Large Synoptic Survey Telescope

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End-to-End Simulations of the LSST System

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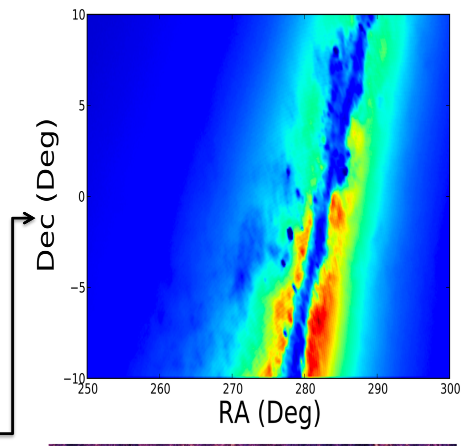
Efficient use of the data produced by the Large Synoptic Survey Telescope (LSST) will require comprehensive *a priori* knowledge of the impact of telescope design and implementation on the resulting catalogs and images. This includes gross characteristics like per band detection limits (coadded and single frame), as well as fine grained information such as point spread function behavior as a function of focal plane position and limits on the ability of the imaging system and reduction pipelines to accurately determine galaxy shapes. The LSST Image Simulation group is leading the effort to simulate the LSST system from end-to-end with high fidelity. Input catalogs including source variability, moving objects, and cosmological transients are matched to the LSST survey depth of r=28. These catalogs can be used to produce simulated images for exercising the data reduction pipelines as well as simulated catalogs for calibration, moving object detection, and probing proposed science questions. We present the progress toward end-to-end simulation of the LSST system.

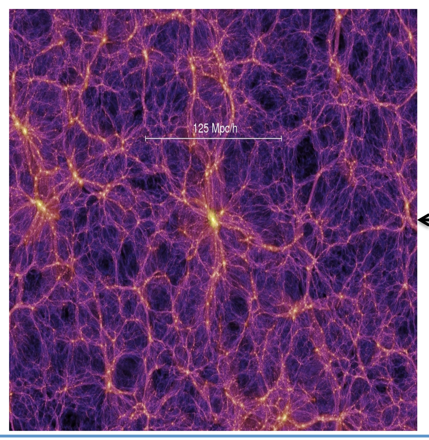
Base Catalogs

Milky Way Model

The model of the Galaxy is based on the model by Jurić et al. (2008). It includes thin disk, thick disk and halo components. In addition to the stellar distribution model, the simulated stars are embedded in a Galactic dust model from Amores and Lepine (2005) normalized to the Schlegel, Finkbeiner and Davis (1998) dust maps.

The plot to the right shows the density of stars as a function of equatorial coordinate. The obscuring dust in the plane of the Galaxy is clearly visible as a dark blue band.





Galaxy Model

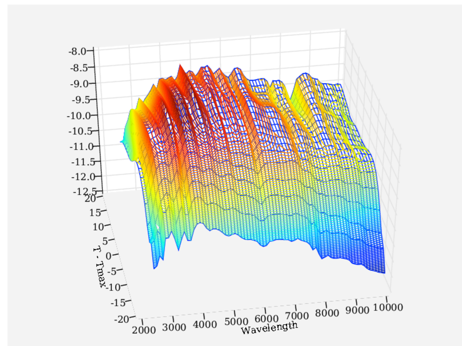
The galaxies are distributed based on the Millennium simulation using light cone software from the N-Body shop at the University of Washington. Physical properties were derived from semi-analytic models of De Lucia et al. (2006). Galaxies have disk, bulge, and AGN components each with an extinction model and SED.

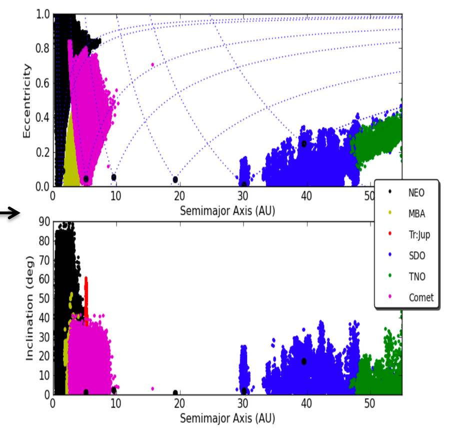
The figure to the left shows the density of particles in the Millennium simulation. We use a four degree radius light cone to populate the base catalogs.

