Large Synoptic Survey Telescope

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Exploring Scheduling and Building Analysis Tools for the LSST Operations Simulations

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The LSST Operations Simulator models the telescope's design-specific opto-mechanical system performance and site-specific conditions to simulate how observations may be obtained during a 10-year survey. We have found that a remarkable range of science programs are compatible with a single feasible cadence. The Simulator incorporates detailed models of the telescope and dome, the camera, weather and an improved model for scheduled and unscheduled downtime, as well as a scheduling strategy based on ranking requests for observations from a small number of observing modes attempting to optimize the key science objectives. Each observing mode is driven by a specification which ranks field-filter combinations of target fields to observe next. The output of the simulator is a detailed record of the activity of the telescope - such as position on the sky, slew activities, weather and various types of downtime - stored in a MySQL database. Sophisticated tools are required to mine this data in order to assess the degree of success of any simulated survey in some detail. An analysis tool has been created (SSTAR) which generates a standard report describing the basic characteristics of a simulated survey; an analysis framework is being designed to allow for the inter-comparison of one or more simulated surveys and to perform more complex analyses. Visualization software is being used to interactively explore the survey history and to prototype reports for the analysis framework, and we are working with the ASCOT team (http://ascot.astro.washington.edu) to determine the feasibility of creating our own interactive tools. The next phase of simulator development will include look-ahead to continue investigating the trade-offs of addressing multiple science goals within a single LSST survey.

SURVEY STRATEGY

The Operations Simulator creates a 10-year survey of the available sky primarily with a universal cadence. Post-processing and analysis tools assess the ability of the survey to meet sky coverage and revisit requirements specified by each of the LSST key science programs (see Tyson *et al.*, this session).

Constraints

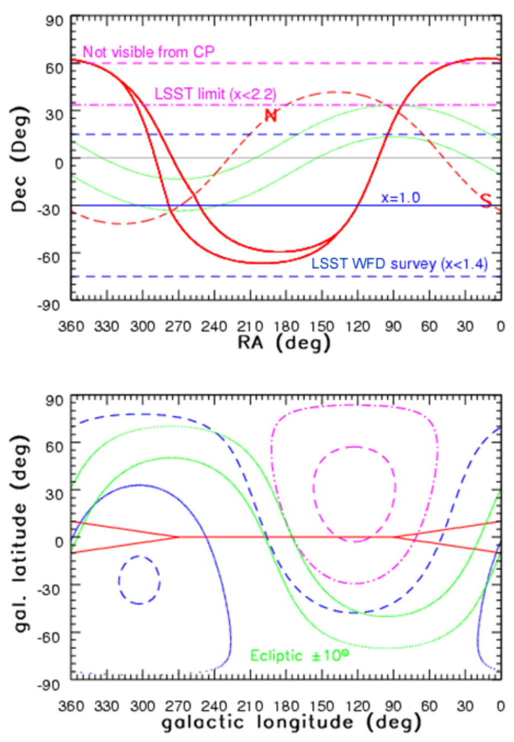


Figure 1. A graphical summary of observing constraints for the LSST survey from Cerro Pachon, in equatorial (*top*) and galactic coordinates (*bottom*). The two dashed blue lines outline the 24,000 deg^2 region for which the minimum airmass reaches values <1.4. The galactic plane regions with the highest stellar density are enclosed by solid red lines and include 1,000 deg^2. For the Wide-Fast-Deep (WFD) observing program, we use 18,000 of the possible 24,000 deg^2 to meet the Science Requirements Document (SRD) design goal. The WFD science program is designed to provide data for cosmology, transients and moving objects.

