LSST Commissioning Science Verification and Validation

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LIneA Webinar
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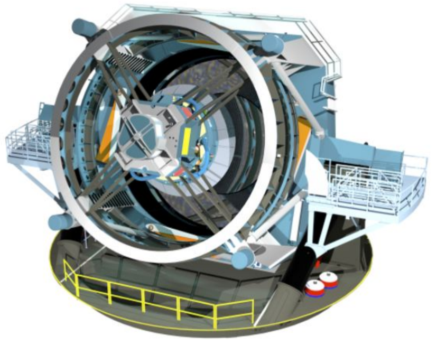
Potential Topics

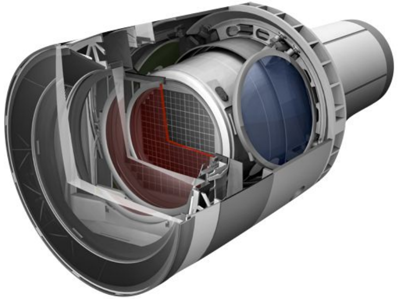
- LSST system requirements flowdown
- Verification, validation, and characterization
- Commissioning SV test approach
- Planning on-sky observations
- Quality assessment and quality control tools

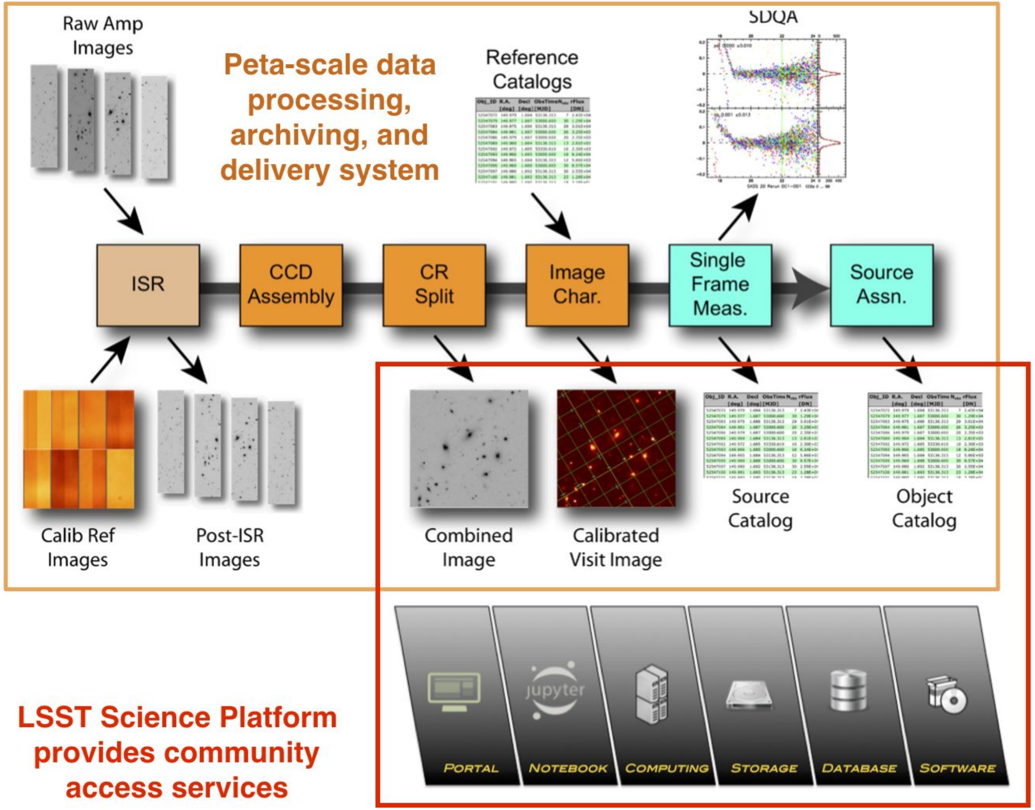
LSST Systems Engineering Approach

8.4 m telescope + observatory



3.2 Gpix camera





Science Validation in Commissioning

As the integrated LSST system comes together and begins collecting on-sky data, we need to understand the degree to which the camera, telescope, and data management system are functioning together in a way that will support the high-level scientific goals of the 10-year survey

Verification
Validation
Characterization

Science Validation in Commissioning

As the integrated LSST system comes together and begins collecting on-sky data, we need to understand the degree to which the camera, telescope, and data management system are functioning together in a way that will support the high-level scientific goals of the 10-year survey

Verification
Validation
Characterization

Especially important given the statistical precision possible with LSST

Verification

Did we build what we said we would build?

Validation

Does the thing we built do what want/expect it to do?

Characterization

Do we understand why the thing we built works the way that is does?

SV Technical Scope and Requirements

1. Determining whether the specifications defined in the ***Science Requirements Document*** (SRD, LPM-17) and ***LSST System Requirements*** (LSR, LSE-29) can be met with the full survey

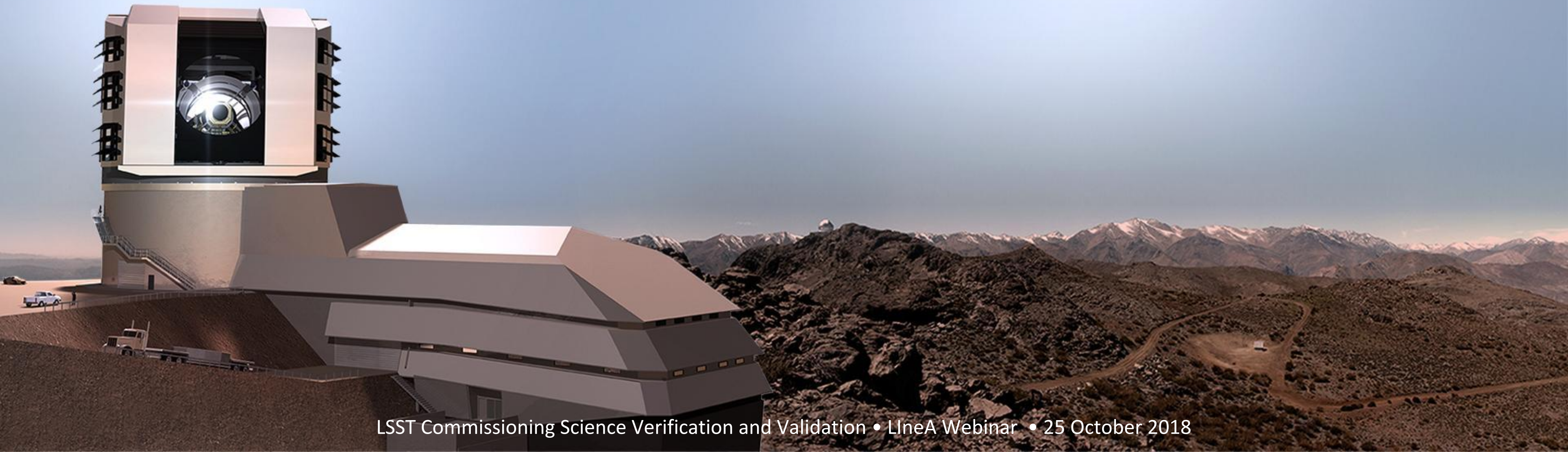
2. Characterizing ***other system performance metrics*** in the context of the four primary science drivers

3. Studying ***environmental dependencies*** and ***technical optimization*** that inform early operations

4. ***Documenting*** system performance and verifying mechanisms to ***monitor*** system performance during operations

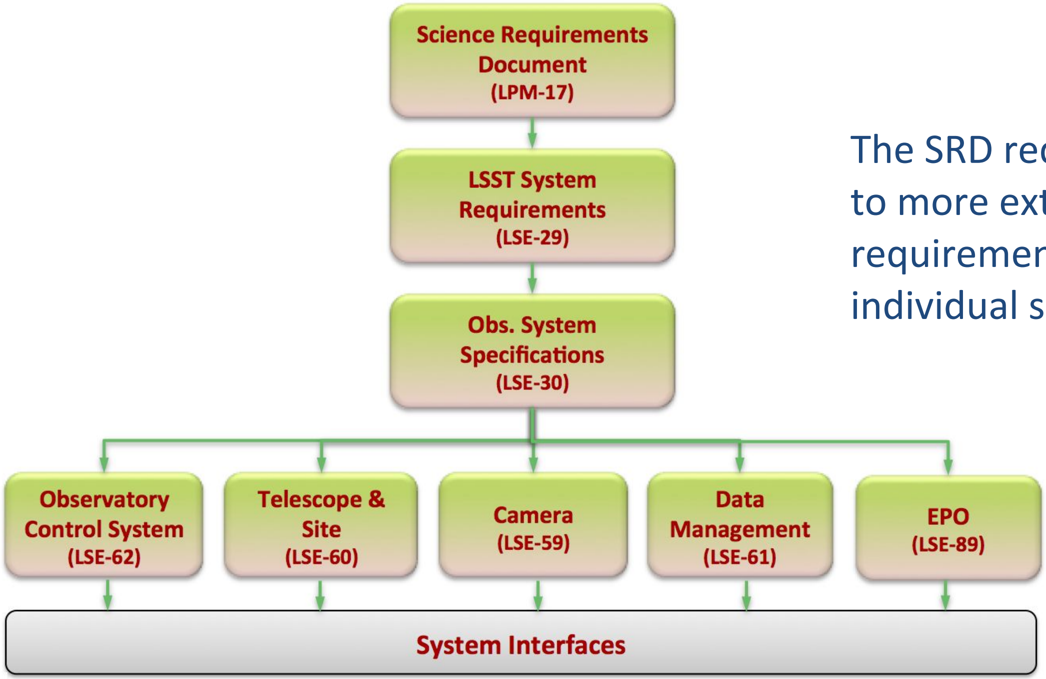
5. Validating ***data delivery***, derived ***data products***, and ***data access*** tools that will be used by the science community

LSST System Requirements



Flowdown of System Requirements

The SRD (LPM-17) lists a minimal set of the most challenging requirements for LSST data products, motivated by the main science themes, that are believed to fully exercise the technical capabilities of the system



The SRD requirements flow down to more extended and detailed requirements for the system and individual subsystems

Verify SRD Requirements

The SRD (LPM-17) lists a minimal set of the most challenging requirements for LSST data products, motivated by the main science themes, that are believed to fully exercise the technical capabilities of the system

Example SRD Requirements

14 single-visit and 10 full survey requirements require detailed analysis

Survey Property	SRD Specification (Design Value)
Image Depth (Single Visit)	r = 24.7 at SNR = 5
Median Delivered Seeing	0.7” FWHM
Photometry (Single Visit)	0.5% repeatability, 1% relative, 1% absolute, 0.5% color
Astrometry (Single Visit)	10 mas relative, 50 mas absolute
Proper Motion	0.2 mas yr^{-1} at r = 20.5, 1.0 mas yr at r = 24.0
Residual PSF Ellipticity Power	2 x 10^{-5} for θ < 1’, 1 x 10^{-7} for theta > 5’
Transient Detection	95% purity at 90% detection efficiency for SNR > 6
Survey Area & Median Number of Visits	18000 deg^2 with 825 visits

Document Flow

Commissioning SV planning focused on the following requirements documents:

- SRD (LPM-17): Science Requirements Document
    - ls.st/lpm-17

- **LSR (LSE-29): LSST System Requirements**
    - ls.st/lse-29

- **OSS (LSE-30): Observatory System Specification**
    - ls.st/lse-30

- **DMSR (LSE-61): Data Management System (DMS) Requirements**
    - ls.st/lse-61

Note: There is substantial repetition in the requirements throughout these documents

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    - ls.st/lse-61

Analysis of commissioning data products is intrinsically a test of both the hardware performance as well as the science pipelines and data access tools

Single Commissioning Science Validation effort coordinated with Data Management construction effort

Note: There is substantial repetition in the requirements throughout these documents

Requirements Documents

SRD (LPM-17): Science Requirements Document

- Defines science-driven requirements for the data products to be delivered by LSST. All of the requirements in the SRD flow down to the LSR, OSS, and DMSR (with the exception of some of the science objectives)

LSR (LSE-29): LSST System Requirements

- Definition of the highest level of LSST Observatory system requirements. Contents generated out of the SysML based LSST System Architecture model (MagicDraw) and from the SRD. This is what the project says it must deliver to meet the SRD

Note: because of the challenge in defining requirements based on astrophysics (e.g. photometric redshifts) the SRD does not include a complete set of numerical requirements for all of the science cases

Requirements Documents

OSS (LSE-30): Observatory System Specifications

- Describes the functional and performance requirements and allocations needed to fulfill the system functionality and survey performance (from the LSR). Defines the error budgets allocated to subsystems to meet LSR. Some of this directly replicates SRD values and requirements

DMSR (LSE-61): Data Management System (DMS) Requirements

- Contains top-level requirements for the Data Management subsystem of the LSST, when combined with the LSR and OSS. Replicates much of OSS, LSR but contains many functional requirements (e.g., a service must exist) and performance related requirements. This is what DM says they will deliver and verify.

Example Requirement Flow

Absolute Astrometry Requirement

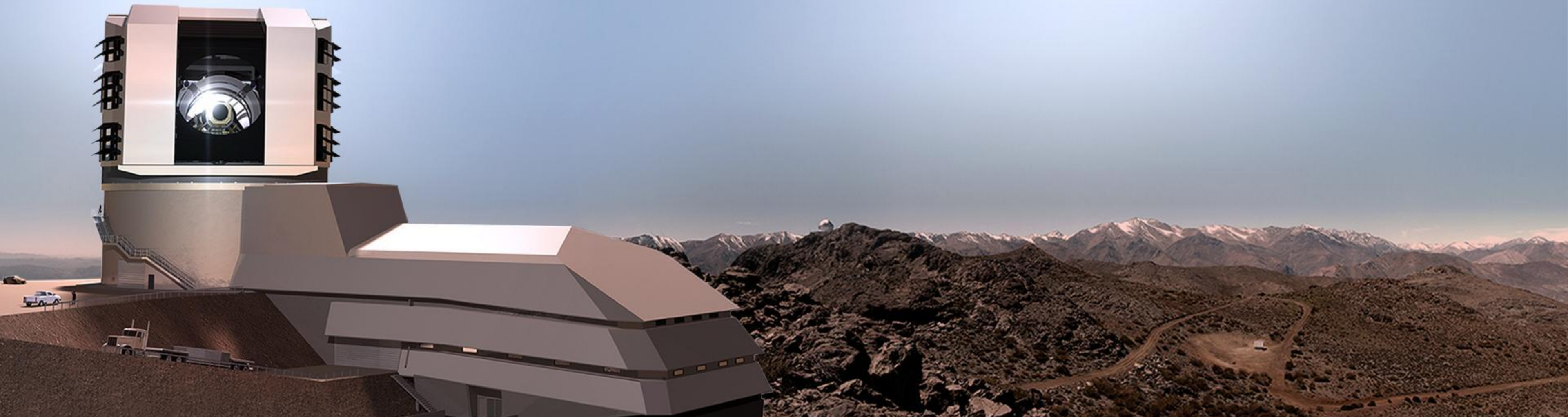
- SRD (3.3.5.2): The LSST astrometric system must transform to an external system (*e.g.* ICRF extension) with the median accuracy of AA1 milliarcsec (Table 20). **AA1** (50 mas)
- LSR (LSR-REQ-0094): The astrometric quality of images from a single visit shall meet the specifications listed in the table **astrometricPerformance** (includes multiple astrometric requirements).
  - Median error in absolute position for each axis, RA and DEC, shall be less than **AA1** (50 mas)
- OSS (OSS-REQ-0388): The astrometric quality of images from a single visit shall meet the specifications listed in the table **below** (includes multiple astrometric requirements).
  - Median error in absolute position for each axis, RA and DEC, shall be less than **AA1** (50 mas)
- DMSR (DMS-REQ-0030): The DMS shall generate and persist a WCS for each visit image. Absolute accuracy of the WCS shall be at least **astrometricAccuracy** in all areas of the image, provided there are at least **astrometricMinStandards** astrometric standards available in each CCD.
  - Absolute accuracy of the WCS across the focal plane **astrometricAccuracy (**50 mas)
  - Minimum number of astrometric standards per CCD. **astrometricMinStandards** (5)

Data Products Definition Document

The **Data Products Definition Document** (DPDD, LSE-163) specifies that the data release data products include:

- Adaptive second moments of source intensity for each source and for the PSF at each source location
- Bulge-disk model (e.g., ~200 samples from likelihood function)
- Photo-z (e.g., ~100 parameters describing likelihood distribution)
- Morphological extendedness parameter
- Statistical variability metrics
- Image data (including representations of survey geometry)