Solar System

The solar system model is based the model presented in Grav et al. (2010). Since the astrometric precision must be good to 10 mas, great care is taken to enable precise calculation of ephemerides quickly. 10 million individual orbits are realized on one day intervals resulting in > 1 billion database entries for 1 year.

The figures to the right show the different solar system groups that make up the model. The black dots are the locations of the planets.

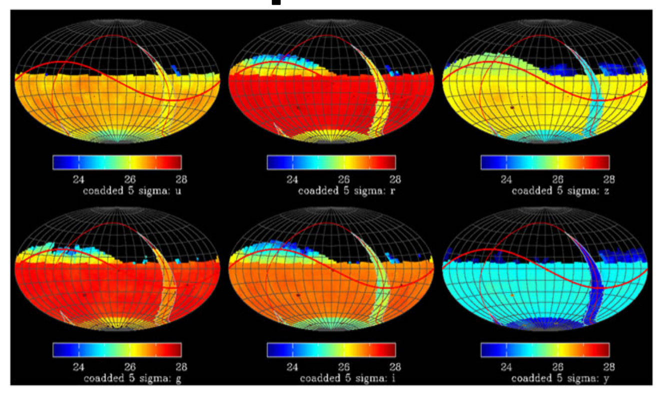




Variable Sources

LSST will catalog more periodic, transient, and moving sources than any single survey has done to date. Thus it is particularly important to be able to simulate the variable sky to high fidelity. We include periodic sources through single band light curves. Where known, we can include full spectro-temporal variability. For example, see the average type Ia supernova variability surface to the left (SALT: Guy (2005)). Capabilities for simulating stochastic variability including stellar flares and AGN variability are in place.

OpSim

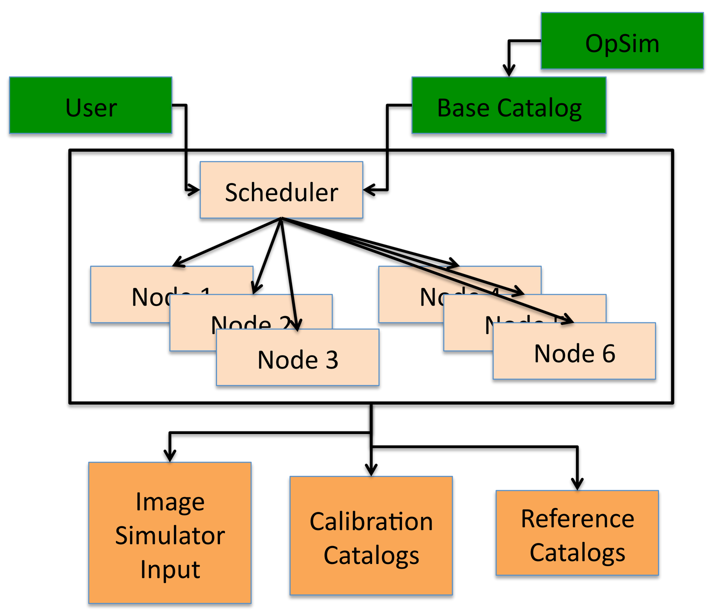


The operations simulator for LSST provides high fidelity realizations of possible 10 yr surveys. Each realization takes into account slew time, weather, scheduled and unscheduled maintenance, and cadence based on drivers from each of the science projects.

