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Optimization of the Observing Cadence for the Rubin Observatory Legacy Survey of Space and Time: A Pioneering Process of Community-focused Experimental Design

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Abstract

Vera C. Rubin Observatory is a ground-based astronomical facility under construction, a joint project of the National Science Foundation and the U.S. Department of Energy, designed to conduct a multipurpose 10 yr optical survey of the Southern Hemisphere sky: the Legacy Survey of Space and Time. Significant flexibility in survey strategy remains within the constraints imposed by the core science goals of probing dark energy and dark matter, cataloging the solar system, exploring the transient optical sky, and mapping the Milky Way. The survey's massive data throughput will be transformational for many other astrophysics domains and Rubin's data access policy sets the stage for a huge community of potential users. To ensure that the survey science potential is maximized while serving as broad a community as possible, Rubin Observatory has involved the scientific community at large in the process of setting and refining the details of the observing strategy. The motivation, history, and decision-making process of this strategy optimization are detailed in this paper, giving context to the science-driven proposals and recommendations for the survey strategy included in this Focus Issue.

Unified Astronomy Thesaurus concepts: Sky surveys (1464)

1. Introduction

Vera C. Rubin Observatory is designing an astronomical survey, the Legacy Survey of Space and Time (LSST), that will be revolutionary in many ways. The amount of imaging data, and the combination of flux sensitivity, area, and the temporal sampling rate, will be dramatically increased compared to precursor surveys at any wave band. Rubin Observatory will observe the Southern Hemisphere sky from the El Peñón peak of Cerro Pachón, Chile, for 10 years, using the 8.36 m aperture Simonyi Survey Telescope and the LSST Camera with its unique 9.6 deg^2 field of view to collect over 2 million sky images. It will do so with multiple filters (*ugrizy*) and with exquisite subarcsecond image quality.[53]

Rubin Observatory's enormous data set, which will reach a size of ∼300 PB when the 10 yr survey ends, will be released with a unique data policy. Every night, millions of LSST alert packets that identify astrophysical transient, variable, and moving objects will be released worldwide in real time with no restrictions. The LSST images and catalogs will be available in their entirety to all Rubin data-rights holders: any US and Chilean scientist and members of international groups that have agreements with the National Science Foundation (NSF) and/or the Department of Energy (DOE) or their managing partners: the Association of Universities for Research in Astronomy (AURA) and SLAC National Accelerator Laboratory, respectively.[54] These include catalogs available within 24 hours of observations, and annual releases of reprocessed images, deep coadded stacks, and associated catalogs.[55] These data will become available worldwide after two years from the original data release. This enormous data set, combined with an open data access policy, sets the stage for a broad and diverse user community and a commensurately huge opportunity for maximum scientific impact from the LSST.

LSST is designed to enable the pursuit of four main science themes: probing dark energy and dark matter, exploring the transient optical sky, mapping the Milky Way, and building a catalog of solar system objects over an order of magnitude larger than presently available. These science goals were chosen to drive the survey design such that a transformational survey addressing all these science themes will also be able to impact many other fields of astrophysics, including, for example, galaxy morphology and evolution, active galactic nuclei (AGN), and quasar studies, etc. LSST science drivers and technical design details are summarized in the LSST overview paper (Ivezić et al. 2019).

Rubin Observatory is constructing a flexible scheduling system that can respond to the unexpected and be reoptimized as the survey progresses. LSST observations will be scheduled automatically, with the scheduling algorithm designed to maximize scientific return under a set of observing constraints. LSST is in fact an umbrella term that refers to a set of surveys that Rubin will perform in its first 10 years: a "main survey" (hereafter referred to as Wide–Fast–Deep, WFD), a series of pointings that will be observed with an intensified cadence leading to deeper coadded image stacks (the Deep Drilling Fields, DDFs), and additional "minisurveys" (or "microsurveys" if they require less than 3% of the total survey time) that cover specific sky regions such as the ecliptic plane, Galactic plane, and the Large and Small Magellanic Clouds, or that vary survey parameters such as the depth of a single visit.

Any implementation of LSST's 10 yr observing strategy must meet the basic requirements described in the LSST Science Requirements Document (SRD[56]) to ensure that the core science goals will be achieved: a footprint for the WFD of at least 18,000 deg^2 which must be uniformly covered to a median of 825 nominal 30 s visits per 9.6 deg^2 field, summed over all six filters. Additional constraints on the temporal distribution of these visits are derived from requirements on parallax and proper-motion accuracy, as well as a requirement for two visits per night to enable the discovery of main-belt asteroids using standard algorithms. Yet, the SRD intentionally places minimal quantitative constraints on the observing strategy, recognizing that science evolves and the LSST plan can be refined until first light and even beyond. To that end, the Rubin Observatory operations team plans to continuously monitor survey progress

[53] A comprehensive set of system and survey properties is included in Appendix A.
[54] See the Rubin Data Policy, https://ls.st/rdo-013, for more information about data rights and data-rights holders.
[55] See the LSST Data Products Definitions Document, https://ls.st/lse-163, for more information about the LSST data products.

[56] The SRD, available at https://ls.st/srd, indicates three levels of requirements: the design requirements, stretch goal, and minimum requirements. Here we report the design requirements.

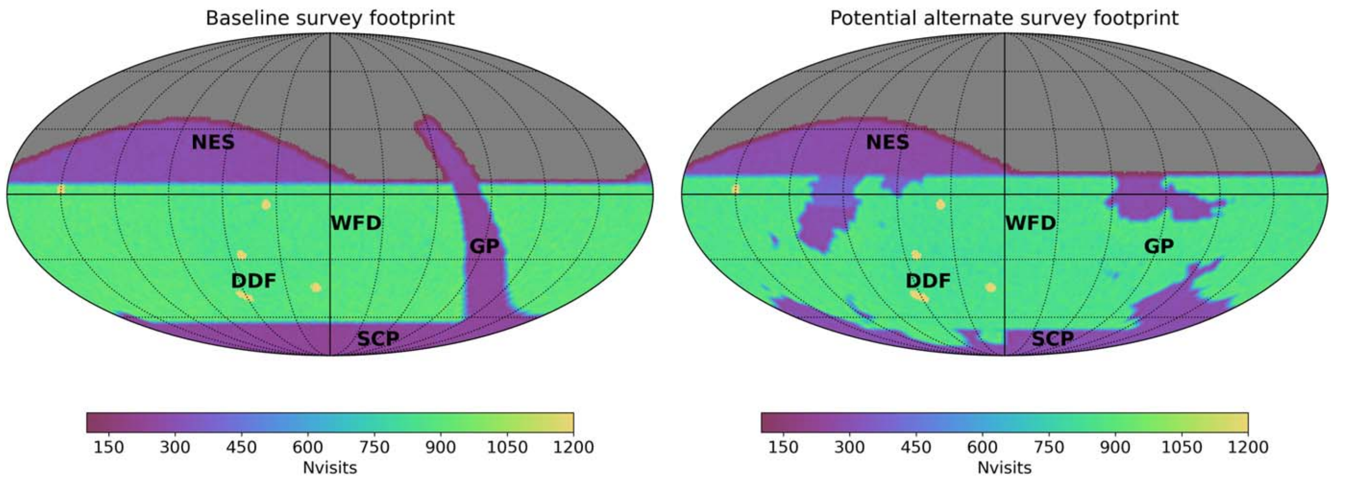

Figure 1. LSST footprint: the color encodes the number of visits across all filters for each position on the sky. The general survey footprint must meet the SRD design specifications: the WFD covers $\gtrsim 18{,}000$ deg^2 to a median of 825 visits. Other surveys, like the Deep Drilling Fields (DDFs, which appear in yellow due to the higher number of observations), North Ecliptic Spur (NES), Galactic Plane (GP, which contains a large region on the bulge side, but also a smaller footprint on the antibulge side), and South Celestial Pole (SCP) that are shown in this figure cover regions outside of the WFD footprint and have more flexibility in the observing strategy, including the number of visits and their distribution among filters. The initial survey footprint was envisioned as in the left panel (map generated from `OpSim baseline_nexp2_v1.7.1_10yrs`, see Section 2), but details of the visit distribution for optimal science return are still being determined, including if this general survey footprint should be modified. Expansion of coverage into additional low dust extinction area and higher coverage of a portion of the Galactic plane, for example, may result in a footprint conceptually similar to what is shown on the right (generated from `OpSim footprint_6_1.7.1_10yrs`). This figure is discussed in Section 1.

