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LSST Optical Design Summary

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Summary This document provides a summary of the LSST optical design including system configuration prescriptions, general optical performance data, optical component descriptions, and a review of the stray light baffle system.

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William Gressler	5/1/2009	Original document creation.
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1.0 LSST Baseline Optical Design

1.1 Optical Design Summary:

The LSST optical design is a wide field of view system comprised of an 8.4-m diameter primary, 3.4-m secondary and 5-m tertiary mirrors. The three-mirror telescope feeds a three element refractive corrector to produce a 3.5-degree diameter field of view over a 63-cm flat focal surface with excellent image quality. The camera housing carries five onboard filters (a manual cartridge holds a sixth) to support imaging in six spectral bands. Each inserted filter configuration requires the refocusing of the camera body relative to M3 via the camera hexapod.

The evolution of the telescope optical system focused on the following goals:

1. Maintaining large integrated throughput with minimal vignetting
2. Limiting camera cantilever for mounting
3. Reducing M2 fabrication risk by decreasing its aspheric departure
4. Maintaining excellent, uniform image quality across grizY bands
5. Reducing lens fabrication risk by simplifying null tests
6. Enable camera installation through M2 inner diameter

The proximity of the primary and tertiary surfaces (233.8mm vertex separation) enables fabrication of both mirrors from a single substrate. This unique design, referred to as the M1/M3 monolith, offers significant advantages in the reduction of degrees of freedom during operational alignment and improved structural stiffness for the otherwise annular primary surface. An unused 50mm diameter radial zone between the two surfaces will define the M1/M3 clear apertures.

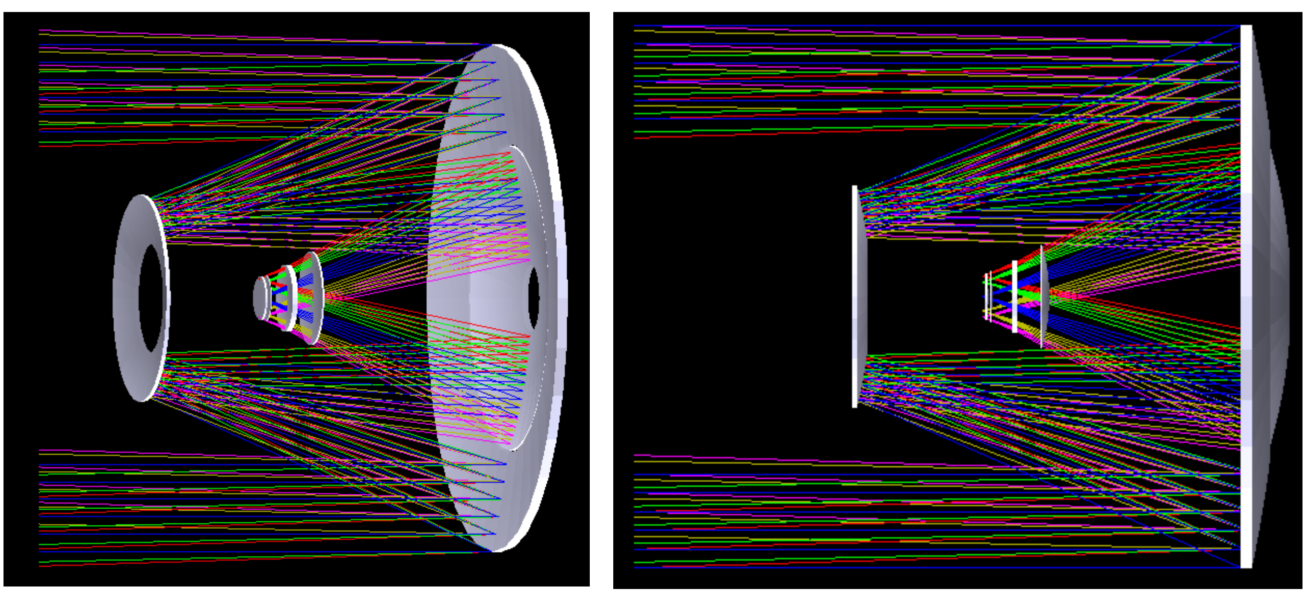


Figure 1: LSST 3.5-Degree FOV Optical System Raytrace

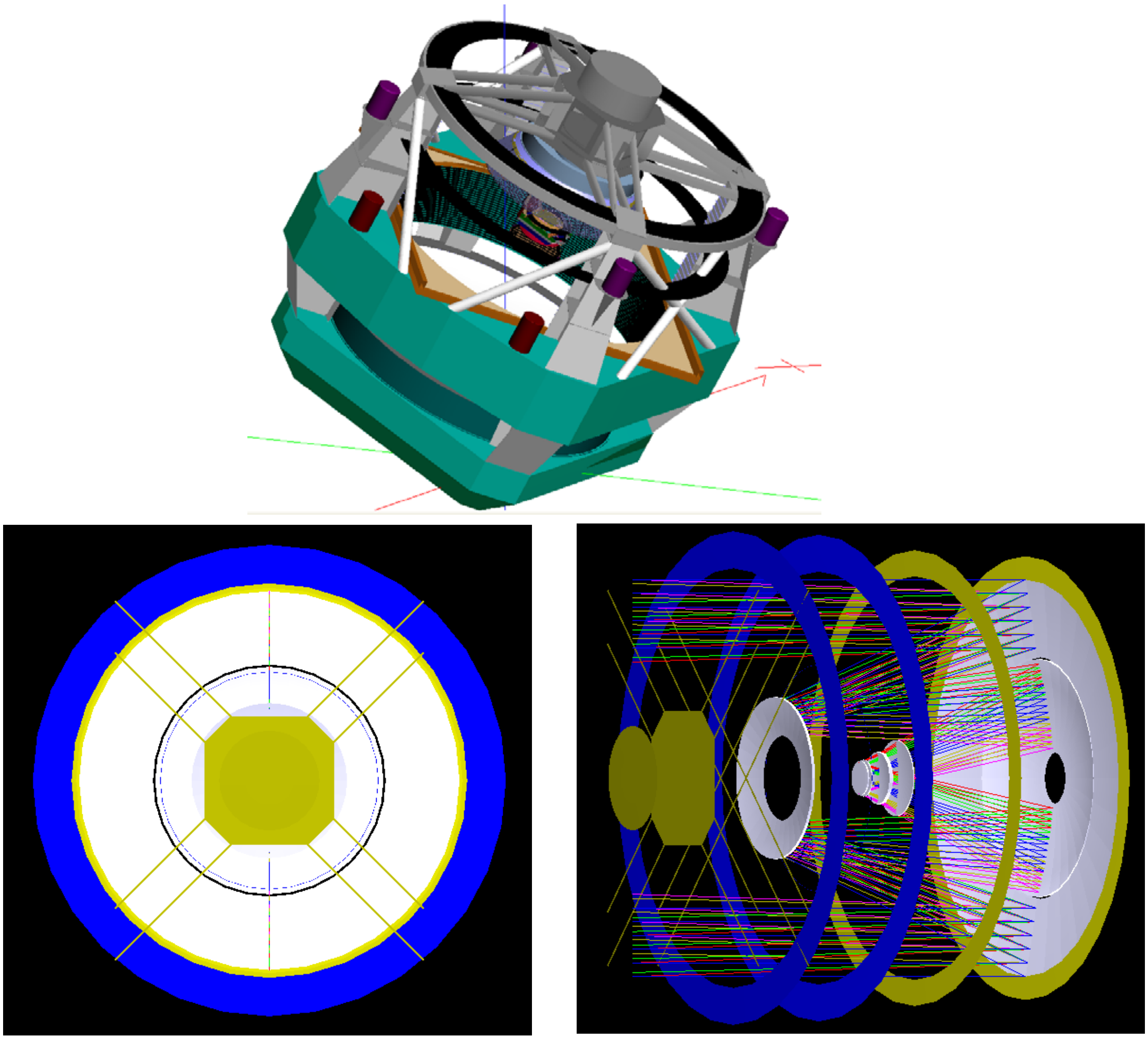


Figure 2: LSST Opto-Mechanical Layout

The telescope Top End Assembly (TEA) supports the integrated M2 cell and hexapod as well as the integrated camera instrument, hexapod, and rotator via eight spiders (50mm diameter cross sectional area, 9600mm long, with +/- 400mm x/y decenter). Camera and M2 support utilities are carried within the shadow of M2.

Baffles are integrated into the telescope support design via circular rings within the TEA and the telescope tube and the M1/M3 mirror cover inner diameter. A circular ring around the periphery of the M1 cell is the aperture stop and a series of ring baffles are attached to the M2 assembly. Stray light control is also performed via the dome wind screen.

1.2 Telescope System Prescription:

The optical prescription data of the baseline system utilizing the r-band filter is shown below.

