Vera C. Rubin Observatory
Rubin Observatory Operations

Criteria to start the Legacy Survey of Space and Time

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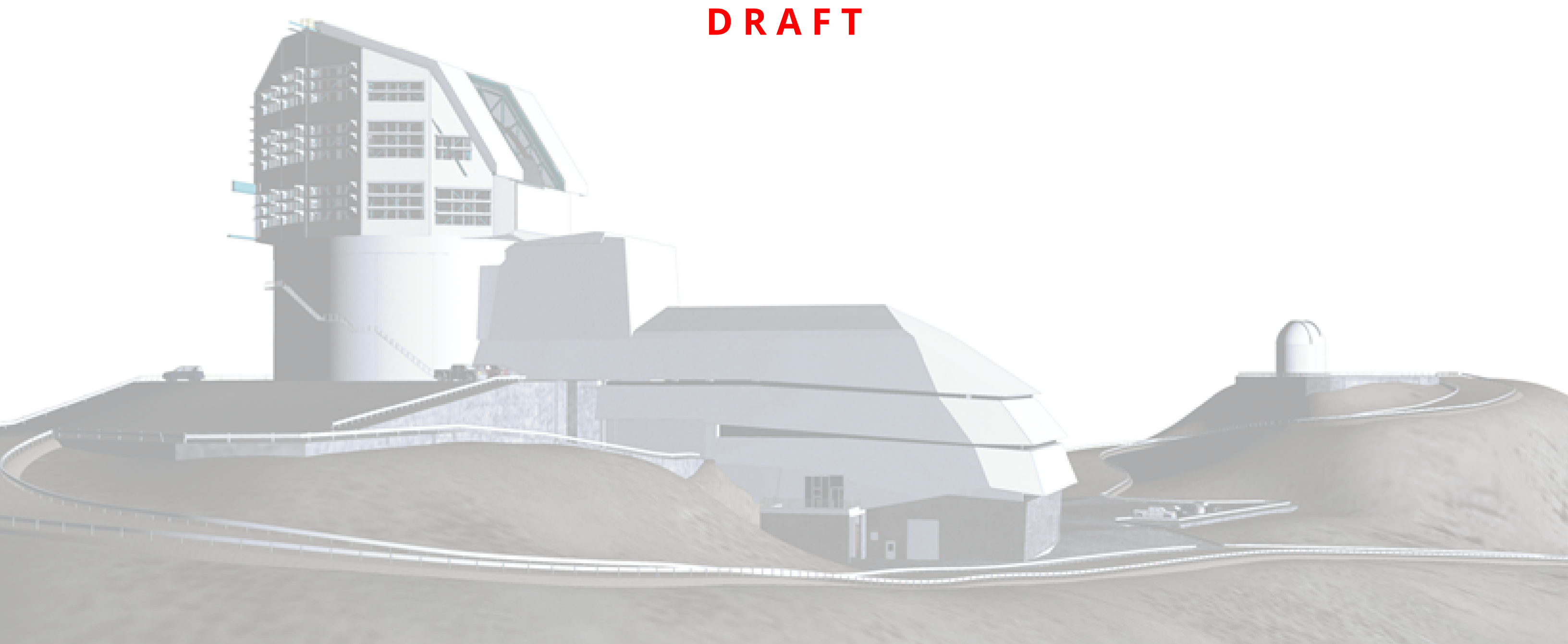

Abstract

This document concisely captures the criteria that must be satisfied to begin regular survey operations for the Legacy Survey of Space and Time (i.e. to begin execution of the planned 10 year survey strategy currently documented in PSTN-056). It is expected that the survey will start in late 2025 1-2 months after the beginning of the formal Operations phase at the completion of construction. The survey can start based on quantitative criteria described herein. The system contribution to the delivered image quality must be $\geq 0.4''$ and the effective survey speed must be 1.01 or better. Both of these are attainable given our experience and knowledge of the current on sky system.