Coverage on the Sky

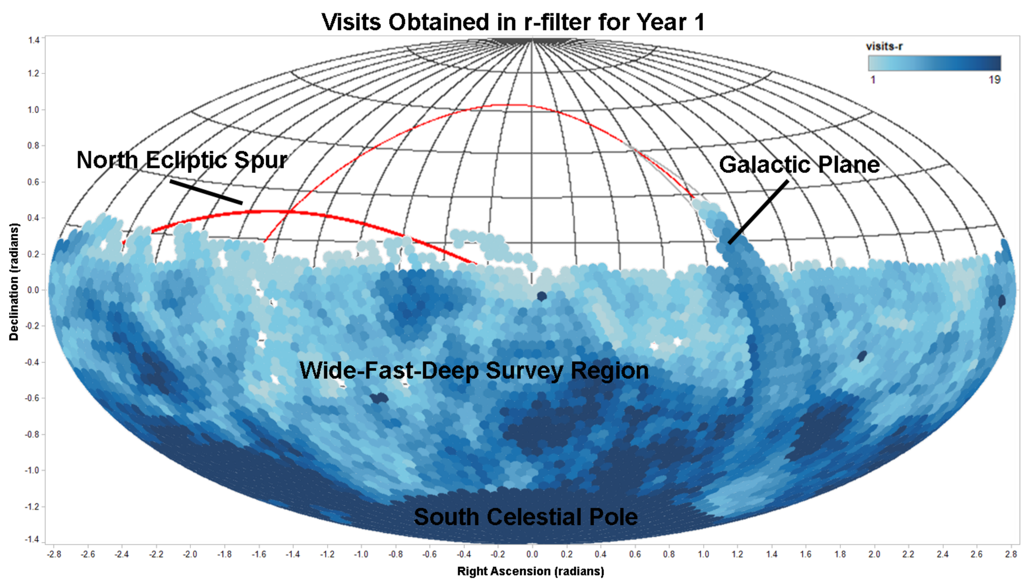
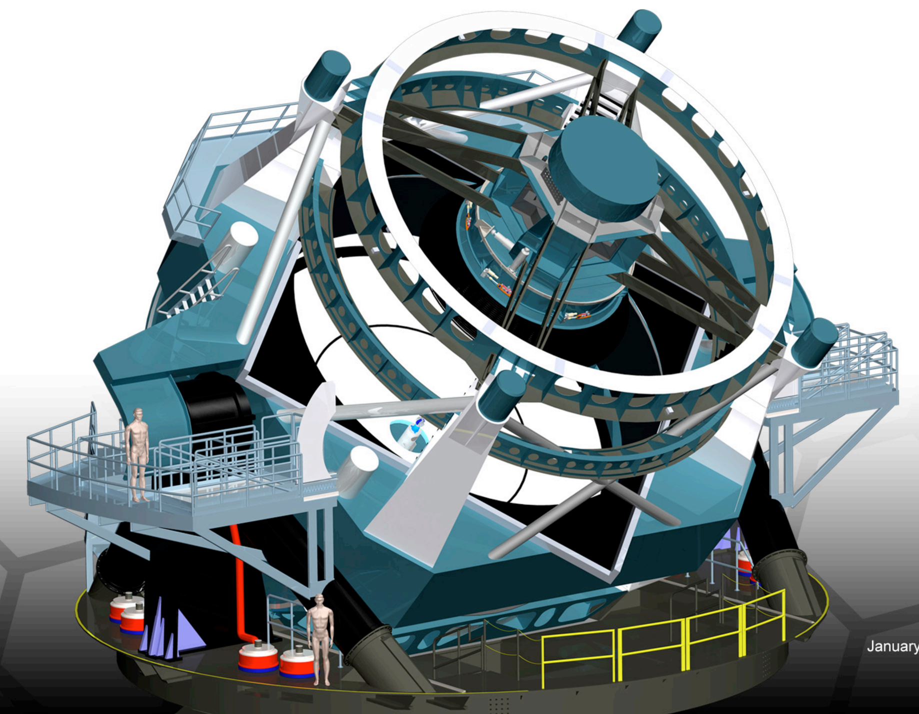


Figure 2. The number of visits obtained in each field in the r-filter for the first year of a survey is indicated by the shaded areas. Each of the areas of interest (*labeled*) has a specific cadence definition. It should be noted that this is the spatial distribution of the number of visits in the **first** year of a survey, and will not be as uniform as for the full 10-year survey (see Figure 9).



