Strong Lensing Validation with the Vera C. Rubin Observatory

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MOTIVATION

Figure 1. The Vera C. Rubin Observatory, located on the El Peñón peak of Cerro Pachón in Chile. [1]

The Vera C. Rubin Observatory's ten year long Legacy Survey of Space and Time (LSST) will utilize a 8.4-m Simonyi Telescope and 3.2-gigapixel, 9.6 deg^2 camera to take hundreds of exposures of a ~18,000 deg^2 sky area. This unprecedented depth and coverage will enable innovative studies of cosmological phenomena, such as strong gravitational lensing. However, the first data release was captured using a lower resolution Commissioning Camera, which covers a limited sky area at a shallow depth. This limits the likelihood of observing real strong lensing, so we simulate it by inject background galaxies, lensed by mass models of real ellipticals, into our cutout images. These realistic injections will aid in preparing for true strong lensing analysis in future LSST data.

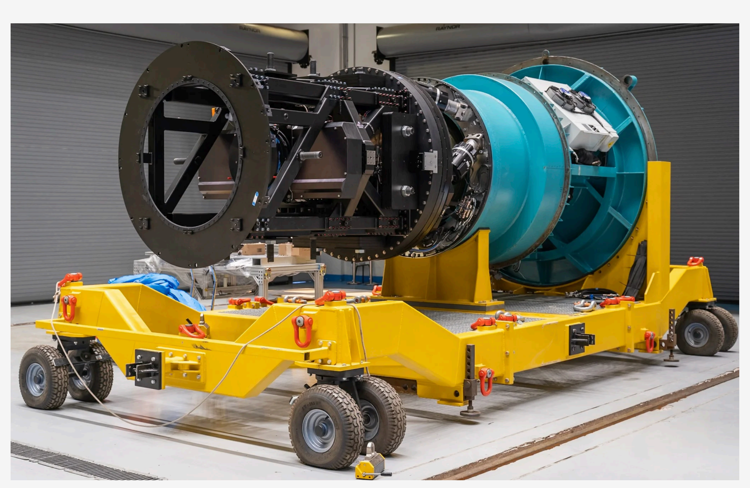


Figure 2. The LSSTComCam. [2]

