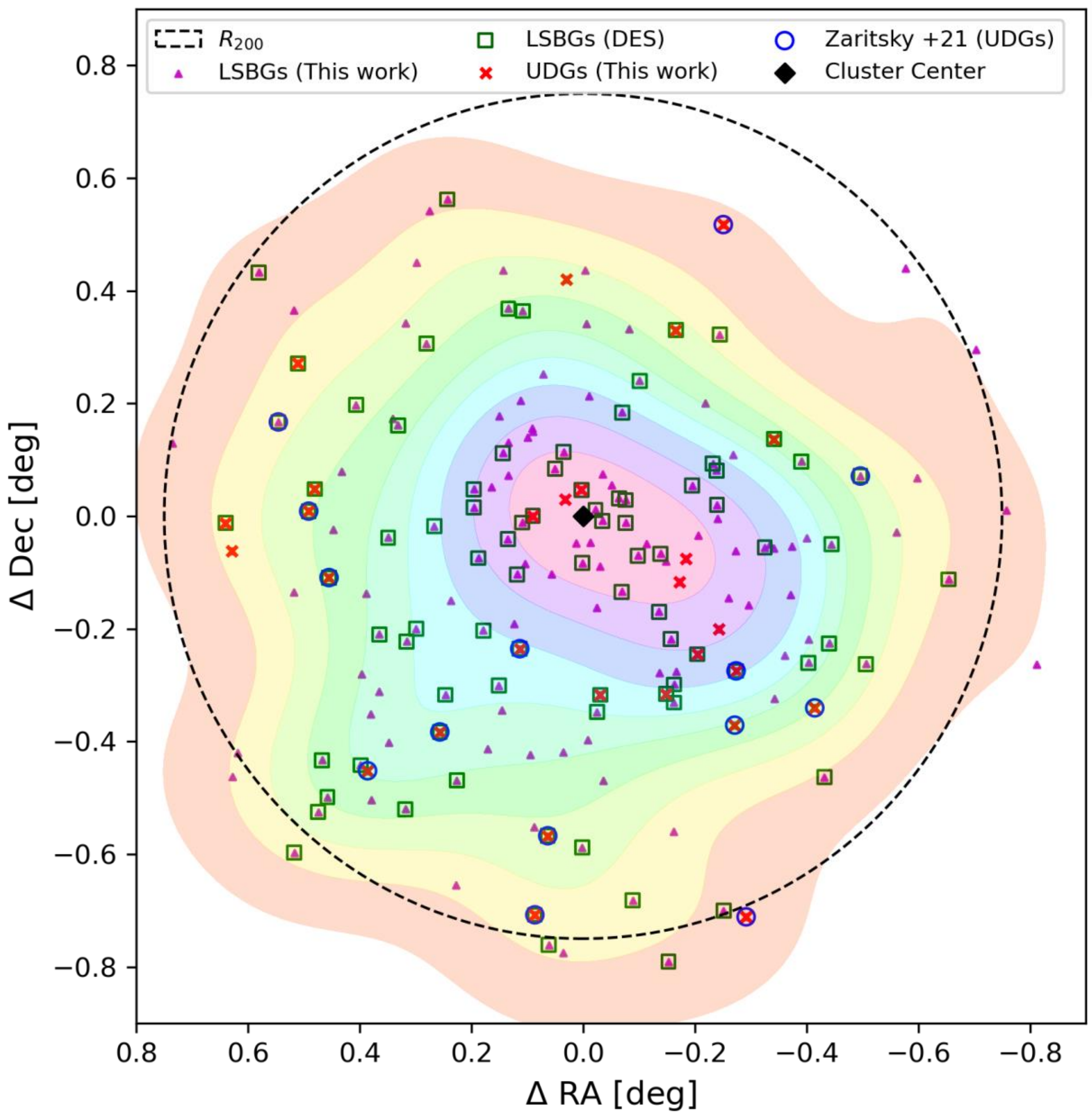
Vey faint (g~22) and representative sample was not present in the training set.



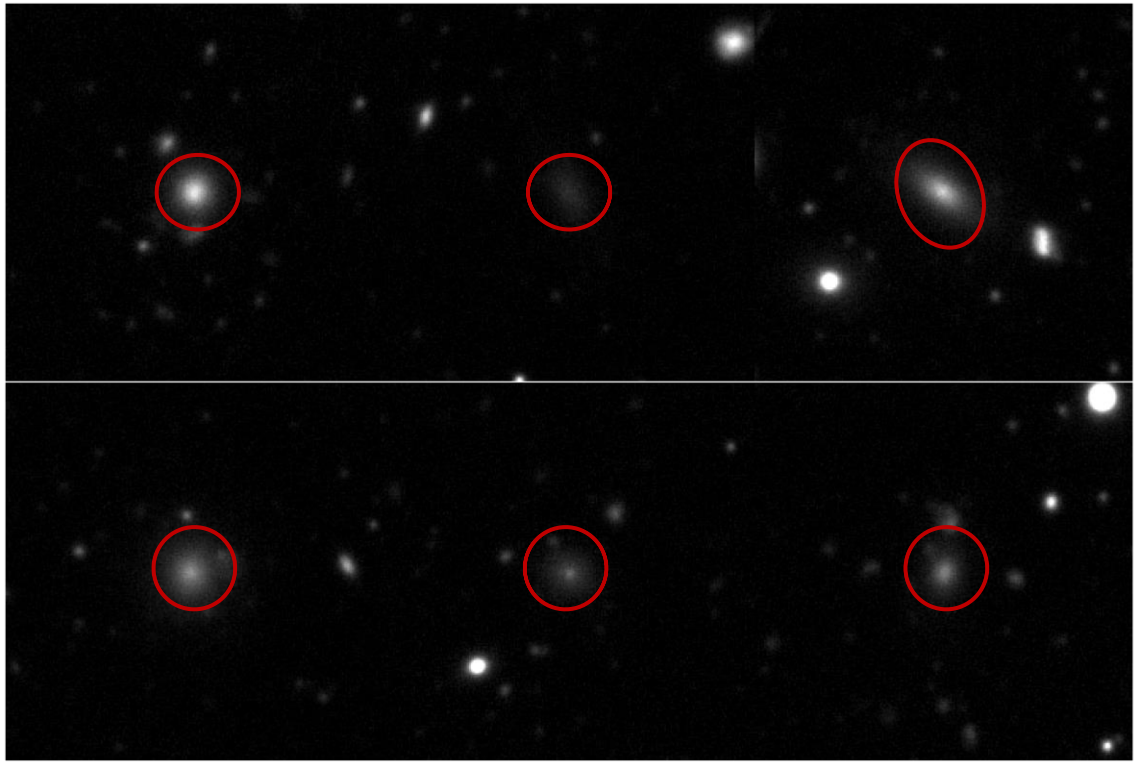
Presence of a bright object near the center.

LSBGs & UDGs

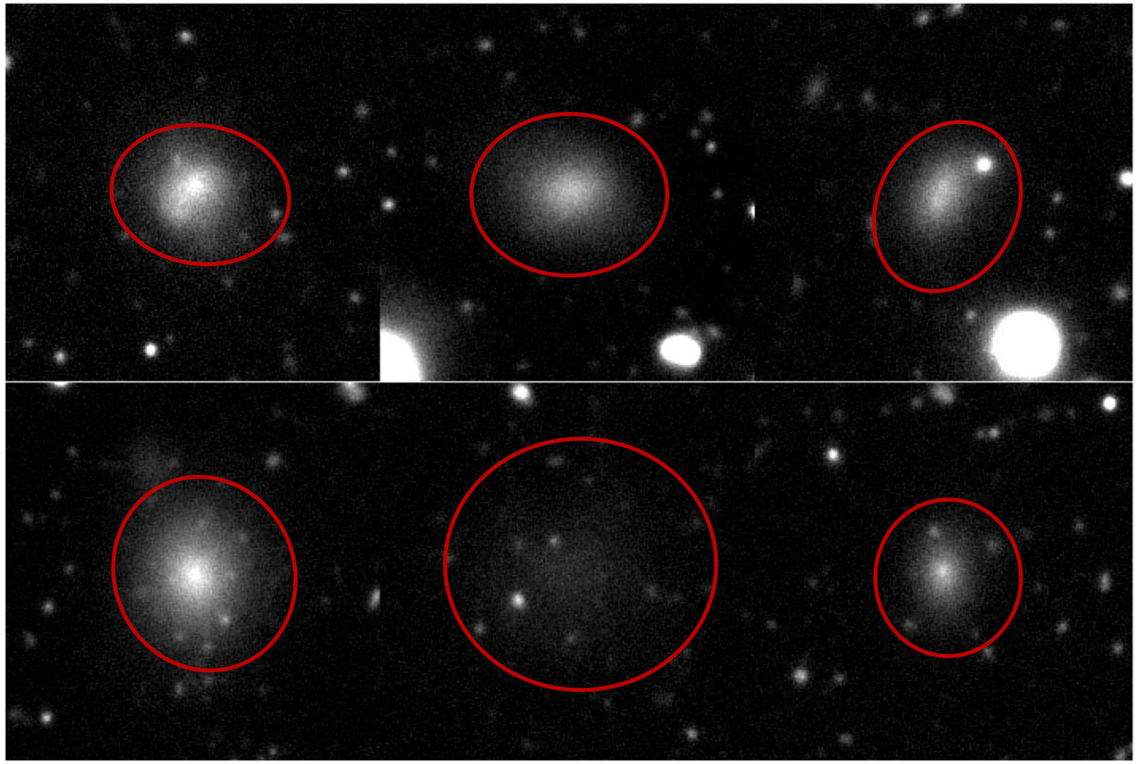
- **171** LSBGs and **28** UDGs found from HSC-data of Abell 194.
- **93%** recovery rate with transformers with-out fine tuning.