Verification, Validation, and Characterization



Verification vs. Validation/Characterization

- **Verification (DM)**: demonstrate the requirements to undertake the survey are met given simulations and prior data sets

- **Verification (Commissioning)**: demonstrate the requirements to undertake the survey are met given ComCam and LSSTCam data

- **Validation (Commissioning)**: Demonstrate we can meet the science objectives of the survey (many of these tests do not have formal requirements, and/or do not have a numerical specification, e.g., deblending)

- **Characterization (Commissioning):** characterize the performance of the system as a function of observing/instrument/astronomical conditions (e.g., deblending in poor seeing, high airmass, high stellar density)

Verification vs. Validation/Characterization

Example: Single-visit imaging depth (from SRD)
*The distribution of the 5σ (SNR=5) detection depth for point sources for all the exposures in the r band will have a median not brighter than **D1** mag, and no more than **DF1** % of images will have a 5σ depth brighter than **Z1** mag.*

Remarks:

1. Although this is a single-visit performance specification, the requirement is stated in terms of a median and outlier fraction from an ensemble of visits.
2. The requirement is stated for photometric dark nights and pointings close to zenith. How does depth vary with observing conditions? What distribution of single-visit depth can be expected for the full survey?
3. The requirement is stated in terms of signal-to-noise, rather than object detection completeness, which is the more relevant quantity for some science cases -- this requires deeper reference imaging

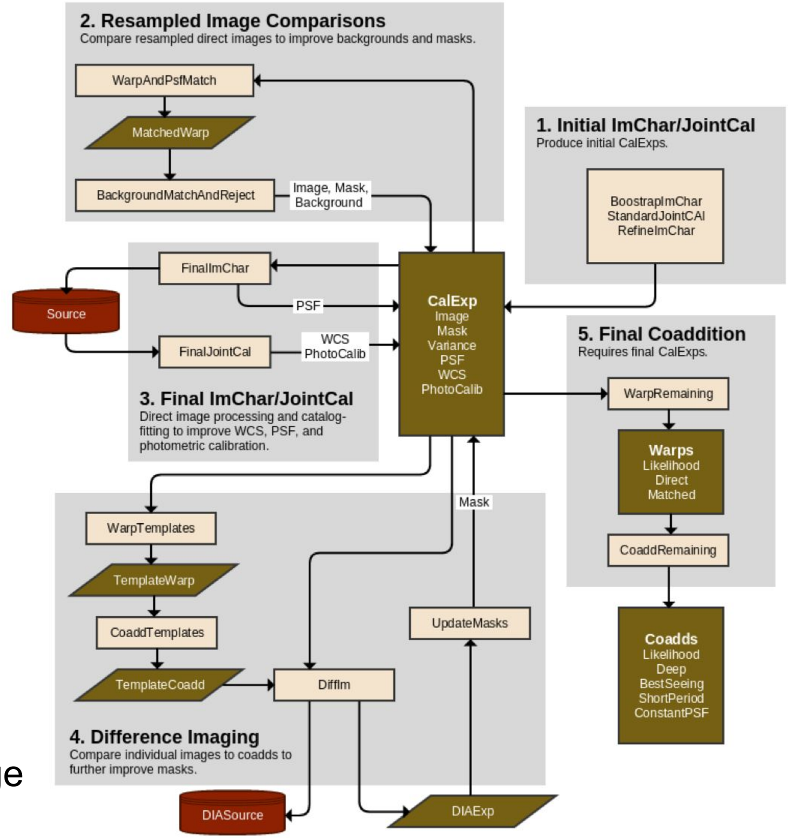
In many cases, analysis of on-sky commissioning data will need to be combined with simulations and/or external datasets to understand whether the system requirements can be met with the full survey

(Re-)Verify Science Pipelines

Science pipelines will have been extensively tested with pre-cursor datasets and LSST simulations as part of DM construction

We will re-verify pipeline components (LDM-151) with data from as-built system:

- 18 calibration products
- 14 APP pipeline components
- 26 DRP pipeline components



Example:
Data Release Processing image coaddition and differencing

(Re-)Verify Science Pipelines

Calibration Production Production

- Master bias
- Master darks
- Master linearity
- Master fringe frames
- Master gain values
- Master defects
- Saturation levels
- Crosstalk
- Master impure broadband flats
- Master impure monochromatic flats
- Master pure monochromatic flats
- Master PhotoFlats
- Master low-resolution narrow-band flats
- Pixel sizes
- Brighter-fatter coefficients
- Charge transfer efficiency (CTE) measurements
- Filter transmission
- Ghost catalog
- Spectral standards
- Spectrophotometric standards
- Astrometric standards

(Re-)Verify Science Pipelines

Alert Production

- Single-image processing
  - Instrument signature removal
  - PSF and background determination
  - Source measurement
  - Photometric and astrometric calibration
- Alert generation
  - Template generation
  - Image differencing
  - Source association
- Alert distribution
  - Alert postage stamp generation
  - Alert queuing and persistence
- Pre-recovery photometry
  - Forced photometry on all DIAObjects
  - DIAObject forced photometry
- Moving object pipeline
  - Tracklet identification
  - Prerecovery and merging of tracklets
  - Linking tracklets and orbit fitting
  - Global prerecovery

(Re-)Verify Science Pipelines

Data Release Production

- Image Characterization Pipeline
  - BootstrapImChar
  - StandardJointCal
  - RefineImChar
  - FinalImChar
  - FinalJointCal
- Coaddition and image difference
  - WarpAndPsfMatch
  - BackgroundMatchAndReject
  - WarpTemplates
  - CoaddTemplates
  - DiffIm
  - UpdateMasks
  - WarpRemaining
  - CoaddRemaining
- Coadd processing
  - DeepDetect
  - DeepAssociate
  - DeepDeblend
  - MeasureCoadds
- Overlap resolution
  - ResolvePatchOverlaps
  - ResolveTractOverlaps
- Multi-epoch object characterization
  - MultiFit (or alternative algorithm?)
  - ForcedPhotometry
- Post processing
  - MovingObjectPipeline
  - ApplyCalibrations
  - MakeSelectionMaps
  - Classification
  - GatherContributed

Verify SRD and LSR Requirements

Single-visit SRD Requirements

- Filters (demonstration)
- Depth
  - *r*-band reference depth
  - *ugrizy*-band reference depth
  - Variation of depth over FOV
  - Minimum exposure time (demonstration)
- Image quality
  - Delivered image quality
  - Image budget at airmass = 2
  - Image sampling (demonstration)
  - Image spatial profile
  - Image ellipticity distribution
- Photometry
  - Photometric repeatability
  - Photometric spatial uniformity
  - Band-to-band photometry
  - Absolute photometry: this will likely require extra work to determine the absolute photometric calibration
- Astrometry
  - Relative astrometry
  - Cross-band relative astrometry
  - Absolute astrometry
- Time recording (demonstration)

Verify SRD and LSR Requirements

Full Survey SRD Requirements

- Sky area
- Total number of visits and visit distribution by band
- Idealized stack depth
- Distribution of visits in time
- Astrometric parallax
- Proper motion
- Residual ellipticity correlations
- Data release cadence (demonstration)
- Transient alert latency (demonstration)
- Number of transients (demonstration)
- Moving object linkage
- Spurious metric efficiency - transients
- Spurious metric efficiency - MOPs

Characterize Other SRD-Motivated Metrics

Between the normative SRD data quality metrics and high-level science analyses there exists a set of intermediate data characteristics that represent important benchmarks of scientific capability:

- Object detection completeness
- Star-galaxy separation
- Galaxy photometry (e.g., for photometric redshifts)
- Difference image analysis photometry (e.g., for statistical variability metrics)
- Low surface brightness features
- Weak-lensing null tests
- Crowded fields / deblending
- ....

Pursuing a selection of such analyses as part of Science Validation
(1) **may reveal more subtle issues** that require hardware/software adjustments and/or inform operations, and

(2) would provide **valuable documentation** to the scientific community

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- ....

Several of the metrics above are directly related to data products included in the **Data Products Definition Document** (LSE-163). Optimization of the algorithms that generate these quantities is beyond the scope of the Commissioning Team. However, baseline characterization of these quantities is a goal of Science Validation.

Characterize Other SRD-Motivated Metrics

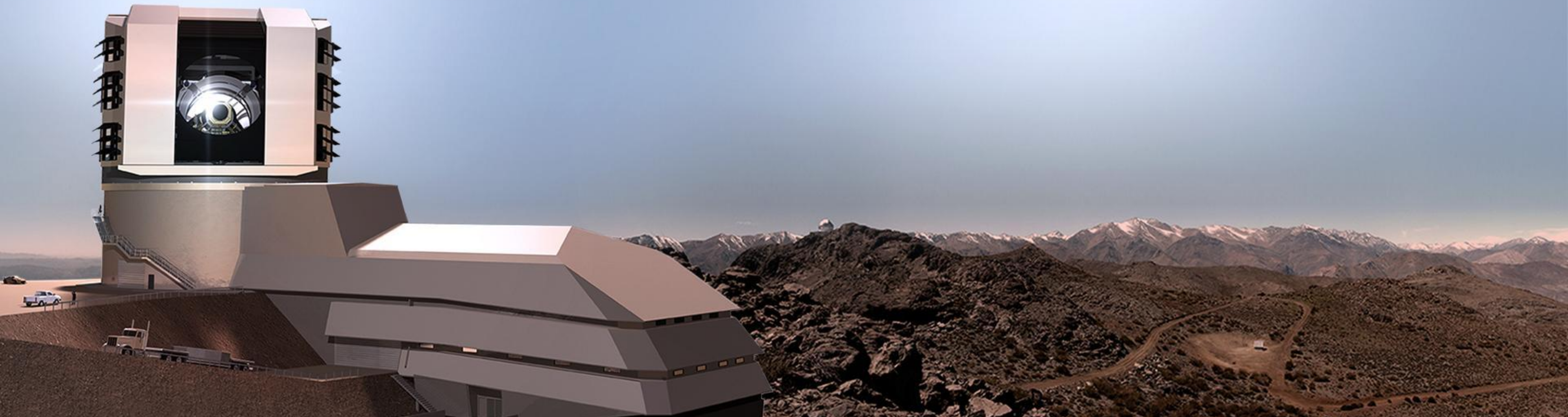
Other SRD-motivated Metrics Associated with AP

- Summary demographics of the transient and variable object population
- Difference imaging on top of bright galaxies and in crowded fields
- Accuracy and precision of flux recovery for transients and variables
- Template optimization, including DCR
- Scattered light/ghosts + diffuse light/low surface brightness object detection (also highly relevant for DRP)
- Detailed study of crosstalk impact on spurious sources
- Recovery of streaked moving objects

Other SRD-motivated Metrics Associated with DRP

- Object detection completeness and spurious objects: this analysis would also include a set of flag recommendations
- Deblending
- Star-galaxy separation
- Photometric redshifts
- Red-sequence galaxy photometry: a sensitive test of color uniformity across the survey
- Weak lensing null tests: stringent requirements on image quality, PSF size and shape, astrometry
- Statistical variability metrics

Commissioning SV Test Approach



Terminology

- System **Requirements** in MagicDraw are decomposed into one or more **Verification Elements** which define specifically what must be verified as well as pass/fail criteria such that the intent of the requirement is considered to be met.
- A JIRA **Test Case** is a set of steps (Test Script) performed to verify the requirements. Test Cases are traced to specific Verification Elements.

Terminology

- JIRA **Test Cycle:** a collection of Test Cases, typically grouped into a logical group
- JIRA **Test Plan:** a collection of Test Cycles that when executed will perform the steps in the subsequent Test Case(s) in the Test Cycle. The Test Plan defines the overall objective of the test, the conditions in which the test is to be performed, when it can be considered completed, and where the resulting evidence is located. Executed at a specific moment in time.
- **Test Report:** reports the results of the corresponding Test Plan at a specific moment in time

Anticipated Workflow

We expect most commissioning SV Test Cycles to consist of Test Cases for

- Data collection, calibration + on-sky observations, including OCS scripts
- Data processing campaign(s), including science pipeline configurations
- Data analysis tools / scripts / notebooks

Notes:

- Aim to take observations that enable multiple tests to be performed with same dataset
- Test Cases can be re-used as needed
- Test Cycles can be repeated as needed, potentially with different configurations as system functionality increases

Why this level of formalism?

- LSST has several thousand individual requirements… *need a robust bookkeeping solution!*
- Unified approach across the LSST system
  - Visible to entire Project
  - Object-oriented approach; re-use where possible
- Traceability both up and down the document tree
- Provides common language for communication
- Ability to assign specific tasks to individuals

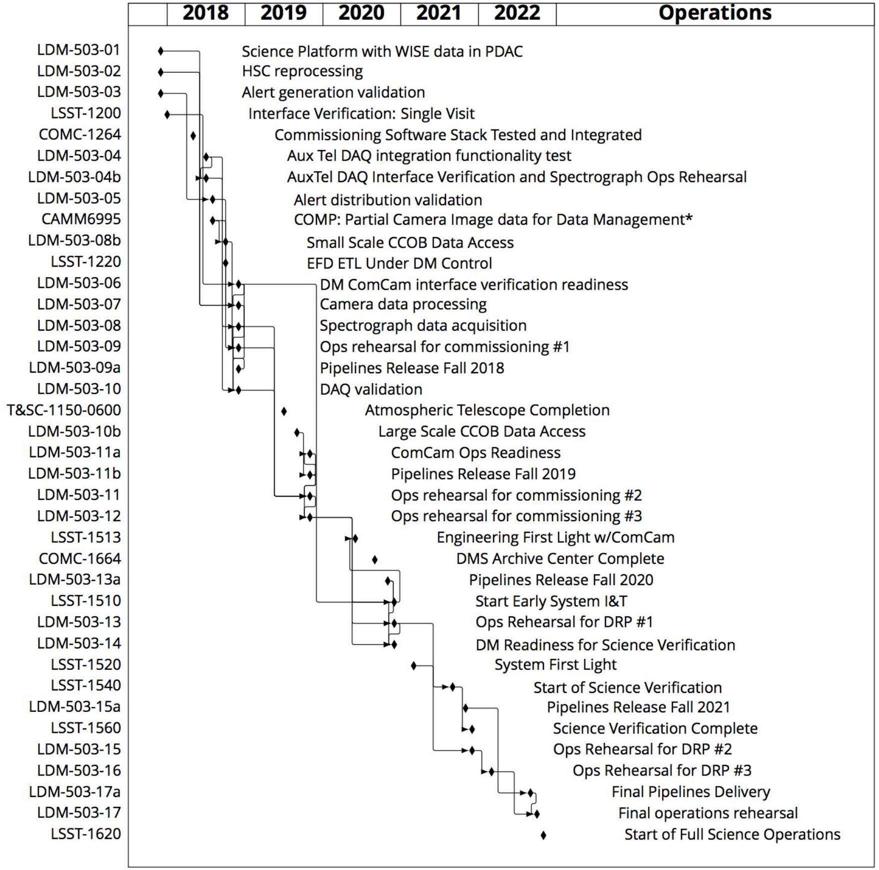
Coordinating w/ Ongoing DM Construction

Coordinated plan with ongoing DM construction effort to stand up functionality in time to support commissioning needs

For example:

- LSST Data Facility (LDF)
- Quality Assessment (QA) and Quality Control (QC) frameworks
- LSST Science Platform (LSP)

