Promising Early Efforts at a Model-Free Sky Subtraction

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with

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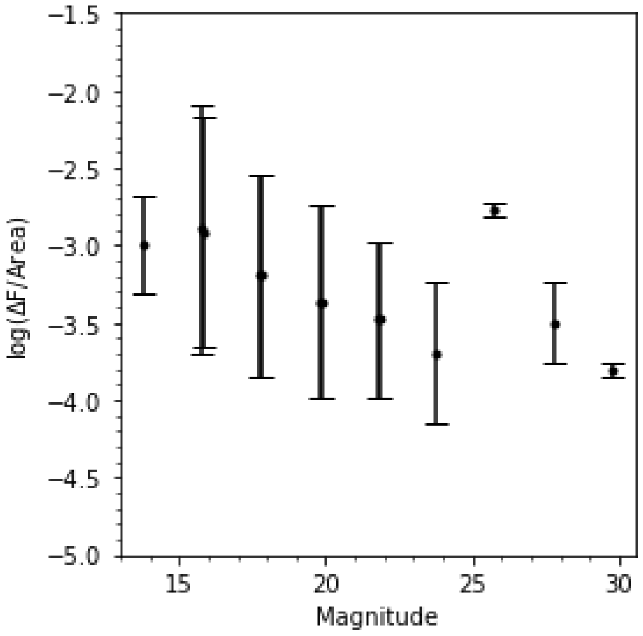
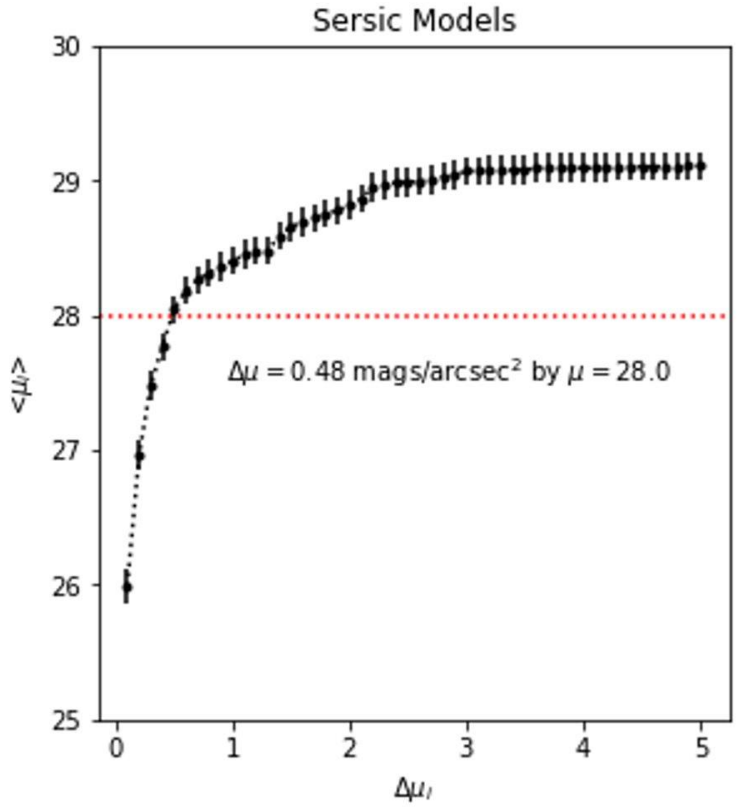
Sky over-subtraction in LSST

- From experiments with model galaxies, in the current pipeline fluxes of extended objects are influencing the local sky subtraction
- This results in systematic over-subtraction of flux at low surface brightness
  - Primarily this affects things with large angular size and/or low surface brightness: point sources are unaffected, for example, save in specific circumstances (e.g., crowded fields)
- **Conclusion**: sky-subtraction needs some adjustment to preserve LSB flux

Flux loss per unit area, as a function of model brightness

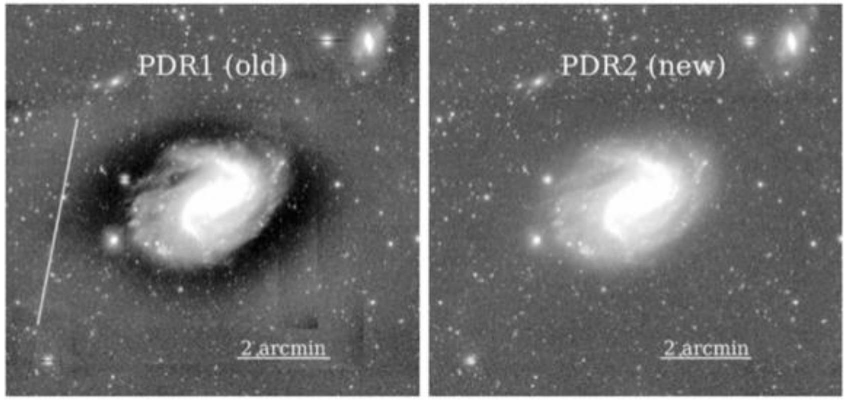


Mean surface brightness change at different model isophotes



Complex sky model = bad?