Examples of LSBGs and UDGs

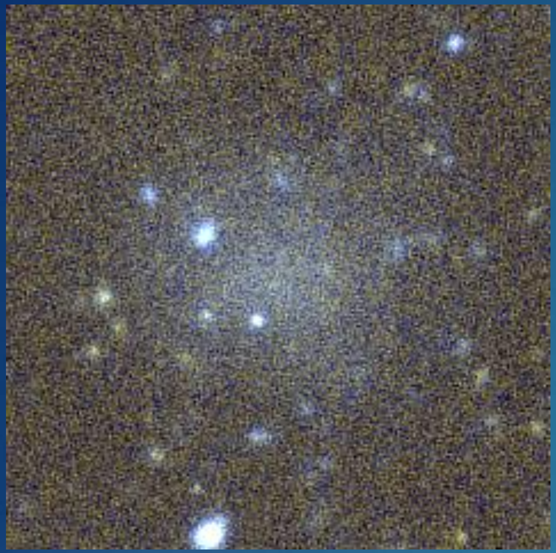


LSBGs (non-UDGs)



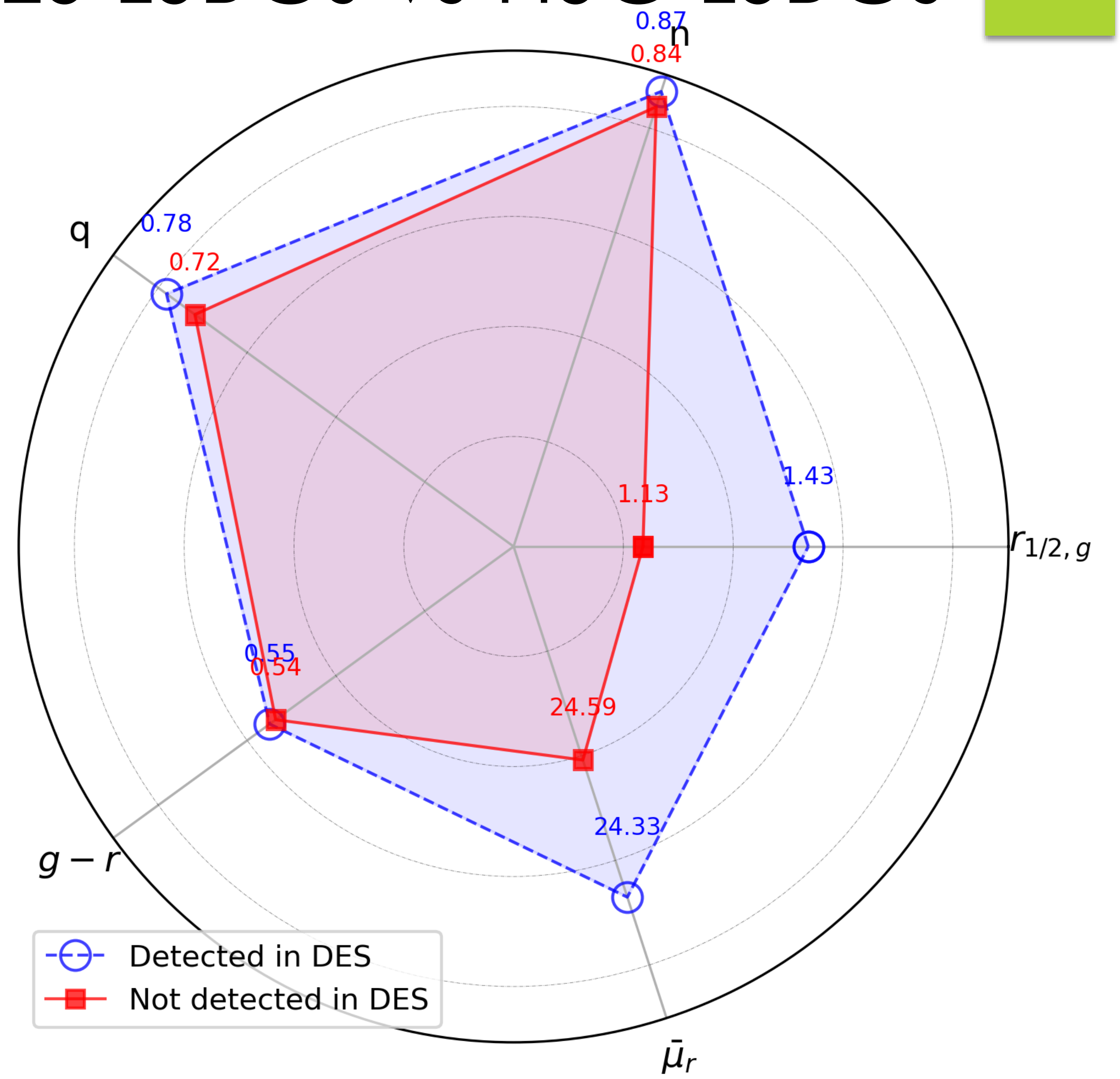
UDGs

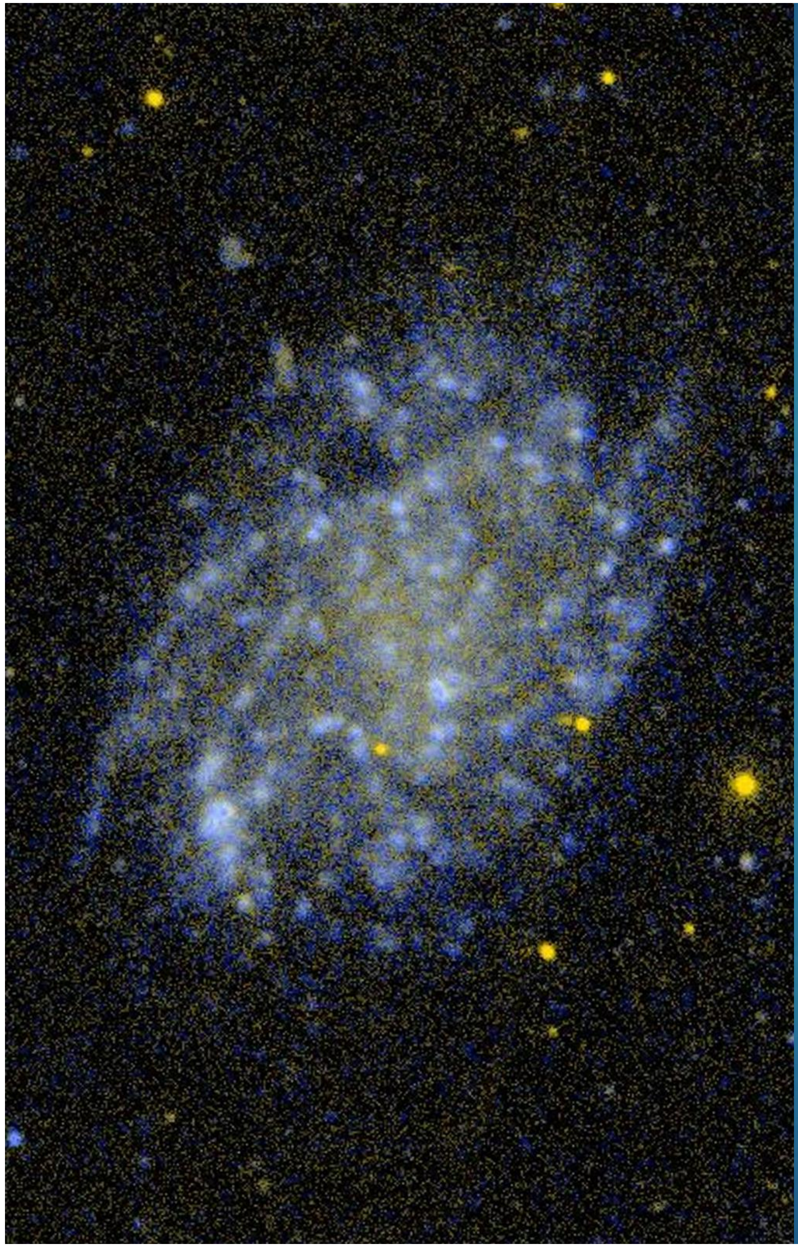
DES LSBGs vs HSC LSBGs



LSBG Detected from HSC.

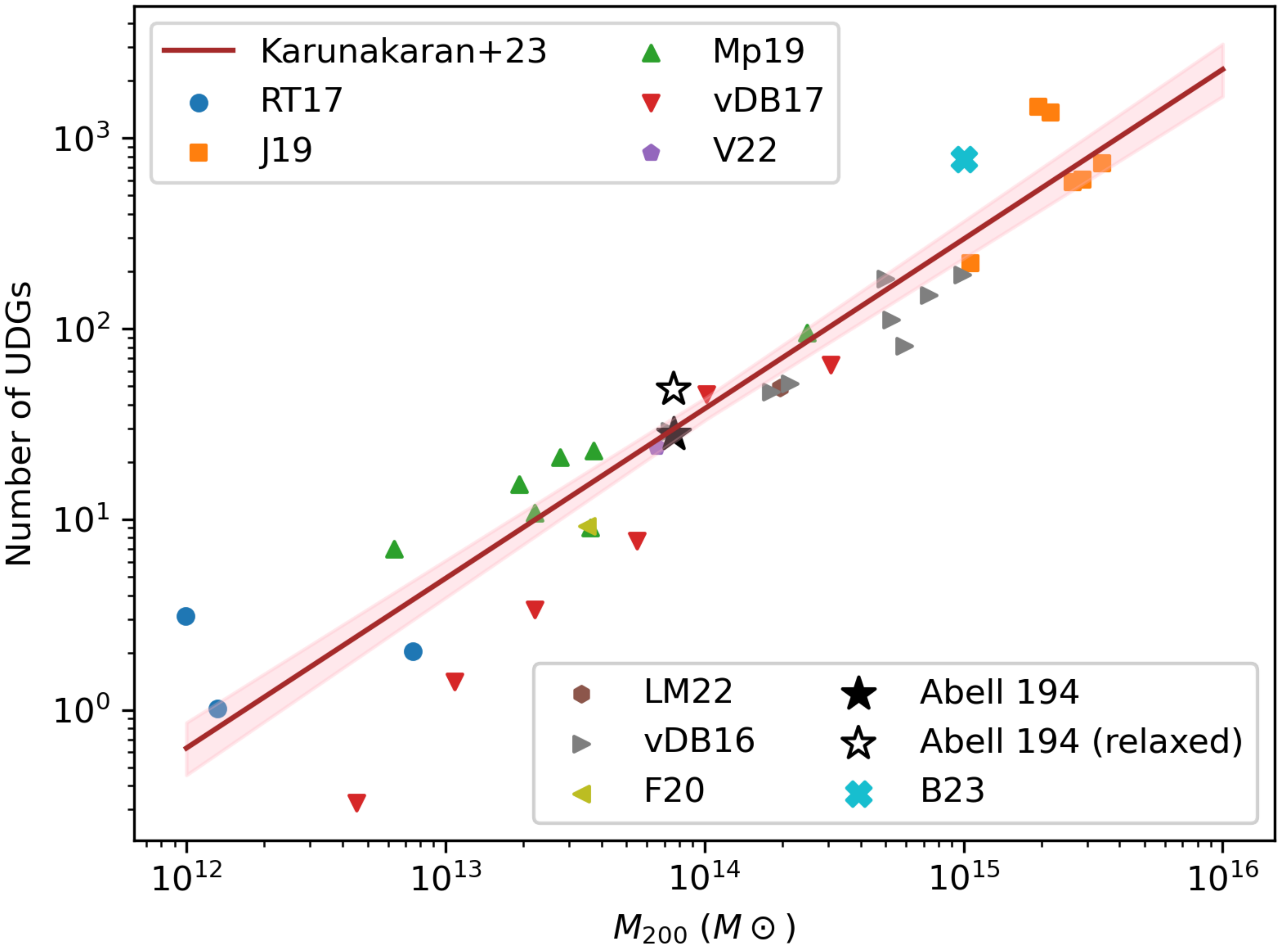
LSBG Detected from DES.





