Instrument Signature Removal and Calibration Products for the Rubin LSST

Andrés A. Plazas Malagón [1,2,4] Agnès Ferté [1,2,4] Chris Waters [3,4] Eli Rykoff [1,2,4] Merlin Fisher-Levine [4] Robert Lupton [3,4] LSST Science Pipelines Team

[1]SLAC National Accelerator Laboratory [2]Kavli Institute for Particle Astrophysics and Cosmology [3]Department of Astrophysical Sciences, Princeton University [4]Vera C. Rubin Observatory

Introduction: Instrument Signature Removal

- Instrument signature removal (ISR) is a crucial step in the processing of astronomical data.
- The raw data obtained from detectors such as charge-coupled devices (CCDs) often contain systematic errors, or "signatures," that are inherent to the instrument itself, rather than being representative of the celestial object being observed. These signatures can include bias levels, dark current, flat-field variations, and readout noise, among others.
- The process of ISR involves applying a series of corrections to the raw data to remove these systematic errors.
- The goal of ISR is to ensure that the final image or spectrum accurately represents the light received from the astronomical object, mitigating systematic errors introduced by the instrument.
- This process is essential for obtaining accurate measurements of astronomical phenomena and for comparing observations made with different instruments or at different times.
- In the context of the Legacy Survey of Space and Time (LSST), which will be systematics limited, ISR is a particularly crucial step.