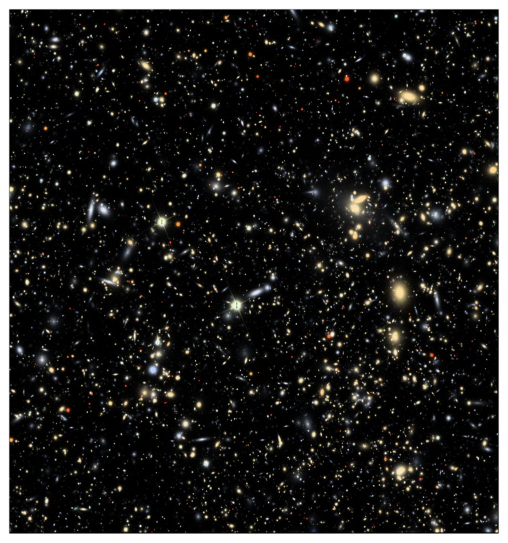
Above is the co-added depth in each of the six bands from blue (u) to red (y) as a function of position on the sky.

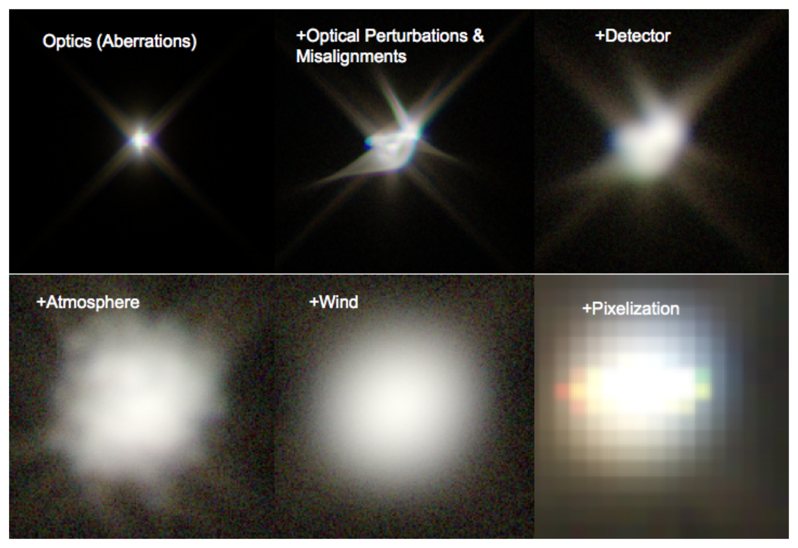
Generation

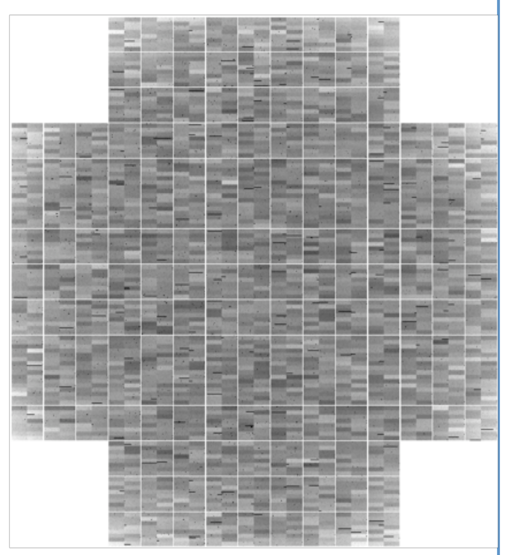
A typical 10 year realization of the LSST operations simulator contains ~3 million individual pointed observations. This puts heavy load on compute resources. In order to produce "instance" catalogs at a rate large enough to exercise the data reduction and analysis facilities, cluster resources must be employed. A framework is in place to query each of the base catalog models. A sub-section of each catalog is then farmed off to a cluster node to calculate apparent magnitudes and positions based on the observing conditions of the pointed observation.



Simulated Images







These images show results from the image simulator. The left image is a false color image produced from the g, r, and i band images before adding the sky background.

