LARGE SYNOPTIC SURVEY TELESCOPE

Large Synoptic Survey Telescope (LSST)

Call for White Papers on LSST Cadence Optimization

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Abstract

The LSST community is invited to play a key role in the refinement of LSST's Observing Strategy by submitting white papers that will describe proposed modifications of the current baseline survey strategy, including both the main survey and the so-called "deep drilling fields" and mini surveys.

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Call for White Papers on LSST Cadence Optimization

1 Introduction

The Large Synoptic Survey Telescope (LSST) will provide an unprecedented optical imaging dataset that will support investigations of our Solar System, Galaxy and Universe, across half the sky and over ten years of repeated observation. LSST observations will be scheduled automatically, with the scheduling algorithm designed to address all science goals and maximize observing efficiency for given observing constraints. LSST is constructing a flexible scheduling system that can respond to the unexpected and be re-optimized. It has already been shown through simulated surveys that a basic implementation of LSST's 10-year observing strategy can deliver on a wide range of science.

Nevertheless, exactly how the LSST observations will be taken is not yet finalized and there are a number of open optimization questions. Indeed, it is anticipated that the observing strategy will continue to be refined and optimized throughout operations. The main purpose of this call for white papers is to solicit detailed proposals from communities interested in LSST science for specific modifications of the current baseline survey strategy, including both the main survey and the so-called "deep drilling fields" and mini surveys.

1.1 LSST community and LSST observing strategy

The LSST community is already playing a key role in the refinement of LSST's observing strategy by developing and analyzing metrics for quantifying the success of simulated surveys. An open github community[1] is where this work is being assembled. The effects of relatively small changes to the LSST survey strategy on the detailed performance of the anticipated science investigations is explored in a living dynamically-evolving community white paper (the first version was published as arXiv:1708.04058 in August 2017). The main lessons learned from the first version of this paper are:

1. The LSST Project should implement, analyze and optimize the rolling cadence idea (a non-uniform sampling in time designed to "compress" observations for better coverage

[1] https://github.com/LSSTScienceCollaborations/ObservingStrategy

of variable phenomena on time scales of a few months, driven by supernovae, asteroids, and short-timescale stellar variability), and

2. The LSST Project should execute a systematic effort to further improve the ultimate LSST survey strategy (e.g., sky coverage optimization, u band depth optimization, special surveys, Deep Drilling Fields).

Through the end of construction and commissioning, this community Observing Strategy White Paper will remain a living document and the main vehicle for the community to broadly communicate to the LSST Project regarding the scientific repercussions of various observing strategies. The LSST Project Scientist will periodically synthesize and act on the results presented in this paper, with support from the Project Science Team, the Science Advisory Committee and the future Survey Strategy Committee.

1.2 Motivation for this white paper call

Guided by the community input summarized in the Observing Strategy white paper, and further advice from the Science Advisory Committee (SAC), the LSST Construction Project has decided to solicit detailed technical proposals for specific modifications of the current baseline survey strategy.

As discussed in more detail in Appendix A, analysis to date indicates that the baseline survey strategy, while meeting the basic science requirements for the LSST survey, can be meaningfully improved (the baseline survey strategy is described in detail in Sections 1.1 and 2.3 in the Observing Strategy white paper, arXiv:1708.04058). The LSST Science Requirements Document[2] is intentionally vague on survey strategy details because it recognized that science evolves and that the initial, by now more than a decade old, survey strategy will have to be re-optimized closer to first light. With LSST first light expected in 2020, now is the time to undertake the final pre-commissioning optimization[3] of the LSST baseline observing strategy. We seek science-driven input for cadence properties such as per-bandpass imaging depth, the sky coverage, temporal coverage, observing rules, etc., as summarized in Appendix A. Investigations of a limited number of such survey strategy modifications are reported in Chapter 2

[2]See ls.st/srd

[3]"Optimization" used here does not imply its strict mathematical meaning. We are attempting to create the best survey strategy possible, but this is not a formal optimization effort of an objective function in part because the concept of an "optimized" survey is difficult to define mathematically.

from the Observing Strategy white paper (and discussed in various supplementary materials listed in Appendix C).

1.3 General guidelines

We solicit detailed proposals for specific modifications of the current baseline survey strategy, including both the main survey and the so-called "deep drilling fields" and mini surveys. There are no specific limitations on what kind of science programs will be considered, but please note that the primary four LSST science themes remain the cornerstones of the LSST survey and cannot be easily abandoned (the LSST Science Requirements Document states that "the adopted observing strategy will not jeopardize the goals of any of the four main science themes"). In addition, LSST's large etendué is a unique resource and science goals which can be carried out with other telescopes (e.g., single object investigations) will not be viewed favorably.

Detailed proposals are also solicited for novel ideas, such as TOOs, twilight observing (see § A.6) and (hypothetical[4]) narrow-bandpass surveys, as well as synergies with other major surveys (*e.g.*, WFIRST, Euclid).

At this time we are not soliciting proposals to optimize observations during the commissioning period. A call for commissioning proposals will be issued once the start date of commissioning is known with adequate accuracy (1-2 months).

Technical constraints imposed by the system and observing conditions are summarized in Appendix B. In cases that require more detail, or in case of specific questions not addressed in this document, please start a discussion at community.lsst.org[5].

