Read Noise Biasing on the Nancy Grace Roman Space Telescope

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Introduction

The Nancy Grace Roman Space Telescope (*Roman*), set to launch in 2026, is one of several "Stage IV" cosmology missions. The telescope will bring unprecedented precision to measurements of different astrophysical phenomena, including but not limited to weak gravitational lensing (WL), an effect whose accurate measurement shows particular promise for the field of cosmology. Weak lensing, measurement of correlations between the shapes of multiple galaxies in a field of view, provides a method of directly inferring the mass distribution along a line of sight. Construction of an extensive mass map will allow us to test the accuracy of our current cosmological model against alternatives.

Motivation

Roman images are inherently Nyquist-Undersampled; the scale of the detector pixels (Fig 1) is too large relative to the angular resolution of the telescope. Undersampled images' intensity function cannot be treated as continuous, creating problems for the usual methods of image processing and inducing measurement biases into the image moments. Weak lensing, which depends on images' second moments, will be significantly impacted by undersampling effects.

Effects from undersampling, along with other detector systematics, can be averaged out using methods of image combination. Multiple dithered images are combined together using linear algebra algorithms such as `IMCOM` [1].

Figure 1. Roman focal plane: 18 Hg-Cd-Te photodiodes. Source: @NASARoman on Twitter/X

In this work, we seek to understand how correlated detector noise propagates through image combination. We investigate the inherent properties of the read noise from the Roman detectors by analyzing detector tests taken at the DCL [2]. Combining the lab noise images with simulated Roman observations [3], we also estimate the magnitude of shear biases we can expect read noise to induce on weak lensing measurements.

Lab Noise Frames

The input noise frames used for this project are taken at and distributed by the Detector Characterization Laboratory (DCL) at NASA Goddard Spaceflight center. We currently make use of two sets of detector tests:

- Triplet tests, in which the detectors were connected to an ACADIA controller
- Focal Plane System tests, where the 18 detectors selected for flight are integrated into the focal plane system and tested there

We also add a simulated sky background of Poisson noise to the test images before processing them.

Before processing through `IMCOM`, the 56 test frames per image are combined into 6 "resultant frames" which would be sent down to Earth from the telescope. Then, those 6 images are combined via least-squares fitting into one single "slopes image," which contains maximal information in one image. We also impose a simple reference pixel correction scheme to remove some electronic and detector effects. Fig. 2 shows an example output, and Figure 3 depicts the whole process.

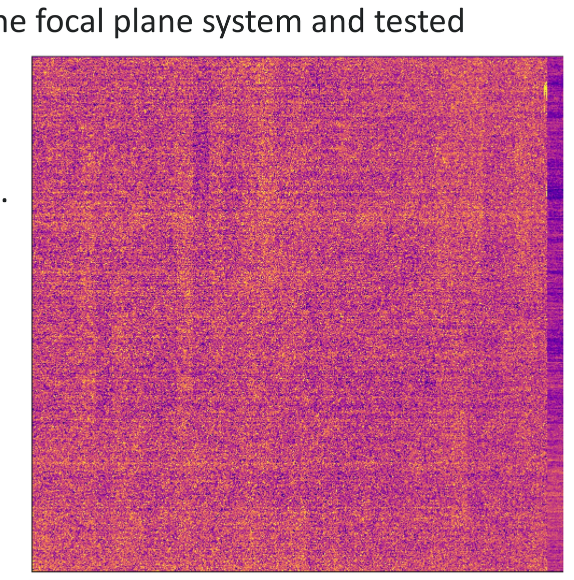


Figure 2. Reference pixel corrected lab noise slope image. This frame is from the triplet test of SCA #7.

