VERA C. RUBIN OBSERVATORY

Introduction to LSST Survey Cadence Optimization

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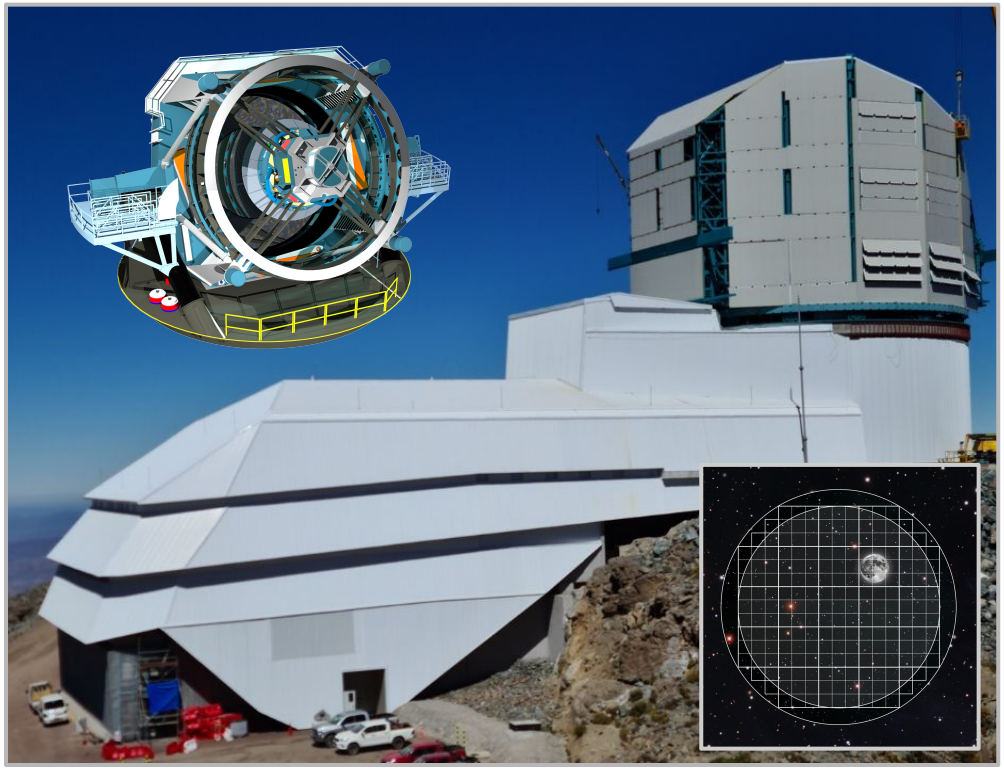
Presented by
the Rubin Observatory LSST Scheduler Team and
the Rubin Observatory Community Engagement Team

NSF NOIR Lab AURA SLAC U.S. DEPARTMENT OF ENERGY

The Vera C. Rubin Observatory



The Vera C. Rubin Observatory is located on Cerro Pachón in Chile. The Simonyi Survey Telescope's primary mirror has an 8.4 meter diameter and its camera an 9.6 deg^2 field-of-view and six optical-NIR filters: *ugrizy*.

