Assessing the potential impact of the LSST sky subtraction algorithm on galaxies science

Aaron E. Watkins, LJMU PDRA

with Chris Collins (LJMU) & Sugata Kaviraj (Hertfordshire)

and the Princeton LSST Data Management team

Motivation: the LSB Universe

- A pipeline that treats LSB flux well treats *all* extended objects well
- LSB science comprises much of the extra-galactic discovery space with LSST and other surveys
- Past surveys (e.g., SDSS) had high limiting SB (~24—25 mag/arcsec^2)
- LSST potentially capable of reaching 30—31 mag/arcsec^2
  - LSST covers the southern sky, so has overlap with SKA, ASKAP, and MeerKAT
- If so, many areas of science will open or expand
  - Dwarf galaxies/UDGs (right)
  - Intracluster/intragroup light
  - Tidal features/galactic halos
  - Galactic cirrus/extended emission regions
  - Comet tails
- **But LSB science requires LSB-specific data reduction!**
  - Specifically, **sky subtraction** must be accurate

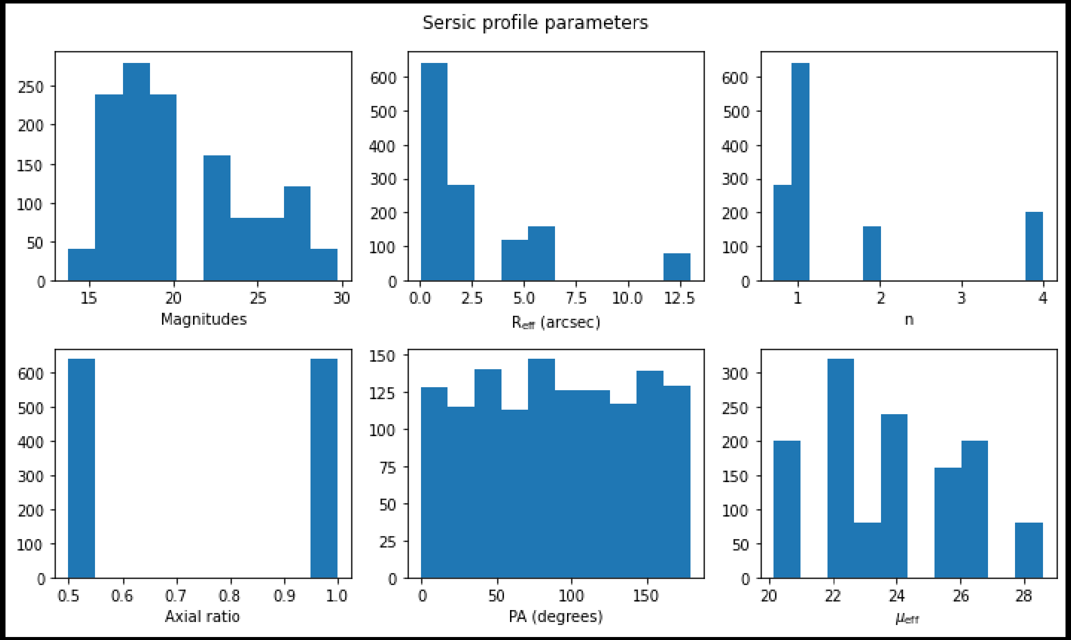
DF44 (van Dokkum et al. 2015)
"Ultra-diffuse galaxy"
Image credit: Teymoor Saifollahi and NASA/HST