Surface	Name	Radius of Curvature (mm)	Center Thickness (mm)	Outer CA radius (mm)	Inner CA radius (mm)	Glass
1		Infinity	2000.0000			
2	M2 Vertex	Infinity	6156.2006			
3	M1	-19835.0	-6156.2006	4180.00	2558.00	Mirror
4	M2	-6788.0	6156.2006	1710.00	900.00	Mirror
5	M1/M3 Offset	Infinity	233.8000			
6	M3	-8344.5	-3630.5000	2508.00	550.00	Mirror
7		Infinity	-0.7610			
8	L1	-2824.00	-82.2300	775.00		Silica
9		-5021.00	-412.6420	775.00		
10	L2	Infinity	-30.0000	551.00		Silica
11		-2529.00	-357.5800	551.00		
12	Filter	-5624.00	-17.8000	375.00		Silica
13		-5594.00	-43.2000	375.00		
14	L3	-3169.00	-60.0000	361.00		Silica
15		13360.00	-28.5000	361.00		
16	Detector			317.00		

Table 1: R-Band Filter Telescope Configuration

The system is comprised of three even aspheric mirror surfaces, three fused silica refractive lenses (with even aspheric surfaces on L2 surface #2 and L3 surface #1), and six interchangeable fused silica transmissive band pass filters.

Rotationally symmetric polynomial aspheric surfaces are described by a polynomial expansion of the deviation from a spherical (or aspheric described by a conic) surface. The even asphere surface model uses only the even powers of the radial coordinate to describe the asphericity.

Taking the z axis as the axis of revolution, an optical surface is defined by:

$$z = \frac{cr^2}{1+\sqrt{\left[1-(1+k)c^2r^2\right]}} + \alpha_1 r^2 + \alpha_2 r^4 + \alpha_3 r^6 + \alpha_4 r^8$$

Where: c = 1 / radius of curvature

k = conic constant

$r^2 = x^2 + y^2$

α_i = aspheric coefficients

This equation is applicable regardless of sign convention. By definition, distances traveling from left-to-right are considered positive and distances from right-to-left are considered negative. If the sign of the radius of curvature is reversed, then the sign of the aspheric terms must also be changed.

Surface	***Conic Constant***	***r2***	***r4***	***r6***	***r8***
M1	***-1.2150***	***0.0***	***0.0***	***1.381E-24***	***0.0***
M2	***-0.2220***	***0.0***	***0.0***	***-1.274E-20***	***-9.680E-28***
M3	***0.1550***	***0.0***	***0.0***	***-4.500E-22***	***-8.150E-30***
L2 Radius #2	***-1.5700***	***0.0***	***0.0***	***1.6560E-18***	***0.0***
L3 Radius #1	***-0.9620***	***0.0***	***0.0***	***0.0***	***0.0***

Table 2: LSST Aspheric Surfaces Summary

The baseline Zemax model files are found on the LSST Archive in Collection 886 (including a base model, one with spiders, and one with spiders and baffles).

The six specific filter band telescope configuration prescriptions are now listed.

1.2.1 U-Band Configuration Prescription

Note: All units in mm.

Lens Data Editor: Config 1/6

Edit Solves View Help

Surf	Type	Comment	Radius	Thickness	Glass	Semi-Diameter	Conic
OBJ	Standard		Infinity	Infinity		Infinity	0.000000
1	Standard		Infinity	2000.000000		4415.769893	0.000000
2	Standard	M2 Vertex	Infinity	6156.200600		4354.664366	0.000000
STO*	Even Asphere	M1	-1.983500E+004	-6156.200600 P	MIRROR	4180.000000 U	-1.215000
4*	Even Asphere	M2	-6788.000000	6156.200600 P	MIRROR	1710.000000 U	-0.222000
5	Standard	M1/M3 Offset	Infinity	233.800000		2731.428835	0.000000
6*	Even Asphere	M3	-8344.500000	-3630.500000	MIRROR	2508.000000 U	0.155000
7	Standard		Infinity	-3.471000		888.178113	0.000000
8*	Standard	L1	-2824.000000	-82.230000	SILICA	775.000000 U	0.000000
9*	Standard		-5021.000000	-412.642020		775.000000 P	0.000000
10*	Standard	L2	Infinity	-30.000000	SILICA	551.000000 U	0.000000
11*	Even Asphere		-2529.000000	-357.580000		551.000000 P	-1.570000
12*	Standard	FILTER	-5624.000000	-26.200000	SILICA	375.000000 U	0.000000
13*	Standard		-5513.000000	-34.800000 P		375.000000 P	0.000000
14*	Even Asphere	L3	-3169.000000	-60.000000	SILICA	361.000000 U	-0.962000
15*	Standard		1.336000E+004	-28.500000		361.000000 P	0.000000
IMA	Standard	Detector	Infinity	-		315.058789	0.000000

Figure 3: U-Band Filter Configuration

1.2.2 G-Band Configuration Prescription

Note: All units in mm.

Lens Data Editor: Config 2/6

Edit Solves View Help

Surf	Type	Comment	Radius	Thickness	Glass	Semi-Diameter	Conic
OBJ	Standard		Infinity	Infinity		Infinity	0.000000
1	Standard		Infinity	2000.000000		4415.769893	0.000000
2	Standard	M2 Vertex	Infinity	6156.200600		4354.664366	0.000000
STO*	Even Asphere	M1	-1.983500E+004	-6156.200600 P	MIRROR	4180.000000 U	-1.215000
4*	Even Asphere	M2	-6788.000000	6156.200600 P	MIRROR	1710.000000 U	-0.222000
5	Standard	M1/M3 Offset	Infinity	233.800000		2731.428835	0.000000
6*	Even Asphere	M3	-8344.500000	-3630.500000	MIRROR	2508.000000 U	0.155000
7	Standard		Infinity	-1.826000		888.178113	0.000000
8*	Standard	L1	-2824.000000	-82.230000	SILICA	775.000000 U	0.000000
9*	Standard		-5021.000000	-412.642020		775.000000 P	0.000000
10*	Standard	L2	Infinity	-30.000000	SILICA	551.000000 U	0.000000
11*	Even Asphere		-2529.000000	-357.580000		551.000000 P	-1.570000
12*	Standard	FILTER	-5624.000000	-21.140000	SILICA	375.000000 U	0.000000
13*	Standard		-5564.000000	-39.860000 P		375.000000 P	0.000000
14*	Even Asphere	L3	-3169.000000	-60.000000	SILICA	361.000000 U	-0.962000
15*	Standard		1.336000E+004	-28.500000		361.000000 P	0.000000
IMA	Standard	Detector	Infinity	-		315.198053	0.000000

Figure 4: G-Band Filter Configuration

1.2.3 R-Band Configuration Prescription

Note: All units in mm.

Lens Data Editor: Config 3/6

Edit Solves View Help

Surf	Type	Comment	Radius	Thickness	Glass	Semi-Diameter	Conic
OBJ	Standard		Infinity	Infinity		Infinity	0.000000
1	Standard		Infinity	2000.000000		4415.769893	0.000000
2	Standard	M2 Vertex	Infinity	6156.200600		4354.664366	0.000000
STO*	Even Asphere	M1	-1.983500E+004	-6156.200600 P	MIRROR	4180.000000 U	-1.215000
4*	Even Asphere	M2	-6788.000000	6156.200600 P	MIRROR	1710.000000 U	-0.222000
5	Standard	M1/M3 Offset	Infinity	233.800000		2731.428835	0.000000
6*	Even Asphere	M3	-8344.500000	-3630.500000	MIRROR	2508.000000 U	0.155000
7	Standard		Infinity	-0.761000		888.178113	0.000000
8*	Standard	L1	-2824.000000	-82.230000	SILICA	775.000000 U	0.000000
9*	Standard		-5021.000000	-412.642020		775.000000 P	0.000000
10*	Standard	L2	Infinity	-30.000000	SILICA	551.000000 U	0.000000
11*	Even Asphere		-2529.000000	-357.580000		551.000000 P	-1.570000
12*	Standard	FILTER	-5624.000000	-17.800000	SILICA	375.000000 U	0.000000
13*	Standard		-5594.000000	-43.200000 P		375.000000 P	0.000000
14*	Even Asphere	L3	-3169.000000	-60.000000	SILICA	361.000000 U	-0.962000
15*	Standard		1.336000E+004	-28.500000		361.000000 P	0.000000
IMA	Standard	Detector	Infinity	-		315.279938	0.000000

Figure 5: R-Band Filter Configuration

1.2.4 I-Band Configuration Prescription

Note: All units in mm.

Lens Data Editor: Config 4/6

Edit Solves View Help

Surf	Type	Comment	Radius	Thickness	Glass	Semi-Diameter	Conic
OBJ	Standard		Infinity	Infinity		Infinity	0.000000
1	Standard		Infinity	2000.000000		4415.769893	0.000000
2	Standard	M2 Vertex	Infinity	6156.200600		4354.664366	0.000000
STO*	Even Asphere	M1	-1.983500E+004	-6156.200600 P	MIRROR	4180.000000 U	-1.215000
4*	Even Asphere	M2	-6788.000000	6156.200600 P	MIRROR	1710.000000 U	-0.222000
5	Standard	M1/M3 Offset	Infinity	233.800000		2731.428835	0.000000
6*	Even Asphere	M3	-8344.500000	-3630.500000	MIRROR	2508.000000 U	0.155000
7	Standard		Infinity	-0.099300		888.178113	0.000000
8*	Standard	L1	-2824.000000	-82.230000	SILICA	775.000000 U	0.000000
9*	Standard		-5021.000000	-412.642020		775.000000 P	0.000000
10*	Standard	L2	Infinity	-30.000000	SILICA	551.000000 U	0.000000
11*	Even Asphere		-2529.000000	-357.580000		551.000000 P	-1.570000
12*	Standard	FILTER	-5624.000000	-15.700000	SILICA	375.000000 U	0.000000
13*	Standard		-5612.000000	-45.300000 P		375.000000 P	0.000000
14*	Even Asphere	L3	-3169.000000	-60.000000	SILICA	361.000000 U	-0.962000
15*	Standard		1.336000E+004	-28.500000		361.000000 P	0.000000
IMA	Standard	Detector	Infinity	-		315.332637	0.000000

Figure 6: I-Band Filter Configuration

1.2.5 Z-Band Configuration Prescription

Note: All units in mm.

