Modifying the HSC pipeline sky-subtraction algorithm for low-surface-brightness science with LSST

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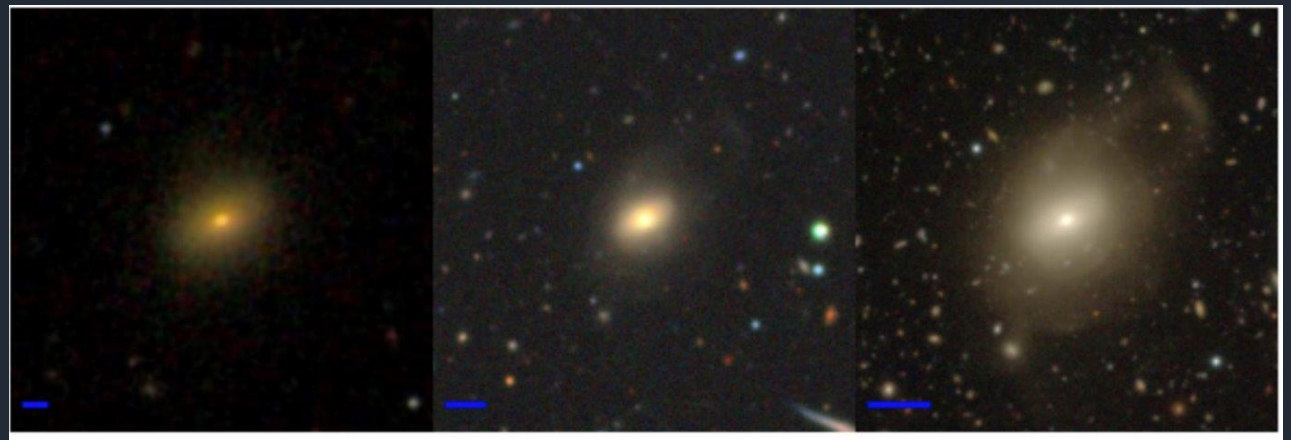
Introduction

- Low-surface-brightness science is a broad category. Includes:
  - Dwarf galaxies (moderate redshift, low stellar mass)
  - Tidal debris
  - Stellar halos/intracluster light
  - Galactic cirrus
  - Outskirts of planetary nebulae
  - Etc.

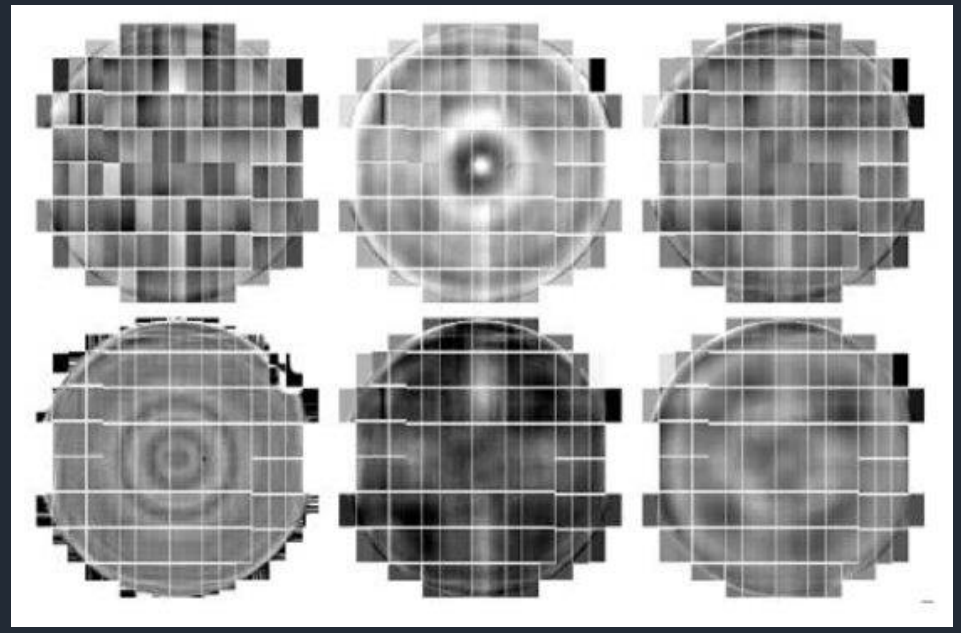


Comparison of a single object between surveys of increasing depth. LSST's wide survey depth should be comparable to HSC-SSP.

