

Identification of Low-Surface Brightness Galaxies and studying their physical properties in the LSST Era

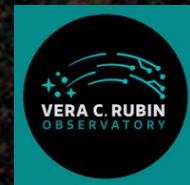
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Hareesh Thuruthipilly, Junais



Narodowe Centrum Badań Jądrowych
National Centre for Nuclear Research

ŚWIERK



Overview and Motivation

Data

Methodology

Results and future goals

Overview and Motivation

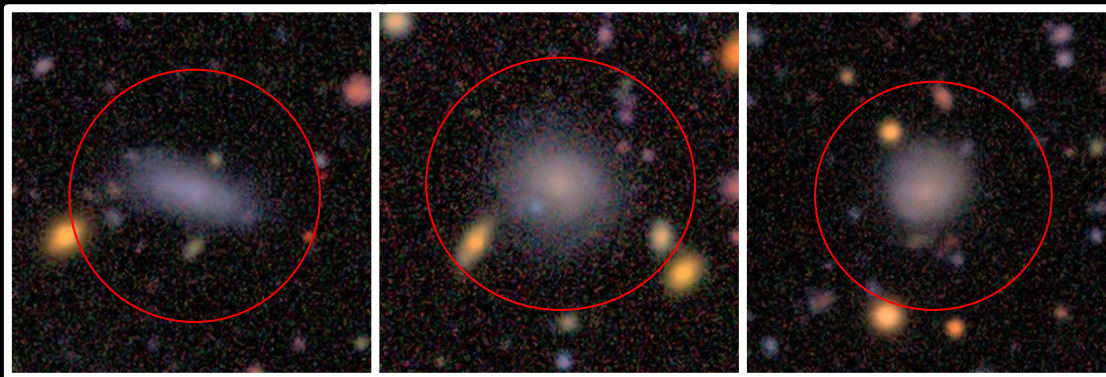
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LOW SURFACE BRIGHTNESS GALAXIES (LSBGs): WHY ARE THEY INTERESTING?

LSBGs are a class of galaxies fainter than the night sky, making them difficult to detect in optical surveys.



NGC 1312

Image credit: ESO.org

Examples of LSBGs identified by Tanoglidis et. al. 2021 in LSST Data Preview I

LSBGs: What makes them difficult to detect?

Surface brightness:

Flux per unit solid angle

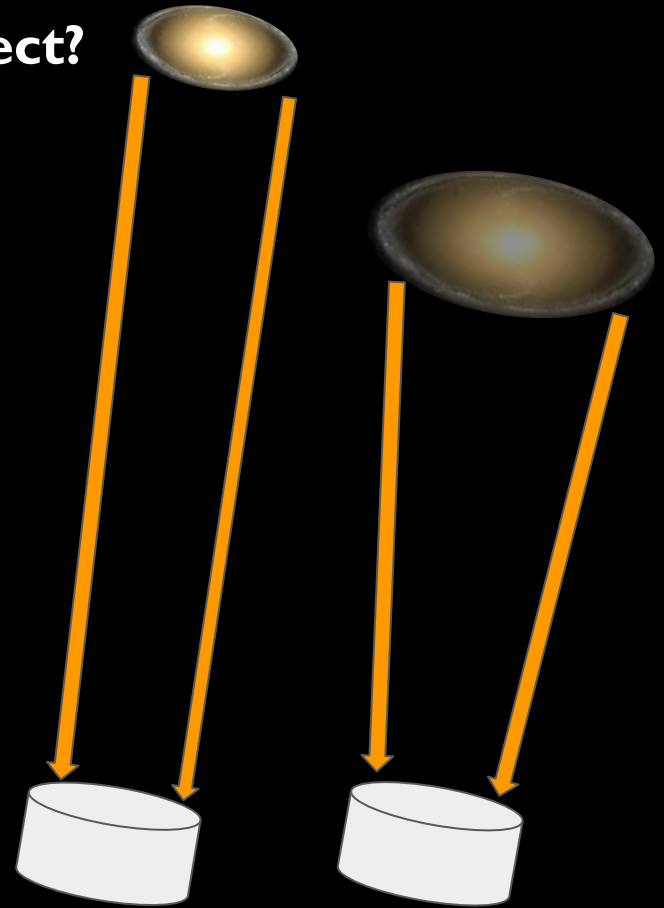
$$m = -2.5 \log_{10}(F/F_0)$$

$$\mu = m + 2.5 \log_{10} A$$

Source detection pipelines biased toward **high-surface brightness objects**

Galaxies with

- **Low stellar density**
- **Extended profiles**
→ **become hard to detect**



LOW SURFACE BRIGHTNESS GALAXIES (LSBGs): A formal definition

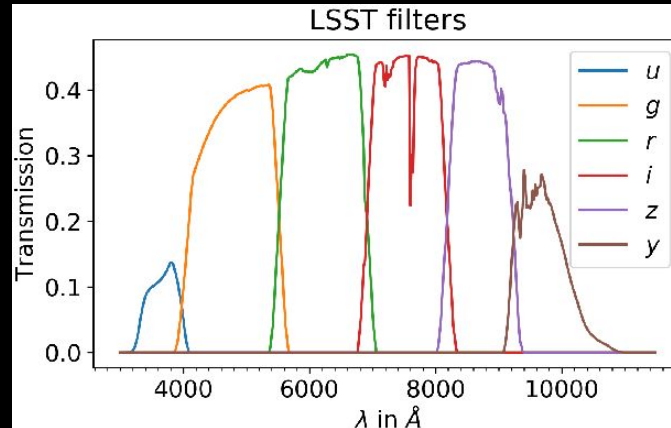
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- Mean surface brightness $\mu(g) > 24.2 \text{ mag/arcsec}^2$
(within half-light radius)

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- **Mean surface brightness $\mu(g) > 24.2 \text{ mag/arcsec}^2$**
(within half-light radius)
- **Size $> 2.5''$**
(Tanoglidis et. al. 2021 & Thuruthipilly et al. 2024)