LDM-503



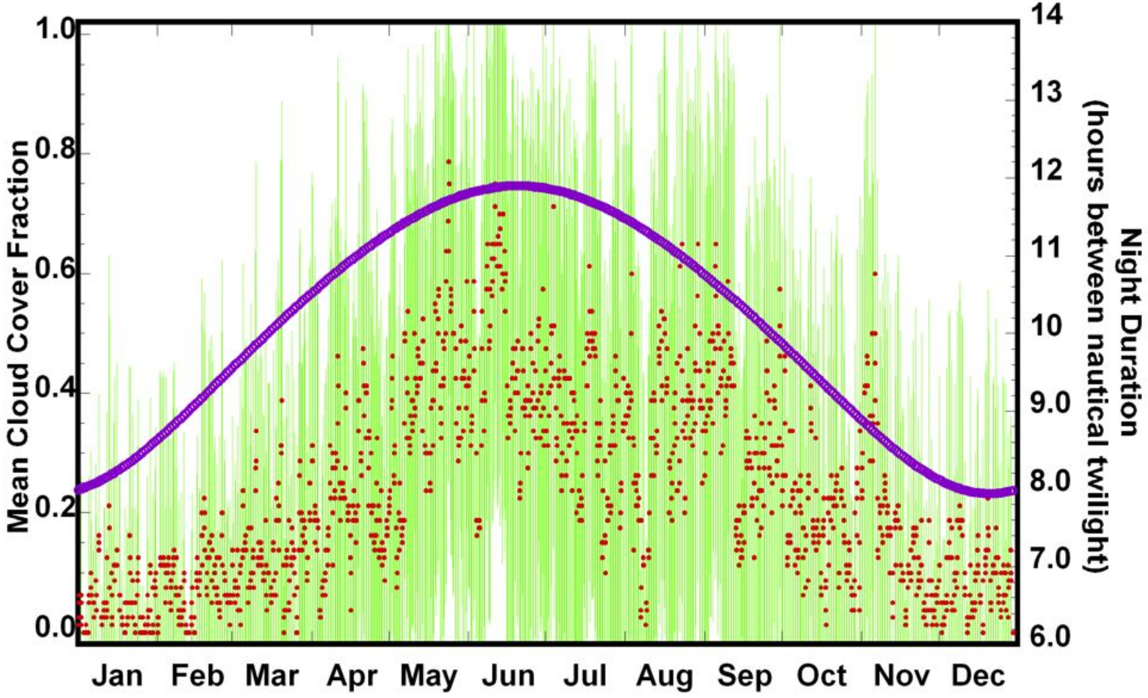
Planning On-sky Observations

Planning Tests of Increasing Sophistication

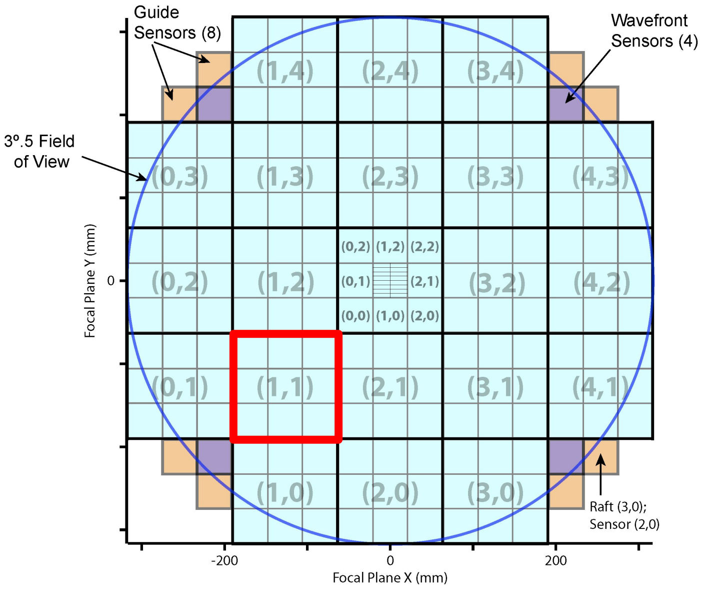
- Verify with on-sky data as early as possible
- Gradual transition from engineering activities to sustained operations
  - Engineering focus during AI&T with ComCam and LSSTCam
  - Allocate ~25% of total time for engineering activities during early Science with ComCam and LSSTCam
  - Approach early operations level during Science Validation Surveys
- Tests of increasing sophistication: calibration products → single-visit performance → image stack performance → other metrics
- Direct test if possible; validate with simulations otherwise
  - Example: simulations used to assess expected 10-yr proper motion precision, 10-year survey coverage, detection completeness

Taking Weather Into Account

When planning the time needed for on-sky observations, we have assumed that (on-average) 85% of time is usable and 53% of time is photometric. Historical weather patterns at CTIO suggest that the number of hours of dark clear skies per night (~8) is approximately uniform over the annual cycle.



Focal Plane Size, Expected Source Counts

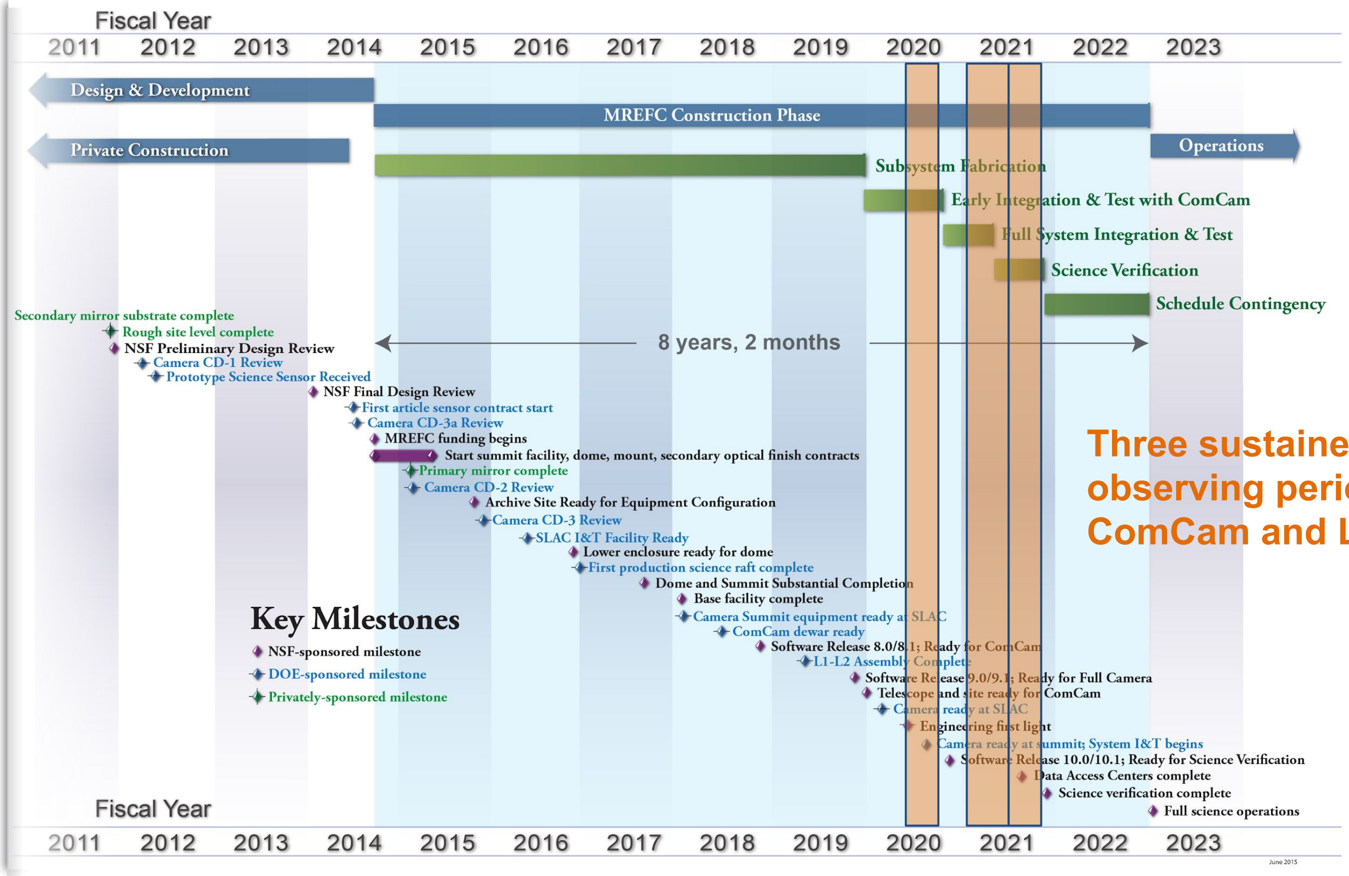


Raft area (ComCam) ~ 1600 arcmin^2
~ 0.45 deg^2

Full LSST camera area ~ 9.6 deg^2

Sample (typical high Galactic latitude field)	Density (arcmin^{-2})	# Per ComCam FOV	# Per LSSTCam FOV
High SNR stars useful for PSF determination	~3	~5K	~100K
“Gold” sample of galaxies	~55	~90K	~2M
Galaxies useful for weak lensing	~40	~60K	~1.4M

Timeline



Three sustained observing periods w/ ComCam and LSSTCam

Planned On-sky Observing Campaigns

Early Science Validation with ComCam

3-4 months: **Installation and Initial Testing** — Engineering focus, algorithm testing, instrument signature removal

4 weeks: **Key Performance Metrics** — Image quality, depth, astrometry, photometry

4 weeks: **20-year Depth Test** — Exploring range of conditions

4 weeks: **Scheduler Tests** — Nominal cadence, ToOs, environmental conditions

Early Science Validation with LSSTCam

3-4 months: **Installation and Initial Testing** — Engineering focus, algorithm testing, instrument signature removal

4 weeks: **Key Performance Metrics** — Image quality, depth, astrometry, photometry

4 weeks: **20-year Depth Test** — Exploring range of conditions

Science Validation Surveys

3 weeks: **Survey 1: Wide Area** — Template generation

6 weeks: **Survey 2: Full Depth** — 10-year survey depth in reference fields overlapping with deep external imaging and spectroscopy datasets

3 weeks: **Survey 1: Wide Area** — Real-time alert production

ComCam AI&T On-Sky Observations

Objectives

- Focus on electro-optical tests, engineering, instrument signature removal
- First on-sky data

Example observations

- Build and test pointing model
- Build and test active optics system look-up table, wave front sensors
- Raster single field across each detector to determine illumination corrections, initial color-term, and verify astrometric solutions (star flats)
- Repeated observations to test stability of photometric and astrometric solutions and statistical precision
- Repeated observations of celestial pole at different rotations (fixed airmass effects)
- Observations of celestial pole through different amounts and kinds of clouds

ComCam KPM Testing

Objectives

- Evaluate Key Performance Metrics (KPMs) for single-visit performance (e.g., relative + absolute photometry and astrometry, image quality, throughput)
- Measure residual PSF ellipticity distribution; test transient and moving object detection + linkage

Observations

- 20 fields x 5 epochs x 5 visits x 6 filters = 3K visits (~4 nights)
  - Several fields contain absolute photometric calibration standards
  - Range of airmass, source densities
- 3 fields x 3 (dither allowance) x 200 visits x 2 filters (r, i) = 3.6K visits (~5 nights)
  - Sample range of source densities, at least one along ecliptic

ComCam 20-year Depth Testing

Objectives

- Focus on image stack performance, sampling range of conditions
- Identify subsets of the data for Data Release Processing (e.g., best/worst seeing, lowest/highest airmass)
- Repeated observations of the same fields are useful for testing template generation algorithms and Alert Processing pipelines (can be offline)

Observations

- Observe 10 fields to depth equivalent to 20 years of Wide-Fast-Deep survey in 6 filters (~1700 visits per field, ~20 nights)
    - Where possible, fields should overlap external reference datasets
    - Explore a range of environmental conditions to examine various potential systematics — observations driven by needs to test pipeline algorithms
    - Dither pointings in each field to approximate Wide-Fast-Deep pattern

ComCam Scheduler Testing

Objectives

- Validate predictions of operations simulator
- Test scheduler feedback with real telemetry (including auxiliary instruments)
- Exercise interfaces and procedures used by human operators during normal operations
- Measurements of slew and settle times with realistic observing patterns

Observations

- Run automated scheduler with normal cadence under range of environmental conditions
- Testing special observation modes, e.g., Target-of-Opportunity interrupts, survey over constrained area, modified tactician
- Observations may be interspersed with 20-year depth test

Science Validation Survey 1: Wide Area

Objectives

- Validate template building with Data Release Processing pipeline
- Alert Processing, real-time alert generation
- Monitor survey progress over wide area to test observation simulations

Observations

- ~1600 deg2 x 15 visits x 6 filters x 2 phases (~30K visits, ~40 nights)
- Phase 1: observations for template generation (3 weeks)
- Phase 2: observations of same area for alert production (3 weeks)
- Phases separated by 6 weeks to allow for astrophysical evolution and template processing (Science Validation Survey 2 scheduled between phases)

Additional Considerations

- Use dithered pointings to match Wide-Fast-Deep pattern
- Use large sky area to explore edge cases (bright stars, high source densities, etc.)

Science Validation Survey 2: 10-yr Depth

Objectives

- Focus on Data Release Products at full survey depth
- Data quality characterization beyond the SRD
- Template generation and real-time alert production (more rapid cadence may enable unique tests)

Observations

- ~300 deg2 x 825 visits across 6 filters (~30K visits, ~40 nights)
- Select fields to overlap with external reference fields
- Scheduler used to optimize data quality across fields

Additional Considerations

- Use dithered pointings to match Wide-Fast-Deep pattern
- Option to select adjoining fields to form larger contiguous full-depth regions
- Alert Processing studies would benefit from early template generation

Planned On-sky Observing Campaigns

	Early Science Validation with ComCam	Early Science Validation with LSSTCam	Science Validation Surveys	
3-4 months	**Installation and Initial Testing** Engineering focus, algorithm testing, instrument signature removal	**Installation and Initial Testing** Engineering focus, algorithm testing, instrument signature removal		
4 weeks	**Key Performance Metrics** Image quality, depth, astrometry, photometry	**Key Performance Metrics** Image quality, depth, astrometry, photometry	**Survey 1: Wide Area** Template generation	3 weeks
4 weeks	**20-year Depth Test** Exploring range of conditions	**20-year Depth Test** Exploring range of conditions	**Survey 2: Full Depth** 10-year survey depth in reference fields overlapping with deep external imaging and spectroscopy datasets	6 weeks
4 weeks	**Scheduler Tests** Nominal cadence, ToOs, environmental conditions		**Survey 1: Wide Area** Real-time alert production	3 weeks

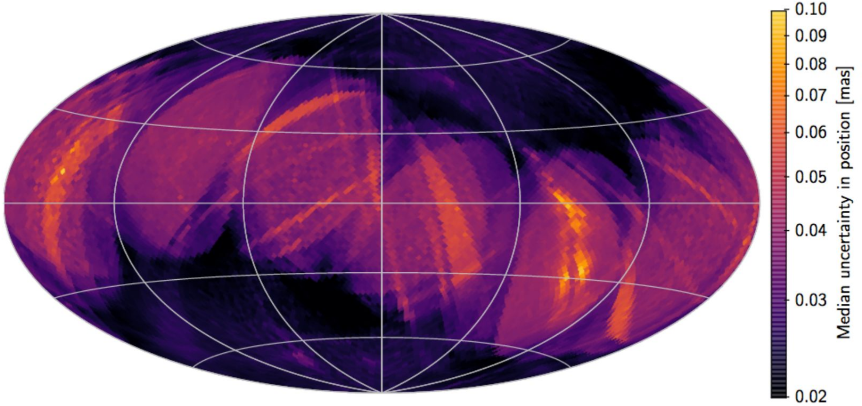
Reference External Datasets

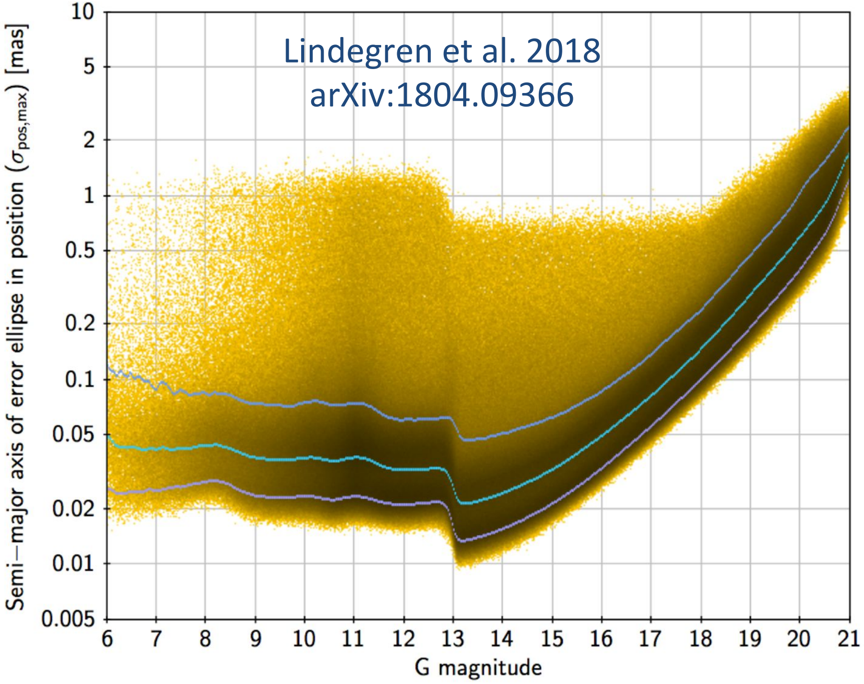
LSST Requirement: Absolute Astrometry

The median error in the absolute astrometric positions < 50 mas per coordinate (design)

GAIA DR2

5-parameter astrometric solution for 1.3 billion sources, tied to extragalactic ICRS by means of quasars. Median positional uncertainty 0.7 mas at G = 20 mag.

