Large Synoptic Survey Telescope

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LSST Operations Simulator

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The LSST Operations Simulator has been developed to investigate observation scheduling algorithms to effectively address multiple science goals with a single LSST cadence within the limits of opto-mechanical system performance and site conditions. The simulator includes sophisticated models of the telescope facility, including the camera and dome, historical weather and seeing distribution derived from many years of site data, and numerous "science programs" that operate within the code to request observations that match particular science criteria. The simulator has continued to develop, adding additional details, configuration parameters, and telescope model attributes. The Operations Simulator has supported engineering investigations to determine survey performance sensitivity to telescope parameters and is in use by scientists to specifically address optimal approaches to recovering transients and variable star characteristics as well as looking at the effect of dithering each visit on co-added image depth. The Operations Simulator is helping LSST determine a cadence that achieves a broad range of science within a single wide-fast-deep survey.

A Single Survey Supports Multiple Science Goals

The fundamental basis of the LSST concept is to scan the sky wide, fast and deep with a single observing strategy, giving rise to a dataset that simultaneously satisfies the majority of the science goals. This concept, the so-called "universal cadence," will yield the main wide-fast-deep survey (typical single visit depth of r=24.5) and use about 90% of the observing time. The remaining 10% of the observing time will be used to obtain improved coverage of parameter space such as very deep (r=26) observations, observations with very short revisit times (~1 minute), and observations of "special" regions such as the ecliptic, Galactic plane, and the Large and Small Magellanic Clouds. Other, micro-surveys, that would use about 1% of the time, or about 25 nights over ten years are also being considered. To evaluate the performance of a single survey under the demands of competing science drivers, the LSST Project has developed an Operations Simulator. This tool is being heavily used to evaluate the technical details of the LSST performance and the impact of these parameters on survey completion. The algorithms will become a fundamental component of the LSST scheduler that will drive the largely robotic observatory and the simulator itself will remain an important asset allowing LSST to adapt and evaluate observing strategies in response to changing scientific demands of the astronomical community.

The LSST Operations Simulator

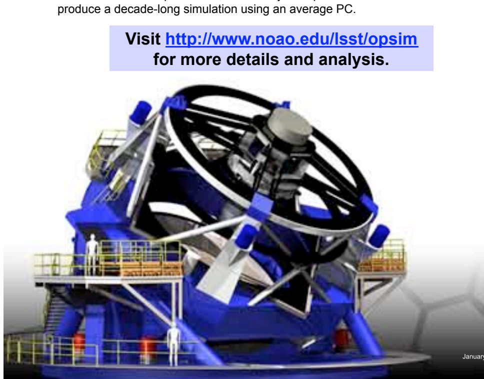
The LSST Operations Simulator creates realizations of the set of observations (visits) that the LSST will make over its 10-year lifetime. It contains detailed models of site conditions, the telescope, camera and facility, and an algorithm for scheduling observations. Its output includes an ordered list of visits for a realization of the entire survey lifetime, including estimates of the depth of the stacked image in a given filter as a function of position.

Observations are scheduled by a ranking algorithm. After a given exposure, all possible next observations are assigned a score, which depends upon their locations, times, and filters according to a set of scientific requirements that can vary with time and location. For example, if an ecliptic field has been observed in the r band, the score for another r-band observation of the same field will initially be quite low, but it will rise in time to peak about 30 min. after the first observation, and decline thereafter. This behavior results in these observations being acquired as pairs roughly 30 min. apart, the goal of which is to assist NEO detections. Of course, the revisit times are adjustable and can be used to explore the survey space. To ensure uniform sky coverage, fields with fewer previous observations will be scored more highly than those that have already been observed more frequently.

Observing conditions during the simulation are based on a model for seeing drawn from actual site data in Chile and a 10 year record of cloudiness from Cerro Tololo. The seeing model includes the auto-correlation spectrum of seeing with time over intervals of minutes to seasons taken from ~4 years of Cerro Pachón DIMM measurements. The ten years of cloud data were collected by 4-m telescope operators 4 times per night and parameterized as octants of the sky covered by cloud. The signal to noise ratio of each observation is calculated in a post-processing step using the following data from the simulation: the dark sky brightness in each filter, the effects of seeing and atmospheric transparency, and an explicit model for scattered light from the moon and/or twilight at each observation. The time taken to move from one observation to the next is given by a detailed model of the camera, telescope, and dome. It includes such effects as the acceleration/deceleration profiles employed in moving in altitude, azimuth, camera rotator, dome azimuth, and wind/stray light screen altitude, the time taken to damp vibrations excited by each slew, cable wrap, time taken for active optics lock and correction as a function of slew distance, filter change, and focal plane readout.

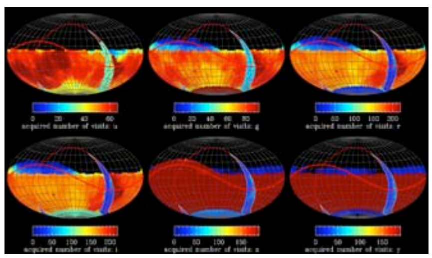
Once all possible next observations have been scored for scientific priority, their scores are modified according to observing conditions (e.g., seeing, airmass, and sky brightness) and to criteria such as low slew delay to move from the current position, time spent to change filters, etc. The highest ranked observation is then performed, and the cycle repeats. It takes about a week to produce a decade-long simulation using an average PC.

Visit http://www.noao.edu/lsst/opsim for more details and analysis.



