Large Synoptic Survey Telescope

LSST: Cadence Design

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A goal of the LSST project is to capture the optical sky into a database so effectively that observing the database is a satisfactory, and even superior, substitute for individual observations. Such a data set of deep, high-quality, and oft-repeated images will enable a wide variety of science. A large part of reaching this goal is designing a smart and adaptive strategy 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 30,000 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. We present results from detailed simulations of LSST operations which include time-dependent descriptions of site conditions and a sophisticated model for the operations of camera, telescope, dome, and data system. We describe current progress in the LSST scheduler design and present recent simulations of prototype ten-year LSST missions 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 60 petabytes of raw image data. Processed in real time, these data will form a deep, exquisitely-calibrated, time-dependent, multi-color movie of 30,000 square degrees of sky. Capturing such a rich photometric record, and making it widely available, will enable a broad variety of scientific investigations to be carried out in parallel by "observing" the database rather than directly observing the sky.

The sequence, or cadence, in which these exposures are made is essential to achieving multiple scientific goals from a single survey. The algorithm which embodies this sequence will be the "brains" of the robotic observatory. We have developed a sophisticated operations simulator for LSST to aid in designing this algorithm. It allows us to explore what science the survey can enable in practice. It provides a detailed connection between scientific requirements and specific elements of the system design. By running sample surveys with given scheduling criteria, we produce simulated catalogs which contain complete information about the observations performed: time, position, sky backgrounds, transparency, and detailed information on telescope configuration. These sample surveys are then analyzed with respect to their success in reaching a wide variety of scientific goals, frequently by coupling them to models of specific astronomical systems and the appropriate analysis pipelines. In this way we can assess the impact of cadence modifications with the greatest possible fidelity.

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 of 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 airmass and sky backgrounds consistent with other survey goals.

Cadence Design

LSST will take data as a sequence of short exposures at a single position on the sky and in a single filter called a "visit". Typically, a visit is two back-to-back 15-second exposures separated by two seconds to read out the focal plane array. 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 and obtaining accurate photometric redshifts with a specified number of visits in each filter; shear measurements benefit by 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.

Making the most effective use of a fixed survey duration requires adopting different survey strategies in different parts of the sky, informed by an understanding of what science is expected from each region and practical astronomical and system constraints. For example, NEA completeness is enhanced by observing near the northern ecliptic. The higher airmass in this region may be compensated by making three exposures per visit, and using filters which maximize the achieved signal-to-noise.

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 twilight. From this must be subtracted times of bad weather and scheduled and unscheduled down-time. 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, active optics acquisition times, filter changes, and focal plane readout. 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 and employs a seeing time series developed from data gathered from on-site MASS/DIMM measurements.

The Baseline Survey

The LSST baseline survey contains four regions:

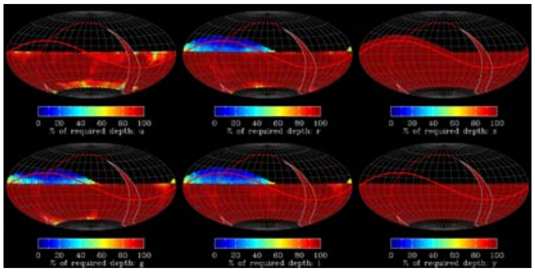
- 20,000 square degrees at the lowest possible airmass, designed to provide deep, uniform coverage of the sky, with uniform progress toward limiting magnitudes in each of six filters required for photometric redshift determination. To provide temporal sampling for discovering time variability and detecting moving solar-system objects, each field is observed in pairs of visits separated by 30 minutes.
- 4,000 square degrees around the northern ecliptic beyond the airmass limits of the main survey, also observed in 30 minutes pairs of visits.
- 1,000 square degrees around the galactic center where the high stellar density leads to a confusion limit at brighter magnitudes than those attained in the rest of the survey
- A small number of individual fields which receive 10 minutes of exposure per night, providing lightcurves with much deeper limiting magnitudes and finer time sampling than in the rest of the survey. These provide high-quality type Ia supernova lightcurves for objects to z~1.2 and enable deeper searches for KBO's and other denizens of the outer solar system.