Properties of LSBGs

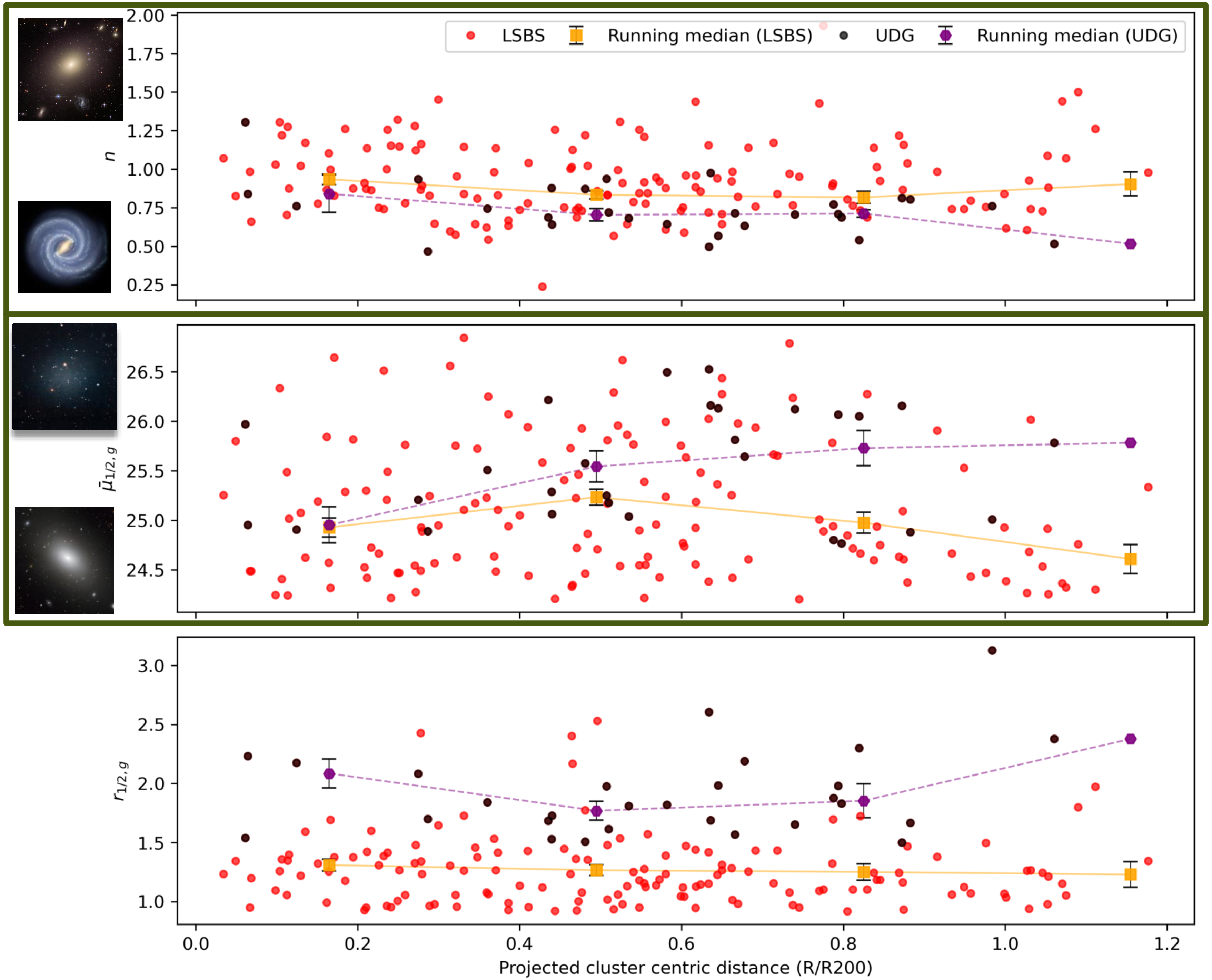
PART 3.1

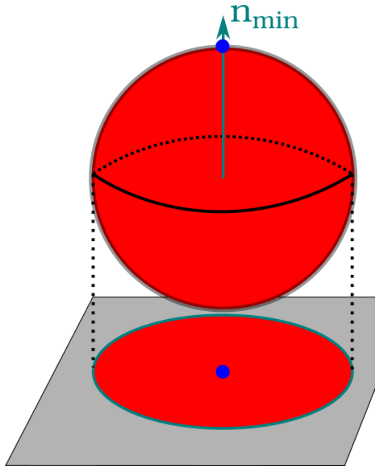


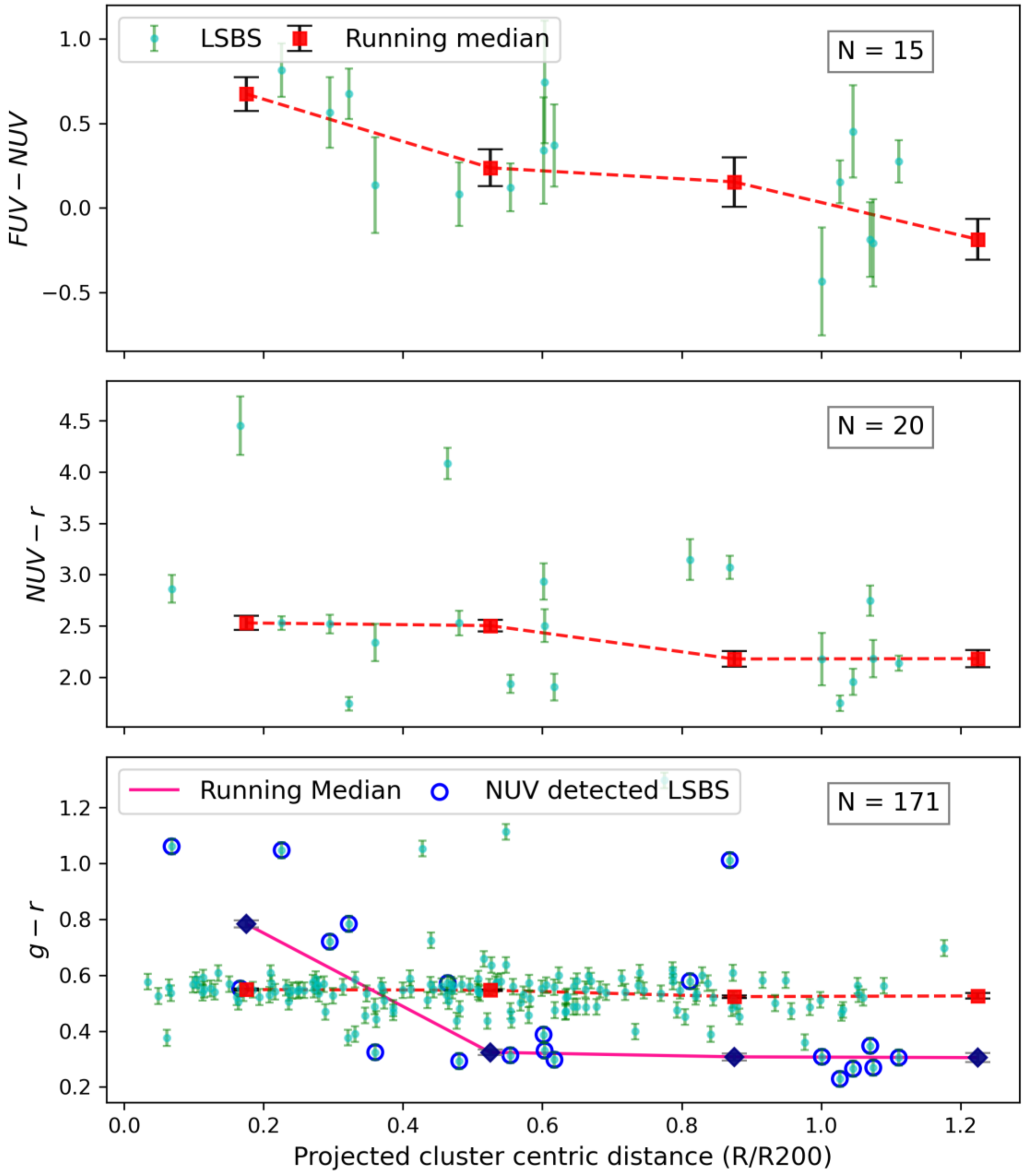
Scaling Relation of UDGs

UDG NUMBER IS PROPORTIONAL TO THE MASS OF THE HOST CLUSTER/GROUP.

Morphological Properties as a function of Projected Cluster-Centric distance