Change Record

Version	Date	Description	Owner name
1	2025-02-28	01.0	Robert Blum
1	2025-09-01	02.0 Criteria and Schedule updates	Robert Blum

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Contents

Criteria to start the Legacy Survey of Space and Time

1 Introduction

Rubin Observatory will be substantially completed by October 2025. In practice this means the Operations team (see Blum, RDO-018) will assume responsibility of the Observatory and regular operations: running the facility on Cerro Pachón each night, transferring data over the long haul network to the USDF, processing and arching the data, etc.

Depending on the reliability of the overall system at the time of handover, it may be necessary to improve processes or sub-system reliability in advance of formally beginning the execution of the the 10 year Legacy Survey of Space and Time. The survey strategy and it's associated cadence in the 10 year period (currently allowing for modest assumed degradation in year 1) are detailed by the Survey Cadence Optimization Committee (SCOC, Rubin's Survey Cadence Optimization Committee et al., PSTN-056).

In this technote, we define the criteria that the Operations team, in consultation with operations partners, the post-handover Construction team, the Rubin Management Board, funding agencies, and the science advisory committee, will use to guide the decision to begin the LSST.

The LSST will begin after the handover to Operations. The handover will happen on October 25th, 2025. Formal transition of construction to staff into Operations from SLAC commissioning and AURA (into NOIRLab) will be on October 1, 2025. See section 4 below for the current schedule.

2 System Performance

Handover means that the system will have passed the NSF and DOE close out review. The as delivered system will be *capable* of delivering images that satisfy the science requirements as defined in SRD (Ivezić & The LSST Science Collaboration (LPM-17)). Following the final phase of commissioning which will include science validation (SV) observations, the state of the system will be assessed and the readiness of the system and team to begin the survey will be made. Further optimization by the Operations team will be planned as needed to ensure the system performs *reliably* at the needed level of capability.

Rubin has developed a high level metric to summarize the system performance with respect to survey efficiency. We need to ensure both that the system is producing science capable images and data products and that the observing is efficient. If the site and system are producing appropriate image quality and the system and team are acquiring data efficiently, we can confidently start the LSST. In Figure 1, we show the system contribution to image quality (and atmospheric contribution) versus the dimensionless survey efficiency or speed, fE.

Effective survey speed is product of instantaneous etendue (ability to capture photons = effective area x field of view), observing efficiency, and system availability

normalized etendue: fE = fA * fS * fO * System Availability

fA: FOV area factor – total solid angle of all live science pixels
fS: sensitivity factor – defined for fiducial observing conditions and based on knowledge of throughput (optics) and sensor properties (QE, read-out noise)
fO: observing efficiency factor – rate of visits within scheduled observing time, including time intervals between visits for a nominal survey strategy (exposure time, slew time, readout time, filter exchange time)
System availability – accounts for weather losses as well as scheduled and unscheduled system downtime

All factors normalized by their nominal (design) value

FIGURE 1: Dimensionless survey efficiency factor, fE. System Availability is the most uncertain at this time. The current state of each factor is discussed below and the quantitative criteria for starting the LSST with respect to each factor is assessed.

All f factors are dimensionless and normalized by the corresponding SRD design values. They can be traded against each other as time. For example, deterioration in the mirror reflectivity can be easily translated to factor fS, and traded against time (e.g. time lost to recoating, the system efficiency), or against loss of sensor area (fA). The key point is that it is possible to define a simple measurable quantity (fE) that is an excellent numerical approximation for LSST science goals. Thus, we can think of the effective speed of executing the LSST (in units of the nominal speed) in terms of recognizable elements: fE = effective area $\times$ effective FOV $\times$ cadence $\times$ 1-downtime.

In Figure 2, we show the state of our understanding of the image quality and survey speed before we went on sky with LSSTCam. The red star in the diagram is the design performance corresponding to $0.35''$ system contribution to delivered image quality (DIQ as measure in the focal plane). The white circle is a forecast based on expectations before we went on sky. We believe there is nothing limiting us reaching that circle, but the current performance is not there yet.

