LSST Survey Strategy: Cadence Design and Simulation

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The LSST will allow a wide variety of science to be done using data from a single survey. A large part of ensuring this claim is designing a smart and adaptive algorithm for scheduling observations, one which can effectively merge multiple requirements into a single program of observations while maximizing time on the sky and coping efficiently with changing conditions in real time. Diverse requirements include multiband imaging of 25,000 square degrees of sky, achieving a uniform depth of exposure across 20,000 square degrees in each of six filters, allowing effective search strategies for NEO's and short- and long-period variables, and providing frequent, deep exposures to characterize faint transients and moving objects. The LSST operations simulator includes a detailed model of seeing and sky transparency derived from data obtained at its site on Cerro Pachon, Chile. It also includes a detailed model of the delays incurred by readout of the camera, filter changes, active optics acquisition, and movements of the dome and telescope. We describe current progress in the LSST scheduler design and present simulations of a prototype ten-year LSST mission which demonstrate that all of the science requirements and constraints can be accommodated successfully into a single survey.

LSST Scheduling Goals

In a ten-year survey, the LSST will take more than five million exposures, collecting over 32 petabytes of raw image data to produce a deep, time-dependent, multi-color movie of 30,000 square degrees of sky. The sequence, or cadence, with which these exposures are made is essential to achieving multiple scientific goals from a single survey, an important feature of the LSST concept. The algorithm which determines this sequence will be the ``brains'' of the robotic observatory; we have developed a sophisticated operations simulator to aid in designing this algorithm. It allows us to explore in detail what science the survey can achieve in practice and provides a detailed connection between scientific requirements and specific elements of the system design.

The LSST survey sequence must provide

- time and color sampling to detect and characterize a wide variety of transient, variable, and moving objects
- time sampling to allow accurate proper motions and parallaxes to be determined over the entire survey area.
- uniform exposure depth over a large area of sky to enable an accurate catalog of photometric redshifts.
- for each position on the sky, a wide range in position angle of the telescope pupil on the sky and the camera angle on the pupil to control photometric and shear systematics.
- the highest possible image signal to noise ratio by obtaining images at the lowest air mass and sky background consistent with other survey goals.

We have simulated a full ten-year survey driven by the current version of our scheduling algorithm. Knowing that scientific priorities can change and that new analysis innovations may lead to changes in cadence requirements, we present this as an existence proof that a rich set of investigations can indeed be carried out with this observing strategy. We anticipate that the process of optimizing LSST's scheduler will continue throughout the lifetime, of the project.

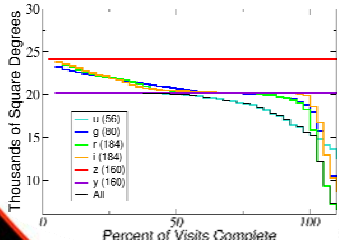


Figure 1: The fractional progress toward survey depth requirements (the indicated number of visits) imposed by photometric redshift accuracy as a function of area on the sky.

The LSST Operations Simulator

LSST will take data as pairs of back-to-back, 15-second exposures to aid in cosmic-ray rejection. We call this pair a "visit", a single observation of one ten-square-degree field through a given filter. Designing the LSST survey requires ordering these visits in time and allocating them among its six filters so as to maximize the return on scientific goals in a fixed survey duration. Cosmological parameter estimation by many techniques requires uniform coverage of 20,000 square degrees of sky. Obtaining accurate photometric red-shifts in every field requires a specified number of visits in each filter (see the poster by Ivezic et al, 86.02). Weak lensing shear measurements benefit from allocating times of best seeing to observations in the r and i bands. Maximizing signal to noise ratios requires choosing the next filter based upon the current sky background. Supernova cosmology requires frequent, deep photometry in all bands, with z and Y observations even during dark time. Detecting the motion of solar system objects and transients, characterizing variability on various timescales, and acquiring the best proper motions and parallaxes place further demands upon the distribution of revisit intervals and observation geometries to each point on the sky. Finally, making uniform progress in time toward these goals facilitates analyses made while the survey is still in progress.

A ten-year survey with perfect weather has an average of slightly more than ten hours per night of available observing time during nighttime and nautical (12 degree) twilight. From this must be subtracted times of bad weather, approximately 21% at Cerro Pachón, and scheduled and unscheduled down-time, assumed to be two weeks every two years and 3% of the total, respectively. A realistic estimate of the time spent actually gathering photons must reflect the performance of the telescope system; the simulator includes a detailed engineering model of telescope, dome, and camera activities such as slew motions specified by accelerations, maximum velocities, and settling times; active optics open- and closed-loop acquisition times; filter changes; and focal plane readout; all of which depend upon the current state of the system. An automated survey should also be able to take advantage, in real time, of weather and seeing conditions; the simulator employs a ten-year database of hourly weather conditions as actually observed at Cerro Tololo from 1994 to 2004, and employs a seeing time series developed from data gathered from on-site MASS/DIMM measurements.

