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

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and the Princeton LSST Data Management team

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Motivation: the LSB Universe

- A pipeline that treats LSB flux well treats *all* extended and/or faint objects well
- LSB science comprises much of the extragalactic discovery space with LSST and other surveys
  - Intracluster/intragroup light
  - Stellar halos/tidal features
  - Disk truncations
  - LSB galaxies, including dwarfs (including UDGs) through giants (e.g., Malin 1)
- But not limited to extragalactic science
  - Galactic cirrus, extended emission line regions (e.g., Hanny's Voorwerp)
  - Milky Way/Local Group stellar streams
  - Comet tails, zodiacal light
- Past surveys (e.g., SDSS) had high limiting SB (~24—25 mag/arcsec^2)
- LSST potentially capable of reaching 30—31 mag/arcsec^2
  - Even one shot w/LSST will be as deep as SDSS Stripe 82
  - And LSST covers the southern sky, so has overlap with SKA, ASKAP, and MeerKAT

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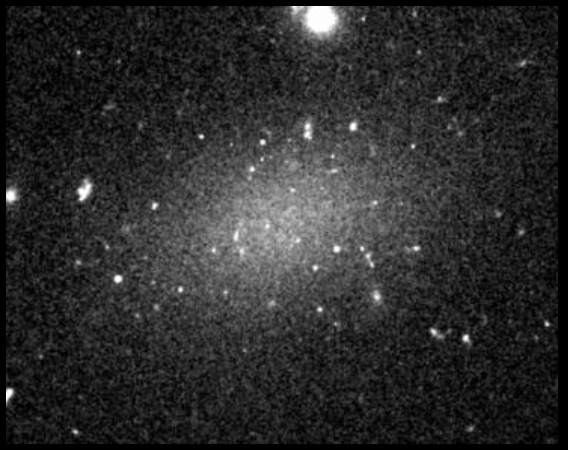
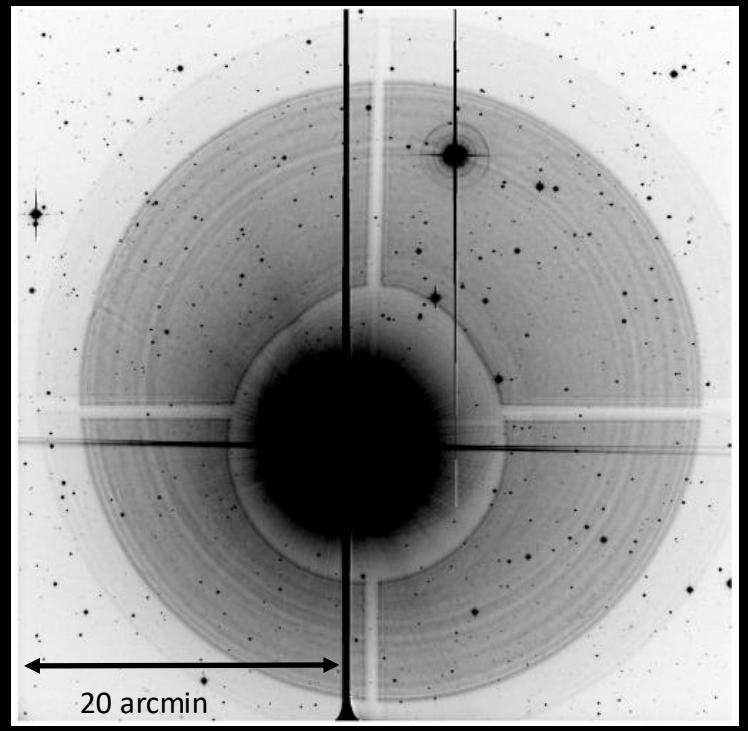


DF44 (van Dokkum et al. 2015)
"Ultra-diffuse galaxy"
Image credit: Teymoor Saifollahi and NASA/HST

Data Reduction for LSB

- More exposure time != more depth!
- Metric is magnitudes/arcsec^2: coherent flux over an area
- Systematics are thus key
  - Flat-fielding better than 1% across entire focal plane
  - Clean removal of instrumental signatures
  - Avoid or remove scattered light
  - Night sky subtraction
    - LSB flux can lie 100s to 1000s of times fainter in surface brightness than the night sky!
- For LSST, DM team controls ISR, but scattered light + **sky subtraction** are potentially alterable
  - The latter is where we come in



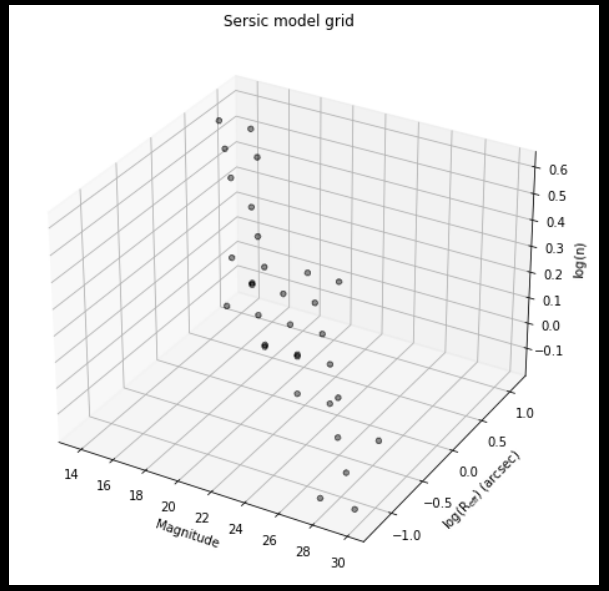
Burrell Schmidt Telescope 450s exposure of Arcturus, V-band (Slater et al. 2009)