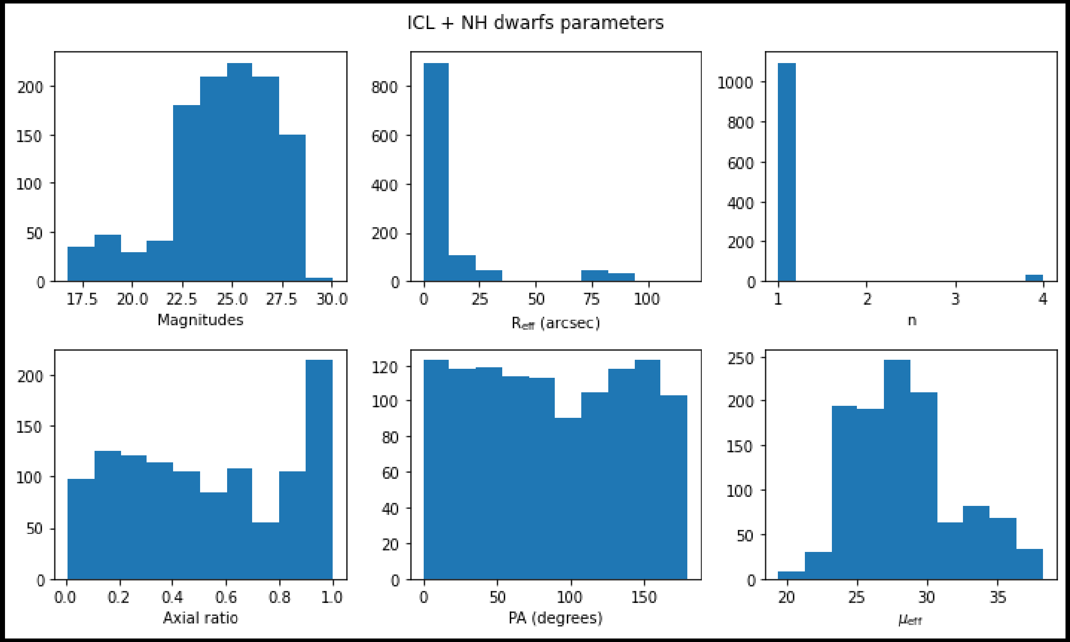
Pipeline Testing Strategy

- Want to see how sky subtraction is doing for LSB flux
- Testing the *current* version of the pipeline, so working directly with DM team
- Using catalogues of model galaxies (next slide)
- Aperture photometry: measuring model profiles at pixel-level both before and after SS, then comparing
- Primary metric: change in model magnitudes post-sky-subtraction
- Alternative metrics:
    1. Change in model flux/area post-SS
    2. Change in model surface brightness profiles post-SS

Model Suites Summary

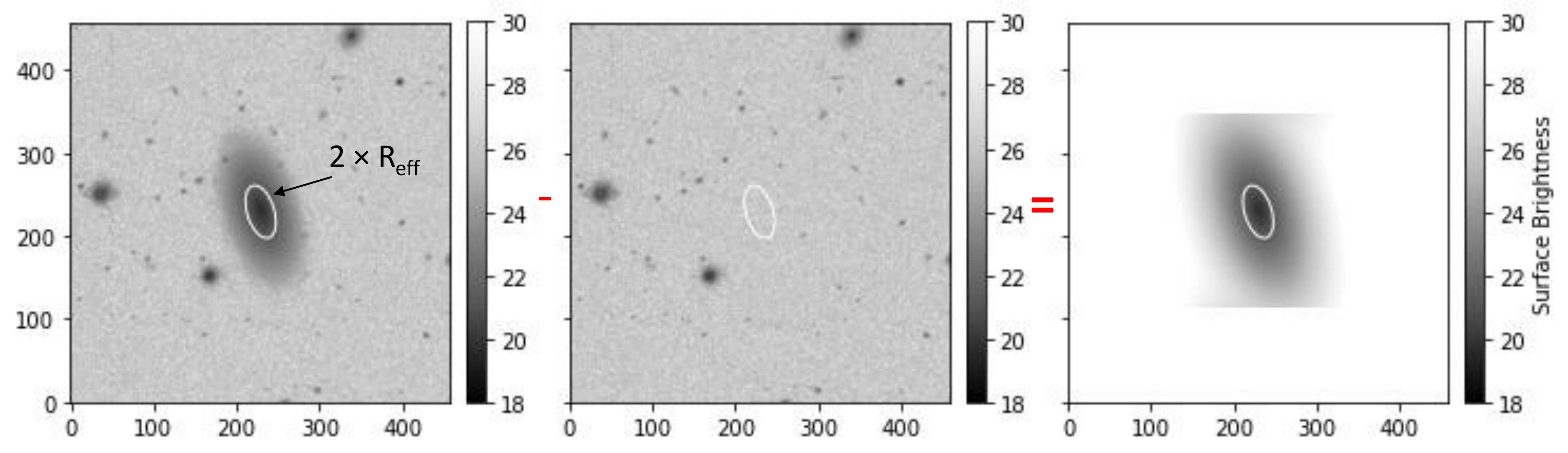
- Suite 1: single Sérsic profiles, parameters in grid drawn from scaling relations
- 40 repeats per grid point, distributed semi-randomly through Tract 9615 in GAMA-15 fields
- For bright galaxy outskirts, LSB disks, dwarfs, and UDGs