- Root cause of over-subtraction seems to be wings of models being incorporated into the local sky estimates →
  - This can happen when wings aren't fully masked and the sky model is too complex

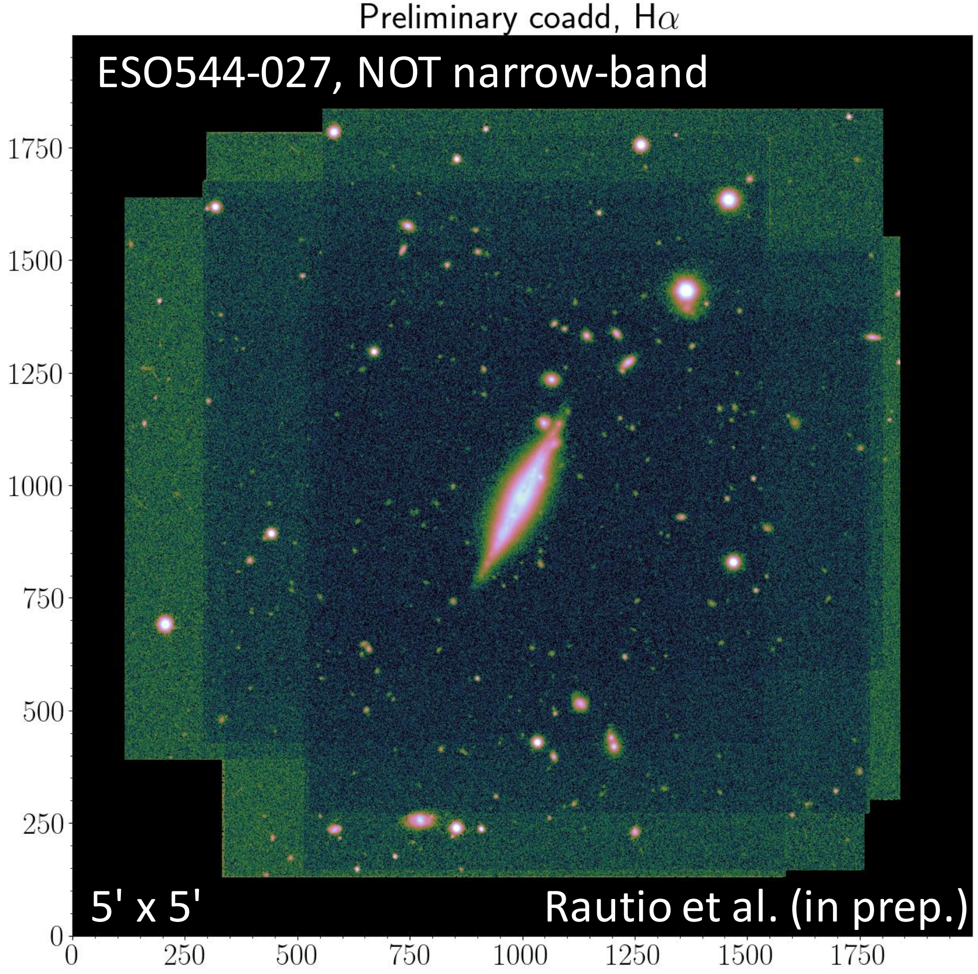


- Ideal scenario: model sky as a single number or a plane
  - But often this just isn't a good model
    - Very red bands have complex sky structure
    - Data is taken with the moon out/near bright sources (planets, naked-eye stars, etc.), with light cloud cover, and so on
- Want: sky subtraction algorithm that accurately removes even complex night skies w/o over-modeling

Notes on data used in development (so far)

- Primary use: Nordic Optical Telescope narrow-band + r-band imaging (Rautio et al., in prep.)
  - Used for a thesis project on diffuse ionized gas (DIG)
  - Observations done under less-than-ideal circumstances, resulting in large-scale scattered-light artifacts on every frame
- Secondary use: Burrell Schmidt Telescope broad-band data
  - Originally published in Watkins et al. (2016), paper on the extended stellar disks of galaxies
  - Testing on images of M64, in a field full of Galactic cirrus
- Beginning tests on NTT data and HSC data (not shown in this talk!)

Method Demonstration (1)

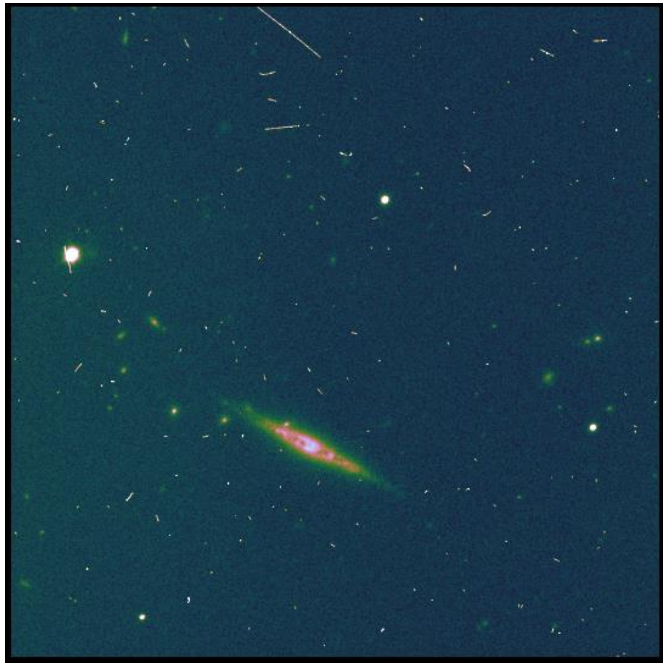


Method credit: Yusra al Sayyad & Robert Lupton (LSST data management team)

- Step 1: construct preliminary sky-subtracted image coadd
  - Just need a ~0 count background (+noise) w/o large-scale structures (planes, donuts, etc.)

