Science Requirements for the Design of the LSST Camera

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The LSST will be a large-aperture, wide-field ground-based telescope designed to obtain sequential images covering the entire visible sky every few nights. The range of scientific investigations which will be enabled by such a survey capability is extremely broad, however in order to optimize the design of the system, we have focused on four main themes: Constraining Dark Energy and Dark Matter, Taking an Inventory of the Solar System, Exploring the Transient Optical Sky, and Mapping the Milky Way. In this poster, we review the science requirements imposed by these four themes, and their specific implications for the technical constraints on the LSST camera.

Four Main Science Themes for LSST

1. Constraining Dark Energy and Dark Matter

The primary science drivers for exploring dark energy and dark matter will involve a suite of studies using “standard rulers” (shear-shear correlation analyses, studies of the shear peak distribution associated with clusters of galaxies, measurements of the galaxy power spectrum and baryon acoustic oscillations) and the use of supernova “standard candles.”

Requirements:

- Coverage of a very large solid angle of sky to faint magnitudes ⇨ High Etendue.
- Careful control of PSF shape systematics ⇨ Many exposures per field (to reduce atmospheric contributions), short exposures for quality assessment, active control of optics and the metrology of the focal plane.
- Photometric redshifts out to z ~ 3 ⇨ Six-color photometry (ugrizY) with an accuracy better than 1%.
- Well-sampled light curves for detected supernovae ⇨ Repeat exposures of each field in multiple colors every few days.

2. Taking an Inventory of the Solar System

The primary science drivers involve the detection of potentially hazardous near-Earth asteroids with diameters >250 m, and a study of Kuiper Belt Objects down to 26 r mag.

Requirements:

- Coverage of most of the sky within +/- 15 degrees of the ecliptic ⇨ High Etendue.
- Proper cadence to enable identification of moving objects ⇨ Closely spaced pairs of observations 2 or 3 times per lunation.
- Precision determination of orbits ⇨ Astrometric accuracy better than 0.1 arcsec.
- Minimization of image trailing ⇨ Short exposures, < 15 seconds.

3. Exploring the Transient Optical Sky

The primary science driver involves the provision of a very large database for studies of multi-color variability of stars, active galactic nuclei, gamma-ray bursts, supernovae, and potentially new transient phenomena on timescales ranging from seconds to years.

Requirements:

- Enhanced probability for the detection of rare events ⇨ High Etendue.
- Synoptic time coverage on many different time scales ⇨ Short exposures, multiple visits at a variety of cadences.
- Accurate color information for object classification ⇨ Six-color photometry with high photometric accuracy.
- Detection of faint variables via image differencing ⇨ Control of image systematics, many exposures per field.
- Prompt alerts for follow-up with other facilities ⇨ Rapid data processing and object classification.

4. Mapping the Milky Way

The primary science drivers involves mapping the 3-D shape and extent of our galaxy through photometry, proper motion, and parallax measurements on a variety of distance scales, and the identification and classification of stellar populations on the basis of color and kinematic properties.

Requirements:

- Large area coverage ⇨ High Etendue.
- Excellent image quality ⇨ Control of systematics, many exposures per field.
- High quality photometry and astrometry ⇨ Well-understood system calibration.

LSST Science Requirements Summary Table

	Parameter	Symbol	Units	Design Spec	Minimum Spec	Stretch Goal	SRD ref.
Filter Set	Filter complement	—	—	ugrizY	ugrizY	ubgrizY	§3.3.1 Table 1
	No. filters in camera	Nfilters	—	5	3	6	§3.3.1 Table 2
	Time to exchange a filter	TDFCmax	hr	8	72	—	§3.3.1 Table 2
	Filter change interval [1]	TFmax	min	2	10	1	§3.3.1 Table 3
	Out-of-band leakage per 10 nm bandwidth	Fleak	%	0.01	0.02	0.003	§3.3.1 Table 4
	Out-of-band leakage, total	FleakTot	%	0.05	0.1	0.02	§3.3.1 Table 4
Camera Rotation			deg	±90			§3.3.6
Single Visit [2] Depth	**Ensemble distribution:**						
	Median 5σ depth (min) [3]	D1	mag	24.5	24.2	24.7	§3.3.2 Table 5
	Fraction of images for which 5σ depth exceeds Z1 (max)	DF1	%	10	20	5	§3.3.2 Table 5
		Z1	mag	24.2	23.8	24.5	
	Spatial variation:						
	Fraction of field for which 5σ depth is brighter than median by Z2 (max)	DF2	%	15	20	10	§3.3.2 Table 6
		Z2	mag	0.2	0.4	0.2	
Minimum Exposure Time		ETmin	sec	5	10	1	§3.3.2 Table 7