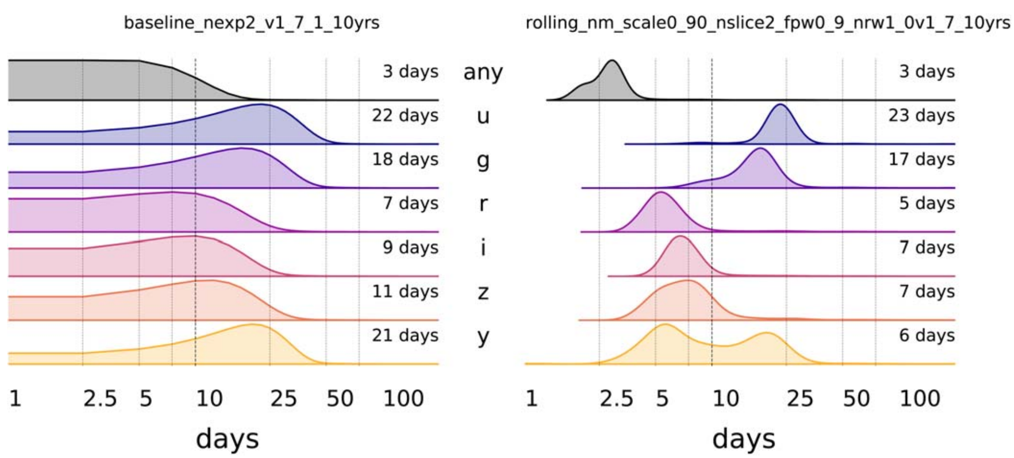

Figure 2. Distribution of median internight visit gaps (the time elapsed between visits to the same field in different nights) at a given location in the sky for two simulated LSST `OpSim` strategies: `baseline_nexp2_v1.7.1_10yrs` (left) and `rolling_nm_scale0.90_nslice2_fpw0.9_nrw1.0v1.7_10yrs` (right; for more details on the simulations see Section 2). Each curve shows the median internight gaps across pointing positions distributed on a `healpixel` grid with $N_{\rm sides} = 64$ (corresponding to $\sim$0.85 deg^2). In the top row the distribution is shown for all observations, and in the following rows it is shown for observations in each of the six Rubin LSST filters (as labeled). The distributions are smoothed via kernel density estimation (Rosenblatt 1956; Parzen 1962); the location of the peak of the underlying distribution is indicated to the right of each curve. This figure shows that different `OpSim` runs, developed in compliance with the SRD requirements, can be very different even in core features. Similarly, within a night, the short 30 s single-visit exposure time (potentially split into 2×15 s) and 2 s readout time enable the exploration of intranight timescales that are relevant for some science cases. Here too, simulations lead to a variety of possible LSST `OpSim` strategies, as explored for example in works responding to the 2018 Cadence White Papers call (Section 4.1, e.g., Bianco et al. 2019) and 2021 Cadence Notes (Section 5, e.g., Bellm et al. 2021; Li et al. 2022). Even shorter timescales have been explored for special surveys, as in Section 10.3 of COSEP, and in several Cadence White Papers (e.g., https://docushare.lsstcorp.org/docushare/dsweb/Get/Document-30579/gizis_brightstar_minisurvey.pdf, https://docushare.lsstcorp.org/docushare/dsweb/Get/Document-30645/olsen_mc_mini.pdf, https://docushare.lsstcorp.org/docushare/dsweb/Get/Document-30601/thomas_startrails_mini.pdf). The figure is discussed in more detail in Section 1.

and, if needed, to modify the strategy to achieve the desired scientific goals (see Section 5). The SRD leaves significant flexibility in the detailed cadence of observations within the main survey footprint, including the distribution of visits within a year, the distribution of images between filters, and the definition of a "visit" itself (e.g., a single exposure or multiple exposures per visit). Furthermore, these constraints apply to the WFD only. Depending on the performance efficiency of the WFD, between 10% and 20% of the sky time will remain available for DDFs and minisurveys, whose design is not strongly prescribed by the SRD.

A nominal survey footprint showing the distribution of visits across the sky, including WFD, some DDFs, and some potential minisurveys, is shown in Figure 1. Even a core parameter such as the median time elapsed between observations of the sky in different nights can be varied significantly for the WFD within the constraints of the SRD. Figure 2 shows the distribution of internight gaps, a critical parameter to enable transient science, in two WFD survey simulations: a baseline proposal, i.e., a straightforward implementation of the survey design as described above, and a rolling-cadence strategy, where the ∼825 visits for each sky pointing in the WFD are distributed unevenly over the 10 yr LSST timeline, front-loading certain areas of the sky with a higher density of observations early on, to later give way to intense observing of others. The rolling cadence is further discussed in Section 4.1 and a more detailed description of the concept of rolling cadence and discussion of its trade-offs can be found in Section 2.5 of LSST Science Collaboration et al. (2017, hereafter COSEP) and Section 4.9 of Jones et al. (2020, hereafter LSST document PSTN-051) as well as online.[57]

With LSST likely to start in 2024—a delayed rebaselined schedule due to the COVID-19 pandemic—Rubin Observatory is undertaking the final planning for the initial observing strategy. To ensure that the survey science potential is maximized and that the survey design does indeed serve the broad scientific community that will have access to the data, Rubin Observatory has, to an unprecedented degree, involved the scientific community in the survey design itself.

To place in context publications containing science-driven proposals and recommendations for the survey strategy that are included in this Focus Issue, we describe here the LSST survey cadence optimization process, a process that has been conducted openly and in close contact with the survey stakeholders and the scientific community at large.

The ongoing preoperations phase of cadence optimization has included three major contributions by the science community:

1. Early community engagement efforts, including the creation of software that enables the community to get involved in survey design. These are described in Sections 2 and 3. This phase culminated in the Community Observing Strategy Evaluation Paper (COSEP), briefly described in Section 3.2;
2. Cadence White Papers, solicited in 2018, briefly described in Section 4;
3. Cadence Notes, solicited in 2020, and discussed in Section 5.

This Focus Issue provides the community with an opportunity to present the work that underlies many of these science-driven cadence recommendations. We highlight some lessons learned so far in this community-focused process for survey design in Sections 6 and 7.

2. Open Software to Enable Community Engagement

To empower the community to make knowledgeable, science-driven recommendations, Rubin Observatory has released a series of simulated LSST pointing histories, using different survey strategies, and open-access software to generate quantitative analyses of these simulations. These software tools originated as part of the overall Rubin Observatory simulations effort (Connolly et al. 2014), and have evolved over time with considerable community input.[58]

To generate potential realizations of the LSST surveys, Rubin developed a simulator that works with the LSST