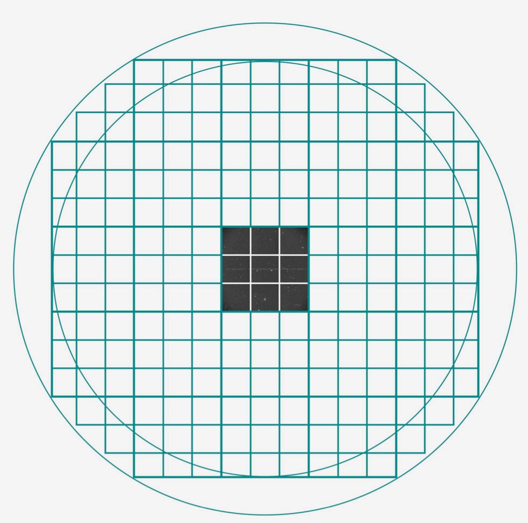
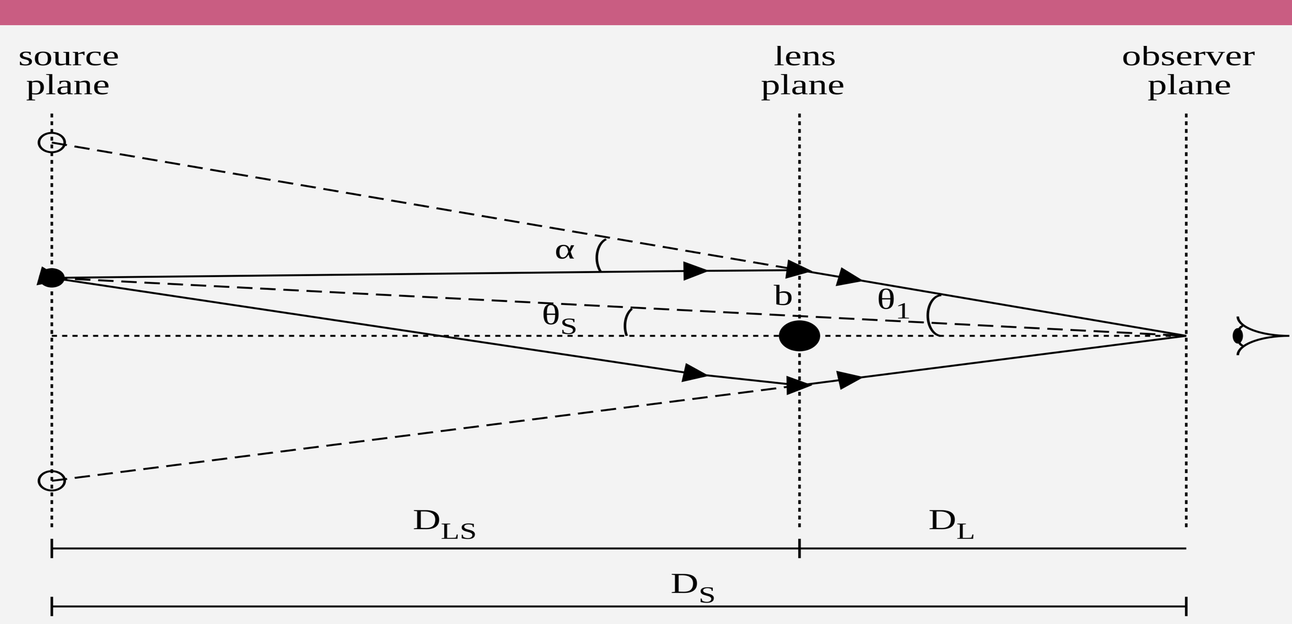


Figure 3. The field of view of the ComCam compared to the full LSST camera. [3]

BACKGROUND



Gravitational lens geometry: α deflection angle; β true source angle; θ lensed image angle; D_l, D_s, D_{ls} angular-diameter distances to lens, source, and between them. [4]

- Gravity from a massive foreground object curves spacetime, bending and magnifying background light into arcs, rings, or multiple images.
- We focus on massive elliptical galaxies as their large mass is centrally concentrated, producing large Einstein radii and bright arcs, making these lenses the easiest to spot and model.