Lens Data Editor: Config 5/6

Edit Solves View Help

Surf	Type	Comment	Radius	Thickness	Glass	Semi-Diameter	Conic
OBJ	Standard		Infinity	Infinity		Infinity	0.000000
1	Standard		Infinity	2000.000000		4415.769893	0.000000
2	Standard	M2 Vertex	Infinity	6156.200600		4354.664366	0.000000
STO*	Even Asphere	M1	-1.983500E+004	-6156.200600 P	MIRROR	4180.000000 U	-1.215000
4*	Even Asphere	M2	-6788.000000	6156.200600 P	MIRROR	1710.000000 U	-0.222000
5	Standard	M1/M3 Offset	Infinity	233.800000		2731.428835	0.000000
6*	Even Asphere	M3	-8344.500000	-3630.500000	MIRROR	2508.000000 U	0.155000
7	Standard		Infinity	0.370000		888.178113	0.000000
8*	Standard	L1	-2824.000000	-82.230000	SILICA	775.000000 U	0.000000
9*	Standard		-5021.000000	-412.642020		775.000000 P	0.000000
10*	Standard	L2	Infinity	-30.000000	SILICA	551.000000 U	0.000000
11*	Even Asphere		-2529.000000	-357.580000		551.000000 P	-1.570000
12*	Standard	FILTER	-5624.000000	-14.200000	SILICA	375.000000 U	0.000000
13*	Standard		-5624.000000	-46.800000 P		375.000000 P	0.000000
14*	Even Asphere	L3	-3169.000000	-60.000000	SILICA	361.000000 U	-0.962000
15*	Standard		1.336000E+004	-28.500000		361.000000 P	0.000000
IMA	Standard	Detector	Infinity	-		315.370823	0.000000

Figure 7: Z-Band Filter Configuration

1.2.6 Y-Band Configuration Prescription

Note: All units in mm.

Lens Data Editor: Config 6/6

Edit Solves View Help

Surf	Type	Comment	Radius	Thickness	Glass	Semi-Diameter	Conic
OBJ	Standard		Infinity	Infinity		Infinity	0.000000
1	Standard		Infinity	2000.000000		4415.769893	0.000000
2	Standard	M2 Vertex	Infinity	6156.200600		5000.000000 U	0.000000
STO*	Even Asphere	M1	-1.983500E+004	-6156.200600 P	MIRROR	4180.000000 U	-1.215000
4*	Even Asphere	M2	-6788.000000	6156.200600 P	MIRROR	1710.000000 U	-0.222000
5	Standard	M1/M3 Offset	Infinity	233.800000		2731.428835	0.000000
6*	Even Asphere	M3	-8344.500000	-3630.500000	MIRROR	2508.000000 U	0.155000
7	Standard		Infinity	0.584300		888.178113	0.000000
8*	Standard	L1	-2824.000000	-82.230000	SILICA	775.000000 U	0.000000
9*	Standard		-5021.000000	-412.642020		775.000000 P	0.000000
10*	Standard	L2	Infinity	-30.000000	SILICA	551.000000 U	0.000000
11*	Even Asphere		-2529.000000	-357.580000		551.000000 P	-1.570000
12*	Standard	FILTER	-5624.000000	-13.500000	SILICA	375.000000 U	0.000000
13*	Standard		-5624.000000	-47.500000 P		375.000000 P	0.000000
14*	Even Asphere	L3	-3169.000000	-60.000000	SILICA	361.000000 U	-0.962000
15*	Standard		1.336000E+004	-28.500000		361.000000 P	0.000000
IMA	Standard	Detector	Infinity	-		317.000000 U	0.000000

Figure 8: Y-Band Filter Configuration

1.3 Telescope Filter Multi-Configurations:

The optical system operates in six configurations, covering six filter bands (u, g, r, i, z, and y). The camera assembly (L1, L2, Filters, and L3 as a unit) is refocused relative to M3 (thickness of surface #7 shown in the configuration prescriptions above) to accommodate the focus shift due to the filter change. Only the filter moves in and out, L2 does not move.

Since each filter has a varying center thickness (26.2mm – 13.5mm), the air space between the filter and L3 is varied to maintain a 61mm total distance from the filter to L3 via the pickup on the thickness on surface #13.

Each filter, made of fused silica, has a unique center thickness (surface #12) and second surface curvature (surface #13). The filters are curved so they are normal about the chief ray so that all portions of the filter see the same angle of incidence range (~+/-14.2° – 23.6°) to assist in coating design.

The multi-configuration editor shown below summarizes the six telescope configurations, including wavelength ranges, wavelength weights, camera body spacing, filter thickness, and filter curvature variation. Note: All units in mm.

Multi-Configuration Editor

Active : 1/6		Config 1*	Config 2	Config 3	Config 4	Config 5	Config 6
1: MOFF	0	U BAND	G BAND	R BAND	I BAND	Z BAND	Y BAND
2: WAVE	1	0.384000	0.481000	0.622000	0.770000	0.895000	0.994000
3: WLWT	1	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
4: WAVE	2	0.362000	0.410000	0.550000	0.694000	0.840000	0.960000
5: WLWT	2	0.710000	1.000000	1.000000	1.000000	1.000000	1.000000
6: WAVE	3	0.391000	0.552000	0.694000	0.847000	0.950000	1.028000
7: WLWT	3	0.690000	1.000000	1.000000	1.000000	1.000000	1.000000
8: WAVE	4	0.328000	0.445000	0.586000	0.732000	0.867500	0.977000
9: WLWT	4	0.250000	1.000000	1.000000	1.000000	1.000000	1.000000
10: WAVE	5	0.398000	0.516000	0.658000	0.808000	0.922500	1.011000
11: WLWT	5	0.240000	1.000000	1.000000	1.000000	1.000000	1.000000
12: THIC	7	-3.471000	-1.826000	-0.761000	-0.099300	0.370000	0.584300
13: THIC	12	-26.200000	-21.140000	-17.800000	-15.700000	-14.200000	-13.500000
14: CRVT	13	-1.81389E-004	-1.79727E-004	-1.78763E-004	-1.78190E-004	-1.77809E-004	-1.77809E-004
15: MOFF	0						

Figure 9: LSST Multi-Configuration Editor Listing

The six configurations each utilize five specific wavelengths labeled below:

Configuration	Filter	Wavelengths (microns)				
1	u	0.384	0.362	0.391	0.328	0.398
2	g	0.481	0.410	0.552	0.445	0.516
3	r	0.622	0.550	0.694	0.586	0.658
4	i	0.770	0.694	0.847	0.732	0.808
5	z	0.895	0.840	0.950	0.8675	0.9225
6	y	0.994	0.960	1.028	0.977	1.011

Table 3: LSST Filter Band Wavelengths

All wavebands except the u-band have unity weighting assigned to their individual wavelengths. The u-band configuration weights are listed below:

Wavelength (microns)	Weight
0.384	1.000
0.362	0.710
0.391	0.690
0.328	0.250
0.398	0.240

Table 4: U-Band Filter Wavelength Weights

The u-band weights are representative of the expected filter passband.

1.4 General Optical Performance Data:

1.4.1 Geometrical Data

The system entrance pupil diameter is 8360mm, with the edge of the primary mirror (M1) being the aperture stop. The effective system f/# varies slightly per each filter band/configuration:

Filter	System F/#	Focal Length (mm)
u	1.232	10302.72
g	1.233	10307.22
r	1.233	10310.17
i	1.233	10311.97
z	1.234	10313.21
y	1.234	10313.91

Table 5: LSST Filter Band F/#

The plate scale of the optical system is 50 microns/arc second.

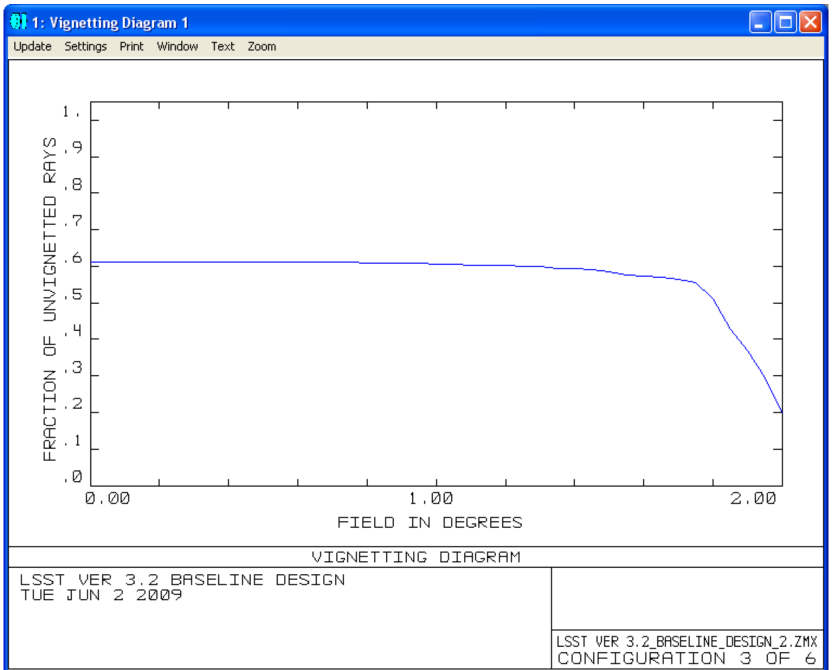
The telescope imaging field of view (FOV) is +/-1.75 degrees. This FOV provides 9.6 square degrees. The resulting image size on the detector is approximately 631mm in diameter.

