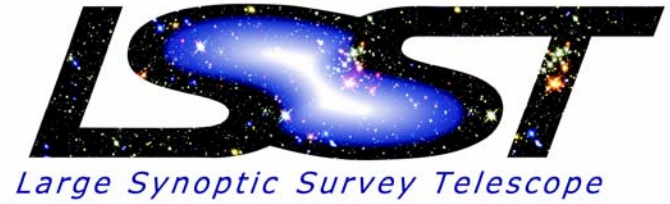


LSST Operations Simulator

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ABSTRACT: We have developed an operations simulator for LSST and used it to explore design and operations parameter space for this large etendue telescope and its ten year survey mission. The design is modular, with separate science programs coded in separate modules. There is a sophisticated telescope module with all motions parametrized for ease of testing different telescope capabilities, e.g. effect of acceleration capabilities of various motors on science output. Sky brightness is calculated as a function of moon phase and separation. A sophisticated exposure time calculator has been developed for LSST which is being incorporated into the simulator to allow specification of S/N requirements. All important parameters for the telescope, the site and the science programs are easily accessible in configuration files. Seeing and cloud data from the three candidate LSST sites are used for our simulations.

The simulator has two broad categories of science proposals: sky coverage and transient events. Sky coverage proposals base their observing priorities on a required number of observations for each field in a particular filter with specified conditions (maximum seeing, sky brightness, etc) and one is used for a weak lensing investigation. Transient proposals are highly configurable. A transient proposal can require sequential, multiple exposures in various filters with a specified sequence of filters, and require a particular cadence for multiple revisits to complete an observation sequence. Each science proposal ranks potential observations based upon the internal logic of that proposal.

We present the results of a variety of mixed science program observing simulations, showing how varied programs can be carried out simultaneously, with many observations serving multiple science goals. The simulator has shown that LSST can carry out its multiple missions under a variety of conditions.

There are a number of distinct science goals for the LSST: weak lensing, large scale structure, detecting potentially hazardous objects, completing the inventory of the Solar System, investigating cosmology using super novae, monitoring the transient universe and mapping the Milky Way through astrometry for proper motions and parallaxes. We have developed a tool, the LSST operations simulator to investigate observing cadences and strategies and investigate the suitability of different sites.

The simulator design

The simulator is coded in an open source based simulation language-- SimPy. SimPy is an object-oriented, process-based discrete-event simulation language based on standard Python and released under the GNU GPL.

The simulator is modular in design and will accept multiple, distinct, observing programs. Each program ranks potential observations based upon user specified parameters, but hard coded algorithms. Rankings are based upon current seeing, sky brightness, and utility for completing a program.

The current simulator ranks potential observations based upon the simulation history prior to the observation. For programs which have a specified cadence, the program increases rankings for observations which will be useful for that cadence, but does not 'look ahead' to determine the consequences of the current ranking.

The simulator uses a sophisticated sky model, calculating sky brightness using the Krisciunas and Schaeffer (1991) model. It tracks the sun, moon and planets using SLALIB routines.

The simulator has a complex telescope model to calculate the time needed to slew to a new field which is used in ranking potential observations. All movements are tracked: mount, dome, optics, instrument rotator, cable wraps and filter changer. The velocities and accelerations for these motions are all settable parameters. There are open-loop optics alignments for all moves and closed-loop alignments for moves in altitude greater than a settable parameter (currently 9 degrees).

The simulator has seeing and cloud data for 1-3 years for the three sites being considered for LSST. The cloud data has been derived from satellite imaging data. The methodology has been calibrated using satellite imagery of the 2MASS observing sites data and 2MASS observing data and logs. Continuous seeing data for a year or more is not available for our sites. Seeing data has been generated by using available DIMM data to determine the power spectrum of the seeing throughout the year and creating complete data sets which have that power spectrum.

There are more than 200 user defined parameters governing the telescope, science program constraints and site characteristics. This is a large parameter space which we are currently exploring. We have not yet found the optimum parameter settings for many of the parameters, and this is a high priority.

The configurations for each simulation and the details of each observation are saved in a MySQL database for post-processing and analysis. A one year simulation takes about 6 hours on a typical PC, but depends on various caching parameters and the complexity of the science programs.

There are significant improvements and changes which are planned. We are implementing a twilight sky model for observing in z and y. We are implementing look-forward capabilities for better handling such things as instrument limits for long visits, increasing rankings of setting fields and probabilistic weather prediction for ranking. We will integrate the LSST exposure time calculator into the simulator to allow science programs to specify signal-to-noise requirements. Signal-to-noise calculations are now a post-processing step. We will implement partly cloudy observing using the satellite data to identify observable regions of the sky.

The figure to the right shows the simulator sky coverage for one year of observing with three science goals: a weak lensing survey as defined in the LSST Science Requirements Document, an ecliptic plane, near Earth asteroid survey using the cadence described in the column to the right and a super nova survey on a limited set of fields requiring 5 filter light-curves spanning 30 days. The needed depth for the weak lensing survey will be reached with 33 visits in r per year, 25 visits in i, 12 visits in y, 8 visits in z and 3 visits in g and this is accomplished for 19,754 square degrees as shown in the Aitoff projections labeled by filter. The lower right panel shows the completed near Earth asteroid sequences (2972) and completed super nova sequences (76). These numbers have been adjusted to reflect an optimization to the slew time, limiting large altitude changes and pre-astronomical twilight observing in z and y. This simulation was done for the San Pedro Martir site, but Las Campanas and Cerro Pachon simulations produce roughly similar results.

Simulator Science Programs and Observation Ranking

There are currently three classes of observing programs which can be used for various science programs. A simulation can run any or all of these classes as well as multiple instances of a class with different parameters. All programs have parameters which define acceptable seeing, airmass and sky brightness conditions. All programs can be limited to defined regions of the sky. The classes are:

Broad area survey: a program which has no cadence requirements, but has requirements on the total number of visits on a per filter basis. This program has been used to implement a weak lensing survey.

Transient survey: a program which has a cadence requirement. The cadence can be simple or complex. The cadence is carried out in a defined set of filters, but is not defined on a per filter basis. This program has been used to implement a near Earth asteroid survey where three pairs of visits to a field are required per lunation. A pair of visits is separated by about 30 minutes and the pairs are separated by about 5 days. Each pair must be in a single filter and observing can be done in g, r or i.

Transient subsequence proposal: a program which can have complex, independent cadences for multiple filters. This program can be used to implement a multi-color super nova survey, a multi-color Kuiper belt object survey and even a weak lensing survey.

The ranking of potential observations within each program accounts for such things as the potential to complete a transient sequence for a given field, how close to completing needed observations in a given field are compared to the time remaining and the angular separation between the current field and the potential field. Each program ranks all available fields internally and then sends a user defined number (commonly about 100) of the top fields to a time allocation module. Each program has a defined priority which is a simple multiplicative factor for its rankings. The combined potential observations from all programs are then re-ranked using the proposal priority, the actual slew time to get to a field and whether the observation will be useful to more than one program. The slew time calculation is computationally intensive, so we have implemented the capability to take a defined number of the highest re-ranked observations and work through them before calculating slew times for many hundreds of fields.

Visualization of One Year of Observing at San Pedro Martir with Three Science Programs