- LSST is the first large-scale survey capable of accessing this regime, making LSB an important science case for the survey
- However, LSB flux is particularly sensitive to the way in which the images are processed, particularly regarding night-sky estimation and removal
- **Q: can we modify the existing LSST pipeline software to do LSB science?**

HSC skyCorr task

- The HSC pipeline is the precursor to LSST's pipeline
- Sky correction has four steps:
  - Mask images via initial local sky estimation
  - **bgModel**: 7024 x 7024px bin in focal plane coordinates, Akima spline interpolation, re-project solution to CCD coordinates, subtract
  - **doSky**: scale sky frame to bgModel-subtracted image, subtract
  - **bgModel2**: 256 x 256px bin in focal plane coordinates, Akima spline interpolation, re-project solution to CCD coordinates, subtract



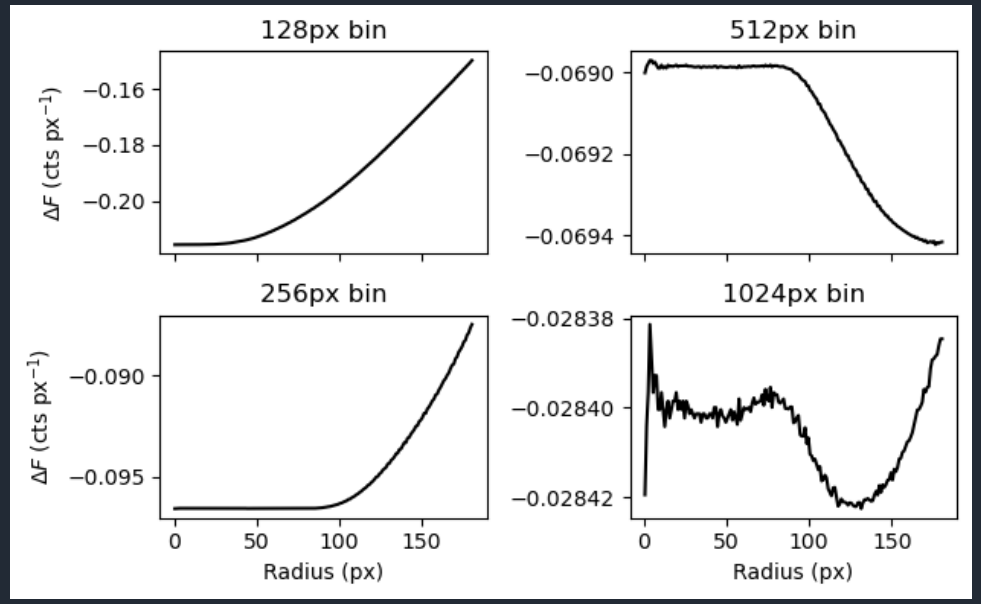
HSC sky frames (Aihara et al. 2019), showing CCD sensitivity, filter transparency variations across focal plane

Experimental setup

- Injected model Sérsic profiles into images pre-sky-subtraction
- Ran **skyCorr** task on images with models, compared model photometry before and after **skyCorr**
- Tested four different bin sizes in **bgModel2:**
  - 128, 256 (default), 512, and 1024px (21.5", 43", 86", 172")
- Tested turning off **bgModel2**
- Miscellaneous
  - Linear interpolation instead of higher-order spline
  - No **doSky**, instead using **bgModel2** to correct sky frame pattern