"Multi-Accum" Processing

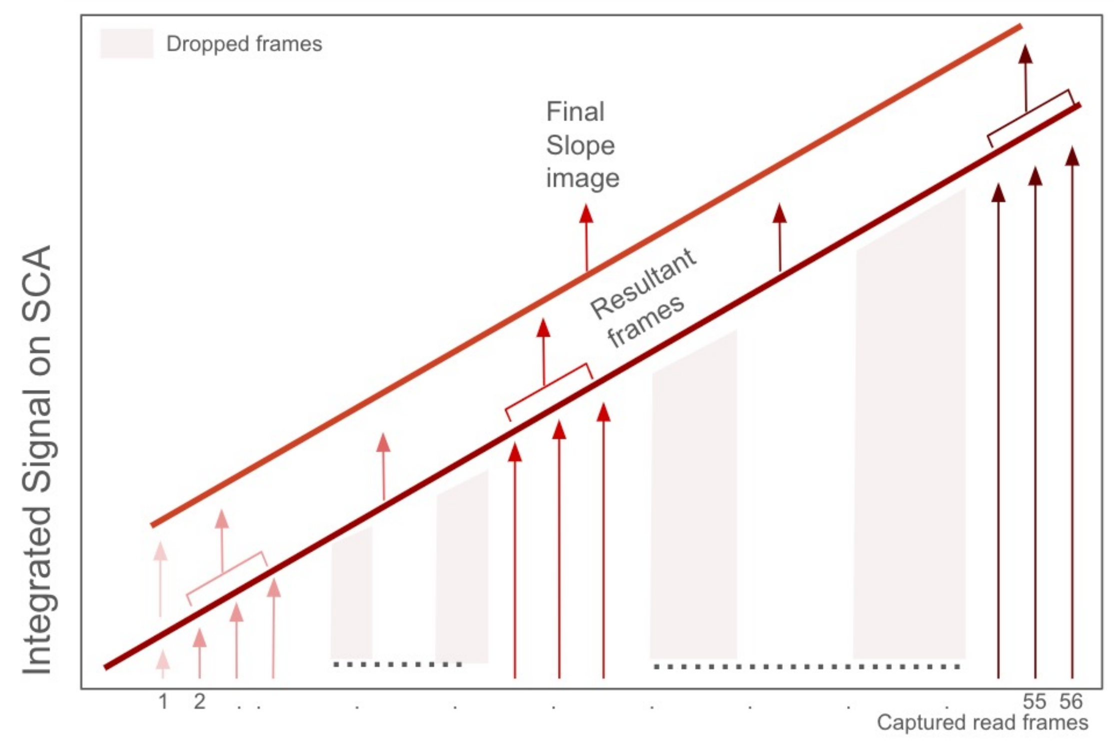


Figure 3. Graphic depicting the Multi-accum process, based on a similar figure by Chris Hirata. Captured read frames are either dropped or averaged into resultant frames to be transmitted to the ground. The signal per pixel in the resultant frames is averaged over the six resultant frames to produce one slopes image.

Image Combination

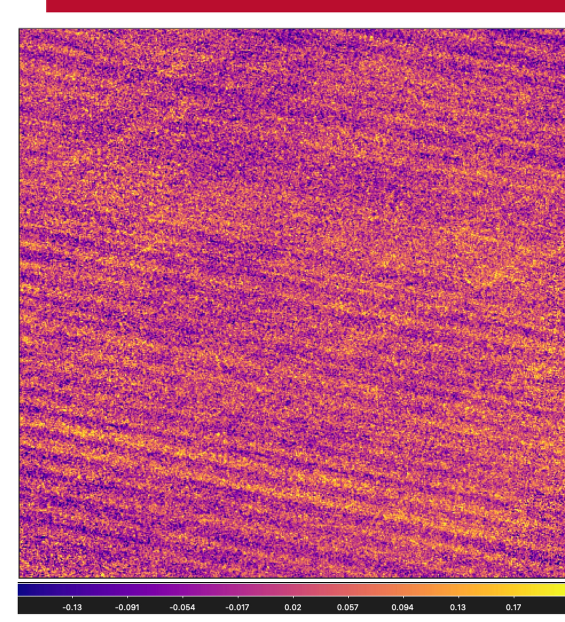


Figure 4. A co-added lab noise block (1x1 arcmin; px scale 0.025 arcsec) in the H band.

The image coaddition algorithm used to produce the coadded lab noise frames shown in this work (ie. Fig. 4) using the detector triplet tests was `IMCOM` [1]. The pre-processing of the triplet test data was only completed in time to get it integrated into the J and H band simulations for image combination.