January 2012

THE OPERATIONS SIMULATOR

Achievements

- Demonstrated the need for a 9.6 deg^2 field of view.
- Motivated the need for 5 filters in dewar instead of 4 filters based on filter usage during each night.
- Provided survey coverage statistics by site to the site selection committee.
- Assessed the impact on the survey of various telescope changes, such as dome crawl.
- Supported engineering requirements analysis.

Software

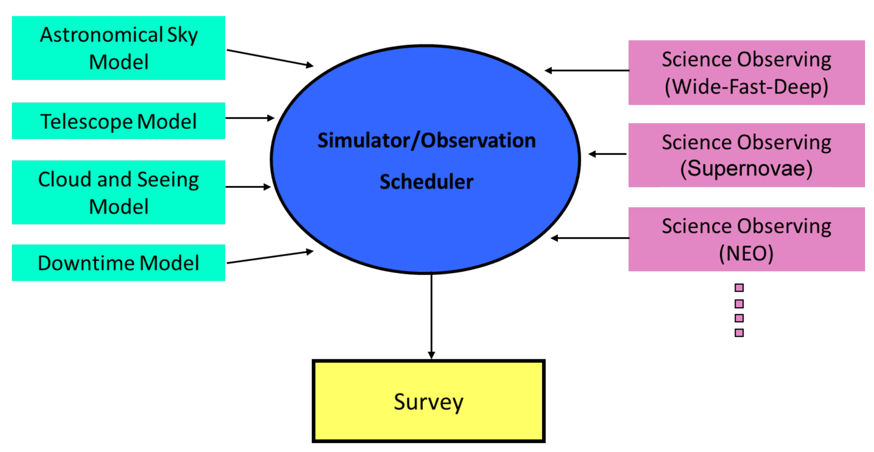


Figure 3. A conceptual model of the Operations Simulator software. In any simulated survey, an observing target is chosen based on the current sky conditions, the time needed to slew to candidate fields, and the simulated observing history, as well as by weighing the needs of all active science observing modes.

There have been three major advancements:

- Improved scheduled downtime implemented with a user-settable configuration file having parameters for timing and duration.
- Implementation of random downtime through addition of a tool which generates a sequence of random downtime intervals.
- Improved execution speed for a simulation by changing the way the cloud and seeing data is accessed.

For more information about cadence design and the science programs, please visit our public website at *http://www.lsst.org/lsst/opsim*

Science Collaboration members can find data sets linked from the Science Wiki and at *https://www.lsstcorp.org/opsim/home*

Future Work

- Develop multiple scheduling algorithms or strategies.
- Expand LSST observing modes (e.g., more flexible cadences).
- Experiment with dithering algorithms.
- Include higher fidelity sky brightness models (e.g., twilight & scattered light).
- Implement an improved weather model.
- Include logic to plan observations based on upcoming events such as sunrise, downtime or cloudy weather (not trivial).

VISUALIZATION, ANALYSIS & REPORTING

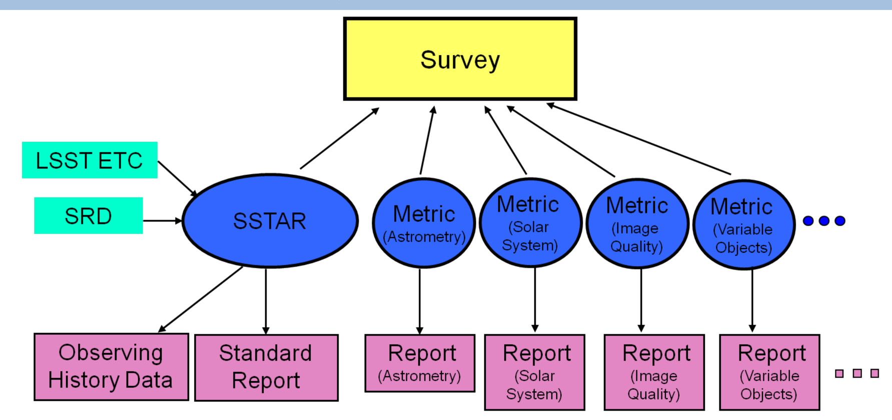


Figure 4. A conceptual model for the current standard analysis tools, the Simulated Survey Tools for Analysis and Reporting (SSTAR). The tool accesses the survey history generated by the Simulator, creates a number of science metrics, and outputs a report.