METHODOLOGY

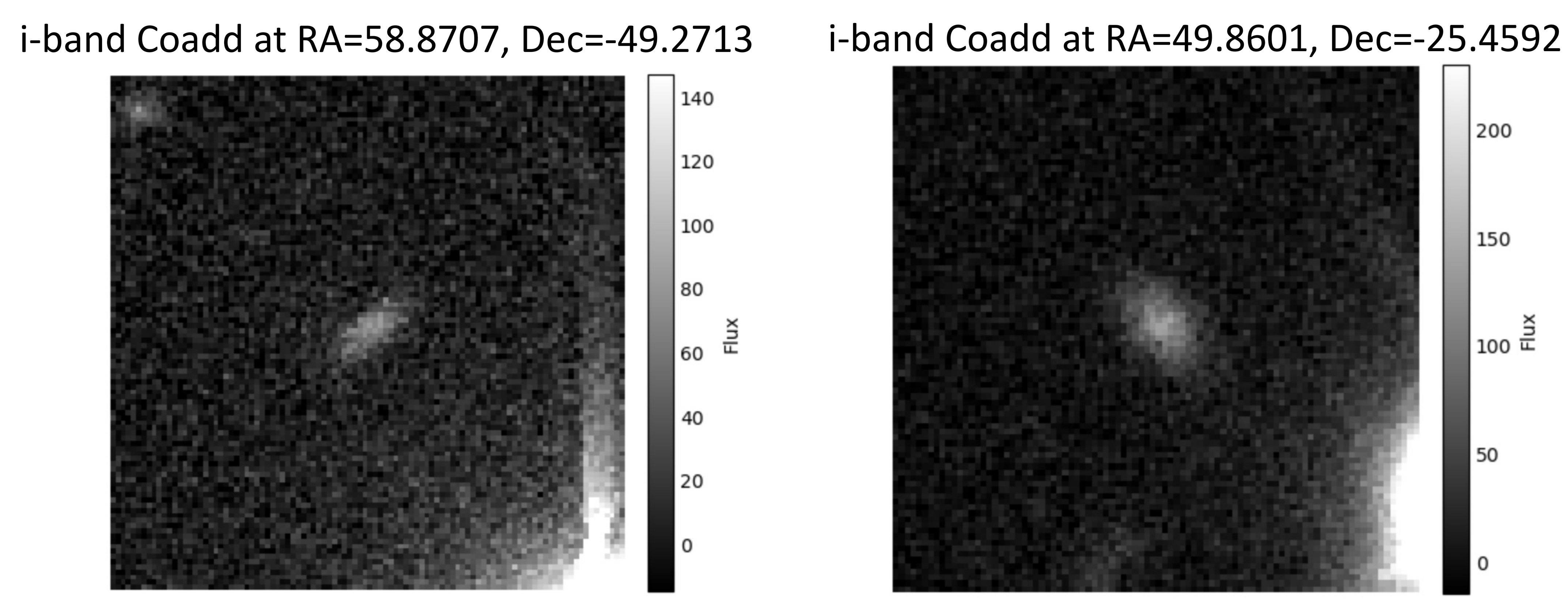
Elliptical Galaxy Extraction

- Analyzed all known galaxies in DP1 release with needed photometry and shape columns for subsequent cuts:
  1. **Bulge Dominant:** Kept galaxies with **bulge-to-total ratio ≥ 0.5** to favor early-type elliptical morphologies.
  2. **Bright:** Required **i-band Sérsic magnitude < 21.0** to select luminous, and subsequently hence high-mass, galaxies.
  3. **Large size:** Required with **Sérsic effective radius ≥ 25 pixels** to bias toward extended, massive galaxies.