- Suite 2: ICL models and New Horizon dwarfs
- ~100 ICL + ~1000 dwarfs
- Using same tract (to preserve dithering pattern)
- For large angular size, LSB objects and higher redshift LSB dwarf galaxies

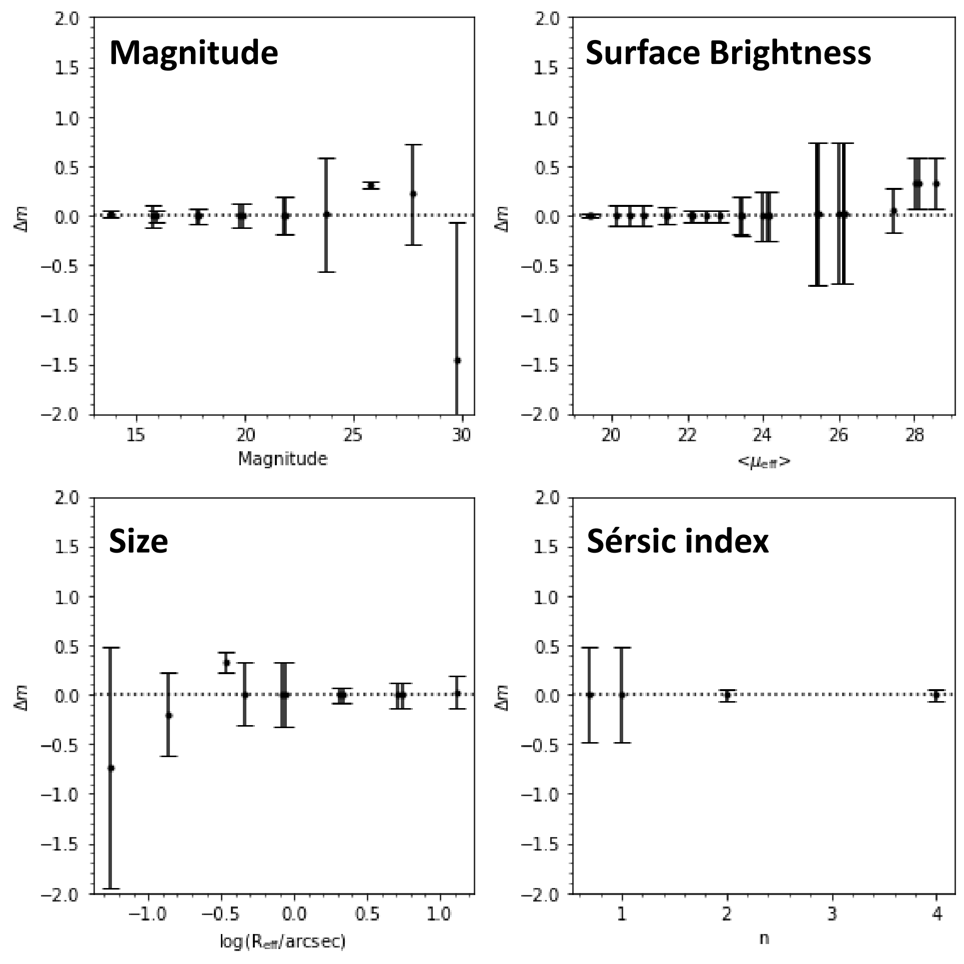