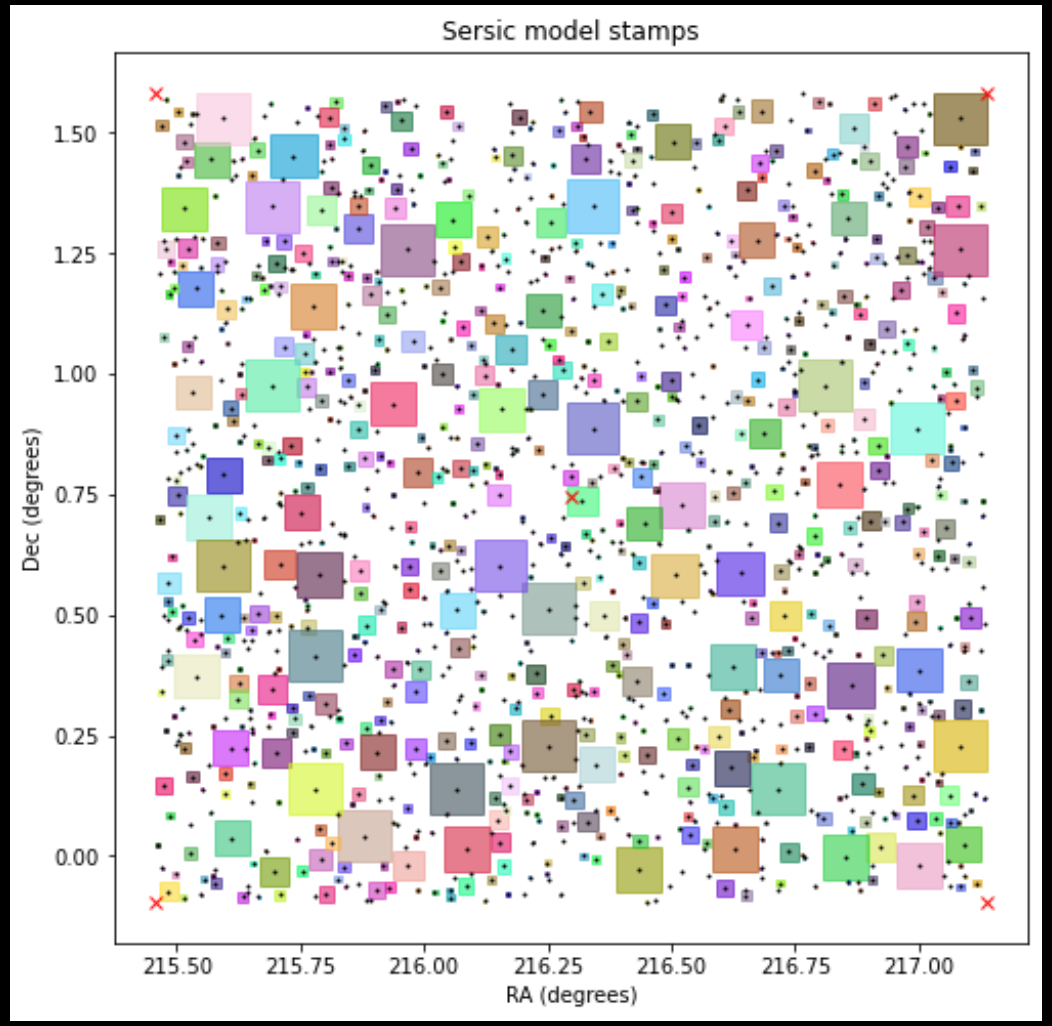
Pipeline Testing Strategy

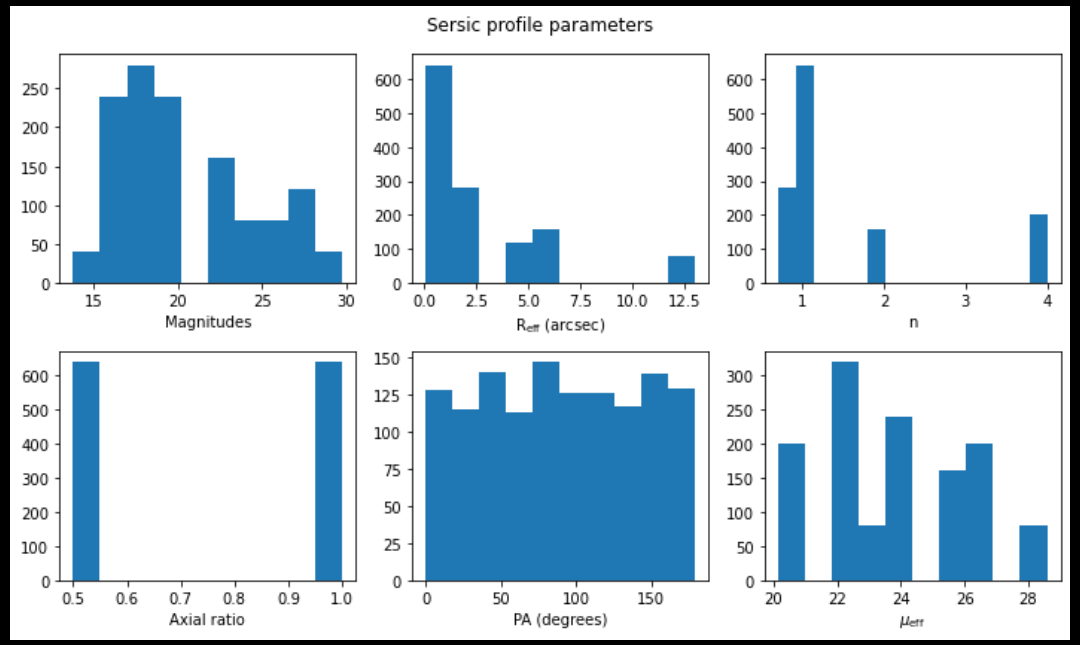
- Testing the *current* version of the pipeline, so working directly with DM team
- Assessing the sky subtraction's impact using catalogues of model galaxies
  - Next two slides
- Aperture photometry: measuring model profiles at pixel-level both before and after SS, then comparing
- Primary metric: change 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 Suite 1