There are three regions in the diagram. Clearly we want to be in the green shaded region and to the lower right in that space. The light gray space is unacceptable for science and the

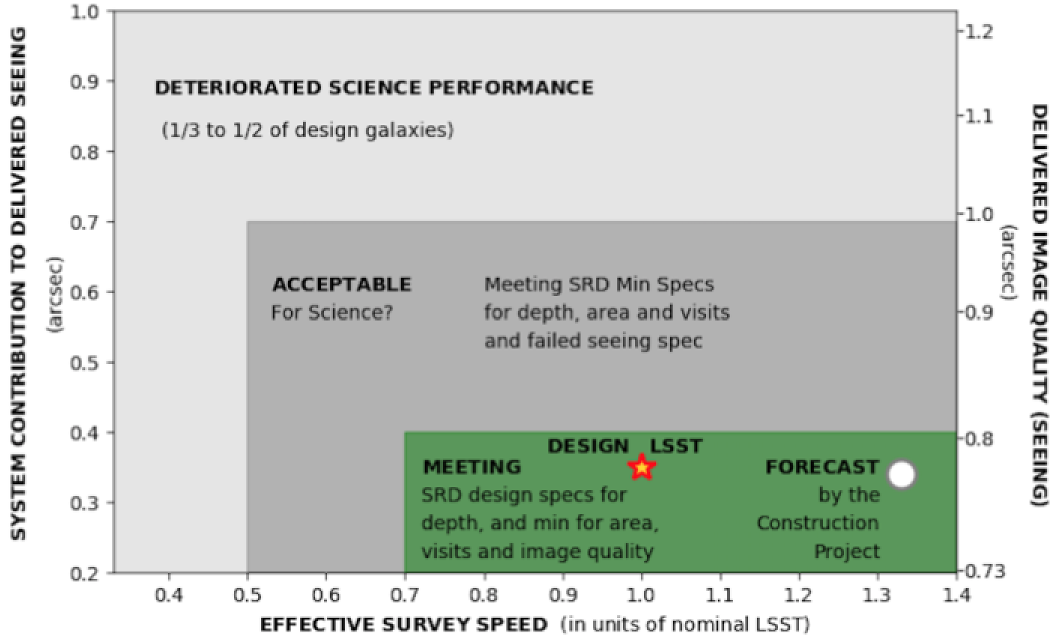

FIGURE 2: Image quality versus effective survey speed, fE. The system contribution to the image quality is shown on the left vertical axis and the delivered image quality including the atmosphere (added in quadrature) is on the right. The LSST design is accomplished with nominal speed 1.0 and system IQ of 0.35′′ in this diagram. Current performance is assessed below. The white circle is representative of where we want to drive the performance, but we have not reached it yet.

dark gray space covers the area where SRD minimum specifications are met for depth, area of LSST, and visits, but fails to meet the specification for minimum system contribution to the DIQ (0.4′′).

As of CCR2/ORR1, the current values for the f factors are given in the following table. For fA, the value is set by the number of science pixels available (each with 0.2×0.2 arcsec^2 on the sky). Accounting for the active pixels meeting specifications, the factor is fully 99%. The fS factor includes read noise, QE, vignetting, optical throughput (filter, lens transmission, mirror reflectance) and DIQ (so DIQ affects both axes in our diagram). The observing efficiency factor, fO, is a function of how many visits of the right exposure time can be observed given telescope performance (how fast we move and settle). Finally, system availability is defined as the open shutter science time compared to the total elapsed time working on the on sky programs. Presently, if we consider only times when we are in the science data taking mode (doing LSST like observations) we have sustained 85% availability over a week long period. If we consider other system tuning in the denominator mixed with the science SV observations, the availability is about 75%.