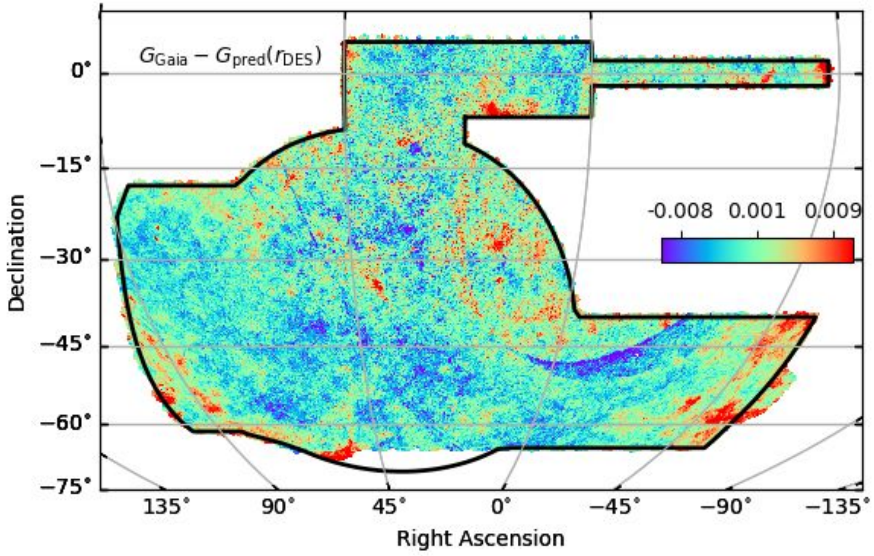


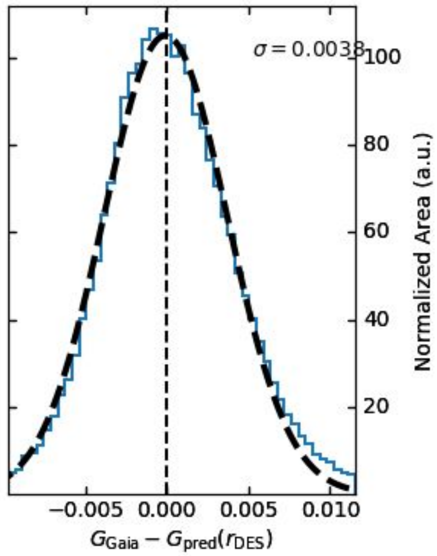


Reference External Datasets

LSST Requirement: Relative Photometry The distribution width (rms) of the internal photometric zero-point error (the system stability across the sky) will not exceed 10 millimag (design)

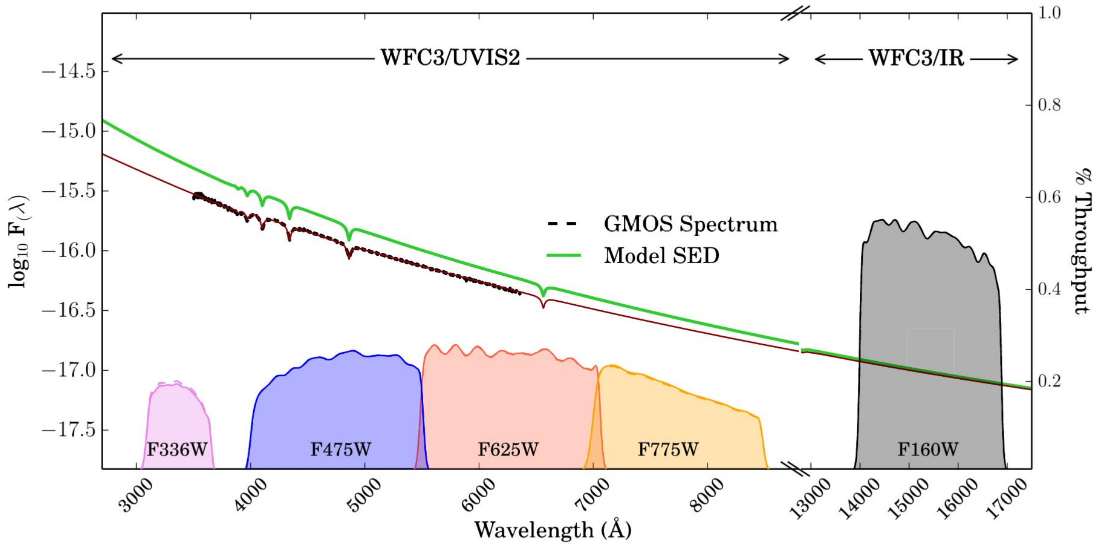
Gaia + DES: Photometric uniformity RMS reduced from 5.1 mmag (DES + Gaia DR1) to 3.8 mmag (DES + Gaia DR2)





Reference External Datasets

- Establishing a network of absolute spectrophotometric standards in a convenient magnitude range for LSST (V ~ 19 mag)
- Hot DA white dwarf stars have simplest known stellar atmospheres; emission calculable from first principles with sufficient precision (~1%) to meet LSST design specifications for absolute photometric calibration



Narayan et al. 2016
arXiv:1603.03825

Reference External Datasets

LSST imaging will be sufficiently deep that comparable external datasets are available only in small regions of the sky

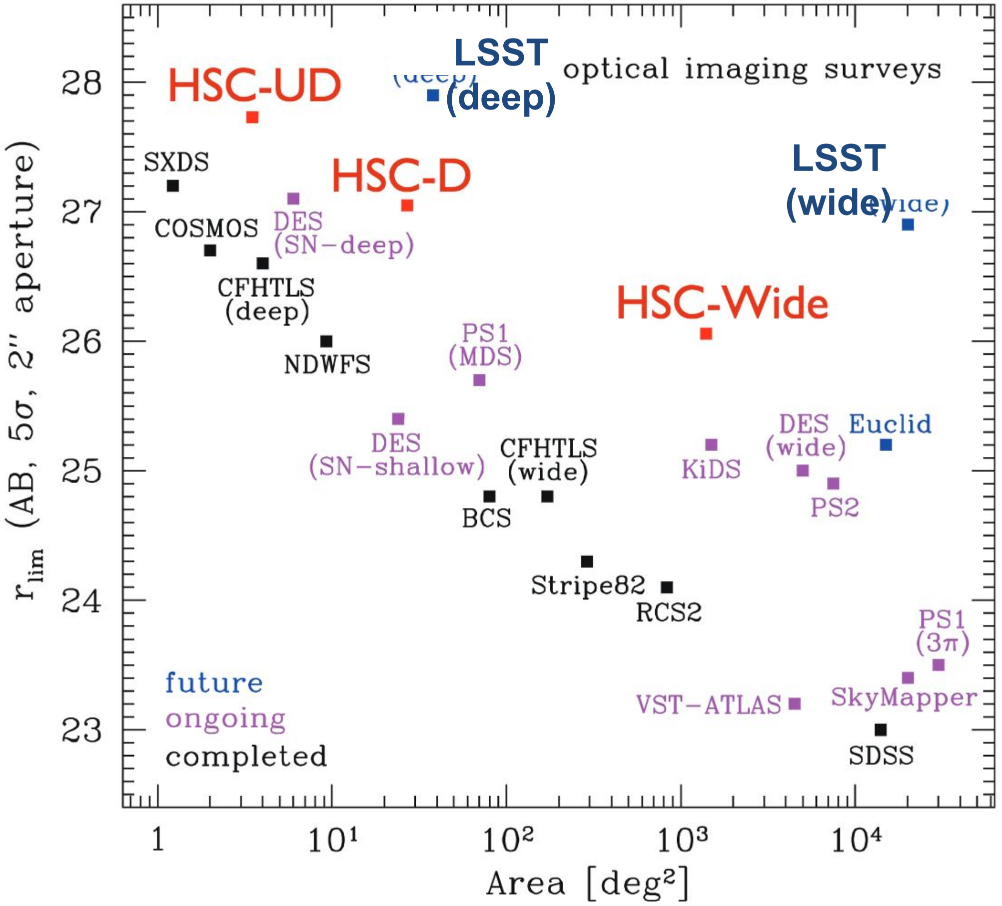
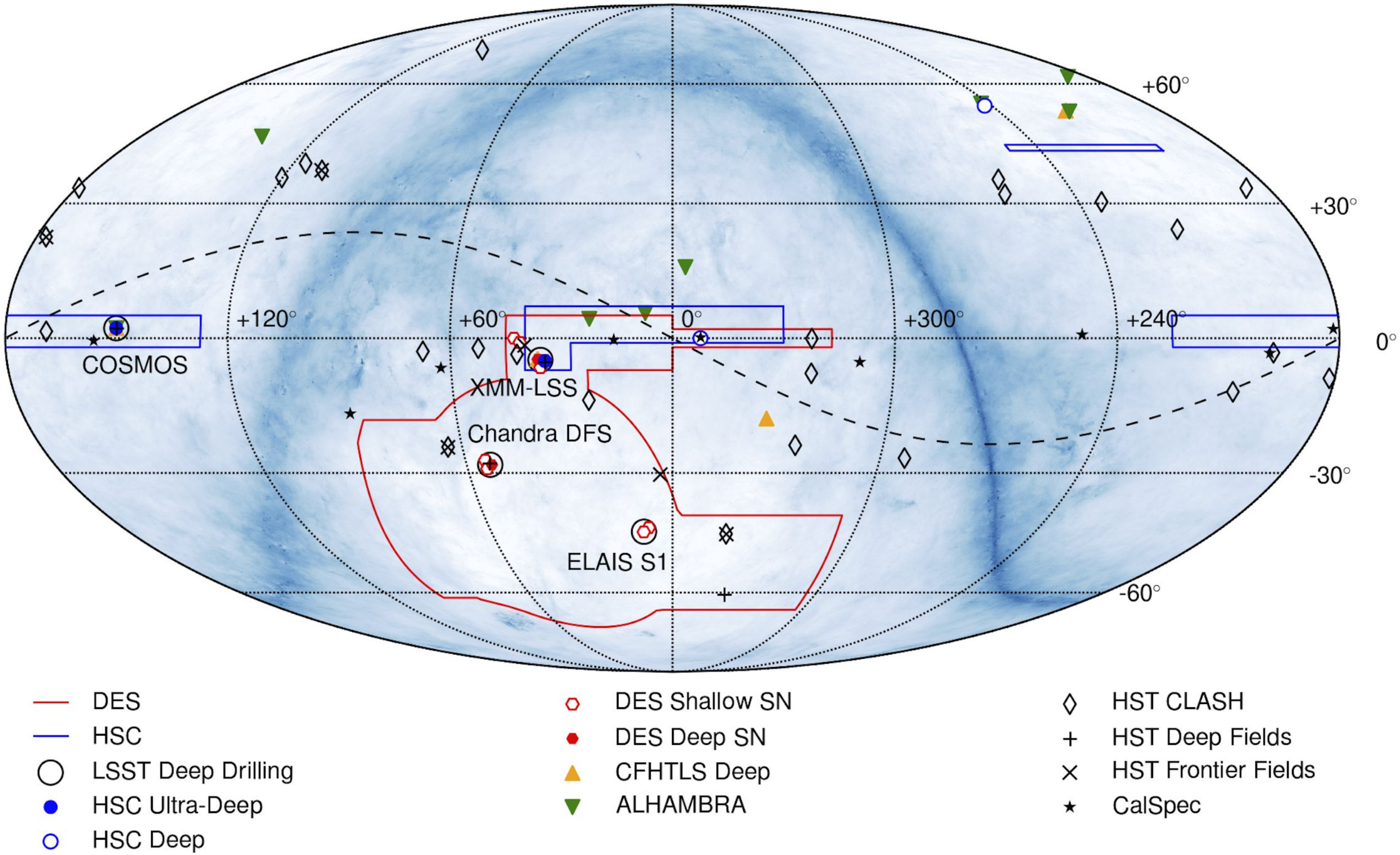


Image Credit:
http://hsc.mtk.nao.ac.jp/ssp/wp-content/uploads/2016/05/hsc_ssp_rv_jan13.pdf

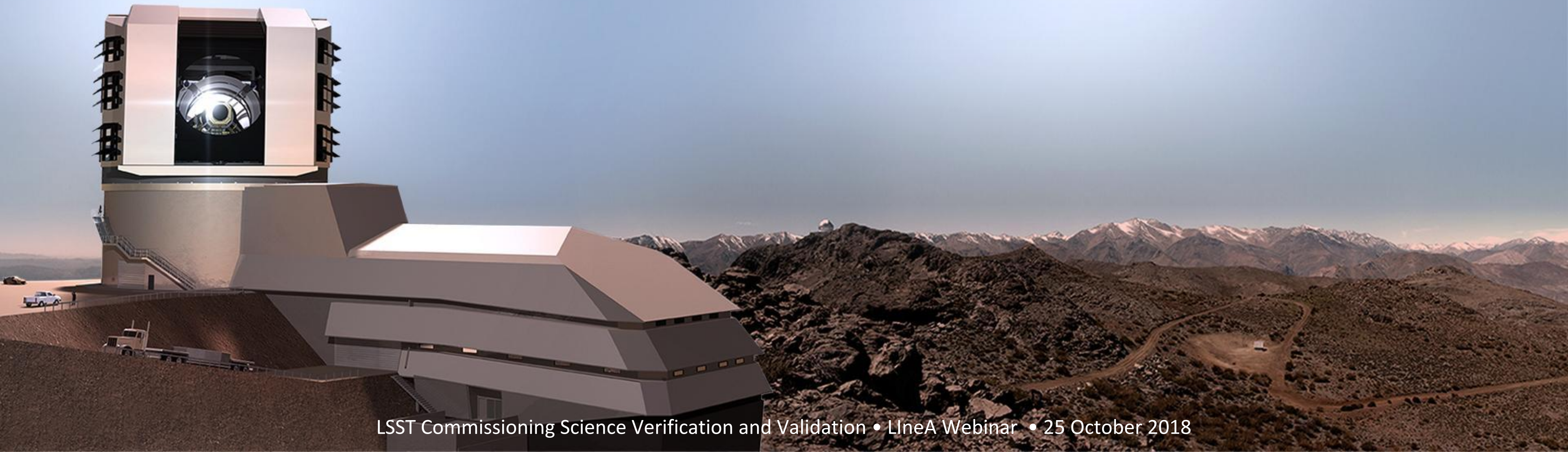
Reference External Datasets

Survey		Notes on band coverage and depth	Total Area (accessible to LSST)
LSST	Single-Visit	{*ugrizy*} = {23.9, 25.0, 24.7, 24.0, 23.3, 22.1} (5σ)	-
	10-yr Wide-Fast-Deep	{*ugrizy*} = {26.1, 27.4, 27.5, 26.8, 26.1, 24.9} (5σ)	18000 deg^2 (design)
HSC	Wide	{*grizy*} = {26.5, 26.1, 25.9, 25.1, 24.4} (5σ)	1400 deg^2 (1350 deg^2)
	Deep	{*grizy*} = {27.5, 27.1, 26.8, 26.3, 25.3} (5σ) + 3 narrow bands	27 deg^2 (13 deg^2)
	Ultra-deep	{*grizy*} = {28.1, 27.7, 27.4, 26.8, 26.3} (5σ) + 3 narrow bands	3.5 deg^2
DES	Wide	{*grizY*} = {24.5, 24.3, 23.5, 22.9, 21.7} (10σ)	5000 deg^2
	SN-Shallow	{*griz*} = {26.8, 25.6, 25.9, 25.7} (5σ)	24 deg^2
	SN-Deep	{*griz*} = {27.1, 27.3, 27.0, 26.8} (5σ)	6 deg^2
HST CLASH	-	{16 filters, 2000-17000 Å} ~ {25.7-27.0} (10σ)	~0.03 deg^2 (17 of 25 fields)
HST COSMOS	-	{F814W} = {27.2} (10σ)	1.7 deg^2
HST Ultra-Deep Field	-	{F435W, F606W, F775W, F850LP} ~ {29} (10σ)	~0.003 deg^2
HST Frontier Fields	-	{7 filters, 4000-17000 Å} ~ {29} (5σ)	0.012 deg^2 (5 of 6 fields)