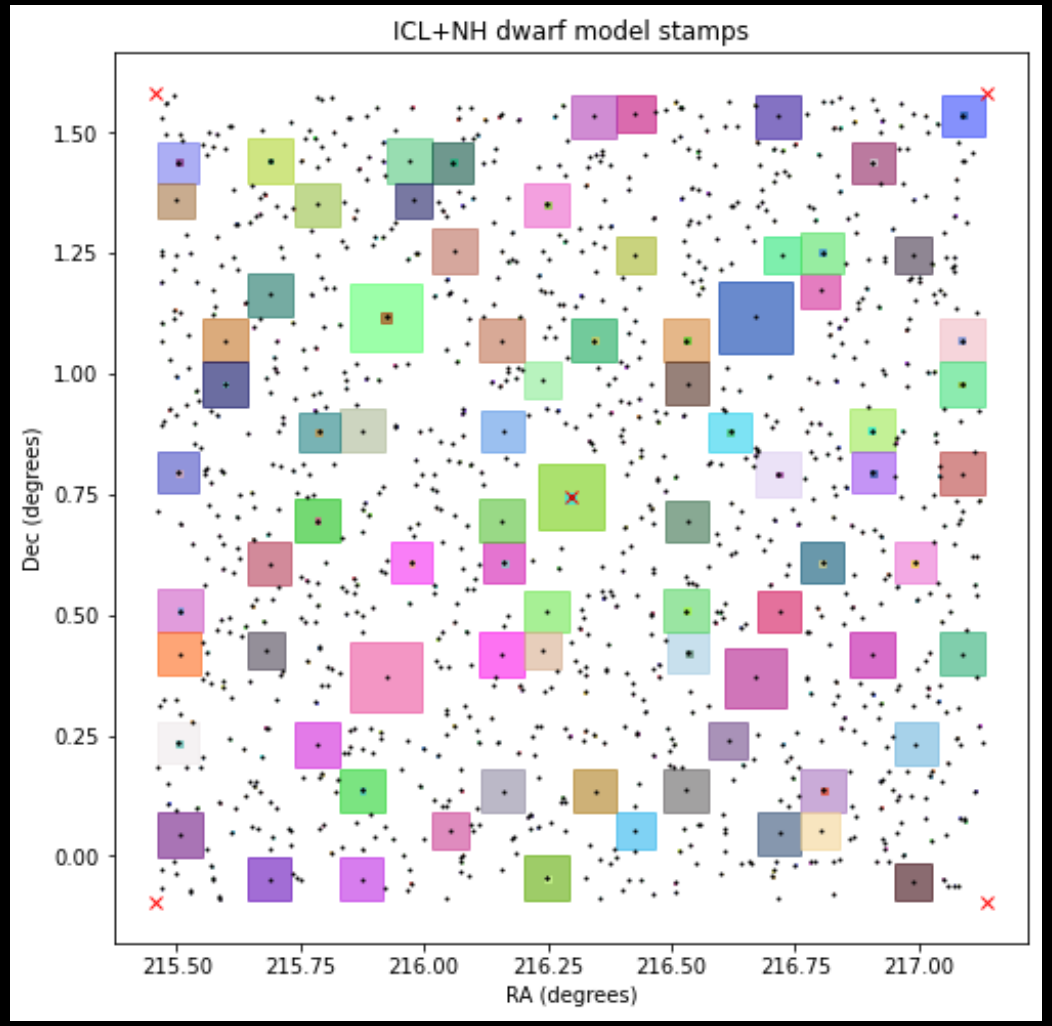
- Grid of parameters
- On-sky distribution
- Full parameter space