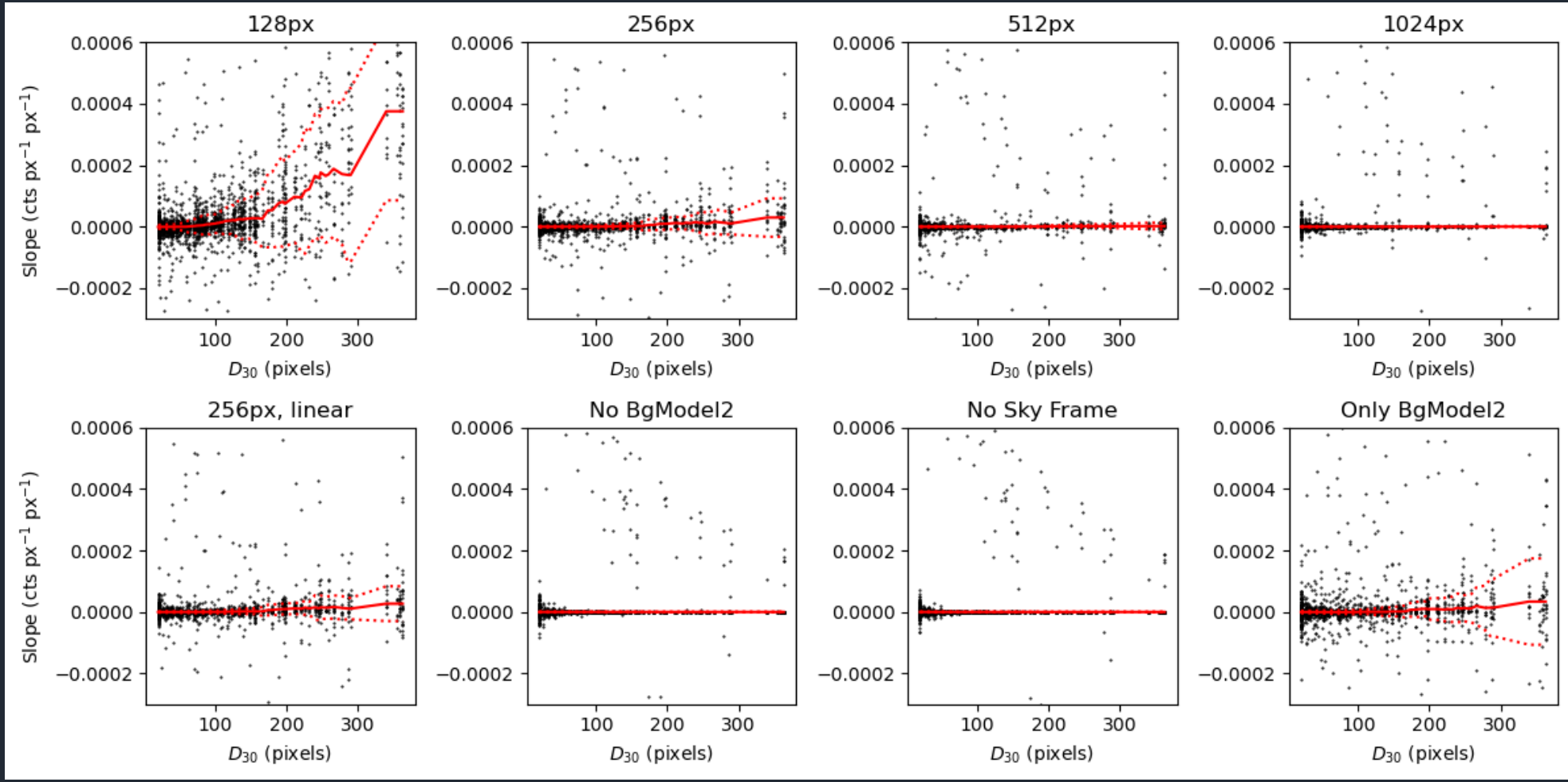
Primary metrics

- Surface brightness difference profiles
  - $\Delta\mu = \mu_{post\text{-}SS} - \mu_{pre\text{-}SS}$ (linear units)
  - Slope: local impact on model
  - Offset: mean of profile, global impact near model
- Stamp size as primary model parameter
  - All models drawn to R_{30}, which is a function of Sérsic parameters
  - Stamp size thus summarizes all other model parameters