The LSST Science Requirements Document states that "the adopted baseline design assumes a nominal 10-year duration with about 90% of the observing time allocated for the main LSST survey.", and further clarifies that "The remaining 10% of observing time will be used to obtain improved coverage of parameter space. . . ". While the detailed time allocation will eventually depend on currently unknown system performance parameters, it is unlikely that the goals of the main survey could be met with a time allocation significantly below 80%. In other words, it is plausible that the time allocated to programs other than the main survey could significantly

[4]See § 2.2 for details.
[5]`https://community.lsst.org/c/sci` XX finish complete link

exceed 10% (perhaps by as much as a factor of two), but no firm commitments beyond this statement of plausibility can be made at this time.

The data from any given specialized survey will be treated in exactly the same way as all LSST data: there is no special proprietary access for the proposers. Indeed, the final set of the so-called deep-drilling fields and other mini-surveys may be based on an amalgam of ideas from different white papers; there will be no sense in which a given proposal must be accepted or rejected as-is.

1.4 Review process and timeline

The deadline for submitting white papers is November 29, 2018. For submission instructions, please see the next section. The input from the submitted white papers will be used to design multiple options in observing strategies and generate quantitative assessments to be used for survey strategy optimization. These multiple strategies will address varying science drivers and will form a "menu" of possible survey strategies (e.g., a main survey with 18,000 deg^2 of sky coverage vs. sky coverage of 23,000 deg^2 to a somewhat shallower depth). The performance evaluation criteria submitted as part of the white paper proposals will be used to generate quantitative assessments to compare these strategies.

Soon after the November 2018 submission deadline, members of the LSST Science Advisory Committee (SAC), with technical support from the Project[6], will triage white papers and decide which meet the criteria of scientific excellence and technical feasibility for further analysis (including suggestions for combining proposals into single programs, and giving suggestions for maturation of the current notional extragalactic observing strategy).

We anticipate that the resulting list of observing strategies that will be simulated and analyzed (the "menu" above) will be available by April 2019. Simulated survey outputs and Metric Analysis Framework (MAF[7]) analyses will become available by the end of 2019.

An advisory report on these survey strategies will be prepared for the LSST SAC during early 2020, in a close collaboration between the Project and the Observing Strategy Github com-

[6] The Project will establish a Survey Strategy Committee to evaluate competing survey strategy proposals and to propose a general survey strategy for commissioning and operation. The committee will be comprised of both project and non-project personnel, with the SAC making recommendations for committee membership.

[7] https://sims-maf.lsst.io

munity and LSST Science Collaborations. The SAC will in turn advise the project on the specific survey strategy to be used at the start of LSST operations. In developing their recommendations to the Director, the SAC will be guided by selection criteria set by the Project Science Team (*e.g.*, restrictions based on technical criteria, such as those discussed in Appendix B). The Director can further consult with the Project Science Team about the SAC survey strategy recommendations. A baseline simulation that reproduces the adopted strategy, and its detailed performance analysis, will be published in 2021. The start of LSST operations is anticipated in 2022.

An overall aim of the Project and all stakeholders is to make this process transparent and to base all decisions on quantitative input and pre-defined criteria to the maximum extent possible. The Project will organize a dedicated session about this call for white papers, to further clarify details, exchange ideas, discuss simulated surveys, and coordinate teams that plan to submit white papers, at the LSST 2018 All-hands meeting (Tucson, Aug 13-17).

2 White paper submission guidelines

2.1 Who can submit a white paper?

All members of the scientific community interested in LSST science can submit a white paper. We reiterate that the data from any given specialized survey will be treated exactly the same way as all LSST data: the proposers will have no proprietary access to it. There will be no formal "acceptance" of proposals; with the overall ranking priority advice provided to the Project by the Science Advisory Committee, the Project Team will implement a number of different strategies that will be used as quantitative input ("a menu of options") by the Science Advisory Committee when recommending strategy for the initial phase of LSST survey.

2.2 Requested input

The current list of surveys, for which quantitative optimization input is requested are:

- the main Wide-Fast-Deep (WFD) survey,
- the Deep Drilling (DD) fields,

- Northern Ecliptic Spur (NES) mini-survey,
- Galactic Plane (GP) mini-survey, and
- South Celestial Pole (SCP) mini-survey.

We seek science-driven input for survey strategy questions such as optimal visit exposure time, co-added per-bandpass imaging depth, the sky coverage, temporal coverage, observing rules, etc.; for a detailed discussion, please see Appendix A. For some special programs, e.g., target-of-opportunity (ToO) observations, it is important that reasonable information is provided to enable proper simulations to be conducted, as well as an estimation of total observing time allocation. The TeX submission template described in § 2.3 provides further submission details.

In addition to existing surveys listed above, we also seek input on new mini-survey ideas to replace and/or enhance the current programs, including special ToO programs. We also solicit novel ideas, such as twilight observing (see § A.6) and (hypothetical) narrow-bandpass surveys[8], as well as observing synergies with other major surveys (e.g., WFIRST, Euclid).

