LARGE SYNOPTIC SURVEY TELESCOPE

Large Synoptic Survey Telescope (LSST)

Camera Subsystem Requirements

Pat Hascall

LSE-59 (rel8.1)

Latest Revision: March 22, 2018

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Change Record

Version	Date	Description	Owner name
1	5/8/2011	Initial Version	Patrick Hascall
1.1	5/9/2011	Added footer formatting	P. Hascall
1.2	7/12/2011	Draft version under camera team internal review	P. Hascall
1.3	7/29/2011	Edited to reflect camera team internal review input; formatting changes	P. Hascall
2	7/17/2013	Incorporates changes from LCR-125 (approved 6/26/2013) and LCR-126 (approved 6/3/2013). Also includes several grammatical/editorial corrections.	P. Hascall and Brian Selvy
3	10/7/2013	Incorporates camera throughput requirements relaxation approved through LCR-133	P. Hascall
4	10/24/2014	Incorporates 18-bit Camera to DM interfaces, barometric pressure data updates, revised OSS timing requirements, exposure time updates in OSS and LSR, revised filter definitions, omnibus OSS updates, updated crosstalk requirements, addition of an optics second surface clear aperture, removal of exposure duration accuracy TBR, and update to plans and standards approved via LCRs 131, 170, 176, 182, 183, 188, 189, 195, 213, and 214	P. Hascall and B. Selvy
5	6/2/2015	Incorporates approved LCRs 166, 233, 253. Updated Camera requirement CAM-REQ-0071 Number of filter swap-outs - changed the description in the constraint block FROM "Maximum number of manual filter swaps per month" TO "Minimum number of manual filter swaps per month". This makes the constraint block consistent with the requirement and also the parent requirement (OSS-REQ-0320).	P. Hascall and B. Selvy
6	2/1/2016	Incorporates approved LCRs 480 and 490.	P. Hascall and B. Selvy

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7	8/5/2016	Implementation of LCR-359: Corrects the flow down from m5 limiting magnitude to system hardware integrals and makes subsystem allocations for throughput. Changes in LSE-59 reflect flow down from LSR and OSS changes also made via the LCR. LCR-646: Move the filter first surface apex in the z-direction away from the focal plane by 3 mm. Corresponding changes were made to the OSS via this LCR.	Chuck Claver and P. Hascall (LCRs), B. Selvy and Kathryn Wesson (SysML), Robert McKercher (DocuShare)
7.1	5/26/2017	Implementation of LCR-687. Word change on CAM REQ-0051 to agree with LSR and OSS changes to accommodate an alternate standard visit with a single 30 second exposure.	G. Angeli (LCR), K. Wesson (SysML), R. McKercher (DocuShare)
8.0	2018-02-08	Implementation of LCR-786 altering CAM-REQ-0059 and CAM-REQ-0060 specifications and constraints. Implementation of LCR-1018 adding new requirement CAM-REQ-0130 to flow down new camera image types. Also contains implementation of LCR-1036	P. Hascall (LCR), R. Carlson (SysML), B. Selvy (SysML and LCR) R. McKercher (DocuShare)
	2018-03-22	Implementation of LCR-1188 updating environmental requirements.	A. Serio (LCR), B. Selvy (SysML and LCR), R. Carlson (SysML)

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The LSST Camera Subsystem Requirements

Introduction and Scope

This document defines the imaging performance, data processing requirements and functional requirements for the Camera portion of the LSST as allocated from the LSST Observatory System Specifications (LSE-30). The requirements in this document, combined with those of the other LSST subsystems satisfy the full functionality and performance for the LSST system.

Supporting Documents

Observatory System Specifications (OSS, LSE-30)

Acronyms and Definitions of Terms

Glossary of Abbreviations (Document-11921)

Glossary of Definitions (Document-14412)

In this document a ***requirement*** refers to a declaration of a specified function or quantitative performance that the delivered system or subsystem must meet. It is a statement that identifies a necessary attribute, capability, characteristic, or quality of a system in order for the delivered system or subsystem to meet a derived or higher requirement, constraint, or function. This document uses the term ***specification(s)*** to mean one or more performance parameter(s) being established by a requirement that the delivered system or subsystem must meet. An ***attribute*** specifies a quantitative performance ***parameter*** in the context of the SysML based SysArch model used to generate this document. A ***constraint*** is used to refer to an external limitation imposed on a delivered item under which it must meet its requirements (e.g., the survey performance must be met under the constraint of the historical weather pattern of the chosen site). A constraint in not a characteristic the system or subsystem itself possesses.