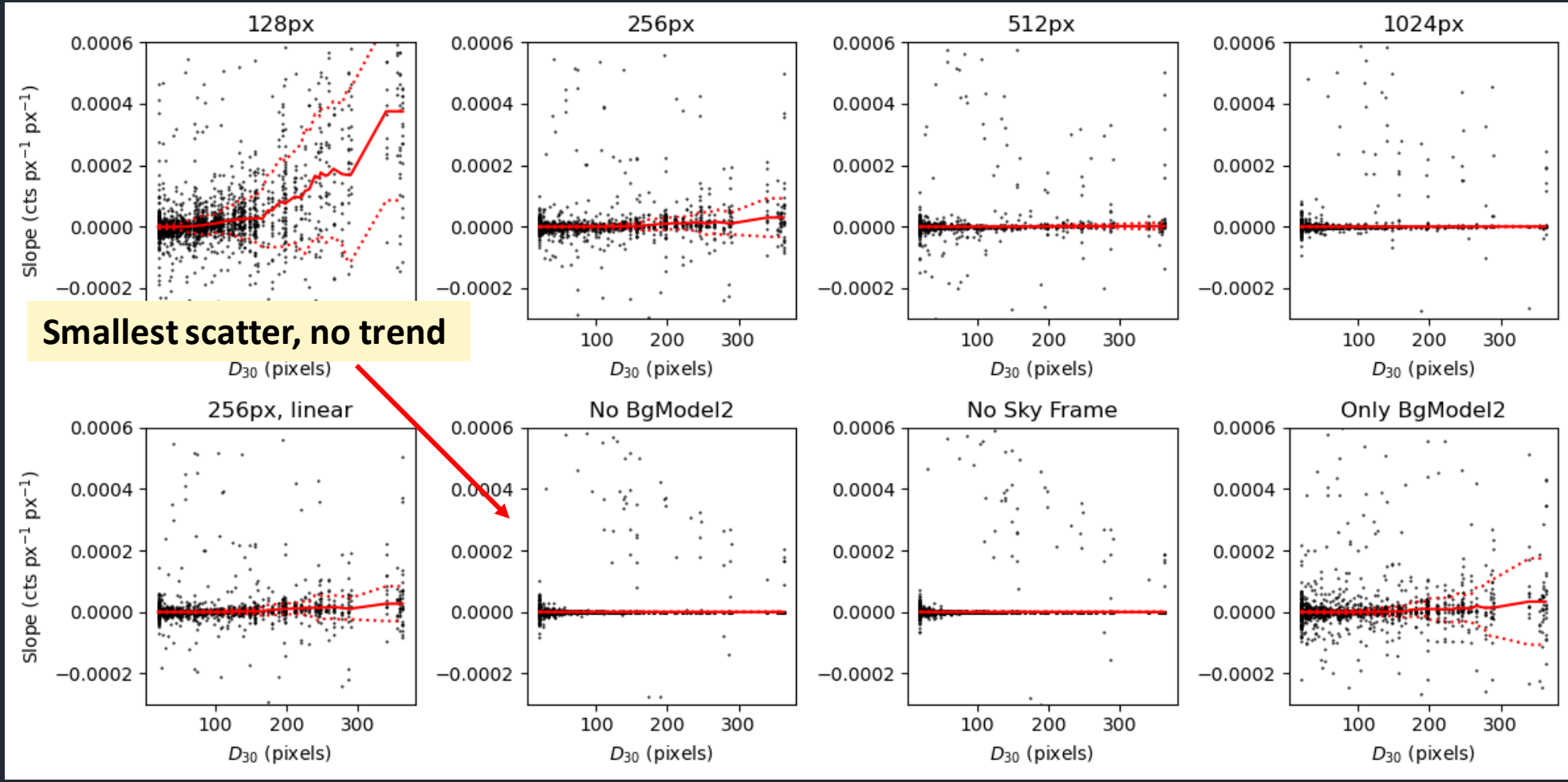


Linear flux difference pre- and post-sky-subtraction vs. radius for a single model. Each panel shows bgModel2 sky subtraction using a different bin size (top of panels). Note changing y-scales.