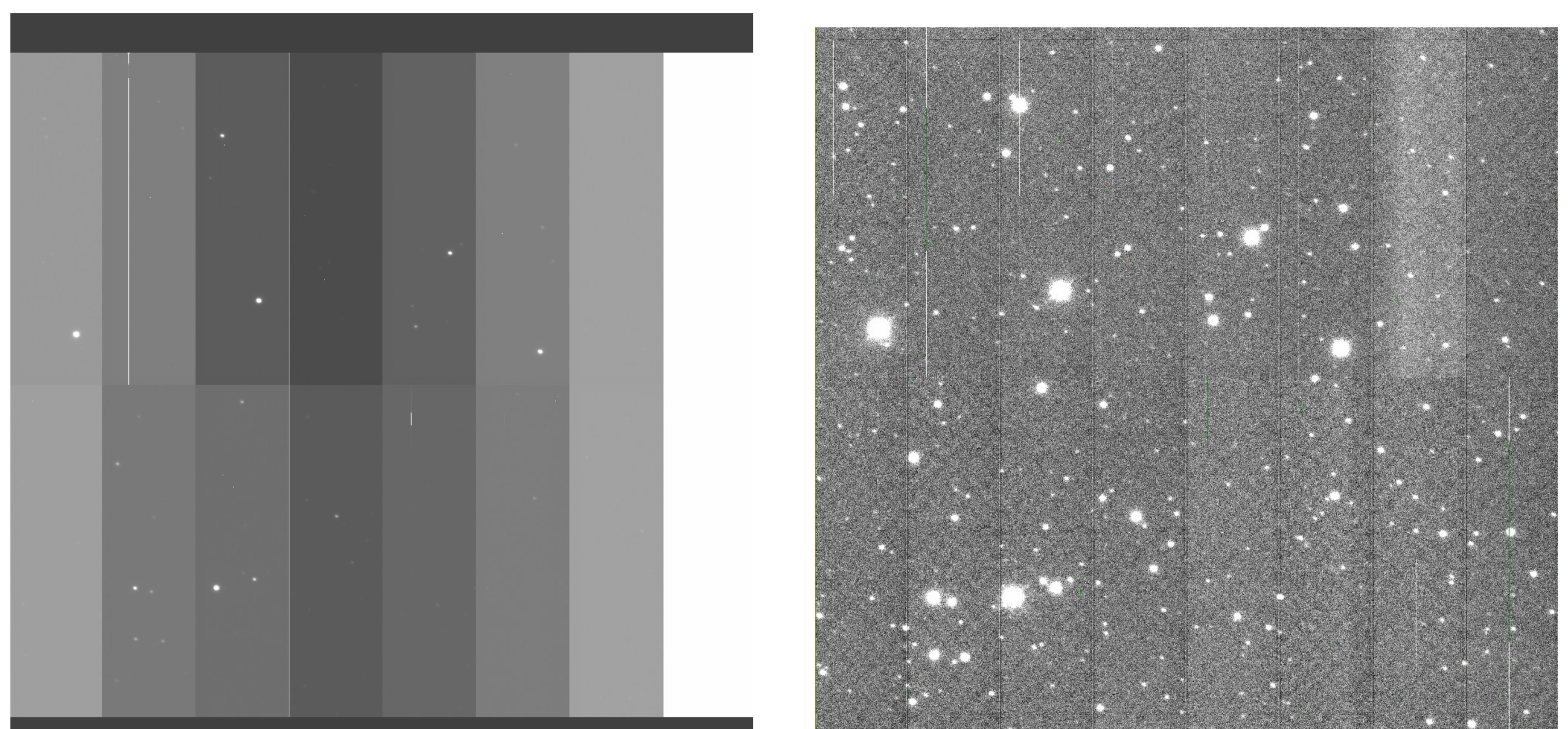

Figure 1. Example of an image before and after partial Instrument Signature Removal (bias, dark, and flat applied).

Background: the Vera C. Rubin Observatory's Legacy Survey of Space and Time (LSST)

- The Legacy Survey of Space and Time (LSST) will be conducted with the Simonyi Survey Telescope at the Vera C. Rubin Observatory, currently under construction on Cerro Pachón in Chile.
- The LSST plans to image 18,000 square degrees of the sky using six filters (ugrizy) in the optical and near-infrared (NIR) spectrum.
- LSST is designed to address four science areas: probing dark energy and dark matter, taking an inventory of the solar system, exploring the transient optical sky, and mapping the Milky Way.
- The instrument for the LSST is a 3.2 gigapixel camera, containing 201 individual CCDs, with 189 specifically for science imaging.
- The CCDs are fully depleted high-resistivity bulk silicon CCDs developed by Imaging Technology Laboratories (ITL) and Teledyne e2v (E2V).
- The CCDs are arranged into 3×3 groups called raft-tower modules (RTMs) or rafts, each capable of operating as an independent camera.
- Each CCD sensor is 4 cm $\times$ 4 cm, made up of sixteen 1 megapixel channels, each read out by its own amplifier and readout electronics.
- Each pixel on the LSST Camera focal plane is 10 μm $\times$ 10 μm and has a thickness of 100 μm.

ISR Steps in LSST

The core of ISR follows these steps:

1. Integer to float conversion.
2. Correction of the non-linearities of the electron to ADU relation.
3. Correction of the serial overscan.
4. Bad amplifier and SATURATED/SUSPECT pixel masking.
5. Correction of the crosstalk from the image to the parallel overscan region.
6. Correction of the parallel overscan.
7. Linearity correction.
8. Correction of the crosstalk between amplifiers.
9. Bias subtraction, using a combined bias frame.
10. Charge-Transfer Inefficiency (CTI) correction.
11. CDD assembly and trimming.
12. Variance calculation (variance image construction).
13. Defect mask interpolation.
14. Saturation trail widening.
15. Dark subtraction, using a combined dark frame.
16. Brighter-fatter effect correction.
17. Fringe correction for exposures taken with redder filters.
18. Flat-field corrections to normalize image to units of fluence.