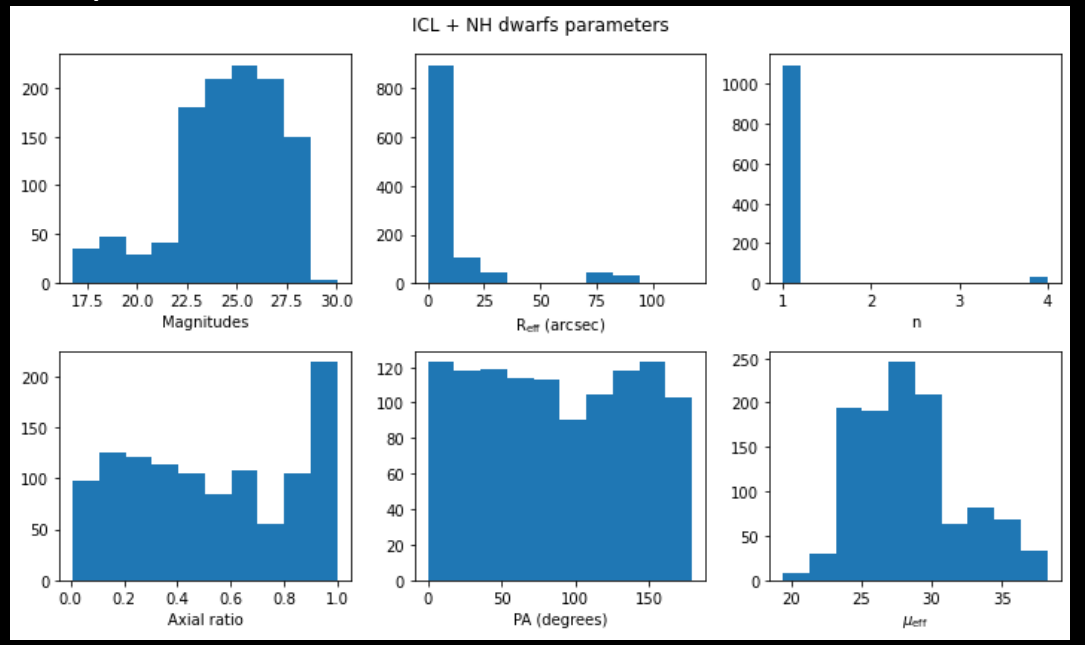


Model Suite 2

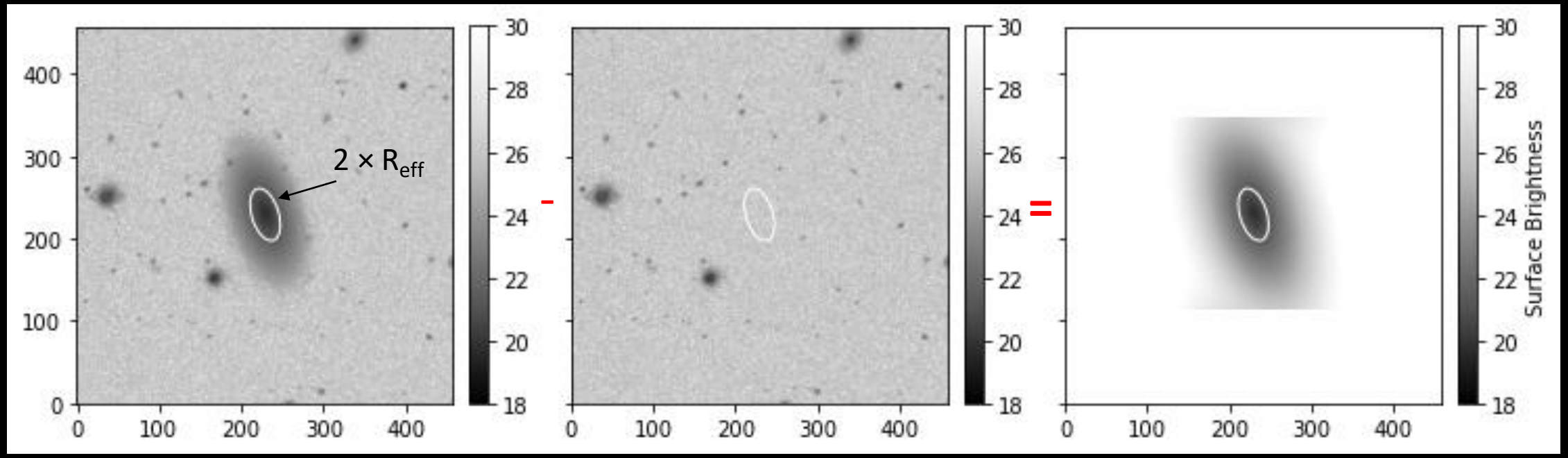


- On-sky distribution
- Full parameter space

Includes model ICL (n=1), model BCGs (n=4), and NH dwarfs



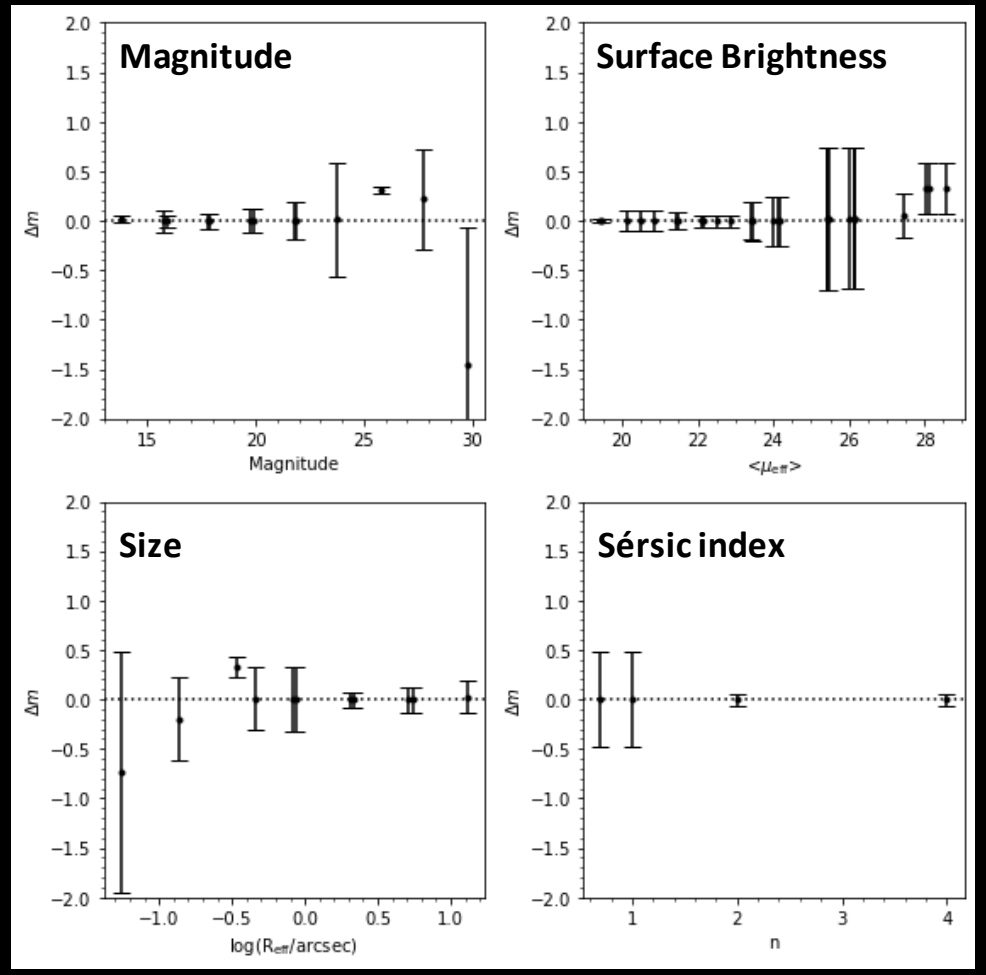
Photometry Demonstration