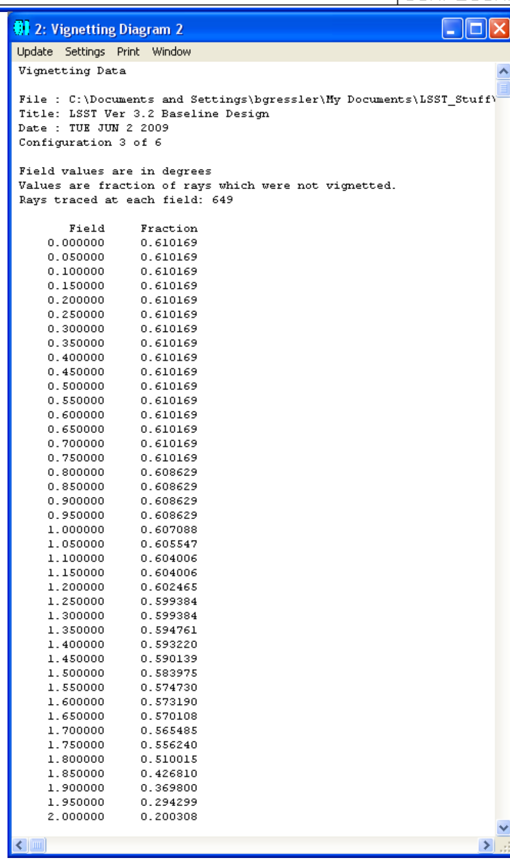
The TEA spiders are 50mm in cross sectional area and eight of them are used in supporting the camera and M2 assemblies. The effective collecting area of the telescope is 6.68m (adjusted for obscuration and TEA spiders).

LSST Document 7512 provides a spreadsheet for calculation of the LSST optical system Etendue (AΩ). Raytracing is performed on a sequential set of annular fields. The annular field area (degree^2) is computed and multiplied by the throughput (via vignetting analysis) and the effective collecting area at the center radius of the annulus pairs (meter^2). This calculation determines the Etendue (AΩ) for each annulus. A summation of all field annulus results in a computation of the total Etendue. Assuming a 95% CCD fill factor, the effective LSST Etendue is 315 meter^2 degree^2.

1.4.2 Vignetting

The plot of vignetting for the r-band filter is shown below.





2: Vignetting Diagram 2

Update Settings Print Window

Vignetting Data

File : C:\Documents and Settings\bgressler\My Documents\LSST_Stuff\
Title: LSST Ver 3.2 Baseline Design
Date : TUE JUN 2 2009
Configuration 3 of 6

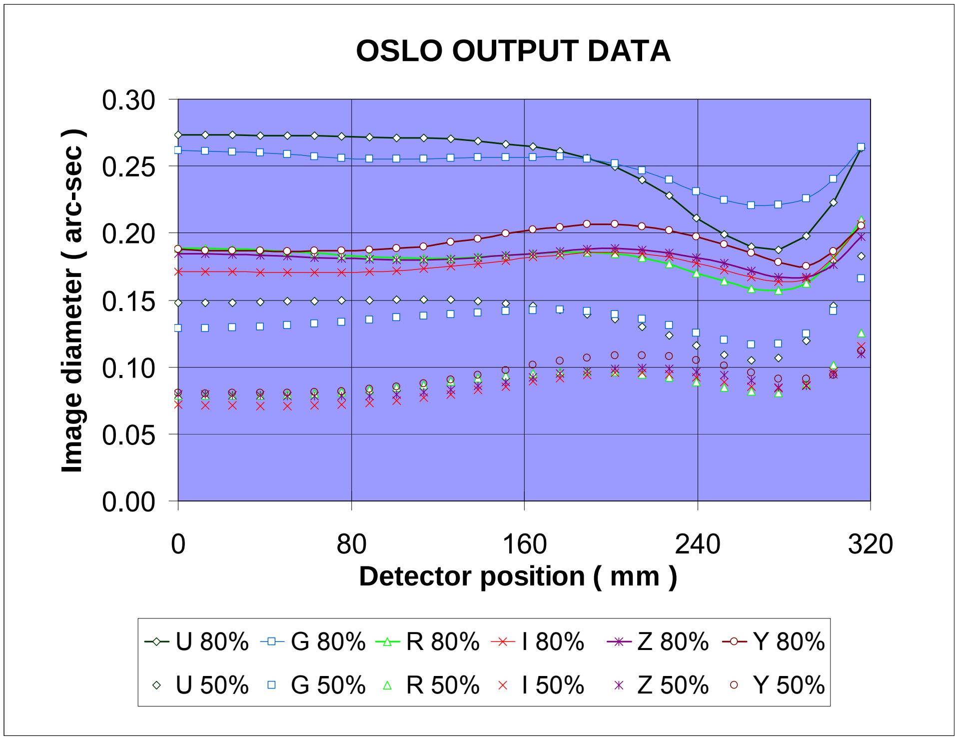
Field values are in degrees
Values are fraction of rays which were not vignetted.
Rays traced at each field: 649

Field	Fraction
0.000000	0.610169
0.050000	0.610169
0.100000	0.610169
0.150000	0.610169
0.200000	0.610169
0.250000	0.610169
0.300000	0.610169
0.350000	0.610169
0.400000	0.610169
0.450000	0.610169
0.500000	0.610169
0.550000	0.610169
0.600000	0.610169
0.650000	0.610169
0.700000	0.610169
0.750000	0.610169
0.800000	0.608629
0.850000	0.608629
0.900000	0.608629
0.950000	0.608629
1.000000	0.607088
1.050000	0.605547
1.100000	0.604006
1.150000	0.604006
1.200000	0.602465
1.250000	0.599384
1.300000	0.599384
1.350000	0.594761
1.400000	0.593220
1.450000	0.590139
1.500000	0.583975
1.550000	0.574730
1.600000	0.573190
1.650000	0.570108
1.700000	0.565485
1.750000	0.556240
1.800000	0.510015
1.850000	0.426810
1.900000	0.369800
1.950000	0.294299
2.000000	0.200308

Figure 10: R-Band Filter Vignetting

1.4.3 Imaging Performance

Plots shown below are from both Oslo and Zemax (1024x1024 sampling).