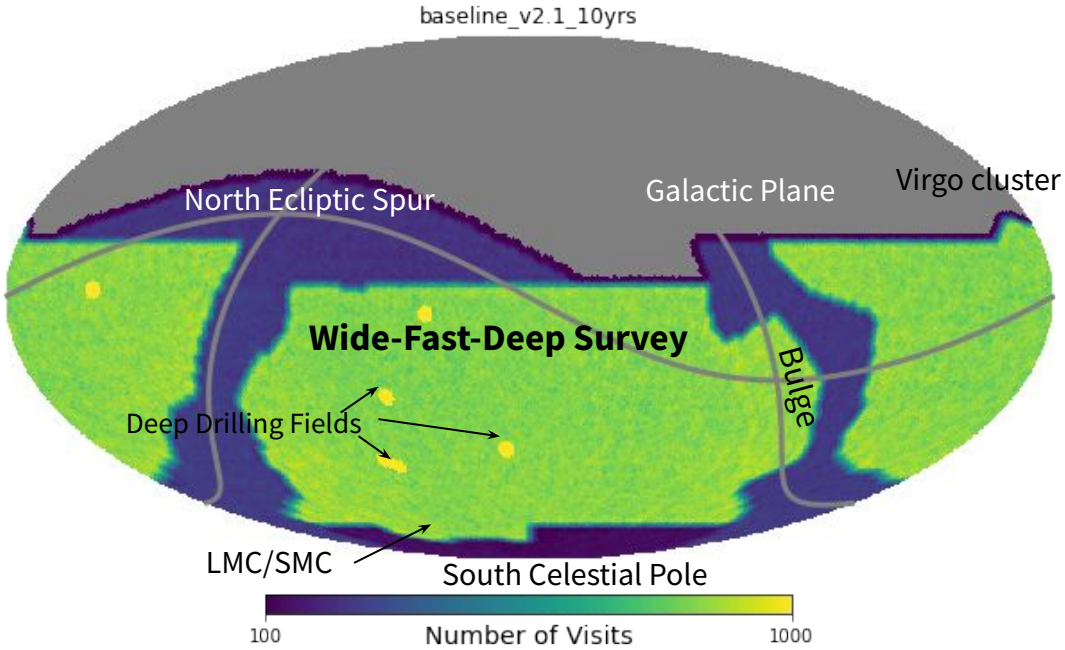
Once construction and commissioning are complete, Rubin Observatory will execute the 10-year Legacy Survey of Space and Time (LSST).

The survey and observatory are designed to make major advances in four core science areas:

1. Probing dark energy and dark matter
2. Taking an inventory of the solar system
3. Exploring the transient optical sky
4. Mapping the Milky Way

This talk provides a basic overview of the process to choose a survey strategy to maximize science.

Survey Strategy Basics



The **Baseline Survey Strategy (v2.0)** is designed to meet the basic requirements to achieve the core science goals of the **Legacy Survey of Space and Time** (LSST; requirements in ls.st/srd).

Baseline design elements for the WFD area:
- should cover at least 18000 deg^2
- average of 825 visits per field over 10 years
- same-night same-field re-visit "pairs"

Additional areas covered will include:
- at least 5 deep drilling fields
- the North Ecliptic Spur, the Galactic Plane, the South Celestial Pole, and the Virgo cluster

How to optimize the LSST to maximize scientific return is an open question.

Source: https://github.com/lsst-sims/sims_featureScheduler_runs2.1/tree/main/baseline

Open Questions About Survey Strategy

Wide-Fast-Deep (WFD) or "Main Survey" characteristics:

- **footprint**: How should the Wide-Fast-Deep (WFD) area be defined?
- **cadence**: How often should WFD fields be revisited -- within a night and between nights?
- **filters**: What is the optimal filter distribution for WFD fields?
- **colors**: What are the optimal intra-night filter pairs for WFD field revisits?

Deep Drilling Fields and Mini-Survey Fields

- What footprints to use for the mini-surveys?
- What cadence and filter sequences should be used for these areas?

Special surveys: e.g. Gravitational Wave Target-of-Opportunity (TOO) Observations

- How frequently could GW TOO be executed without risk to the core science goals?

Operations Simulation (OpSim)

To address these open questions, the Rubin Observatory LSST Scheduler Team is generating a wide variety of simulated surveys.

One *OpSim run* consists of:

Input: strategy parameters like area, revisit rate, etc.
Generate: 10 years of moon cycles, weather patterns, TOO, etc.
Schedule: 10 years of observations based on the input strategy
Output: an *OpSim database* of observational metadata

To help scientists evaluate these simulations, the LSST Scheduler Team built the *Metrics Analysis Framework* (MAF), a code package that enables the derivation of scientific results from the OpSim database.