Photometry Demonstration



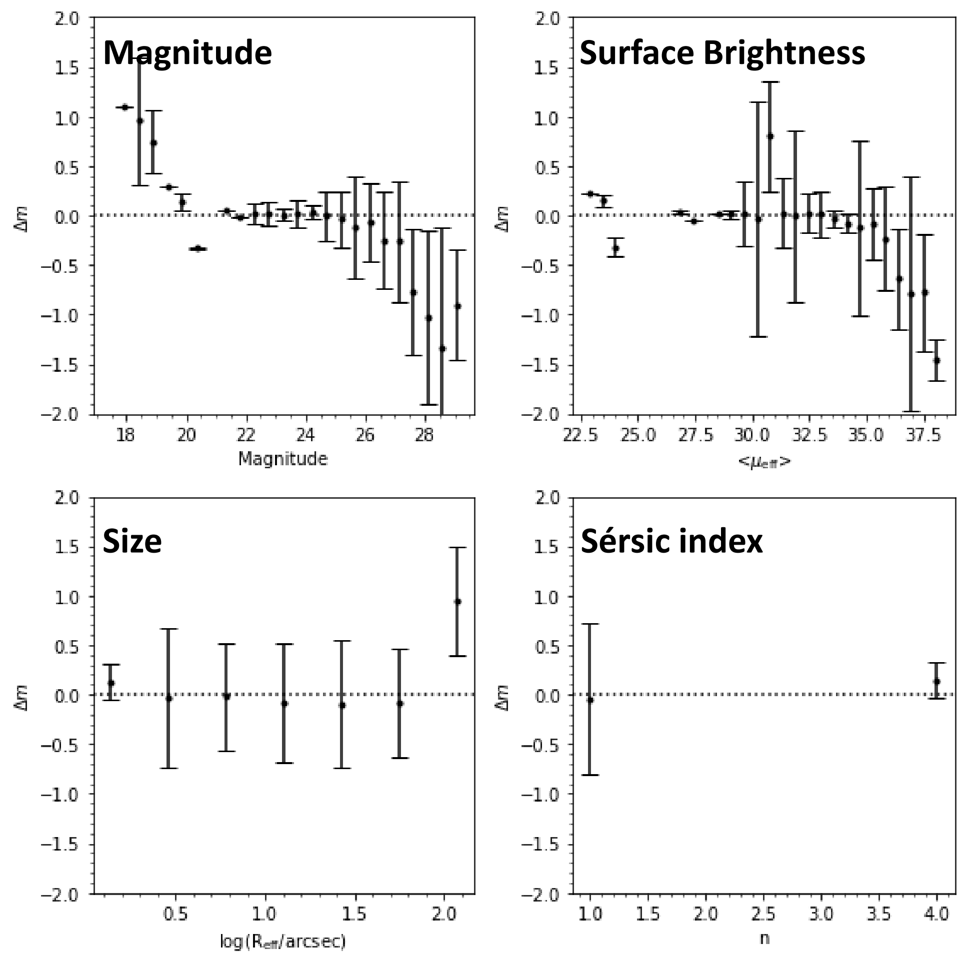
- Image with model, subtract image without model, yields only the model
- Do the same on image post-SS, yields only model post-SS
- All models truncated to μ = 32.0 to save space

