Large Synoptic Survey Telescope

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Image Quality and Performance of the LSST Camera

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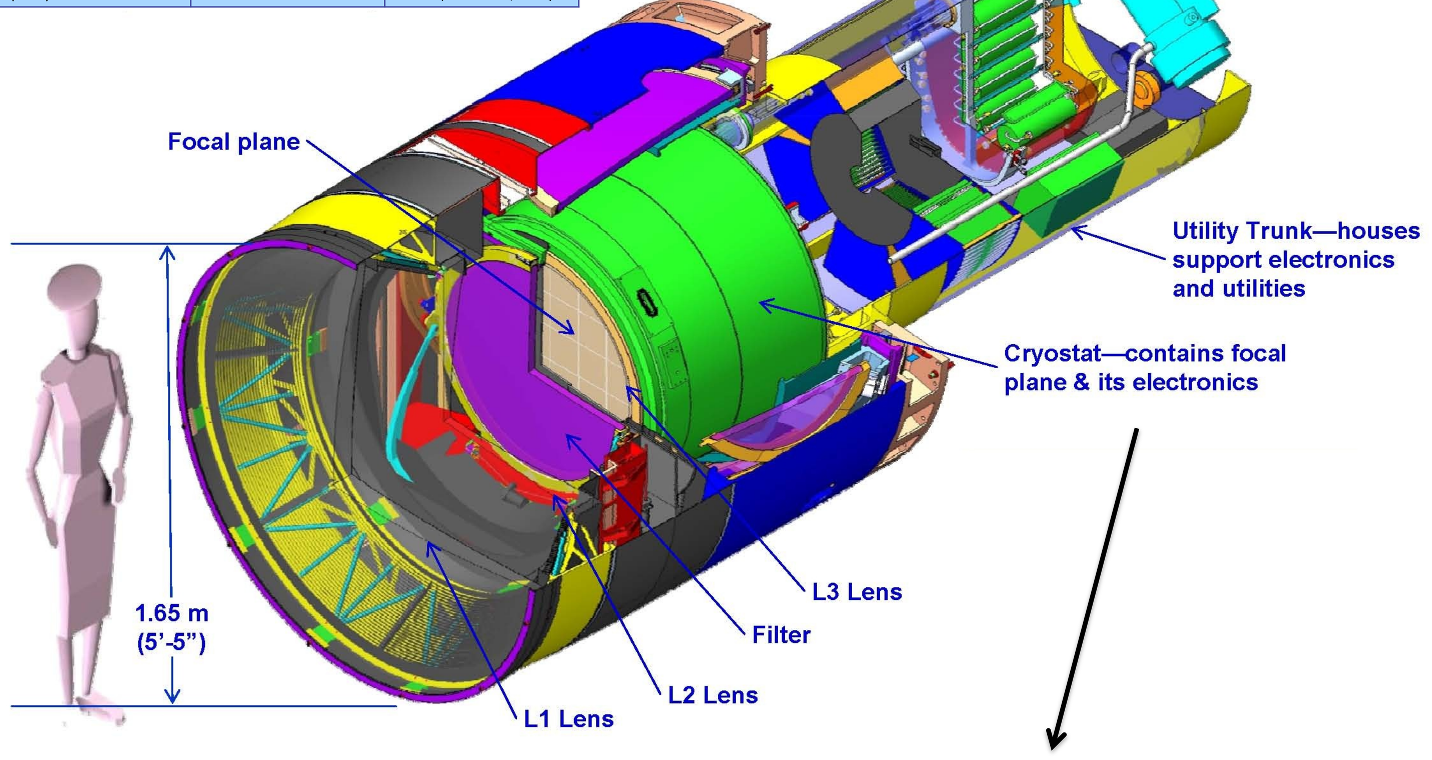
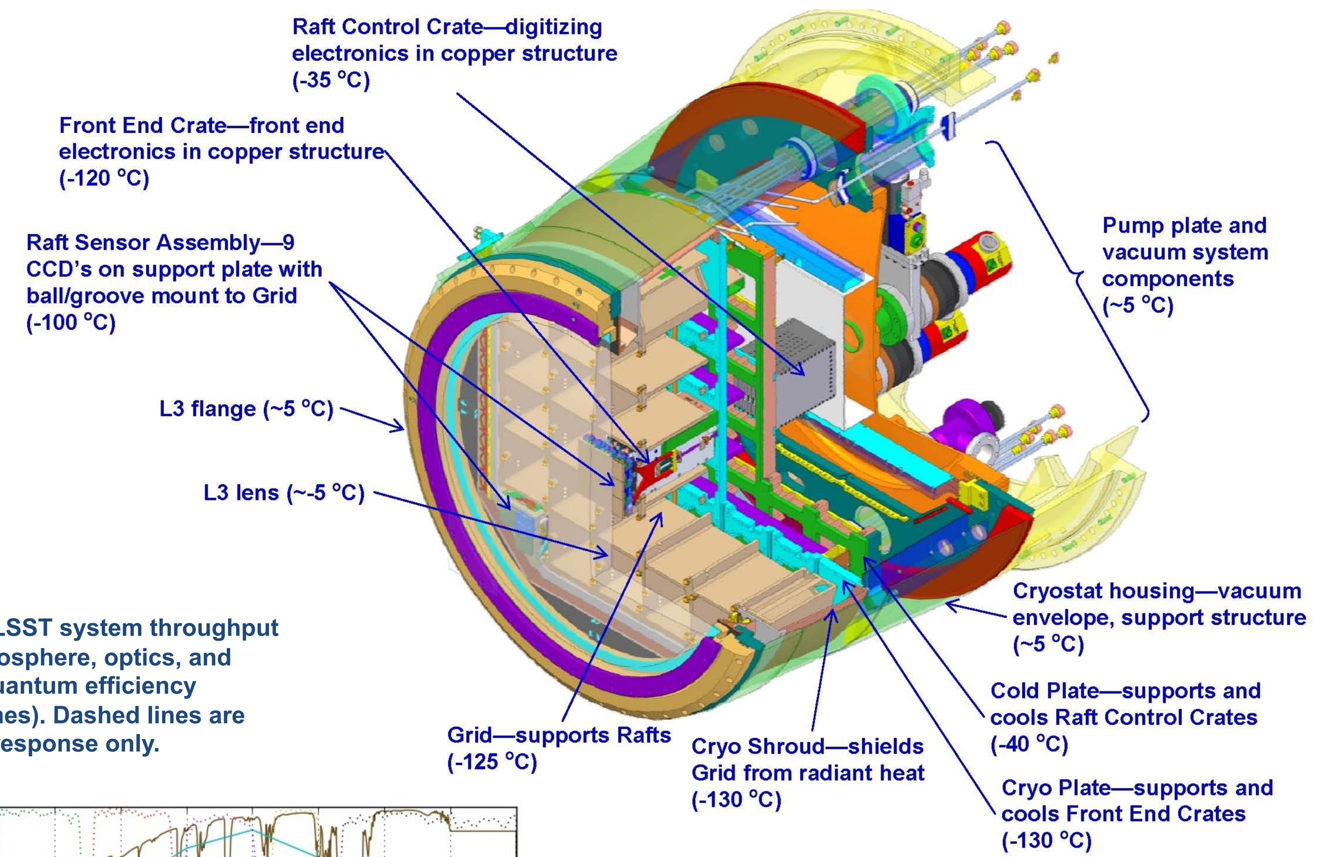
The LSST camera, which will be the largest digital camera built to date, presents a number of novel challenges. The field of view will be 3.5 degrees in diameter and will be sampled by a 3.2 billion pixel array of sensors to be read-out in under 2 seconds, which leads to demanding constraints on the sensor architecture and read-out electronics. The camera also incorporates three large refractive lenses, an array of five wide-band large filters mounted on a carousel (six total), and a mechanical shutter. Given the fast optical beam (f/1.2) and tight tolerances for image quality and throughput specifications, the requirements on the optical design, assembly and alignment, and contamination control of the optical elements and focal plane are crucial. We present an overview of the LSST camera, with an emphasis on models of camera image quality and throughput performance that are characterized by various analysis packages and design considerations.