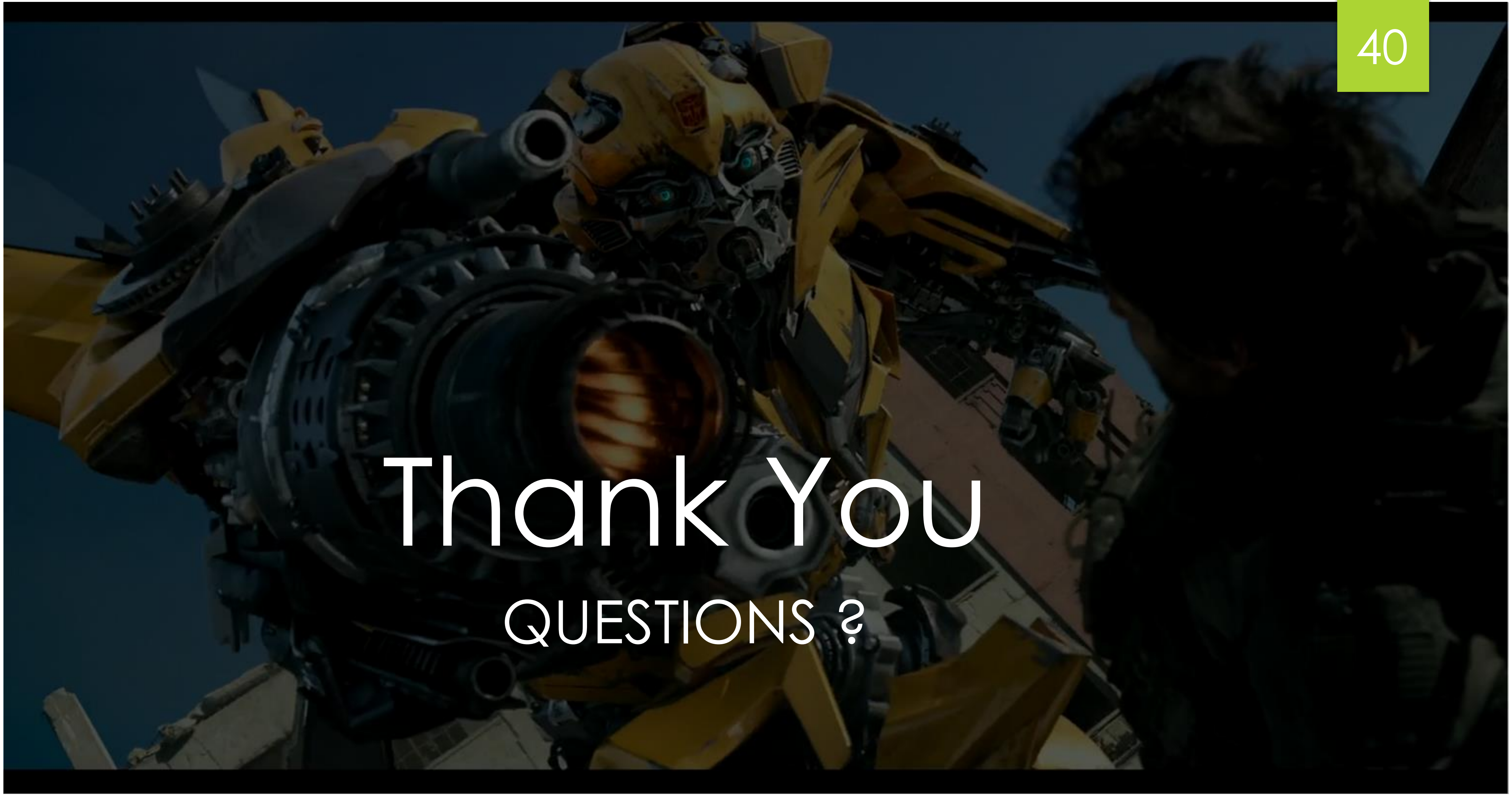


Color as a function of Projected Cluster-Centric distance

Galaxies in the cluster center tends to be redder with low star formation rate and galaxies in the outer skirts tends to be bluer with relatively high star formation.