The Baseline LSST Survey

The simulator has shown that the LSST efficiently observes the available sky with ~5.6 million 15-second exposures in 10 years, distributing these observations in pairs temporally, spatially, and among the 6 filters in a variety of ways as driven by the specific science parameters. Simulations show how the baseline cadence successfully addresses LSST science requirements and how some program details can strongly impact scientific investigations. As these parameters continue to be investigated and further fidelity is added to the simulator, the baseline survey for LSST is captured and adopted. The attached report, available at http://www.noao.edu/lsst/opsim, describes the LSST Baseline survey, providing the input configuration parameters and a host of data to describe the output results.



The number of visits in one realization of a simulated ten-year survey in all six LSST filters, shown in Equatorial coordinates. The project goals are to have 56, 80, 180, 180, 164, & 164 visits in the u, g, r, i, z, & y filters, respectively, over 20,000 deg^2 of sky. One of the deep-drilling fields is apparent at α= 90°; δ= -32°.

Simulated Survey Tools for Analysis and Reporting - SSTAR

A standard report has been created to assist scientists and engineers in evaluating a particular simulated survey. This report is automatically generated from the output of each simulation. It aims to provide scientists with a standard set of statistics and scientific figures of merit from which to assess general survey performance. The observation history table is also provided to the Science Collaborations for more detailed evaluation of specific science cases.

Below is the SSTAR report for the current LSST reference survey.

Simulated Survey Technical Analysis Report

Operations Simulator Team
Large Synoptic Survey Telescope

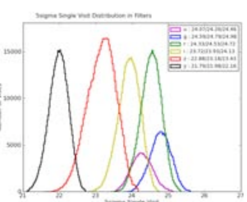
Contents

Actual SSTAR Report Stapled to Poster Here!

The Operations Simulator Continues to Develop: More Science Programs, Better Fidelity, & Broader Performance Metrics

Single Visit Depth

The 5σ limiting magnitude for each visit to a field is plotted for each of the six filters. The inset box contains the values of the 25th, 50th (median), and 75th percentiles for each curve. The Simulator has limits for sky brightness and seeing conditions for each filter in each observing cadence. These limits result in the relatively tight distributions of limiting magnitudes for each filter .



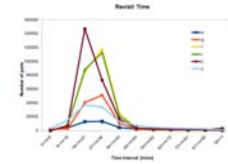
Variable Stars – *an Example*

Period	Recovered	S/N	Tolerance
0.1	100%	All	<1x10^{-5}
1.0	60%	100	2x10^{-5}
1.0	50%	10	2x10^{-5}
1.0	50%	7	2x10^{-5}
1.0	50%	5	2x10^{-5}
1.0	20%	3	2x10^{-5}
10	100%	100, 10, 7, 5	2x10^{-4}
10	90%	3	2x10^{-4}
100	100%	All	2x10^{-3}
1000	100%	100	2x10^{-2}
1000	100%	10	2x10^{-2}
1000	70%	7	2x10^{-2}
1000	90%	5	2x10^{-2}
1000	50%	3	2x10^{-2}

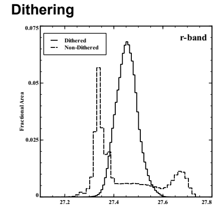
A light curve is constructed from an average Delta Scuti light curve's Fourier coefficients with an arbitrary mean and amplitude. The measurement errors are drawn from a Gaussian distribution with a mean of amplitude/Signal to Noise (for S/N of 100, 10, 7, 5, and 3) and a phase from a flat distribution of phases. The curve is sampled using r-band observations from fields in the wide, fast, deep cadence in the baseline survey, opsim1.29, and analyzed with the cleanest algorithm. Periods range from 0.1 to 1000 days. The period is considered recovered if found within the listed tolerance. The cadence does well except for a 1 day alias.

Transient & Moving Object Science

The figure to the right shows the number of revisits to a field within a given time interval for each filter. The distribution is strongly peaked near 30 minutes because of the wide, fast, deep cadence. There are however, significant numbers of pairs across a wide range of times probing fast and slow moving objects and fast and slow transients.



Dithering



The current Operations Simulator assumes each visit is taken with the field centers placed onto a fixed grid of an optimally packed tessellation. This strategy gives a variation of the effective depth across the sky, as shown in the dashed line in the Figure. Using a simple dithering pattern based on a triangular tessellation of the inscribed hexagon, we have shown that the co-added 5σ depth is significantly increased relative to the non-dithered cadence. The distribution of depth values is also much smoother, and well behaved in the dithered case.

Look-ahead and General Metrics

The Operations Simulator design is being adapted to take advantage of knowledge about the future when determining priorities for field observations. The current "greedy" algorithm awards a visit to the field that generates the highest priority at the current moment in time. The existing simulations are therefore pessimistic in that sequences of visits to fields are started based on current conditions without fore-knowledge of impending future events, such as the end of observing (12 deg twilight), which will prevent the sequence from completing. The capability of forecasting events, such as the end of night, set time of a field, lunar phase, scheduled maintenance, or even some expectation of pending weather, would favor selection of other fields that will satisfy science objectives.

The current simulation includes parametric input of key science specifications from the Science Requirements Document, and the analysis compares to these values as the merits of success. Effort is now underway to plan figures of merit to measure survey completeness and to enable results that are more generic and support other science programs. As LSST approaches operational status, interest in enabling other science will grow and with it these more complex metrics.

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.