Since the focal plane integrated tests were taken, a new and optimized version of `IMCOM`, `PyImcom` [5], has been undergoing development and testing. At the same time, a new suite of Roman image simulations has been generated through the Roman+Rubin collaboration. We are currently in the process of repeating the analysis shown here on the focal plane integrated tests using both the new simulations and the new `PyImcom`. This new set of read noise analysis will be more flight-like than the version shown here, and allow us to accurately and carefully estimate the amount of bias we expect to see from noise on the Roman detectors.

Noise Correlations

The power spectrum allows us to visualize scales over which shape measurements will be affected by read noise. We calculate the full spectrum:

$$P_{2D}(u,v) = \frac{s_{out}^2}{N^2}\left|\sum_{j_x,j_y}\frac{1}{A\, s_{in}^2} S_{j_x,j_y}\, e^{-2\pi i\, s_{out}(u j_x + v j_y)}\right|^2$$

and a 1-dimensional version by azimuthally averaging the results. There are several distinct features in the power spectra (see Fig. 5) which we can predict:

- Output PSF imprint
- Postage stamp boundaries
- AC circuit receiving power
- Dithering roll angles

Average Power Spectra

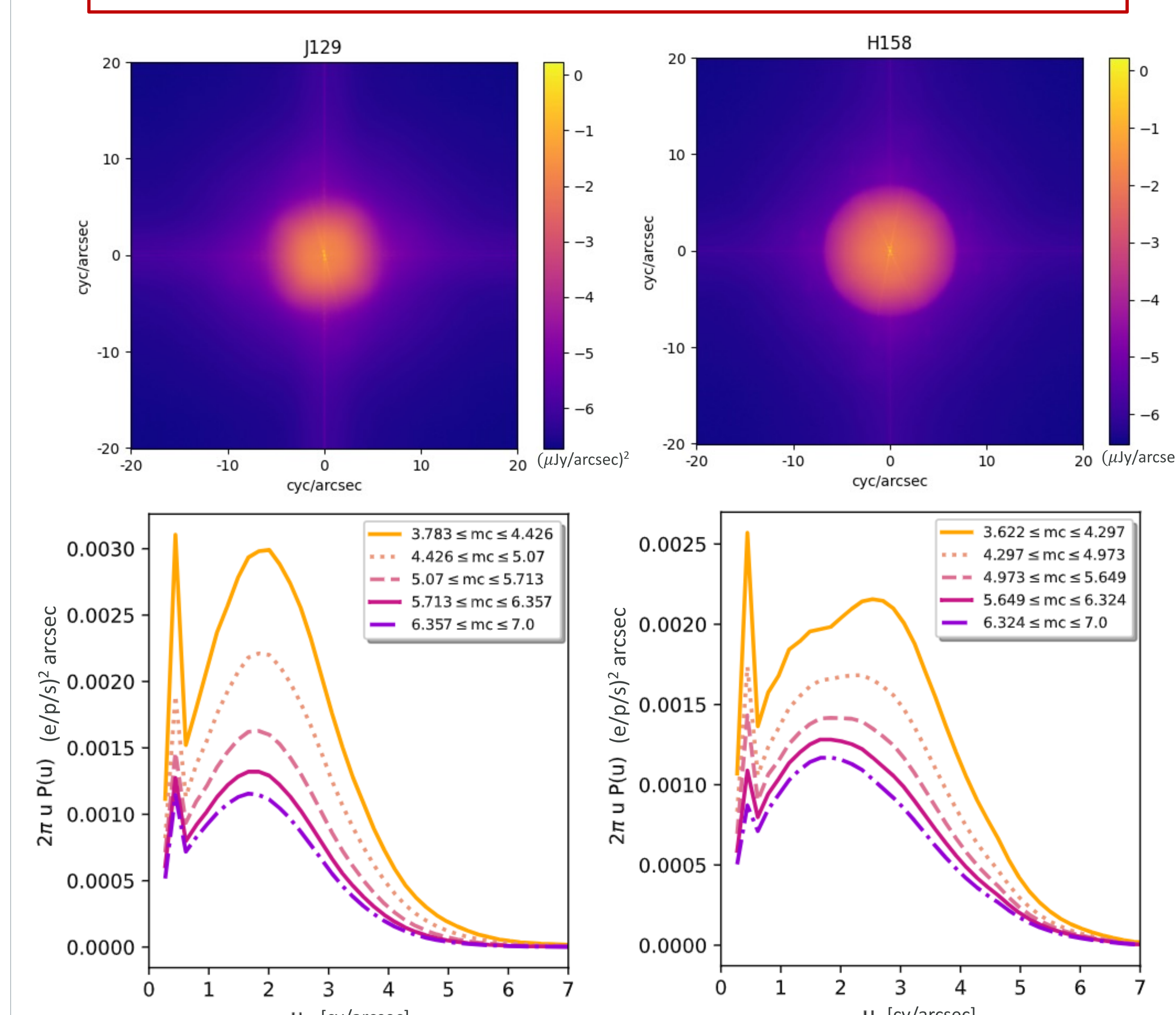
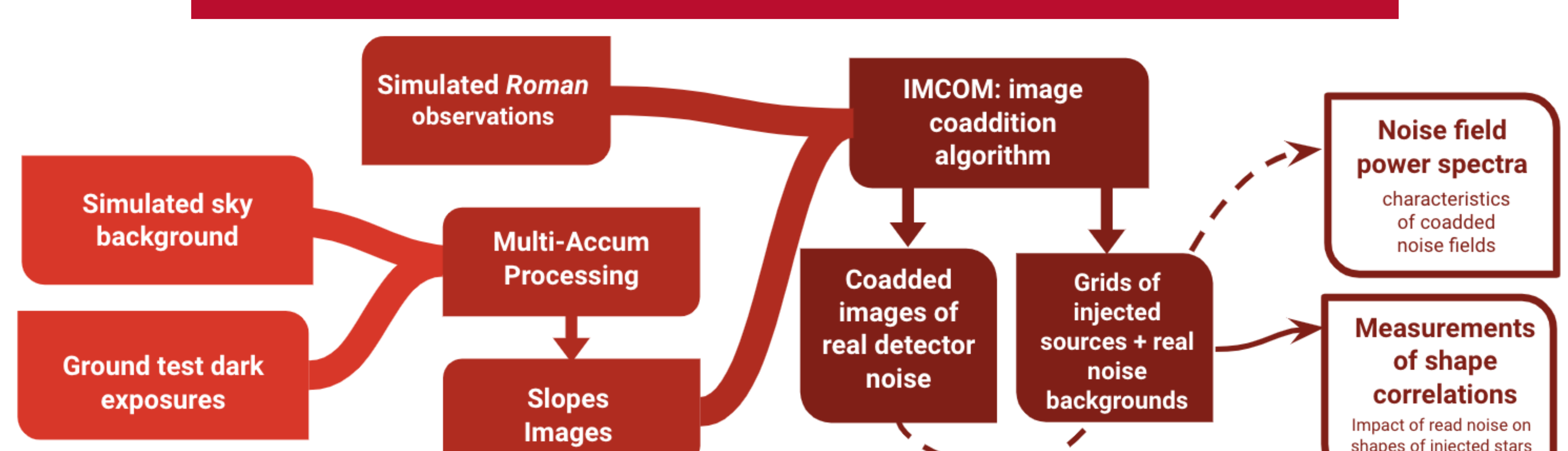


Figure 5. Top: The 2D averaged power spectrum of the lab noise field in the J and H bands, plotted on a log scale. **Bottom**: Azimuthally averaged versions of the above 2D power spectra. Each line denotes a different bin of mean sky coverage.

Noise Analysis Flowchart



Additive Bias Estimation

Weak lensing is measured by correlating the shapes of objects. We parameterize shapes in terms of the dimensionless shear parameters $g_{(1,2)} = |g|(cos, sin)(2\beta)$ where the reduced-shear $|g| = \frac{a-b}{a+b}$ and the position angle is β. We insert a grid of injected stars with unit flux and measure their shapes via the image second moments **M**:

$$(g_1, g_2) = \frac{(M_{xx} - M_{yy},\ \ 2M_{xy})}{M_{xx} + M_{yy} + 2\sqrt{M_{xx}M_{yy} - M_{xy}^2}}$$

Noise correlations in the images will cause a bias in the measurements of $g_{1,2}$. We estimate this *additive noise bias* Δg via Monte Carlo methods using the object and coadded noise images. Finally, since weak lensing measures correlations, we autocorrelate Δg for the injected stars plus lab noise for an estimate of the magnitude of additive noise biasing we can expect to measure (Figure 6).