Early Works on LSBGs

Publications of the
Astronomical Society of the Pacific

Vol. 109 1997 July

Publications of the Astronomical Society of the Pacific
109: 745-758, 1997 July

Invited Review Paper

Low-Surface-Brightness Galaxies

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Received 1997 February

ABSTRACT. In 20 years, low-surface-brightness galaxies have become a major discovery and the characterization of their population in the night-sky background is a strong testament to the progress of astronomy. LSB galaxies have a number of remarkable properties, including a wide sequence of spirals. The two most important features are their experience star formation outside of the dark-matter halos which are of low surface brightness. LSB galaxies are high-surface-brightness (HSB) disk galaxies dominated at all radii and show a system of dark-matter halos. In addition, the recognition that large numbers of LSB galaxies have a low galaxy luminosity function and has clear implications for galaxy formation surveys have uncovered a population of LSB galaxies detected at moderate redshifts. LSB galaxies are a new class of galaxies which is every bit as important as those processes which have dominated galaxy formation. Indeed, the apparent youth of some LSB galaxies suggest that galaxy formation is still an active process. While the discovery of LSB galaxies has led to new insights, it remains to be seen how long this process will last.

arXiv:astro-ph/9612070v1 6 Dec 1996

Testing the Dark Matter Hypothesis with Low Surface Brightness Galaxies and Other Evidence

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ABSTRACT

The severity of the mass discrepancy in spiral galaxies is strongly correlated with the central surface brightness of the disk. Progressively lower surface brightness galaxies have ever larger mass discrepancies. No other parameter (luminosity, size, velocity, morphology) is so well correlated with the magnitude of the mass deficit.

The rotation curves of low surface brightness disks thus provide a unique data set with which to probe the dark matter distribution in galaxies. The mass discrepancy is apparent from $R = 0$ giving a nearly direct map of the halo mass distribution. The luminous mass is insignificant.

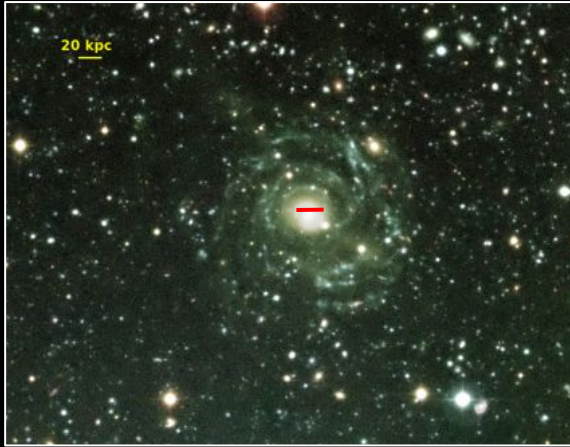
Interpreting the data in terms of dark matter leads to troublesome fine-tuning problems. Different observations require contradictory amounts of dark matter. Structure formation theories are as yet far from able to explain the observations.

Subject headings: cosmology; dark matter — galaxies: formation — galaxies: halos — galaxies: kinematics and dynamics — galaxies: structure — gravitation

What gets us into trouble is not what we don't know.
It's what we know for sure that just ain't so.
— Yogi Berra

arXiv:astro-ph/9801123v1 13 Jan 1998

The Diversity in LSBG population



Malin-1 Giant LSBG

Boissier et. al. 2016



Dwarf Galaxies

Lazar et. al. 2024

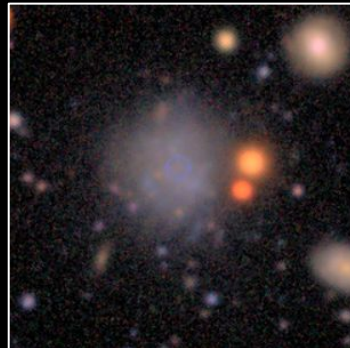


NGC 1052-DF2: a Dark Matter free UDG

Credits: science.nasa.gov
Van Dokkum et al. 2019

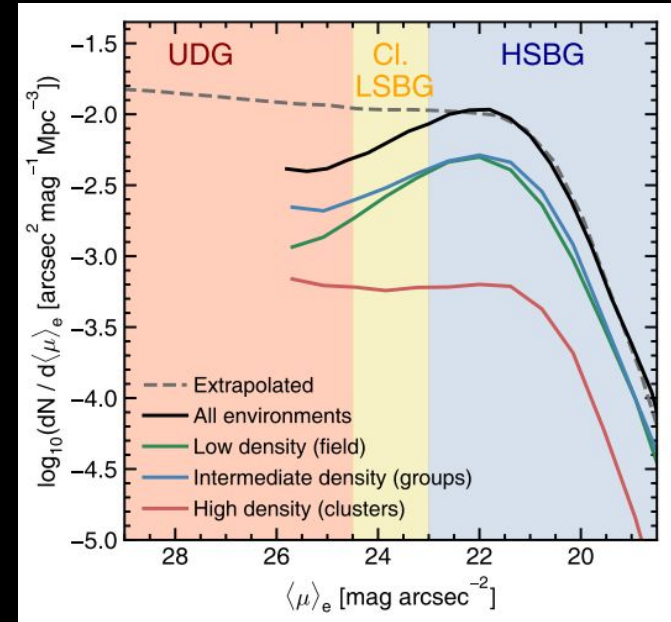
Ultra Diffuse Galaxy (UDG)