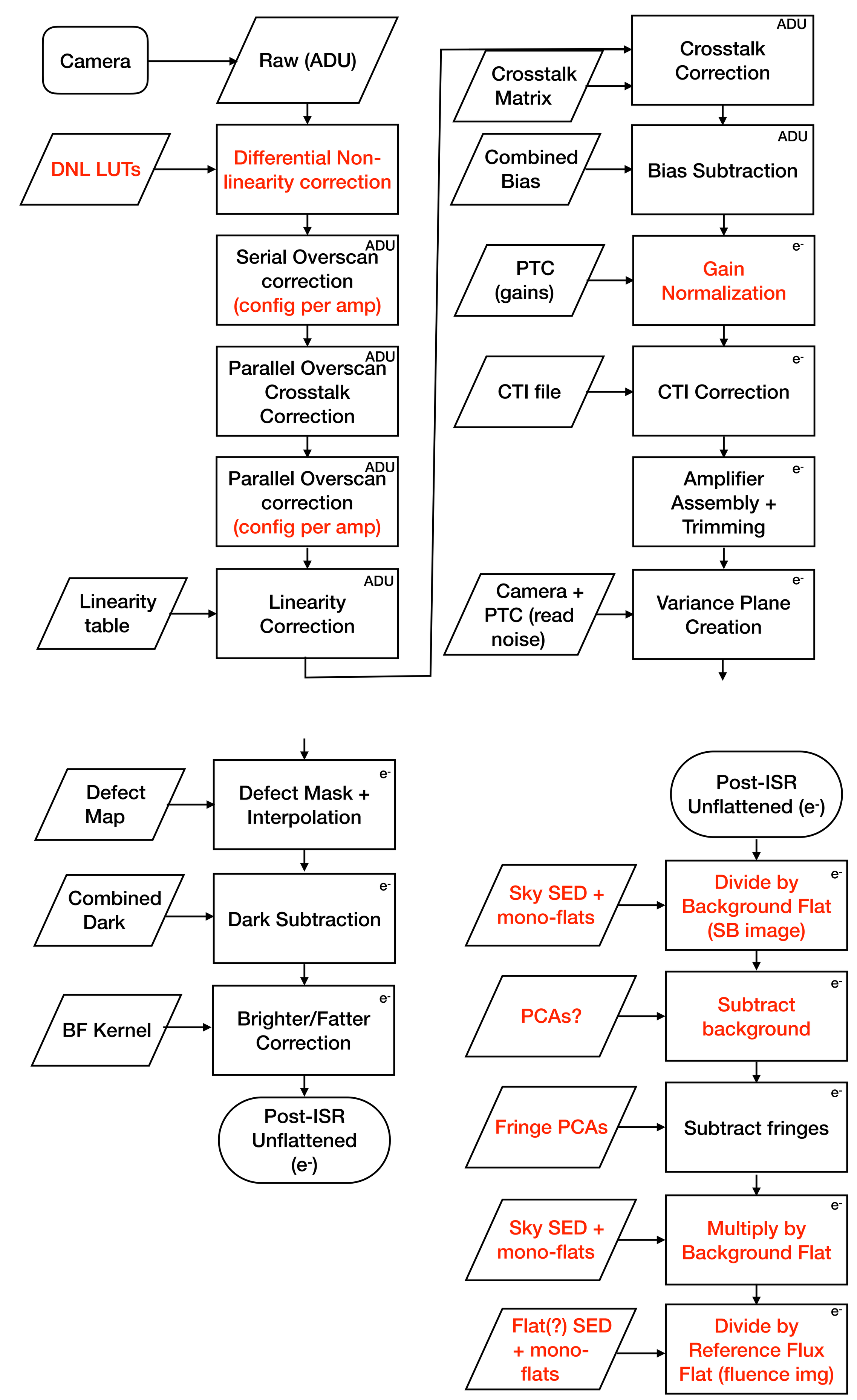

Figure 2. ISR steps and necessary calibration products. Units are displayed in each box, and the steps in red are in the process of being implemented. Diagram credit: E. Rykoff, from discussions at Rubin Calibration Workshop at SLAC, October 2023.

Calibration Products for LSST ISR

Calibration Verification and `cp_verify`

Calibration products are required to carry out the ISR steps. To validate a new combined calibration for use, metrics are measured on a calibration residual image and compared to expectations and limits (tests defined in the LSST Data Management Technical Note 101, `DMTN-101` [1]). This is accomplished via the `cp_verify` package. If all metrics are within limits, the calibration is certified for a date range during which it will be used, though the end date may be unknown. These validations are also used with daily calibrations to monitor the stability of the camera and telescope by confirming that existing combined calibrations remain suitable. Figure 3 shows the relationship between construction, validation, and usage of combined calibrations. It can be summarized as:

- A proposed calibration is constructed,
- `cp_verify` tasks check that it meets verification metrics,
- If the tests pass, the calibration can be certified by a Calibration Acceptance Board, assigned a validity range, and deployed as a standard calibration.