It would greatly help if each white paper could be assigned to one of the following categories:

- a specific observing strategy to enable specific time domain science, that is relatively agnostic to pointing (e.g., a science case enabled by relatively deep precise time-resolved multi-color photometry).
- a specific pointing(s) that is (relatively) agnostic of the detailed observing strategy (e.g., a science case enabled by very deep precise multi-color photometry)
- an integrated program with science that hinges on the pointing/detailed observing strategy combination (e.g., search for variable stars in the LMC/SMC).

If a specific white paper does not fit any of these categories, please state so.

We reiterate that that the observing time allocated to **all** the mini-surveys (including DD) is "about" 10%, and is unlikely to exceed 20% of the total available observing time. We note

[8]This idea is somewhat hypothetical because it implies that additional hardware would be procured. For more details and discussion of science drivers, please see the Narrow band LSST filters white paper at `http://ls.st/741`

that implementation details for mini-surveys and DD fields are coupled at some level to the main survey: more time for the former means less for the latter, and some of the design decisions for the latter affect the science case for the former. For example, some rolling cadence strategies for the main survey may allow some variable and transient science to happen that would otherwise be the focus of a deep drilling field, and changes in the main survey footprint will affect the definition of a Galactic Plane survey.

2.3 TeX template for submission

Each proposed modification of the survey strategy must contain a Scientific Motivation, Technical Description, and Performance Evaluation section, instructions for which are expanded in the white paper submission template. The Scientific Motivation section is intended to explain why this survey strategy modification is important and what can be learned if the proposed observations were obtained. The Technical Description section details what observations are being requested and should provide enough detail to enable proper simulations to be created, as well as additional information that can help in the process of combining similar but separate survey strategy modification requests. The Performance Evaluation section must contain methods to evaluate the effectiveness of the survey strategy modifications, particularly in light of the potential effect of survey strategy changes proposed in other white papers. It is unlikely that any given proposal will be able to accomplished in its "ideal" form, thus metrics (along with threshold values for these figures of merit) to evaluate the science performance of non-ideal simulations are crucial.

The submission template and an example of the submission, with instructions about all the required information, can be found in the git repository hosted at lsst-pst/survey_strategy_wp[9]. The submission process includes the following steps:

1. Fork the repository using your (the PI's, or a selected collaborator's) Github account.
2. Clone the forked repository to your local machine.
3. Create a directory with the PI name as LASTNAME_FIRSTNAME_NUMBER, where NUMBER is a counter for multiple proposals submitted by the same person (or the case of two people with the same name).
4. Copy the template to the directory created in the last step.

[9] `https://github.com/lsst-pst/survey_strategy_wp`

5. Fill the latex template file with the proposal information. It is possible to make intermediate commits to keep track of the changes to the proposal and share it with collaborators.
6. Once the proposal is ready, make a Pull Request (PR) to the master branch of the main repository.
7. A team member will accept your PR, or contact you in case of problems.

For additional help or questions, please ask on LSST Community[10].

3 Proposal ranking criteria

The ultimate LSST observing strategy will aim to deliver a cutting-edge data set to enable the four LSST's cornerstone scientific programs, while at the same time maximizing the science possible with specialized observing using about 10% of the total observing time.

We anticipate that the adopted observing strategy will be based on an amalgam of ideas from different white papers; therefore, there will be no formal "acceptance" of proposals. The overall ranking priority advice provided to the Project by the Science Advisory Committee will be based on the following considerations[11]:

- **Science** Importance and robustness of proposed science program, including its match to the unique abilities of the LSST system, and its consistency with the main four LSST science themes.
- **Versatility** The ability of proposed dataset to maximally enable LSST's diverse science objectives. Functionally, this means (for programs with large area footprints) that Solar System and Milky Way science will be prioritized for pointing selection, with Time Domain science likely driving the temporal sampling window, and extragalactic science driving the sky coverage and co-added depth. Programs proposing datasets that are of interest to other astronomical facilities (e.g., observable by other flagship facilities on ground and in space) also demonstrate good versatility.

[10] `http://community.lsst.org/c/sci`

[11] The PST is expected to review these ranking criteria before the call for white papers is published.

- **Feasibility** Programs should be feasible from the hardware and software point of view (see Appendix B), specifically including any special data processing required.
- **Time requested** The amount of time (including overheads) required should be justified by the associated science.

As always, the science program properties such as importance and robustness are open to interpretation. It is inevitable that some science drivers will be in conflict, and even observing efficiency may not be defined in an absolute sense. The Project and the Science Advisory Committee will strive to make the proposal ranking process transparent to the maximum extent possible.

Acknowledgments: this document has greatly benefited from discussions between the LSST Project Science Team, the LSST Science Advisory Committee and Kem Cook, Phil Marshall, Steve Ridgway, Daniel Rothchild, Peter Yoachim and numerous other members of the LSST Science Collaborations.

A Examples of open survey strategy optimization questions

The quantitative optimization of the LSST observing strategy requires many detailed decisions to be made, often with only an indirect science justification, or with conflicting science drivers. The current most significant open questions and associated tradeoffs are listed below for the main survey and each mini survey. White papers are specifically encouraged to address these questions.

