Vera C. Rubin Observatory
Systems Engineering

Survey Cadence Optimization Committee's Survey Start Recommendations

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PSTN-057

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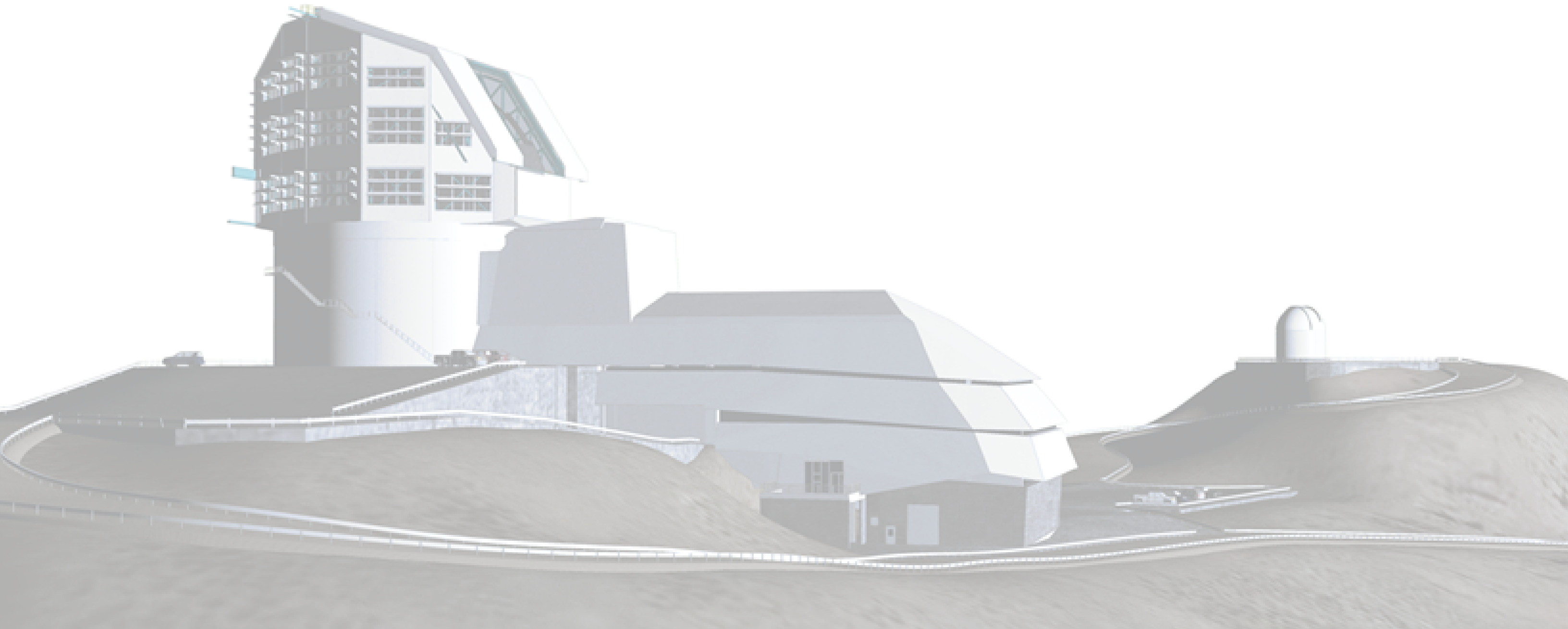

Abstract

A recommendation for adjustments to the initial LSST survey strategy is delivered to the Observatory Director. These adjustments respond to improved knowledge and understanding of the system performance and completeness of science verification activities at the start of LSST.

Change Record

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With the Vera C. Rubin Observatory (Rubin) now having completed the transition from Construction to Operations, and on the eve of the start of the Legacy Survey of Space and Time (LSST Ivezić & The LSST Science Collaboration, LPM-17), Rubin remains committed to continuing to optimize the LSST survey strategy to maximize the scientific return on the four LSST Science Pillars and beyond.