Summary

- Machine Learning models trained in shallow data can be used to identify LSBGs with a **93%** recovery rate in deeper data even with-out fine tuning.
- We identified **171** LSBGs and **28** UDGs in the Abell 194 cluster, doubling the amount of LSBGs and UDGs known in Abell 194, but still might be missing more!
- The newly identified LSBGs tends to be smaller in size as well as fainter than the previously known LSBG population.
- No unexpected trends are seen in the distribution of morphological properties as a function of the projected cluster centric distance as well as in the color.

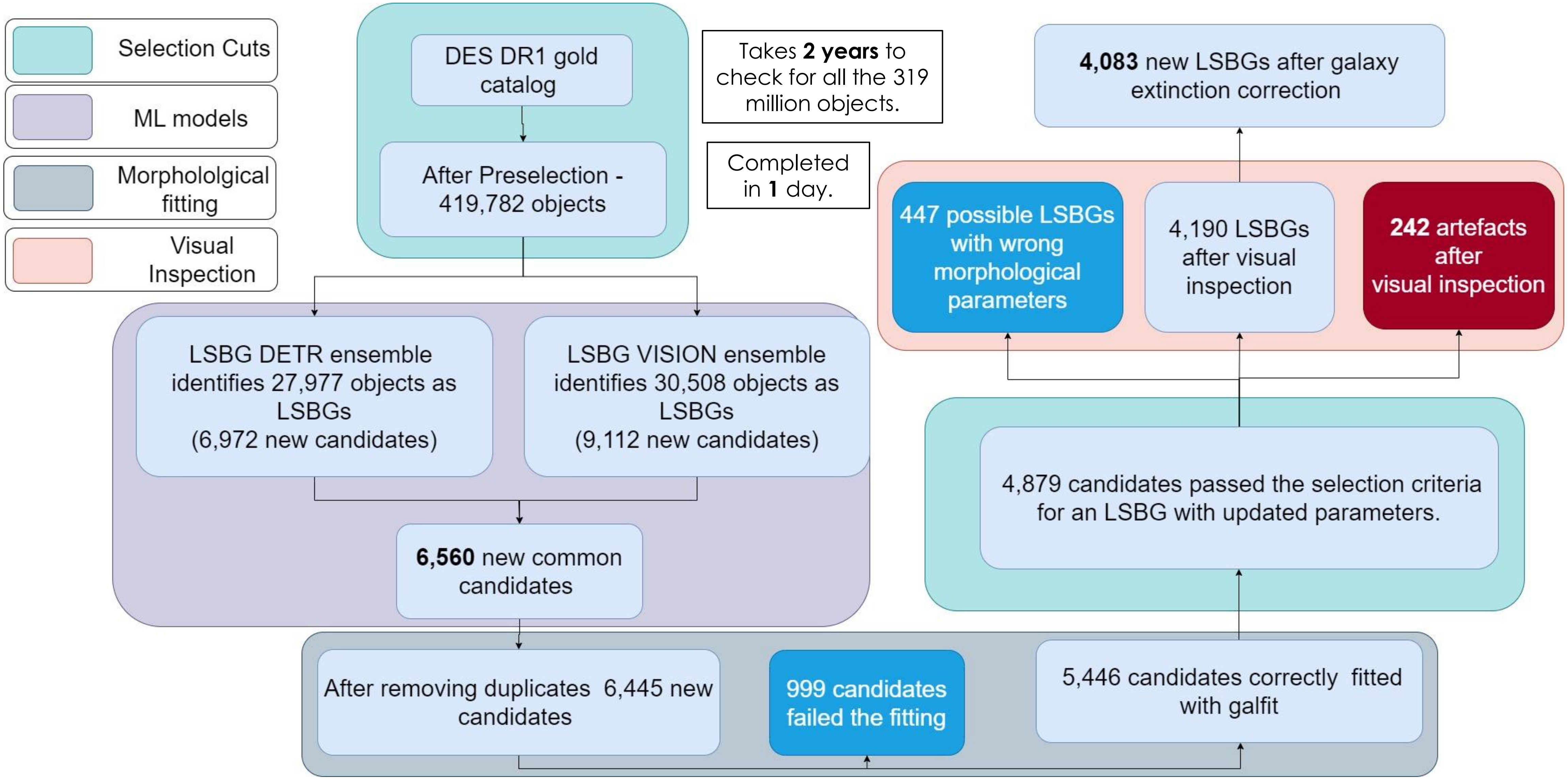


Thank You

QUESTIONS ?

Back UP

LSBGs from DES DR1: A Detailed Picture



LSBGs in A194 – Original Pipeline

Sextractor identified the objects (170,328)

Preselected 991 candidates with 20''>$r_{1/2}$>2'' and 24.0 <$\bar{\mu}_g$ 32 mag arcsec^2

Model identified 272 objects as LSBG candidates.

LSBGs definition followed is $r_{1/2}$>2.5'' and $\bar{\mu}_g$> 24.2 mag arcsec^-2

159 LSBGs after Galfit and visual inspection.

26 sources (artefacts) did not converge for Galfit and 87 sources had 24.0 <$\bar{\mu}_g$< 24.2 mag arcsec^-2.