A *metric* is a measure of scientific performance, such as the number of detections of a type of object, the 10-year co-added depth, etc.

Terminology

OpSim run
A simulated 10-year survey for a given strategy.

OpSim database
Observational metadata for one OpSim run.

MAF
Metrics Analysis Framework, a software package of tools to read and analyze an OpSim database.

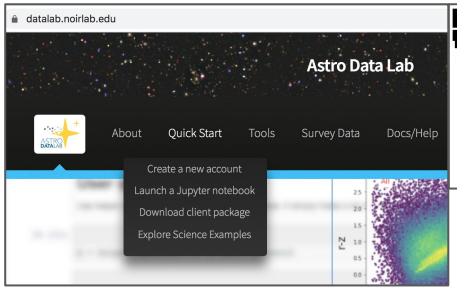
Metric
A measure of scientific performance that can be applied to all OpSim runs.

Analyze OpSims with rubin_sim + DataLab

The **`rubin_sim`** package includes tools to analyze simulated survey strategies.

GitHub repository: github.com/lsst/rubin_sim
Documentation: rubin-sim.lsst.io
Tutorials available: github.com/lsst/rubin_sim_notebooks

Recommendation: use **`rubin_sim`** in the NOIRLab Astro Data Lab, datalab.noirlab.edu.
Launch a Jupyter Notebook and git clone **`rubin_sim_notebooks`** locally.
Start with **`rubin_sim_notebooks/maf/tutorial/Notebook_00_Preparing_for_tutorials.ipynb`**.




```
[redacted]datalab> cd /sims_maf/fbs_2.0
[redacted]datalab> ls
total 40
0 baseline/                    4 long_gaps_nopair/  4 presto/           0 rolling_bulge/
0 baseline_nexp2_v1.7.1_10yrs/ 0 long_u/            4 presto_half/      0 rolling_bulge_6/
0 bluer/                       4 microsurveys/      0 retro/            0 rolling_early/
0 ddf/                         0 noroll/            4 rolling/          0 rolling_six/
4 long_gaps/                   8 opsim_list         0 rolling_all_sky/  0 vary_expt/
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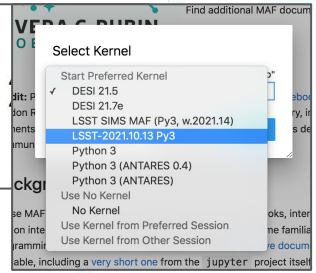

OpSim databases (above) and kernel (right) with the rubin-sim package installed already are available in Datalab (left).

Decision Process and Timeline

2020: Formation of the LSST **Survey Cadence Optimization Committee** (**SCOC**).

- committee will stand for the duration of Rubin Observatory operations
- consists of 10 individuals representing the LSST science community
- charged to recommend specific survey cadences be adopted
  - for the commissioning phase, early science, and the 10-year survey
- charged to consider input from both scientists and Rubin staff
  - the LSST Science Collaborations and the science community
  - the Rubin Observatory Survey Evaluation Working Group (SEWG)

2021: **Cadence Notes & SCOC Phase 1 Recommendations** on survey strategy

- based on v1.x series of simulations
- all Cadence Notes: lsst.org/content/survey-cadence-notes-2021

2022: Final recommendations on baseline survey strategy (expected timeline*)

*lsst.org/sites/default/files/for-scientists/SCOChandoutWorkshop2.pdf

Community-focused Process (arXiv:2108.01683)

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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"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…"

This is the introductory paper of an ApJ Focus Issue on Rubin LSST cadence and survey strategy.

Cadence Notes

Browse all ~40 Cadence Notes: lsst.org/content/survey-cadence-notes-2021

AUTHORS	TITLE	LINK
Abrams	Microlensing Discovery and CharacterizationEfficiency at Different Timescales	DocuShare
Andreoni	MaximizingSerendipitous Kilonova and Fast Transient Discovery	DocuShare
Anguita	LSST Strong Lensing Science Collaboration responseto the SurveyCadence Optimization Committee Call on Cadence	DocuShare
Assef	Type-1 Quasar Colors in the Context of Photometric Redshifts	DocuShare
Assef	Quasar Counts	DocuShare
Assef	Type-1 Quasar Variability in the Context of Photometric Redshifts	DocuShare