Romanowsky et. al. 2025



Low Surface Brightness Galaxies

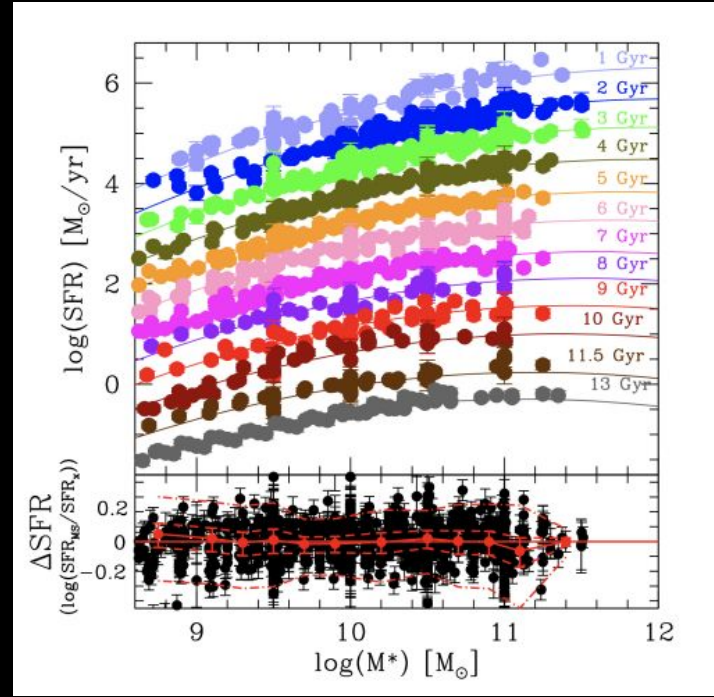
- Simulations suggest that a large fraction of the galaxy population should reside in the low-surface brightness regime (Martin et al. 2019)
- >50% of local number density (Martin et al. 2019)
- With wider and deeper telescopic observations, we surely must expect to find more LSBGs



Cosmological Context: What are we missing?

Incomplete picture of galaxy formation:

Completeness for main-sequence scaling relation of galaxies.



Popesso et. al. 2022

Cosmological Context:

- Λ CDM cosmology reliably explains large-scale structure
- Simulations vs Observations: The missing satellite problem: LSBGs?

For Milky-way:

- $\sim 100\text{--}300$ Dark Matter (DM) halos are expected to be massive enough to potentially host visible dwarf galaxies
- Observed $\sim 50\text{--}60$



Cosmological context: Dark Matter on Astrophysical Scales

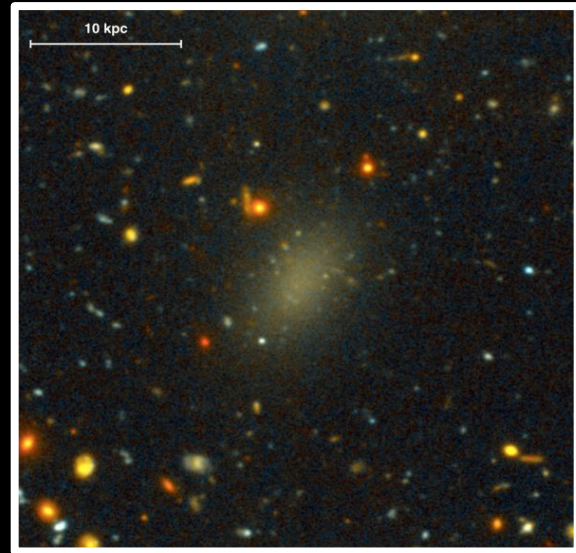
Dark Matter: Invisible mass in the Universe

LSBGs can potentially provide interesting insights?



NGC 1052-DF4: a DM free UDG

Credits: science.nasa.gov Van Dokkum et al. 2019



Dragonfly 44: a DM dominated UDG

Van Dokkum et. al. 2016

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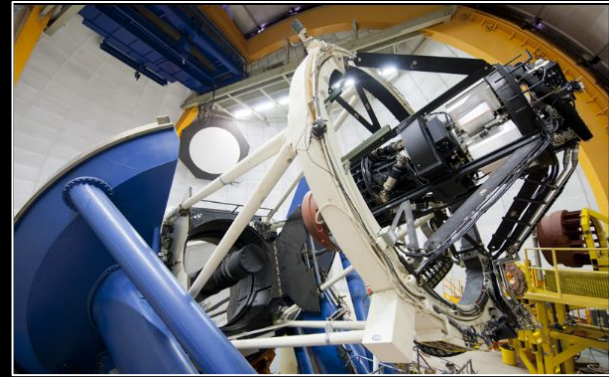
Results and future goals

LARGE OPTICAL SURVEYS

And the hunt for LSBGs

LSBGs studied in the Dark Energy Survey (DES)

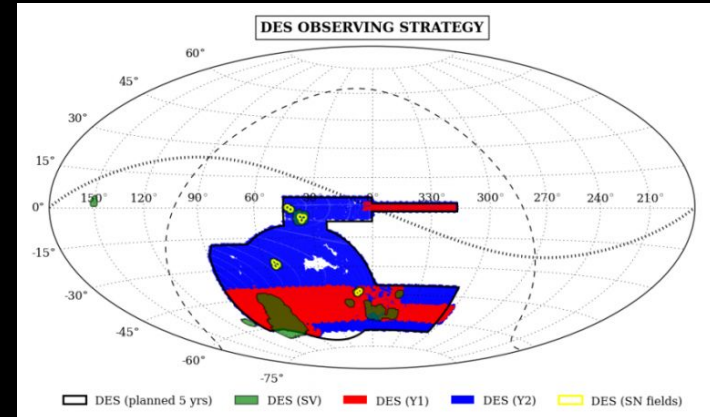
Conducted using DECam on the Víctor M. Blanco 4-m Telescope, Chile



DECam

DES

- Covered **~5000 deg²** of the southern sky.
- Dark energy survey point source depth **~ 24.5 mag**
- Imaged in **5 optical bands g, r, i, z, y**
- Survey duration: **2013–2019**



The Advent of the Legacy Survey of Space and Time (LSST)