Current Investigations

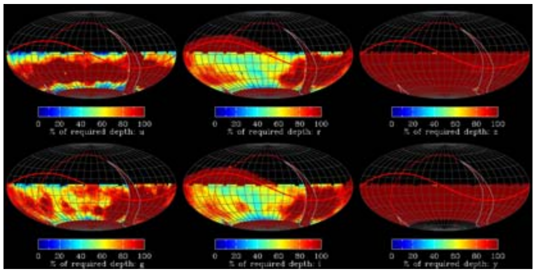
We are currently working to increase the efficiency and completeness of the NEA search, examining the effects of deeper visits in the northern ecliptic region and of observing closer to twilight.

Increasing the survey area to include the south celestial pole and the Magellanic Clouds is of great interest to a wide constituency; we are working to develop cadences with good performance on detecting and characterizing variable objects, with an exposure distribution among filters optimized to work in stellar populations.

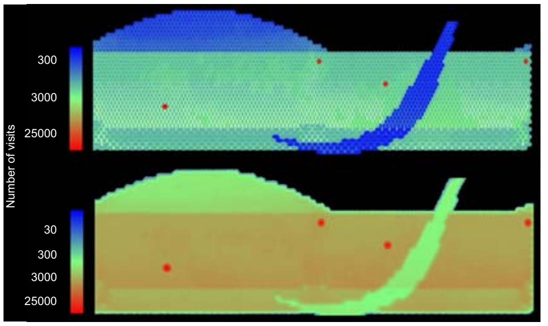
The simulator employs a tessellation of the sky by 3.5 degree fields with fixed locations. This leads to regions of overlap between fields which receive, on average, double the exposure of the rest of the survey. The resulting signal-to-noise variation, with its fixed pattern on the sky, can introduce spurious signals in cosmological measurements. The effect can largely be eliminated by dithering the field centers over time, distributing the extra exposure uniformly over the sky.



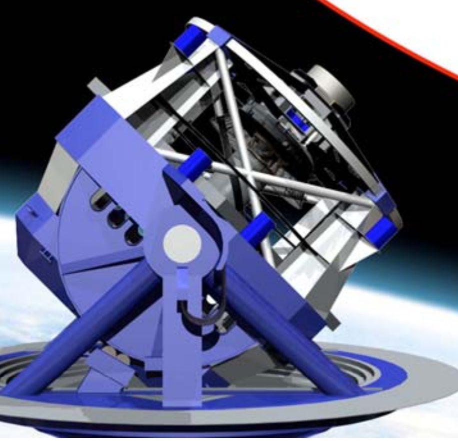
Baseline survey sky coverage: 20,000 square degrees is covered to the required depth of 56, 80, 184, 184, 160, and 160 visits in u, g, r, i, z, and y, respectively. The galactic plane region is covered to the required 30 visits in each filter.



Adding the south celestial pole: an additional 2500 square degrees, with 11, 16, 100, 37, 100, and 0 visits in u, g, r, i, z, and y, was observed simultaneously with the baseline survey. Requiring the southern region to complete in ten years decreases completeness in the main 20,000 square degree region by ~15%. The z and y bands are observed in part during nautical twilight, allowing more complete coverage. The northern ecliptic region employed visits of 3 x 27 seconds in r and i to increase NEA survey completeness.



Increasing exposure uniformity: The example surveys shown above, and in the upper panel in this figure, employed a fixed set of field centers which were visited repeatedly. The lower panel shows the result of dithering the field locations systematically throughout the course of the survey, distributing the extra exposure obtained in field overlap regions smoothly across the sky. The red regions are those receiving 10 minutes of exposure per night.



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