Model Magnitude Changes

SÉRSIC MODELS

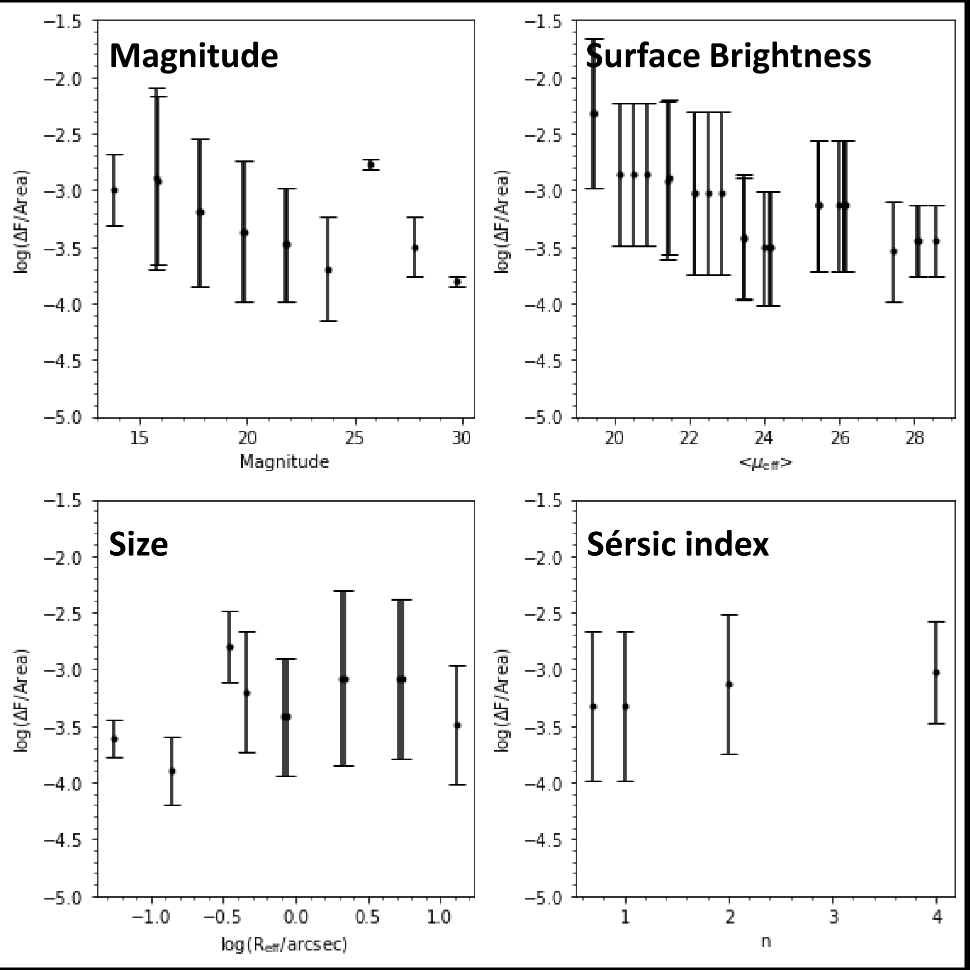


ICL+NH DWARFS

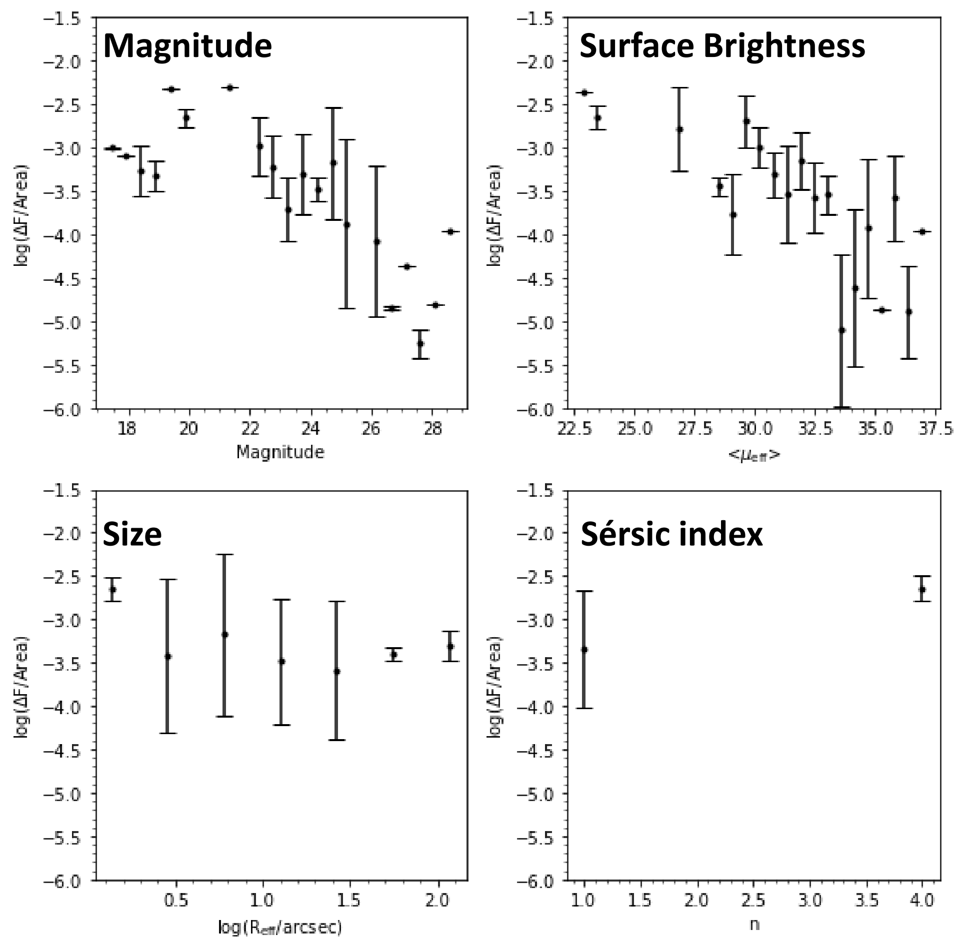


Total Flux Lost per Unit Area

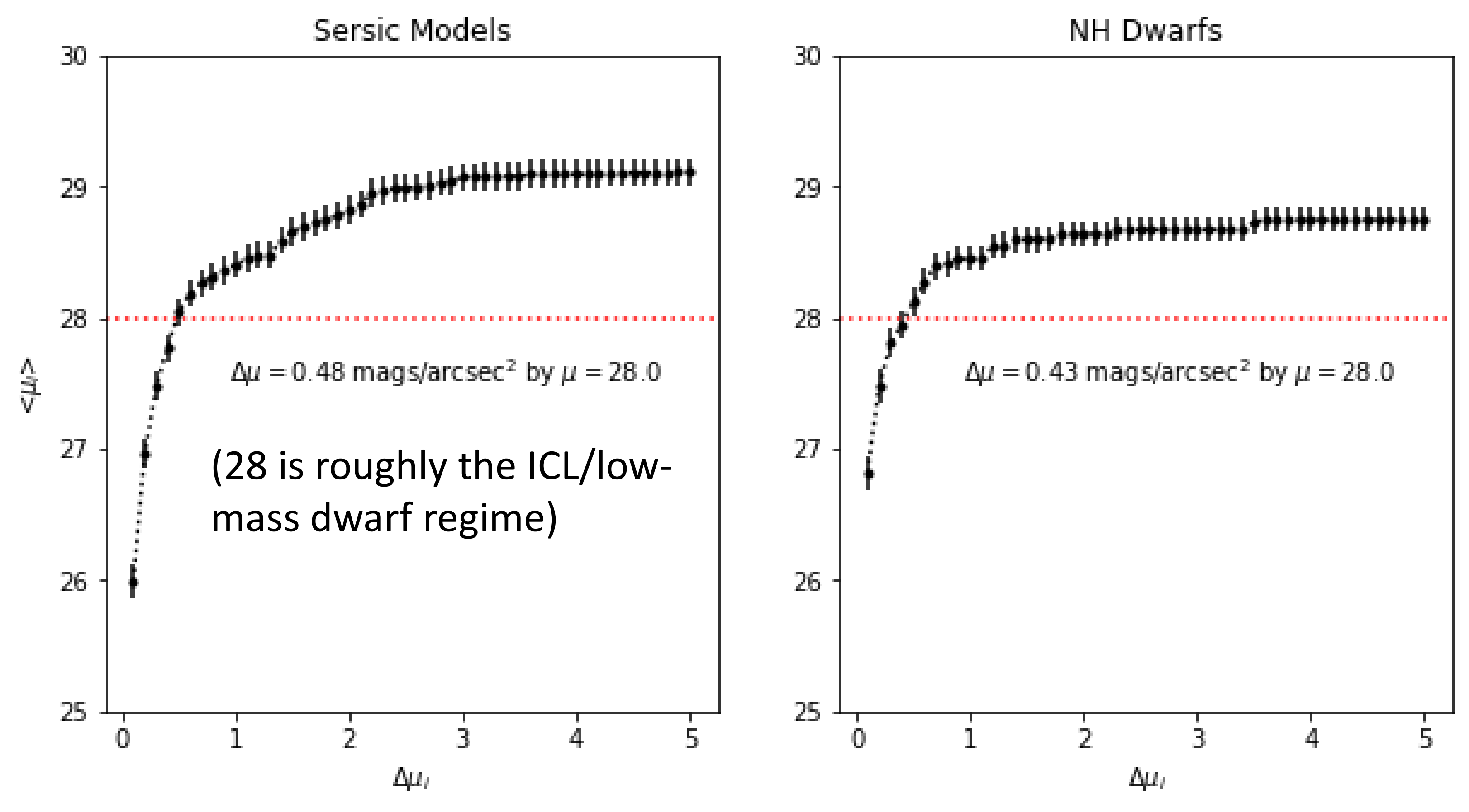
SÉRSIC MODELS



ICL+NH DWARFS



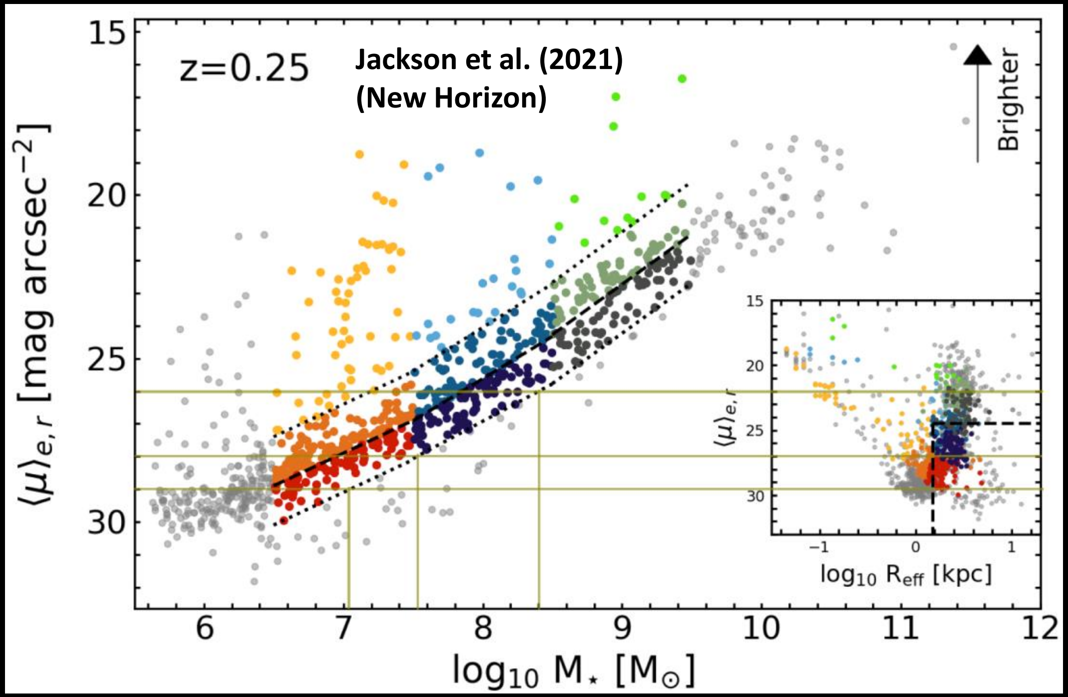
Over-subtraction vs. Surface Brightness