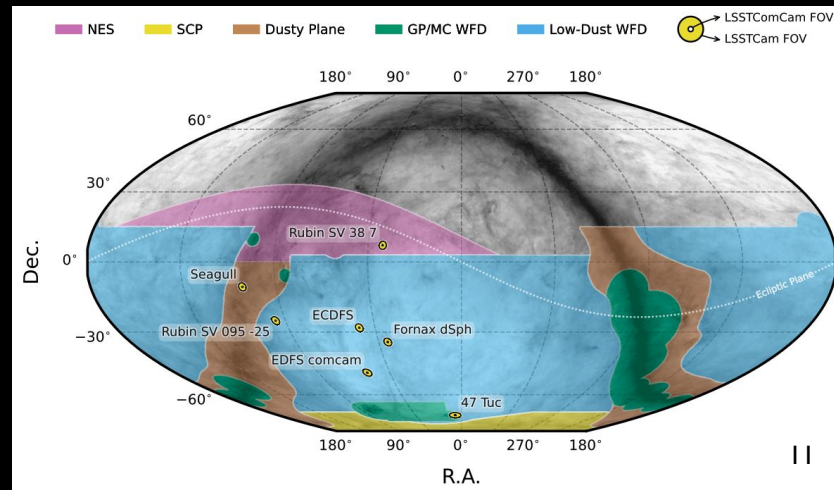
Vera C. Rubin: Located in Chile
8.4m mirror telescope, world's largest digital camera, 3.2 gigapixel resolution

Designed for a wide range of science cases from large scale structure to transients



LSST

- ~18,000 deg² in the Southern sky
- 10 year; point source depth: 27.5 mag in r-band
- Current depth in LSST Data Preview 1: 24.5
- u, g, r, i, z, y bands



DES

Depth: 24.5 mag

Area of coverage:
~5,000 deg²

LSST

Depth: 27.5 mag
(10 year survey)

Area of coverage:
~18,000 deg²

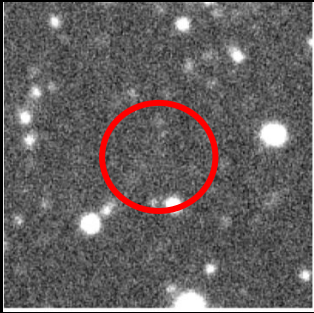
>27,000 LSBGs discovered in the footprint of
DES.

When we combine the samples from Tanoglidis et. al.
2021 and Thuruthipilly et. al. 2024

The Advent of Legacy Survey of Space and Time (LSST)

What to expect from LSST?

- Source detection pipelines not optimized for low surface brightness sciences.
- Simply scaling, **>100,000** LSBGs expected.
- But with new LSBGs also come loads of new contaminants



Nothing obvious~
Maybe diffused light
from nearby objects?



Tidal tails from nearby
galaxies



Diffused light from stars or nearby spiral galaxies

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Shift to Machine-Learning based techniques



Image credits: dople.ai

Image from: Hareesh Thuruthipilly

Transformers are deep learning models that excel in learning relevant features of an input.

We use pre-trained transformers which were trained on Dark Energy Survey data and adapt them to work in the LSST environment

We match the domains of DES data and LSST data

Surface brightness normalization across different surveys.

Integrating Transformers in the Rubin Science Platform

The screenshot shows the homepage of the Rubin Science Platform. At the top, there are logos for VERA C. RUBIN OBSERVATORY, U.S. National Science Foundation (NSF), and U.S. DEPARTMENT of ENERGY Office of Science. Below the logos is a navigation menu with links for Portal, Notebooks, APIs, Documentation, Support, and Community. A user profile dropdown for 'saptarshipal' is visible in the top right. The main content area features a large title 'Rubin Science Platform' with a 'PREVIEW' button below it. Three main sections are highlighted: 'Portal' (Discover data in the browser), 'Notebooks' (Process and analyze LSST data with Jupyter notebooks in the cloud), and 'APIs' (Learn how to programatically access data with Virtual Observatory interfaces). Each section includes an illustration and a 'Learn more' link.

VERA C. RUBIN
OBSERVATORY

U.S. National
Science Foundation

U.S. DEPARTMENT
of ENERGY | Office of
Science

Portal Notebooks APIs Documentation Support Community

saptarshipal

Rubin Science Platform

PREVIEW

Portal
Discover data in the browser
Learn more about the portal.

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*Data Preview 1 and future releases will be hosted on the Rubin Science Platform (RSP)
All analysis will be conducted by users “next-to-the-data”*

Identification methodology of LSBGs

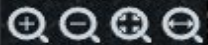
Initial catalog
selection of
potential LSBG
candidates



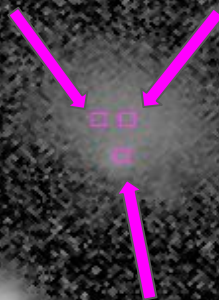
LSBG/ non-LSBG
confidence for each
candidate.



Visual inspection?
Photometric studies
of the LSBG
candidate outputs



Challenges in initial catalog selection



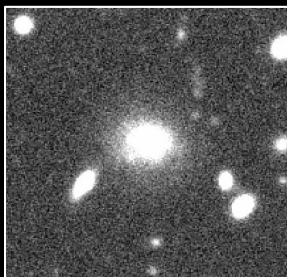
2.5 ''

Shredding, unreliable catalog estimates for LSB candidates

Re-estimation of photometry for LSBG candidates

Galfit (Peng et. al. 2002)

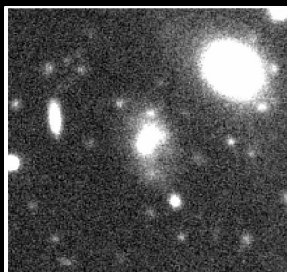
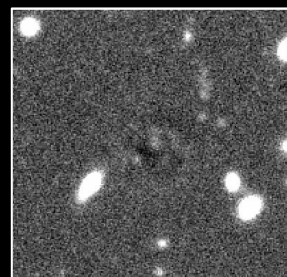
Original



