Large Synoptic Survey Telescope

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LSST Image Simulations

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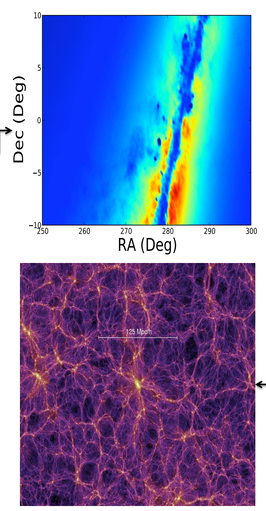
The precise measurements planned for the Large Synoptic Survey Telescope (LSST) require careful algorithmic studies before the telescope begins operating with its unprecedented image production rate. The LSST Image Simulation group is leading the effort to perform end-to-end simulations using a high fidelity framework. We first synthesize input astrophysical object catalogs that include stars based on a Milky Way model, asteroids, and cosmologically based galaxy catalogs with morphological parameters. We then use a novel approach to simulate images using a photon Monte Carlo approach. We draw photons from the objects using their spectral energy distributions and propagate those photons through the Universe, atmosphere, telescope, and camera using complex wavelength-dependent photon simulation physics. We describe the simulation framework and discuss the photon simulation approach that has been used to generate millions of high fidelity images.

Catalog Simulations: the Universe is parameterized in 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 simulation 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

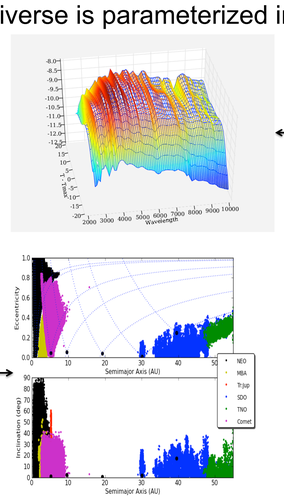
The galaxies are distributed based on the Millennium simulation using light cone software from the N-Body shop at the University of Washington. Physical properties were derived from semi-analytic models of De Lucia et al. (2006). Galaxies have disk, bulge, and AGN components each with an extinction model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

The figure to the left shows the density of particles in the Millennium simulation. We use a 4.5 x 4.5 degree field to populate the base catalogs.

Solar System

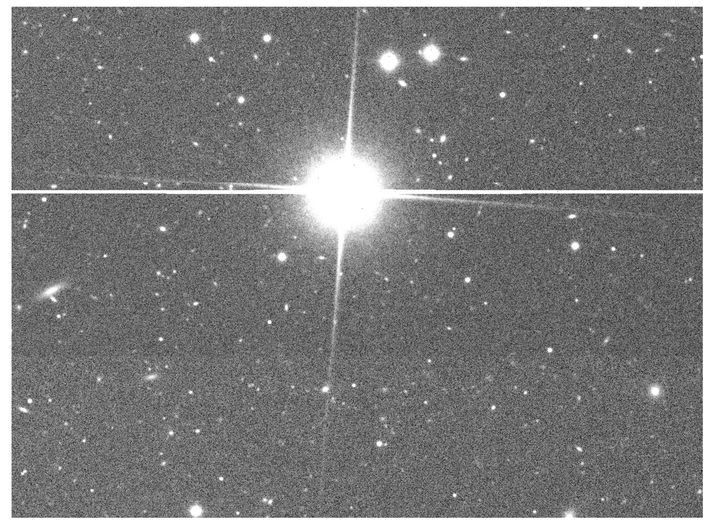
The solar system model is based on the model presented in Grav et al. (2010). Since the astrometric precision must be good to 10 mas, great care is taken to enable precise calculation of ephemerides quickly. 10 million individual orbits are realized on one day intervals resulting in > 1 billion database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