The Survey Cadence Optimization Committee (hereafter SCOC[1]) is a Rubin standing committee tasked with soliciting, collecting, and aggregating community input on the expected science performance of proposed LSST survey strategies and optimizing it to make strategy recommendations to the Rubin Director, who makes the final decision on implementation (see Bianco et al. 2021).

We now have an updated understanding of system performance, which indicates a decrease in expected survey time of about 10% once accounting for more realistic expectations for engineering and downtime, as well as telescope performance. A plan has also been developed to start LSST while Rubin continues to improve both the delivered image quality and effective survey speed during the first 1-2 years of the survey, resulting in additional engineering time and decreased image quality than originally expected, both improving through Year 1 (Y1). Finally, while a plan to collect incremental sky templates during Y1 (Guy et al., RTN-011) was designed based on the assumption that the desired template depth and image quality could be achieved with ~ 3 exposures of sufficient quality (specifications of quality were not originally well defined), a deeper understanding of the process of template construction and requirements on image quality reveal that templates constructed with < 5 images would be incomplete due to chip gaps and masking. Additionally, image FWHM values better than the expected median are needed, along with cuts on the extinction values, which are not yet well defined. This requires modification to the incremental template construction strategy. Within this framework, we recommend updates to the most recent SCOC recommendation in Rubin's Survey Cadence Optimization Committee et al. PSTN-056 for the observing planned to take place at the start of LSST and during Y1 of the survey.

[1] https://rubinobservatory.org/for-scientists/committees-teams/scoc

1 Recommended changes to the observing strategy

The SCOC had proposed the survey design for Y1 implemented in `baseline_v4.0` and described in PSTN-056 (which itself builds on earlier SCOC recommendations Rubin's Survey Cadence Optimization Committee et al. PSTN-053 and Rubin's Survey Cadence Optimization Committee et al. PSTN-055) which includes the following survey strategy details:

- for footprint (PSTN-056 recommendation vi and xxiii),
- filter balance (i, ii, viii, ix, xx),
- rolling (iii, and v), including not starting rolling in Y1 (xxi),
- special surveys (DDF, xvi and xviii; ToO, x-xiv; Twilight microsurvey, xxii),
- observing in single exposures rather than "snaps" (xv), and
- cadence (with no recommended modifications from PSTN-055).

We now recommend the following changes, which have been implemented in `baseline_v5.3`:

1. We introduce a "template-tier" observing mode that is activated when sky conditions (atmospheric seeing) are conducive to the collection of good PSF images that can be used to build sky templates. This observing mode attempts to collect five images in each filter and relaxes the constraints on image pairs implemented in the main survey (but see point two) to accelerate the production of templates over the LSST footprint (as recommended in PSTN-056 and described in Guy et al. RTN-011 to support early science).
2. The template tier collects images in pairs (primarily in different filters), but the pairs are spaced by median $t_{pairgap} = 25$ minutes, slightly less than the median time gap for image pairs collected in main survey mode. Some bands (g and r) are acquired in same-filter pairs as well as mixed-filter pairs; u is only acquired in same-filter pairs. This is to more tightly pack these visits into the available good-seeing dark time, while also allowing r band to float a little more easily through the lunar cycle, accounting for the fact that the total number of visits expected in the redder bands is larger than in the bluest. Observing in pairs enables tracking of solar system objects even in the absence

of templates, and provides colors for transients and variables observed in the images, although the color will only be measured retroactively once the templates are available. Overall, this observing mode preserves the efficiency gains of the template tiers while enabling additional science outcomes.