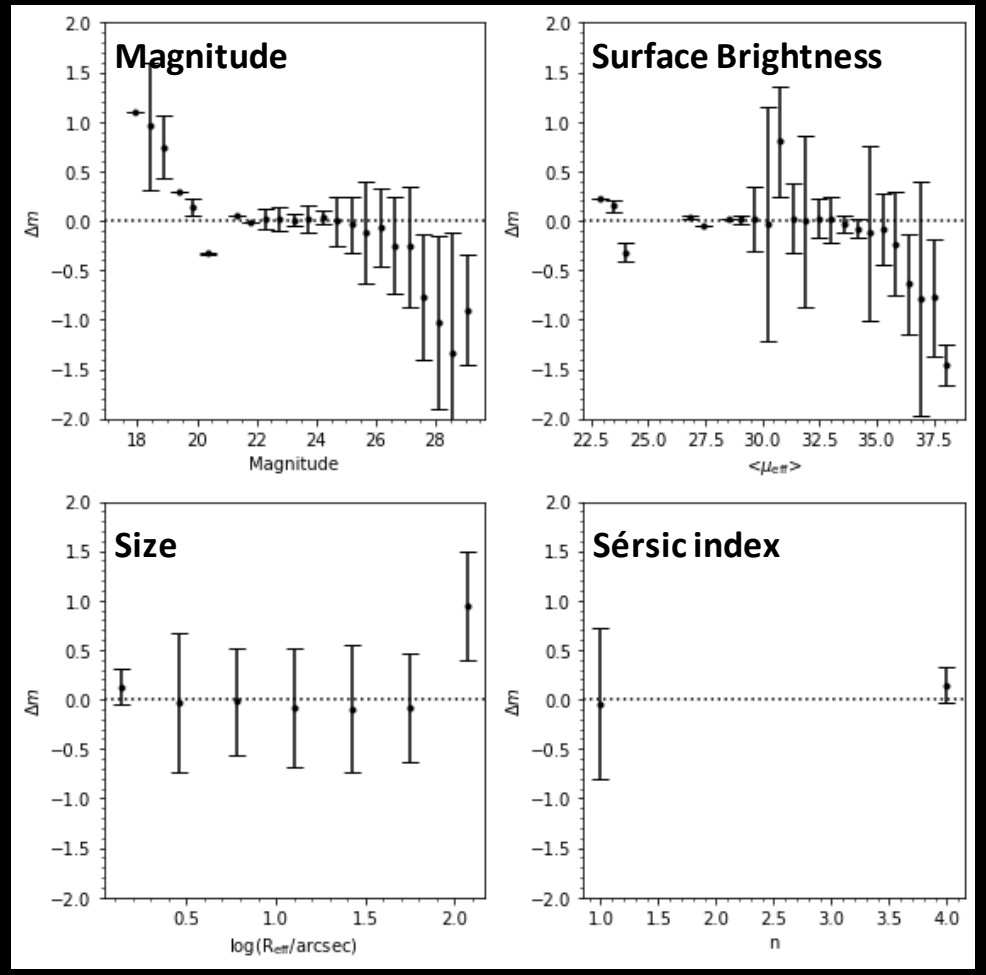
- Image with model, subtract image without model, yields only the model
- Do the same on image post-SS, yields only model+changes induced in SS by the model
  - Image + model + SS - (Image + SS w/o model) = ΔSS + Model
- All models truncated to μ = 32.0 to save space