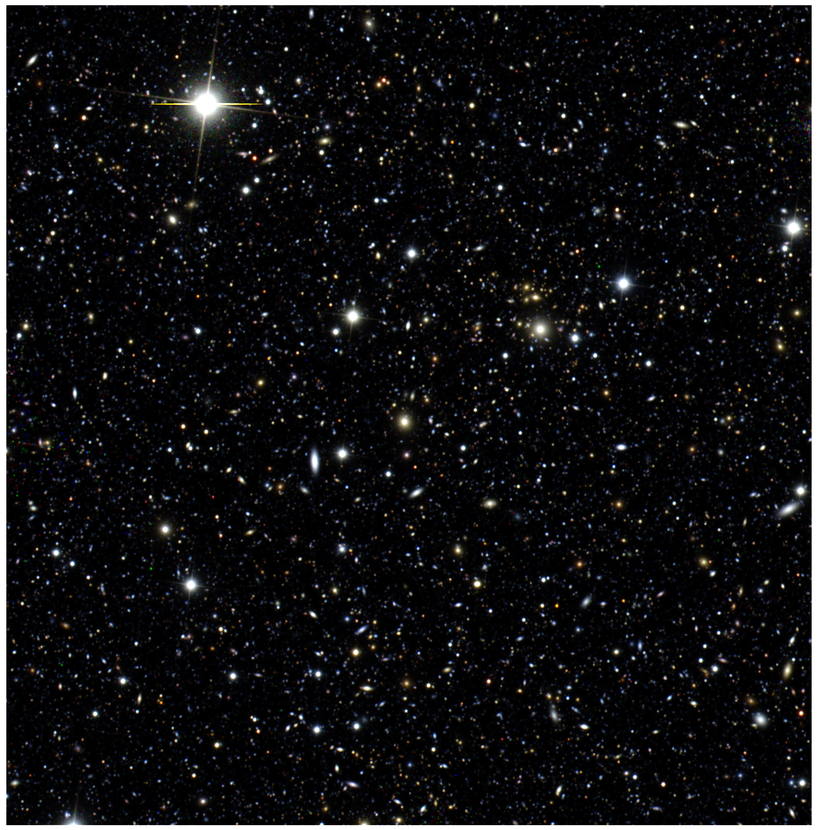


Variable Sources

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.

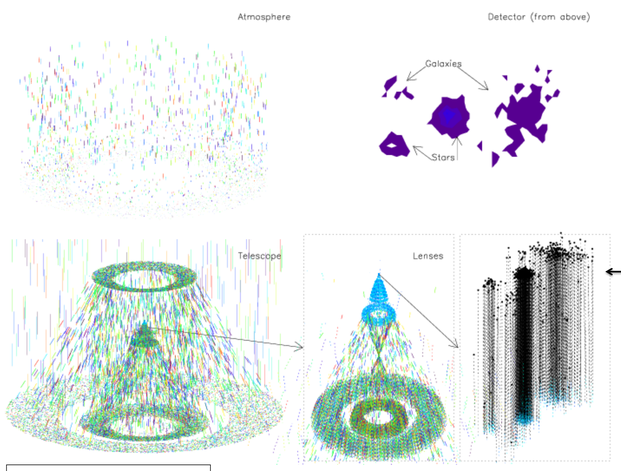


An image simulation of stars and galaxies in a region about 6 by 5 arcminutes. A bright star shows the effect of saturation and diffraction. LSST will produce ~1000 images of this size every 15 seconds. We have simulated a few million of these to date.



A 3-color composite image simulation (g,r,i) of stars and galaxies covering a single chip of LSST's focal plane. Every photon has been raytraced through the full physical model. The image covers about 13 by 13 arcminutes.

Photon Simulations: a high fidelity photon Monte Carlo turns the catalogs into images