Method Demonstration (2)

Flat-fielded image (w/sky)



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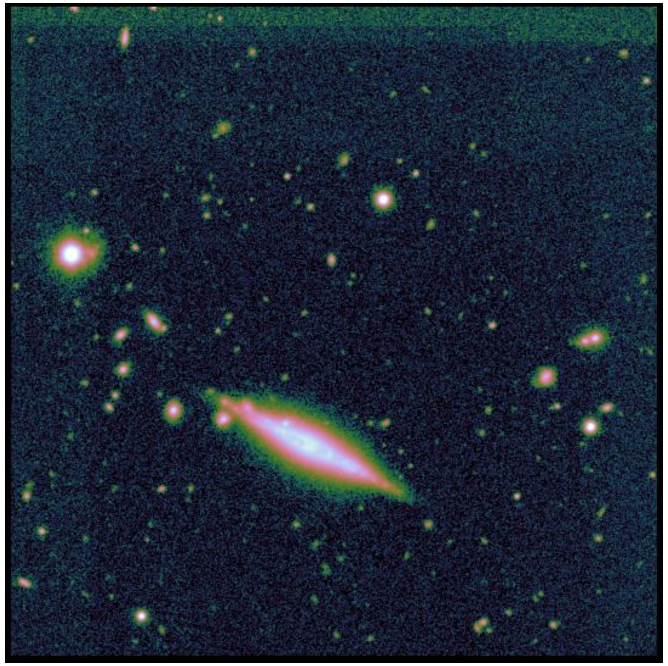
Rotated, scaled, cropped coadd



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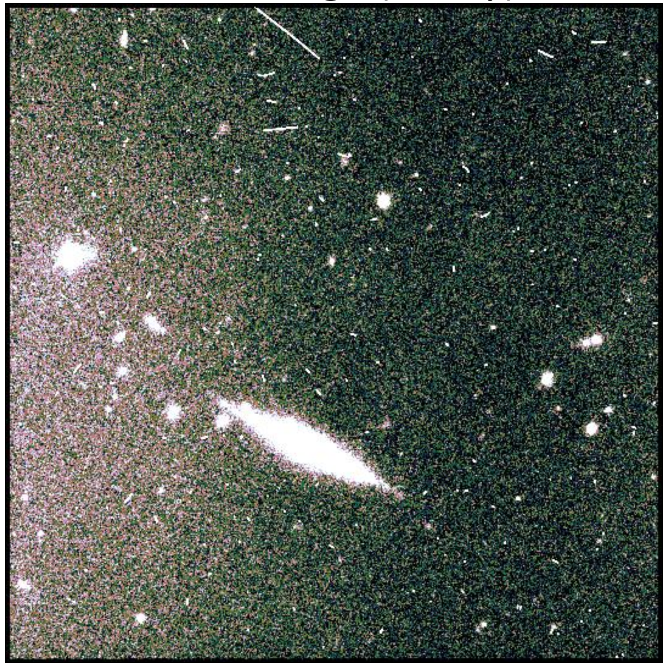
Noisy sky map

- Align, flux scale, and subtract the preliminary coadd from each frame
- Removes astrophysical flux, leaves behind sky
    - But also extremely noisy & contains CRs, PSF residuals, etc.

Method Demonstration (3)

Flat-fielded image (w/sky)



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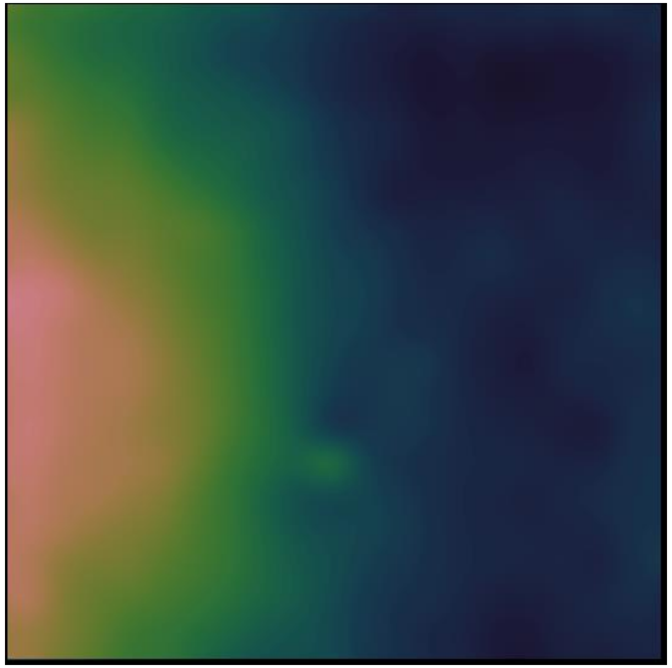
Smoothed sky map