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The LSST Camera Subsystem Requirements

1 Camera Performance Allocations

1.1 Camera throughput

ID: CAM-REQ-0126

Discussion: The total throughput is composed of several effects. One is the optical throughput which addresses losses through the optics and CCD responsivity. The second effect is the percentage of the focal plane that is sensitive to light (fill factor and dead pixels). The third effect is the percentage of time the camera is available (covered elsewhere as down time).

1.1.1 Camera optical throughput

ID: CAM-REQ-0001

Specification: The Camera optical hardware throughput integrals between 300-1200nm shall exceed the allocations given in the table below for **S_cam(u)** through **S_cam(y)**.

Discussion: For the purpose of flowdown to individual surfaces and/or compoinents the Camera subsystem may use the implied mean fractional thorughput for each filter band. These are derived from the hardware integrals given in CAM-REQ-0001, the implied mean throughput for each filter band as measured between the referenced upperBlue and upperRed limits shall be at least **thruCam(u)** through **thruCam(y).**

Technical memo LSE-240 outlines a method of approximation that allows the combination of component throughput integrals using a simple algebraic expression. Using this method the total system throughput integral, S_sys, through given filter, f, can be estimated by S_sys(f) ~ [S_tel(f) * S_cam(f)]/W(f), where W(f) is the "window" integral of unity response, S_tel is the telescope integral and S_cam is the camera integral between the red and blue wavelength limits of the filter. The limits for each filter are taken as the upperBlue and upperRed wavelengths defined in OSS-REQ-0240 - OSS-REQ-0245, giving window integral values of 0.291, 0.374, 0.274, 0.209, 0.155 and 0.191 for the u, g, r, i, z and y-band filters respectively.

The camera throughput integral allocations have been determined by solving for each filter, f, the equation provided in the discussion above using the referenced values for the total system throughput integral, S_sys(f), telescope integral, S_tel(f) and window integral, W(f).

The implied mean fractional throughput for each filter, f, is derived by thruCam(f) = S_Cam(f)/W(f). Note: The mean fractional throughput for the Camera is calculated for each filter between the upper envelope wavelength limits, upperBlue and upperRed, inherited from the OSS and defined in CAM-REQ-0010 - CAM-REQ-0015. These limits include the effects of the tapered filter band edges where the nominal response drops to near zero at upperBlue and upperRed envelope wavelength limits, hence the apparently low values.

Description	Value	Unit	Name

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Description	Value	Unit	Name
The allocated minimum integrated g-band throughput for the Camera is:	0.170	unitless	S_cam(g)
The allocated minimum integrated i-band throughput for the Camera is:	0.097	unitless	S_cam(i)
The allocated minimum integrated r-band throughput for the Camera is:	0.135	unitless	S_cam(r)
The allocated minimum integrated u-band throughput for the Camera is:	0.065	unitless	S_cam(u)
The allocated minimum integrated y-band throughput for the Camera is:	0.024	unitless	S_cam(y)
The allocated minimum integrated z-band throughput for the Camera is:	0.065	unitless	S_cam(z)
The implied mean fractional Camera throughput in the g-band is:	45.4	percent	thruCam(g)
The implied mean fractional Camera throughput in the i-band is:	46.3	percent	thruCam(i)
The implied mean fractional Camera throughput in the r-band is:	49.1	percent	thruCam(r)
The implied mean fractional Camera throughput in the u-band is:	22.5	percent	thruCam(u)
The implied mean fractional Camera throughput in the y-band is:	12.6	percent	thruCam(y)
The implied mean fractional Camera throughput in the z-band is:	42.1	percent	thruCam(z)

1.1.2 Effective Area

ID: CAM-REQ-0127

Discussion: This section defines the camera active area on the focal plane. This defines the required area and density of the science pixels on the as designed CCDs. Pixels that do not meet spec are included in the area and density calculations (the percent of dead pixels allowable is covered in CAM-REQ-0005).