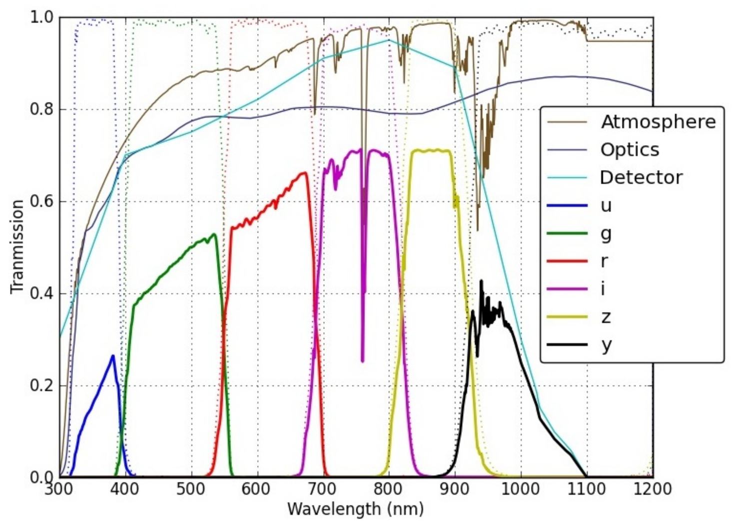
Overview of LSST Camera Assembly

Large field of view implies physically large focal plane (64cm F)	Modular mosaic focal plane construction	21 rafts × 9 4K x 4K CCDs/ raft = 189 CCDs total 3.1Gpix
Fast f/1.2 beam, shallow depth of focus	Tight alignment and flatness tolerance	Flatness: 5 um Alignment (z axis): 10mm
Plate scale 20"/mm	Small pixels, close butting	Pixel size: 10μm² Chip-chip gap: 250μm
Fast readout (2s) with low noise (5 e⁻)	Highly parallel readout electronics	16 amplifiers/4K CCD
Broadband, high spectral sensitivity	Thick silicon sensor, back illuminated, AR coat	100μm thickness for IR sensitivity Thin conductive window
Seeing-limited image quality	Internal electric field to minimize diffusion	High resistivity, biased silicon (> 3 kΩ-cm, -50V)