Reference External Datasets



Wrap-up



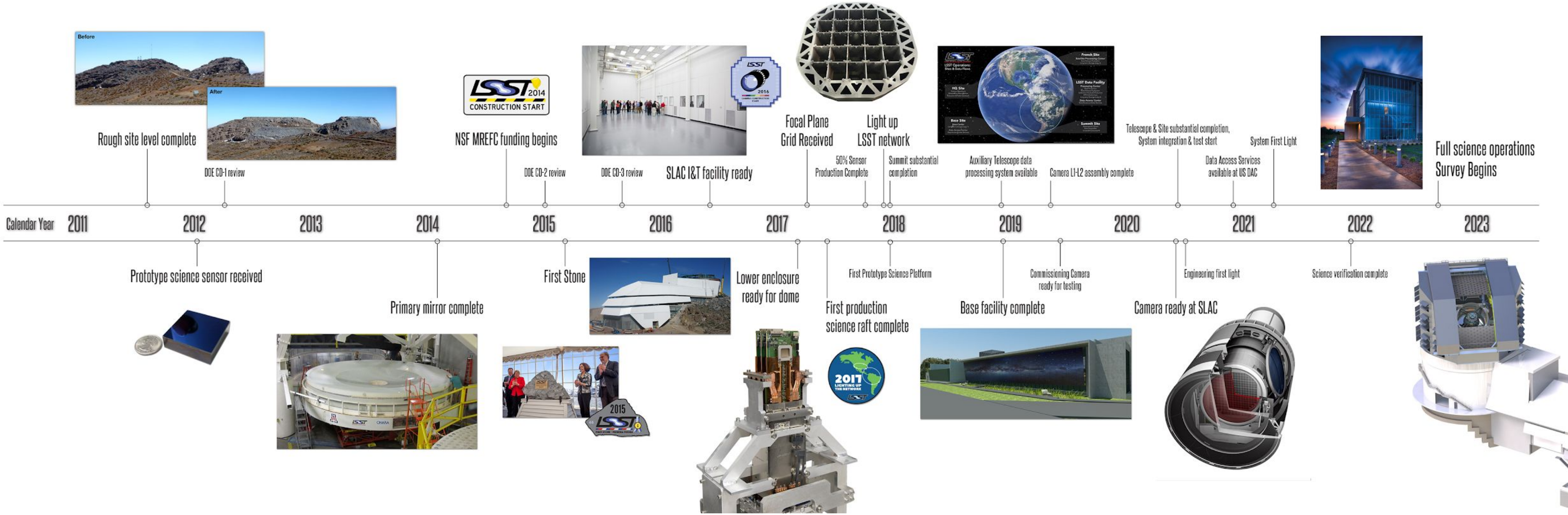
Where Flexibility Exists

- The plans described in previous slides represent a proof of concept that we could use the scheduled sustained observing periods to evaluate the normative system requirements; Project will adapt plans as needed
- In many cases, there is flexibility in exact field choice, cadence, dither pattern, etc.
- Commissioning team wants a “menu” of candidate fields at a range of RA values
- If alternative and/or specialized calibration measurements and/or on-sky observations would enable additional system validation/characterization studies, we welcome input on what data is needed (and why)
- Prioritized, specific recommendations for system characterization (including quantitative metrics) are most helpful for commissioning planning and preparations

Commissioning Data Release Policy

- Early operations team will commit to supporting the following
  - Images from a given commissioning phase will be released 3 months after the completion of that phase
  - Catalogs will be released another 3 months thereafter

Timeline



Before
After
Rough site level complete
DOE CD-1 review
LSST 2014 CONSTRUCTION START
NSF MREFC funding begins
DOE CD-2 review
DOE CD-3 review
SLAC I&T facility ready
Focal Plane Grid Received
50% Sensor Production Complete
Light up LSST network
Summit substantial completion
Auxiliary Telescope data processing system available
Camera L1-L2 assembly complete
Telescope & Site substantial completion, System integration & test start
Data Access Services available at US DAC
System First Light
Full science operations Survey Begins
Calendar Year
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
Prototype science sensor received
Primary mirror complete
First Stone
2015
Lower enclosure ready for dome
First production science raft complete
2017
First Prototype Science Platform
Base facility complete
Commissioning Camera ready for testing
Camera ready at SLAC
Engineering first light
Science verification complete

Summary of Key Dates

Milestone	Date
Start of On-Sky Data from Auxiliary Telescope	19-Mar-19
Start of On-Sky & Calibration Data with ComCam	16-Jul-20
Sustained Observing with ComCam	26-Oct-20
Start of On-Sky & Calibration Data with LSSTCam	10-May-21
Sustained Observing with LSSTCam	20-Jul-21
Start of Science Verification Surveys	08-Sep-21
Operations Readiness Review	18-Jan-22

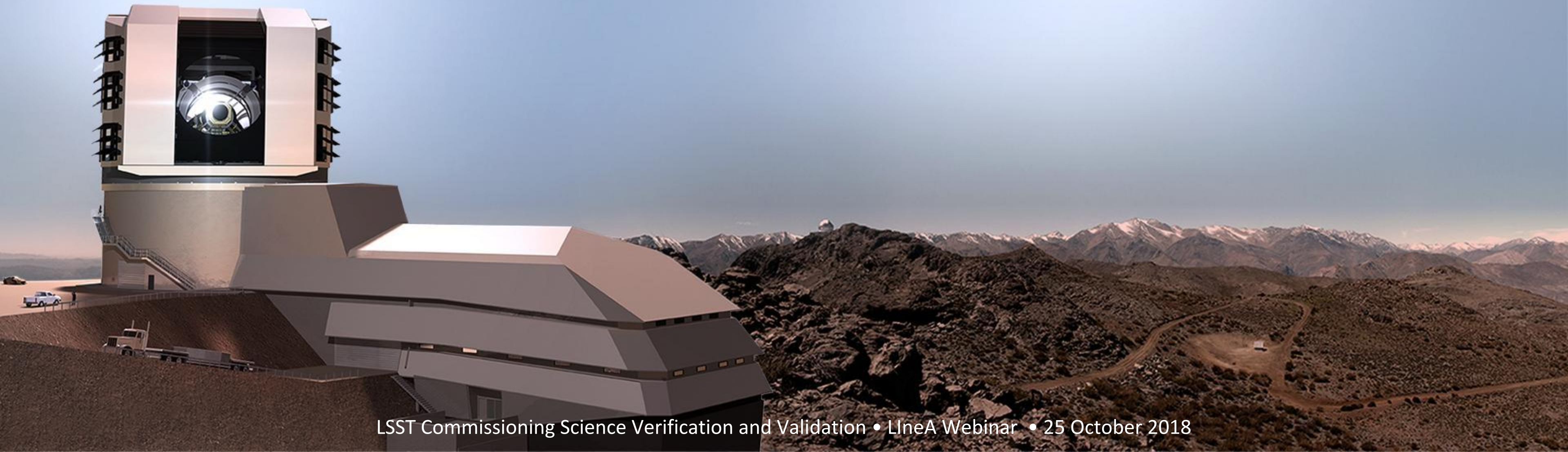
Summary

Commissioning SV aims to characterize the distribution of demonstrated performance of the as-built LSST system using a combination of on-sky data, external datasets, and informed simulations.

Systems engineering approach adopted across the LSST Construction Project is being extensively used during commissioning for planning and execution

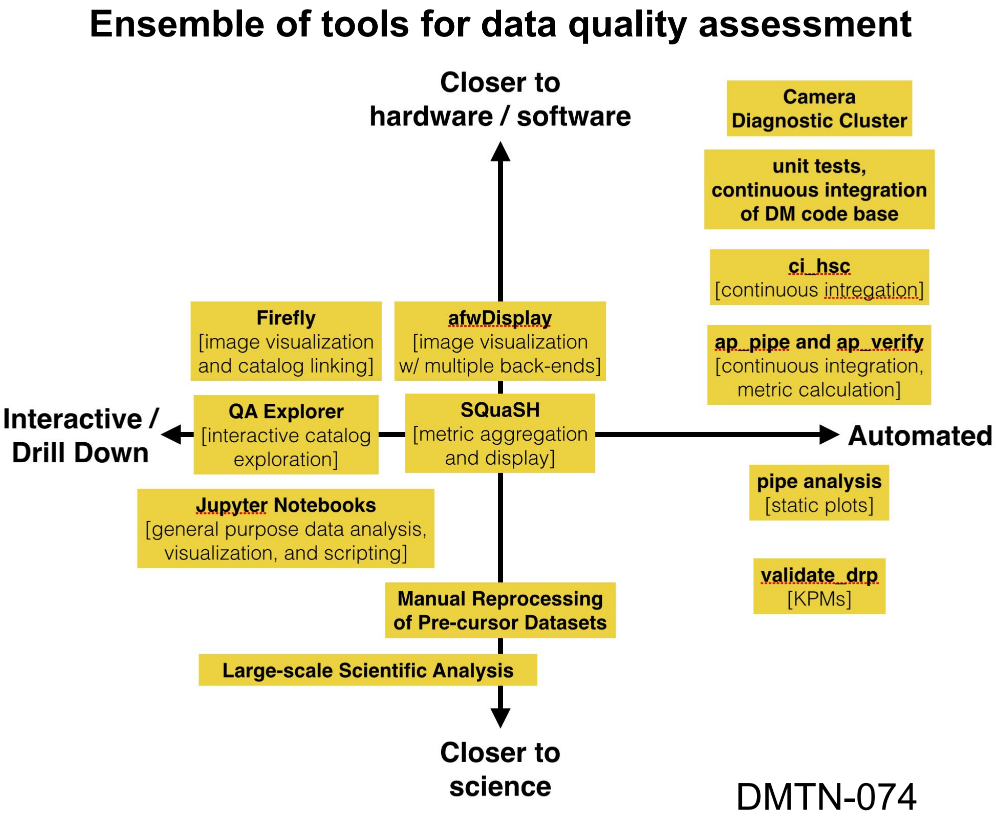
Commissioning is upon us!

Data Quality Assessment Tools

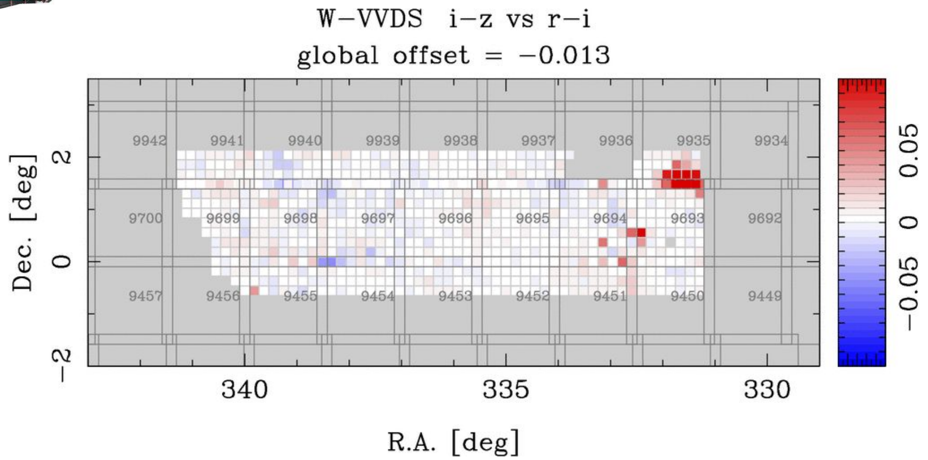


Coordinating w/ Ongoing DM Construction

- To the extent possible, Science Validation analyses by Commissioning team will make use of Quality Assessment (QA) and Quality Control (QC) tools developed during DM construction
- **Quality Assessment:** versatile pipelines to calculate performance metrics and other diagnostics (e.g., validate_drp)
- **Quality Control:** ensure that metrics are calculated and track their distributions as the pipelines evolve and encounter new data (e.g., SQuaSH)

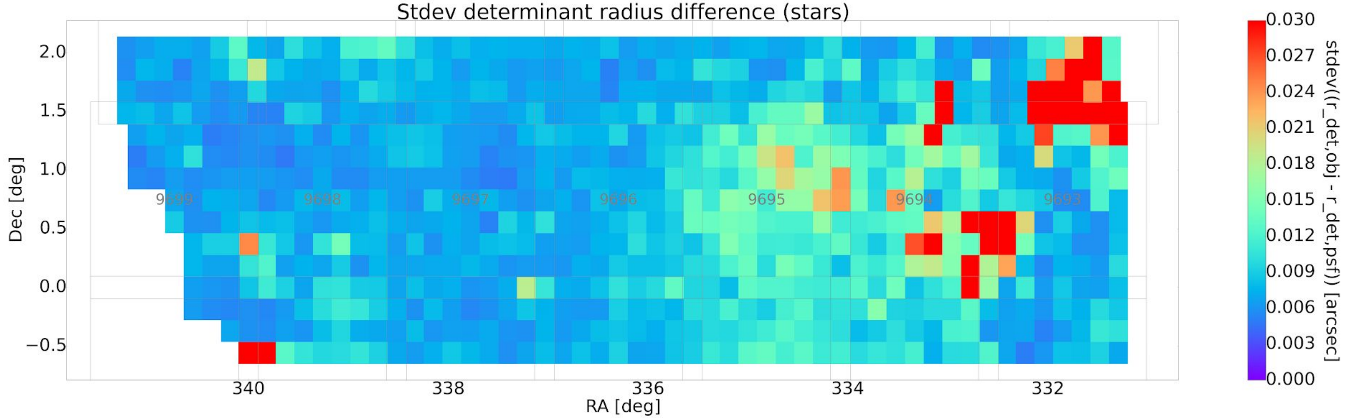


Patch-level QA Plots from HSC SSP-DR1



Example: An indication that stellar photometry in a small region might be affected by imperfect PSF modeling

Many more example QA plots:
https://hsc-release.mtk.nao.ac.jp/doc/index.php/data/