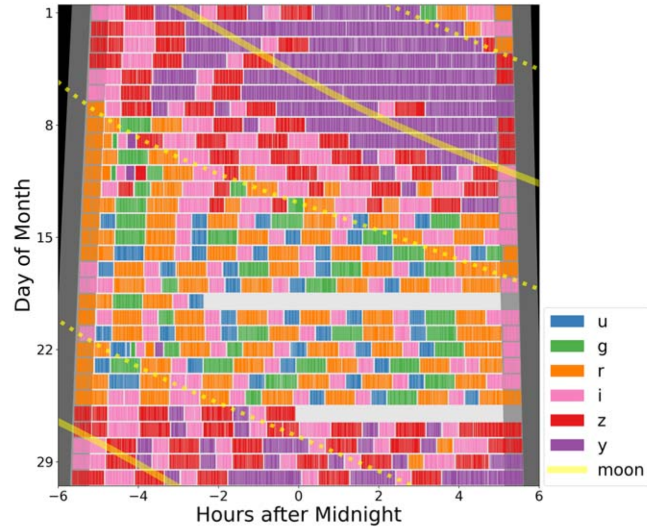

Figure 3. A segment of an "hourglass plot" showing a sequence of observations in conjunction with astronomical constraints. A simulated calendar of observations for the month of April in year 1 of LSST operations is shown, color coded by the bandpass of each visit (as indicated in the legend). The *x*-axis shows time away from midnight; the *y*-axis separates visits by the day of the month. The gray edges of the plot indicate twilight time, with observations continuing to $-12°$ twilight in redder filters. Astronomical ($-18°$) twilight is shown with light gray, $-12°$ twilight is dark gray, and periods where the Sun is above the horizon are in black. The time of lunar transit is shown as a wide yellow stripe; lunar rise and set times are shown by dotted yellow lines. Redder filters are used when the Moon is up and bluer filters when the Moon is down and the sky is dark. Each 30 s visit is separated from adjacent visits by thin white vertical lines indicating the time between exposures, which depends on the time it takes the telescope to slew to a new pointing and it is typically short (and often not visible in practice here). Thicker lines indicate longer than typical slew and setup times; for example, the time to change filters is about 2 minutes. Weather and telescope maintenance are also simulated: observing time lost to weather or telescope maintenance appears as larger white gaps on days 19 and 26. This figure is discussed in Section 2.

scheduler, collectively known colloquially as the Operations Simulator, or `OpSim` for short (Naghib et al. 2019; Delgado & Reuter 2016; Delgado et al. 2014), which can generate databases containing 10 yr pointing histories, complete with weather, seeing, and sky brightness information (Yoachim et al. 2016). A short sample of a resulting simulated observing history is shown in Figure 3. The version of the scheduler used at the time of writing, generally referred to as the "Feature Based Scheduler" or FBS, is the fifth generation of scheduler codes developed for the LSST.[59] In general, this software is used by Rubin Observatory to produce and release databases of observations following recommendations from the community.[60] Sets of `OpSim` runs are released as "families" in which survey-strategy parameters are varied along a specific simulation axis. For example, the `wfd_scale` family explores allocating different fractions of the overall survey time to the WFD, the `footprint` family of simulations modifies the survey footprint according to different recommendations, and the `filter_dist` family varies the distribution of visits in the survey between different filters.[61]

[57] https://project.lsst.org/meetings/ocw/sites/lsst.org.meetings.ocw/files/OpSim%20Rolling%20Cadence%20Stratgey-ver1.3.pdf

[58] In 2021 the entire simulation software stack for Rubin was consolidated and repackaged in https://rubin-sim.lsst.io.

[59] https://community.lsst.org/t/from-opsim-v4-to-fbs-1-2/3856

[60] https://community.lsst.org/tag/opsim

[61] The name of the `OpSim` runs are composed of a root indicating the `OpSim` family (e.g., `baseline` or `footprint`), the specific parameters of the run within the family, the `OpSim` release (e.g., v1.7.1), and the duration of the simulation (e.g., 10 yr).

The second open-access software package released by Rubin to facilitate community engagement in survey design is the Metric Analysis Framework (Jones et al. 2014, hereafter MAF), which is intended to enable the calculation of metrics pertaining to the observations in a standardized and easily extensible manner. The MAF provides a simple application programming interface (API) for calculating image properties (e.g., seeing, proper motion) over a variety of spatial scales as well as tools to predict the properties of photometric measurements for objects implanted in the survey simulations (including light curves). The MAF thus allows the user to create metrics associated with specific science goals, and to evaluate them over existing survey simulations (the OpSim runs). That is: the user can test scientific cases and identify effective (or ineffective) cadences associated with them. Along with the API, many ready-to-run metrics, generally referred to as MAF metrics (hereafter simply metrics), have been released. Furthermore, the most advanced metrics have been the result of collaborations with or direct contributions from the community[62] in the three phases of survey evaluation described below. The outputs of standard metrics on existing OpSim runs are provided to Rubin Observatory and made available online to the community to help guide survey-strategy choices.[63]

3. Community Engagement in LSST Cadence Optimization—pre-2018

Planning for LSST has been undertaken hand-in-hand with the community from the start of the project. For example, the choice of four main science themes was guided by the community-wide input assembled in Science Working Group of the LSST & Strauss (2004). Similarly, the current design of the DDFs was driven by a set of eight science white papers[64] written in 2011 by about 75 members of the LSST Deep-Drilling Interest Group. This led to the current selection of four DDF fields that maximize synergy with legacy data and ongoing surveys to enable a number of extragalactic science investigations. The Rubin Observatory Science Advisory Committee[65] (SAC) has been providing valuable advice to Rubin on cadence issues since its inception in 2014.

3.1. The LSST Scientific Community and the Science Collaborations

Rubin Observatory and its construction and operation teams include hundreds of people supported by investments of the NSF and DOE[66] to create the Observatory, and design and run the LSST, including preparing, distributing, and supporting the usage of data and data products from the survey. Rubin's plan to maximize science from the LSST includes crucial support, engagement, and coordination with the scientific community. The community, in turn, needs funding support from all possible sources, including the US agencies and philanthropic organizations, to produce "User-generated Data Products" that drive the science analyses to the fullest extent embraced by Rubin's scientific vision and mission. User-generated Data Products come from the community and take the Prompt and Data Release Products produced by Rubin to the next level to ensure the mission of Rubin Observatory is fulfilled. These data products and analyses can only happen through a high level of planning, coordination, and effort from the scientific community.

Embracing these exciting challenges and promises of the LSST, the scientific community has organized into Science Collaborations (SCs). The SCs were formed to provide a forum for the community to interact with Rubin Observatory's construction team (then the LSST Project), and to make the scientific case to be presented to the 2010 Decadal Survey (LSST Science Collaboration et al. 2009). Today, the SCs are eight independent teams, self-governed and self-managed, that include over 1000 scientists from six continents[67] (Bianco et al. 2019). They work in close contact with Rubin to prepare to turn the LSST data into science and to help the Observatory make scientifically informed choices. Thus the SCs have been optimally placed to be core contributors of cadence recommendations throughout the cadence optimization process. For example, early survey-strategy investigations using some of the initial OpSim simulations were driven by SCs, including Dark Energy Science Collaboration (DESC) analyses of potential dither patterns (Carroll et al. 2014; Awan et al. 2016) that motivated a random nightly shift of pointing centers to become the FBS default. Nonetheless, Rubin has sought input on cadence optimization from the entire scientific community, and suggestions have been welcomed from any group, both within and outside of the community of data-rights holders.

3.2. Community Observing Strategy Evaluation Paper

Members of the LSST science community gathered in 2015 to help design an observing strategy that would maximize the scientific output of the survey. This community includes scientists primarily (but not exclusively) drawn from people engaged in the LSST SCs and LSST construction Project.

The core product delivered by this group is the COSEP, a document coauthored by over 100 scientists and currently over 300 pages long, that lists a compendium of ideas and results. It is designed as a living document with the aim to bring together the group of people who are thinking about the LSST observing strategy problem, and facilitate their collective discussion.[68] It provided a first venue for evaluations produced by the community through the systematic use of the MAF and enabled the evaluation of the survey throughput based on a set of simulations representing small variations of the baseline survey for a variety of science cases. In order to standardize various constraints derived from diverse science cases and enable comparisons, each section contains the explicit answers to 10 questions (available in full in Appendix B.1) designed to examine constraints and trade-offs between, for example: sky coverage and depth; uniformity and frequency of sampling (e.g., a rolling cadence); single-visit depth and number of visits; Galactic plane coverage (spatial, temporal, or depth); DDF sampling and depth; fraction of observing time allocated to each band; pairing of filters; and any requirements placed on commissioning.

The COSEP is articulated in nine topical chapters that cover 25 specific science cases. Additional sections discuss

[62] https://github.com/LSST-nonproject/sims_maf_contrib

[63] The outputs of survey metrics are available at http://astro-lsst-01.astro.washington.edu:8081.