Table 1: Current f factor status

factor	Description	Sustained Performance	Demonstrated Capability
DIQ	System Contribution (PSF FWHM)	0.6′′	0.4′′
fA	FoV area factor	0.99	0.99
fS	Sensitivity factor	0.94	1.30
fO	Observing Efficiency	0.97	1.05
SA	System Availability (up and taking data)	0.75	0.85
fE	Normalized Étendue	0.68	1.15

The range of performance between what has been achieved over periods of SV and the best performance is shown in Figure 3. The goal of further optimization is to use the available technical ”knobs” to tune the performance and make it more reliable. These are at a high level, the active optics system (AOS) and associated wavefront analysis, thermal control of the M1M3 cell, thermal control of the top end assembly (volume around M2), and the dome ventilation (active control of louvers and installation of the air distribution ducting). All of these are under active work and progress has been made on a number of fronts not yet reflected in Figure 3. Mostly because the time available on sky has been limited since CCR2/ORR1.

The current capability and reliability of the system as described in Table 1 and Figure 3 form the basis of optimization criteria described in the next section that the Operations team will use to gate starting the LSST.

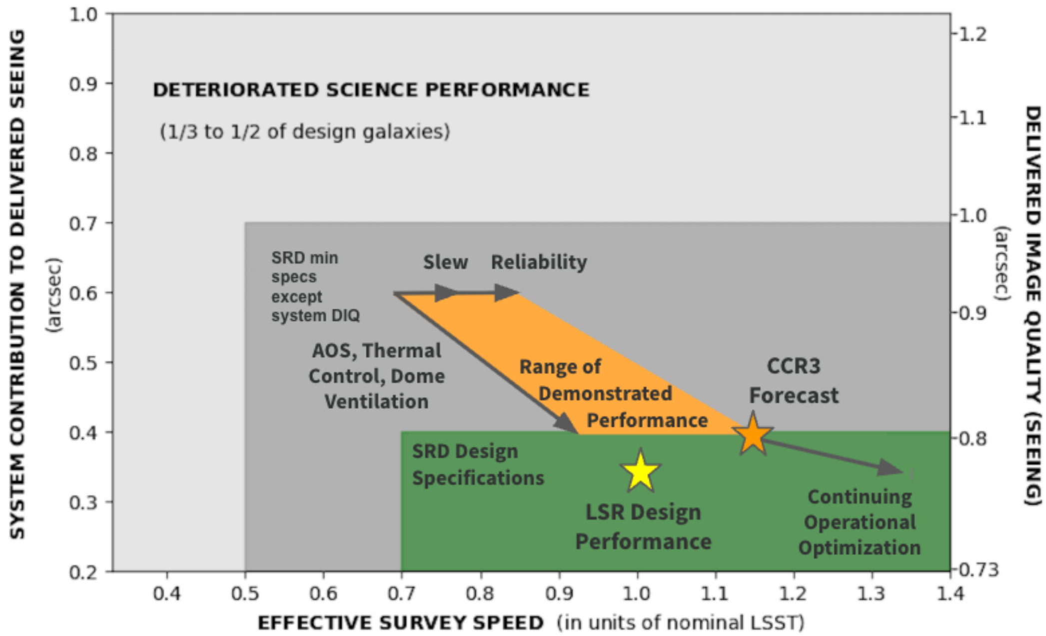

FIGURE 3: Image quality versus effective survey speed, fE with performance presented at CCR2-ORR1. Upper left of the orange performance region is sustained over week long periods in SV. The best performance (capability) is represented by the lower right vertex of the region. This forecast to be the typical performance by CC3. This may or may not happen depending on teh progress made in the remaining month of on sky work.

3 Criteria to begin the LSST

Armed with an understanding of the system performance as outlined above and the Operations team readiness, we will use a set of objective criteria to gate the start of the LSST. These criteria will be concise and easily understandable so that the community of scientists and stakeholders counting on Rubin and the survey will have confidence the Observatory is on track.

The criteria we will use that are listed below are only to start the survey. There may be key processes within the overall system, including data management and processing that require further work after handover (beyond the construction project requirements), but unless they would prevent delaying the survey start, they are not discussed or enumerated here.

The Operations team discussed an initial set of criteria with the Science Advisory Committee and community at the 2024 Rubin Community Workshop. The current criteria have been evolved since that meeting and are shown in the table below.