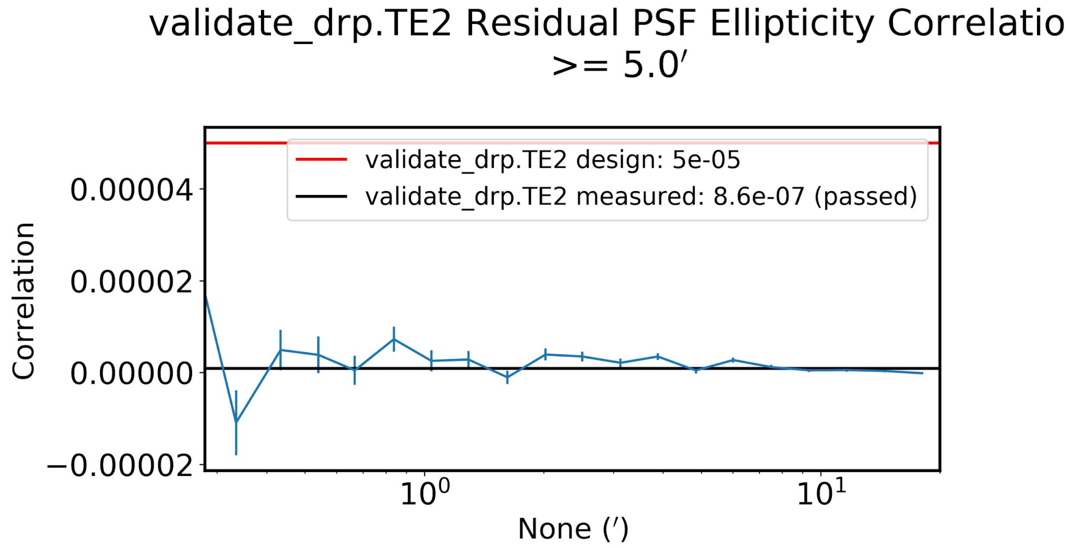
Validate DRP

Summary report by tract

Metric	Filter	Unit	Operator	SRD Requirement: design	Release Target: FY17	Value	Comments
AM1	HSC-G	marcsec	<=	10.0	30.0	7.84	
AD1	HSC-G	marcsec	<=	20.0	20.0	8.58	
AF1	HSC-G	%	<=	10.0	10.0	2.15	
AM2	HSC-G	marcsec	<=	10.0	40.0	8.22	
AD2	HSC-G	marcsec	<=	20.0	20.0	9.14	
AF2	HSC-G	%	<=	10.0	10.0	2.03	
AM3	HSC-G	marcsec	<=	15.0	40.0	**	
AD3	HSC-G	marcsec	<=	30.0	30.0	**	
AF3	HSC-G	%	<=	10.0	10.0	**	
PA1	HSC-G	mmag	<=	5.0	8.0	17.6	
PA2	HSC-G	mmag	<=	15.0	22.5	37.3	
PF1	HSC-G	%	<=	10.0	10.0	39.3	
TE1	HSC-G		<=	2e-05	nan	1.62e-06	
TE2	HSC-G		<=	5e-05	nan	1.51e-07	
AM1	HSC-I	marcsec	<=	10.0	30.0	7.9	
AD1	HSC-I	marcsec	<=	20.0	20.0	8.01	
AF1	HSC-I	%	<=	10.0	10.0	2.19	
AM2	HSC-I	marcsec	<=	10.0	40.0	8.2	
AD2	HSC-I	marcsec	<=	20.0	20.0	9.84	
AF2	HSC-I	%	<=	10.0	10.0	3.7	
AM3	HSC-I	marcsec	<=	15.0	40.0	**	
AD3	HSC-I	marcsec	<=	30.0	30.0	**	
AF3	HSC-I	%	<=	10.0	10.0	**	
PA1	HSC-I	mmag	<=	5.0	8.0	18.7	
PA2	HSC-I	mmag	<=	15.0	22.5	38.6	
PF1	HSC-I	%	<=	10.0	10.0	44.1	
TE1	HSC-I		<=	2e-05	nan	3.77e-06	
TE2	HSC-I		<=	5e-05	nan	8.59e-07	
AM1	HSC-R	marcsec	<=	10.0	30.0	9.7	
AD1	HSC-R	marcsec	<=	20.0	20.0	11.1	
AF1	HSC-R	%	<=	10.0	10.0	4.13	
AM2	HSC-R	marcsec	<=	10.0	40.0	9.34	
AD2	HSC-R	marcsec	<=	20.0	20.0	13.1	
AF2	HSC-R	%	<=	10.0	10.0	6.12	
AM3	HSC-R	marcsec	<=	15.0	40.0	**	
AD3	HSC-R	marcsec	<=	30.0	30.0	**	
AF3	HSC-R	%	<=	10.0	10.0	**	
PA1	HSC-R	mmag	<=	5.0	8.0	21.6	
PA2	HSC-R	mmag	<=	15.0	22.5	44.5	
PF1	HSC-R	%	<=	10.0	10.0	48.4	
TE1	HSC-R		<=	2e-05	nan	5.53e-06	
TE2	HSC-R		<=	5e-05	nan	9.41e-08	
AM1	HSC-Y	marcsec	<=	10.0	30.0	3.7	
AD1	HSC-Y	marcsec	<=	20.0	20.0	12	
AF1	HSC-Y	%	<=	10.0	10.0	3.71	
AM2	HSC-Y	marcsec	<=	10.0	40.0	6.64	
AD2	HSC-Y	marcsec	<=	20.0	20.0	11.1	
AF2	HSC-Y	%	<=	10.0	10.0	2.79	
AM3	HSC-Y	marcsec	<=	15.0	40.0	**	
AD3	HSC-Y	marcsec	<=	30.0	30.0	**	
AF3	HSC-Y	%	<=	10.0	10.0	**	
PA1	HSC-Y	mmag	<=	7.5	12.0	19.3	
PA2	HSC-Y	mmag	<=	22.5	22.5	41.6	
PF1	HSC-Y	%	<=	10.0	10.0	29.6	
TE1	HSC-Y		<=	2e-05	nan	8.61e-06	

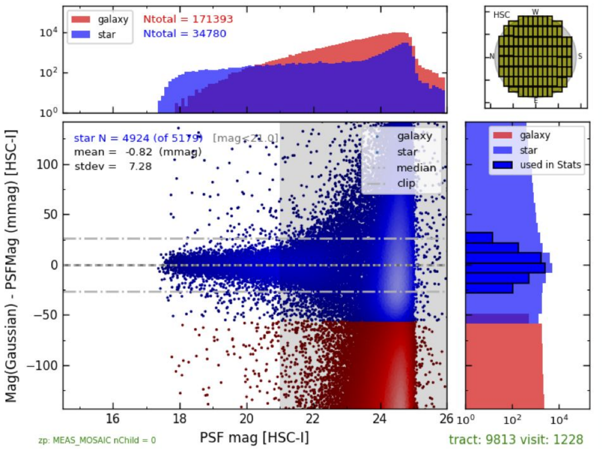
Calculates LSST SRD Key Performance Metrics designated by DM using coadd object catalogs produced by the DRP science pipeline

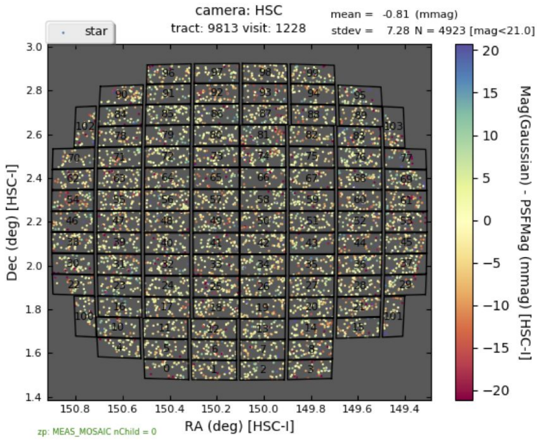
Example diagnostic plot

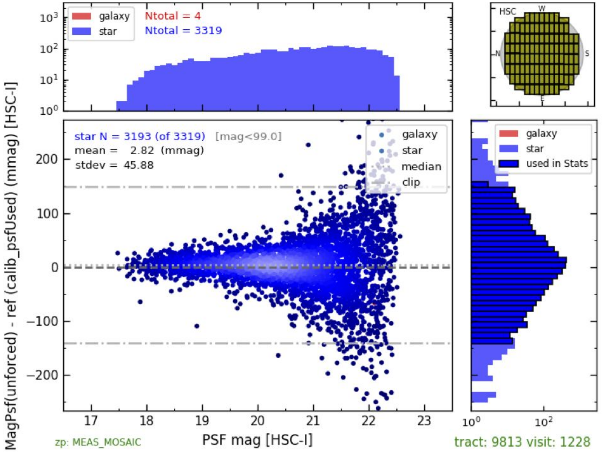


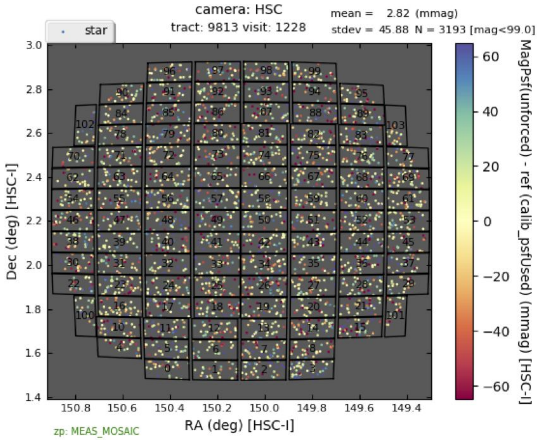
Pipe Analysis

Generates ensemble of static plots for both individual visits and coadds using catalog-level quantities. Current set of diagnostic plots motivated largely by testing the Stack pipelines on HSC data









SQuaSH

In DM construction, focus on changes with respect to science pipelines. In commissioning, tracking metrics for accumulating on-sky data also likely to be useful

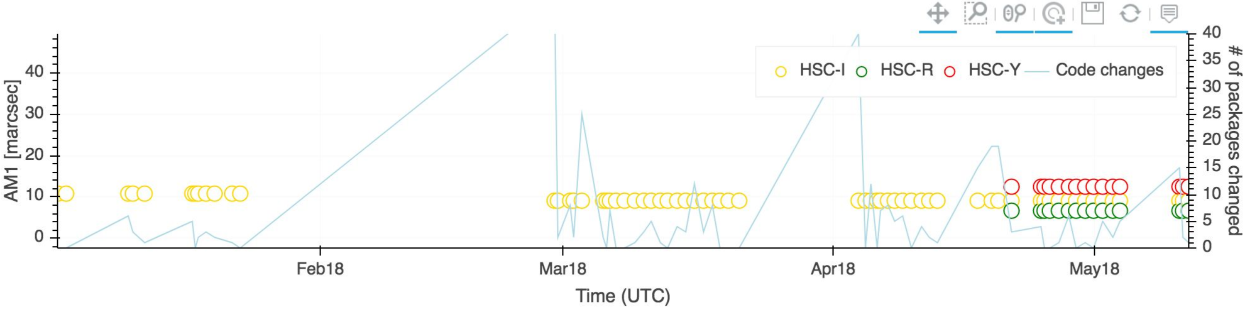
SQUASH Monitor

The impact of code changes on Key Performance Metrics

Dataset: validation_data_hsc **Verification package:** validate_drp **Metric:** validate_drp.AM1

All | Last Year | Last 6 Months | Last Month

AM1: The maximum rms of the astrometric distance distribution for stellar pairs with separations of D=5 arcmin (repeatability).



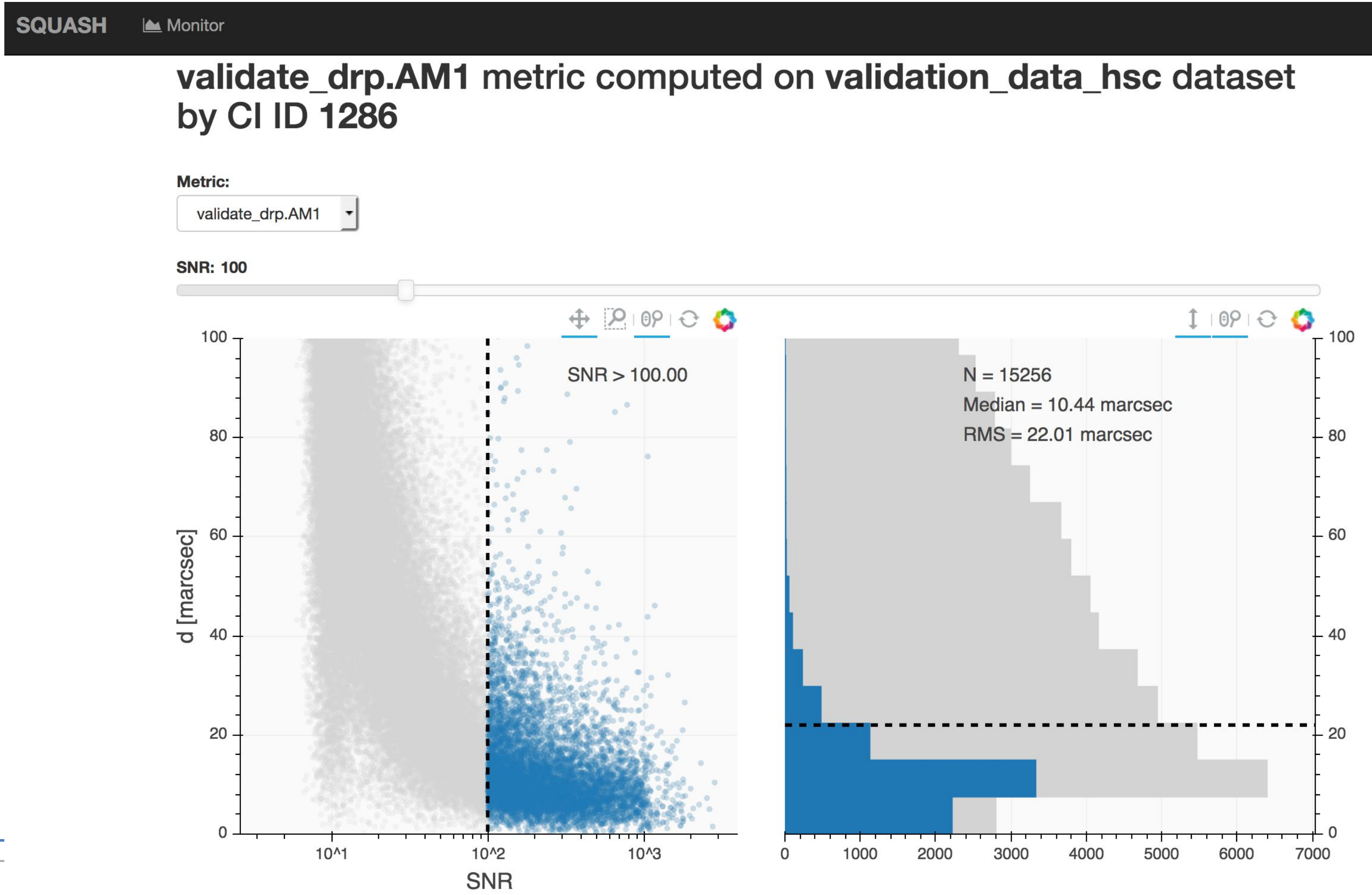
Ref.: LPM-17, page 23.

#	Time (UTC)	CI ID	AM1 [marcsec]	Code changes
0	2018-01-01T19:52:12Z	1176	10.792	
1	2018-01-02T19:42:11Z	1177	10.792	
2	2018-01-09T23:04:26Z	1180	10.792	verify, astshim, pipe_tasks, afw, starlink_ast, obs_lsstSim
3	2018-01-10T11:42:44Z	1181	10.792	pipe_drivers, afw, jointcal
4	2018-01-11T20:21:20Z	1182	10.792	xrootd

Access to interactive plots for points on the "timeline"

SQuaSH

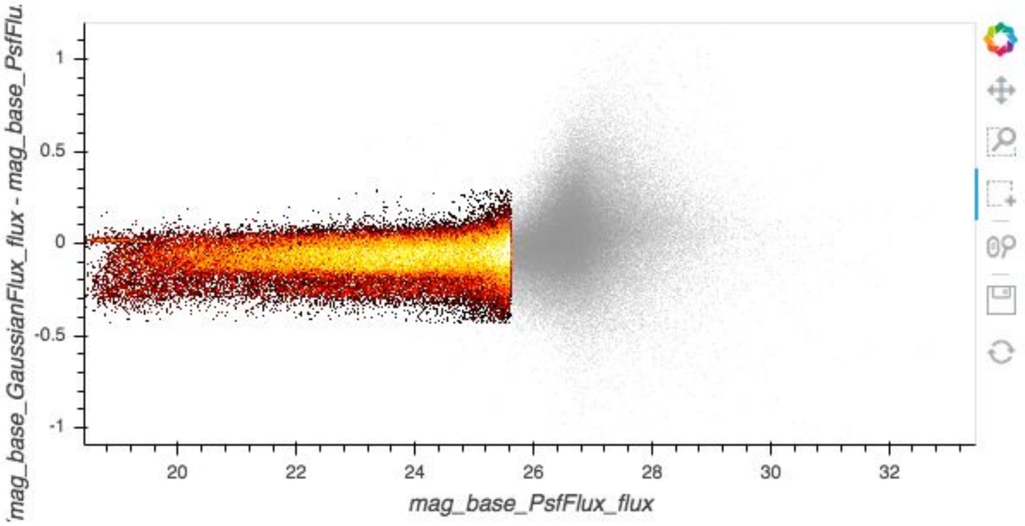
Access to interactive diagnostic plots corresponding to performance metrics

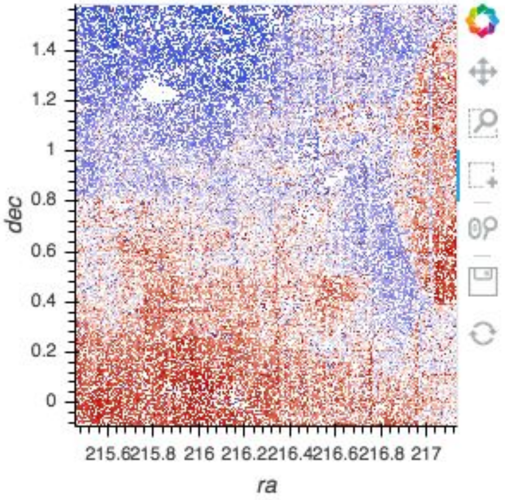


QA Explorer

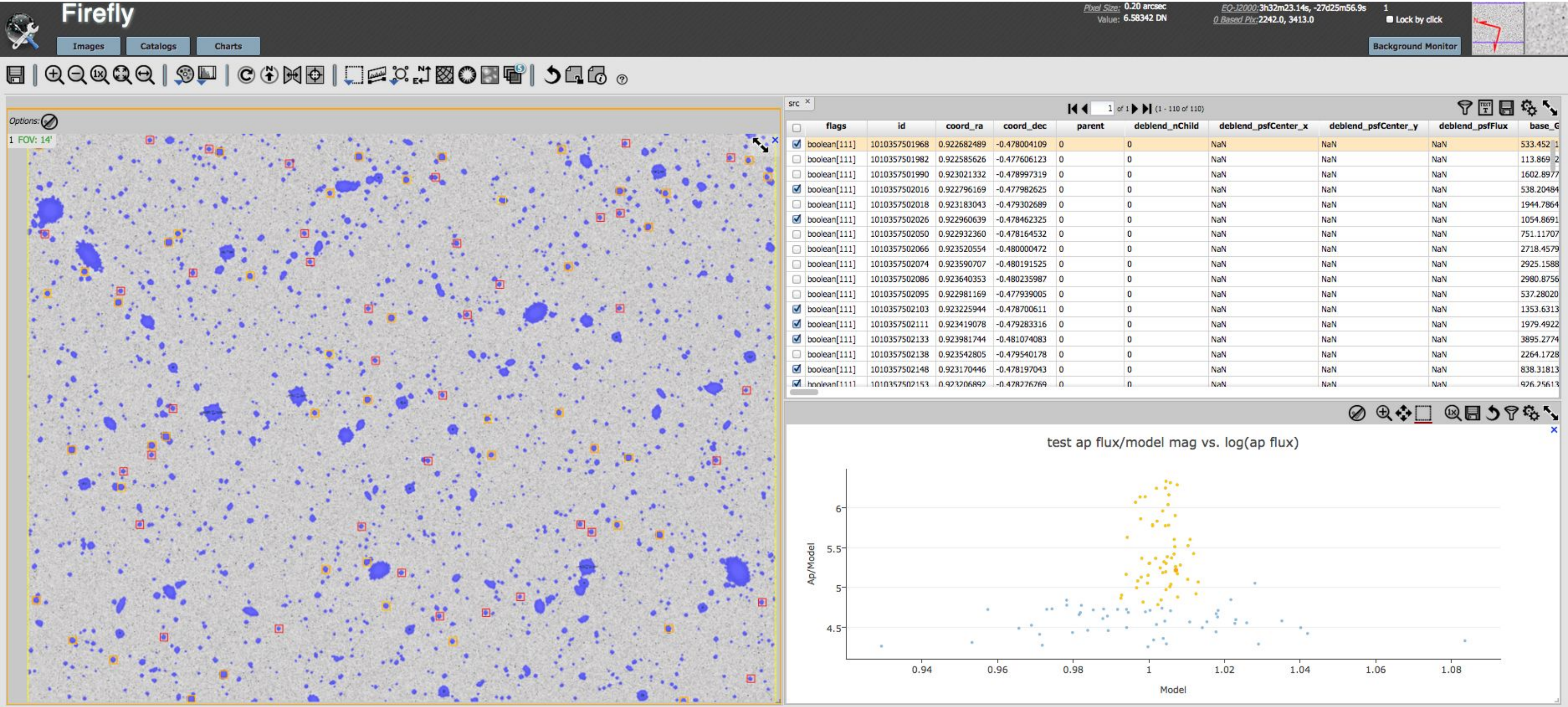
Featuring bokeh visualizations with holoviews and datashader to allow dynamical re-binning of two-dimensional histograms as well as brushing and linking between multiple plots for efficient exploration of large datasets in high-dimensional spaces