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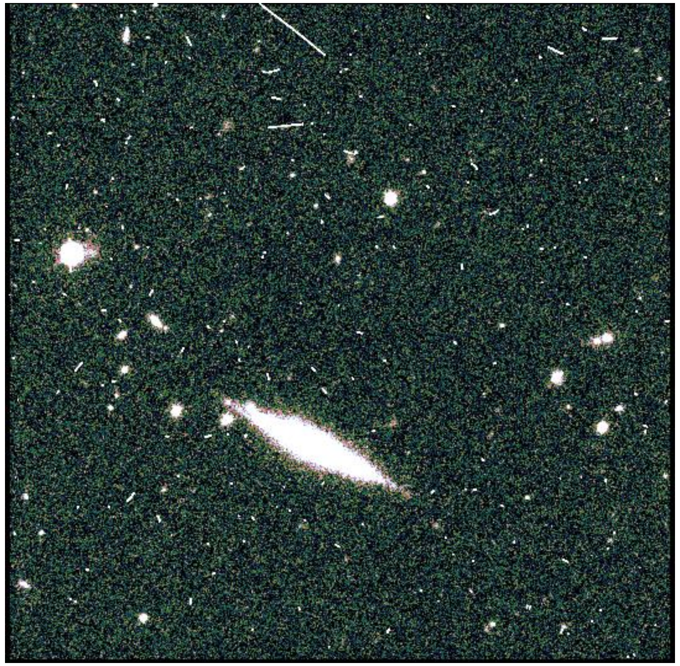
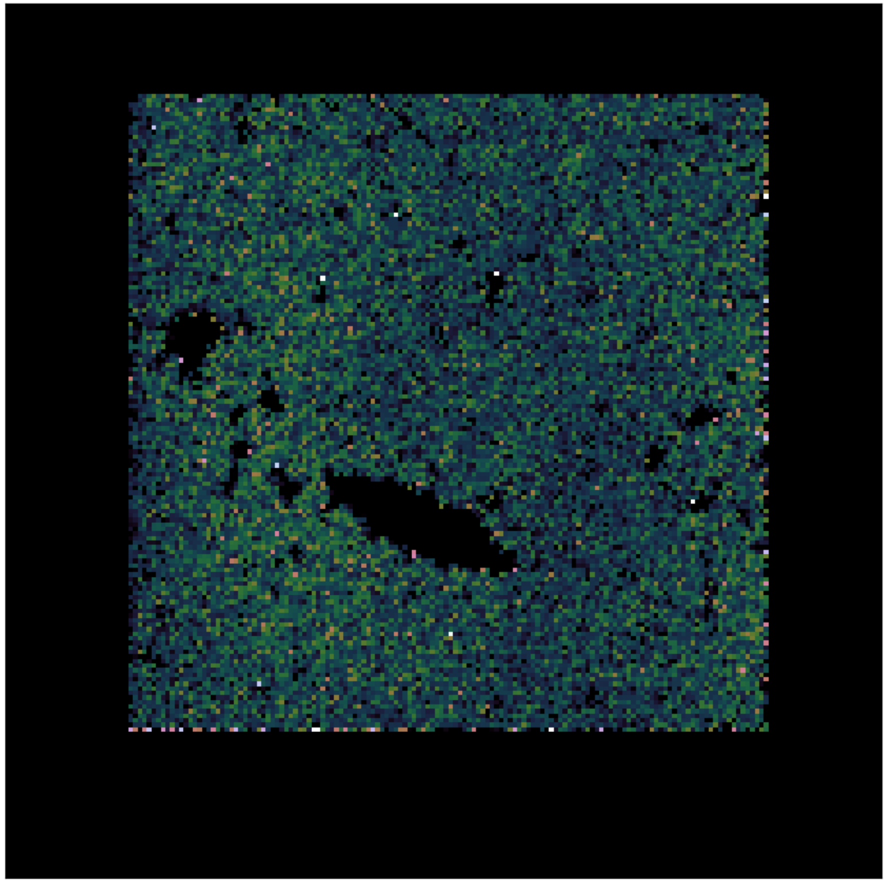
Sky-subtracted image

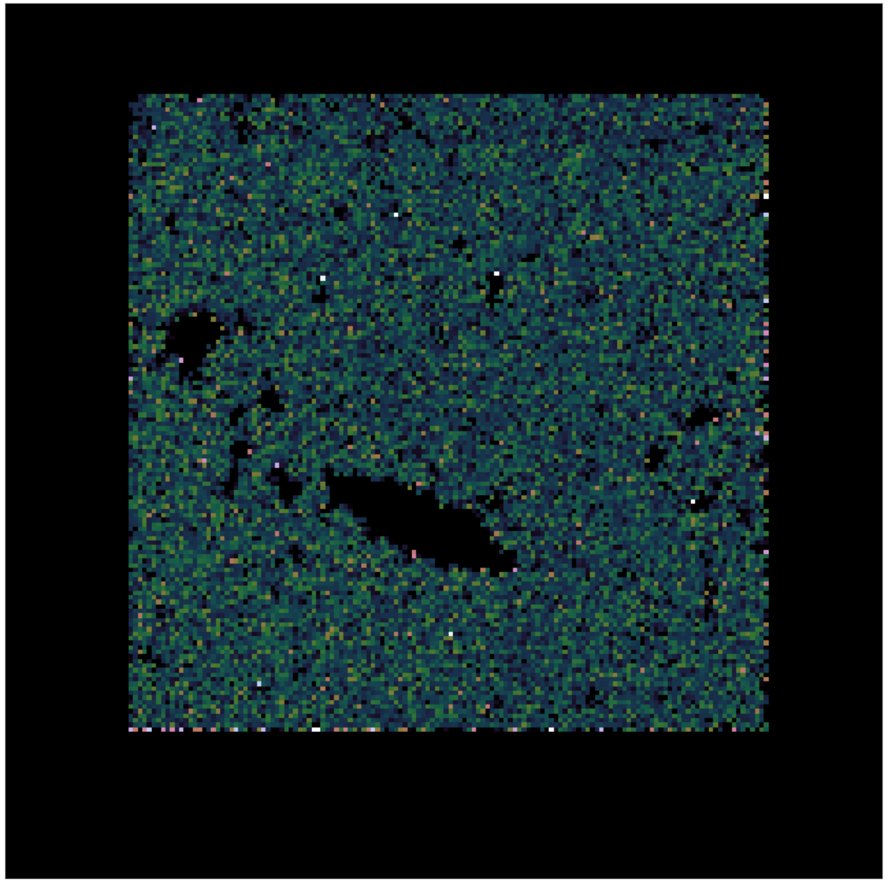


- Mask residual stars &c. in sky map, bin image (large bins; of order target galaxy size), interpolate flux across masked pixels, then Gaussian smooth with FWHM = ½ bin size
  - This reduces the per-pixel noise, resulting in a low-resolution but less noisy map of sky structure
- Subtract this smoothed map from the flattened images to yield sky-subtracted images