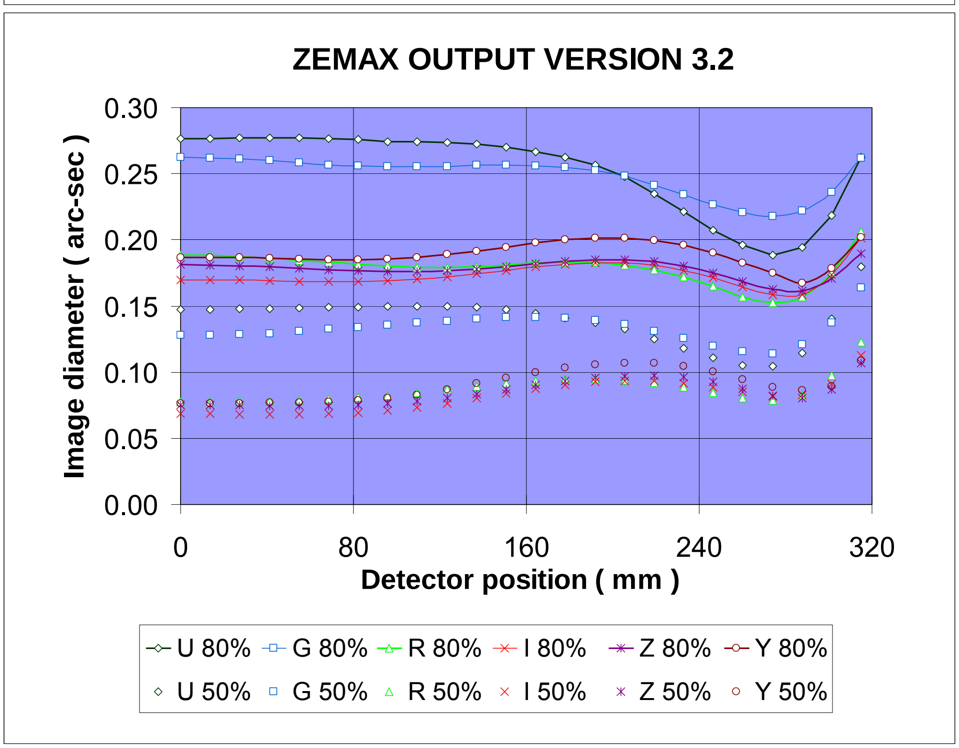
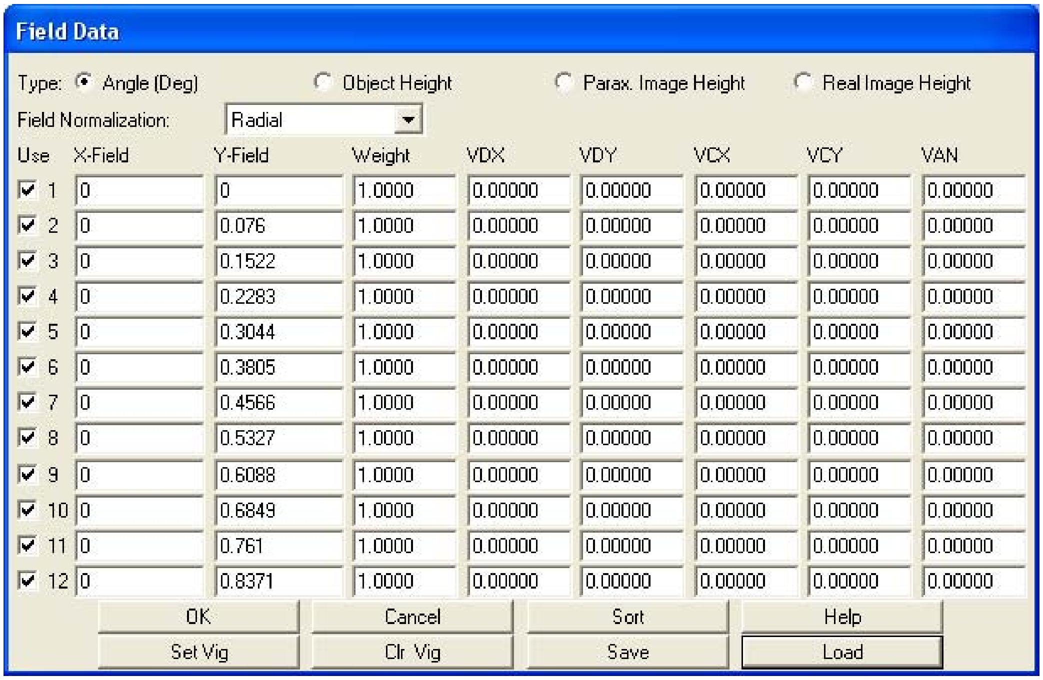


Figure 11: EE(80)/EE(50) Summary

The encircled energy calculations computed with Zemax and Oslo display a high degree of consistency. For comparison between Oslo and Zemax, a similar set of field points were chosen. Since Zemax is limited to 12 field positions, two field data sets were used (inner and outer field) for EE calculations as shown below.



Field Data

Type: Angle (Deg) | Object Height | Parax. Image Height | Real Image Height

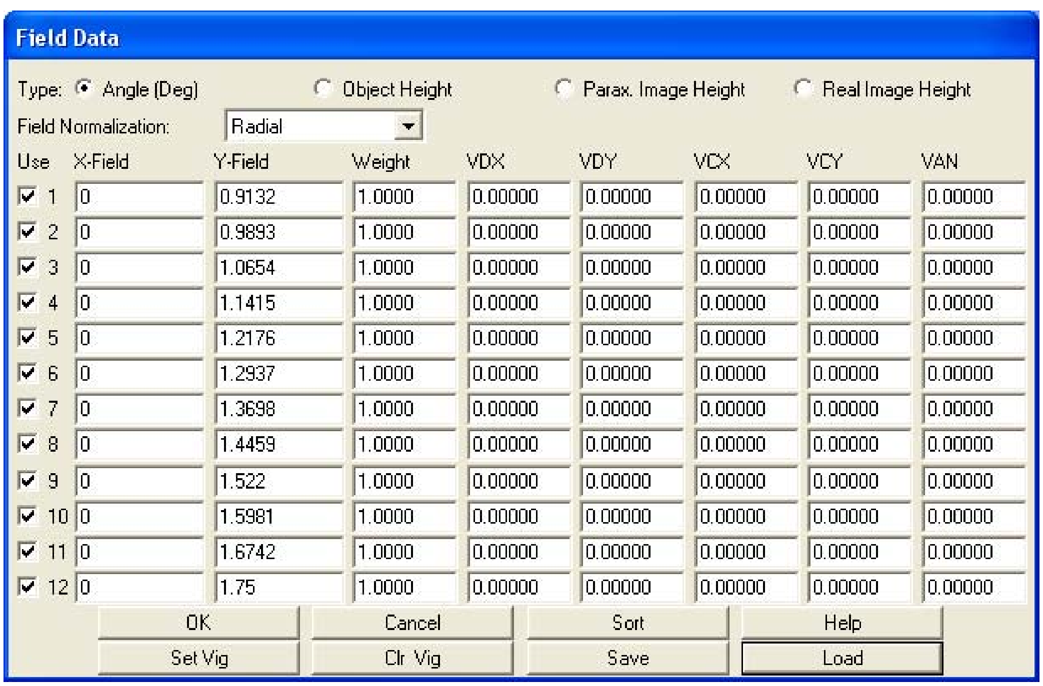
Field Normalization: Radial

Use	X-Field	Y-Field	Weight	VDX	VDY	VCX	VCY	VAN
1	0	0	1.0000	0.00000	0.00000	0.00000	0.00000	0.00000
2	0	0.076	1.0000	0.00000	0.00000	0.00000	0.00000	0.00000
3	0	0.1522	1.0000	0.00000	0.00000	0.00000	0.00000	0.00000
4	0	0.2283	1.0000	0.00000	0.00000	0.00000	0.00000	0.00000
5	0	0.3044	1.0000	0.00000	0.00000	0.00000	0.00000	0.00000
6	0	0.3805	1.0000	0.00000	0.00000	0.00000	0.00000	0.00000
7	0	0.4566	1.0000	0.00000	0.00000	0.00000	0.00000	0.00000
8	0	0.5327	1.0000	0.00000	0.00000	0.00000	0.00000	0.00000
9	0	0.6088	1.0000	0.00000	0.00000	0.00000	0.00000	0.00000
10	0	0.6849	1.0000	0.00000	0.00000	0.00000	0.00000	0.00000
11	0	0.761	1.0000	0.00000	0.00000	0.00000	0.00000	0.00000
12	0	0.8371	1.0000	0.00000	0.00000	0.00000	0.00000	0.00000

OK | Cancel | Sort | Help

Set Vig | Clr Vig | Save | Load

Figure 12: Zemax Inner Field Points



Field Data

Type: Angle (Deg) | Object Height | Parax. Image Height | Real Image Height

Field Normalization: Radial

Use	X-Field	Y-Field	Weight	VDX	VDY	VCX	VCY	VAN
1	0	0.9132	1.0000	0.00000	0.00000	0.00000	0.00000	0.00000
2	0	0.9893	1.0000	0.00000	0.00000	0.00000	0.00000	0.00000
3	0	1.0654	1.0000	0.00000	0.00000	0.00000	0.00000	0.00000
4	0	1.1415	1.0000	0.00000	0.00000	0.00000	0.00000	0.00000
5	0	1.2176	1.0000	0.00000	0.00000	0.00000	0.00000	0.00000
6	0	1.2937	1.0000	0.00000	0.00000	0.00000	0.00000	0.00000
7	0	1.3698	1.0000	0.00000	0.00000	0.00000	0.00000	0.00000
8	0	1.4459	1.0000	0.00000	0.00000	0.00000	0.00000	0.00000
9	0	1.522	1.0000	0.00000	0.00000	0.00000	0.00000	0.00000
10	0	1.5981	1.0000	0.00000	0.00000	0.00000	0.00000	0.00000
11	0	1.6742	1.0000	0.00000	0.00000	0.00000	0.00000	0.00000
12	0	1.75	1.0000	0.00000	0.00000	0.00000	0.00000	0.00000

OK | Cancel | Sort | Help

Set Vig | Clr Vig | Save | Load

Figure 13: Zemax Outer Field Points

The following are the Zemax computed average EE(50) and EE(80) image sizes across the six filter bands.

Residual Design Aberrations		
Filter Band	***Average EE(50)***	***Average EE(80)***
u	***0.14 arc sec***	***0.25 arc sec***
g	***0.13 arc sec***	***0.25 arc sec***
r	***0.09 arc sec***	***0.18 arc sec***
i	***0.08 arc sec***	***0.17 arc sec***
z	***0.08 arc sec***	***0.18 arc sec***
y	***0.09 arc sec***	***0.19 arc sec***

Table 6: LSST Filter Band EE(50)/EE(80) Averages

2.0 Optical Components Descriptions:

2.1 Mirror Summary:

2.1.1 M1/M3

The M1/M3 monolithic mirror is a cast borosilicate mirror fabricated by the University of Arizona Steward Observatory Mirror Lab (CTE = 28 / K E-7). The finished mirror dimensions can be found in LSST Doc. 3972. The M1/M3 vertex offset is 233.8mm. An unused 50mm diameter radial zone between the two surfaces will define the inner M1/M3 clear apertures.