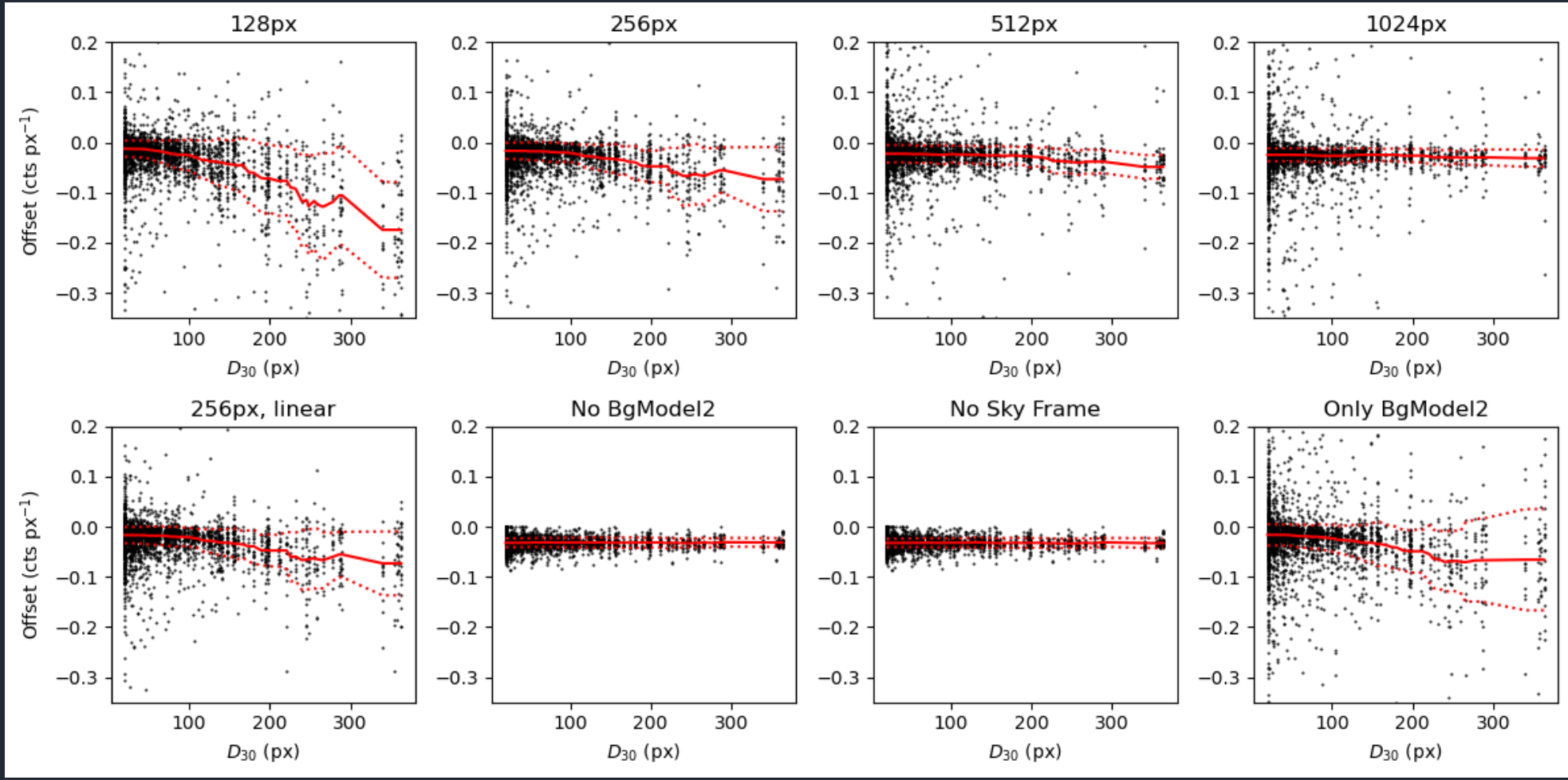
Results: slope (local impact)