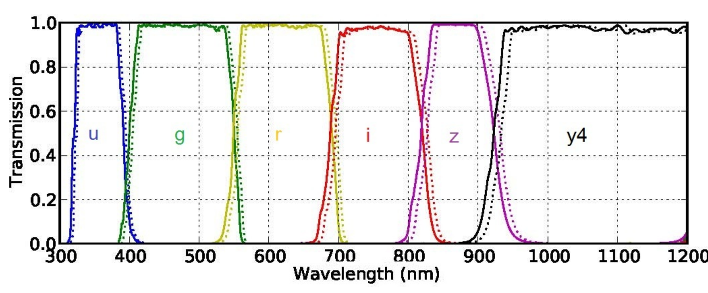


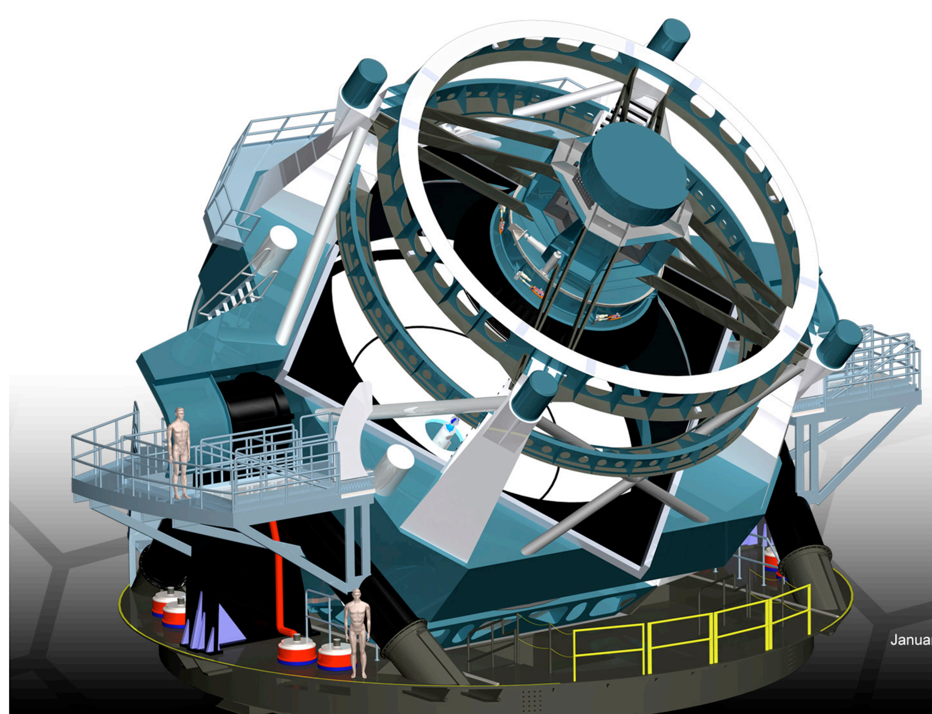


Predicted LSST system throughput due to atmosphere, optics, and detector quantum efficiency (colored lines). Dashed lines are total filter response only.



Baseline filter curves (solid, colored) and a potential (1% of the central wavelength) shift due to nonuniformity in the filter bandpass (dashed).

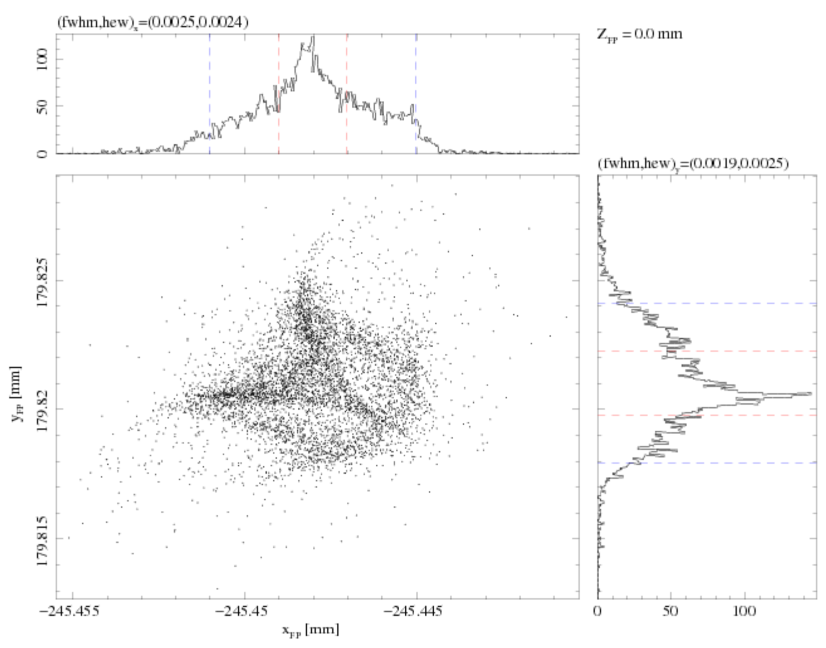




January 2012

Image Quality Modeling

We model the image quality performance of the LSST optical system with the method of ray bundles. The field of view is populated with simulated sources from which rays are propagated through the telescope and camera optical elements with geometric optics. Each geometric ray is actually a bundle of rays at many wavelengths, which can, as a group, behave realistically for the wavelength dependent reflection and refraction properties of each optical surface.



Detected focal-plane position of ray bundles from simulated source 'star' onto the LSST camera focal plane, for a particular off-axis viewing angle (1.68°) and focal plane piston position (z=0) for a given focal plane area of 15μm² (one LSST pixel=10μm²).