[64] Available from https://www.lsst.org/scientists/survey-design/ddf.

[65] https://project.lsst.org/groups/sac/welcome

[66] Financial support for Rubin Observatory comes from the National Science Foundation (NSF) through Cooperative Agreement No. 1258333, the Department of Energy (DOE) Office of Science under Contract No. DE-AC02-76SF00515, and private funding raised by the LSST Corporation.

[67] https://www.lsstcorporation.org/science-collaborations

[68] The GitHub repository containing the living source for the COSEP is https://github.com/LSSTScienceCollaborations/ObservingStrategy.

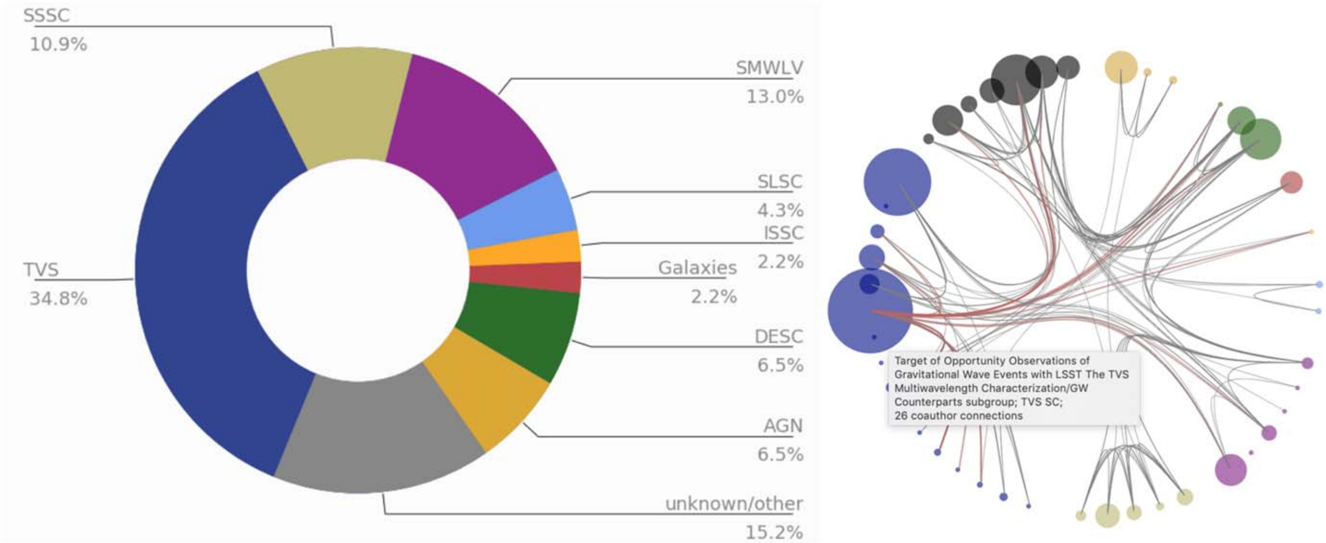

Figure 4. A synopsis of the 46 Cadence White Papers submitted in response to the call issued in 2018: on the left the papers are grouped by the Rubin LSST Science Collaboration (SC) of the lead author with fractions from each SC indicated in the figure. 15% of the papers were submitted by lead authors unaffiliated with a SC. The right panel shows a screenshot of an interactive plot (available at https://observablehq.com/embed/@f7f7156e50925896/rubin-lsst-science-collaborations-cadence-white-paper-by-s?cells=chart) describing the co-authors network through a chord diagram. Each circle represents a paper, the size of the circle reflecting the size of the authoring team (the largest is 72 co-authors for Target of Opportunity Observations of Gravitational Wave Events with LSST), color coded, as in the left panel, by the SC of the lead author. Papers are linked by their co-authors. This figure is discussed in Sections 4 and 6.

minisurveys (e.g., covering specific sky locations and proposing modified exposure parameters), and plans for coordinating LSST observations with other missions (e.g., the Nancy Grace Roman Observatory; Spergel et al. 2015, then WFIRST).

The SAC reviewed this work and made recommendations to Rubin that shaped the next phase of the survey-strategy optimization, including:

1. The Rubin construction Project should implement, analyze, and optimize the rolling-cadence idea (driven by supernovae, asteroids, short timescale variability).
2. The Rubin construction Project should execute a systematic effort to further improve the ultimate LSST cadence strategy, including optimization of the sky coverage, *u*-band depth, filter pairing, minisurveys, DDFs, etc.

4. The 2018 Cadence White Papers Solicitation

In part as a result of the SAC recommendations, and with an overarching goal of maximizing the science impact of the LSST, in 2018 Rubin Observatory issued a call to the entire scientific community for white papers on survey-strategy ideas. Although the COSEP is a living document that can continue to be updated, this call expanded the reach of the community engagement in the survey optimization process. The call[69] solicited discussions of science cases in which Rubin could have an impact and associated science-driven cadence suggestions for the main survey, the minisurveys, the DDFs, as well as the first Target of Opportunity strategy suggestions for gravitational-wave counterpart detection with Rubin (Margutti et al. 2018). It was supported by a new and more extended set of `OpSim` runs, itself enabled by progress in the simulator development[70] (Section 2).

The aim of the Cadence White Papers call was to create a portfolio of survey ideas, to be vetted and prioritized by the SAC, that would become the basis for a larger and more comprehensive set of `OpSim` runs. The 46 submitted white papers[71] represent a wide swath of the astronomical community, and, together with the COSEP, shaped the next stage of the survey-strategy evaluation. Most submissions arose within SCs (Figure 4, left) and many are the result of collaborative work across SCs, as demonstrated by the interconnectivity of the authors' network (Figure 4, right), but contributions were submitted as well by authors outside the SCs and interest groups related to other surveys (e.g., the Nancy Grace Roman Observatory, then WFIRST; Spergel et al. 2015 and Euclid; Capak et al. 2019). The contents of these white papers were distilled into several areas for investigation by the SAC in their 2019 report.[72] The ongoing cadence optimization process discussed in detail below is a direct result of those recommendations. The SAC also identified some vulnerabilities in the process: "many of the white papers only outline what an appropriate metric would be, and coding these up will require substantial effort. The SAC is concerned about how this work will be done; [...] we recommend that the `OpSim` team be given the resources to code the metrics suggested in the white papers [...]."

4.1. Survey Simulations and Cadence Optimization following the Cadence White Papers

Following the SAC response to the 2018 Cadence White Papers, the Rubin survey-strategy team produced a series of simulations exploring the particular survey-strategy options recommended for further investigation. These include investigations into the survey footprint, the amount of survey time devoted to WFD observations, various options for pairing visits

[69] The call for white papers is available at http://ls.st/doc-28382.

[70] Changes to `OpSim` leading to the Cadence White Papers call are described in http://ls.st/Document-28453.

[71] https://www.lsst.org/submitted-whitepaper-2018

[72] The SAC report on the Cadence White Papers is available at http://ls.st/doc-32816.

within a night or adding more nightly visits, the exposure time per visit, enforcing seeing requirements at each point in the sky in certain filters, dithering options for the DDFs, and exploring the effect of adding specific minisurveys, such as short exposures, twilight near-Earth object discovery visits, or additional visits at high airmass for better differential chromatic refraction measurements, and more.

Sets of these new simulations were released in groups. For this call, a total of 173 OpSim runs were made available under OpSim releases 1.5–1.7.1. These simulations and their analysis with sets of standard metrics are described in detail in PSTN–051.

The metrics written to analyze the science return of these simulations through the MAF API, both those created by the Rubin survey-strategy team and those created by the community, need to be ultimately combined into a comprehensive view of an OpSim run that can enable comparative studies and, in the end, the definition of the survey design. This is a complex exercise in and of itself, which is at the heart of the last phase of the survey cadence optimization process described in Section 5. An example of a visualization of a subset of metrics indicating the effect of rolling cadence on a variety of science areas is shown in Figure 5.