TABLE 2: Survey Start Criteria

Item	Criterion	Description	Status
1	LSSTCam Maintenance	Before the completion of SV, it is understood whether or not off TMA Camera maintenance will be needed within the first year of Operations.	No off TMA maintenance required.
2	SRD	All science requirements that can be verified with SV data are verified or expected to be verified within 3 months of completion of SV.	Status at CCR3
3	Dome	The dome environment is not limiting typical performance.	Not controlled until after Handover
4	Calibration	All necessary calibration data products are available at the time any LSST data are obtained or can be obtained after the fact without invalidating the observed data for inclusion in the LSST.	Status at CCR3
5	DIQ	Delivered Image quality contribution of system is better than or equal to $0.4''$	Currently $0.6''$ system contribution
6	Normalized Étendue	Survey speed is > 0.7.	Currently 0.68
7	Cadence	The first six months of survey schedule as expected to be executed includes details of the system as currently performing.	In progress
8	Early Science	DP2 observations are completed as planned (Guy et al., RTN-011).	Status at CCR3

These criteria are not comprehensive with respect to LSST success. They are intended only to guide the confident commencement of the survey. The initial boundary condition is a successful completion of the construction project. This means the construction completeness reviews have been successfully completed and NSF and DOE have accepted the system as the one they intended to build.

The criteria cover a range of contexts. Most look to be well in hand based on what we know about commissioning progress and what has been reported at CCR2/ORR1. Item 1 is already met. We do not expect to have to remove the camera for maintenance before we begin the survey. Item 2 is needed to ensure some key aspects of the system don't need verification before we embark on the LSST. Some long term SRD requirements need a significant amount of data to finally validate. But we can be assured data being taken are going to be valid for the LSST if the requirements that can be validated with SV data have been. This will be confirmed at CCR3. The calibration system (item 4) is in the advanced stages of validation. By CCR3, we can be assured no outstanding calibration needs will limit the taking of images for the LSST. For item 7, we are already folding in as delivered performance into the survey simulations. We can be confident the remaining performance status can be adapted into the initial LSST cadence by the time we are ready to start. Once SV data taking is complete, we will know the content of DP2 (item 8) and be able to decide whether or not any augmentation is critical for community preparation before data release 1 (DR1; see Guy et al., RTN-011).

This leaves the "big 3," the dome environment, system contribution to DIQ, and Normalized Étendue. These are discussed next in more detail.

3.1 Dome Environmental Control

The dome is the last major subsystem to be completed. Indeed it will not be done until mid 2026. The critical aspects that are needed are to install, provide control for, and optimize the actuators for the dome louvers. There are 40 louvers, and some large fraction need to be operable (open at fractions consistent with telemetry in real time for temperatures and wind). The first actuators are installed now and may be operable before the shutdown. Still more will need to be brought on line after the handover. If the louvers limit us to worse than typical min SRD performance, we won't be able to start the LSST until they are largely deployed and in routine operation.

There are large ducts that will provide for air distribution via the main air handlers inside the facility. This system should improve our ability to maintain the enclosure at closer to the required nighttime temperature during the day time. Hitting the right temperature in the environment around the telescope is critical to good IQ during the night. The ducts are necessary but not sufficient. We will also need to gain experience in forecasting the coming night's temperature to be able to use the air conditioning effectively (i.e. to set the system to hit the right target).

Further use of available temperature sensors on the telescope and in the dome will help on going analyses aimed at improving the AOS and thermal control of the optics in real time.

The total contribution to DIQ from the dome environment is modest. Including all sources of turbulence generated by the facility, the budget to contribute to the DIQ is only 0.09′′. Clearly all systems for controlling these contributions need to be working well and reliably. The observatory will need to rely on the ability to characterize parts of the DIQ coming from this environment. Thus we will prioritize reliable operation and calibration of our DIMM, in-dome seeing monitors, as well as the atmospheric profiler on Cerro Pachó, RINGSS.