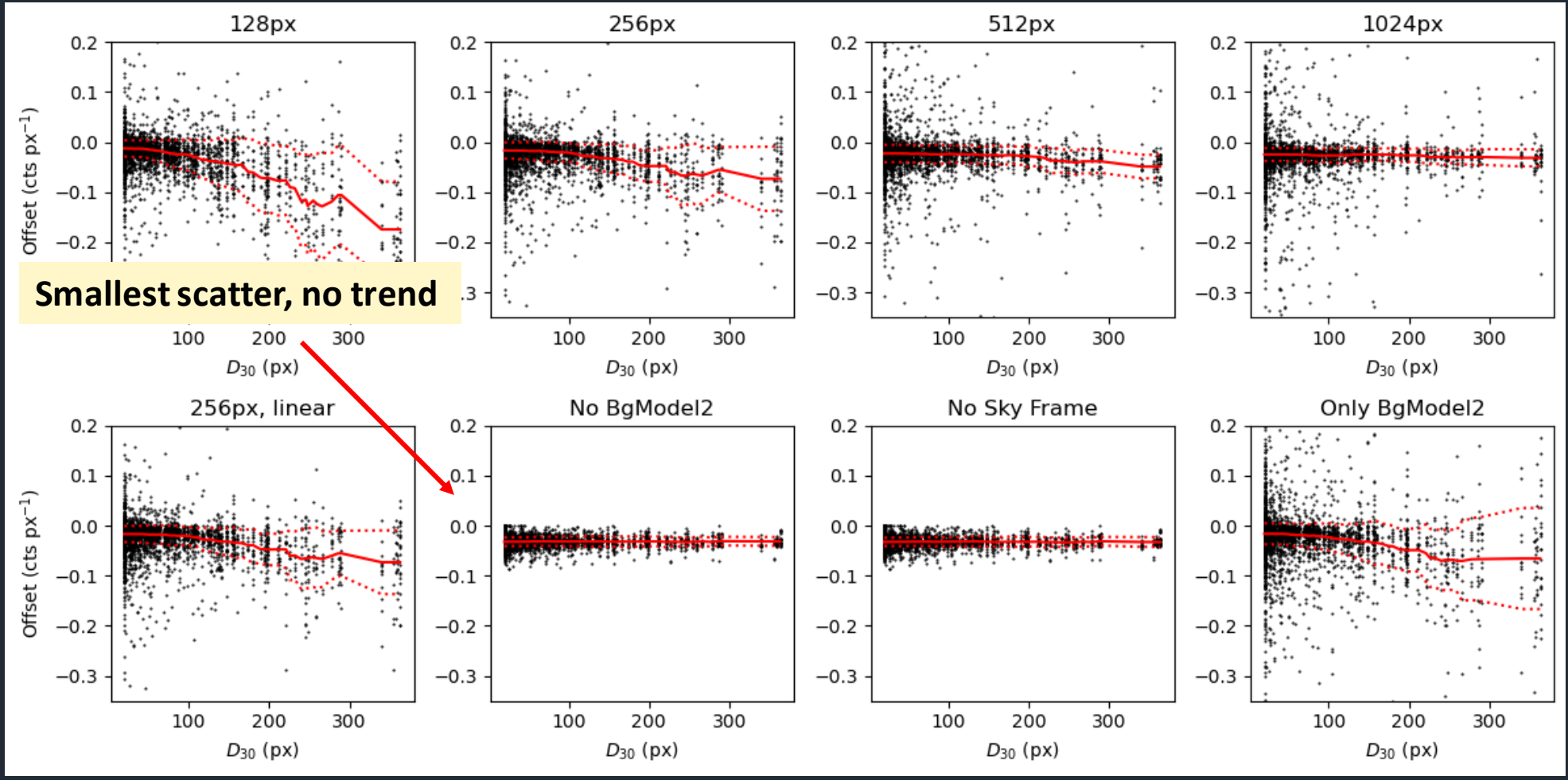
Results: slope (local impact)



Results: offsets (global impact)



Results: offsets (global impact)



The problem is over-fitting

- Even with deep masking, using local or high-order sky subtraction will tend to over-subtract LSB flux
  - For reference, difference between 29 and 29.5 mag/arcsec^2 in HSC images is ~0.5 ADU
  - Even over-fitting by a tiny amount causes problems for LSB science!
- Optimal solution: use pipeline as constructed (vetted for LSST!) but w/o bgModel2
  - Cleanup best done via alternative means, e.g. PSF subtraction, reflection modeling and removal, etc.

Future work & conclusions

- Big next step: science validation
  - E.g., comparison of dwarf mass functions w/smaller scale existing deep surveys
- LSB detection/deblending a lingering issue
- **We found a convenient way to ensure that the LSST pipeline sky-subtraction preserves LSB flux**
  - LSB science will be possible with LSST when this is implemented