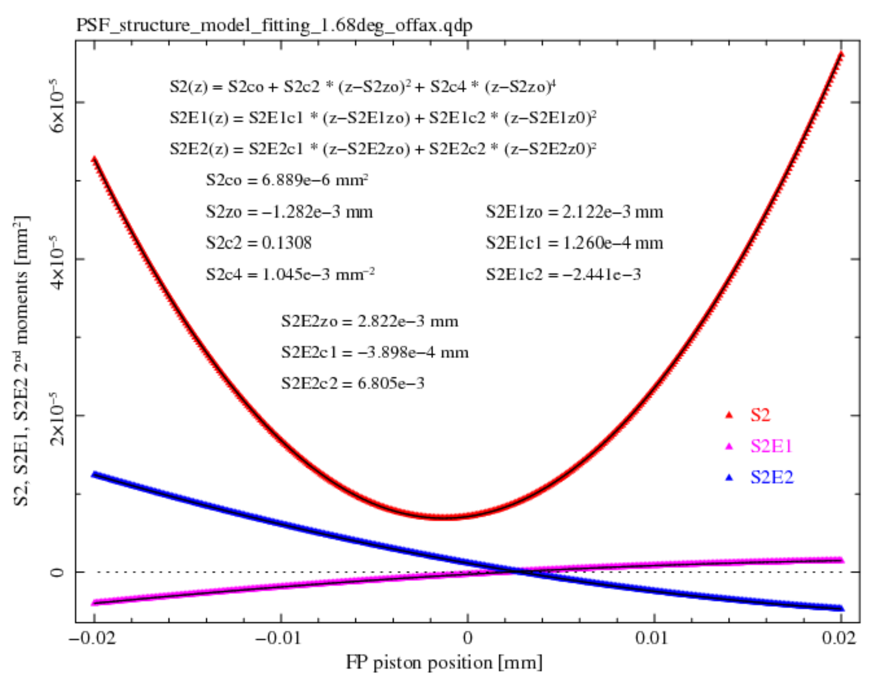
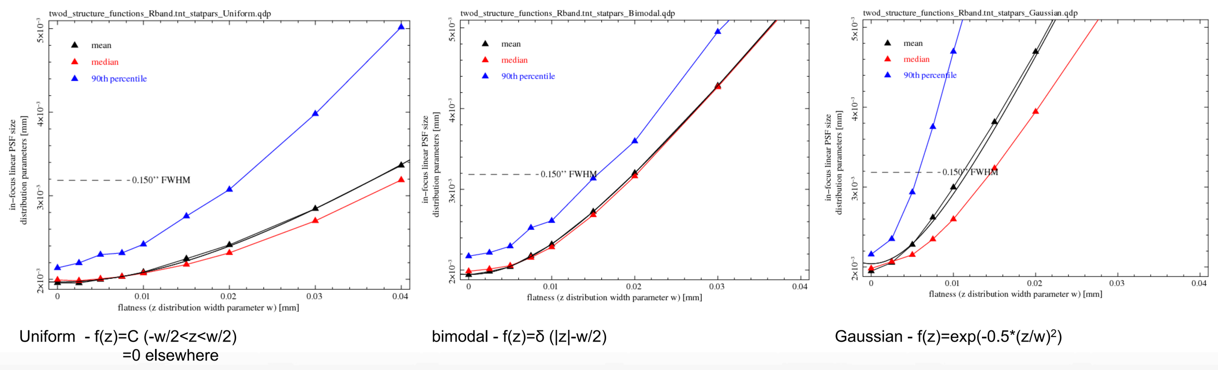


Image second moment quantities S2, S2E1 and S2E2 plotted against focal plane axial position, for a simulated star at 1.68° off-axis viewing angle. The red curve (S2) is simply related to the image size, whereas the magenta and blue curves (S2E1 & S2E2) are measures of instrument-induced ellipticity. The full description is captured in 10 x,y dependent parameters. They are available for each of 6 wavebands.

The 10 x,y dependent PSF parameters and the z piston position of any x,y position on the focal plane uniquely determine the spot size and ellipticity at that point. We can use this model to determine, for example, the effects on image quality arising from focal plane non-flatness.

Focal plane non-flatness contributions to image quality (r band), for three separate model distributions (left to right: uniform, bimodal & Gaussian). Spot size second moment (S2) distribution means (black), medians (red) and 90% levels (blue) are plotted against the width parameters (w) in each case. Irreducible contributions from the optical design are seen near w=0, and correspond to approximately 0.100" FWHM.



