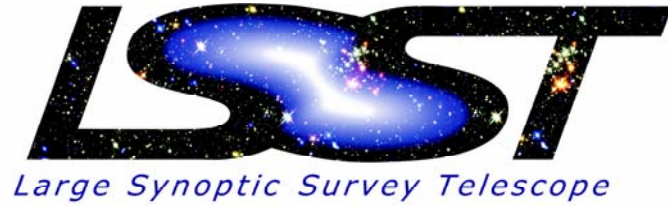


LSST Atmosphere and Instrument Simulation

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We have developed a science end-to-end simulator of the atmosphere, optics, and detector for the Large Synoptic Survey Telescope (LSST). The organization of the models for each component is based on a Monte Carlo realization of each photon emitted by galaxies and stars. The concept end-to-end refers to the history of the photons from the sky model, through the layers of a Kolmogorov atmosphere, into and through the optics of LSST, and finally the conversion of the photon into an electron that diffuses in the depletion layer of a silicon detector that is readout as charge detected in a single pixel. These simulations have been used to inform the design of LSST, verify scientific performance, and aid in the construction of algorithms to analyze the anticipated large data sets. The primary goal of these simulations is to understand systematics of weak lensing shear measurements. We present a billion photon simulation based on a tiled replication of the Hubble Ultra Deep Field.

End-to-End Simulation Outline:

We have developed a science end-to-end simulator for the full LSST system. The organization of the models for each photon emitted by sky objects such as galaxies or stars. The input to the simulator is a model of the sky composed of galaxies and stars with their associated spectral energy distributions in the form of images with a fine spatial resolution much better than the LSST resolution. The concept end-to-end refers to the history of the photons from the sky model, through the layers of the atmosphere, into and through the optics of LSST, and finally the conversion of the photon into an electron that diffuses in the depletion layer of a Si detector that is readout as charge detected in a single pixel.

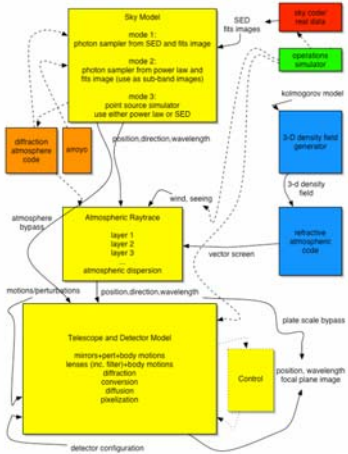
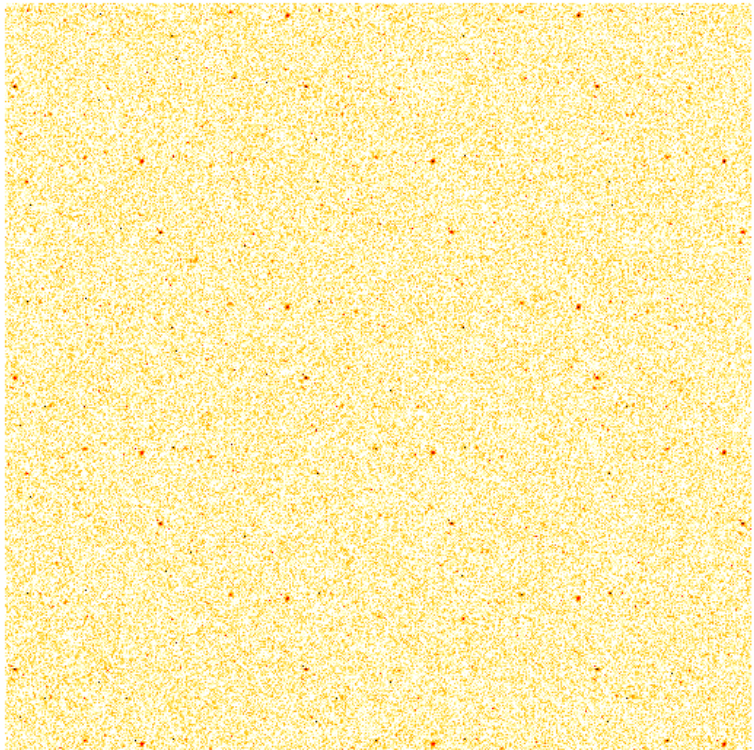
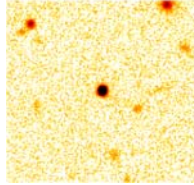


Figure 1: Flowchart of the set of codes used in the end to end simulations. Yellow boxes are the main simulation codes; whereas the other boxes map external codes used as input to the simulator.