#	gauss
0	89,429.0
1	-0.088401
2	0.09237

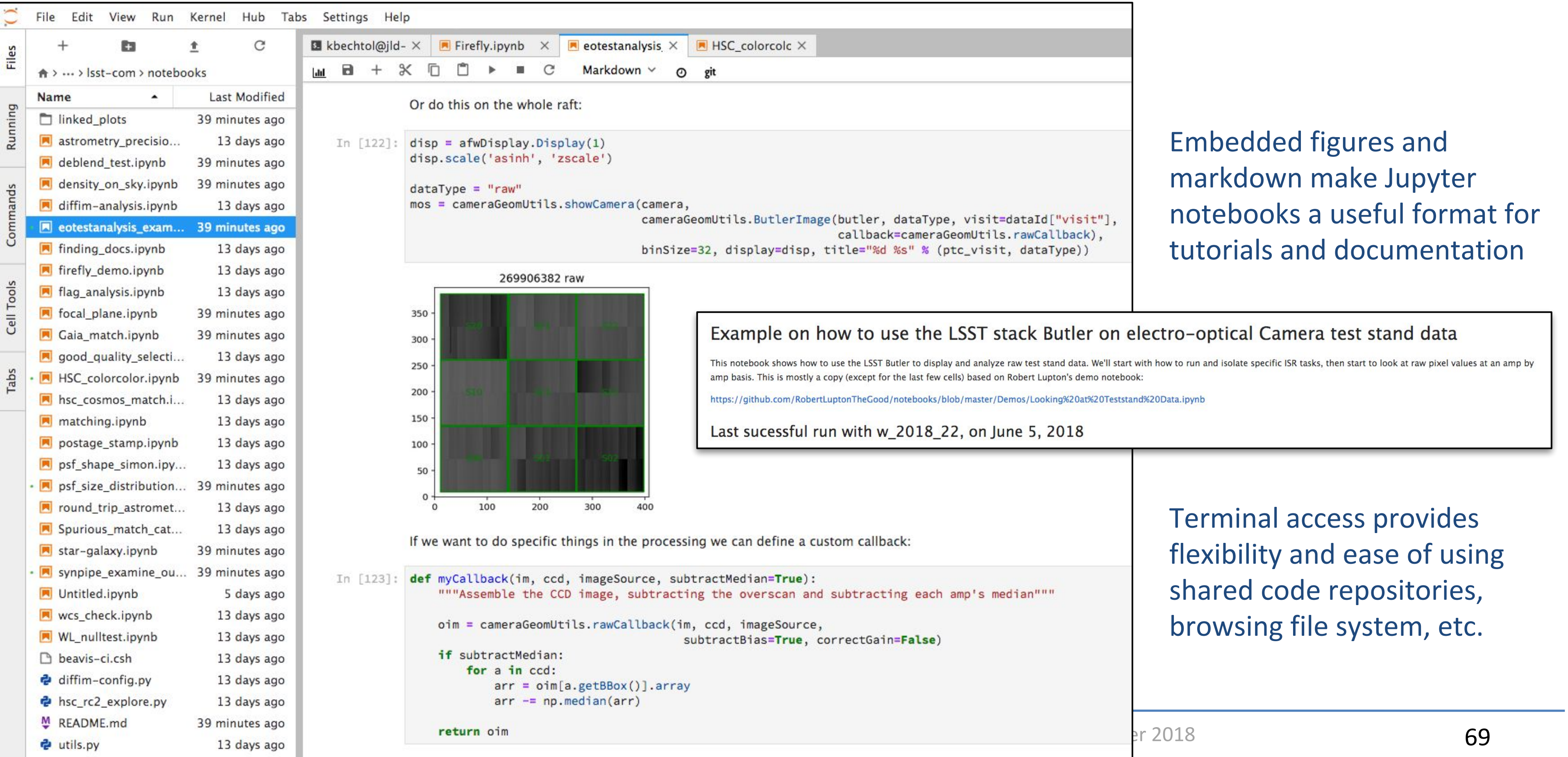




Firefly


Firefly
Images
Catalogs
Charts
Background Monitor
Options:
src
flags
id
coord_ra
coord_dec
parent
deblend_nChild
deblend_psfCenter_x
deblend_psfCenter_y
deblend_psfFlux
test ap flux/model mag vs. log(ap flux)
Ap/Model
Model

LSST Science Platform Notebook Aspect

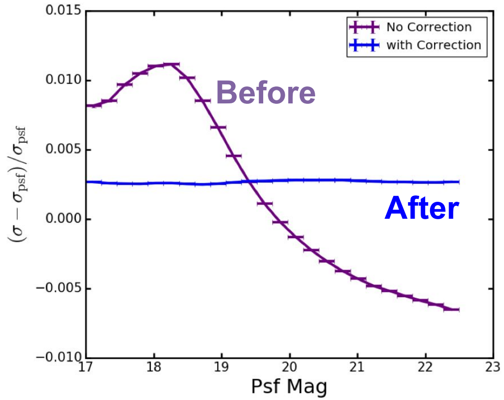


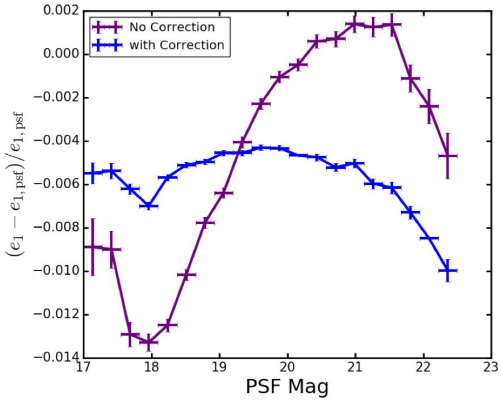
Embedded figures and markdown make Jupyter notebooks a useful format for tutorials and documentation

Terminal access provides flexibility and ease of using shared code repositories, browsing file system, etc.

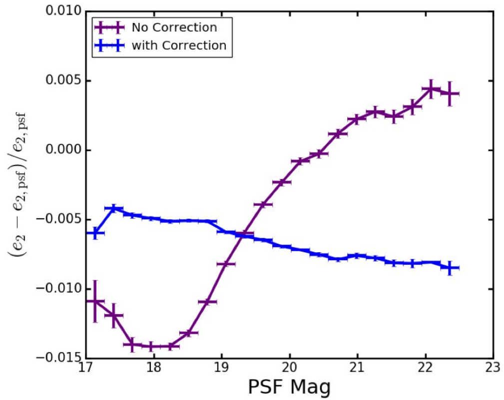
Verification and Validation Example Studies

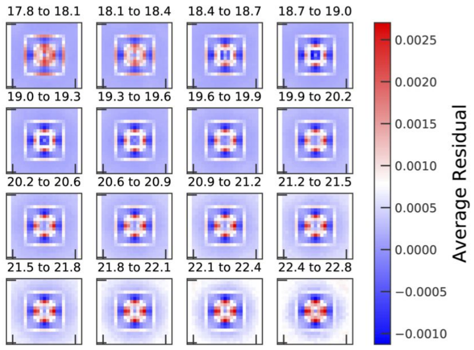
Science Pipeline Verification





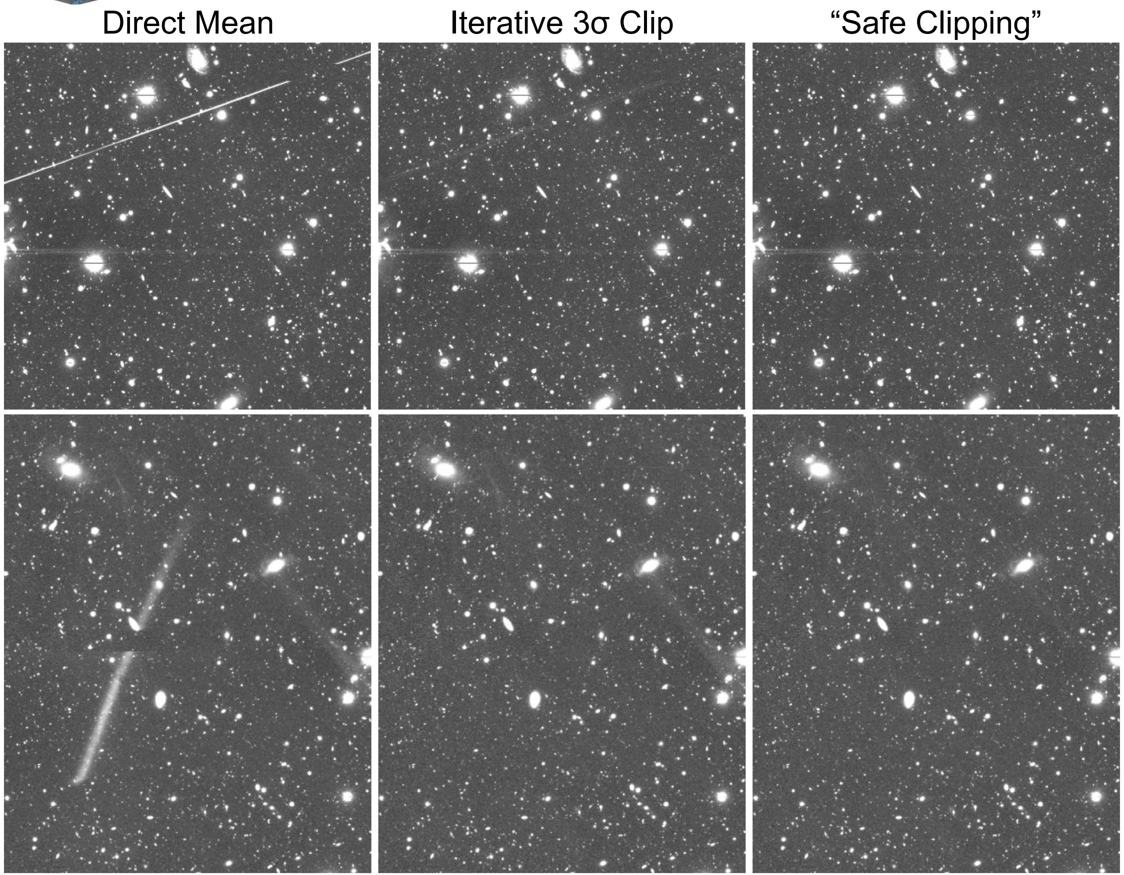
Verify correction of brighter-fatter effect for the delivered LSST sensors





Bosch et al. 2017
arXiv:1705.06766

Science Pipeline Verification



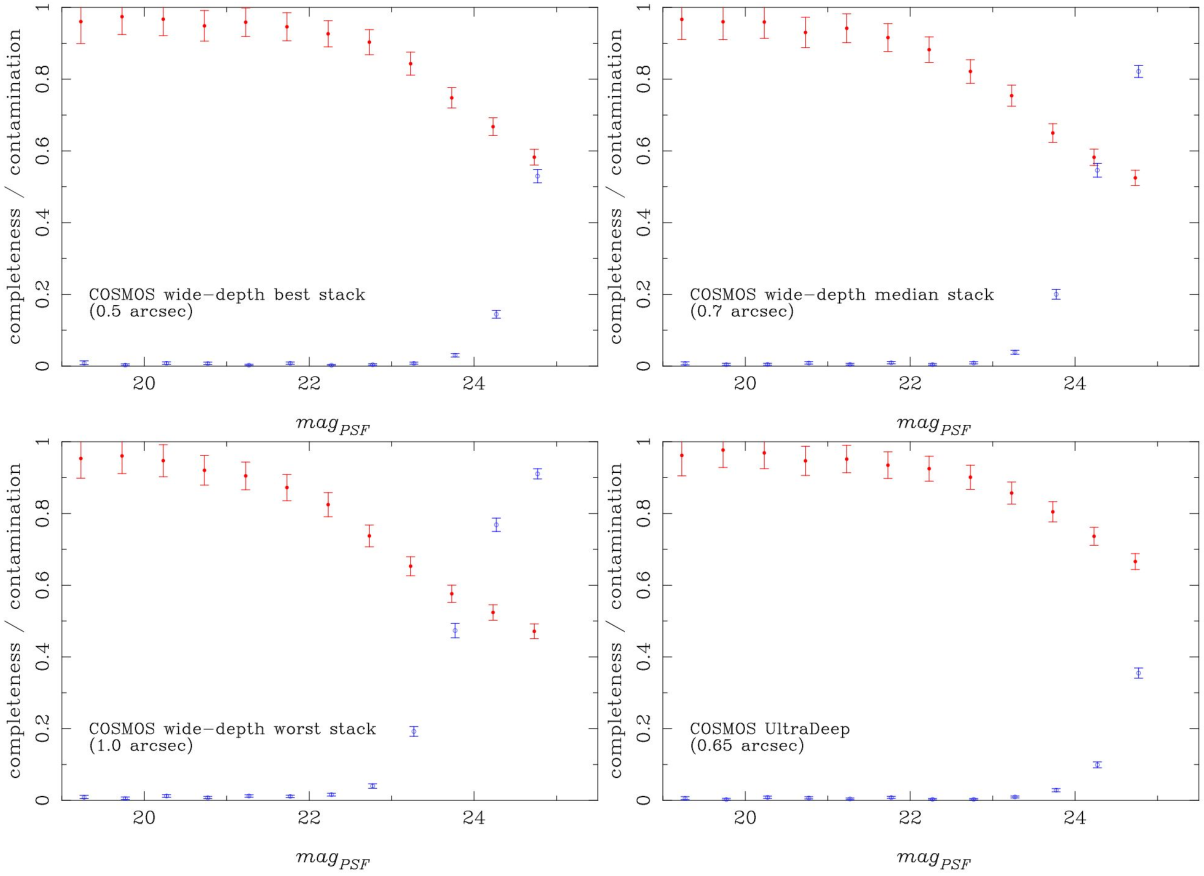
Removing image artifacts observed in individual visits from the coadd

Bosch et al. 2017
arXiv:1705.06766

Exploring Environmental Conditions

Evaluating star-galaxy separation of HSC-SSP using HST-COSMOS as “truth”.

Notice the variations in performance found in three different sets of wide-depth image stacks composed of the best, median, and worst seeing single-visit images.