3.2 Normalized Étendue

Much of the effective speed (Normalized Étendue) is already demonstrated to be sufficient to start the LSST, The field of view factor, fA, is excellent and stable. The sensitivity factor, fS, is also very good. This factor has the potential to help overall performance because of its dependence on delivered image quality. Getting the system contribution from 0.6 to 0.4 (coupled with site atmospheric seeing of 0.7′′) would raise fS from 0.94 to 1.3. Apart from this, all the optics are delivered as is the focal plane. The performance of all these components is excellent and can be maintained. The observing efficiency or fO is also in good shape. The telescope dynamic performance (slew speed, acceleration, and jerk) is sufficient for the LSST planned cadence.

The TMA currently can move faster than we operate it due to the need to improve the control of dynamic loads on the glass via force actuators. However the current performance with glass is captured in the scheduler simulator and is only a modest hit to LSST. We will continue to work on improved dynamic control even as we operate for LSST. Slew and settle performance are well understood and adequate. Modest gains on fO are forecast for the rest of SV and early operations. We expect the current value to go from 0.97 to 1.05.

This leaves the System Availability, Current performance of 0.75 needs to be improved. Doing only science like observations we have reached 85% at times. We need to continue to improve on procedures and reliability of systems throughout the summit facility as we go forward. This means training for faster troubleshooting and fault recovery, making communications on the telescope system bus more reliable, improving reliability of telescope, dome, and camera functions. These have all seen marked progress as expected though out system integration, test, and commissioning. We will assume current performance of 75% conservatively.

The minimum Normalized Étendue is 0.7′′ in the SRD. This level is nearly in hand; see Table 1 and the ”Sustained Performance values.” We will start the LSST consistent with System Availability of 75% which leads to fE = 1.01 using the Demonstrated Capability column f factors in Table 1. However, the actual value will be better given that we expect the System Availability to improve significantly.

3.3 DIQ

The single most important gain needed to get to the LSST start is clearly the typical DIQ. We will not start the LSST until this sustained performance reflects a system contribution of $\leq 0.4''$, the minimum SRD requirement. The very best the system contribution can be given current as build measurements is 0.327′′.

Improving the system contribution to the DIQ requires continued effort on the control of optics and the dome environment. Putting this together with the criteria above results in the region of the performance diagram we can use to gate starting the LSST as depicted in Figure 4. The survey can begin once the system contribution to DIQ is 0.4′′ or less and the effective survey speed is 1.01 or better (see Table 1 and assume System Availability is 75%).