Model Magnitude Changes

SÉRSIC MODELS

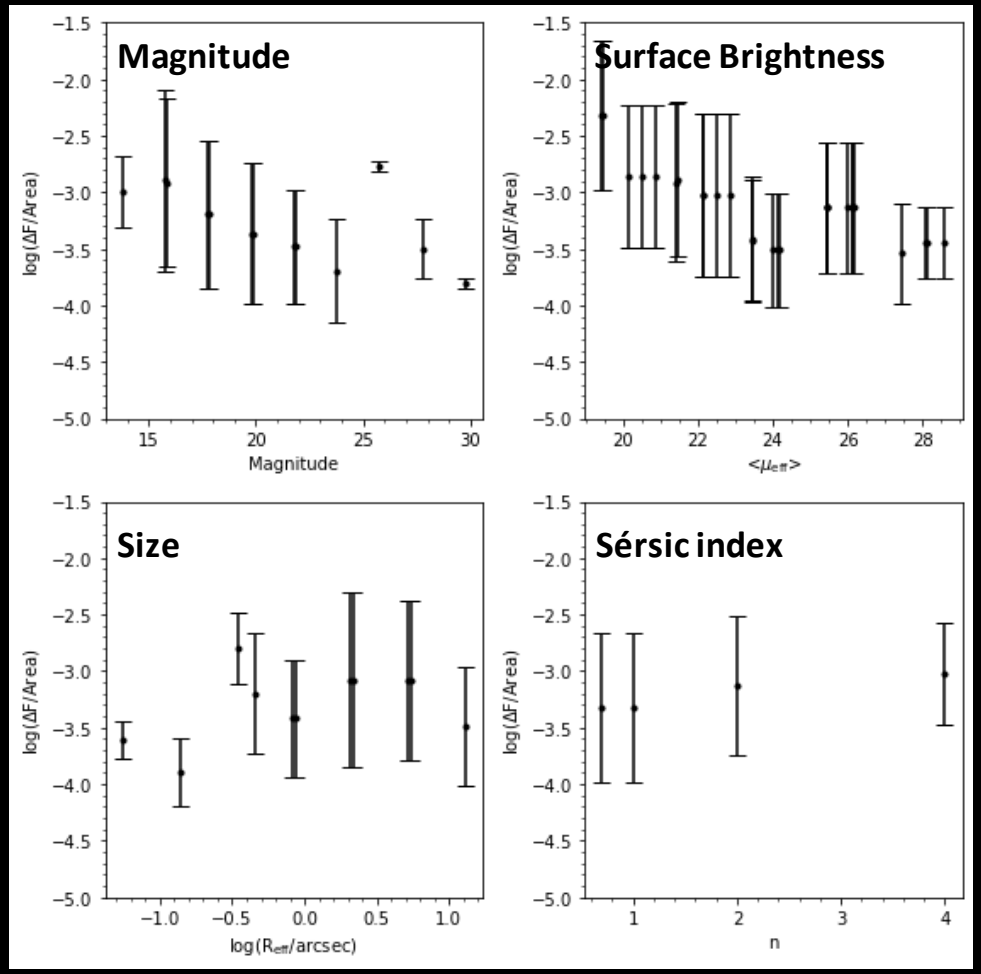


ICL+NH DWARFS

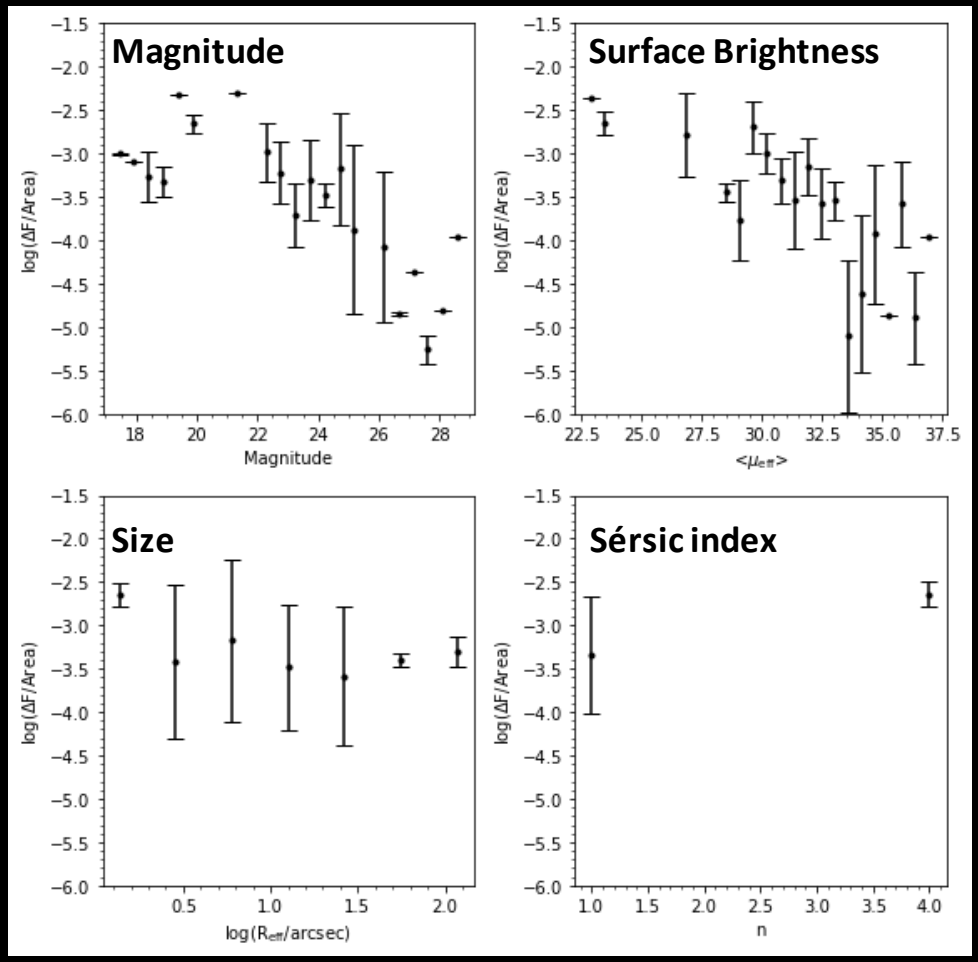


Total Flux *Lost* per Unit Area

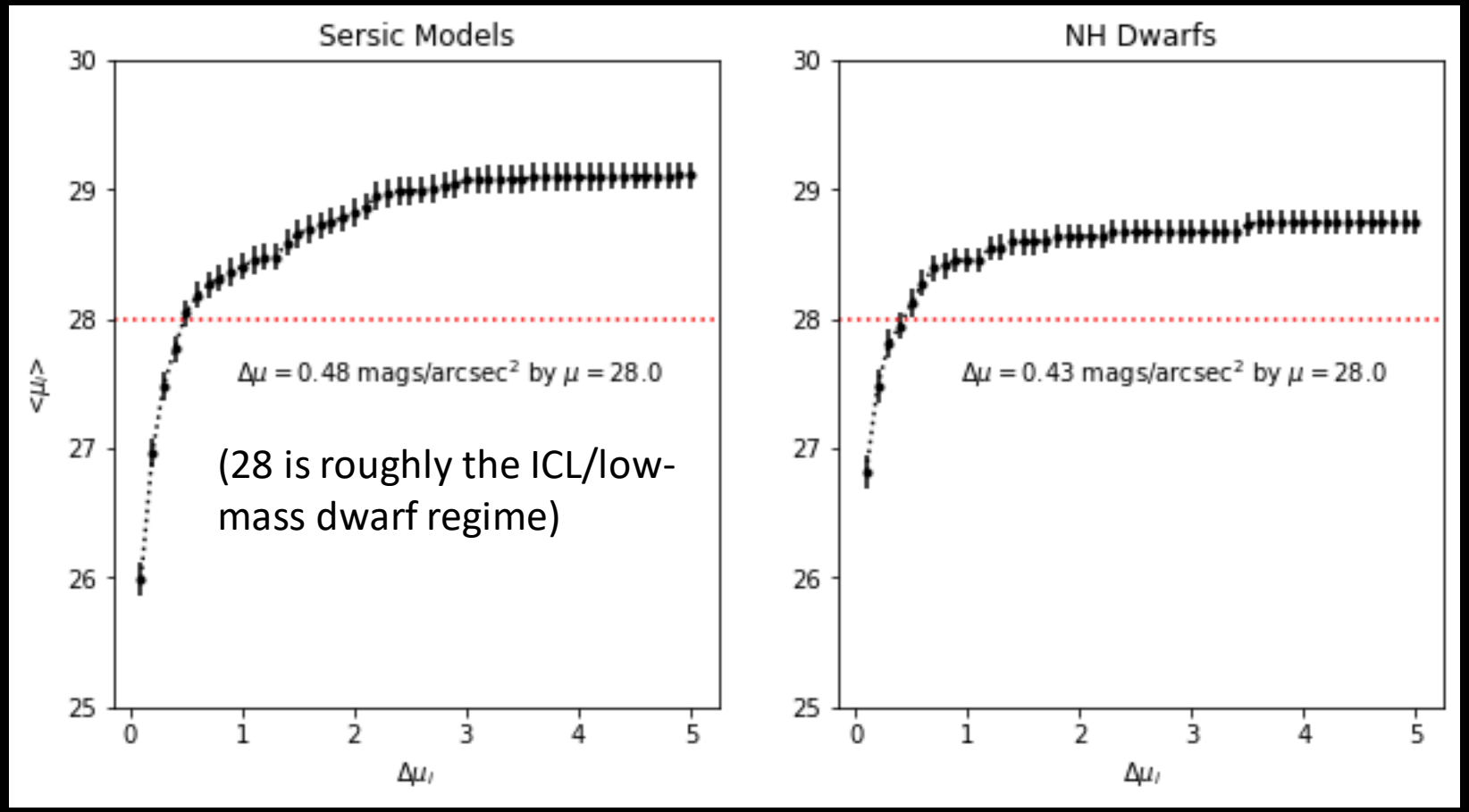
SÉRSIC MODELS



ICL+NH DWARFS



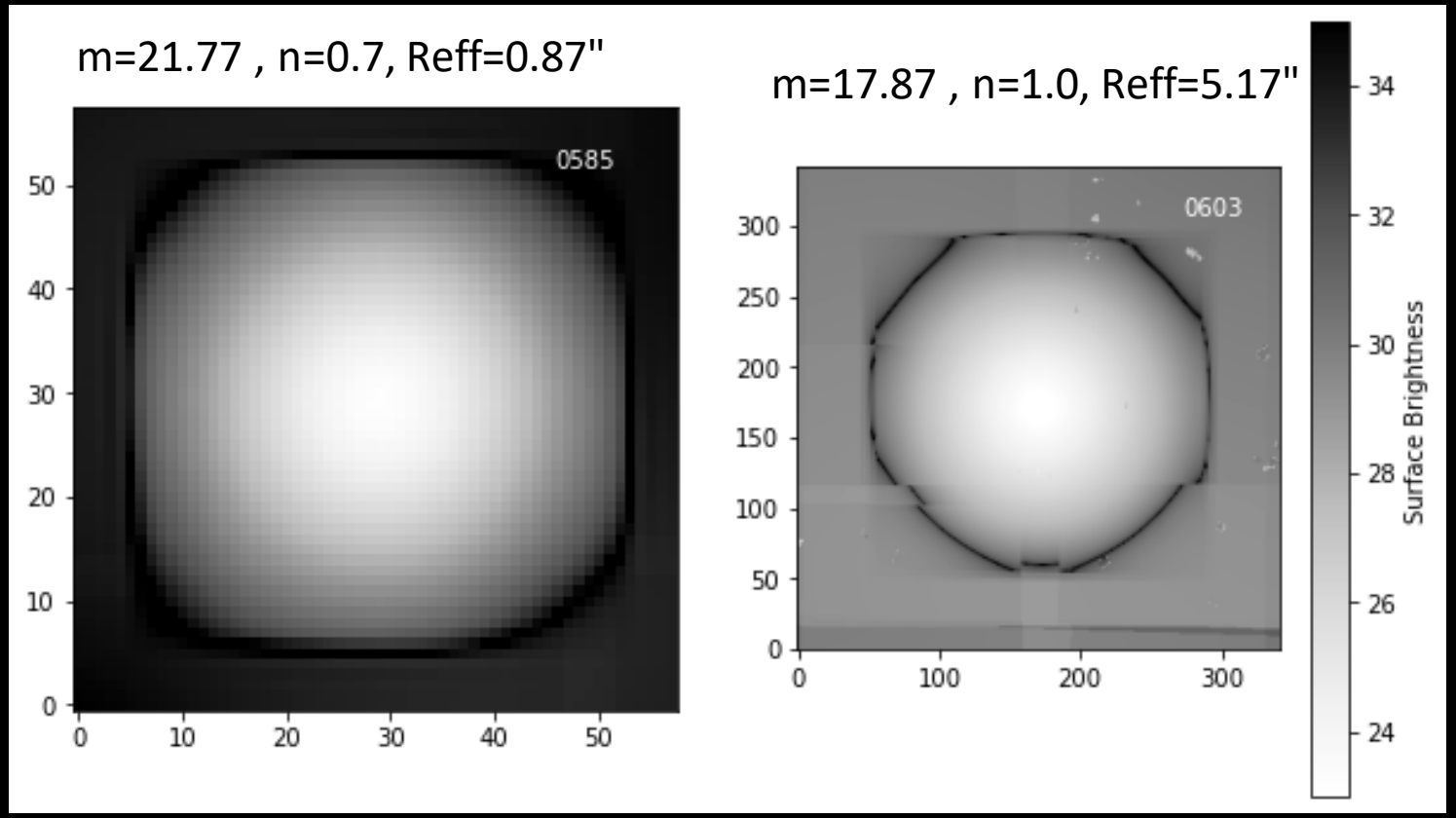
Over-subtraction vs. Surface Brightness



- How the surface brightness profiles are being modified:
  - X-axis = amount of over-subtraction
  - Y-axis = median surface brightness 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

Dark Ring Over-subtraction Artifact

Two Sérsic models post-SS



Photometry Summary

- Model brightness influences how much sky is subtracted locally to them
  - The brighter the model, the more over-subtraction occurs
- Most flux lost below μ≈26, so models with larger fraction of their total flux below μ≈26 show the biggest changes in magnitude.
  - ICL central surface brightnesses >28, so they show the biggest changes
- Faintest dwarfs?
  - These show an excess of flux (see also Huang et al. 2018)
  - If their presence has little influence on the SS, then this could imply that the sky being subtracted in blank fields is too faint

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 μ>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
  - Faintest objects gaining some flux—in absence of bright models, sky is under-subtracted? Hinted at also in HSC PDR2 (Huang et al., 2018)
- Fainter surface brightnesses are affected much more than brighter surface brightnesses, resulting in dark donuts in models' faintest wings
- LSB science currently affected the most, with some potential impact on all galaxies science
- Next step: mitigation.
  - We are now developing an alternative sky-subtraction algorithm (see Wednesday talk) to start addressing this