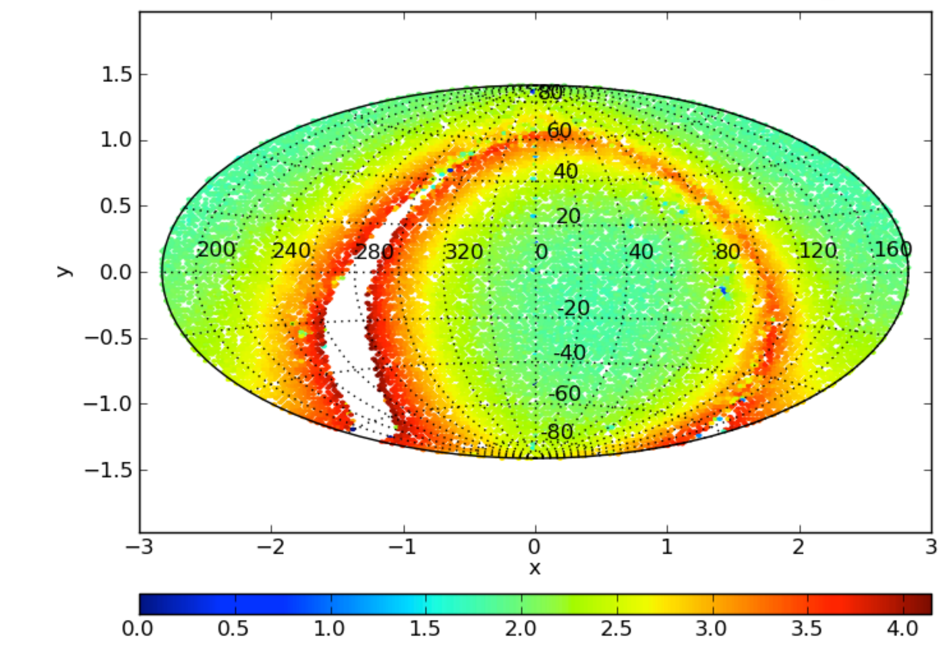
The right image shows the variation in QE across the focal plane. Vignetting is also clearly visible. In the image in the center, we show the major effects that contribute to the PSF.

Images for each of the 189 chips in the focal plane are generated independently with consistent tracking and atmosphere. This allows the generation to be parallelized. After the raw image of electrons trapped by the detector is generated, sky noise with moon illumination is added.

Catalogs are generated with the properties appropriate to an observation under the conditions predicted by the OpSim. These catalogs are then used as input to the image simulator. This can be repeated to build up large sections of the survey that can be used in testing endeavors.

The simulated images are one of the major data products for testing the system. The images provide input for completing scaling tests, I/O tests, and other data management tasks. They also provide a set of truth images for evaluating algorithmic challenges.

Simulated Catalogs



Shown above is a plot of the number of calibration stars in a patch of sky the size of a single 0.2'x0.2' LSST CCD. Along with simulated images, simulated catalogs like the one shown above are very useful for testing certain aspects of the LSST system. In circumstances where simulating images is either prohibitive because of compute time or unnecessary from an algorithmic standpoint, catalogs that simulate observations may be just has helpful as images for testing purposes. A single set of simulated catalogs is not sufficient for all testing purposes. Each test requires that a different set of effects are included. For example, reference catalogs should represent mean apparent brightness and position, whereas source catalogs will contain cloud obscuration, differential chromatic refraction, and proper motion.

Examples of simulated catalogs:

- ✧Calibration catalogs—for testing calibration solution algorithms
- ✧Reference catalogs—Provide truth values for object properties and astrometric and photometric solution algorithms
- ✧Input for moving object pipelines—Simulated source detection for testing moving object detection
- ✧Science catalogs—Mimic outputs of full data reduction pipelines for community scientists to practice working with.

Testing Opportunities

Algorithmic:

Variability
Moving Objects
Transient Detection
Star/Galaxy Separation
Deblending
Difference imaging
Photometric/Astrometric calibration
PSF modeling
Source classification

Infrastructure:

Data throughput
Meeting science goals
Data quality metrics
Testing completeness criteria
Alert production
Database interfaces
Processing time

Design:

Survey Cadence
Logging system
Data reduction architecture
Filter shapes
Data access architecture