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The active area is defined in terms of the central area on the focal plane equivalent to a 3.5 degree field of view. At the focal plane, the diameter of that circle is **areaDiameter**.

Description	Value	Unit	Name
Diameter of the 3.5 degree FOV at the focal plane	634.17		areaDiameter

1.1.2.1 Detector Plane central fill factor

ID: CAM-REQ-0003

Specification: The fraction of the area covered by science sensors in the central circle with a radius of **[areaDiameter]** shall be at least **[CentralFill]**

Discussion: The area covered by science sensors includes unresponsive areas on the CCDs and the gaps between the CCDs.

Description	Value	Unit	Name
3.5 degree FOV fill factor	85	percent	CentralFill

1.1.2.2 Detector plane fill factor

ID: CAM-REQ-0004

Specification: The fill factor of nominally active pixels in the area covered by science grade imaging devices shall be at least [**TotalFill**]

Discussion: The allowed fraction of dead pixels is specified in a separate requirement

Description	Value	Unit	Name
Fill factor of active pixels in the area covered by science grade imaging devices	90	percent	TotalFill

1.1.3 Detector plane allowable dead pixels

ID: CAM-REQ-0005

Specification: The maximum percent of pixels on the detector plane within the 634.17 mm diameter FOV that do not meet their requirements at delivery shall be **[deliveredPixelLoss]**. The additional pixel loss over and above the [**deliveredPixelLoss]** when averaged over the 10-year survey lifetime shall be no more than [**agedPixelLoss].**

Discussion: This includes pixels in otherwise live detectors that do not meet spec, and includes dead pixels, hot pixels, dead columns, and dead segments/amplifiers.

Description	Value	Unit	Name
The additional allowed pixel loss over and above the **deliveredPixelLoss** when averaged over the 10-year survey lifetime	2	percent	agedPixelLoss

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Description	Value	Unit	Name
The minimum fraction of unusable pixels (those that cannot be calibrated to meet the requirements in this document) at the time of instrument delivery	2	percent	deliveredPixelLoss

1.2 Filter Response

ID: CAM-REQ-0109

Specification: Evaluation of the filter response shall use the area weighted mean response function as defined in Document-16295 using the r-band beam defined in LSE-11.

Discussion: The following definitions apply to the filter response requirements below

1. The "filter response" function of a given point on the filter substrate refers to the net wavelength response integrated over the incident optical beam centered at that point that has been normalized to a unity mean between the "in-band" wavelength limits as defined for each filter. The normalized response function can have values greater than unity by no more than maxFiltRipple due to response wiggles within the in-band region.
2. The area weighted mean response function (as defined in Document-16295) is used combine the filter response functions for points on the filter substrate into an average response.
3. The r-band beam footprints defined in LSE-11 have been designated the nominal beam footprints for use in evaluating filter performance. That footprint definition includes the annulus and beam angles at both surfaces of each filter. The r-band filter annulus is typically within a few percent of the filter annulus for the other bands. The u-band second surface is 7% smaller. The incident angle of the beam varies linearly from the outer edge of the annulus to the inner edge of the annulus.

1.2.1 Filter Out of Band Constraints

ID: CAM-REQ-0110

Specification: Each of the 6 defined filters must block it's out of band transmission according to the specifications in the table below.

Discussion: For leakage that occurs in the wavelength region beyond 1050 the response of 100 micron thick silicon at -100 C can be multiplied against the filter response in the total integrated leak evaluation.

Description	Value	Unit	Name
Up to **fLeakException** of the 10nm intervals 1 FWHM from the central wavelength (between 300nm and 1200nm) may be greater than **fLeak_10nm** but no more than **fLeakMax.**	5.0	percent	fleakException
The maximum allowed leakage.	0.1	percent	fleakMax
The integrated transmission over all wavelengths between	0.03	percent	fLeakTotal

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Description	Value	Unit	Name
300-1200nm outside the wavelength span between the first time the filter response goes below 0.1% of the peak the total leakage shall not exceeded **fleakTotal** relative to the total integrated transmission between 300nm and 1200nm.			
The average leakage in any 10nm segment between 300-1200nm outside the wavelength span one FWHM from the central wavelength shall be no more than **fLeak_10nm.**	0.01	percent	fLeak_10nm

1.2.2 Filter Response Uniformity

ID: CAM-REQ-0008

Specification: The wavelength of the blue and red 50% response points of the response function at any given point within the filter clear aperture shall not deviate by no more than **grizy_filtUniformity** and **u_filtUniformity** from that of the area weighted mean response function.