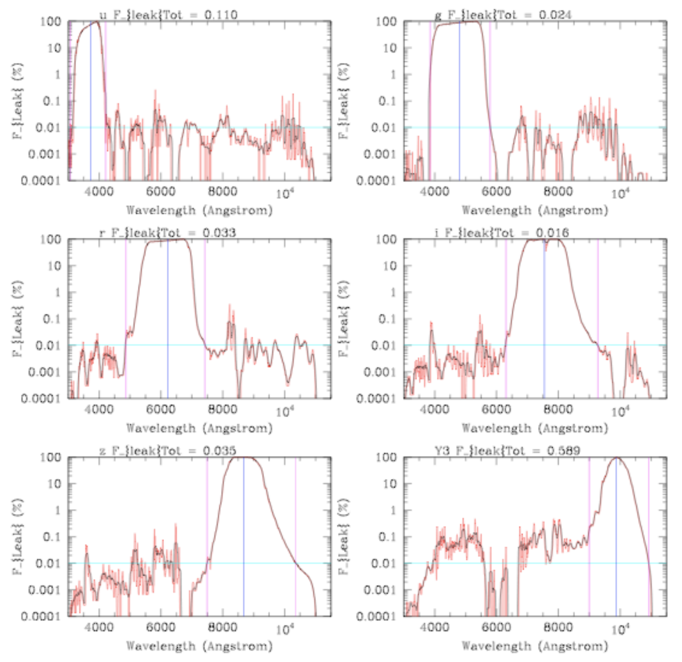
Uniform - f(z)=C (-w/2<z<w/2) =0 elsewhere

bimodal - f(z)=δ (|z|-w/2)

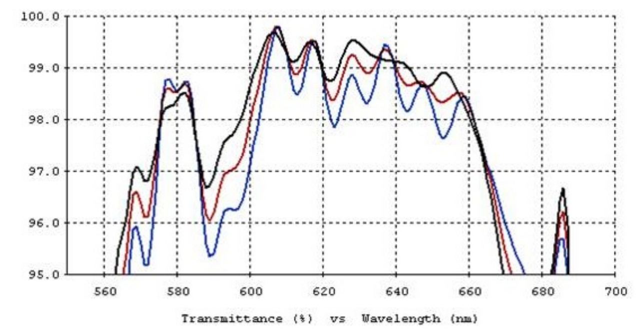
Gaussian - f(z)=exp(-0.5*(z/w)²)

Throughput Analysis

The system throughput depends on the wavelength-dependent optical properties of every surface. Understanding the effects of nonuniformity, misalignments, deformations, and contamination is an important goal of the camera model, which will inform engineering, construction, and data analysis. The budgeted throughput change is 0.5 millimag (0.046%) between calibrations.



First design of the LSST filters showing the out-of-band leaks and threshold objectives.



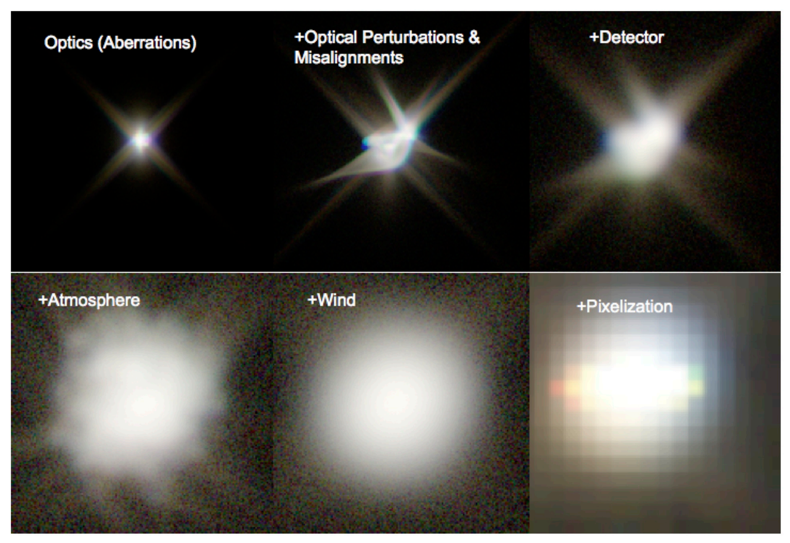
Effect on transmittance of r band filter with 0 (black), 5 (red) and 10 (blue) nm layer of H_2O contamination on either side.

Effects of contamination due to diffraction and absorption (Rayleigh and Mie scattering) and change in index of refraction can be simulated with TFCalc, a thin film design and analysis package including AR (anti-reflection) coatings.