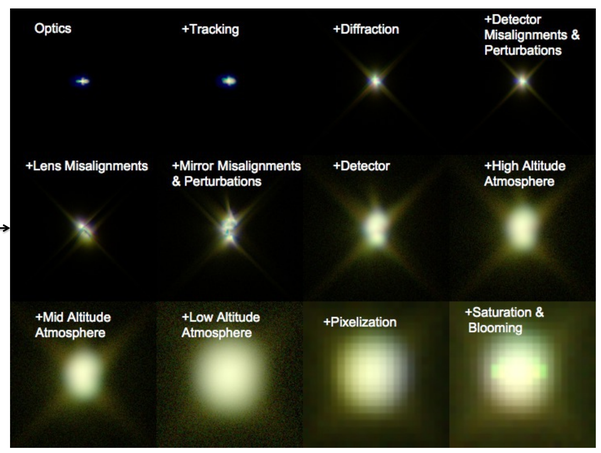


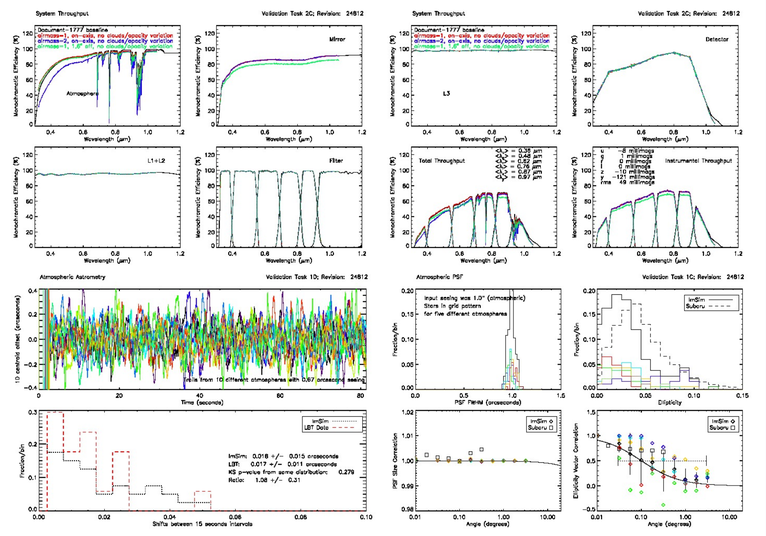
Photon Monte Carlo Approach:

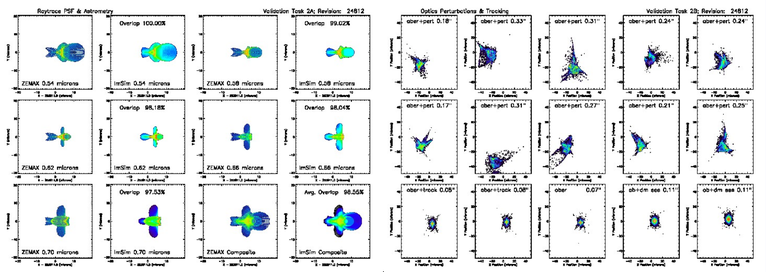
We use a photon Monte Carlo approach to choose photons from the catalog of objects using their spatial properties and SEDs. We then propagate these photons through the atmosphere, telescope, and into the silicon of the CCD where they convert photoelectrons. The images are then built one photon at a time. The images to the left show the paths of the photons on several different scales. The colors are proportional to the wavelengths of the photons.

High Fidelity Physics:

We have a variety of physical models that alter the photons' trajectory or destroy photons as they are being raytraced. The most important effects are the turbulence in the atmosphere, the misalignments and perturbations of the optics, and the charge diffusion in the CCD. The PSF images to the right show simulations of a single star with more physics being added to the simulation by turning on more physical effects. The colors combine separate band simulations to demonstrate the wavelength-dependence of these effects.

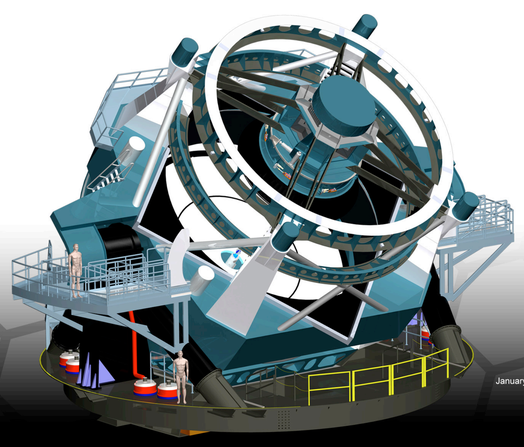






Detailed Validation:

We have done a variety of tests to make sure the simulations are accurate through validation tasks. The top plots compare independent LSST throughput calculations with the actual number of photons making it through each piece of the simulation. The middle plots compare the atmospheric astrometric jitter and atmospheric PSF properties with data from real telescopes. The bottom plots show the instrumental design PSF shapes compared to alternative raytrace calculations (left) and physical effects compared to their design tolerances (right).



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