Bachelet	On the observational synergies between all-sky surveys for thecharacterization of microlensing events	DocuShare
Bellm	Give Me a Few Hours: Missing Timescales in Rubin Cadence Simulations	DocuShare
Musella	Classical variable stars in different Galacticenvironments: pulsation behaviour recovery	DocuShare
Olsen	A census of dwarf satellites and substructure around the Magellanic Clouds	DocuShare
Prisinzano	Maximize volume and uniformitycoverage of Star Forming Regions in the Galactic Plane	DocuShare
Raiteri	BLAZAR VARIABILITY	DocuShare
Schwamb	Vera C. Rubin Observatory Legacy Survey of Spaceand Time (LSST) Solar System Science Collaboration (SSSC)	DocuShare
Street	LSST Survey Footprint in the Galactic Plane and Magellanic Clouds	DocuShare
Tisanić	Simulations of multiband Lomb-Scargle-derived variable star periods	DocuShare
van Velzen	Tidal Disruption Events	DocuShare
Yu	Non-Parametric Structure Function Metric	DocuShare
Yu	Differential Chromatic Refraction	DocuShare

SCOC: Phase 1 Recommendations Highlights

- Increase the amount of low-dust area while adding WFD-level coverage around the galactic Bulge
- Visits in *u* band should be a single exposure of (at least) 1x30s; visits in other bands must remain 2x15s ('two snaps') until verification of single snap in commissioning
- No strong drivers to vary from the current filter balance for most of the survey area
- Pairs of visits within a night should be split between different filters
  - Evaluation of the timing and number of visits per night should be continued
- A two-band rolling cadence should be implemented for the low-dust WFD
  - Evaluation of rolling cadence should be continued
- Evaluate micro-surveys (<3% of overall time) for science contributions and impact on the overall survey strategy

2022 Timeline for Survey Cadence

- Mar 1, 2022: simulations of the recommended strategy available (with detailed baseline variations to enable fine tuning of the baseline cadence)
- Summer 2022: draft Phase 2 SCOC recommendation available, the 3rd workshop to fine-tune the recommended baseline strategy, including start of "early science optimization" discussions
- Dec 15, 2022: the simulation of the adopted observing strategy (the new baseline for starting LSST) produced and made publicly available; finalized Phase 2 SCOC recommendation delivered to the Rubin Observatory Operations Director
- Apr 1, 2023: the observing strategy fixed and implemented in the Scheduler and the Observatory Control Software (note: this date is exactly one year before currently anticipated start of operations)
- Dec 15, 2023: SCOC, informed by system performance estimates from the commissioning team, recommends baseline strategy modifications to address "early science optimization"

Find more information about LSST cadence

Drop by the Vera C. Rubin Observatory booth in the AAS winter 2021 Exhibit Hall, where staff are available to answer your questions.

Visit the Rubin Observatory **Community Forum**, especially the category "Science - Survey Strategy". Forum contents are publicly viewable and anyone may obtain an account to post. community.lsst.org

Join one of the eight **LSST Science Collaborations**, independent worldwide communities of scientists self-organized into working groups based on research interests. All collaborations are actively engaged in evaluating OpSim runs. Membership is open to all. ls.st/lsstc-sc

Resources

The Survey Cadence Optimization Committee (SCOC)
ls.st/55y

Survey Cadence Optimization Committee's Phase 1 Recommendation
ls.st/pstn-053

Pre-recorded talks about the survey scheduler and metrics
ls.st/clo4305