Comparison—single exposure



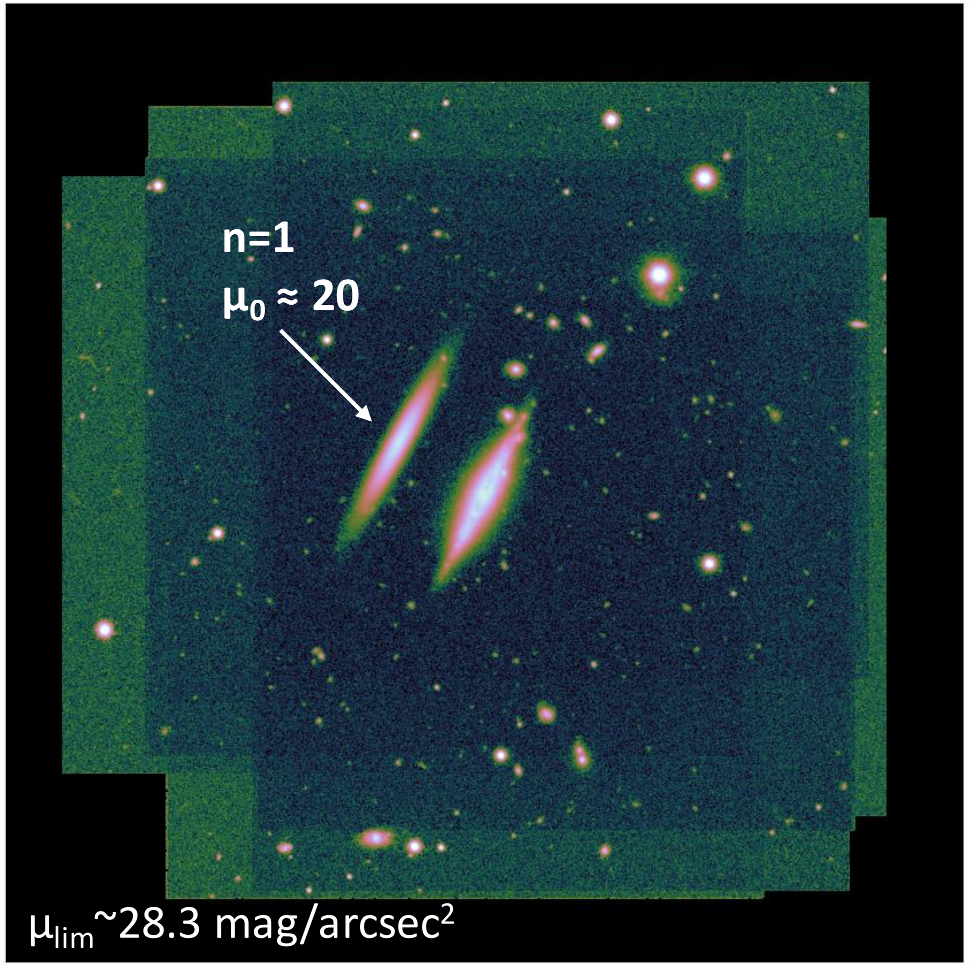
Polynomial fit sky subtraction (order 2)
Used to build initial coadd



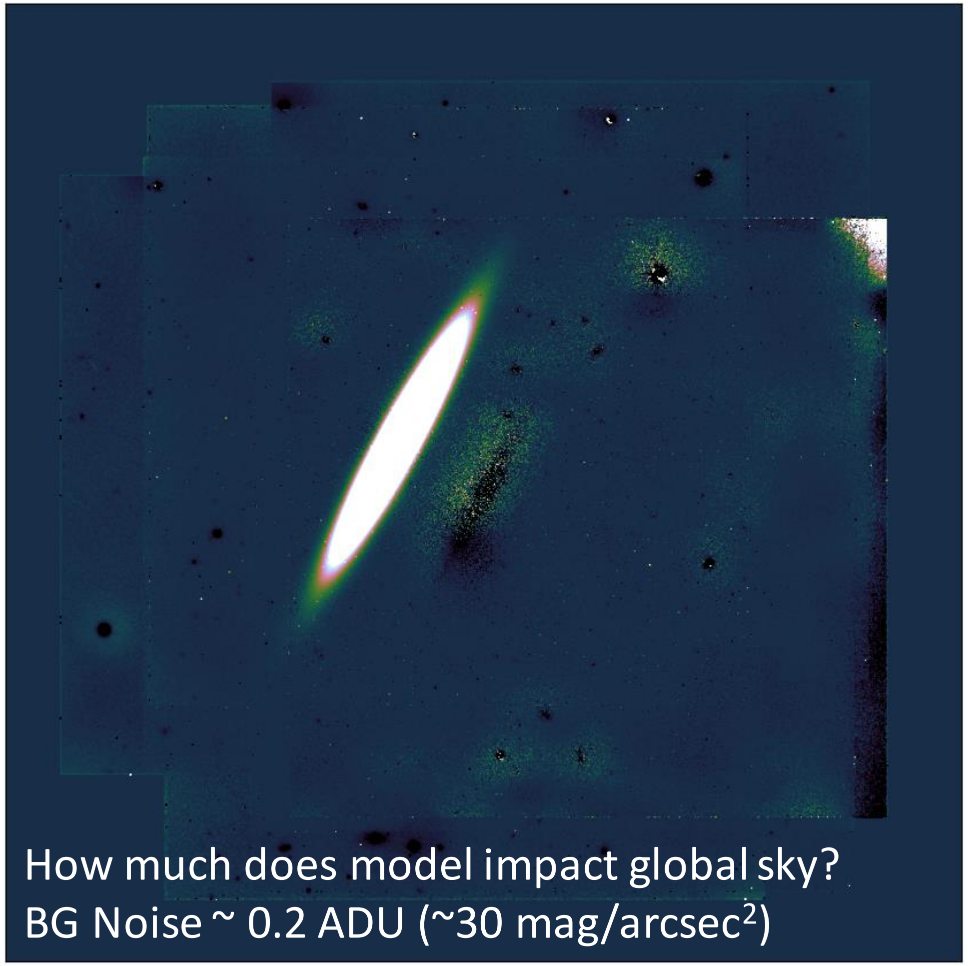
Coadd-subtraction sky modeling
Used for final coadd