Model



Residual



Parameters:

Centroid of the galaxy

Sersic Index

Effective Radius

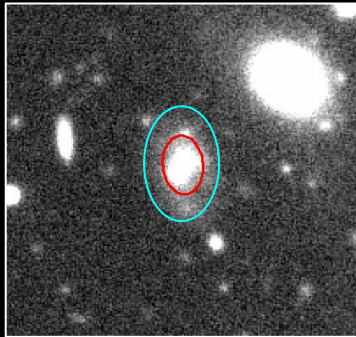
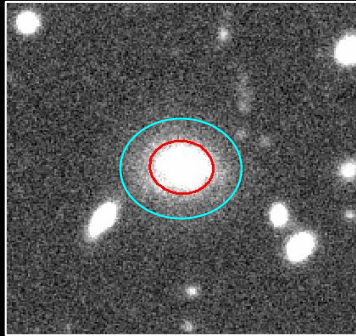
Magnitude

Axis ratio

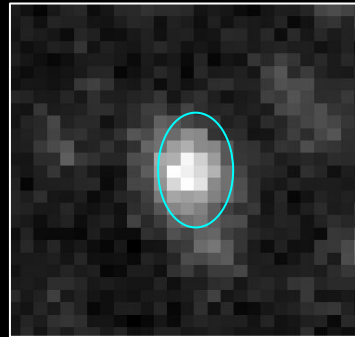
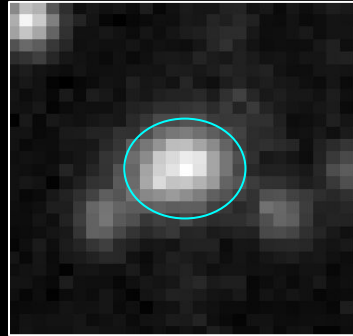
Position angle

Multi-band characterization of LSBGs

LSST i-band



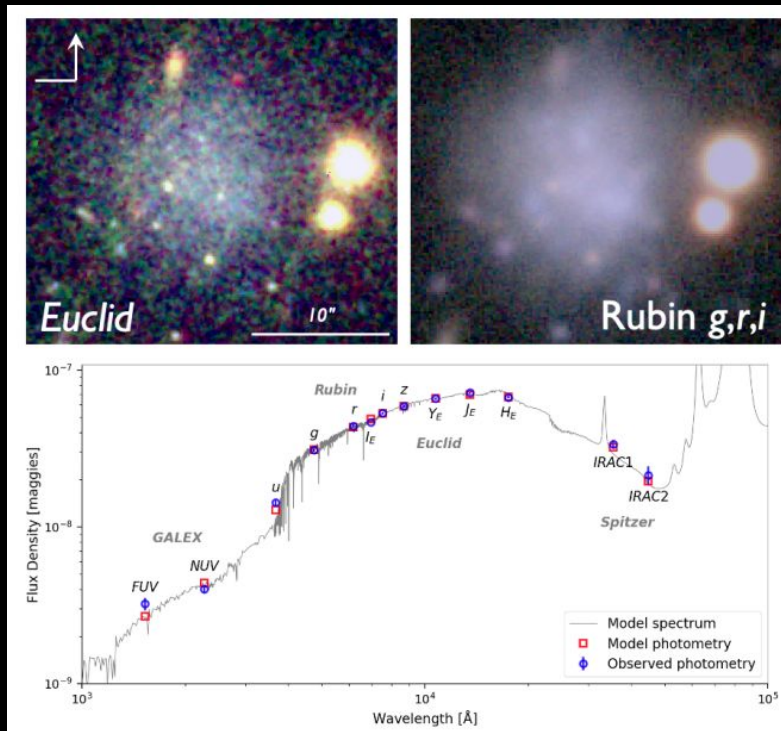
Galex (NUV)



Aperture photometry

Estimating fluxes across different bands which would be useful for spectral energy distribution (SED) fitting of galaxies

Spectral Energy Distribution Fitting of LSBGs



Estimate parameters for the galaxy:

Input model parameters:
Star formation history
Dust attenuation
Stellar populations
Metallicity

Star Formation Rate
Dust Content
Stellar-Mass of the galaxy
Infrared Luminosity

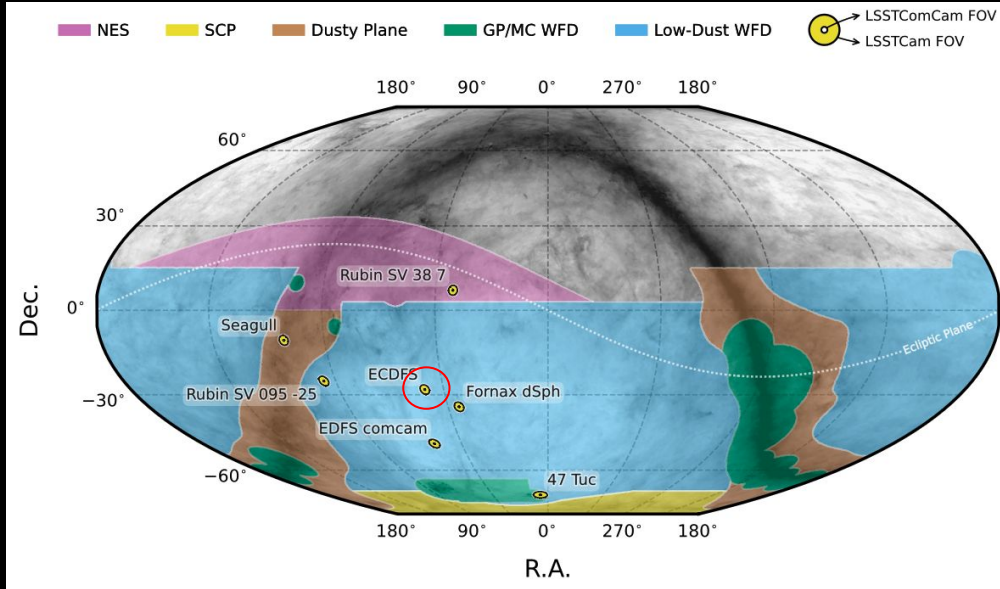
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Sample selection