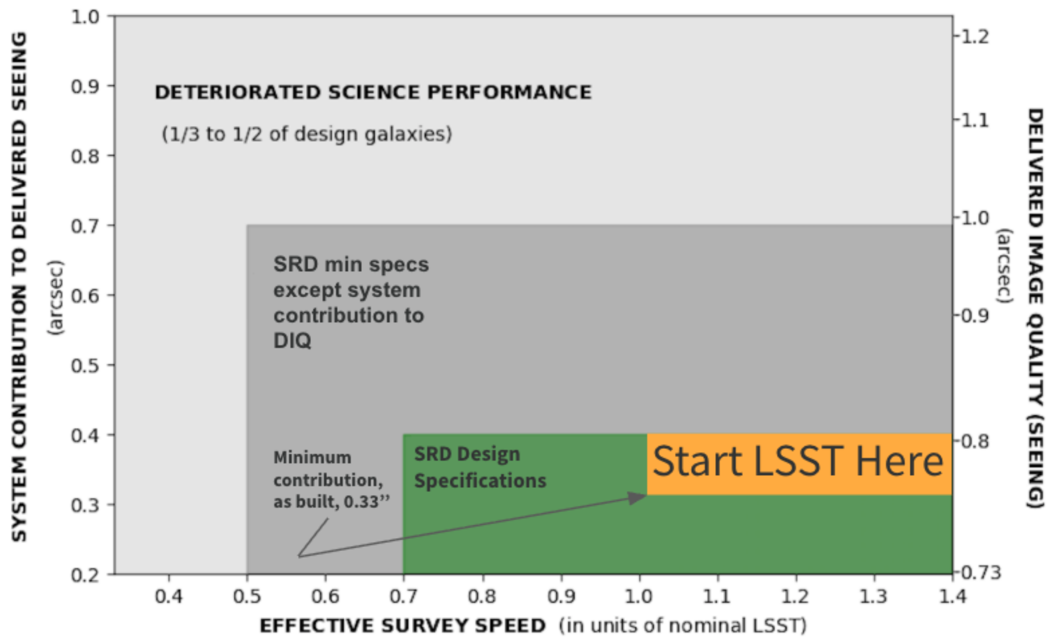

FIGURE 4: Image quality versus effective survey speed or Normalized Étendue. The large orange rectangle represents the region in this space within which we can confidently start the LSST.

4 Schedule

The Project and Operations teams will complete several reviews as described below in order to closeout the construction phase, handover to Operations, and demonstrate readiness to begin the LSST. The first of these, Construction Completeness Review (CCR) 1, was held in October, 2024. CCR2 took place in July, 2025. Concurrent to CCR2, the Operations team went through the Operations Readiness Review (ORR) 1. Both reviews were run in parallel with the same NSF–DOE review panel convened to review and report out for the Observatory as a whole. A modest set of recommendations were made and Construction and Operations are addressing them.

Construction Closeout and Operations Readiness Reviews:

- CCR1 – readiness for the start of on-sky commissioning, as exemplified by substantial completion and integration of subsystems, and evidenced by direct measurement of the optical throughput of the integrated system
- CCR2 – capability to support LSST science goals, as exemplified by the System First Light

technical milestone, and evidenced by delivered single-visit image quality (including active control of optics)

- CCR3 – reliability to initiate the LSST survey, as exemplified by the Science Validation Surveys, and evidenced by the readiness of Rubin Observatory Operations to accept the as-built Observatory
- CCR4 – closeout of the Construction project, as exemplified by service of scientifically validated survey-scale data products as part of the Operations Early Science Program, and evidenced by completed scope of system-level requirement verification, reporting, and final accounting

As of September 2025, the science validation phase of Construction is nearly complete. SV and system optimization will run through September 22. The facility will then shut down until October 24 to complete the remaining large integration activities that are required before starting regular operations. It is known that a number of activities will continue in operations managed by the construction project. These activities are captured in the ”punch list”. It is expected approximately 10 FTE of effort in FY26 going through at least June will be required to finish the punch list.

CCR3/ORR2 will be held in October at the end of the observatory shut down. The combined review will be held with Observatory, partner, and agency staff. No review panel will be present. The team will present the status of the observatory following SV and the shutdown activity, the plans for the punch list, and the plans for early operations regarding continued optimization and readiness to start the LSST.

Following CCR3/ORR2 and the concurrent ”Handover”, the Operations team will begin to regularly run the system, taking responsibility for the observatory on October 25th. The priority for the Operations team is to drive the system to the state captured by the criteria in this document and start the LSST. Figure 5 shows the current milestones for the Project and Operations. The period after CCR3/ORR2 is uncertain, but likely will involve continued pre–survey optimization.