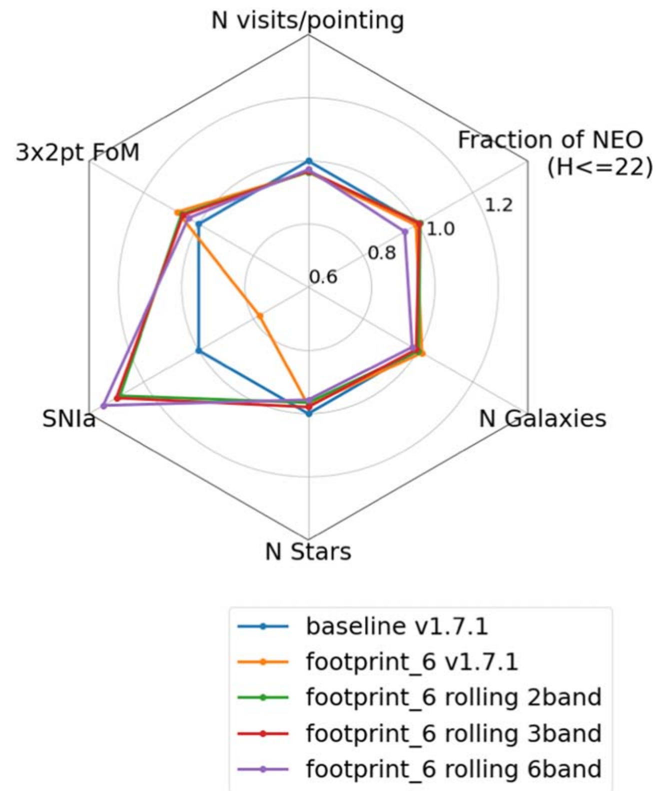

Figure 5. Illustration of a "radar plot" comparing science metrics from a variety of core science areas for five OpSim realizations (as indicated in the legend). Each corner of the hexagon represents a different metric, whose value is mapped to the distance from the center of the hexagon. Clockwise from the top, the metrics measure: the median number of visits per pointing in the WFD (N visits/pointing), the fraction of near-Earth objects of magnitude $H \leqslant 22$ detected (Fraction of NEO), the numbers of galaxies (N Galaxies) and stars (N stars) expected to be recovered, the expected number of supernovae type Ia (SNIa) observed sufficiently well to contribute to cosmological measurements (Lochner et al. 2018), and a collective metric for static probes of the extragalactic sky (3x2pt FoM, combining weak lensing and galaxy clustering, Lochner et al. 2018). This set of OpSim runs varies the footprint (which impacts the science throughput for cosmological supernovae as measured by SNIa) and introduces a rolling cadence (which improves SNIa performance as a denser cadence enables better characterizations at relevant, short timescales and the distribution of visits in a more concentrated sky area leads to small efficiency improvements). This figure is discussed in Section 4.1.

5. The 2020–2022 Optimization Phase

With the publication of PSTN–051, Rubin (including now both the construction and the early operations teams) has started the final phase of the LSST cadence optimization before the start of the 10 yr survey with the creation of the Survey Cadence Optimization Committee (SCOC).

5.1. The Survey Cadence Optimization Committee

The SCOC is an advisory body to the Rubin Observatory Operations Director. The committee was formed in 2020, and it will be a standing committee throughout the life of Rubin Observatory operations. The SCOC is responsible for optimizing the LSST cadence within the constraints imposed by the observing system, observing conditions, science drivers, and scientists invested in its mission and legacy. Its tasks are as follows:

1. Make specific recommendations for the initial survey strategy for the full 10 yr survey and disseminate these recommendations via public reports and ongoing engagement with the community.
2. Make specific recommendations for "Early Science" observations, which might be carried out after the end of commissioning during the first months of operation of Rubin Observatory.
3. Continue its activities throughout operations by evaluating reports prepared by the Survey Evaluation Working Group, a project-internal group set up to measure the performance of the survey and scheduler, and make necessary recommendations for adjustments of the survey strategy.

The SCOC consists of 10 voting members (12 total)[73], named by the SAC. Most members are drawn from the science community and are not Rubin Observatory employees. The SCOC membership is expert and diverse, and its deliberations are transparent and inclusive.[74] To ensure continuous communication with the scientific community, the SCOC members also serve as designated liaisons with each SC. This direct line of communication between the SCs and SCOC allows the SCs to be kept informed about the ongoing simulation generation process, and promptly identify gaps in the landscape of simulations or issues with the implementation of metrics that measure their efficiency (see also Section 6).

The SCOC cadence recommendation process is itself split into two phases. The first phase, to be concluded by the end of calendar year 2021, aims to select a cadence family that will capture an overall strategy. By the end of calendar year 2022, the SCOC will fine-tune the selected cadences to come to a final recommendation for the initial cadence to begin execution when operations starts, though this recommendation will be continuously re-evaluated and revised if necessary after the start of operations, as discussed in Section 1. A detailed schedule of the SCOC activities and decision process, including workshops that put the SCOC in direct contact with

[73] See https://www.lsst.org/content/charge-survey-cadence-optimization-committee-scoc.
[74] For the SCOC charge, membership, meeting minutes, recommendations and other documents, please see https://ls.st/scoc.

the scientific community at large, can be found on the SCOC web pages.[75]

5.2. Cadence Notes

The COSEP and the Cadence White Papers provided the necessary framework to identify needed simulations, as well as defining how further cadence recommendations should be structured to be maximally useful in the optimization process. To receive formal feedback from the SCs and other stakeholders about this new generation of simulated surveys, and with a more significant adoption of the MAF software by the community, the SCOC issued one further call[76] requesting community input, in the form of Cadence Notes, to explore and evaluate survey-strategy options presented in the PSTN–051. Seven specific questions (listed in full in Appendix B.3) were posed in the Cadence Notes.

Following the SAC recommendations, in this stage of the process the Rubin LSST survey-strategy team was in close communication with the SCs and the scientists working on Cadence Notes, offering, for example, regular office hours. The SCs self-organized to collaboratively work on notes and share expertise on the use of the MAF software.[77]

The community submitted 39 Cadence Notes.[78] These notes are under review by the SCOC and they represent a significant additional source of information for the SCOC in its deliberations toward the "phase 1" recommendation. The definition of the initial Rubin LSST observing strategy is yet to be finalized at the time of this writing. The remaining phases of the survey optimization process will be described in detail in the closing paper of this Focus Issue.

6. Lessons Learned So Far

Over the last six years of intensive community involvement in optimizing LSST's observing strategy, many initial lessons have been learned. One key lesson has been that effective involvement of the broad community in LSST's survey strategy requires significant coordination across all elements of the Rubin ecosystem, including the construction Project, SAC, and SCs.

A multistep process was required to (i) engage the most diverse possible user community, (ii) to iterate on initial community analysis and construction Project progress, and (iii) to be agile in response to evolving scientific opportunities. This process began with preconstruction community engagement on the choice of LSST DDFs. Since then, survey input from the community has been solicited in three phases:

- through the creation of a single collaborative document, the COSEP, employing, for the first time, community analysis through the MAF and OpSim;
- through the submission of Cadence White Papers broadly including new cadence ideas and considerations;
- and finally through the submission of Cadence Notes to specifically review a comprehensive set of OpSim runs, and fine-tune survey parameters that remain open to optimization.

Table 1 summarizes the key differences between these three phases. We now highlight five aspects of our community engagement process that have been important to its success to date.

1. Simulated surveys and open analysis software—The release of open software that supports direct interaction with the LSST simulations (OpSim and MAF, see Section 2) was critical to enable contributions from the community. Rather than simply soliciting suggestions on preferred strategies, which would lead to a large set of options without a clear path to optimization, this software framework allowed the users to interact with the simulated survey and see the impact of cadence changes on a science case in conjunction with astronomical and technical constraints, as well as the impact that the same changes have on other science cases. The preparation and release of these software packages were key steps in the process of involving the community in survey-strategy decisions.