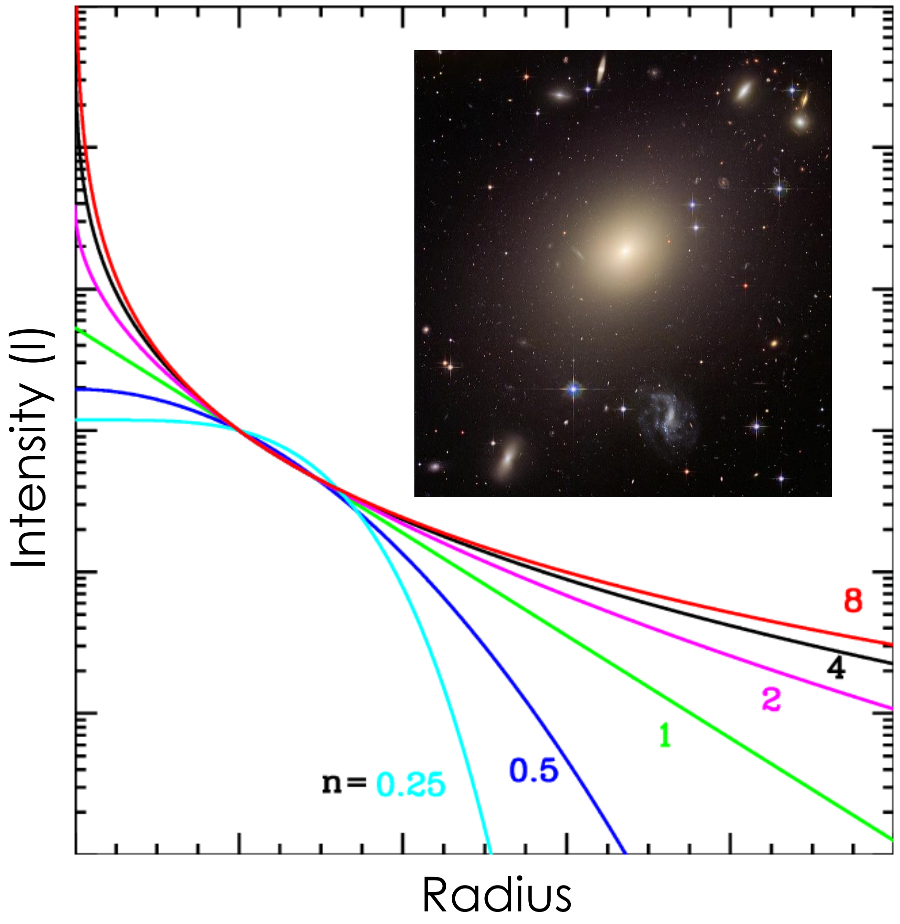
Sérsic Profile of Galaxies

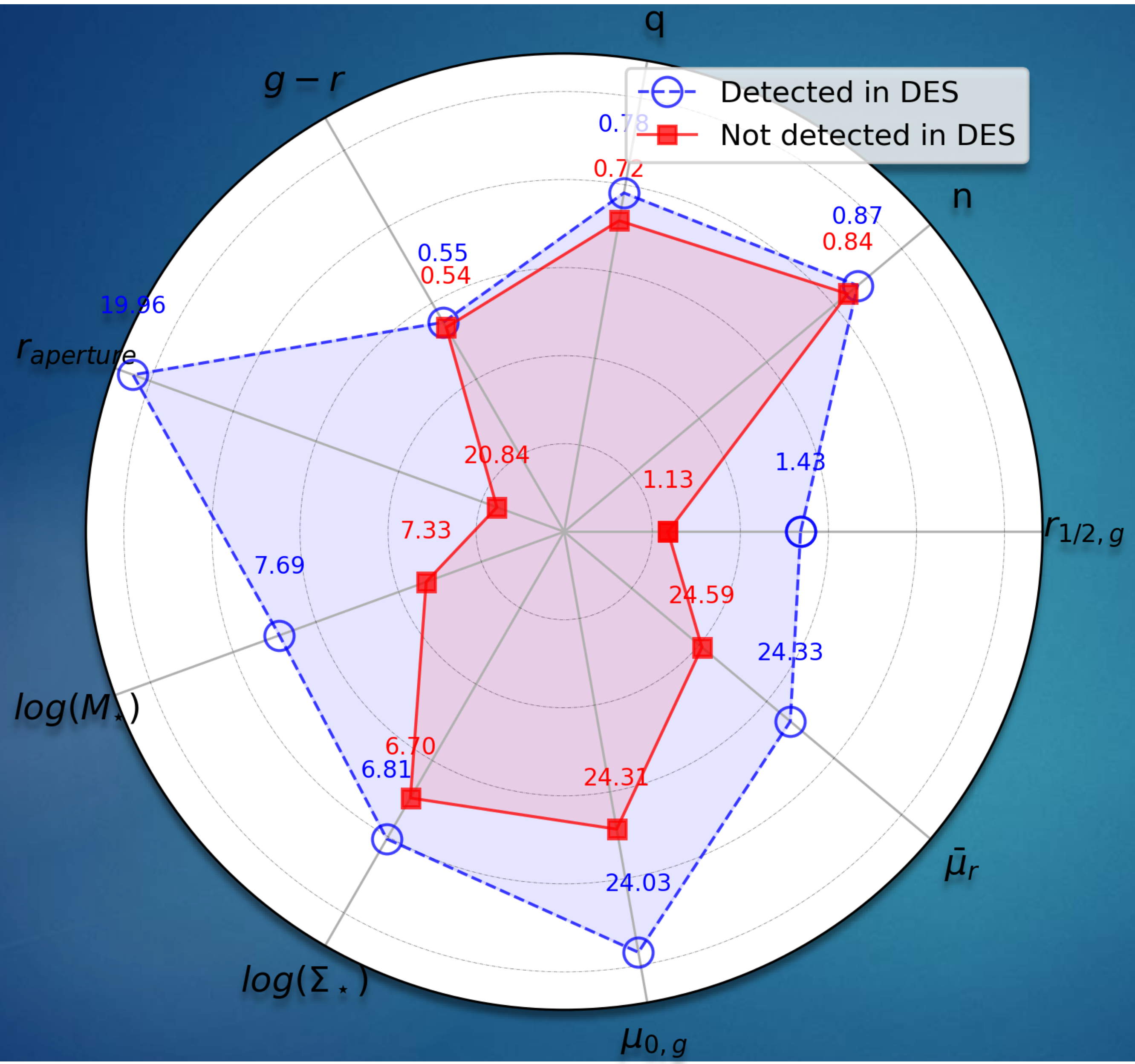
The Sérsic profile is a mathematical function that describes how the surface brightness of a galaxy varies with distance r from its centre.

$$I(r) = I_e \exp\left[-b\left(\left(\frac{r}{r_e}\right)^{1/n} - 1\right)\right]$$

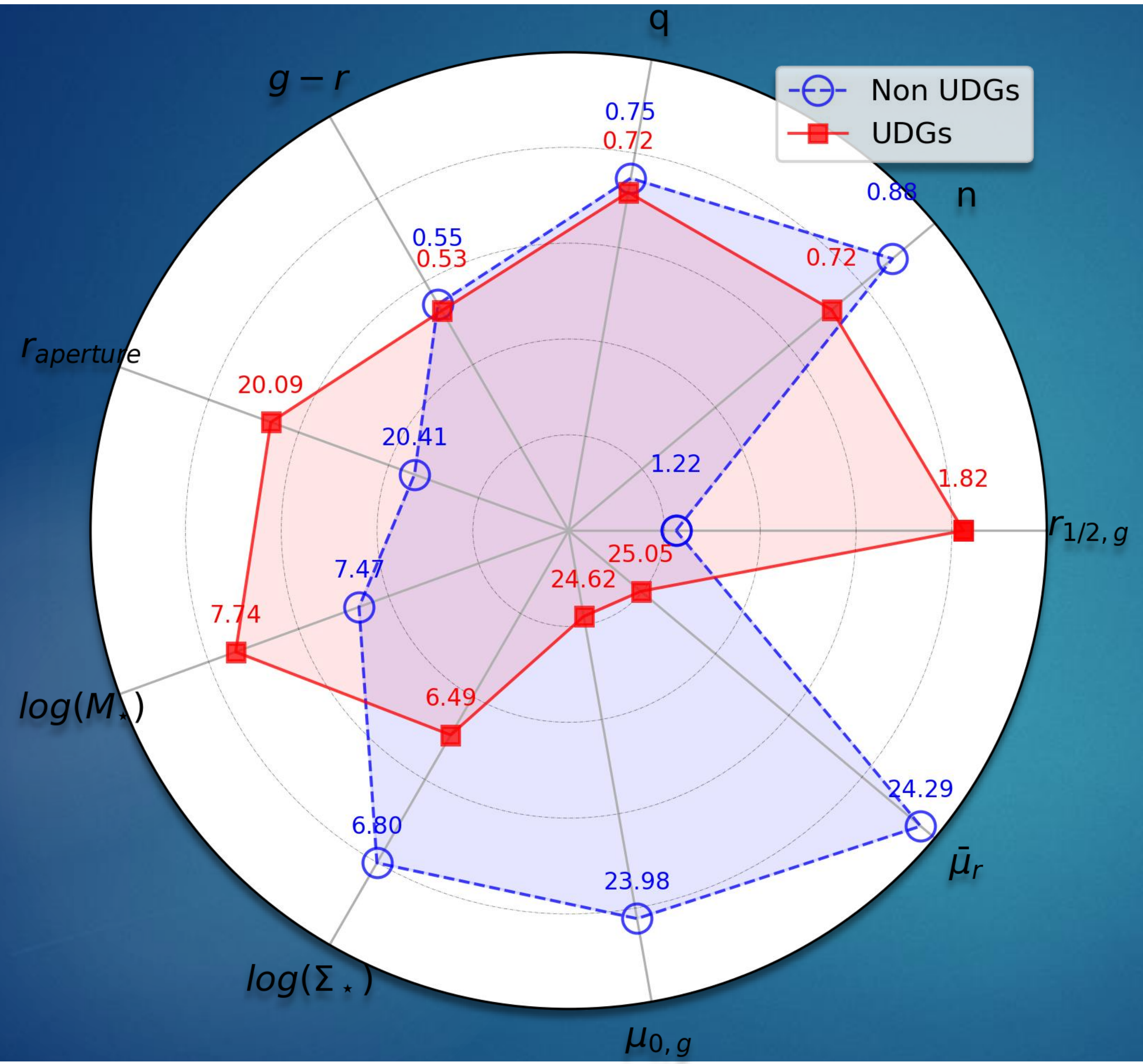
Sérsic index (n)