Model injection: edge-on disk

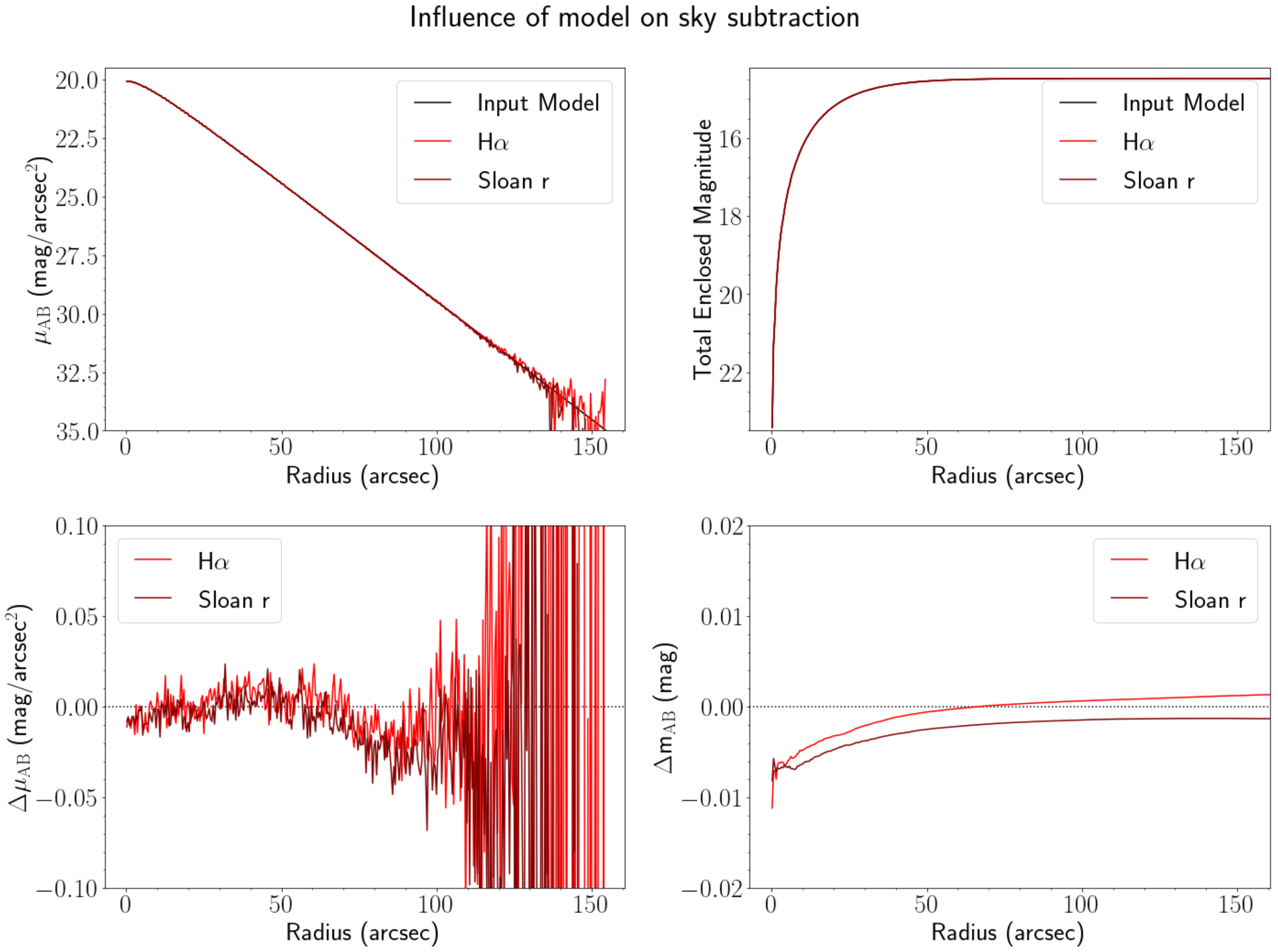
Final Hα coadd with model



Final coadd with model – coadd w/o model



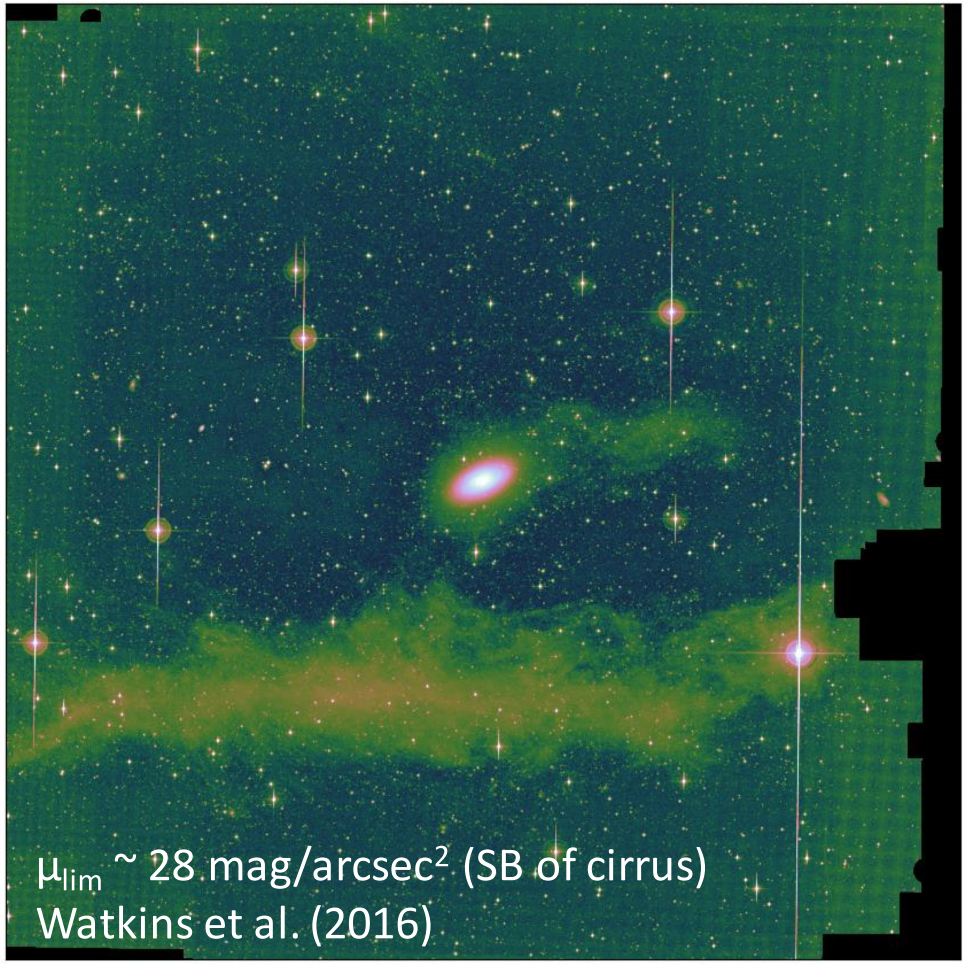
Edge-on model photometry



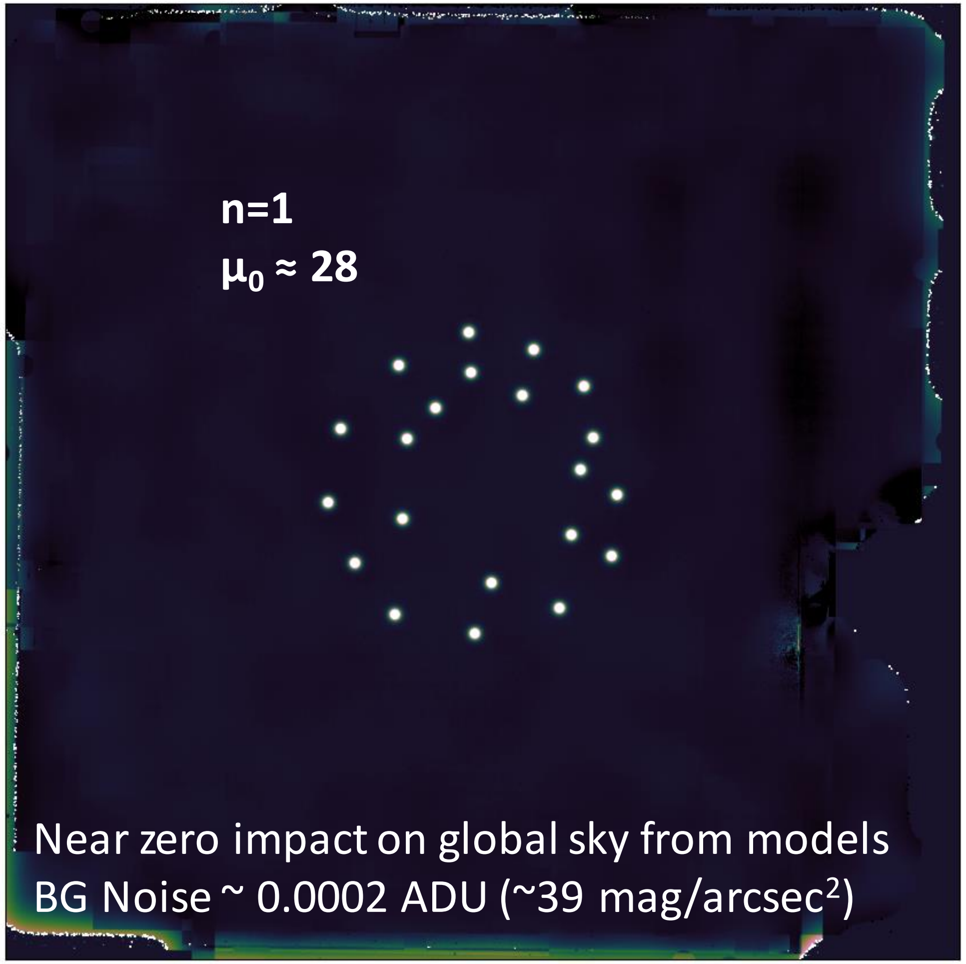
- How does the model impact the sky estimate local to it?
- Surface brightness profiles (left) and curves of growth (right) of isolated models
  - Measured coadd w/model subtracting coadd w/o model
  - Showcases the difference in sky subtraction with and without the model present
- Relative sky subtraction under-subtracts at most ~3% down to μ=31 mag/arcsec^2
- Curve of growth nearly unaffected (<1% error), strongest deviation in model core, of order 1% under-subtracted flux

