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Science Validation of LSST Data Release Processing

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ABSTRACT

The Vera C. Rubin Observatory (Rubin Observatory) was designed and constructed to conduct a 10-year wide-area, deep, multi-band optical imaging survey of the night sky visible from Chile. This Legacy Survey of Space and Time (LSST) will catalog billions of individual stars and galaxies and detect millions of time-domain events each night, enabling a broad range of astrophysics research including studies of dark matter and dark energy, the transient and variable universe, the structure of the Milky Way, and an inventory of the Solar System. Here we report a first scientific characterization of the as-built Rubin Observatory based on commissioning observations taken in May 2022 for two LSST Camera pointings centered on an LSST Deep Drilling Field and a dense stellar field, respectively, each with more than 800×30-second visits across the *ugrizy* bands. The delivered image quality, achieved signal-to-noise, astrometric and photometric calibration, and quality of object detection and difference image analysis are found to be within the design specifications of the observatory.

1. INTRODUCTION

We plan to produce a series of papers on science verification and validation leading up to the first LSST public data release (LSST DR1) occurring about 12 months into LSST science operations. We envision three stages of science verification papers:

1. Papers supporting the Operational Readiness Review (ORR), *including this paper*: Given expected time constraints between the start of sustained observations with LSSTCam and the ORR, we plan to keep the scope of these papers relatively modest and to focus on a more limited set of on-sky observations that can be acquired quickly (e.g., one week), and potentially reprocessed multiple times as science pipelines evolve during commissioning.

2. Papers supporting Data Preview 2 (DP2): The next round of papers would go into further detail describing the distribution of delivered performance for the commissioning science verification surveys. A primary objective is to support the science community to use the DP2 data products.

3. Papers supporting LSST DR1: These would be normal data release papers proving a more extensive characterization at survey scale.

Due to the expected tight timeline for this paper, and the plan for additional papers appearing within a few months, topics that we are *not* planning to address in this paper include:

- Description of data model, example queries, data access services, etc. This paper is more of a first scientific characterization report than supporting a data release.
- Detailed description of science pipelines
- Absolute photometric calibration, detailed study of deblending, galaxy shape measurements and weak lensing shear, photometric redshifts, classification of transients, etc., and similar "science validation" topics that would likely benefit from community interactions over a longer timeline than a few weeks.

We should start planning the outlines of papers associated with DP2 soon so that we have a more clear overall vision for the series of early science verification and validation papers. Note that the current set of construction papers does not have a paper dedicated to science performance evaluation of ComCam. Given the expected commissioning schedule and planned set of papers mentioned above, we would prefer to focus the publications on characterization of the observatory performance with the LSST Camera. Of course we plan to test as many analysis procedures as possible with ComCam and to document the results of those tests, at least internally.

- Paragraph to introduce the LSST, including the four main science drivers.
- Paragraph to describe how the science drivers translate to high-level requirements on scientific performance of the survey and flow-down to observatory specifications, written a level to be intelligible to a general scientific audience.
- Paragraph to give a brief description of commissioning on-sky observations, introducing the selection of on-sky observations analyzed in this work. Plan to focus on an LSST Deep Drilling Field and a dense stellar field, each taken to approximately the LSST 10-year depth in multiple bands, with the visits concentrated over a few nights. The purpose is to get an early evaluation of delivered data quality from the Rubin Observatory.
- Summary table of selected commissioning observations and delivered performance including band coverage, area coverage, number of visits, single-epoch depth, coadded-depth, astrometric and photometric calibration, ...
- Pointers to other relevant Rubin Observatory construction papers for context

2. COMMISSIONING ON-SKY OBSERVATIONS

2.1. *Instrumentation*

Paragraph on the state of the system at the time of observations. Heavily reference other construction papers here.