The provision of software environments and support for using them was essential for including a wide range of astronomers in OpSim analysis and MAF metrics development. In the Cadence White Paper phase, Docker images (Merkel 2014) were provided so that astronomers did not need to install and maintain the full set of interdependent software packages required to use MAF. In later phases, virtual analysis platforms such as the SciServer[79] and NOIRLab's Astro Data Lab[80] provided accounts to scientists working on Rubin optimization. The OpSim databases, which are ∼1 GB each, were made available on these platforms alongside software environments, example codes, and computer resources for processing. Use of these platforms lowered the barrier to participation and enabled collaboration among scientists.

2. Leverage SC expertise—Developing, maintaining, releasing and supporting software and training the community in its usage are expensive, time-consuming activities. Future surveys that wish to engage the community in the survey design process as Rubin did should scope resources specifically for these dissemination and support activities. With limited resources available to the Rubin LSST survey-strategy team, the SC environment became critical for sharing knowledge and know-how and bringing this software to a large community of users by employing a sort of self-arranged "train-the-trainer" model (Pearce et al. 2012).

In order to respond to the opportunity to contribute to the survey design, Rubin Observatory, the SCs, and the LSST Corporation[81] (a nonprofit engaging in fundraising to support the scientific community in preparation for LSST) have organized a number of workshops, hackathons, and meetings to enable knowledge transfer, exchange of expert opinions, and communication with the Observatory. The Rubin survey-strategy team has participated in many of these gatherings making suggestions on metrics and metric implementation. Some of these activities were hosted within Rubin meetings (e.g., at the annual Project Community Workshop, the all-hands Rubin meeting), others within SC meetings, and others in purposely organized events (e.g., the Heising–Simons Foundation sponsored a cadence hackathon supporting the participation of members of all SCs with travel grants

[75] https://www.lsst.org/sites/default/files/SCOC%20Handout.pdf
[76] https://ls.st/cadencenotes
[77] E.g., https://lsst-tvssc.github.io/metricshackathon2020.
[78] Available from https://www.lsst.org/content/survey-cadence-notes-2021.
[79] https://www.sciserver.org/about
[80] https://datalab.noirlab.edu
[81] https://www.lsstcorporation.org

Table 1
Community Contributions to Rubin LSST Cadence Design

	COSEP	Cadence White Papers	Cadence Notes
Date	2015–2017	2018 June (call)–2018 November (submission deadline)	2020 December (call)–2021 April (submission deadline)
Goal	To explore the effects of changes to the baseline survey strategy as specified by the SRD on the detailed performance of the anticipated science investigations	To propose significant modifications of the survey strategy, including minisurveys	To evaluate a broad collection of `OpSim` runs that implement suggestions from the white papers with refined metrics
Target community	The LSST Science Collaborations	Open submission	Open submission
Response	Single document articulated in 9 topical chapters, 25 science cases, 3 suggestions for minisurveys, and a discussion of synergy with space-based surveys (Roman Observatory, then WFIRST), 104 unique authors	46 papers, 467 unique authors	39 notes, 218 unique authors
Format	Open discussion and 10 questions (Appendix B.1)	Open discussion, ranked-priority table, and five questions (Appendix B.2)	Seven questions (Appendix B.3)
`OpSim` version	v3.3.5	v4	FBS
Number of available `OpSim` runs	14	16	173
`OpSim` software changes		Optimizations in the rate of observing over time to better balance the time coverage of the minisurveys over the survey lifetime, ability to strongly prioritize observing closer to the meridian.	Modularized survey algorithms to allow for more flexible reward calculations (beyond just slew time and target maps), leading to more flexible observing strategies. Evolutions of the scheduler algorithm between simulation releases 1.5 and 1.7.1 allowed improved rolling-cadence simulations, where visits are distributed on variable timescales in regions of sky over the 10 yr survey.

and the development of Cadence White Papers with seed grants[82]). The SCs particularly acknowledge the support of the LSST Corporation in securing and directing private funds toward activities that supported the recommendations presented to Rubin.

The SCs have been leveraging their internal network structure to coordinate the presentation of different scientific cases within and across SCs. Being in close communication with Rubin allowed the SCs to be central in this process and contribute scientific expertise and insight (see also Sections 3 and 5). The majority of the 2018 white papers and 2021 Cadence Notes were created within or in connection with one or more SCs (Figure 4). However, this exercise stretched the organizational capabilities of an unfunded organization that operates largely on a volunteer basis (Bianco et al. 2019).

Some SCs converged on a single document to present their recommendations with one voice (e.g., DESC, Solar System SC; SSSC, Strong Lensing SC; SLSC). Other SCs (e.g., the Transient and Variable Stars SC; TVS SC, that covers topics related to time-domain astronomy in both the Galactic and extragalactic environments, the Stars, Milky Way, and Local Volume SC; SMWLV SC, and the AGN SC) have responded to the calls for contributions with multiple papers and notes. In practice, the ability to present a single response, which requires internal reconciliation of competing science cases, has depended on the breadth of the science encapsulated within a single SC, as those with a greater diversity of science cases require more substantial management effort to enable that reconciliation. Coordination between SCs with overlapping interests also required additional work: for example, SMWLV and TVS SCs collaborated closely on Galactic science topics and produced additional documents to the SCOC to summarize the SC contributions that were split among multiple notes. The SCs, except for DESC,[83] have no operational budget to support these efforts (see also Section 7 and Bianco et al. 2019).

3. Providing templates—Expecting a large response, Rubin provided templates for the Cadence White Papers and Cadence Notes that ensured the responses would be concise, and limits to the number of pages were provided. This framework was helpful to limit the amount of work required from the committees reviewing the papers, and from the community itself. This Focus Issue, then, provides the opportunity to share the detailed work that underlies these papers and notes.

4. Reliable and continuous communication—Ensuring continuous communication with the entire scientific community was also crucial in this process: for example, new `OpSim` runs need to be distributed broadly and promptly for the community to be able to answer the most relevant questions regarding survey-strategy contributions. In addition to providing direct lines of communication with the SCs (Section 5.1), Rubin kept the community at large updated on discussion about new simulations and metrics or cadence-related events via the Rubin Community public forum[84], while metrics contributed by the community and vetted by the Rubin survey-strategy team are collected on a dedicated `GitHub` repository.[85] As the process

[82] ls.st/hcca

[83] DESC efforts on observing strategy are partially supported under DOE Contract DE-AC02-76SF00515.

[84] See, for example, https://community.lsst.org/t/july-2019-update/3760.

[85] https://github.com/LSST-nonproject/sims_maf_contrib

of cadence optimization moves through its final stages, more simulations will be produced and shared to respond to particular questions and aid in tuning the chosen survey strategy. Even during Rubin operations, additional simulations will be prepared for yearly evaluations of the ongoing survey and to determine the best choices of survey strategy for the remainder of the LSST.

5. Aiming for broad community input—Rubin's community approach to survey optimization was designed with the goal to enable all potential users to have a voice in LSST survey-strategy planning. Scientists from a wide range of institutions participated in the process. The SCs, for example, include members affiliated with research-focused institutions (Research 1; R1),[86] teaching-focused institutions, community colleges, labs, and virtual institutes. The geographic span of the SCs reaches five continents.

Enabling the publication of the work underlying the cadence recommendations in peer-reviewed journals is an important step to ensure that individuals outside of the Rubin Observatories employees group can get academic recognition for the time they invest in the process. This Focus Issue collects work related to the optimization of the Rubin LSST observing strategy, as produced by the scientific community throughout the multiple phases of the cadence optimization, providing an opportunity to present the work that underlies 2021 Cadence Notes presented to Rubin Observatory, but also including earlier work, such as the 2018 Cadence White Papers.

7. A Look Ahead

Although our community-driven optimization of Rubin's LSST cadence has delivered initial lessons and the science analyses described in this Focus Issue, challenges remain. Community engagement in optimizing Rubin's WFD survey has increased Rubin LSST science potential and supported community preparation to conduct science, but it has also been a time- and labor-intensive endeavor. It has taken six years of active community engagement in survey optimization to reach this point of our work. We aim for this Focus Issue to support future survey-driven missions in their aim to maximize survey science through community engagement in survey optimization.