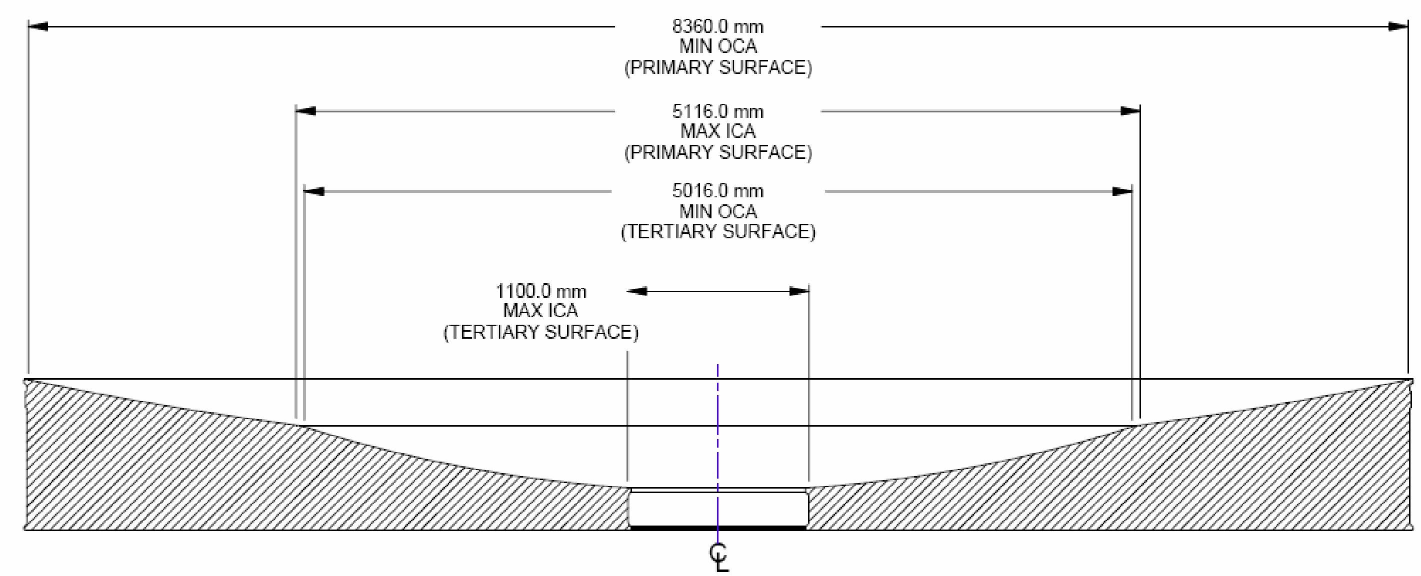


Figure 14: LSST M1/M3 Profile Geometries

Element	*OD (mm)*	*ID (mm)*	*Outer CA Semi-diameter (mm)*	*Inner CA Semi-diameter (mm)*
M1	*8405*	*5116*	*4180*	*2558*
M3	*5016*	*1067*	*2508*	*550*

Table 7: LSST M1/M3 Physical Properties

2.1.2 M2

The M2 substrate is made of Corning ULE material (CTE = 0.3 / K E-7). At this time the fabrication contract has not been awarded.

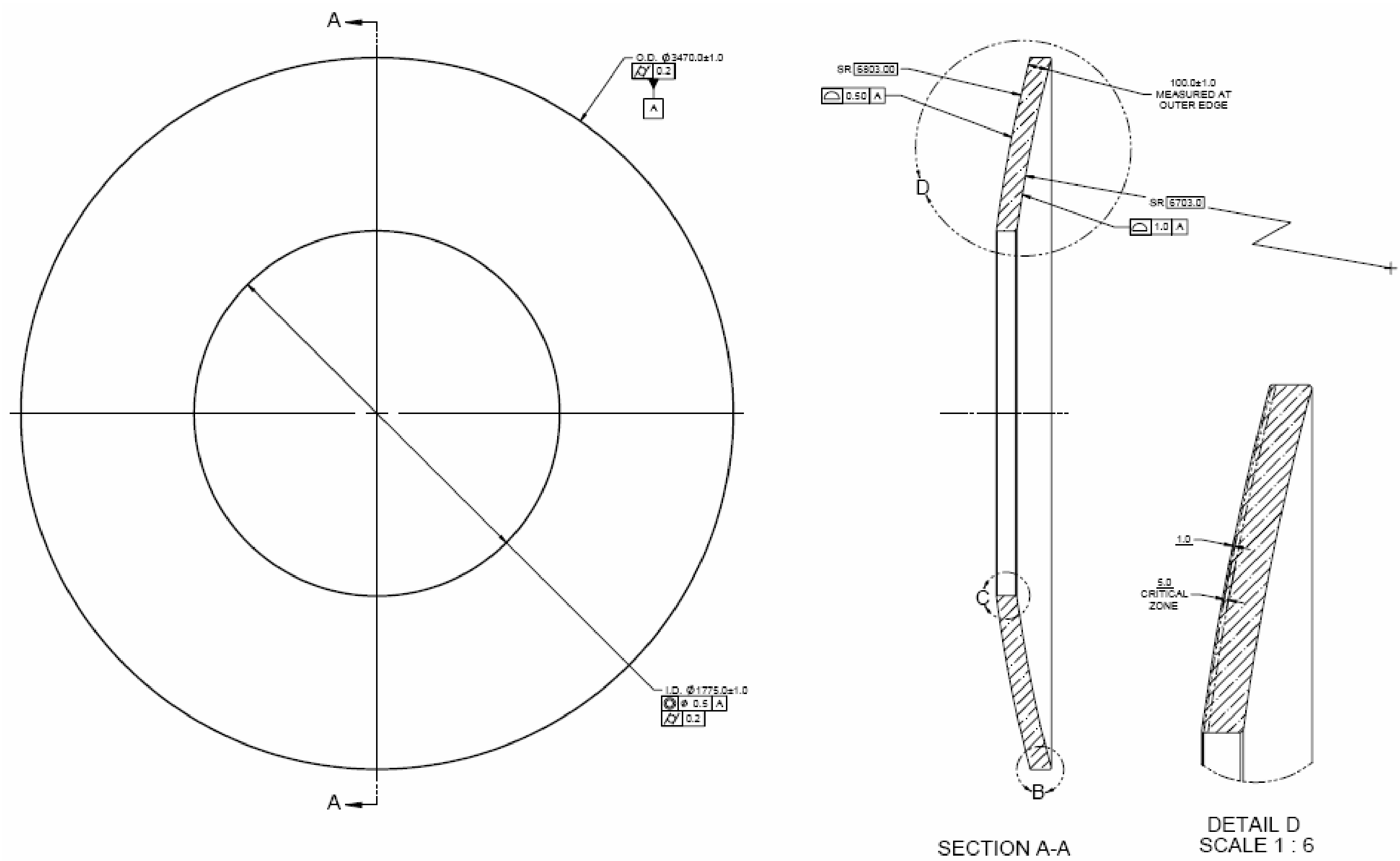


Figure 15: LSST M2 Profile Geometry

Element	*OD (mm)*	*ID (mm)*	*Outer CA Semi-diameter (mm)*	*Inner CA Semi-diameter (mm)*
M2	*3470*	*1775*	*1710*	*900*

Table 8: LSST M2 Physical Properties

2.2 Camera Optics Summary:

Adequate chromatic correction is possible using a single glass type (fused silica) in the camera optical system. The camera elements acting in unison contribute no net power; rays entering and leaving the corrector are nearly parallel. The focal length of the telescope is approximately constant over a small bandwidth.

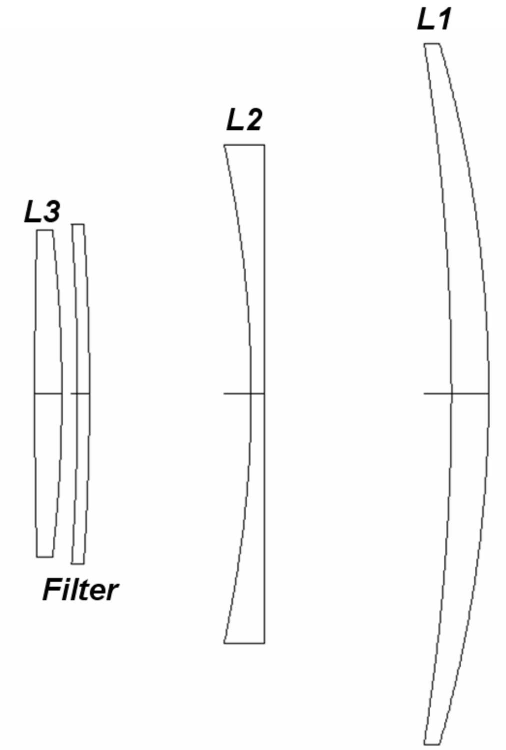


Figure 16: LSST Camera Optics Profile Geometry

Element	CA Semi-diameter (mm)	CA Diameter (mm)	OD (mm)
L1	775	1550	1590
L2	551	1102	1140
Filter	375	750	790
L3	361	722	782

Table 9: LSST Camera Optics Physical Properties

Camera optics physical diameters (OD) are reference dimensions.