3. Since depth is not the limiting factor that requires the use of > 3 exposures for templates, reduced exposure time for each image may enable the construction of templates that are sufficiently complete and deep to enable DIA processing and DIA-based science, while increasing the efficiency of construction of the incremental templates. The SCOC favorably reviews the scientific impact of collecting 20 (28) seconds exposures for $grizy$ (u) template exposures in the template tier observing mode. However, a feasibility study is pending, to ensure the shorter exposure (1) does not impact data processing negatively, (2) truly leads to a higher efficiency in delivering templates (*e.g.* are the image cycles correspondingly faster and the image quality as good based on AOS performance), (3) does not negatively affect system calibration. Particular attention should be paid to the image quality expectations in u band, where 25 seconds is close to the readout limit. Retaining the standard 38 sec exposure time in u while reducing exposure time in other filters may be the optimal solution, and we expect the feasibility study to deliver an answer. Due to the aggressive template collection schedule in Y1 (see point #2 and RTN-011), this would result in the majority of LSST images in Y1 being collected with shorter exposures. Thus, the scientific advantages of this strategy must weigh the expected improved template completeness and timeline with potential scientific loss caused by reduced sensitivity on shorter exposures in Y1. Pending the outcomes of this feasibility study, at this time, the SCOC recommends the collection of templates with shorter exposures as described above. We continue to collect feedback from the Science Collaborations and the scientific community at large on this topic and will continue to reevaluate this recommendation.

4. Translational and rotational dithering between visits within a night in the Deep Drilling Fields (DDFs) is added to translational and rotational dithering between nights following the current recommendations from Data Management (DM), although the SCOC continues to invite studies of options to reduce dithering to maximize the DDF stack depth and highest-cadence region footprint (PSTN-056 recommendation xvii).

5. Finally, in PSTN-056 and `baseline_v5.0` we introduce a specific DDF observing strategy (PSTN-056 recommendation xviii) dubbed "ocean" that observes DDFs in either "deep" or "ultradeep" seasons. Each field receives one ultradeep season (except COSMOS, which receives three), with long sequences of visits within a night. The deep seasons have

shorter sequences (typically two or three visits in each filter). Both the deep and ultradeep seasons have high cadence, with nightly observations in alternating filters (so typically two-night cadence in any given filter), and this strategy is retained in the current recommendation.

At this stage, the SCOC is not recommending any additional changes to the observing strategy. However, as system performance continues to evolve, we remain responsive to changes and opportunities.

We invite the community to continue interacting with the SCOC (via the SCOC liaisons into the Science Collaborations and via the community forum[2]). We recommend that the community pay particular attention to survey strategy topics on the forum, [3] where we regularly release minutes of SCOC meetings and descriptions of simulations that broadly represent variations of the survey strategy under consideration. We also invite the community to review the content of the most recent SCOC workshop[4] —the webpage contains slide decks and video recordings of all sessions.

2 Baseline 5.3

The `baseline_v5.3` simulation includes our current best estimates for the system on-sky uptime, slew performance, and engineering time needs, which are still evolving. The simulation's start date is broadly estimated to be consistent with the start date for LSST, but should not be considered as a forecast or a commitment to the official start date of the survey.[5]

The addition of more maintenance time in every year (46 weeks total instead of 20), additional engineering test time (one night every month plus two half-nights a week for the first six months), and a more realistic fault time per night result in a reduction of the overall number of visits on-sky of about 10% compared to the `baseline_v5.0` simulation upon which the Phase 3 SCOC recommendation is based (PSTN-056). This 10% reduction is seen in each year (the reader is reminded that previous simulations starting with `OpSim v3.6` already included significant additional downtime within Y1).

[2] community.lsst.org
[3] https://community.lsst.org/c/sci/survey-strategy/37
[4] https://project.lsst.org/meetings/scoc-sc-workshop6/home
[5] The start of LSST is proposed by Rubin's Start of LSST Board to the Rubin Observatory Director, who will make the final decision after consulting with the Rubin Management Board and funding agencies.

In more detail, in OpSim v5.3 we increased the planned maintenance from 2 weeks/year to 3 weeks/year plus 8 weeks in years 4 and 8; added 2 half-nights of engineering observations per week for the first 6 months and 1 night every 25 days later (including calibration); kept the v5.0 19 weeks of unplanned downtime in years 2-10 and extended this into year one for a total of 21 weeks of unplanned downtime; and modified short intervals of unplanned downtime early in the survey, which was modeled starting at $\sim 25\%$ and progressively reducing to $\sim 3\%$ over year one in v5.0, now is $\sim 20\%$ to $\sim 5\%$ ramping down over three years.

The TMA performance is modeled as 20% maximum slew speed and a 3-second settle time. This performance is undergoing optimization, with some known avenues for improvement. This estimate is expected to be slightly optimistic at the start of LSST and pessimistic later on. However, we conservatively maintain this performance throughout the survey as the timeline for improvements is still uncertain.