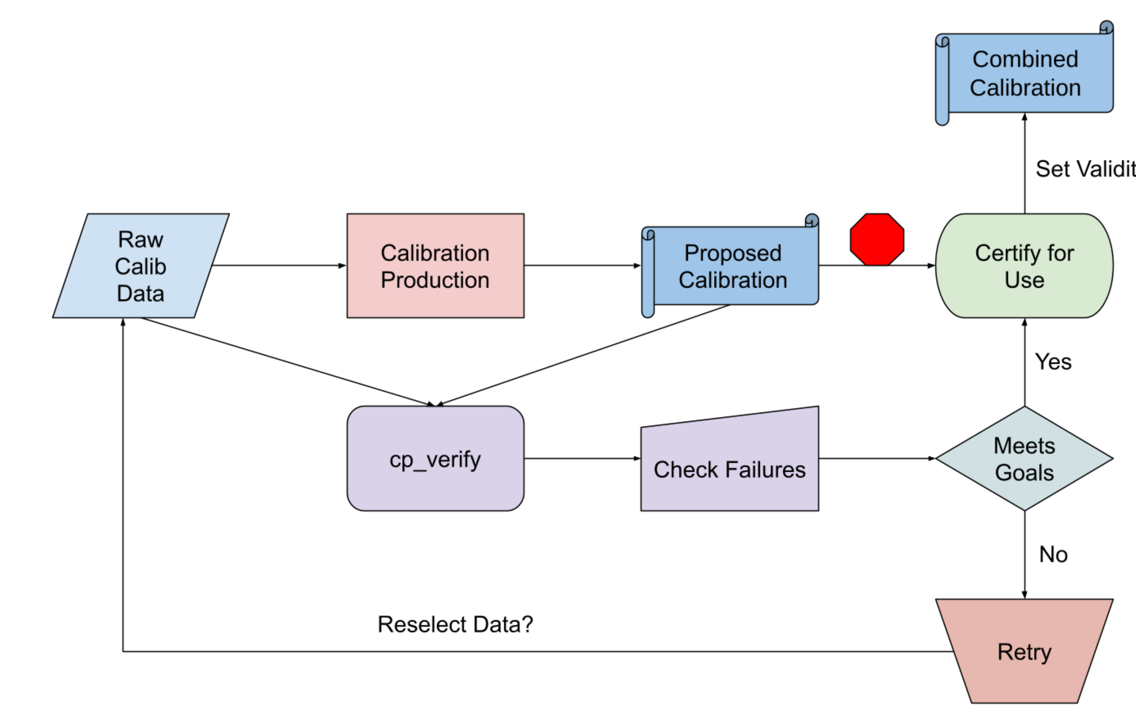

Figure 3. Calibration flow chart. Credit: Chris Waters, LSST Data Management Technical Note 222, `DMTN-222` [2]

Verification Metrics Examples

- Bias (bias-corrected bias exposures) and Dark (bias, dark corrected dark exposures):
  - Mean consistent with zero.
  - Clipped standard deviation consistent with read noise.
  - Cosmic rays rejected standard deviation consistent with read noise.
- Flat (bias, dark, flat corrected flat exposures):
  - Noise consistent with Poissonian statistics.
  - Amp-to-amp mean scatter small.
  - Detector-to-detector mean scatter small.
- Brighter-fatter correction (full ISR processed science exposures):
  - Slope of source second-moment size as a function of source magnitude small.

References

[1] R. Lupton and A. Plazas Malagón.
Verifying lsst calibration data products.
LSST Data Management Technical Note, 2023.

[2] C. Waters.
Calibration generation, verification, acceptance, and certification.
LSST Data Management Technical Note, 2023.