A significant challenge is that any community involvement plan such as this one remains selective unless participation support is provided. The learning curve to master the cadence analysis remained significant through all three engagement phases. In many cases, this work did not fall under the specification of research grants and was done as service, supported by funds with unusual flexibility (e.g., start-ups and sabbaticals), or even performed outside of working hours. It was difficult for most members of the community to dedicate the time required to conduct these activities at a meaningful level, because not everyone is in a position to dedicate substantial unfunded time and effort to this work owing to workload and funding constraints. Very few are able to do so for extended periods of time. Likewise, the work of the committees in the evaluation of survey-strategy input from the community is a time-consuming activity. This effort was also uncompensated and performed as service to the scientific community. This framework biases the contributions to the cadence and the evaluation committee membership toward certain job profiles and seniority levels, particularly toward well-funded scientists with significant job flexibility, potentially also biasing the domain expertise to well-funded areas of astrophysics.

The closing paper of this Focus Issue will detail the cadence choice planned for the start of Rubin LSST and the process and considerations that led to its finalization. This opening paper has outlined the initial lessons learned from our community engagement to date. This is not the end of the story. The optimization of the observing strategy is an ongoing process with the goal of maximizing science through fine-tuning the LSST survey strategy. In the months and years to come, we expect to learn new things about the most effective way to incorporate community input into this survey optimization.

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[86] https://carnegieclassifications.iu.edu/classification_descriptions/basic.php

Table 2
Expected Properties of the Rubin System and LSST Survey

System Constraints	
Readout time	2 s
Time needed for filter exchange	2 minutes[a]
Minimum slew+settle time between fields	3 s[b]
Expected fraction of time lost to weather	∼30%[c]
Expected fraction of time lost to maintenance	∼10%
Maximum number of filter loads on filter carousel	3,000
Maximum number of filter changes over the lifetime of the carousel	100,000
Maximum number of filter changes per filter	30,000
Filter effective wavelength for *u*, *g*, *r*, *i*, *z*, *y* filters in angstroms	3887.9, 4746.4, 6201.5, 7535.7, 8701.8, 10103.6[d]
Survey characteristics from the Science Requirements Document[e]	
Standard visit exposures (expected)	2 × 15 s[f]
Expected number of visits in *u*, *g*, *r*, *i*, *z*, *y*	56, 80, 184, 184, 160, 160
Single image 5σ depths in *u*, *g*, *r*, *i*, *z*, *y*	23.9, 25.0, 24.7, 24.0, 23.3, 22.1[g]
10 yr coadded image stack 5σ depths in *u*, *g*, *r*, *i*, *z*, *y*	26.1, 27.4, 27.5, 26.8, 26.1, 24.9[h]
Photometric precision (at the bright end)	5 mmag
Photometric accuracy	10 mmag
Astrometric precision (at the bright end)	10 mas
Astrometric accuracy	50 mas
Survey characteristics from the baseline simulated survey[i]	
Median slew time between visits	4.94 s
Median (mean) visit time (including shutter, readout and slew time)	39 s (42.2 s)[j]
Median seeing in *u*, *g*, *r*, *i*, *z*, *y* in arcseconds	1.10, 1.03, 0.99, 0.95, 0.93, 0.92
Single image median 5σ depths in *u*, *g*, *r*, *i*, *z*, *y*	23.50, 24.44, 23.98, 23.41, 22.77, 22.01
10 yr coadded image stack 5σ depths in *u*, *g*, *r*, *i*, *z*, *y*	25.73, 26.86, 26.88, 26.34, 25.63, 24.87

Notes.
[a] This is the time required if the filter is already mounted on the filter wheel. The filter wheel houses five of the six filters at once.
[b] See https://github.com/lsst-pst/survey_strategy/blob/main/wp-call/WPcall2018.pdf page 22.
[c] A conservative estimate based on weather statistics for the Gemini Observatory South telescope; https://www.gemini.edu/.
[d] Filter throughputs available at https://github.com/lsst/throughputs.
[e] More detailed information, including minimum requirements and stretch goals for the WFD are included in the SRD (https://ls.st/srd).
[f] 30 s single exposures are explored in several `OpSim` simulations, especially in `OpSim` release 1.5.
[g] Single-visit depths are referenced to zenith and dark sky.
[h] Based on expected single-visit depths, expected number of visits, and expected 0.2 mag loss due to various observational effects.
[i] More details and additional metrics based on this baseline simulation are available at http://astro-lsst-01.astro.washington.edu:8082/allMetricResults?runId=5.
[j] This time includes exposure, readout, and slew—no filter change.

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We used the following `Python` packages: `numpy` (Harris et al. 2020), `maplotlib` (Hunter 2007), `seaborn` (Waskom et al. 2017).

Facility: Rubin.

Appendix A
Rubin LSST Expected System Properties

Table 2 summarizes some design characteristics of the Rubin system and the expected characteristics of the LSST resulting from the interplay of system and observational constraints with the science requirements, as described in the SRD and measured from survey simulations. More detailed information, including minimum requirements and stretch goals for the surveys characteristics and more information about the mechanical system, are included in the SRD.[87] Note that the SRD reported requirements refer to design goals set in place to constrain the basic throughput of the system, while the survey characteristics from simulations include additional observational constraints and effects. Further information about the system can also be found in Gressler et al. (2014). The characteristics described in Table 2 are exclusively set for the WFD, while similar specifications for mini- and microsurveys are deliberately not set (see Section 1). The 10 yr image stacks for the DDFs are expected to be at least one magnitude deeper than those for the WFD fields. The approximate coordinates of the four DDFs that have already been selected can be found on the Rubin website[88] (see also Brandt et al. 2018 and the associated Cadence Note.)[89]

Appendix B
Guiding Cadence Contribution with Targeted Questions

To standardize the community cadence contributions, the COSEP (Section 3), Cadence White Papers (Section 4), and Cadence Notes (Section 5) templates included targeted

[87] https://ls.st/srd

[88] https://www.lsst.org/scientists/survey-design/ddf
[89] https://docushare.lsst.org/docushare/dsweb/Get/Document-37655/agnddf-cadence-note01.pdf

questions aimed at identifying trade-offs and constraints for every science case and strategy suggestion offered by the community. A complete list of these questions follows here.

B.1. Full List of Questions Included in the COSEP

1. Does the science case place any constraints on the trade-off between the sky coverage and coadded depth? For example, should the sky coverage be maximized (to ∼30,000 deg^2 , as e.g., in Pan-STARRS) or the number of detected galaxies (the current baseline of 18,000 deg^2)?
2. Does the science case place any constraints on the trade-off between uniformity of sampling and frequency of sampling? For example, a "rolling cadence" can provide enhanced sample rates over a part of the survey or the entire survey for a designated time at the cost of reduced sample rate the rest of the time (while maintaining the nominal total visit counts).
3. Does the science case place any constraints on the trade-off between the single-visit depth and the number of visits (especially in the *u* band where longer exposures would minimize the impact of the readout noise)?
4. Does the science case place any constraints on the Galactic plane coverage (spatial coverage, temporal sampling, visits per band)?
5. Does the science case place any constraints on the fraction of observing time allocated to each band?
6. Does the science case place any constraints on the cadence for deep drilling fields?
7. Assuming two visits per night, would the science case benefit if they are obtained in the same band or not?
8. Will the case science benefit from a special cadence prescription during commissioning or early in the survey, such as: acquiring a full 10 yr count of visits for a small area (either in all the bands or in a selected set); a greatly enhanced cadence for a small area?
9. Does the science case place any constraints on the sampling of observing conditions (e.g., seeing, dark sky, airmass), possibly as a function of band, etc.?
10. Does the case have science drivers that would require real-time exposure time optimization to obtain nearly constant single-visit limiting depth?