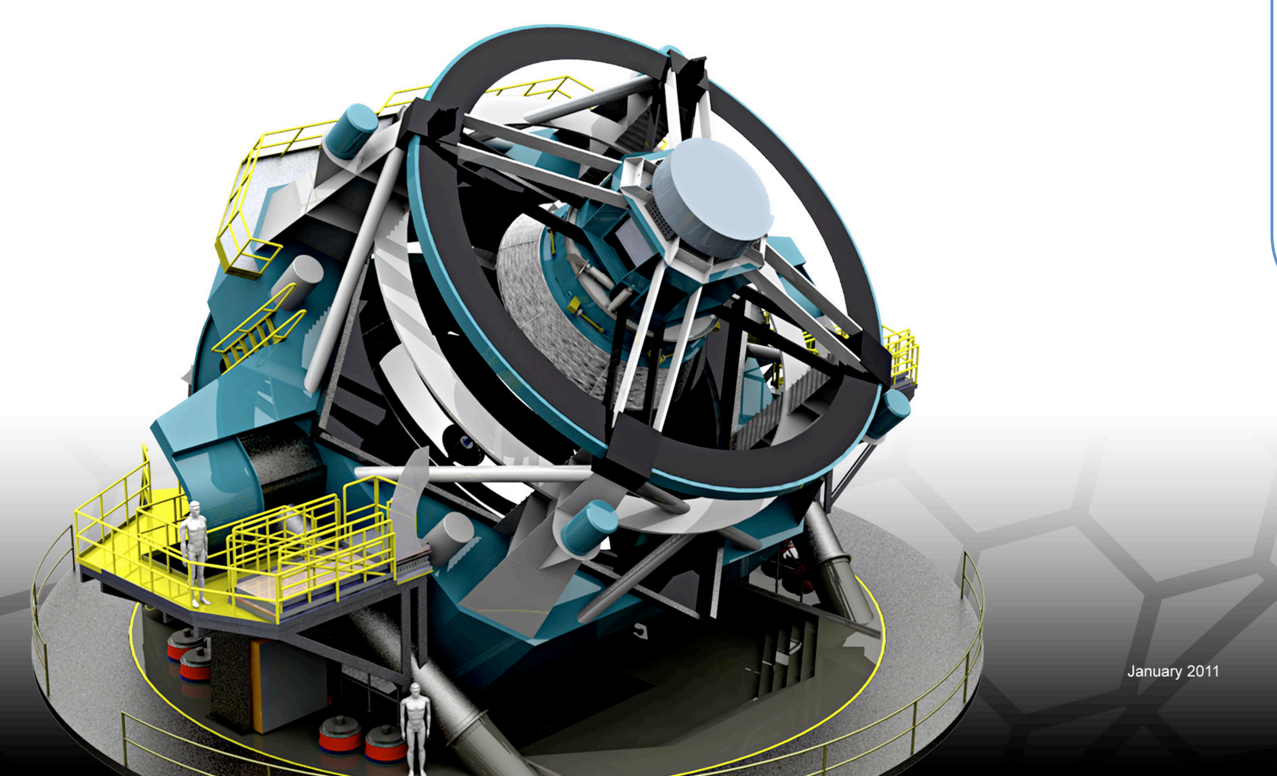
Images – Catalogs – Both

Future Work

Future efforts will focus on improving all areas of the testing framework. Specifically, work is under way to improve the base models by including more stellar populations, improving variability models, and including more realistic galaxy spatial models.

The interface structure is also being improved to supply simulated images and catalogs in near real time.

Amôres, E.B., & Lèpine, J.R.D. 2005, AJ, 130, 659; De Lucia, G., Springel, V., White, S.D.M., Croton, D., & Kauffmann, G. 2006, MNRAS, 366, 499; Grav et al. Submitted, Icarus; Guy, J., Astier, P., Nobili, S., Regnault, N., & Pain, R. 2005, AAP, 443, 781; Jurić, M., et al. 2008, ApJ, 673, 864; Schlegel, D.J., Finkbeiner, D.P., & Davis, M. 1998, ApJ, 500, 525; Springel, V., et al. 2005, Nature, 435, 629; OpSim-- http://www.noao.edu/lsst/opsim/



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