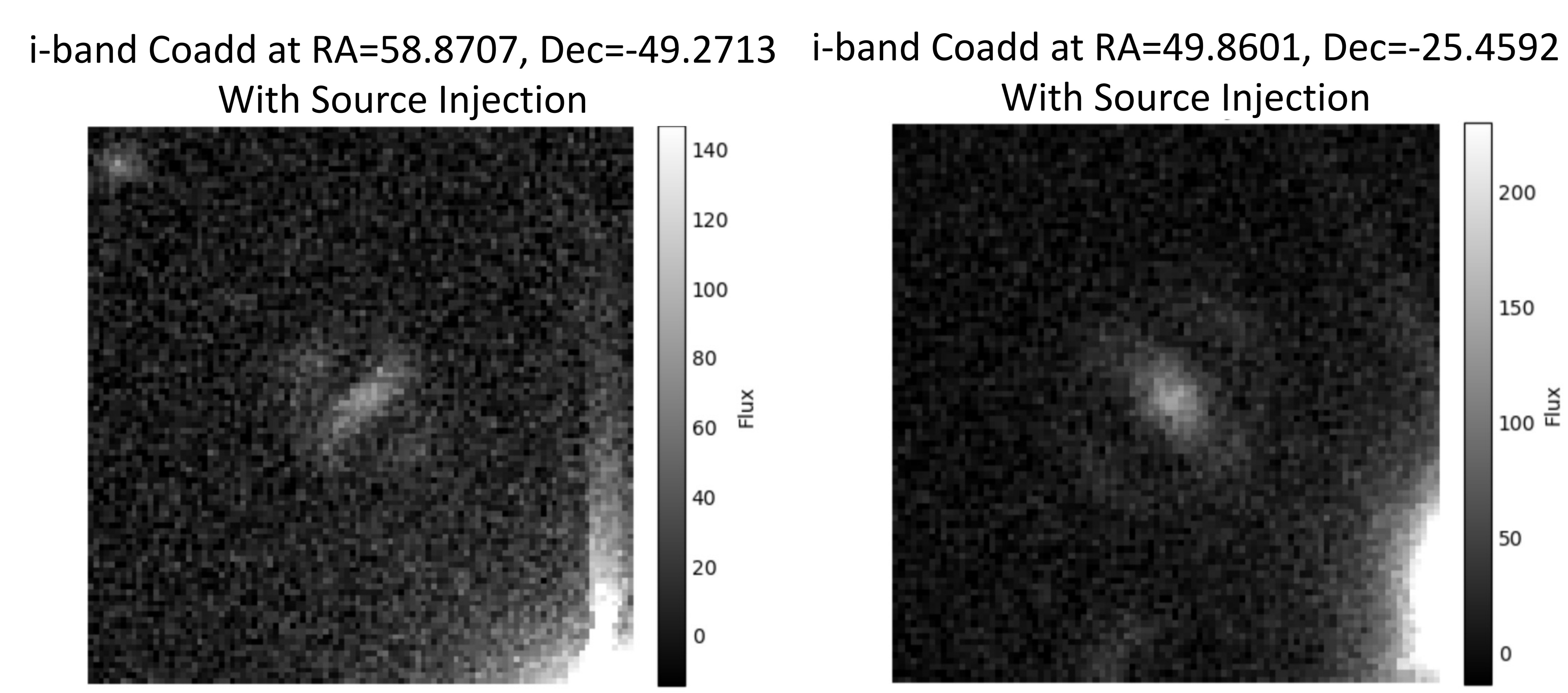
Cutouts and Source Galaxy Injection with SLSim

- We produce deep coadd cutout images of each candidate galaxy in the **i-band**.
- We generate a simulated background galaxy and lens it using a mass model derived from the real foreground galaxy [5].
- Simulations are then convolved with real DP1 PSFs and noise injected into the real deep-coadd cutout.

RESULTS



Figures 4 & 5. i-band Deep coadd cutout images of potential massive elliptical galaxies captured by the Vera C. Rubin Observatory.



Figures 6 & 7. i-band Deep coadd cutout images of potential massive elliptical with simulated lensed source galaxies injected in.

CONCLUSIONS

Elliptical Galaxy Sample Yield

- **1,374 of 255,525 galaxies** matched our criteria for ellipticity, visualized in deep coadd images.

Realistic Strong Lensing Visualization

- We generated simulated source-deflector systems modeled after observed galaxies.
- This produced realistic strong lensing morphology, matching the matching the PSF noise characteristics of true Rubin DP1 cutouts.

FUTURE WORK

Preparing for Future Data Releases:

- Visual analysis of the simulated lens system allows for training to better identify strong lensing in the complete LSST survey.

Source Galaxy Characterization via Simulations

- Simulations quantify lensing and observational biases, enabling recovery of true source sizes, fluxes, and morphologies.
- How well morphological features, such as rings or arcs, survive lensing and reconstruction informs expectations for real source imaging.

REFERENCES

1. RubinObs/NOIRLab/SLAC/NSF/DOE/AURA/B. Quint. *Gallery.* Vera C. Rubin Observatory, 2022
2. RubinObs/NOIRLab/SLAC/NSF/DOE/AURA/A. Pizarro D. *Gallery.* Vera C. Rubin Observatory, 2024
3. Wikimedia Commons. *Gravitational lens geometry, 2012*
4. NSF–DOE Vera C. Rubin Observatory. *Single-raft LSSTComCam position*. The Vera C. Rubin Observatory Data Preview 1 (RTN-095), 2025
5. A versatile strong-lensing simulation library used throughout this work. Contributions are welcome at the GitHub repository.

ACKNOWLEDGMENTS

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