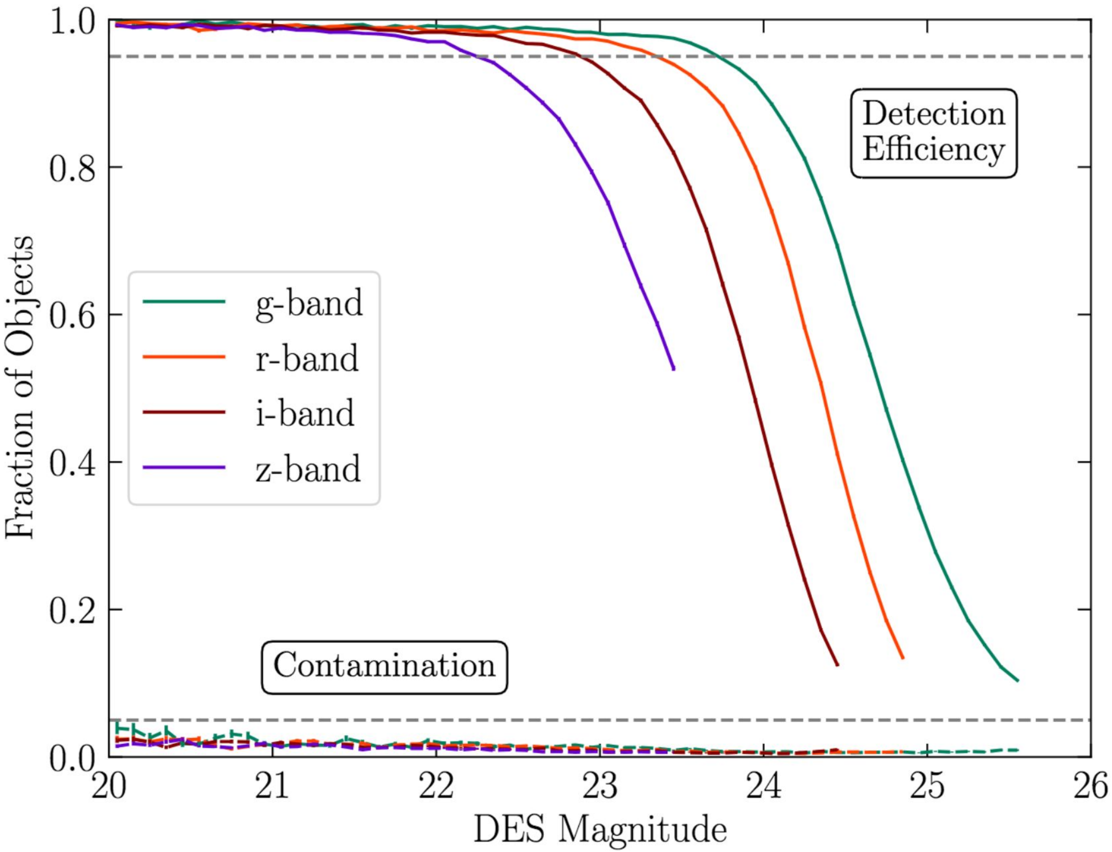
HSC SSP-DR1
arXiv:1702.08449

Other SRD-Motivated Metrics

Object detection completeness and spurious rate measured against deeper imaging

Requires high-fidelity survey geometry information for both surveys if done empirically

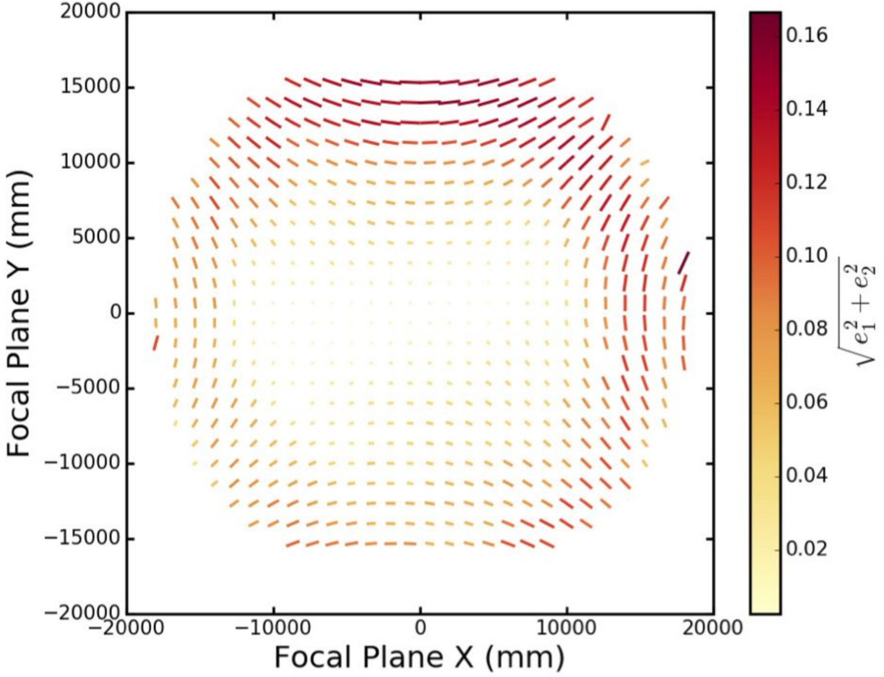
Alternative approach is artificial source injection

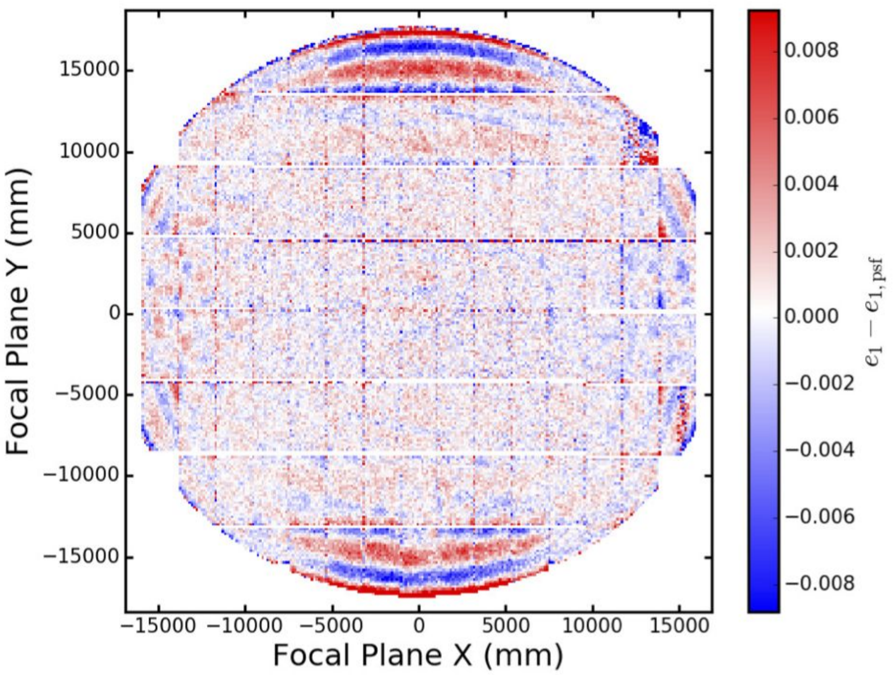


Example for DES DR1
arXiv:1801.03181

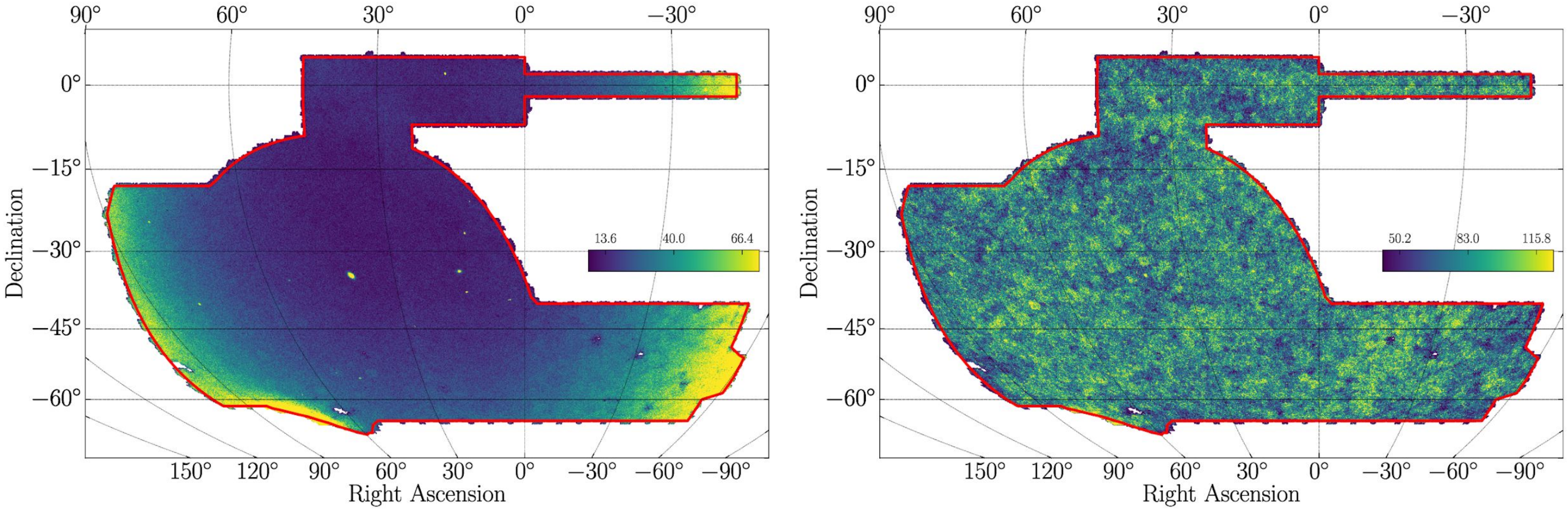
Performance Across Focal Plane

Bosch et al. 2017
arXiv:1705.06766



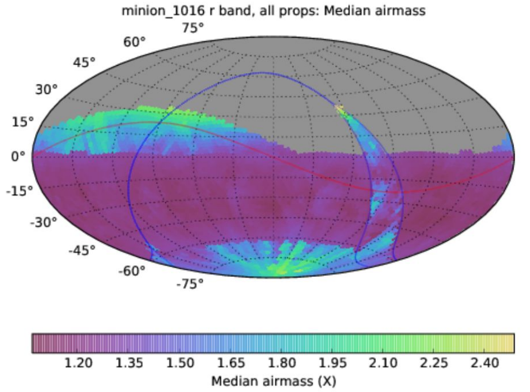


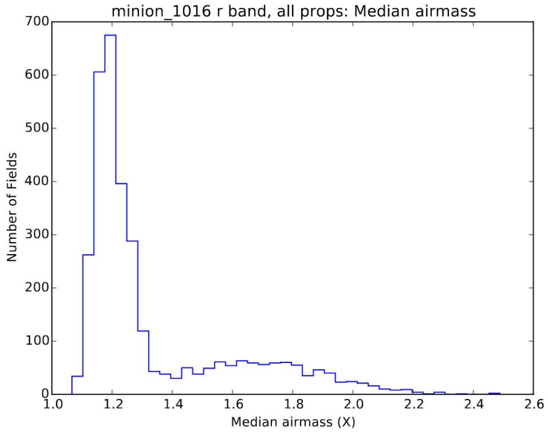
Wide-area density stellar and galactic maps a useful diagnostic

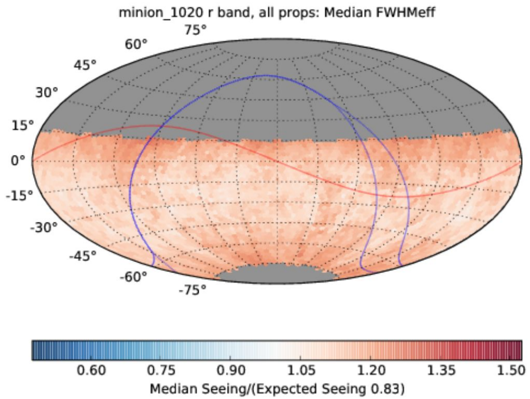


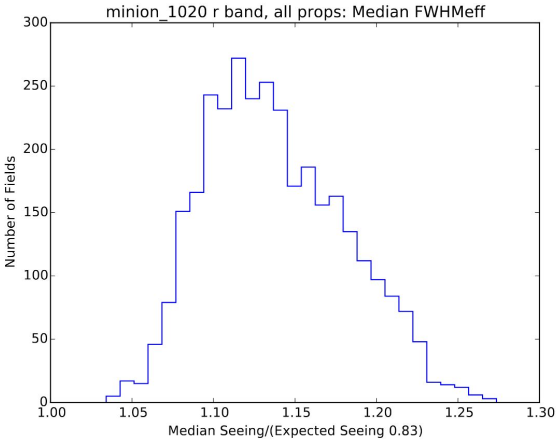
Example for DES DR1
arXiv:1801.03181

Simulating the 10-yr Survey





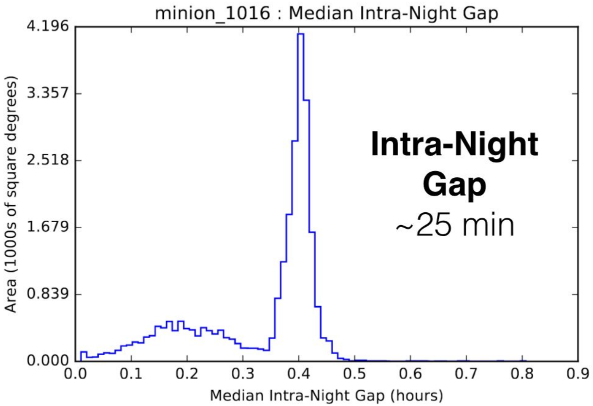


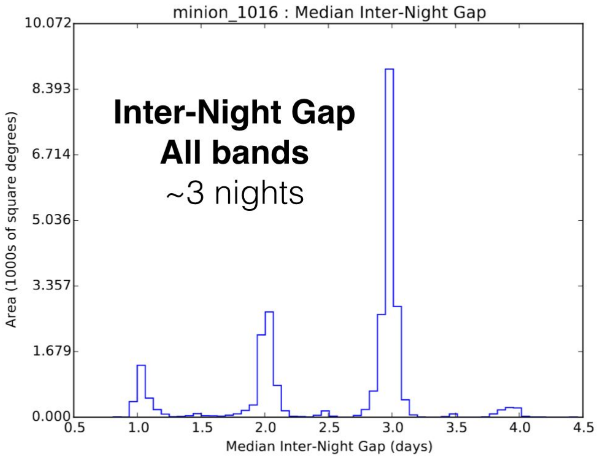


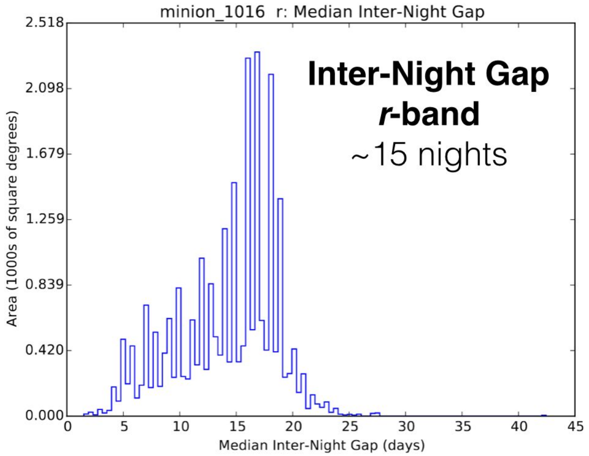
On-sky commissioning observations will enable more realistic forecasting of the expected survey speed and delivered throughput, image quality, etc., that would be needed to predict the 10-yr survey performance

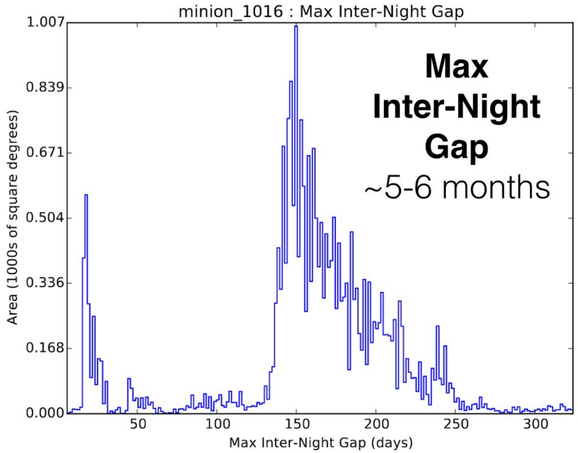
Survey Strategy Community White Paper
arXiv:1708.04058

Simulating the 10-yr Survey









On-sky commissioning observations will enable more realistic forecasting of the expected survey speed and delivered throughput, image quality, etc., that would be needed to predict the 10-yr survey performance

Survey Strategy Community
White Paper
arXiv:1708.04058