Model injections: face-on LSB disk

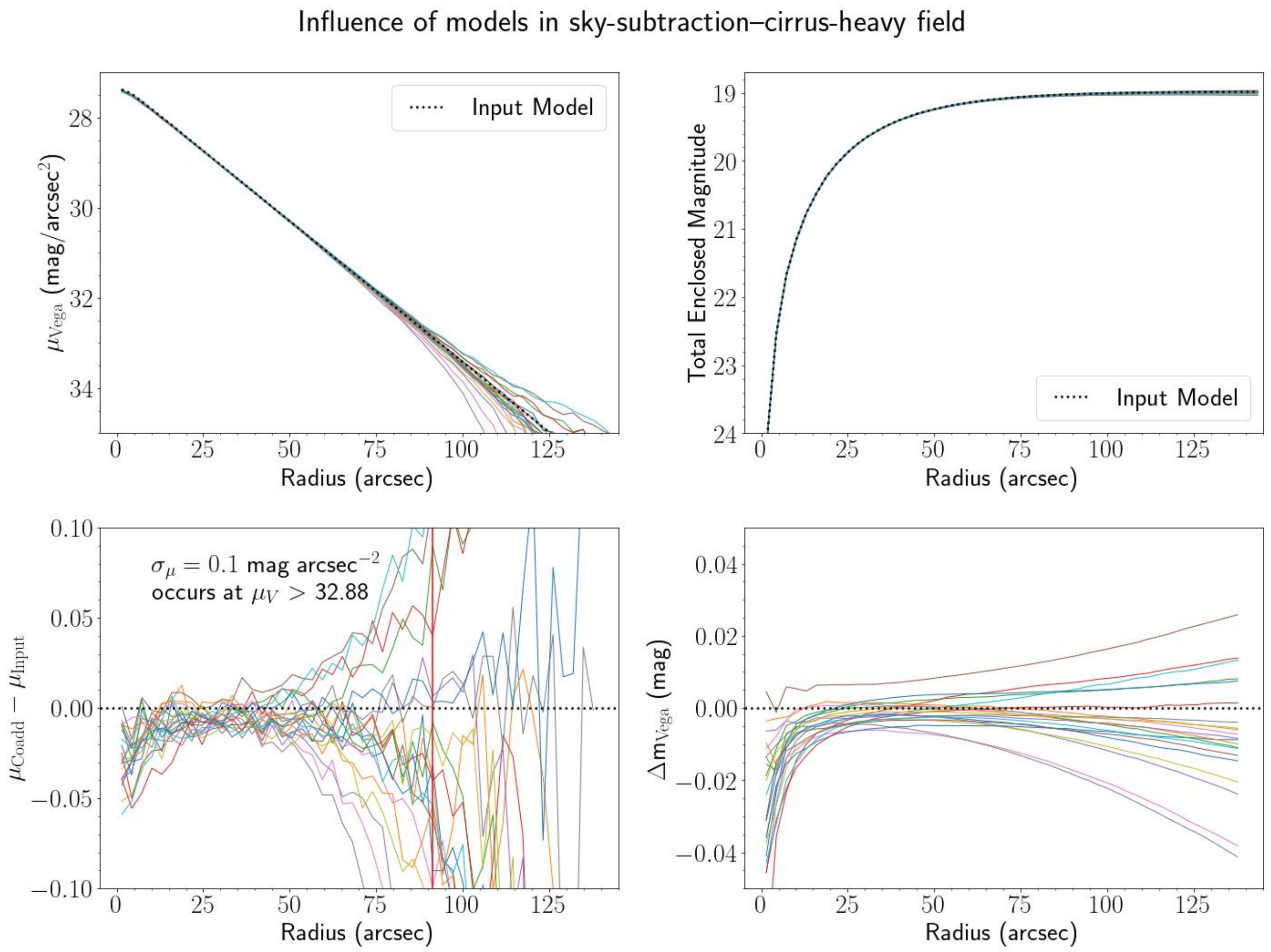
Coadd of M64, Johnson V (BST imaging)



Coadd w/models - coadd w/o models



LSB-disk model photometry



- How do these LSB models impact the local sky estimates?
- Surface brightness profiles (left) and curves of growth (right) for face-on, LSB n=1 models
- Some under-subtraction in model cores (max. ~5%) for some models
  - Seems to be an issue with flux interpolation across masks
- Error stays within ~10% down to nearly 33 mag/arcsec^2
- Curves of growth similarly stable: <5% offset across whole profile

Method works well in fields full of Galactic cirrus, too!

Summary

- Given the unique opportunity afforded by up-coming large-scale surveys like LSST, desire a sky subtraction routine that reduces noise and preserves flux when not all data is taken under conditions ideal for LSB work
- By subtracting a preliminary sky-subtracted coadd from individual frames, can isolate the sky in individual images
  - Only resolution limit on sky structure is how much binning/smoothing is done to reduce noise
- Current tests are cause for optimism: preserving flux to within ~5% in model galaxies down to below 31 mag/arcsec^2
  - Works well in fields heavily contaminated with Galactic cirrus, too
- Potentially broad applicability, too (e.g., IR imaging)