A.1 The main Wide-Fast-Deep survey

The baseline survey strategy optimizes the amount of sky covered in any given night (subject to the constraint of observing at airmass less than 1.5 and gathering pairs of visits in each night), and allows the entire sky visible at any time of the year to be covered in about three nights. The basic strategy is designed to give roughly uniform coverage at any given time, and to reach the survey goals for measuring stellar parallax and proper motion, and the number of visits per field (825 visits, summed over the six filters). In the baseline implementation, the main survey covers about 18,000 deg^2 of high Galactic latitude sky, and spends about 85% of the available observing time.

Open questions and optimization options associated with the main survey are as follows:

- With the current declination boundaries at Dec = -65° and Dec = $+5^\circ$, the main survey area includes about 18,000 deg° (without the Galactic plane confusion zone, see A.3). These boundaries were set to optimize the number of detected galaxies and galaxies useful for cosmological studies. These galaxy counts stay within 5-10% of the current baseline values even with a much larger survey area. For example, Section 2.4 in the Observing Strategy white paper describes a simulated survey that covers 27,400 deg^2 to about 0.15 mag shallower co-added depth than in the baseline survey (the airmass limit is relaxed to 1.5 and declination boundaries are at Dec = -78° and Dec = $+18^\circ$, with the mean number of visits per field about 20% smaller that in baseline survey). This tradeoff between the sky coverage and co-added depth is still open to optimization and it is important to receive science-driven optimization arguments from all science programs.
- The observing time allocation per band (number of visits per filter) listed in the Science Requirements Document (Table 24) is given only as an illustration. Further optimiza-

tion of this allocation for the main survey, and different fractional allocations for mini surveys, are likely possible.

- A "rolling cadence" (as opposed to uniform temporal sampling) can provide enhanced sampling rates over a part of the survey for a designated time, at the cost of reduced sampling rate the rest of the time (while maintaining the nominal total visit counts). While it is likely that science programs such as supernovae, asteroids, and short-timescale stellar variability would benefit from rolling cadence, detailed cadence parameters have not been optimized yet (*e.g.*, how much of the survey area to "roll" at once and how long to "roll" for, or whether to "roll" in RA or Dec).
- The current baseline survey strategy obtains two visits per night (within 15-60 minutes) in order to enable easy linking of asteroid detections, and robust identification of rapid photometric transients. Whether the two visits on the same night should be obtained in the same filter or in different filters has not been decided yet (e.g., in the context of photometric transients, same filters would provide a more accurate measurement of the brightness change, while different filters would provide a color constraint).
- The current strategy for the main survey which obtains two visits per night could be modified to obtain a single visit, or more than two visits, per night.
- The current baseline survey strategy assumes that a visit is composed of two 15-second exposures, the so-called snaps. While snaps enable search for very rapid variability, and help with cosmic ray rejection, there are compelling technical arguments to abandon them, with observing efficiency being the main argument. Arguments for retaining the snaps would be very useful in further optimization of the main survey strategy.

White papers addressing all or some of these optimization efforts are strongly encouraged.

A.2 "Deep Drilling" fields

The Deep Drilling (DD) fields are single pointings that are observed in extended sequences. In the first call for white papers in 2011 on survey strategy optimization, the Project received 8 white papers from the community[12]. These proposals often include certain filter combinations to ensure that near-simultaneous color information is available for variable and transient objects. While science programs suggested in DD proposals are ideally well matched to

[12] These white papers are available from https://project.lsst.org/content/whitepapers32012

the size of LSST field of view (9.6 deg^2), it is plausible that some programs may require several fields.

Four of the LSST DD fields have been selected and announced (Elias S1, XMM-LSS, Extended Chandra Deep Field-South, and COSMOS). It is guaranteed that they will be observed with deeper coverage and more frequent temporal sampling than the main survey fields, but details are still open. It is expected that there will be more DD fields selected for the final survey (a plausible but not prescriptive range is 5-10).

The observing sequences for these DD fields are not well determined. The current baseline cadence includes sequences of $grizy$ observations during bright time, and sequences of u band observations during dark time. The large number of filter changes in the bright time sequences are inefficient and the large gap in multi-color sampling during dark time is likely problematic for variable and transient characterization. White papers addressing improved cadences for DD sequences are desirable.

A.3 Galactic plane survey

The baseline main survey excludes observations at low Galactic latitudes, where the high stellar density leads to a confusion limit at much brighter magnitudes than those attained at high Galactic latitudes. Assuming median seeing, this confusion limit corresponds to a source density of about 1-2 million per deg^2. The current boundary of this "Galactic confusion zone" starts at $|b| = 10°$ towards $l = 0°$ and linearly drops to $b = 0°$ at $l = 90°$ and $l = 270°$. Along this boundary, the confusion limit is reached at a depth of $i \sim 26$; therefore, the useful coadded depth is at least 1-2 magnitudes shallower than for the main survey. Within this boundary, the fraction of galaxies is only a few percent and an assumption that all sources are stars works well. For example, DECAPS survey generated a catalog with 2 billion sources in the Southern Galactic Plane to a depth of about $r = 23$ (with seeing around 1 arcsecond; Schlafly et al. 2018, arXiv:1710.01309).

As guidance, stellar count simulations with the TRILEGAL code (Girardi et al. 2005, arXiv:astro-ph/050404) show that to the depth of $r = 27.5$ there are about 2 billion stars in the main survey area, with another 5 billion stars in the Galactic confusion zone. Of the latter, about 3 billion are brighter than $r = 24.5$. XXX ZI: this is based on Galfast simulations and will be updated with TRILEGAL results.