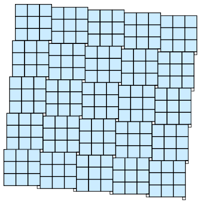
[1] Maximum elapsed time between two visits in different filters

[2] Co-added pair of 15 sec back-to-back exposures

[3] r band, AB magnitude scale, A0V spectrum point source; see SRD Table 5 caption for specifications in other filter bands

Implications for the LSST Camera

1. Large Etendue



To meet the image depth requirements in a single exposure and over the full ten-year mission of LSST requires an etendue > 300 m^2 deg^2. With the 8.4 m aperture of the primary mirror, the required focal plane coverage is 10 square degrees.

Assuming median seeing of 0.7 arc-sec, and three times oversampling, this requires a 3.2 billion pixel focal plane – considerably larger than has ever been previously achieved. With 4k x 4k devices, ~ 200 sensors are required.

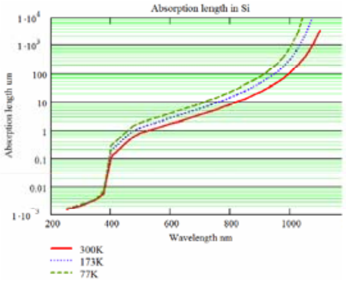
The sensors must be 4-side buttable with narrow gaps between them to achieve high focal plane efficiency.

2. Excellent Image Quality and Control of PSF Systematics

The physical size of the camera is limited by its placement in the telescope beam near the secondary mirror. The very large field-of-view required to achieve the high etendue then implies a low focal ratio (f1.2).

With such a fast beam, the entire focal plane must be assembled and maintained flat to an accuracy of +/- 10 μm (p-p). Allowing 5 μm flatness in the sensor itself, implies very tight tolerances for integration and control.

This may require in situ monitoring the focal plane alignment.



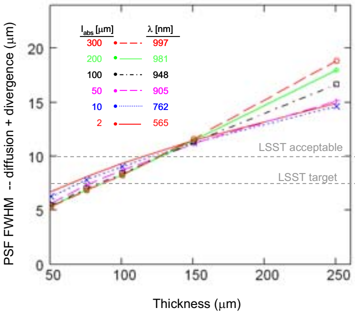
3. High Quantum Efficiency Over the Range 320 – 1,050 nm.

Six-color photometry (ugrizY) requires high QE with good imaging properties over a very wide-band.

Given the large absorption depth in silicon in the IR, the sensor depletion depth must exceed 75 μm.

However, both charge and light spreading in the silicon limit the depletion depth to less than ~ 150 μm to avoid degradation of the image resolution.

These requirements can only be achieved in a fully-depleted device with back-side contacts.



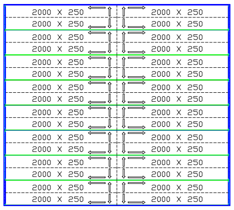
4. Fast Readout

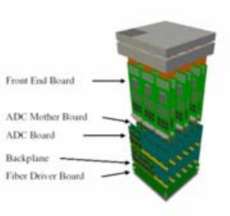
Integrations as short as 15 seconds require that the whole focal plane array be read-out in less than 2 seconds.

To reduce noise and cross-talk, the clocking rate should not exceed 250 kHz. At this rate, 32 read-out ports per 4k x 4k sensor are required.

Our baseline CCD design is thus highly segmented. This also aids in reducing the image loss due to charge bleeding from bright stars.

With 200 sensors, 6400 channels of electronics are required. This would yield an enormous number of vacuum penetrations, unless the electronics are highly integrated inside the dewar with extensive use of ASICs. Our baseline design involves assembly of the sensors into 3 x 3 rafts, each operating as a kind of independent camera with both front-end and back-end boards contained entirely within the footprint of the sensors themselves.




Raft based front end / back end electronics package

5. Multi-Color Photometry with Fast Cadence

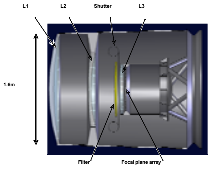
The optimization of the observing strategy requires that at least five of the six filters be resident available for insertion at any given time.

Given the location of the camera in the telescope beam, there is no room for an external filter compartment.

This requires that the filters be mounted on a carousel, with an appropriate insertion mechanism. Filters must be exchangeable within 2 minutes.

Replacement of one of the five with the sixth filter must be accomplished during the daytime.

These requirements place stringent demands on the design of the camera body and interface with the telescope structure.



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