- X-axis = amount of over-subtraction in surface brightness profiles post-SS
- Y-axis = median SB of isophote among all models at which that amount of over-subtraction occurs
- Dark ring problem (HSC PDR1) has not vanished, but has moved to lower SB

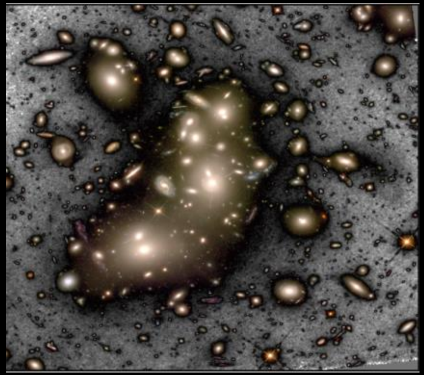
SUMMARY: most flux lost below μ≈26; LSB models show biggest magnitude changes

Potential Impact on Galaxy Mass Completeness



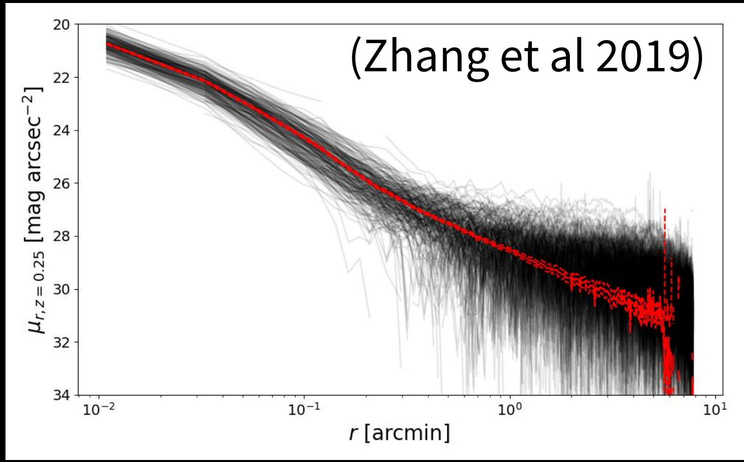
- Taking μ = 26 mag/arcsec^2 as a starting point:
  - Mass incompleteness for galaxies sets in around $10^{8.5}$ $M_\odot$ at z=0.25
  - Higher for higher z
  - To probe unexplored region of parameter space in nearby Universe, need at least μ = 28 mag/arcsec^2