B.2. Full List of Questions Included in the Cadence White Paper Templates

1. What is the effect of a trade-off between your requested survey footprint (area) and requested coadded depth or number of visits?
2. If not requesting a specific timing of visits, what is the effect of a trade-off between the uniformity of observations and the frequency of observations in time? E.g., a "rolling cadence" increases the frequency of visits during a short time period at the cost of fewer visits the rest of the time, making the overall sampling less uniform.
3. What is the effect of a trade-off on the exposure time and number of visits (e.g., increasing the individual image depth but decreasing the overall number of visits)?
4. What is the effect of a trade-off between uniformity in number of visits and coadded depth? Is there any benefit to real-time exposure time optimization to obtain nearly constant single-visit limiting depth?

Table 3
Constraint Rankings from the Cadence White Paper Template

Properties	Importance
Image quality	
Sky brightness	
Individual image depth	
Coadded image depth	
Number of exposures in a visit	
Number of visits (in a night)	
Total number of visits	
Time between visits (in a night)	
Time between visits (between nights)	
Long-term gaps between visits	
Other (please add other constraints as needed)	

Note. Summary of the relative importance of various survey-strategy constraints. Please rank the importance of each of these considerations, from 1 = very important, 2 = somewhat important, 3 = not important. If a given constraint depends on other parameters in the table, but these other parameters are not important in themselves, the authors were directed to only indicate the final constraint as important. For example, individual image depth depends on image quality, sky brightness, and number of exposures in a visit; if a science case depends on the individual image depth but not directly on the other parameters, individual image depth would be "1" and the other parameters could be marked as "3", giving maximum flexibility when determining the composition of a visit.

5. Are there any other potential trade-offs to consider when attempting to balance this proposal with others which may have similar but slightly different requests?

In addition, the paper template contained a table for ranking constraints on the survey strategy, which we reproduce in Table 3.

B.3. Full List of Questions to be Answered in the Cadence Notes

1. Are there any science drivers that would strongly argue for, or against, increasing the WFD footprint from 18,000 square degrees to 20,000 square degrees? Note that the resulting number of visits per pointing would drop by about 10%. If available, please mention specific simulated cadences, and specific metrics, that support your answer.
2. Assuming that current system performance estimates will hold up, we plan to utilize the additional observing time (which may be as much as 10% of the survey observing time) for visits for the minisurveys and the DDFs (with an implicit assumption that the main WFD survey meeting SRD requirements will always be the first priority). What is the best scientific use of this time? If available, please mention specific simulated cadences, and specific metrics, that support your answer.
3. Are there any science drivers that would strongly argue for, or against, the proposal to change the *u*-band exposure from 2 × 15 s to 1 × 50 s? If available, please mention specific simulated cadences, and specific metrics, that support your answer.
4. Are there any science drivers that would strongly argue for, or against, further changes in observing time allocation per band (e.g., skewed much more toward the blue or the red side of the spectrum)? If available, please mention specific simulated cadences, and specific metrics, that support your answer.

5. Are there any science drivers that would strongly argue for, or against, obtaining two visits in a pair in the same (or different) filter? Or the benefits or drawbacks of dedicating a portion of each night to obtaining a third (triplet) visit? If available, please mention specific simulated cadences, and specific metrics, that support your answer.
6. Are there any science drivers that would strongly argue for, or against, the rolling-cadence scenario? Or for or against varying the season length? Or for or against the AltSched N/S nightly pattern of visits? If available, please mention specific simulated cadences, and specific metrics, that support your answer.
7. Are there any science drivers pushing for or against particular dithering patterns (either rotational dithers or translational dithers?) If available, please mention specific simulated cadences, and specific metrics, that support your answer.

Appendix C
Glossary of Acronyms and Abbreviations

Table 4 details acronyms and shorthands used in this paper and in general in LSST cadence-related work, so as to enhance the readability of this work and works within this Focus Issue. More definitions are available on the Rubin website.[90]

Table 4
Table of Acronyms and Shorthands

	Extended Name	Description	URL and References
Rubin	Vera C. Rubin Observatory	Rubin is used as a shorthand to refer to the physical observatory, collection of software infrastructure including data reduction pipelines and software that enables cadence considerations, and the observatory employees	https://www.lsst.org
LSST	Legacy Survey of Space and Time	The 10 yr survey, or, more explicitly, collection of surveys including the WFD, DDF, and minisurveys, that will be performed over the first 10 yr of life of Rubin Observatory. LSST was formerly the acronyms to refer to the Rubin Observatory Project by its earlier name of Large Synoptic Survey Telescope	https://www.lsst.org
SRD	System Science Requirements Document	Core Rubin document defining the system requirements that will enable the pursuit of the four core science goals of LSST (see Section 1)	https://ls.st/srd
WFD	Wide–Fast–Deep	The main survey performed within LSST which is designed to enable, in conjunction with DDFs, the pursuit of the four core science goals of LSST (see Section 1)	(Ivezić et al. 2019, Section 3.1)
DDF	Deep Drilling Fields	Selected single pointings in the Southern Hemisphere that will be observed at a denser observing cadence reaching a higher magnitude limit in stacked images	https://www.lsst.org/scientists/survey-design/ddf
OpSim	Operation Simulator	Rubin software that enables the simulation of 10 yr survey pointing databases, including observing strategy, weather, and telescope maintenance and operation constrains	https://community.lsst.org/t/from-opsim-v4-to-fbs-1-2/3856; Naghib et al. (2019); Delgado & Reuter (2016); Delgado et al. (2014)
MAF	Metric Analysis Framework	Rubin software API that enables interaction with the databases containing simulated observing histories generated through `OpSim`	https://github.com/LSST-nonproject/sims_maf_contrib; Jones et al. (2014)
SAC	Science Advisory Committee	Comprised of scientists familiar with but external to the Rubin Project, the SAC advises the Rubin Constructions and Operations Directors on both policy questions and technical topics of interest to the Project and the science community	https://project.lsst.org/groups/sac/welcome
SCOC	Survey Cadence Optimization Committee	Advisory body to the Rubin Observatory Operations Director formed in 2020, responsible for optimizing the LSST cadence (see Section 5.1)	https://ls.st/scoc
SCs	Rubin LSST Science Collaborations	Self-governed teams independent of Rubin Observatory but recognized by the SAC that come together to address specific scientific challenges and focus on specific science themes and their pursuit through LSST	https://www.lsstcorporation.org/science-collaborations
AGN SC	AGN Science Collaborations	SC pursuing active galactic nuclei studies	https://agn.science.lsst.org

[90] https://www.lsst.org/scientists/glossary-acronyms

Table 4
(Continued)

	Extended Name	Description	URL and References
DESC	Dark Energy Science Collaboration	SC pursuing dark energy studies	https://lsstdesc.org
Galaxies SC	Galaxies Science Collaborations	SC addressing studies of galaxies and galaxy evolution	https://sites.google.com/view/lsstgsc/home
ISSC	Informatics and Statistics Science Collaboration	SC addressing methodological challenges specific to the LSST data	https://issc.science.lsst.org
SLSC	Strong Lensing Science Collaborations	SC addressing strong-lensing studies	https://sites.google.com/view/lsst-stronglensing
SMWLV	Stars, Milky Way, Local Volume Science Collaboration	SC addressing Milky Way and local volume studies	https://milkyway.science.lsst.org
SSSC	Solar System Science Collaborations	SC addressing solar system studies	https://lsst-sssc.github.io
TVS SC	Transient and Variable Stars Science Collaboration	SC addressing the study of the variable and transient sky, both Galactic and extragalactic	https://lsst-tvssc.github.io
COSEP	Community Observing Strategy Evaluation Paper	Living document collecting observing strategy consideration and analyses through MAF, primarily written by the Science Collaborations	https://github.com/LSSTScienceCollaborations/ObservingStrategy; LSST Science Collaboration et al. (2017)
LSSTC	LSST Corporation	A not-for-profit 501(c)3 corporation formed to initiate the LSST Project and advance the science of astronomy and physics. LSSTC represents a consortium of nearly 40 institutional members, as well as 34 international contributors representing 23 countries. LSSTC will partner with NSF/AURA and DOE/SLAC in Rubin Observatory LSST operations and enable the exploitation of the Rubin Observatory LSST's data by advocating for and supporting LSST science	https://www.lsstcorporation.org

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