- n = 4 gives the de Vaucouleurs profile which is a rough approximation of ordinary elliptical galaxies.
- n = 1 gives the exponential profile which is a good approximation of spiral galaxy disks and a rough approximation of dwarf elliptical galaxies





New LSBGs vs Old LSBGs



LSBGS and UDGs

Each attention head can be implemented in parallel

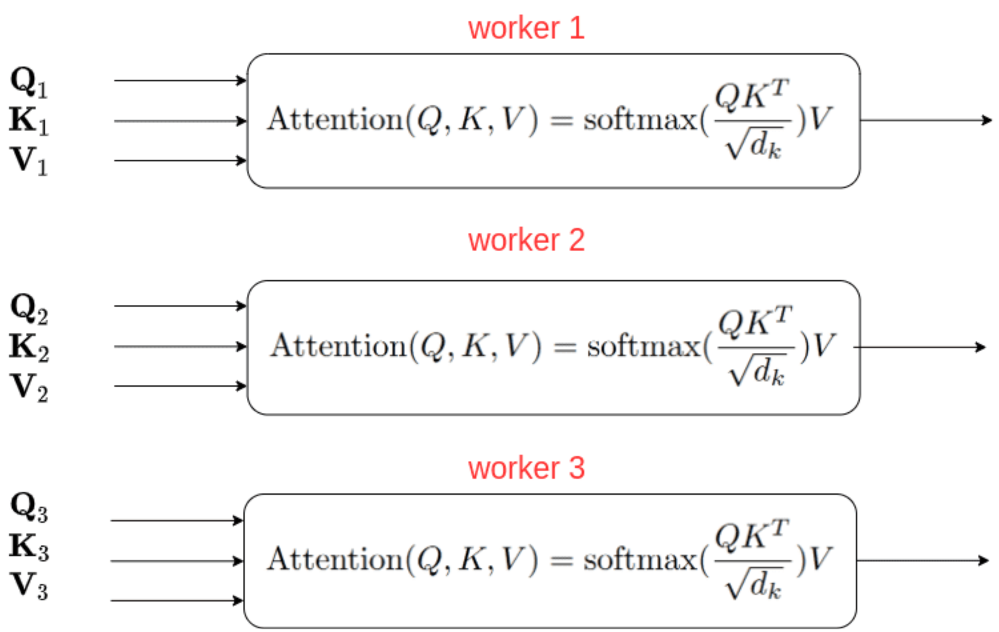


Image credits :https://theaisummer.com/self-attention/

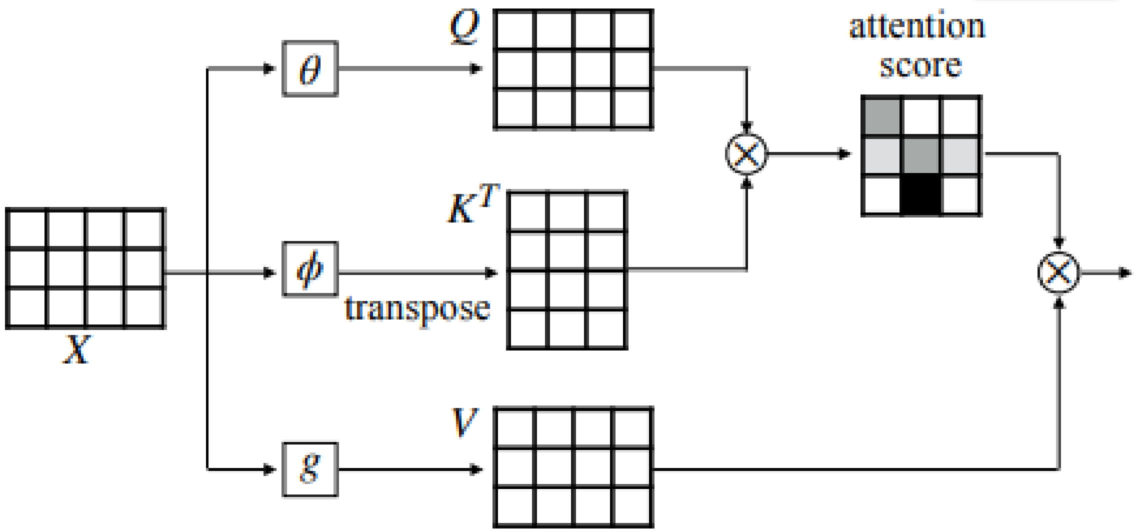
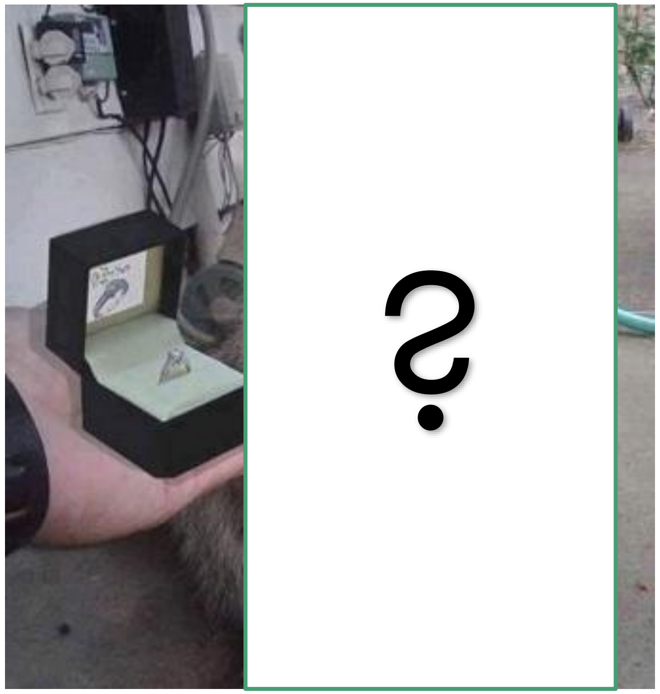
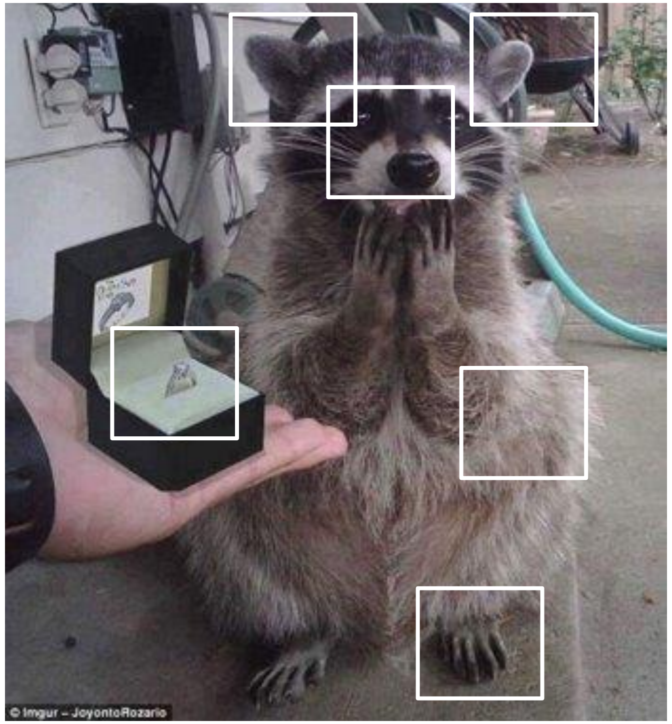


Image credits : https:// blogs.oracle.com/datascience/multi-head-self-attention-in-nlp

Transformers and Self-Attention

Attention in Action





Ensemble Models

- Ensemble models in deep learning refer to combining multiple models to create a single model that performs better than the individual models.

- The idea behind ensemble models is to reduce the generalisation error and increase the stability of the system by taking into account multiple sources of information.