Region of overlap where we studied LSBGs: EDFS

9 previously known LSBGs cross-matched, and confirmed by the transformers

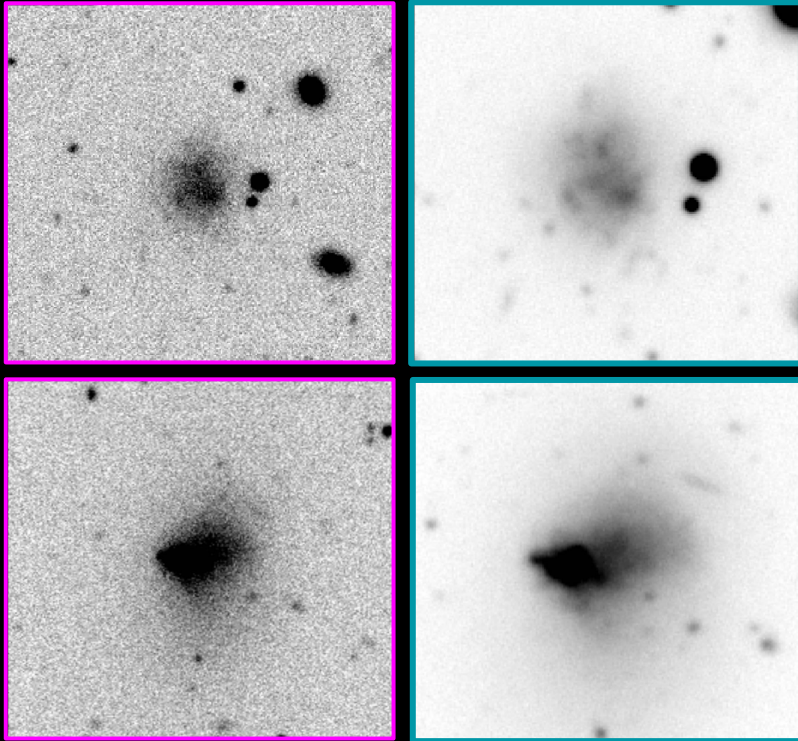
3 new LSBGs added to the sample

We make our own photometric measurements for all these sources and estimate their physical properties