2.2. *Observations*

- Selection and observations of the Deep Drilling Field
- Selection and observations of the dense stellar field
- Figure showing the footprint of the two fields
- Figure for distribution of single-visit image quality (e.g., FWHM) in each band, or perhaps image quality versus airmass
- Figure for sky brightness in each band (single-visit)
- Figure for system throughput in each band (e.g., single-visit depth corresponding to SNR = 5 in each band)

Information on system modeling goes into "Performance of Delivered LSST System" (PSTN-032). Information on survey speed goes in "Performance Verification of the LSST Survey Scheduler" (PSTN-043).

3. DATA PROCESSING

Heavily reference papers on data management system and science pipelines specifically. It may be that construction papers such as "LSST Data Release Processing" (PSTN-020) will appear later, e.g., around DP2. The amount of detail in this section depends on the data management domain construction papers. The intended focus of this paper is characterization of science performance for on-sky data rather than a description of the science pipelines.

- Brief description of science pipelines, including outline of stages of processing.
- Figure to show coadded color-image of each field, zoomed in enough to see some details that data processing generally looks reasonable.

4. SCIENTIFIC CHARACTERIZATION

Scientific characterization of difference image analysis and alert production to appear in "Science Validation of LSST Alert Processing" (PSTN-038).

4.1. *PSF modeling*

- Series of plots to test PSF modeling
- PSF size and ellipticity residual across the focal plane
- PSF size residuals versus flux
- PSF ellipticity correlations

4.2. *Astrometric Calibration*

- Series of plots to test astrometric performance
- Single-visit astrometric repeatability
- Cross-band astrometric residuals
- Single-visit astrometric residuals vs. Gaia across the focal plane
- Single-visit astrometric residuals vs. Gaia to test DCR (or other residuals vs. airmass, seeing, color of stars, etc.)
- Histogram of astrometric residuals in the coadd vs. Gaia

4.3. *Photometric Calibration*

- Single-visit photometric repeatability (fluxes)
- Single-visit photometric repeatability (colors)

- Histogram of photometric residuals vs. Gaia (photometric uniformity)
- Photometric residuals across focal plane vs. Gaia
- Photometric residuals vs. airmass, seeing, color of stars, etc.
- Comments on the translation to physical scale, e.g., AB magnitude
- Photometry from different measurement methods for unresolved objects

4.4. *Object Detection*

- Brief comments on deblending
- Residuals in images
- Suggested quality flags
- Spurious objects, artifacts, scattered light, ghosts, satellite trails, background level estimation, etc.

4.5. *Depth*

Focusing on the coadd here because the single-visit depth will be covered in "Performance of Delivered LSST System" (PSTN-032).

- Flux distribution of detected objects in the coadd
- Flux limit at fixed signal-to-noise
- Depth from image properties
- Object detection completeness

4.6. *Object Classification*

- Figure of size-flux showing star-galaxy separation
- Completeness and purity for star-galaxy classification vs. space-based imaging and/or using near-IR
- Density maps of stars and galaxies
- Stellar locus in color space
- Galaxies in color space

5. KNOWN ISSUES

This section is a placeholder for anomalies of areas of ongoing investigation.

6. SUMMARY AND OUTLOOK

- Brief summary of how demonstrated performance compares to expectations
- Extrapolating from these two fields to survey performance
- Brief description of additional commissioning observations

APPENDIX

Initial paper list added here for reference.

"Editor" is a responsible team leader but not necessarily the person who will do most of the required work, or who will eventually become the first author. Both issues will be handled by individual teams.

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domain: Telescope & Site
editor: Jeff Barr
title: Overview of the LSST Telescope

domain: Telescope & Site
editor: Sandrine Thomas
title: Performance of the LSST Telescope

domain: Telescope & Site
editor: Lynne Jones
title: The LSST Scheduler Overview and Performance

domain: Telescope & Site
editor: Bo Xin
title: Performance of the LSST Active Optics System

domain: Telescope & Site
editor: Tiago Ribeiro
title: LSST Observing System Software Architecture

domain: Camera
editor: Justin Wolfe
title: LSST Camera Optics

domain: Camera
editor: Chris Stubbs
title: LSST Camera Rafts

domain: Camera
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editor: Steve Ritz
title: LSST Camera Cryostat