The current strawman implementation of the Galactic confusion zone coverage allocates 30 observations in each of the six filters. Detailed optimization of this strategy has not been done yet. In particular, science-driven input is needed for both "static science" programs (e.g., The Blanco DECam Bulge Survey, BDBS Collaboration; DECAPS survey) and time domain surveys (e.g., Gould 2013, arXiv:1304.3455).

The footprint in the current baseline survey strategy extends to far north along the Galactic plane, to the region that can only be observed at relatively large airmass from the LSST site at Cerro Pachón ($X > 1.4$ at Dec=$+15°$). Originally, this extension was designed to extend longitudinal coverage of the Galactic plane with Galactic structure studies in mind. With the advent of other surveys (e.g., Pan-STARRS and DECAPS), the reasons for obtaining these less efficient observations (due to unavoidable high airmass) are less compelling. Unless a strong case is made in submitted white papers, the Project is likely to limit the coverage of the Galactic plane to Dec=$< +5°$.

A.4 Southern Celestial pole mini survey

Due to its southern declination limit ($Dec > -65°$), the main survey misses large fraction of both the Magellanic Clouds. To allow coverage of the Large and Small Magellanic Clouds, baseline survey strategy uses relaxed limits on airmass and seeing for the ~2,000 deg^2 region around the South Celestial Pole, but with fewer observations than for the main survey.

Detailed optimization of this strategy has not been done yet. Given recent informative observations obtained by the SMASH survey (Nidever et al. 2017, arXiv:1701.00502), as well as calibration and legacy aspects of this mini survey, a white paper with more detailed cadence prescriptions (e.g., is it necessary to extend the coverage all the way to the South Celestial pole?) would greatly inform further cadence optimization and help retain this mini survey.

A.5 Northern Ecliptic spur mini survey

The main survey footprint provides most of LSST's power for detecting Near Earth Objects (NEO) and Kuiper Belt Objects (KBOs) and naturally incorporates the southern half of the ecliptic within its 18,000 deg^2 sky area. Additional coverage of a crescent reaching to +10 degrees of the Northern ecliptic plane would sample the full azimuthal distribution of TNOs, crucial for understanding the different dynamical families in which they fall, and would improve the light curve sampling and completeness of asteroid populations in the inner Solar System. The baseline survey strategy covers this region using the $griz$ filters only, along with more relaxed limits on airmass and seeing. A more detailed and robust science-driven justification addressing both outer Solar System (e.g., TNOs) and inner Solar System (e.g., main-belt and NEO asteroids) populations is needed to retain and improve this mini survey.

A.6 Twilight survey

LSST's short read-out time (2 sec) enables efficient taking of short-exposure images during twilight time that would otherwise go unused. Science drivers and technical details are discussed in Section 10.3 in the Observing Strategy white paper (arXiv:1708.04058); the former include a bright star survey for Galactic science, obtaining light curves for nearby supernovae, and observations of near-Earth asteroids towards so-called "sweet spots" (on the Ecliptic, at Solar elongations of $\sim 60°$). This cadence has not been simulated yet because sufficiently detailed and accurate sky brightness model, that includes twilight effects, has become available only recently (Yoachim et al. 2016, Proc. SPIE, 9910-48, 99101A-1).

The Project plans to simulate twilight observing in the next round of simulations (scheduled for late 2018). Assuming exposure times of 1 second (the stretch goal from the LSST Science Requirements Document, which is already met and corresponds to the Camera baseline requirement), the saturation limit would improve by about 3 mag relative to 15-sec exposures; in the r band from about $r = 16$ to $r = 13$, with about 1.5 mag loss of limiting depth. The improvement in dynamic range of 1.5 mag would gradually diminish and eventually dynamic range would vanish as the sky brightness increases. About 20-30 minutes of additional observing time could be utilized during twilight before dynamic brightness range becomes too small. Assuming 7-sec visits (1 sec exposure + 1 sec for shutter + 5 sec for read and slew), about 2,000 deg^2 of sky could be imaged in 25 minutes (assuming no filter changes). Alternatively, over 350 exposures (1 sec + 1 sec + 2 sec) of the same field could be obtained instead. Detailed strategies should consider limitations on the number of filter changes (see § B.1). White papers addressing the science justification and strategies for using twilight time are desired.

The shortest exposure stretch goal in the Camera baseline requirements is set to 0.1 sec. Science-driven studies that would advocate pursuing this goal would be a welcome contribution to further system optimization; twilight observing would especially benefit from shorter exposures.

B Constraints on survey strategy imposed by the LSST system

B.1 Hardware constraints

Several hard constraints prevent observations in certain directions. The telescope altitude limit prevents observations at altitudes below 20°. As a consequence of alt-az mount, there is also a zenith exclusion zone with a radius of 3.5°.