Autocorrelation of Δg

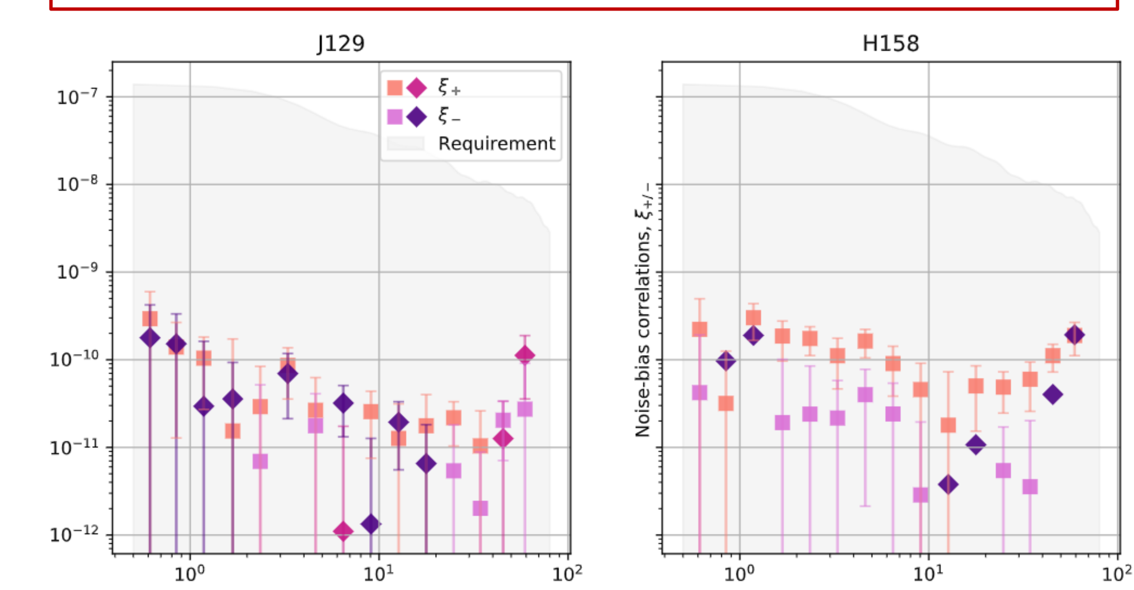


Figure 6. Raw noise bias auto-correlations (Δg) estimated for the injected stars with lab noise fields in J and H bands. Square markers indicate positive-valued correlations, while diamond markers indicate negative-values correlations, but plotted as the absolute value

Results + Future Work

The power spectra from the noise fields display the effects we expect from the image combination process and from the detector and test characteristics. The significance of noise biasing is maximized for regions with the minimum coverage from dithers. Even so, estimation of the additive noise bias shows that the biasing on shape measurements from read noise is below the mission requirements as defined in the SRD [4].

We are currently re-running this analysis on new detector noise frames taken in the lab after detectors were integrated into the telescope focal plane, to obtain even more flight-like estimates of correlated noise biasing. Additionally, as evidenced by Fig. 4, there are still visible noise correlations in the coadded noise frames. We are in the early stages of developing a de-striping algorithm, using Roman's multiple dithers observation strategy to remove correlated read noise from the images.

References

[1] Rowe B., Hirata C., Rhodes J., 2011, ApJ, 741, 46
[2] The detector tests used in this work were acquired by the Detector Characterization Lab at NASA Goddard. We thank the DCL team for making this work possible!
[3] Troxel M. A., et al., 2021, MNRAS, 501, 2044
Troxel M. A., et al., 2023, MNRAS, 522, 2801
[4] https://asd.gsfc.nasa. gov/romancaa/docs2/RST-SYS-REQ-0020C_SRD.docx.
[5] Cao et al., *Simulating image coaddition with the Nancy Grace Roman Space Telescope: III. Software improvements and fine-tuning*, 2024 (*in prep*)