All filters share the same clear aperture and physical dimensions. Five filters will be loaded on the telescope with the ability to manually change the sixth filter as needed.

The table below summarizes the camera filters (negative distance means the vertex is located to the left).

Filter	***S1 Radius of Curvature (mm)***	***S2 Radius of Curvature (mm)***	***Center Thickness (mm)***
u	***-5624.00***	***-5513.00***	***26.20***
g	***-5624.00***	***-5564.00***	***21.14***
r	***-5624.00***	***-5594.00***	***17.80***
i	***-5624.00***	***-5612.00***	***15.70***
z	***-5624.00***	***-5624.00***	***14.20***
y	***-5624.00***	***-5624.00***	***13.50***

Table 10: LSST Filter Dimensions

3.0 Optical Baffle System Description:

Baffles are integrated into the telescope support design via circular rings within the TEA and the telescope tube and the M1/M3 mirror cover inner diameter. The outer edge around the M1 cell is the aperture stop and a series of ring baffles are attached to the M2 assembly. Stray light control is also performed via the dome wind screen that blocks a ring of off-axis rays from entering the telescope optical system.

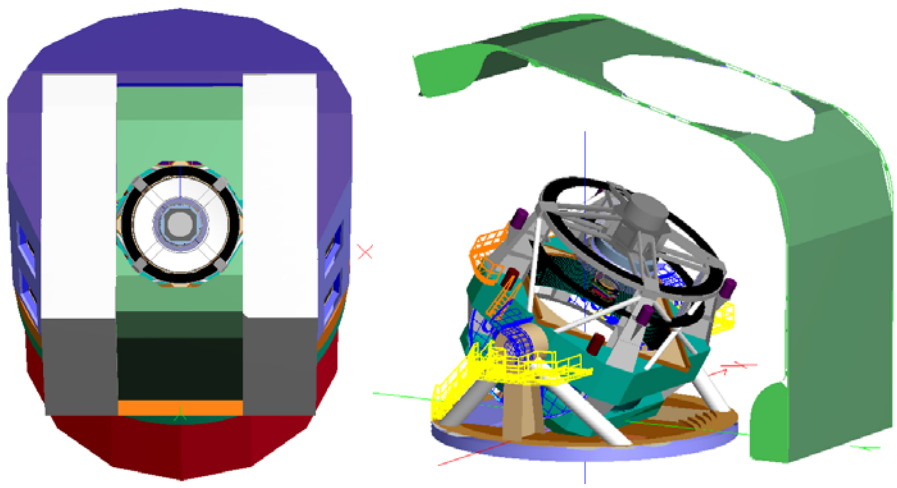


Figure 17: LSST Dome Wind Screen Light Baffle

The wind screen opening consists of a set of triangles spanning the 11 meter dome slit opening to form a faceted aperture which blocks unwanted stray light from entering the telescope from the outer edges.

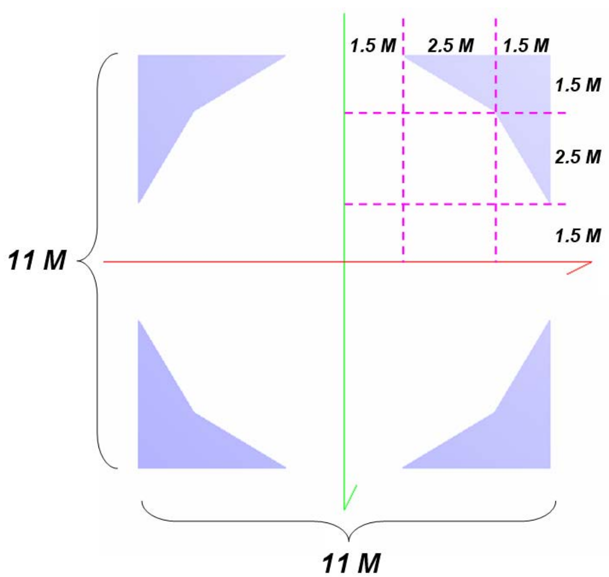


Figure 18: LSST Dome Windscreen Light Baffle Geometry

The TEA holds two additional circular baffles (black rings), with the lower baffle located in a vertical plane with the bottom of the M2 baffle.

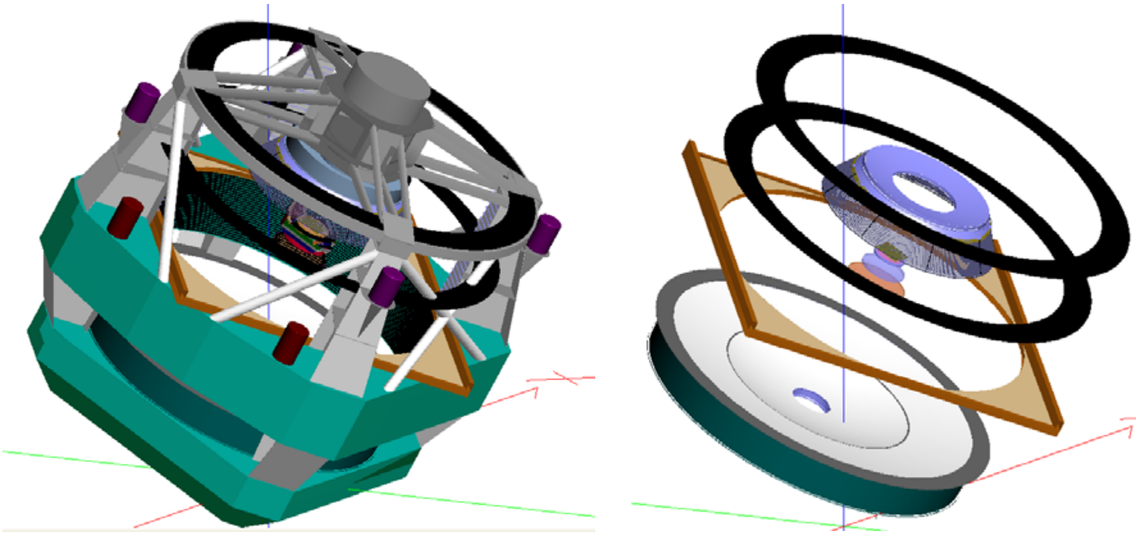


Figure 19: LSST Opto-Mechanical Baffle Geometries

The tan structure shown is the protective M1/M3 cover which is closed when the telescope is not in operation, but also acts as a baffle when opened via its inner diameter.

This section below highlights the ring baffles and shows the M2 baffle, whose outer diameter is slightly less than the M3 aperture.

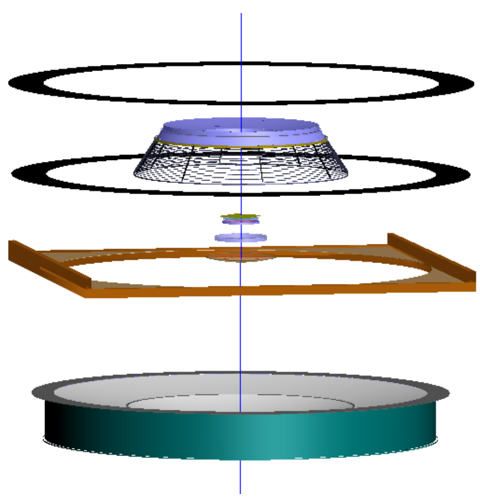


Figure 20: LSST Baffle Section View

The M1 aperture stop baffle defines the 8360 mm clear aperture diameter and extends beyond the edge of the mirror cell to provide additional stray light baffling. An unused 50mm diameter radial zone between the two surfaces will define the inner M1/M3 clear apertures.

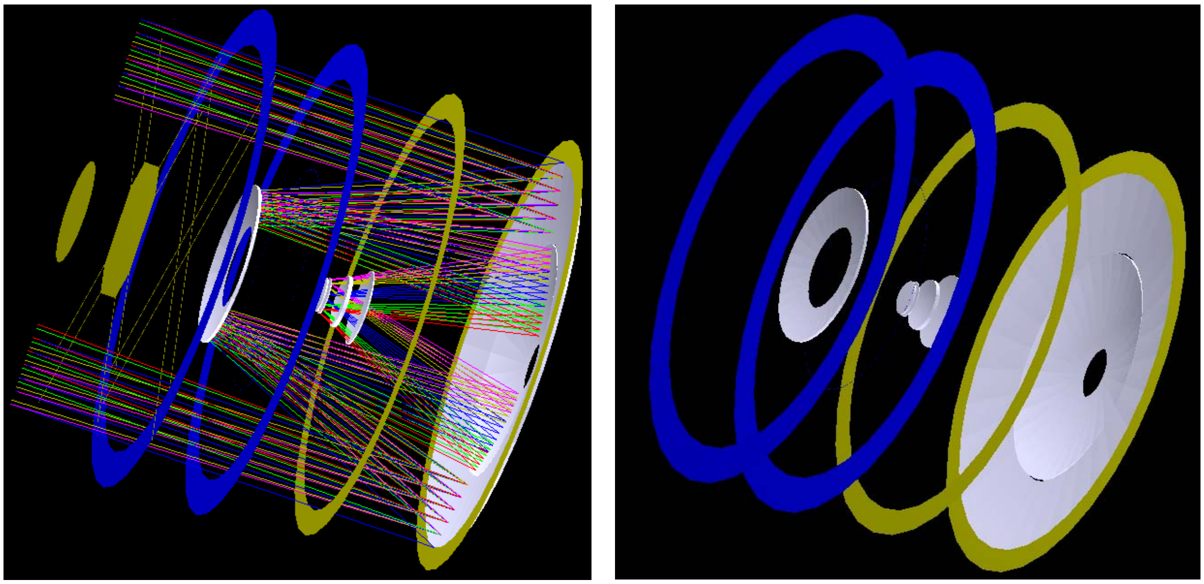


Figure 21: LSST Baffle Geometry

Baffle Position	*Inner Semi-Diameter (mm)*	*Outer Semi-Diameter (mm)*	*Distance from M1 Vertex (mm)*
Windscreen	*See windscreen dimensions*		*15500*
Upper TEA Baffle	*4419.6*	*5200*	*7418*
Lower TEA Baffle	*4350*	*5125*	*5377*
M1/M3 Mirror Cover	*4250*	*4800*	*2852*
M1 Aperture Stop	*4180*	*4675*	*439.4*

Table 11: LSST Baffle Physical Properties

The M2 baffle is an aggregate structure comprised of an upper ring attached to the M2 cell and a series of eight tapered struts which reinforce a series of 23 concentric vanes.