Full End-to-End Simulation:

The figure below and to the right shows a simulation of the Hubble Ultra Deep Field simulated through the LSST end-to-end simulator. Every photon was raytraced using complete wavelength-dependent effects through 12 layers of atmospheric turbulence, the complete LSST designed optics, and the detector. Stars and galaxies were simulated from the UDF and sky noise background was added. The complete end-to-end simulation of a 800"x800" image (one CCD chip) takes only 20 hours on a single workstation due to extensive effort to make the code run as fast as possible. Approximately 3x10⁸ photons were simulated. The image to the right is a 10"x10" piece.



Atmosphere Module:

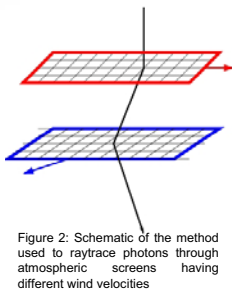
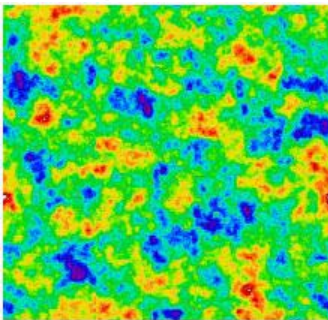


Figure 2: Schematic of the method used to raytrace photons through atmospheric screens having different wind velocities

Figure 3 (left): Kolmogorov Phase Screen (200m by 200m)

The atmosphere is modeled by a series of layers each with an independent 3D Kolmogorov model that is averaged into an equivalent screen with refractive index variations in 2D (Figure 3). The time dependence of the atmospheric seeing is modeled by the frozen translating screen approximation with a wind velocity and direction. The single photon history is traced through each layer of the atmosphere via a newly invented technique as shown in Figure 2.

Optics/Detector Module:

Figure 4 shows a geometric raytrace code for the LSST design optics, which handles reflection/refraction after calculating ray intercepts. On the surfaces of all the mirrors we apply a set of perturbations consisting of a set of orthogonal functions with a power spectrum resembling realistic perturbations found with the Kitt Peak 4m telescope when the active optics control system was operating. The detector model treats conversion of individual photons into charge carriers collected at the channel (Figure 5).

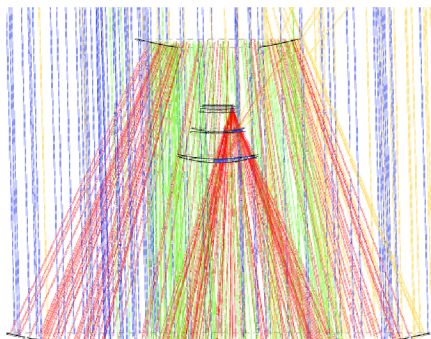


Figure 4: Geometric raytrace of the LSST optics Showing the 3 mirrors, 3 lenses, filter, and detector

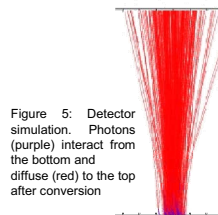


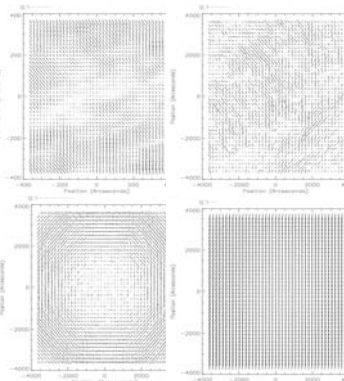
Figure 5: Detector simulation. Photons (purple) interact from the bottom and diffuse (red) to the top after conversion

Simulated PSFs and Grids of Stars:

Figure 6: PSFs for optics including mirror perturbations (upper left), charge diffusion (upper right), atmosphere (lower left), and atmosphere with wind (lower right). Images are 2 by 2 arcseconds.

The ellipticity of the point spread function (PSF) of any ground based telescope depends both on the properties of the atmosphere and the design and operation of the telescope and detector. Understanding the ellipticity of the PSF and its correlation across the field is critical to the success of weak lensing measurements. Figure 6 demonstrates the expected PSF function when we turn on various parts of the simulator. The upper left image shows the PSF due to the optics alone with the mirror perturbations. The second image shows the PSF after the detector simulator is included. The lower left image shows the PSF when the atmosphere with no wind is included. The lower right shows the same but with wind. Clearly, the effect of wind reduces the ellipticity due to a larger part of the atmospheric turbulence that is being averaged. We have studied the effect of the atmosphere by generating grids of stars where the photons have been refracted by the atmospheric turbulence screens. Figure 7 shows the ellipticity vectors measured from a set of stars produced on various grids. The ellipticity is highly correlated from the optics, but less correlated with the atmosphere.

Figure 7 (right): Grids of stars with their ellipticity vector measured. The top simulations are using the atmosphere, the bottom two simulations use only the optics with (right) and without (left) perturbations on the mirrors.



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