LSST telescope mount uses direct drive motors and there should not be any mechanical limits on slewing from the mount. However, there are observing efficiency considerations: the slew time depends on slew distance. Approximately[13], in the azimuth direction,

$$t_{slew}^{Az} = C^{Az} + 0.66\,\mathrm{sec/deg} * \delta Az(\mathrm{deg}), \tag{1}$$

where $C^{Az} = 3$ sec (note that even when the telescope doesn't move, there is an overhead of 2 sec due to read-out time). For slewing in altitude

$$t_{slew}^{Alt} = C^{Alt} + 0.57\,\mathrm{sec/deg} * \delta Alt(\mathrm{deg}), \tag{2}$$

where $C^{Alt} = 3$ sec for slews below 9° and $C^{Alt} = 36$ sec for longer slews (because of the need to recompute optics corrections). In the baseline simulated survey, about 2% of slews move in altitude more than 9°.

The shortest exposure time is 1 second, with the shortest exposure stretch goal in the Camera baseline requirements set to 0.1 sec. For exposures shorter than about 10 sec, the seeing due to atmospheric turbulence may be harder to characterize (more irregular) than for longer exposures, and moving objects may trail in long exposures (for more details see Section 5.1.4 in Jones et al. 2018; Icarus 303, 181). Short exposures will have a low observing efficiency due to finite read-out time (2 sec) and the shutter open/close time (1 sec).

There are important constraints on the filter exchange strategy. As the system is not yet completely built and characterized, the following represents current understanding, based on the design and on engineering judgement. As such, some of the details should be considered preliminary and subject to change. Expanded ranges could be possible if there are strong scientific motivations along with sufficient resources during operations.

[13] Precise values can be obtained using method "get_approximate_slewdelay" from ts.observatory.model

- The filter change mechanism is designed to undergo a total of 100,000 changes over its lifetime (about 27 changes per day of the survey, 17 during the night and 10 for daylight calibrations).
- Each filter is designed to support up to 30,000 changes over its lifetime.
- A maintenance cycle is anticipated, and this would nominally occur after 10,000 changes or one year, whichever is reached first.
- During a given observing night, the system could support as many changes involving the 5 filters loaded in the carousel as desired, without any practical limitation beyond the two-minute change interval (which consists of 90 seconds for the exchange plus up to 30 seconds to put the camera into the required orientation).
- Filter loader operations (swapping a filter in the carousel) will be done during daytime. The system is designed for 3000 loads over its lifetime.
- The currently implemented filter-swap strategy is to replace one of the z or y by the u band at the start of dark time, when the lunar phase reaches 20%. The process is reversed at the end of dark time when the lunar phase is above the same threshold.

B.2 Software constraints

The LSST Science Requirements Document specifies that "As a general principle, the measurement errors for fundamental quantities, such as astrometry, photometry and image size, should not be dominated by algorithmic performance.". Data products that LSST will produce are described in LSST Data Products Definition Document (ls.st/dpdd) and more algorithmic detail is provided in LSST Data Management Science Pipelines Design document (ls.st/ldm-151).

The Project will not take formal responsibility for specialized data reduction algorithms needed to process data, including that taken in "non-standard" modes; detailed discussion is available in Data Management and LSST Special Programs document (ls.st/dmtn-065) and should be perused when proposing non-standard observing sequences. In addition, we strongly recommend to consult Sections 5 and 6 in the LSST Data Products Definition Document. If a proposed dataset will require special processing, a plan to obtain necessary software and compute resources must be provided in the white paper proposal.

There is an additional caveat regarding crowded field processing (see also Section A.3). A fraction of LSST imaging will cover areas of high object (mostly stellar) density, such as the Galactic plane, the Large and Small Magellanic Clouds, and a number of globular clusters (among others). LSST image processing and measurement software, although primarily designed to operate in non-crowded regions, is expected to perform well in areas of crowding. The current LSST applications development plan envisions making the deblender aware of Galactic longitude and latitude, and permitting it to use that information as a prior when deciding how to deblend objects. While not guaranteed to reach the accuracy or completeness of purpose-built crowded field photometry codes, we expect this approach will yield acceptable results even in areas of moderately high crowding.

The above discussion only pertains to processing of direct images. Crowding is not expected to significantly impact the quality of data products derived from difference images (i.e., Prompt products).

B.3 Observing efficiency constraints

The LSST Science Requirements Document "...assumes a nominal 10-year duration with about 90% of the observing time allocated for the main LSST survey.", and thus 10% of observing time is left for all other programs. However, if the system will perform better than expected, or if science priorities will change over time, it is conceivable that 90% could be modified and become as low as perhaps 80%, with the observing time for other programs thus doubled. At this time, details are TBD but the Project is developing flexible scheduling procedures to enable such modifications.

We note that the uncertainty in our system performance estimates due to weather and solar activity is about 10%. In addition, the system has not been built yet and many hardware performance parameters are still taken at their design values.

Sustained observing, such as the main survey, with exposures much shorter than standard visits will result in diminished observing efficiency. Given total visit exposure time t_{vis} (30 sec for standard visits), with two exposures/readouts (snaps) per visit, and assuming a slew and settle time of 5 sec (also including the second readout), the observing efficiency can be computed as

$$\epsilon = \left(\frac{t_{vis}}{t_{vis} + 9\,\mathrm{sec}}\right). \tag{3}$$

To maintain efficiency losses below ∼30% (i.e., at least below the limit set by the weather patterns), and to minimize the read noise impact, $t_{vis} > 20$ seconds is required for sustained observing.

