

## Performance and Analysis of the LSST Optical System

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The LSST uses a modified Paul-Baker 3-mirror optical design with 8.4-m primary, 3.4-m secondary and 5-m tertiary mirrors. The system prescription has evolved to enable its deep, wide, fast mission. The proximity of the primary and tertiary surfaces enables fabrication of both mirrors from a single substrate. This unique design, referred to as the M1M3 monolith, offers significant advantages in the reduction of degrees of freedom during operational alignment and improved structural stiffness for the otherwise annular primary surface. The 3-mirror telescope feeds a 3 element refractive corrector to produce a 3.5-degree diameter field of view over a 64-cm flat focal surface in 6 spectral bands with excellent image quality. The most recent design optimization included null tests for each of the three camera lenses and resulted in significantly simpler test configurations and reduced asphericity on the secondary mirror. Detailed analysis of the optical effects of lens displacements, gravity distortions, glass quality, and fabrication errors have been carried out and show this system to be well within industry fabrications capabilities. Stray and scattered light analysis shows the LSST will achieve its signal to noise requirements. Further progress has been made on the development of mirror, anti-reflection, and filter coatings showing that the system throughput meets the depth requirements of the survey and the out of band filter rejection requirements.

### Mirror Testing

The First and third reflective surfaces will be manufactured into a single mirror blank. Each surface is suited to standard optical metrology. Establishing the relationship between M1 and M3 is achieved through a combination of simultaneous optical tests, Laser tracker positioning, and mechanical run-out measurements.

The convex secondary mirror surface was limited to 19 microns aspheric departure from a sphere. This surface can be measured with a matrix optical test in 12 sub-apertures.

50-inch Fused Silica lens  
48-inch aspheric test plate  
secondary mirror

### Optical Design

M2 3.4m f/1.00  
M3 5.0m f/0.83  
M1 8.4m f/1.18

Flat 3.5 deg. FOV  
0.64m dia. @ f/1.23

L3 0.70m  
Filter 0.76m  
L2 1.10m  
L1 1.55m

1.75 deg  
1.0 deg  
0 deg

Image diameter (arcsec)  
Detector position (mm)

Legend: U 50%, G 60%, R 80%, I 80%, Z 80%, Y 90%, U 50%, G 50%, R 50%, I 50%, Z 50%, Y 50%

### Lens Null Tests

L1, spherical  
L2, aspheric  
L3, aspheric

Individual null tests for each of the three refractive elements were included as part of the final design optimization. This resulted in the balancing of the aspheric terms throughout the optical system to simplify manufacturability. In the end L1 remained a fully spherical optic, a small amount of asphericity on L2 resulted in a simple null test and a reduction of asphericity on M2, similarly added asphericity on L3 greatly simplified its null test. Each null test is conducted in the orientation with gravity in the downward direction. By testing the lenses in their preferred operational orientation compensates to first order any optical error caused by gravitation distortion.

### Stray & Scattered Light Analysis

Scattered light analysis for the LSST has been done using a non-sequential ray-trace modeling within the FRED (Photon Engineering, LLC) software package. The LSST scattered light model (left) includes all optical elements along with structural elements representing the dome (1), the telescope mount (2) and the camera assembly (3). Each optical surface is characterized by a micro-surface roughness specification and particulate contamination level. Non-optical surfaces are characterized by the properties of Z306 Aerogel black surface treatment.

- A critical surface analysis has been carried out by analyzing illuminated model elements from 2 points of view: 1) from the detector (right) and 2) from the dome exterior (upper right). In the former case a critical surface is identified from the detector's point of view by those elements visible off the primary (blue), secondary (green) and tertiary (purple). In the latter case, anything illuminated through the dome opening (right panel in red) is tagged as a critical surface. Model elements common to both ray-traces are categorized as 1<sup>st</sup> order scattering surface. Over 300 such surfaces exist in the LSST as currently designed. The integrated impact over the full field of view as a function of source angle is characterized by the Point Source Transmittance (PST - far right), where the most significant surfaces are identified. Mitigation strategies for these surfaces are part of the current design effort.

RED-Direct BLUE-reflection from PM GREEN-reflection from SM PURPLE-reflection from TM

Direct from camera: Camera interior, dome floor, dome walls, azimuth assembly, PM-TM interface

From tertiary: outer camera housing, SM baffle vanes, SM spider

From secondary: PM cell, azimuth assembly, PM-TM interface

From primary: PM cell, main baffles, windscreen aperture panels, dome interior

BLUE-reflection from PM GREEN-reflection from SM Purple-reflection from TM RED-direct from camera

### R Band Point Source Transmittance (Log scale)

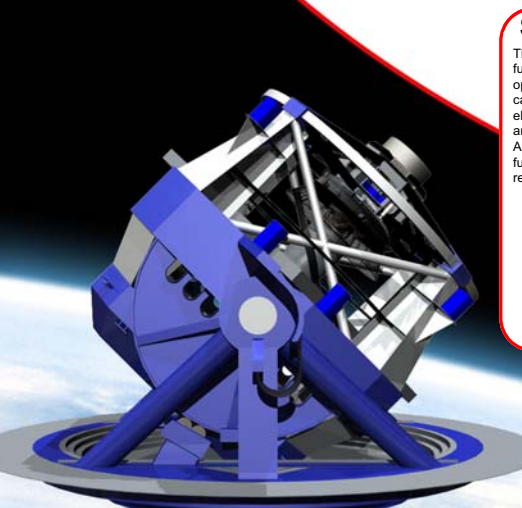
Telescope FOV  
Scatter from L3-L2 inner cone  
Scatter from PM cell  
Scatter from telescope azimuth axis  
Scatter from PM cell  
Scatter from diffuse edge of L2  
Scatter from internal dome structure

Log(TPS)

Input Angle (deg)

### Ghost Image Analysis

On-Axis  
1.5° off-axis



### System Throughput

The six-band system throughput for the LSST is determined from the product of 5 system element response functions. The full system response (lower left - black) combines the functions for the atmosphere, the optics, and sensor QE. The atmospheric transmission (lower left - blue) over Cerro Pachon has been calculated using MODTRAN under average temperature, humidity and pressure conditions at the site elevation of 2700m. The lens-mirror response function (lower left - purple) combines three mirror surfaces and six lens surfaces with broadband anti-reflection coatings. The mirror reflectivities are based on a hybrid Al-AG coating under development in collaboration with the Gemini Observatory. The ideal filter response functions (lower right) are computed with multi-layer thin-film models using TFCALC. The final six-band system response (right) is the multiplicative sum of the individual response functions.

Response (percent)  
Wavelength (nm)

Filter Response (percent)  
Wavelength (nm)

System Throughput (percent)  
Wavelength (nm)

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