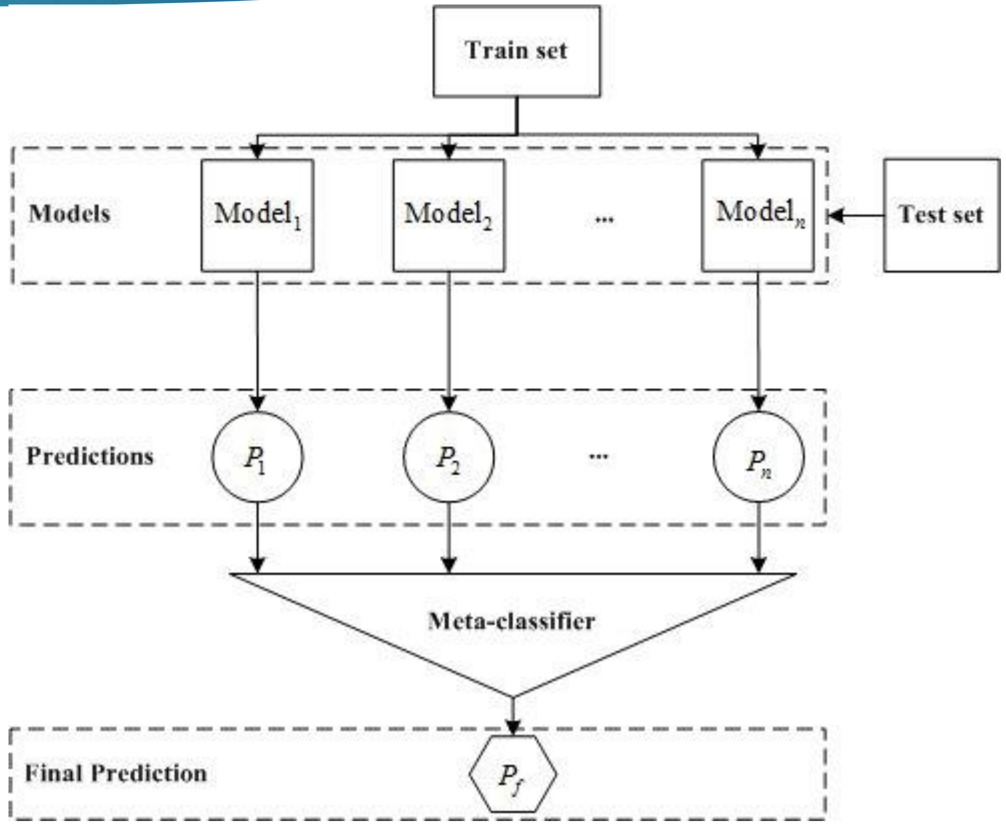


Image taken from W. Jiang et al, (IEEE Access, vol. 7, pp. 120337-120349, 2019)

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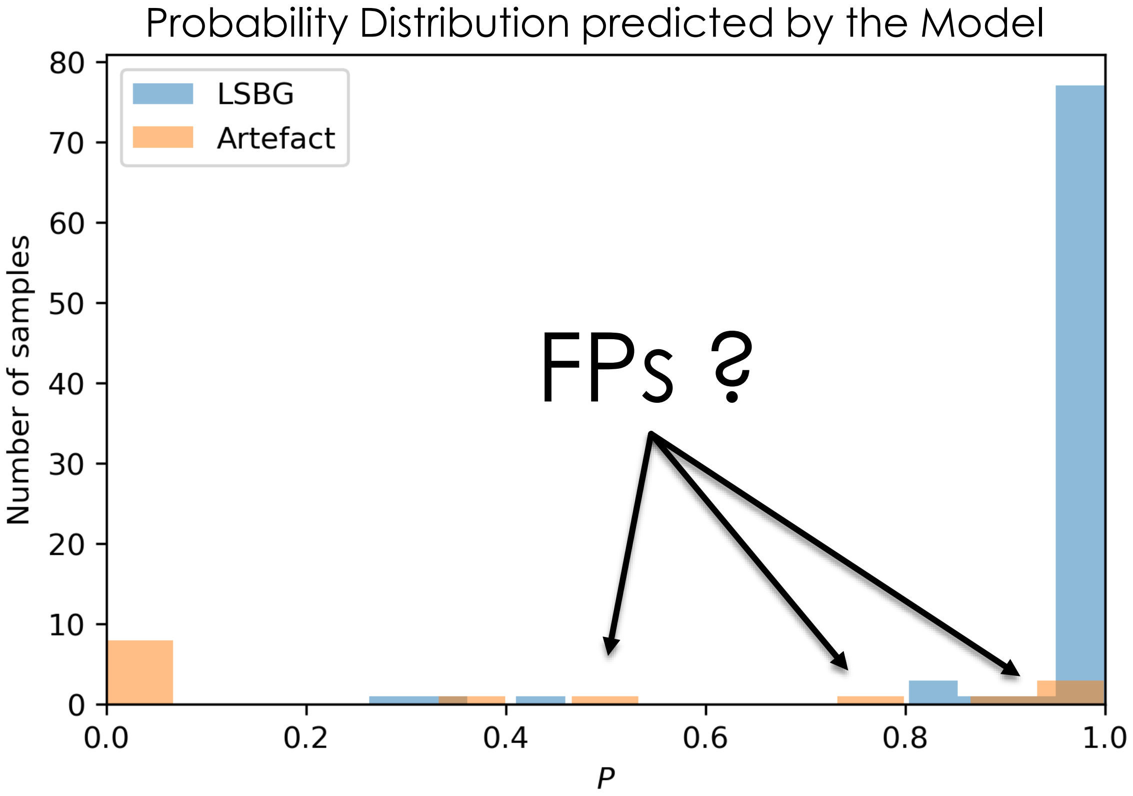
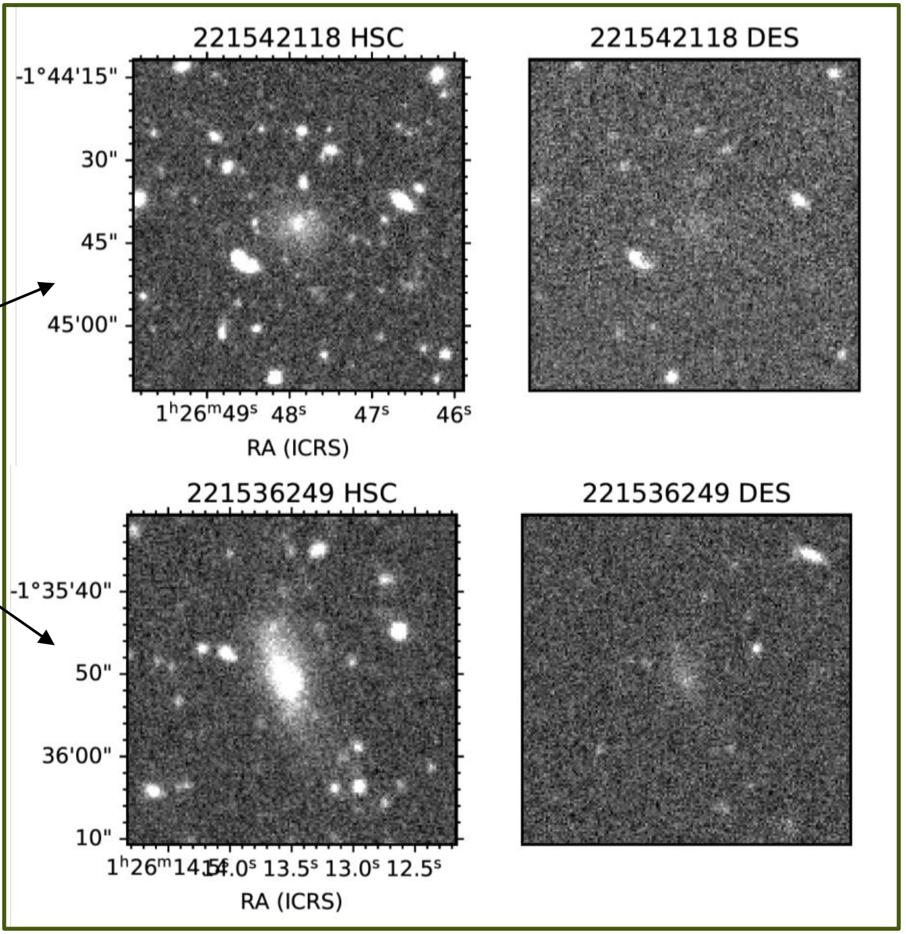
Performance on HSC Data with Known LSBS and Artefacts



FPs predicted by the model



Also identified 13/14 UDGs in the SMUDGES catalogue (Zaritsky+2023).