Variations in exposure time for the main survey affect not only the limiting depth, but also the total number of acquired visits and revisit time because the total observing time is finite. For more detailed discussion of these tradeoffs, please peruse Section 2.2.2 in the Overview paper.

The number of filter changes and size of slews also affects efficiency.

B.4 Limiting depth and uncertainty estimates

Methods for estimating individual image depth (5σ point source magnitude limits) for a given exposure time and other observing parameters is discussed in detail in Section 3.2 in the LSST Overview paper (see C.1). Tradeoffs between exposure time per visit, single-visit depth, the mean revisit time, and the total number of visits, as well as justification for the adopted standard exposure time of 30 sec, are discussed in Section 2.2 from the same paper. The improvement in measurement uncertainties as the surveys progresses, as a function of time t, can be approximately summarized as follows.

The co-added depth (the 5σ depth for point sources), $m_5^{\rm co-add}$, scales with time as (see eq. 6 in the overview paper)

$$m_5^{\rm co-add} = m_5^{\rm co-add, Final} + 1.25 \, \log_{10}\left(\frac{t}{10\,{\rm yrs}}\right) \tag{4}$$

where $m_5^{\rm co-add, Final}$ is the target depth achieved with 10-year survey. With airmass and other losses taken into account, $m_5^{\rm co-add, Final} = 27.2$ for the r band in the baseline simulated survey.

The photometric errors (inverse signal-to-noise ratio) at the faint limit of the so-called "gold" galaxy sample (4 billion galaxies with $i < 25.3$ which will be used for cosmological programs, see Section 3.7.2 in the LSST Science Book), is computed from (see eq. 5 and Table 1 in the overview paper):

$$\sigma_{i=25} = 0.04 \left(\frac{t}{10\,{\rm yrs}}\right)^{-1/2} {\rm mag.} \tag{5}$$

The volume of the 5-dimensional color space per source with $i = 25$, which controls the ability to classify sources using colors (including photometric redshift estimates for galaxies and star/quasar separation, for example) is computed assuming uncorrelated color errors, as proportional to $\sigma^5_{i=25}$, and normalized by the value corresponding to 10-year survey.

The trigonometric parallax accuracy for a point source with r=24 (see section 3.3.3 in the overview paper) scales with time as

$$\sigma_\pi = 3.0 \left(\frac{t}{10\,\mathrm{yrs}}\right)^{-1/2} \mathrm{mas}. \tag{6}$$

The proper motion accuracy for a point source with r=24 (see section 3.2.3 in the overview paper) scales with time as

$$\sigma_\mu = 1.0 \left(\frac{t}{10\,\mathrm{yrs}}\right)^{-3/2} \mathrm{mas/yr}. \tag{7}$$

Note the very strong dependence of σ_μ on time ($t^{-1/2}$ comes from the increase in the square root of the number of visits, analogously to σ_π, and an additional t^{-1} from the linear increase in temporal baseline). In both expressions, the number of visits is assumed proportional to time, with a value of 825 corresponding to the main deep-wide-fast 10-year survey.

The behavior of these quantities as a function of time is summarized in Table 3. While the co-added depth and σ(i=25) rapidly improve during the first few years, several important quantities continue to show marked improvement between the survey years 8 and 10: most notably, the color volume per source for faint sources ($i = 25$) shrinks by a factor of 1.7. Substantial improvement is also seen for proper motions, with errors larger by 40%, after 8 years than at the end of the 10-year survey.

C Supplementary materials

C.1 Useful publications and websites

Note that various websites and documents references here are still in development (if not an official LSST change control document).

The LSST Overview paper provides a short summary of the four primary science drivers, as well as the expected performance of LSST in terms of throughputs, and calibration. It also

TABLE 1: Various science metrics as functions of survey duration.

Quantity	Year 1	Y3	Y5	Y8	Year 10
r_5 coadd[a]	26.0	26.5	26.8	27.1	27.2
$\sigma(i{=}25)$[b]	0.12	0.07	0.06	0.05	0.04
color vol.[c]	316	20	6	1.7	1
# of visits[d]	83	248	412	660	825
σ_π (r=24)[e]	9.5	5.5	4.2	3.3	3.0
σ_μ (r=24)[f]	32	6.1	2.8	1.4	1.0

[a] The co-added depth in the r band (AB, 5σ; point sources).
[b] The photometric error for a point source with $i = 25$.
[c] The volume of the 5-dimensional color space, normalized by the final value.
[d] The number of visits per sky position (summed over all bands).
[e] The trigonometric parallax accuracy for a point source with r=24 (milliarcsec).
[f] The proper motion accuracy for a point source with r=24 (milliarcsec/yr).

discusses high-level survey constraints and tradeoffs. Available as `http://ls.st/pif`

The Observing Strategy White Paper (OSWP) is a community-driven paper describing a wide variety of science cases and their implications for survey strategy. This paper is primarily aimed at helping define the main (90%) WideFastDeep survey. Available as `http://ls.st/3y1`

The LSST Science Requirements Document (SRD) describes the official requirements for LSST science deliverables. Section 3.4 is the most relevant for survey strategy, although other sections are relevant for telescope and camera performance such as throughputs and readout time. Available as `http://ls.st/srd`

The LSST Data Products Definition Document (DPDD) describes the data products that LSST will provide, with some high-level background on how they will be produced. If you want to know what will be contained in various catalogs, this is a good place to look. Available as `http://ls.st/dpdd`

The LSST Data Management Science Pipelines Design (LDM-151) document describes the LSST data management processing pipelines. This provides details of how and when images will be processed and catalogs will be generated, including information on the algorithms used in each processing stage. If you want to know more about the details of a value in an output catalog and how it will be calculated, this is the place to look. Available as `http://ls.st/ldm-151`

Documentation about OpSim (SOCS and Scheduler), including a high-level overview and description of scheduling options, is available at `http://sims-opsim.lsst.io`.