The static SSTAR standard report is a useful initial characterization of a simulated survey and contains analyses which compare to the design and stretch specs from the SRD. To more fully assess how well a survey meets a particular science goal, the development of **science metrics** is needed (see Chandrasekharan *et al.*, this session). The process of making sense of the data requires the ability to **explore and analyze** it in an **interactive** way, and to **communicate and collaborate** about the results. To this end we are

- Working with Science Collaborations to develop figures of merit.
- Designing an efficient and extensible framework for the figures of merit.
- Enabling comparisons between simulated surveys.
- Using visualization software for fast analysis and rapid prototyping.
- Working with the ASCOT Team to explore the feasibility of creating our own interactive analysis tools (*http://ascot.astro.washington.edu*).

BASELINE / REFERENCE SURVEY – OPSIM3.61

Inventory of Observation Time in 10-Year Survey

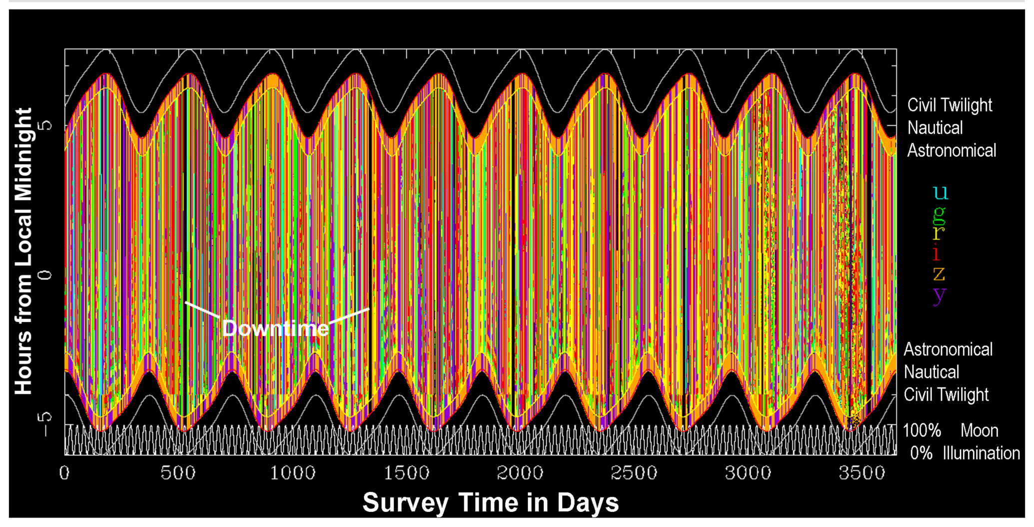


Figure 5. A graph showing the time spent observing during the night color-coded by filter. The enclosing curves indicate the time of civil (−6°), nautical (−12°), and astronomical (−18°) twilight. Note that only z- and y-filters are used between astronomical and nautical twilight. The Moon's illumination (in percent) is indicated by the arbitrarily scaled white curve at the bottom of the plot.