domain: Camera
editor: Ralph Schindler
title: LSST Camera Refrigeration

domain: Camera
editor: Steve Ritz
title: LSST Camera Body and Mechanisms

domain: Camera
editor: Mark Huffer and Tony Johnson
title: LSST Camera Control System and DAQ

domain: Camera
editor: Tim Bond and Aaron Rodman
title: LSST Camera Integration and Tests

domain: Data Management
editor: Leanne Guy
title: Overview of LSST Data Management

domain: Data Management
editor: Michelle Butler
title: LSST Data Facility

domain: Data Management
editor: Tim Jenness
title: LSST Data Management Software System

domain: Data Management
editor: Jim Bosch
title: LSST Data Release Processing

domain: Data Management
editor: Eric Bellm
title: LSST Prompt Data Products

domain: Data Management
editor: Gregory Dubois-Felsmann

title: LSST Science Platform

domain: Data Management
editor: Simon Krughoff
title: LSST Data Management Quality Assurance and Reliability Engineering

domain: Data Management
editor: Leanne Guy (with likely delegation to new DM V&V Scientist)
title: LSST Data Management System Verification and Validation

domain: Data Management
editor: Mario Juric
title: LSST Moving Object Processing

domain: Data Management
editor: Robert Lupton
title: LSST Calibration Strategy and Pipelines

domain: Calibration
editor: Patrick Ingraham
title: Performance of the LSST Calibration Systems

domain: Calibration
editor: Patrick Ingraham
title: Atmospheric Properties with the LSST Auxiliary Telescope

domain: EPO
editor: Amanda Bauer
title: Overview of LSST Education and Public Outreach

domain: EPO
editor: Ardis Herrold
title: LSST Formal Education Program

domain: EPO
editor: Amanda Bauer
title: LSST EPO: The User Feedback

domain: Commissioning
editor: Chuck Claver
title: LSST Observatory System Operations Readiness Report

domain: Commissioning
editor: Bo Xin
title: Performance of Delivered LSST System

domain: Commissioning
editor: Chuck Claver
title: Active Optics Performance with LSST Commissiong Camera

domain: Commissioning
editor: Chuck Claver
title: LSST Active Optics Performance with the LSST Science Camera

domain: Commissioning
editor: Brian Stalder
title: Integration, Test and Commissioning Results from LSST Commissiong Camera

domain: Commissioning
editor: Kevin Reil
title: LSST Camera Instrumental Signature Characterization, Calibration and Removal

domain: Commissioning
editor: Patrick Hascal
title: Installation and Performance of the LSST Camera Refrigeration System

domain: Commissioning
editor: Andy Connolly
title: Science Validation of LSST Alert Processing

domain: Commissioning
editor: Keith Bechtol
title: Science Validation of LSST Data Release Processing

domain: Commissioning
editor: Michael Reuter
title: Tracking of LSST System Performance with Continuous Integration Methods

domain: Commissioning
editor: Chuck Claver
title: The LSST Science Platform as a Commissioning Tool

domain: Commissioning
editor: Chuck Claver
title: Commissioning Science Data Quality Analysis Tools, Methods and Procedures

domain: Commissioning
editor: Lynne Jones
title: Performance Verification of the LSST Survey Scheduler

A. REFERENCES

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B. ACRONYMS

Acronym	**Description**
ADS	Astrophysics Data System
DAQ	Data Acquisition System
DCR	Differential Chromatic Refraction
DM	Data Management
EPO	Education and Public Outreach
FWHM	Full Width at Half-Maximum
LPM	LSST Project Management (Document Handle)
LSE	LSST Systems Engineering (Document Handle)
LSST	Legacy Survey of Space and Time (formerly Large Synoptic Survey Telescope)
LaTeX	(Leslie) Lamport TeX (document markup language and document preparation system)
NEO	Near-Earth Object
ORR	Operations Readiness Review
OpSim	Operations Simulation
PSF	Point Spread Function
PSTN	Project Science Technical Note
TBD	To Be Defined (Determined)