Large Synoptic Survey Telescope

Performance and Analysis of the LSST Optical System

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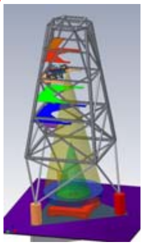
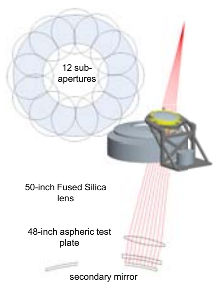
The LSST uses a modified Paul-Baker 3-mirror optical design with 8.4-m primary, 3.4-m secondary and 5-m tertiary mirrors. The system prescription has evolved to enable its deep, wide, fast mission. The proximity of the primary and tertiary surfaces enables fabrication of both mirrors from a single substrate. 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

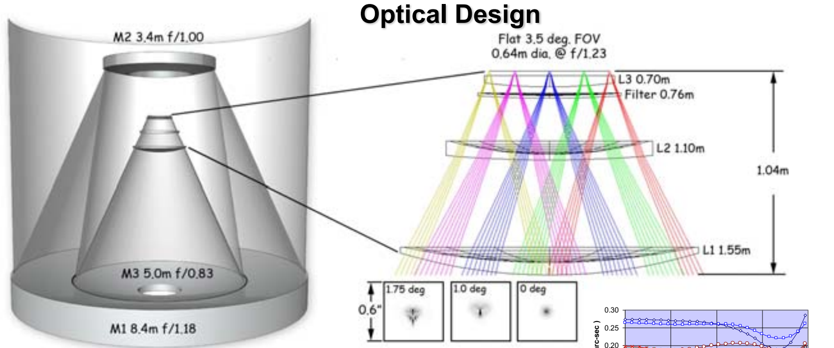


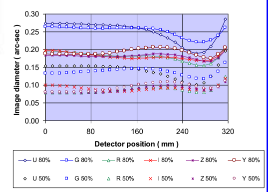
The First and third reflective surfaces will be manufactured into a single mirror blank, Each surface is suited to standard optical metrology.. Establishing the relationship between M1 and M3 is achieved through a combination of simultaneous optical tests, Laser tracker positioning, and mechanical run-out 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. The low order surface errors with limited sensitivity in this test are easily corrected.

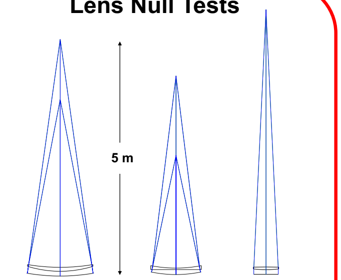
Optical Design





At the heart of the LSST optical design is a three mirror system that derives its origins from the Mersenne-Schmidt family of optical systems, that produce excellent image quality over very wide fields of view. The LSST system adds a 3-element refractive camera to further improve image performance, compensate for chromatic aberrations from the filters and dewar window, and flatten the focal plane. The meniscus filter substrates keep the beam telecentric across the full field of view, thus eliminating any wavelength shift in the filter response. The thickness of L3 is determined by the required stress safety margin needed to serve as the dewar window and vacuum barrier. The resulting image quality (right) is <0.2" at 50% (lower curves) and <0.3" at 80% encircled energy (upper curves) across the full visible spectrum (330 – 1080 Å).

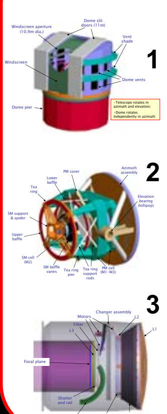
Lens Null Tests



L1, spherical L2, aspheric L3, aspheric

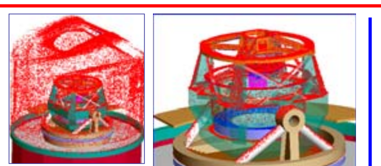
Individual null tests for each of the three refractive elements were included as part of the final design optimization. This resulted in the balancing of the aspheric terms throughout the optical system to simplify manufacturability. In the end L1 remained a fully spherical optic, a small amount of asphericity 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 prefered 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 surface are characterized by the properties of Z306 Aeroglaze black surface treatment.

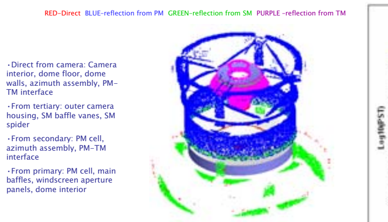
A critical surface analysis has been carried out by analyzing illuminated model elements from 2 points of view: 1) from the detector (right) and 2) from the dome exterior (upper right). In the former case a critical surface is identified from the detector's point of view by those elements visible off the primary (blue), secondary (green) and tertiary (purple). In the later 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 1st 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.