Description	Value	Unit	Name
The maximum allowed grizy-band filter response uniformity.	1.5%	percent	filtUniformity_grizy
The maximum allowed u-band filter response uniformity.	2.5%	percent	filtUniformity_u

1.2.3 In-band Ripple

ID: CAM-REQ-0009

Specification: The in-band filter response function at any given point within the filter clear aperture shall have peak-to-valley ripple of no more than +/- **maxFiltRipple** relative to the in-band mean for that location.

Discussion: The region for measuring ripple is defined by the in-band limits provided in the specifications below. The in-band limits are allowed to be shifted by the measured shift allowed by CAM-REQ-0008.

Description	Value	Unit	Name
Allowed filter ripple	3	percent	maxFiltRipple

1.2.4 u-band Response

ID: CAM-REQ-0010

Specification: The area weighted mean u-band filter response normalized to the in-band average (as measured between **u_inBandBlue** and **u_inBandRed**) shall lie between the upper and lower envelopes defined in the tables below.

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1.2.4.1 u-band not to exceed envelope

ID: CAM-REQ-0113

Specification: Over the wavelength range defined by the upper envelope - excluding the in-band range, 30% (by wavelength) of the area weighted average u-band filter response with may lie outside the nominal upper and lower envelope, but shall lie completely within the minimum and maximum envelopes defined below.

Discussion: Specific instances of non-compliance to this specification will be evaluated by the project to assess acceptability.

Description	Value	Unit	Name
The in-band blue limit for the u-band filter response normalization.	335.5	nanometre	u_InBandBlue
The red side 97% response wavelength of the u-band lower envelope.	379.25	nanometre	u_lowerRed(0.97)
The red side zero response wavelength of the u-band lower envelope.	403.5	nanometre	u_lowerRed(0)
The blue side 97% response wavelength of the u-band lower envelope.	334.75	nanometre	u_lowerBlue(0.97)
The blue side zero response wavelength of the u-band lower envelope.	310.5	nanometre	u_lowerBlue(0)
The in-band red limit for the u-band filter response normalization.	378.5	nanometre	u_InBandRed
The blue side zero response wavelength of the u-band upper envelope.	305.5	nanometre	u_upperBlue(0)
The blue side 103% response wavelength of the u-band upper envelope.	331.25	nanometre	u_upperBlue(1.03)
The red side zero response wavelength of the u-band upper envelope.	408.5	nanometre	u_upperRed(0)
The red side 103% response wavelength of the u-band upper envelope.	382.75	nanometre	u_upperRed(1.03)
The blue side zero response wavelength of the u-band minimum envelope.	313.5	nanometre	u_minBlue(0)

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Description	Value	Unit	Name
The blue side 97% response wavelength of the u-band minimum envelope.	334.75	nanometre	u_minBlue(0.97)
The red side zero response wavelength of the u-band minimum envelope.	400.5	nanometre	u_minRed(0)
The red side 97% response wavelength of the u-band minimum envelope.	379.25	nanometre	u_minRed(0.97)
The red side 103% response wavelength of the u-band maximum envelope.	385.75	nanometre	u_maxRed(1.03)
The red side zero response wavelength of the u-band maximum envelope.	411.5	nanometre	u_maxRed(0)
The blue side zero response wavelength of the u-band maximum envelope.	302.5	nanometre	u_maxBlue(0)
The blue side 103% response wavelength of the u-band maximum envelope.	328.25	nanometre	u_maxBlue(1.03)

1.2.5 g-band Response

ID: CAM-REQ-0011

Specification: The area weighted mean g-band filter response normalized to the in-band average (as measured between **g_inBandBlue** and **g_inBandRed**) shall lie between the upper and lower envelopes defined in the tables below.