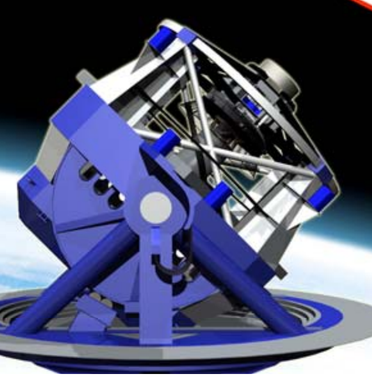
Before each observation, a series of functions called "proposals" rank potential visits according to criteria such as timing, sky background, seeing, air mass, and progress toward survey goals. These rankings are then merged, penalties are applied for slew and filter change times and other operational considerations, and ranked again. The best visit is then made, and the process repeats. We have found that four proposals are sufficient to ensure meeting all requirements:

Deep-Wide-Fast is designed to provide the deep, uniform coverage of the sky with uniform progress toward the specified number of visits over ten years. In times of good seeing and at low airmass, preference is given to r and i band observations. It provides most of the temporal sampling for discovering time variability and detecting moving solar system objects. It requires, as often as possible, that each field be observed twice with visits separated by 15 – 60 minutes to provide motion vectors to link moving object detections and fine time sampling for measuring short-period variability.

Northern Ecliptic extends Deep-Wide-Fast to 4,000 square degrees of the northern ecliptic beyond the airmass limit of the main survey.

Deep-Drilling: A small fraction of time spent employing different strategies can significantly enhance the overall science return. This proposal allocates ten minutes' exposure per night to a small number of fields; the time is distributed among filters on a five-day cycle so as to provide high-quality type-Ia supernova light curves at redshifts to z~1.2. Many of the these fields are distributed across the ecliptic plane to enable deeper searches for KBO's and other denizens of the outer solar system.

Galactic Plane allocates thirty observations in each of six filters in a region of 1000 square degrees around the galactic center where the high stellar density leads to a confusion limit at much brighter magnitudes than those attained in the rest of the survey.



Simulation Results

2,767,596 visits (5,535,192 15-second exposures) in 10-year survey

Deep-Wide-Fast: 20,000 square degrees at airmass < 1.4:
per-visit limiting magnitude (5σ, AB):
u: 23.9 g: 25.0 r: 24.7 i: 24.0 z: 23.3 y: 22.1
uniform stacked limiting magnitude (5σ, AB):
u: 26.0 g: 27.4 r: 27.5 i: 27.0 z: 26.2 y: 24.8
average airmass over all observations: 1.2
746,667 pairs of observations separated by 15-60 minutes in griz, an average of 6 per field per lunation
86% recovery of >140m NEA's
excellent period recovery for periods > 0.1 day (see figure 3)

Northern Ecliptic: 4,000 square degrees:
63,497 pairs of observations separated by 15-60 minutes in griz, an average of 2.3 pairs per field per lunation

Deep-Drilling: 150 sequences of 100 day duration with > 85% of observations completed. Dense grizy lightcurves to per-visit limiting magnitude (5σ, AB, for z=1 SN Ia):
g: 26.2 r: 26.3 i: 25.8 z: 25.1 y: 23.7

Galactic Plane: 30 observations in each of ugrizy in each field over 10 years
Uniform stacked limiting magnitude (5σ, AB) :
u: 25.6 g: 26.8 r: 26.5 i: 26.0 z: 25.3 y: 23.9

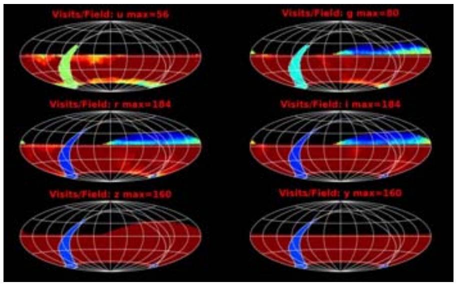


Figure 2: Sky coverage of the ten-year survey. The predominantly red regions are the 20,000 square degrees in which the airmass < 1.4; the galactic plane region, with 30 visits per filter, is seen as the blue sliver; and the northern ecliptic region is in the upper right.

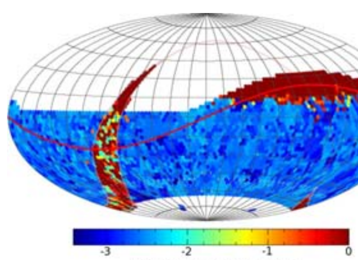


Figure 3: Error in recovering periods from 0.14 to 120 days from RR Lyrae-like lightcurves with an amplitude-to-noise ratio of 5, sampled on the observation times of each field. Fields were assigned errors of unity if a catastrophic error occurred at any period.

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