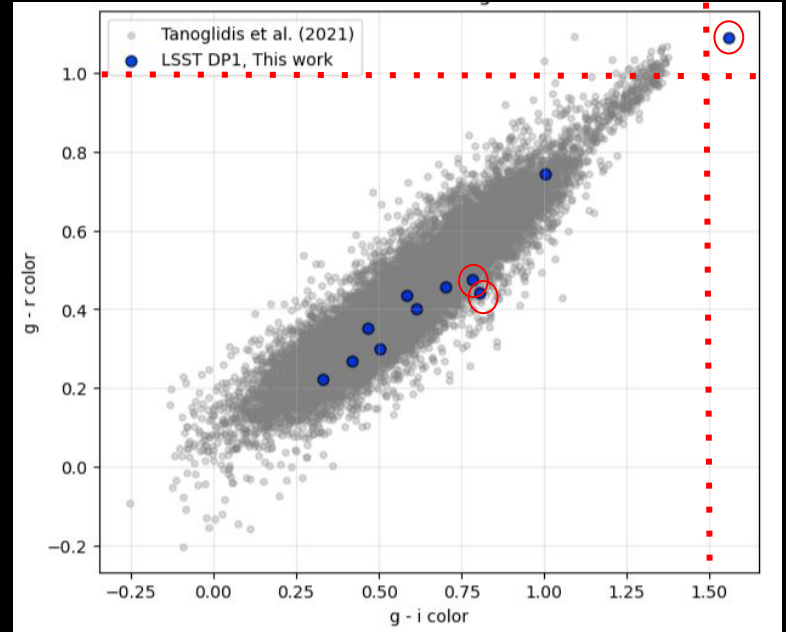
DES overlap with DPI

DES DRI

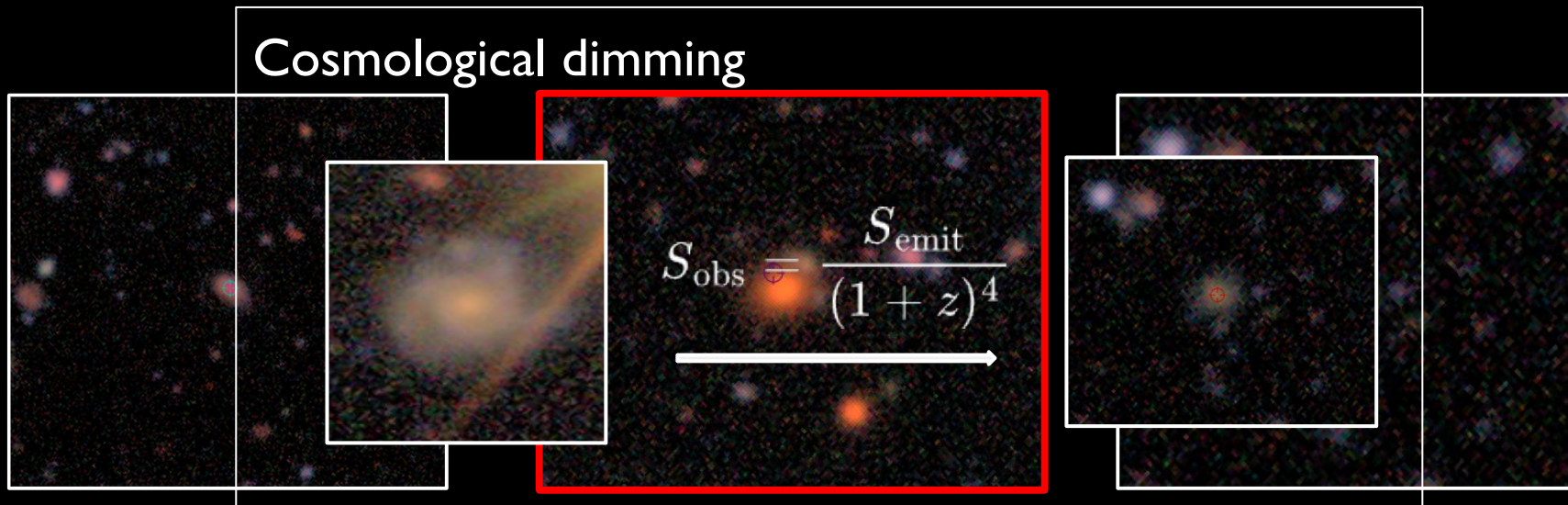
LSST-DPI



All galaxies in the common sample are identified as LSBGs by the transformers

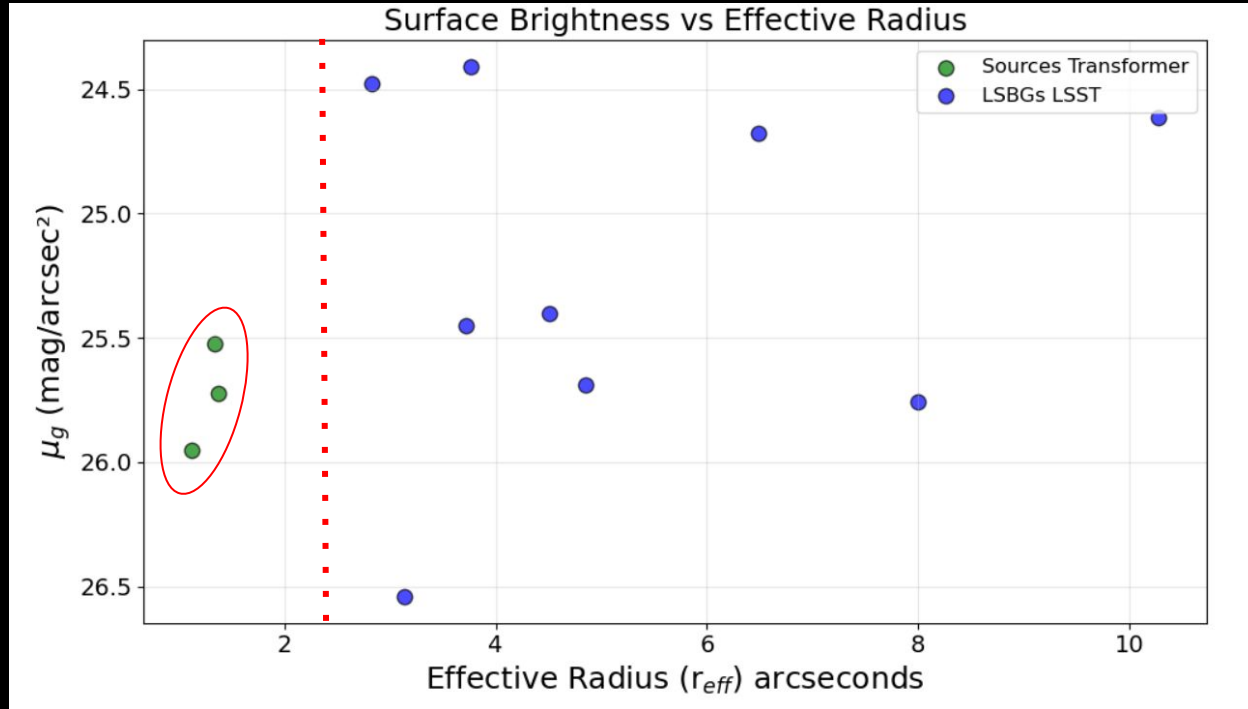


Background galaxies?