Correlation between Sky Brightness & Filter Choice

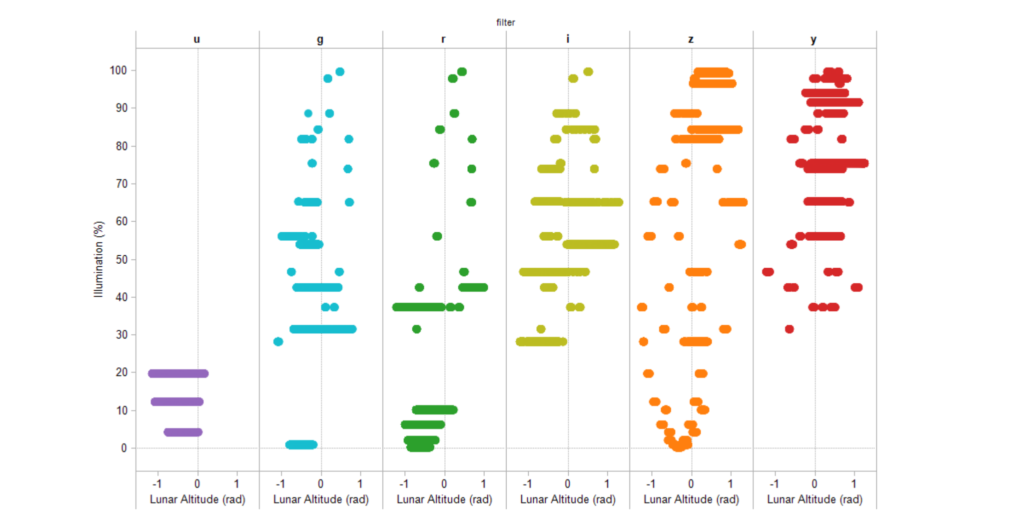


Figure 6. An example of a survey diagnostic. This plot shows that observations during an arbitrary lunar cycle are made using bluer filters in darker skies (low Moon illumination or Moon is set) and redder filters when the sky is brighter. The y-filter is taken out of the camera during new moon when the u-filter is put in, so there are no y-observations during low moon illumination.

Single Visit Depth

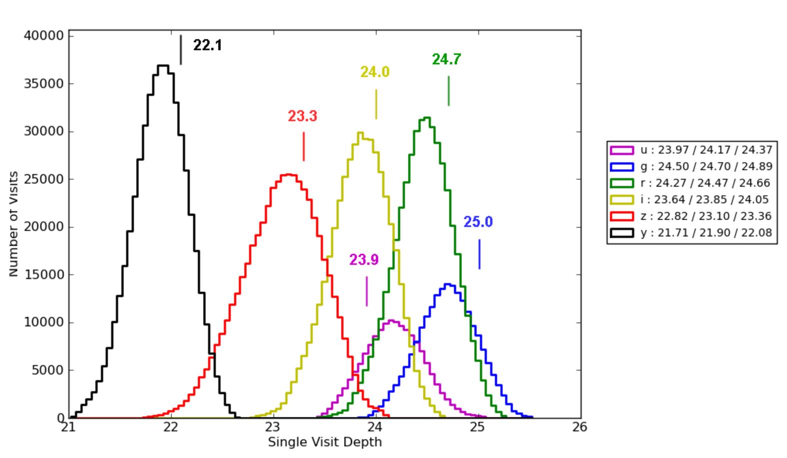


Figure 7. The number of visits with single visit depth (magnitudes) in each filter. The legend shows 25th, 50th (median), and 75th percentiles for each curve. The tickmarks above each curve indicate the value of single visit depth in ideal seeing and an airmass of 1.0.