Potential Impact on Intracluster Light



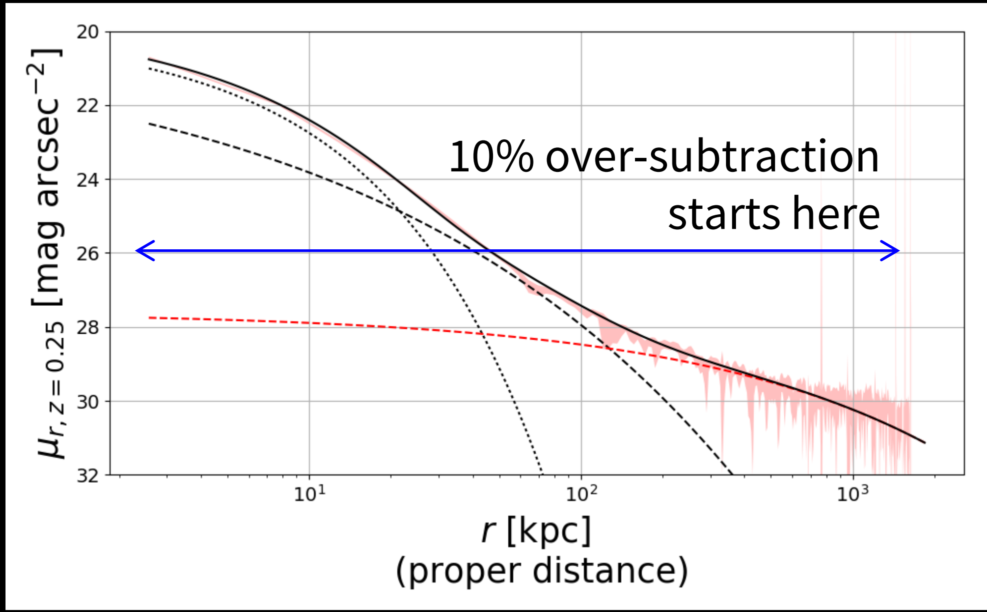
HFF cluster A2744
z=0.348
(Montes & Trujillo 2019)

- Studies to z>1 are needed to understand cluster evolution and constrain cluster mass distribution (e.g. Burke et al, 2015, Montes & Trujillo 2019, Zhang+ 2019) with deep LSST data



Raw ICL+BCG profiles and stack (red)

Sample: 300 clusters z=0.2-0.3 from DES Year 1 (Zhang et al 2019)



Diffuse ICL (red) dominates >200 kpc to 1 Mpc at **~28-30 mag arcsec^2**: this data is typical of rich relatively local clusters at z=0.2-0.3

Strong impact on ICL studies currently

Potential Solutions

- HSC-PDR1: used tight local sky estimations to produce full-focal-plane solution
- If the same problem is present here, can mitigate in two ways:
  1. Better masking: want to avoid the wings of extended objects being included in the local sky estimation (see work by Lee Kelvin)
  2. Swapping to a more global sky model to minimize the impact of masking
- The first solution is potentially a very simple way to improve things by a few orders of magnitude
- The second is ideal, and might be necessary to achieve our goal of μ=30—31 mag/arcsec^2, but is more difficult to implement
  - Specifically, large angular size objects like ICL might require this

Summary

- We are testing the *current* version of the LSST sky-subtraction using model galaxy injections
- At the moment, systematic >10% over-subtraction of flux for $\mu>26$ mag/arcsec^2 is yielding measurable changes in total model magnitudes for faint, LSB models and ICL models
  - With non-zero scatter even for bright models
  - Bright models are also losing substantial flux (more per unit area than faint models); fraction lost is merely small enough not to affect total magnitudes as much
  - ICL fare worst of all: on average 1 magnitude loss of flux
- Fainter surface brightnesses are affected much more than brighter surface brightnesses, resulting in dark donuts in models' faintest wings
- LSB science currently strongly affected, with some potential impact on all galaxies science
  - Next step is to discuss and start work on mitigation