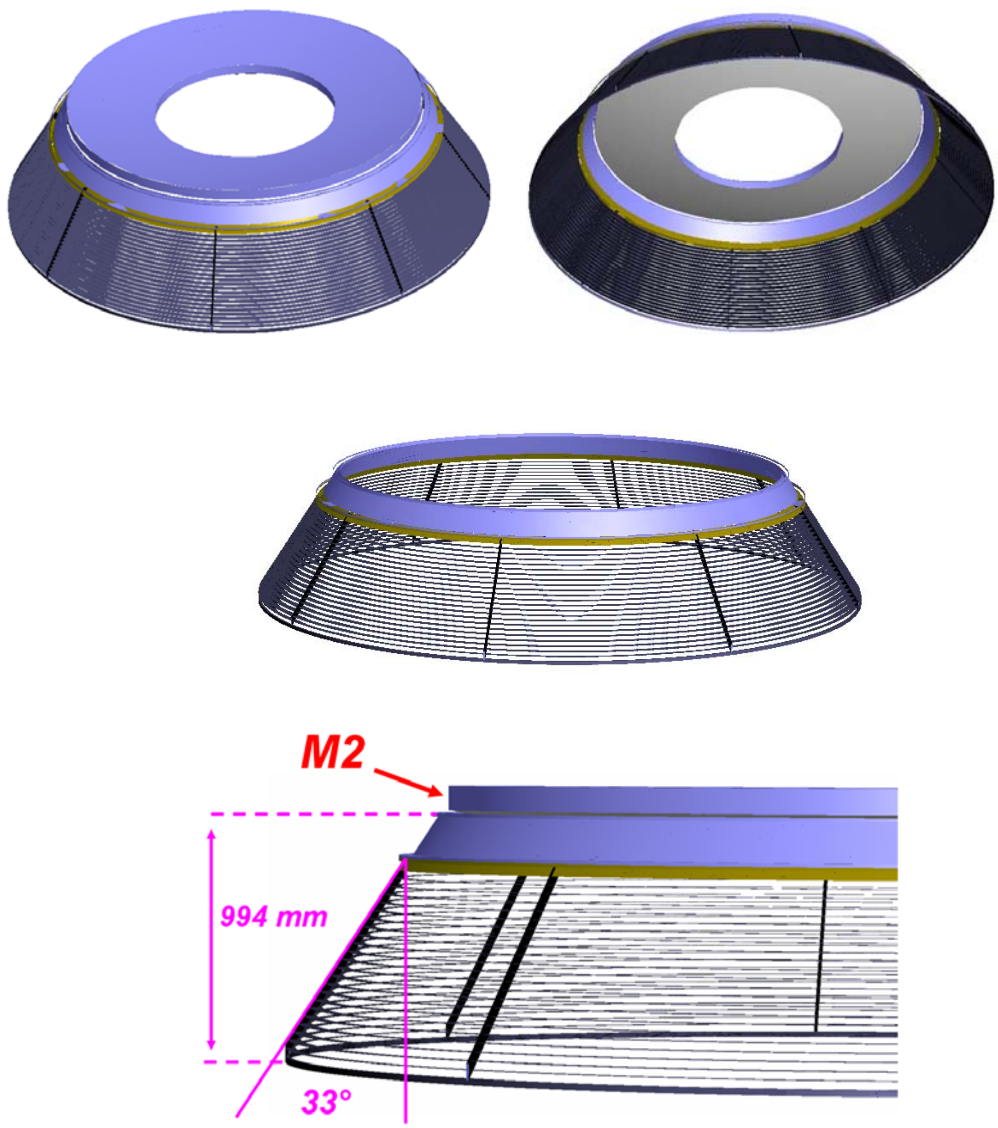


Figure 22: LSST M2 Baffle Profile Geometry

The baffle stands 994mm high with an upper inner radius of 1750 (same as M2) and a lower outer radius of ~2400 mm (note the M3 outer CA is 2505mm). It is comprised of 23 circular vanes of varying diameters, each 1.3mm thick, separated by 33.1mm with a 33 degree cone angle. Its overall design supports stray light rejection, enables air flow, has low thermal mass, and accommodates telescope installation and removal for recoating.

The r-band filter configuration including all TEA spiders, center obscurations, baffle locations and sizes is shown below. Note: All units in mm.

Lens Data Editor: Config 3/6

Edit Solves View Help

Surf:Type		Comment	Radius	Thickness		Glass	Semi-Diameter		Conic
OBJ	Standard		Infinity	Infinity			Infinity		0.000000
1*	Standard	Center Cap	Infinity	1200.000000			4466.542475		0.000000
2*	Standard	Center plate 1	Infinity	0.000000			4429.879159		0.000000
3*	Standard	Center plate 2	Infinity	0.000000			4429.879159		0.000000
4	Coordinate B..			0.000000		-	0.000000		
5*	Standard	Center plate 3	Infinity	0.000000			4429.879159		0.000000
6	Coordinate B..			0.000000		-	0.000000		
7	Coordinate B..			0.000000		-	0.000000		
8*	Standard	Center plate 4	Infinity	1200.000000			4429.879159		0.000000
9	Coordinate B..			0.000000		-	0.000000		
10	Coordinate B..			-1200.000000		-	0.000000		
11*	Standard	Spider top 1	Infinity	0.000000			4800.000000	U	0.000000
12*	Standard	Spider top 2	Infinity	1200.000000			4800.000000	U	0.000000
13*	Standard	Upper TEA Baffle	Infinity	0.000000			5200.000000	U	0.000000
14*	Standard	Spider bottom 1	Infinity	0.000000			4800.000000	U	0.000000
15*	Standard	Spider bottom 2	Infinity	1261.800000			4800.000000	U	0.000000
16	Coordinate B..			0.000000		-	0.000000		
17	Standard	M2 Vertex	Infinity	779.010000			4354.664366		0.000000
18*	Standard	Lower TEA Baffle	Infinity	4937.790600			5125.000000	U	0.000000
19	Standard	Dummy to M1 CA	Infinity	-2852.000000			4180.000311		0.000000
20*	Standard	M1/M3 Mirror Cover	Infinity	2852.000000	P		4800.000000	U	0.000000
21*	Standard	M1 CA Baffle	Infinity	439.400000			4180.000311		0.000000
STO*	Even Asphere	M1	-1.983500E+004	-439.400000	P	MIRROR	4180.000000	U	-1.215000
23*	Standard	M1 CA Baffle	Infinity	-4937.790600	P		4179.995936		0.000000
24*	Standard	Middle TEA Baffle	Infinity	-779.010000			2191.029288		0.000000
25*	Even Asphere	M2	-6788.000000	779.010000	P	MIRROR	1710.000000	U	-0.222000
26*	Standard	M2 Baffle Bottom	Infinity	5377.190600			1932.583879		0.000000
27	Standard	M1/M3 Offset	Infinity	233.800000			2731.428835		0.000000
28*	Even Asphere	M3	-8344.500000	-3630.500000		MIRROR	2508.000000	U	0.155000
29	Standard		Infinity	-0.761000			888.178113		0.000000
30*	Standard	L1	-2824.000000	-82.230000		SILICA	775.000000	U	0.000000
31*	Standard		-5021.000000	-412.642020			775.000000	P	0.000000
32*	Standard	L2	Infinity	-30.000000		SILICA	551.000000	U	0.000000
33*	Even Asphere		-2529.000000	-357.580000			551.000000	P	-1.570000
34*	Standard	Filter	-5624.000000	-17.800000		SILICA	375.000000	U	0.000000
35*	Standard		-5594.000000	-43.200000	P		375.000000	P	0.000000
36*	Even Asphere	L3	-3169.000000	-60.000000		SILICA	361.000000	U	-0.962000
37*	Standard		1.336000E+004	-28.500000			361.000000	P	0.000000
IMA	Standard	Detector	Infinity	-			317.000000	U	0.000000

Figure 23: LSST R-Band Filter Configuration with Spiders and Baffles