Beyond these updates, the baseline_v5.3.0 observing strategy implements the SCOC recommendations described in section 1.

Figure 1 shows the performance of the proposed baseline_v5.3 for a core set of selected science-driven metrics (the extended set of metrics used by the SCOC for its deliberation includes hundreds), compared to earlier simulations of the LSST survey starting with baseline_v3.0, which implements the recommendation in PSTN-055; baseline_v3.6 introduces more realistic downtime expectations in Y1 and slew jerk; baseline_v4.0 implements the recommendation in PSTN-056; baseline_v5.0.1 uses single 30 second snaps as opposed to 2x15 second exposures (PSTN-056 recommendation xv) and includes the "ocean" Deep Drilling Strategy (see section 1 #5). Additionally, starting with baseline_v5.0.1 all OpSims reflect small software changes in rubin_scheduler (see post on LSST community forum for details on these OpSims[6]). baseline_v5.1.2 introduces the template tier observing mode (described in section 1, #1), and is otherwise consistent with baseline_v5.0.1; comp_v5.3 assumes the same sky availability as baseline_v5.0, but implements the template tier in pairs in different filters (section 1, #2), and DDF observing schema (section 1, #4 & 5) as in baseline_v5.3. This simulation is made available to demonstrate that the specific strategy choices recommended in this note are not *per sè* causing any scientific losses, rather they generate gains in most metrics, and the lower performance of baseline_v5.3 as compared to earlier baselines is in fact entirely driven by lower sky availability. Finally, 20s fast templates_v5.3 implements the shorter exposure time for the template tier observations (section 1, #3).

[6] https://community.lsst.org/t/release-of-v5-0-simulations/11114

Figure 2 shows the coverage of the LSST footprint as a function of the minimum number of visits acquired at any point in the given area. The range between SRD ((Ivezić & The LSST Science Collaboration, LPM-17)) minimum and goal requirements is marked as a shaded region. Here, we include a version of 5.3.1, which extends LSST to 11 years to highlight what can be recovered with an extension of the survey while keeping the survey strategy as designed.

A Acknowledgements

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B References

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[RTN-011], Guy, L.P., AlSayyad, Y., Bechtol, K., et al., 2026, *Rubin Observatory Plans for an Early Science Program*, Technical Note RTN-011, NSF-DOE Vera C. Rubin Observatory, URL https://rtn-011.lsst.io/, doi:10.71929/rubin/2584021

[LPM-17], Ivezić, Ž., The LSST Science Collaboration, 2018, *LSST Science Requirements Document*, Project Controlled Document LPM-17, NSF-DOE Vera C. Rubin Observatory, URL https://ls.st/LPM-17