Allowable deposition layer thickness of H_2O on CCDs between calibrations for 0.046% transmittance change, for two different antireflective coatings. One monolayer of H_2O is 0.25 nm.

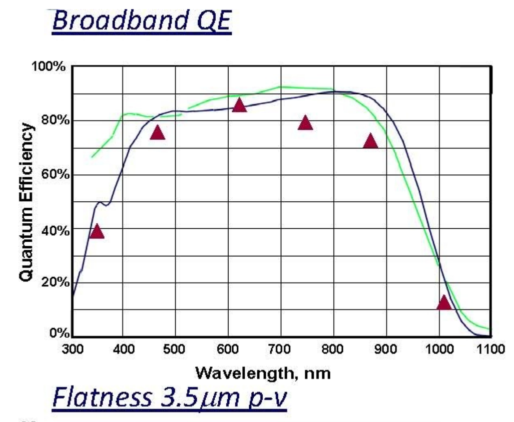
AR layer	u	g	r	i	z	y4
60nm HfO_2	0.069 nm	1.11 nm	0.28 nm	0.29 nm	0.34 nm	0.41 nm
110nm HfO_2	0.067 nm	0.48 nm	0.23 nm	0.57 nm	5.0 nm	0.94 nm

The LSST image simulator incorporates many of the camera and telescope image quality and throughput effects modelled here, and also includes atmospheric effects and simulated fields of view.

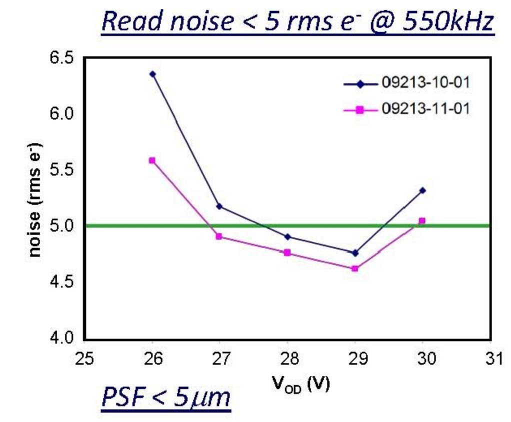


Both image quality and throughput are highly dependent on CCD QE specifications (Red triangles). Measurements of prototype CCDs indicate that specifications can be met. Read noise measurements show optimum output amplifier voltage at 28-29Volts and the diffusion in the CCD silicon shows that about 35-40 volts is optimum for minimum spot size.

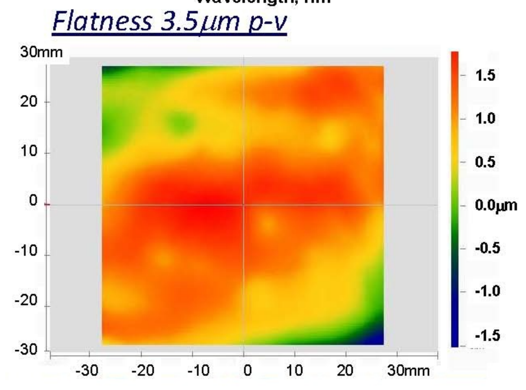
Broadband QE



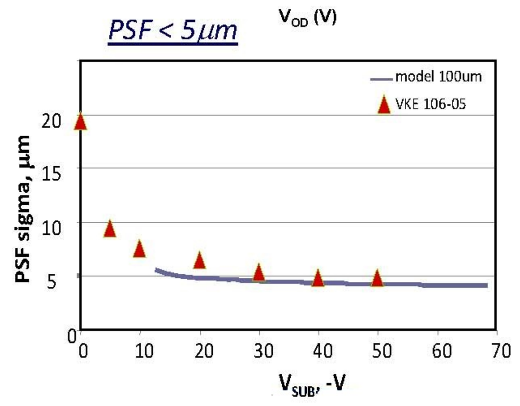
Read noise < 5 rms e⁻ @ 550kHz



Flatness 3.5μm p-v



PSF < 5μm



LSST is a public-private partnership. Design and development activity is supported in part by the National Science Foundation. Additional funding comes from private gifts, grants to universities, and in-kind support at Department of Energy laboratories and other LSSTC Institutional Members.