Co-Added Depth Compared to a Zenith Depth Spec

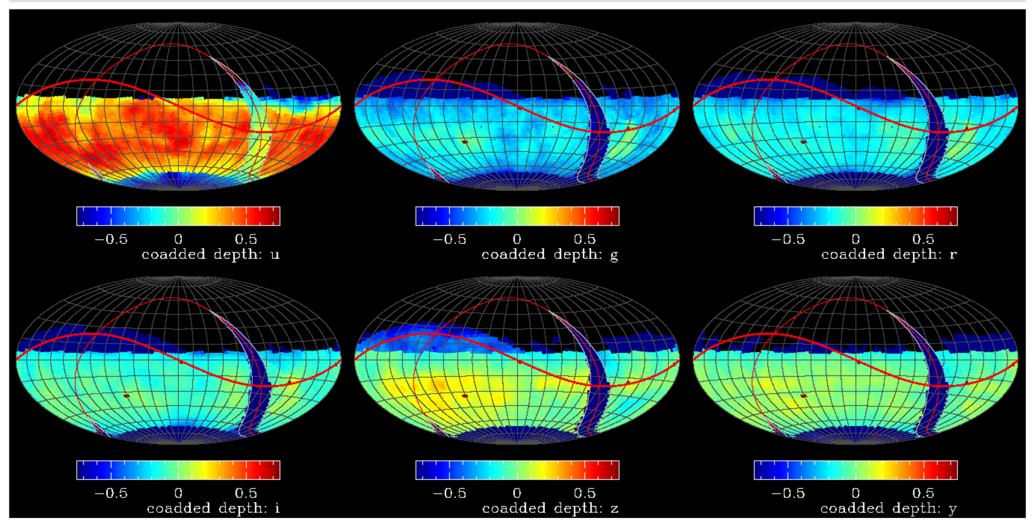


Figure 8. A map of the difference between the co-added depth calculated for each field and the design specification for the Wide-Fast-Deep co-added depth at zenith. Positive values exceed this ideal specification.

Number of Visits to Each Field

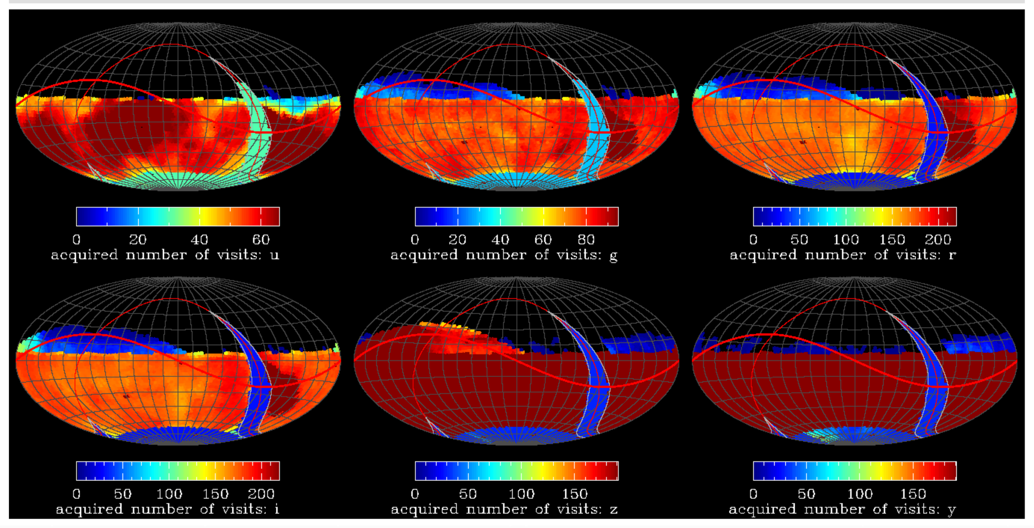


Figure 9. The number of visits acquired for each field is plotted in Hammer-Aitoff projection for each filter.

Co-Added Depth

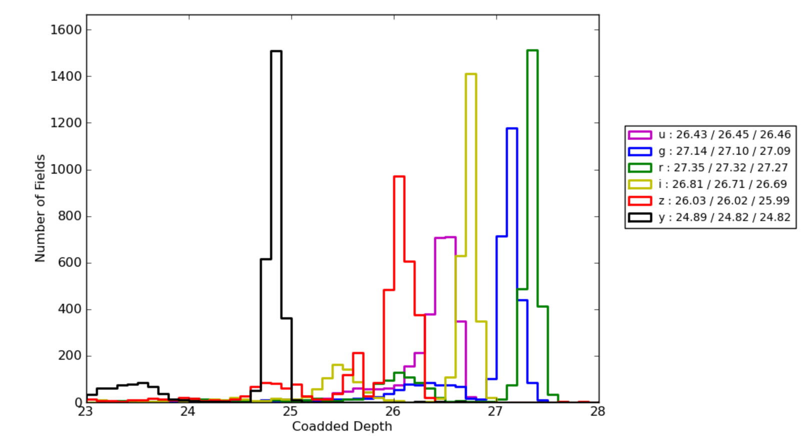


Figure 10. The number of fields with co-added depth in each filter. The legend shows 25th, 50th (median), and 75th percentiles for each curve.

LSST is a public-private partnership. Design and development activity is supported in part by the National Science Foundation. Additional funding comes from private gifts, grants to universities, and in-kind support at Department of Energy laboratories and other LSSTC Institutional Members.