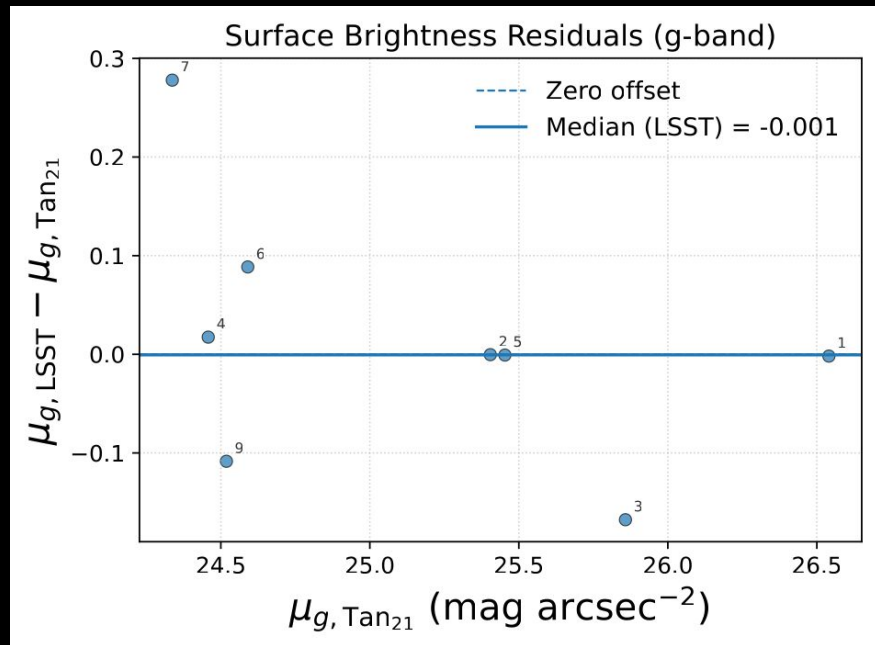
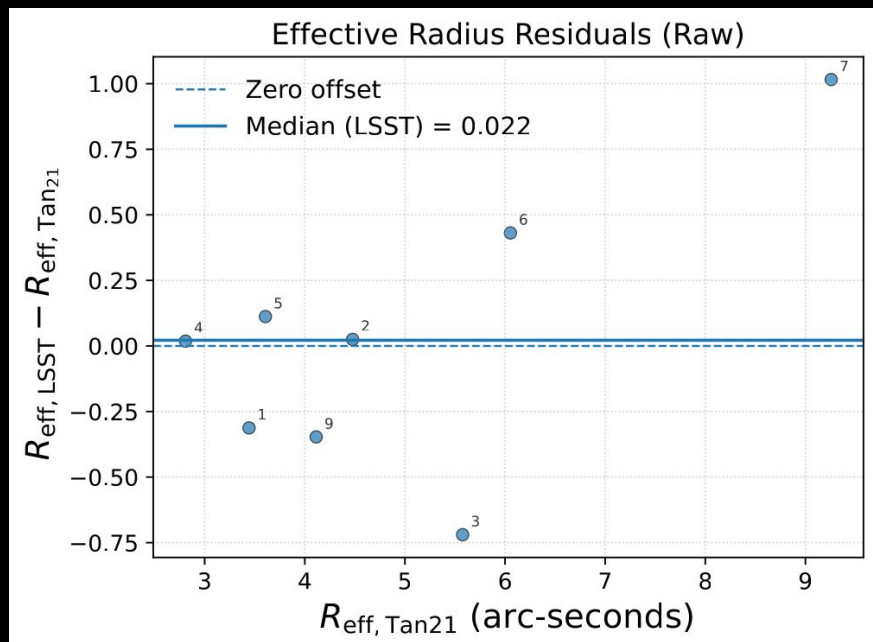
LSST DPI galaxies picked up by our object catalog, flagged as LSBGs by the transformers

DES overlap with DPI



Weeding out non-LSBGs

Comparison between Surveys for LSBGs in the ECDFS region



LSST Data Preview-1 (DPI): released June 2025

LSST Data Preview-2 (DP2): to be released soon

LSST Data Release-1 (DR1): To be released in 2 years

Data analysis pipelines ready to scale-up

Future works and plans

Expanding the population of LSBGs in the LSST footprint using transformers and photometry based selections

Photometric classification and statistical studies of the sample of LSBGs

Characterizing physical properties using SED fitting techniques

Testing the Dark Matter Hypothesis with Low Surface Brightness Galaxies and Other Evidence

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ABSTRACT

The severity of the mass discrepancy in spiral galaxies is strongly correlated with the central surface brightness of the disk. Progressively lower surface brightness galaxies have ever larger mass discrepancies. No other parameter (luminosity, size, velocity, morphology) is so well correlated with the magnitude of the mass deficit.

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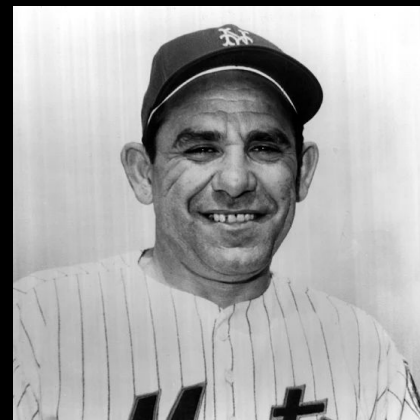
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It's what we know for sure that just ain't so.
— Yogi Berra

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~ Yogi Berra (American baseball catcher)



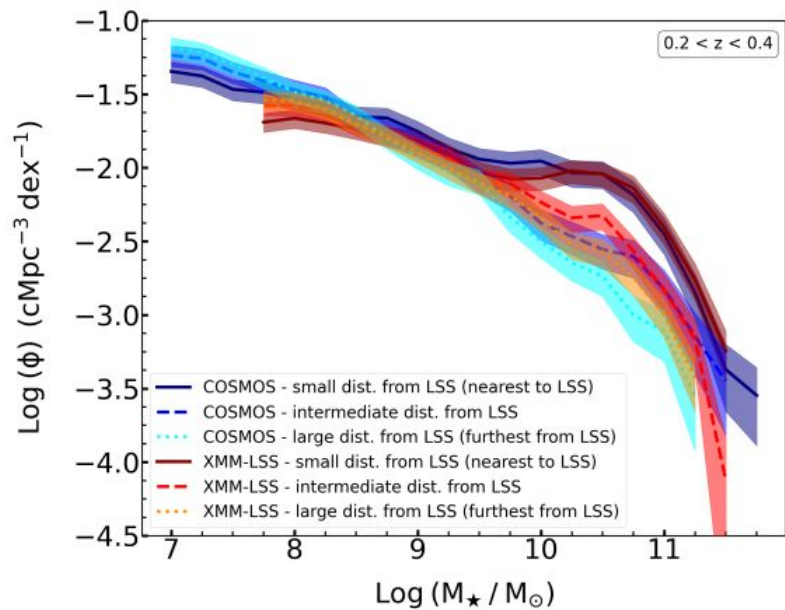


Figure 3. The galaxy stellar mass function for the COSMOS and XMM-LSS fields in different environments. Galaxies at small distances from LSS (i.e. nearest to LSS) are defined as those that reside in the lowest tercile (0th – 33rd percentile values) of both the distances to nodes and the distances to filaments. Galaxies at intermediate and large distances from LSS are defined as those that reside in the middle (33rd – 66th percentile values) and upper (66th – 100th percentile values) terciles of both the distances to nodes and the distances to filaments respectively.

Supplement

$$\Sigma(r) = \Sigma_e \exp \left[-\kappa \left(\left(\frac{r}{r_e} \right)^{1/n} - 1 \right) \right].$$