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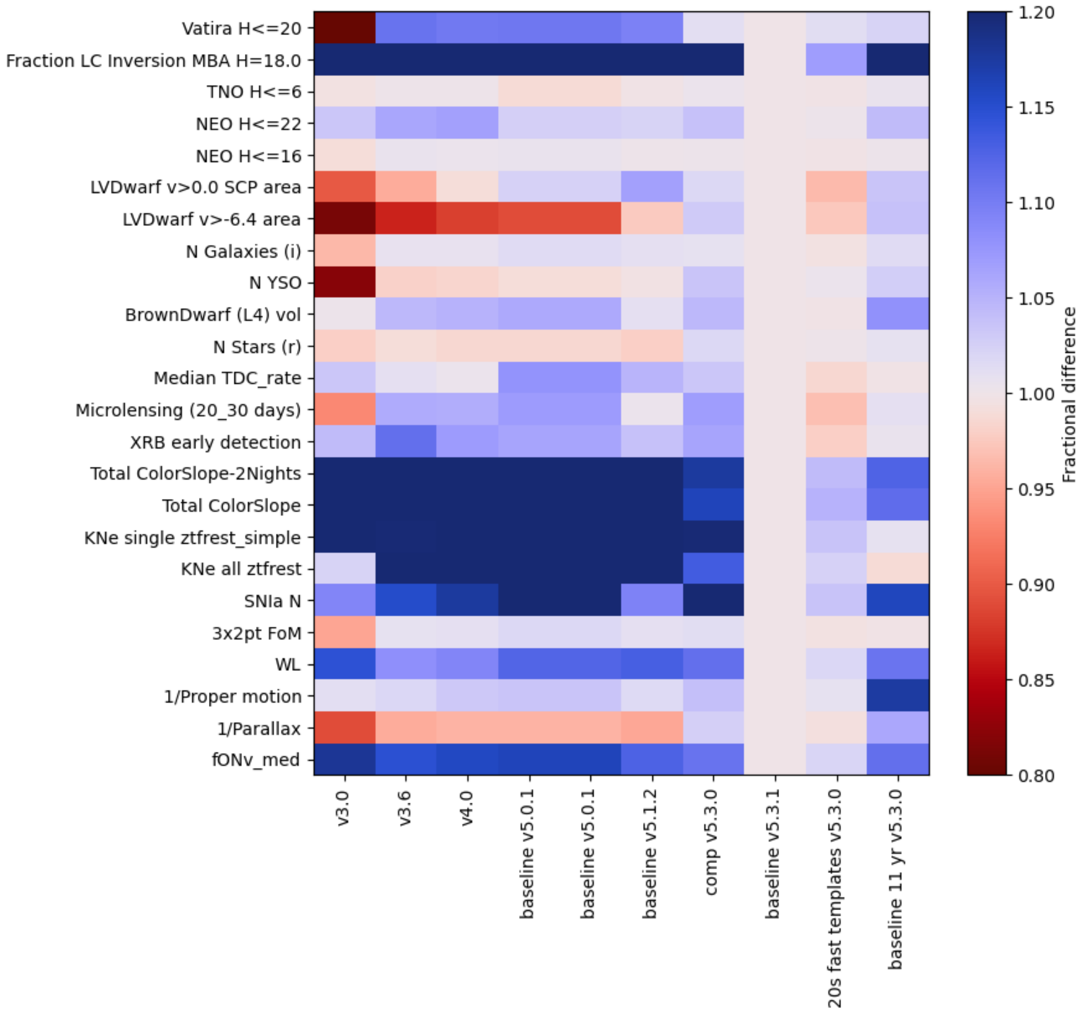

FIGURE 1: Performance of the presently recommended strategy compared to previous baselines. The plot compares the performance for selected metrics (labeled along the y axis) across baseline simulations (along the x axis) from `baseline_v3` through `baseline_v5.3` and its short-template exposure implementation (see section 1). We also include a version of 5.3.1 which extends LSST to 11 years to highlight what can be recovered with an extension of the survey while keeping the survey strategy as designed. The details of each `OpSim` are included in section 2. Using `baseline_v5.3` as the reference (value = 1 for all metrics), blue indicates improvement and red indicates degradation. The reduced sky time availability drives the performance loss in `baseline_v5.3`. Note that the darkest blue (red) indicates a ≥20% improvement (drop) and several metrics are impacted by 20% or more and are saturated in this plot, in particular, the ones measuring time-domain phenomena: `color-slope` that measure our ability to identify anomalies; kilonovae metrics, (`KNe`); the supernova metric (`SNIa N`); and the solar system light curves characterization metric (`Fraction LC Inversion MBA H=18.0`). An 11th year has an overall positive impact, but not all time-domain metrics recover. The introduction of shorter template exposures (`20s fast templates_v5.3`) has a modest impact on most metrics and an overall positive impact on most time-domain metrics, partially recovering performance for those that were most severely affected by sky availability. However, none of these metrics incorporates template readiness effects, so the benefits of earlier template availability and improved Y1 completeness are not captured here.