Documentation about MAF, including a high-level overview and descriptions of current standard metric analyses, is available at `http://sims-maf.lsst.io`.

The baseline simulated survey document describes the new features enabled in Opsim v4, as well as characteristics of the updated baseline simulated survey.

The outputs of MAF analyses for the new baseline survey, as well as runs demonstrating potential options for mini surveys and Deep Drilling fields (a subset of the runs described in Chapter 2 of the OSWP) are available online at `http://astro-lsst-01.astro.washington.edu:8080`.

A short description of the current Deep Drilling fields and links to further materials (including white papers submitted in response to the 2011 call for input on the DD strategy) are available on the LSST website at http://ls.st/57q. Additional posts on LSST Community can be found by searching for 'deep drilling'.

Additional information is available in the following presentations:

- "Overview of the LSST Observing Strategy" (Nov 16, 2015): `http://ls.st/4yh`
- "The LSST Deep-Drilling Fields: White Papers and Science Council Selected Fields" (Aug 15, 2016): `http://ls.st/wzy`
- "Observing Strategy White Paper Status Report" (Mar 5, 2017): `http://ls.st/zj2`
- "LSST Plans for Cadence Optimization" (May 30, 2017): `http://ls.st/ot2`
- "Special Programs" (Aug 15, 2017): `http://ls.st/10o`

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C.2 Communication about the LSST survey strategy

The Project Scientist (Željko Ivezić, e-mail: ivezic at astro.washington.edu) is formally responsible for survey strategy optimization efforts and is the formal liaison between the community and the LSST Scheduler and Operations Simulation teams.

The LSST Science Advisory Committee (SAC) is charged with collecting and delivering various community input to the Project. Strategic and political issues about the LSST survey strategy should be communicated via the SAC (chair: Michael Strauss, strauss at astro.princeton.edu).

In addition to this call for white papers, the Observing Strategy white paper[14] provides a coordinated mechanism for providing scientific input about survey strategy. LSST science collaborations are also official channels for communication with the LSST project — a Data Management liaison is assigned to each Science Collaboration to answer specific questions about data products generated by the project.

An open, searchable resource for asking questions not addressed in this document is available on LSST Community, in the Science category, SurveyStrategy subcategory. Team members will monitor and respond in a timely manner to questions posted there. Please go to `http://community.lsst.org`

There is a mailing list available (email: lsst-survey-strategy at lsstcorp.org) to contact the survey strategy team in case of specific questions and/or concerns. Messages posted to the mailing list are broadcasted to the survey strategy team and archived.

Throughout the survey strategy design process there will be open community meetings. The first of these will be at the LSST All Hands Meeting 2018 in Tucson, AZ (August 13-17, 2018).

Note that our teams cannot support individuals or groups wishing to run the Operations Simulator themselves. We will provide documentation on running OpSim and docker images (as well as the source code) will be made available, however we do not have resources to provide help desk facilities on this topic.

[14] A living document available at https://github.com/LSSTScienceCollaborations/ObservingStrategy

C.3 Additional Simulated Survey Strategies

By the time this call for white papers is officially released, we anticipate that we will provide several more sample simulated surveys for the community to use as test cases. These modified survey strategies will include (approximately):

- The baseline survey strategy, with the main survey having a 18,000 deg^2 footprint, the North Ecliptic Spur, South Celestial Pole, Galactic Plane and Deep Drilling minisurveys operating in the current example baseline survey strategy manner.
- A survey with a much larger main survey footprint (27,000 deg^2 – defined by airmass limit $X < 1.5$ and declination limits $-78 <$ Dec $< +18$, and including only the Deep Drilling mini-survey (and no other mini surveys).
- A survey strategy with 'more visits': each visit being 20 seconds long with a single exposure per visit, and 40 second visits in the u band (and probably another similar survey with exposures of 40 sec and 60 sec, respectively).
- A survey similar to the current baseline, with the Galactic Plane at the main survey cadence (and the northern tip of the galactic plane minisurvey removed).
- A survey similar to the current baseline, but with additional Deep Drilling fields.
- A survey similar to the current baseline, but with a modified cadence for Deep Drilling fields (ideally: observe in only 3 filters per night, but with a shorter gap between nights; rotating among the 3 filters used in each night).
- Rolling cadence simulations in the main survey – concentrating observations in bands of declination in some simulations, and in bands of R.A. in other simulations
- A survey similar to the current baseline, but obtaining pairs of visits in different filters (vs. the same filter).
- A survey similar to the current baseline, but only observing with single visits per night.