1.2.5.1 g-band not to exceed envelope

ID: CAM-REQ-0114

Specification: Over the wavelength range defined by the upper envelope - excluding the in-band range, 30% (by wavelength) of the area weighted average u-band filter response with may lie outside the nominal upper and lower envelope, but shall lie completely within the minimum and maximum envelopes defined below.

Discussion: Specific instances of non-compliance to this specification will be evaluated by the project to assess acceptability.

Description	Value	Unit	Name
The in-band blue limit for the g-band filter response normalization.	416.5	nanometre	g_InBandBlue
The in-band red limit for the g-band filter response	537.0	nanometre	g_InBandRed

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Description	Value	Unit	Name
normalization.			
The blue side zero response wavelength of the g-band lower envelope.	391.5	nanometre	g_lowerBlue(0)
The blue side 0.97% response wavelength of the g-band lower envelope.	415.75	nanometre	g_lowerBlue(0.97)
The red side 0.97% response wavelength of the g-band lower envelope.	537.75	nanometre	g_lowerRed(0.97)
The red side zero response wavelength of the g-band lower envelope.	562.0	nanometre	g_lowerRed(0)
The red side zero response wavelength of the g-band upper envelope.	567.0	nanometre	g_upperRed(0)
The blue side zero response wavelength of the g-band upper envelope.	386.5	nanometre	g_upperBlue(0)
The blue side 103% response wavelength of the g-band upper envelope.	412.25	nanometre	g_upperBlue(1.03)
The red side 103% response wavelength of the g-band upper envelope.	541.25	nanometre	g_upperRed(1.03)
The blue side zero response wavelength of the g-band minimum envelope.	394.5	nanometre	g_minBlue(0)
The red side zero response wavelength of the g-band minimum envelope.	559.0	nanometre	g_minRed(0)
The red side 97% response wavelength of the g-band minimum envelope.	537.75	nanometre	g_minRed(0.97)
The blue side 97% response wavelength of the g-band minimum envelope.	415.75	nanometre	g_minBlue(0.97)
The blue side zero response wavelength of the g-band maximum envelope.	383.5	nanometre	g_maxBlue(0)
The blue side 103% response wavelength of the g-band maximum envelope.	409.25	nanometre	g_maxBlue(1.03)

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Description	Value	Unit	Name
The red side 103% response wavelength of the g-band maximum envelope.	544.25	nanometre	g_maxRed(1.03)
The red side zero response wavelength of the g-band maximum envelope.	570.0	nanometre	g_maxRed(0)

1.2.6 r-band Response

ID: CAM-REQ-0012

Specification: The area weighted mean r-band filter response normalized to the in-band average (as measured between **r_inBandBlue** and **r_inBandRed**) shall lie between the upper and lower envelopes defined in the tables below.

1.2.6.1 r-band not to exceed envelope

ID: CAM-REQ-0115

Specification: Over the wavelength range defined by the upper envelope - excluding the in-band range, 30% (by wavelength) of the area weighted average u-band filter response with may lie outside the nominal upper and lower envelope, but shall lie completely within the minimum and maximum envelopes defined below.

Discussion: Specific instances of non-compliance to this specification will be evaluated by the project to assess acceptability.

Description	Value	Unit	Name
The blue side zero response wavelength of the r-band minimum envelope.	545.0	nanometre	r_minBlue(0)
The blue side 97% response wavelength of the r-band minimum envelope.	566.25	nanometre	r_minBlue(0.97)
The red side 97% response wavelength of the r-band minimum envelope.	676.75	nanometre	r_minRed(0.97)
The red side zero response wavelength of the r-band minimum envelope.	698.0	nanometre	r_minRed(0)
The blue side zero response wavelength of the r-band maximum envelope.	534.0	nanometre	r_maxBlue(0)
The blue side 103% response wavelength of the r-band maximum envelope.	559.75	nanometre	r_maxBlue(1.03)
The red side 103% response wavelength of the r-band	683.25	nanometre	r_maxRed(1.03)