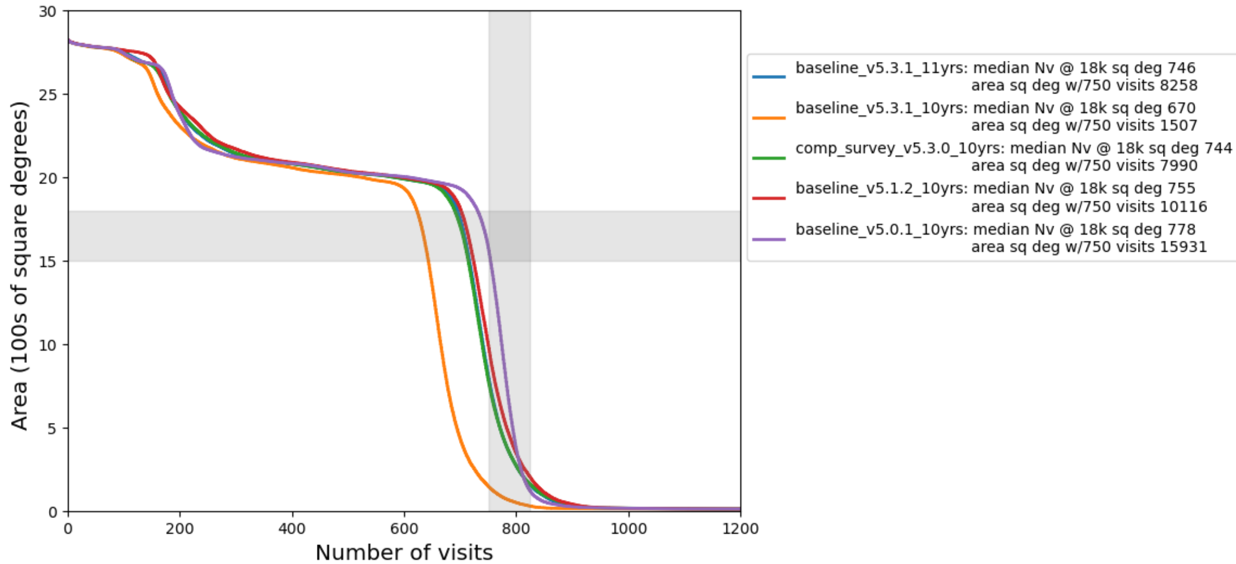

FIGURE 2: The LSST footprint area as a function of the minimum number of visits covering that area at the end of the LSST. Vertical and horizontal shaded regions represent the range between minimum and design LSST requirements (LPM-17) for the number of visits and sky area, respectively. A selected subset of `OpSims` is included. See section 2 and Figure 1 for details on each included simulation.

[PSTN-055], Rubin's Survey Cadence Optimization Committee, Bauer, F.E., Bianco, F.B., et al., 2023, *Survey Cadence Optimization Committee's Phase 2 Recommendations*, Project Science Technical Note PSTN-055, NSF-DOE Vera C. Rubin Observatory, URL `https://pstn-055.lsst.io/`, doi:10.71929/rubin/2585249

[PSTN-056], Rubin's Survey Cadence Optimization Committee, Bianco, F.B., Jones, R.L., et al., 2025, *Survey Cadence Optimization Committee's Phase 3 Recommendations*, Project Science Technical Note PSTN-056, NSF-DOE Vera C. Rubin Observatory, URL `https://pstn-056.lsst.io/`, doi:10.71929/rubin/2585402

C Acronyms

Acronym	Description
AOS	Active Optics System
AST	NSF Division of Astronomical Sciences
AURA	Association of Universities for Research in Astronomy
B	Byte (8 bit)

COSMOS	Cosmic Evolution Survey
DDF	Deep Drilling Field
DE-AC02	Department of Energy contract number prefix
DIA	Difference Image Analysis
DM	Data Management
FWHM	Full Width at Half-Maximum
LPM	LSST Project Management (Document Handle)
LSST	Legacy Survey of Space and Time
LSST-DA	LSST Discovery Alliance
MBA	main belt asteroid
OpSim	Operations Simulation
PSF	Point Spread Function
PSTN	Project Science Technical Note
RTN	Rubin Technical Note
SCOC	Survey Cadence Optimization Committee
SLAC	SLAC National Accelerator Laboratory
SRD	LSST Science Requirements; LPM-17
TMA	Telescope Mount Assembly
ToO	Target of Opportunity