5 References

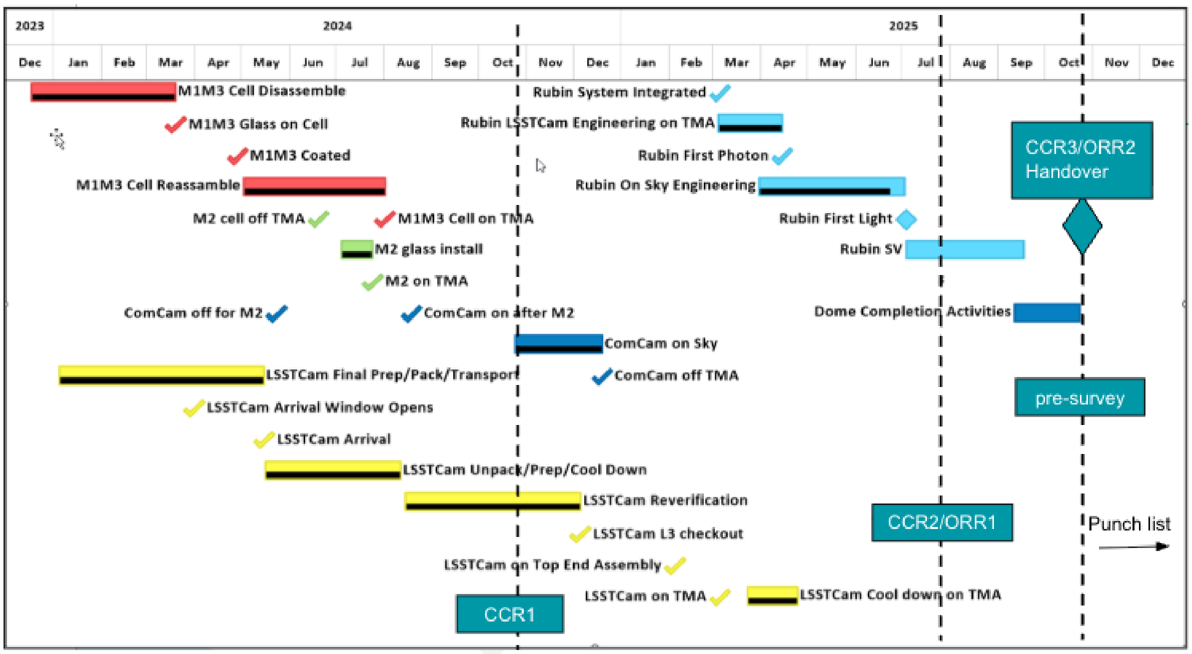

FIGURE 5: Rubin Observatory Schedule as of September 01, 2025. Formal completeness reviews including operations readiness are shown in the Figure and described above. Handover to the Operations is set for October 25, 2025 and pre-survey optimization will continue until the performance criteria described in this document are met for starting the LSST. In parallel, some activities and work by the Construction team will continue in FY26. Some of these activities will positively impact on sky performance.

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6 Acronyms

Acronym	Description
AOS	Active Optics System
AURA	Association of Universities for Research in Astronomy
CCR	Construction Completeness Review
CCR1	Construction Completeness Review 1
CCR2	Construction Completeness Review 2
CCR3	Construction Completeness Review 3
CCR4	Construction Completeness Review 4
DIMM	Differential Image Motion Monitor
DIQ	Delivered Image Quality
DOE	Department of Energy
DP2	Data Preview 2
DR1	Data Release 1
FOV	field of view

FTE	Full-Time Equivalent
FWHM	Full Width at Half-Maximum
FY26	Fiscal Year 2026
FoV	Field of View (also denoted FOV)
IQ	Image Quality
LPM	LSST Project Management (Document Handle)
LSST	Legacy Survey of Space and Time (formerly Large Synoptic Survey Telescope)
LSSTCam	LSST Science Camera
M1M3	Single piece of glass for Primary Mirror/Tertiary Mirror
M2	Secondary Mirror
NOIRLab	NSF's National Optical-Infrared Astronomy Research Laboratory; `https://noirlab.edu`
NSF	National Science Foundation
ORR	Operations Readiness Review
ORR1	Operations Readiness Review 1
ORR2	Operations Readiness Review 2
PSF	Point Spread Function
PSTN	Project Science Technical Note
QE	quantum efficiency
RDO	Rubin Directors Office
RINGSS	
RTN	Rubin Technical Note
SA	System and Services Acquisition
SCOC	Survey Cadence Optimization Committee
SLAC	SLAC National Accelerator Laboratory
SRD	LSST Science Requirements; LPM-17
SV	Science Validation
TMA	Telescope Mount Assembly
USDF	United States Data Facility