Dome walls have been hidden for clarity

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

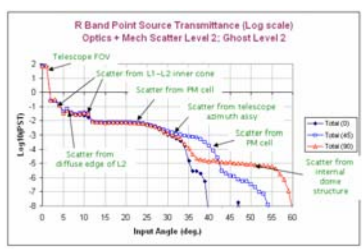
- Direct from camera: Camera interior, dome floor, dome walls, azimuth assembly, PM–TM interface
- From tertiary: outer camera housing, SM baffle vanes, SM spider
- From secondary: PM cell, azimuth assembly, PM–TM interface
- From primary: PM cell, main baffles, windscreen aperture panels, dome interior



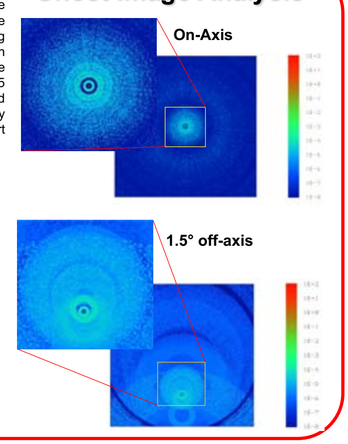
Dome walls and telescope structure has been hidden for clarity

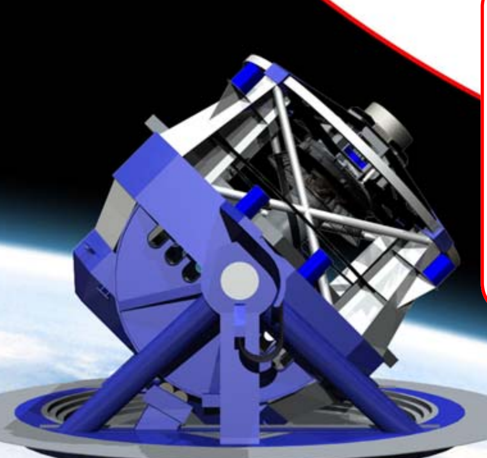
BLUE–reflection from PM GREEN–reflection from SM Purple–reflection from TM RED–direct from camera

With refractive elements secondary reflections will cause unwanted ghost images. All combinations of two-surface ghost in the LSST optical system have been analyzed. The fast f/1.23 LSST beam combined with anti-reflection coating on each lens surface results in very low surface brightness in the ghost images. The worst case ghost generated by the filter substrate (insets left, inner most circle) is 10^8 times (22.5 magnitudes) fainter than its source. The ghost generated from reflections off the sensor and L2 surface 2 is nearly stationary with field angle. Removal of this "pupil" will be part of the routine instrumental calibration image processing.



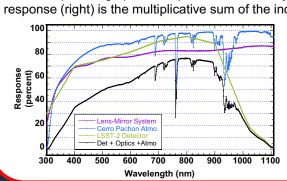
Ghost Image Analysis

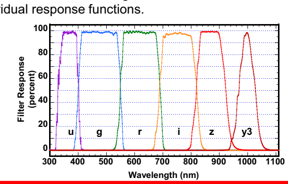


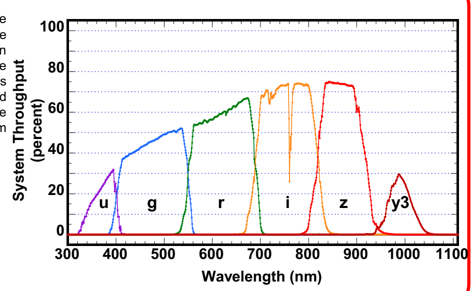


System Throughput

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 TCALC. The final six-band system response (right) is the multiplicative sum of the individual response functions.







LSST is a public-private partnership. Design and development activity is supported by in part the National Science Foundation under Scientific Program Order No. 9 (AST-0551161) and Scientific Program Order No. 1 (AST-0244680) through Cooperative Agreement AST-0132798. Portions of this work are supported by the Department of Energy under contract DE-AC02-76SF00515 with the Stanford Linear Accelerator Center, contract DE-AC02-98CH10886 with Brookhaven National Laboratory, and contract W-7405-ENG-48 with Lawrence Livermore National Laboratory. Additional funding comes from private donations, grants to universities, and in-kind support at Department of Energy laboratories and other LSSTC Institutional Members.

Brookhaven National Laboratory, California Institute of Technology, Columbia University, Google, Inc., Harvard-Smithsonian Center for Astrophysics, Johns Hopkins University, Kavli Institute for Particle Astrophysics and Cosmology - Stanford University, Las Cumbres Observatory Inc., Lawrence Livermore National Laboratory, National Optical Astronomy Observatory, Princeton University, Purdue University, Research Corporation, Stanford Linear Accelerator Center, The Pennsylvania State University, The University of Arizona, University of California at Davis, University of California at Irvine, University of Illinois at Urbana-Champaign, University of Pennsylvania, University of Pittsburgh, University of Washington