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Description	Value	Unit	Name
maximum envelope.			
The red side zero response wavelength of the r-band maximum envelope.	709.0	nanometre	r_maxRed(0)
The in-band blue limit for the r-band filter response normalization.	567.0	nanometre	r_InBandBlue
The in-band red limit for the r-band filter response normalization.	676.0	nanometre	r_InBandRed
The blue side zero response wavelength of the r-band lower envelope.	542.0	nanometre	r_lowerBlue(0)
The blue side 97% response wavelength of the r-band lower envelope.	566.25	nanometre	r_lowerBlue(0.97)
The red side 97% response wavelength of the r-band lower envelope.	676.75	nanometre	r_lowerRed(0.97)
The red side zero response wavelength of the r-band lower envelope.	701.0	nanometre	r_lowerRed(0)
The red side zero response wavelength of the r-band upper envelope.	706.0	nanometre	r_upperRed(0)
The red side 103% response wavelength of the r-band upper envelope.	680.25	nanometre	r_upperRed(1.03)
The blue side 103% response wavelength of the r-band upper envelope.	562.75	nanometre	r_upperBlue(1.03)
The blue side zero response wavelength of the r-band upper envelope.	537.0	nanometre	r_upperBlue(0)

1.2.7 i-band Response

ID: CAM-REQ-0013

Specification: The area weighted mean i-band filter response normalized to the in-band average (as measured between **i_inBandBlue** and **i_inBandRed**) shall lie between the upper and lower envelopes defined in the tables below.

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1.2.7.1 i-band not to exceed envelope

ID: CAM-REQ-0116

Specification: Over the wavelength range defined by the upper envelope - excluding the in-band range, 30% (by wavelength) of the area weighted average u-band filter response with may lie outside the nominal upper and lower envelope, but shall lie completely within the minimum and maximum envelopes defined below.

Discussion: Specific instances of non-compliance to this specification will be evaluated by the project to assess acceptability.

Description	Value	Unit	Name
The blue side zero response wavelength of the i-band minimum envelope.	684.0	nanometre	i_minBlue(0)
The blue side 97% response wavelength of the i-band minimum envelope.	705.25	nanometre	i_minBlue(0.97)
The red side 97% response wavelength of the i-band minimum envelope.	803.75	nanometre	i_minRed(0.97)
The red side zero response wavelength of the i-band minimum envelope.	825.0	nanometre	i_minRed(0)
The blue side zero response wavelength of the i-band maximum envelope.	673.0	nanometre	i_maxBlue(0)
The blue side 103% response wavelength of the i-band maximum envelope.	698.75	nanometre	i_maxBlue(1.03)
The red side 103% response wavelength of the i-band maximum envelope.	810.25	nanometre	i_maxRed(1.03)
The red side zero response wavelength of the i-band maximum envelope.	836.0	nanometre	i_maxRed(0)
The in-band blue limit for the i-band filter response normalization.	706.0	nanometre	i_InBandBlue
The in-band red limit for the i-band filter response normalization.	803.0	nanometre	i_InBandRed
The blue side zero response wavelength of the i-band lower envelope.	681.0	nanometre	i_lowerBlue(0)

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Description	Value	Unit	Name
The blue side 97% response wavelength of the i-band lower envelope.	705.25	nanometre	i_lowerBlue(0.97)
The red side 97% response wavelength of the i-band lower envelope.	803.75	nanometre	i_lowerRed(0.97)
The red side zero response wavelength of the i-band lower envelope.	828.0	nanometre	i_lowerRed(0)
The red side zero response wavelength of the i-band upper envelope.	833.0	nanometre	i_upperRed(0)
The red side 103% response wavelength of the i-band upper envelope.	807.25	nanometre	i_upperRed(1.03)
The blue side 103% response wavelength of the i-band upper envelope.	701.75	nanometre	i_upperBlue(1.03)
The blue side zero response wavelength of the i-band upper envelope.	676.0	nanometre	i_upperBlue(0)

1.2.8 z-band Response

ID: CAM-REQ-0014

Specification: The area weighted mean z-band filter response normalized to the in-band average (as measured between **z_inBandBlue** and **z_inBandRed**) shall lie between the upper and lower envelopes defined in the tables below.

Description	Value	Unit	Name
The red side 97% response wavelength of the z-band lower envelope.	909.25	nanometre	z_lowerRed(0.97)
The red side zero response wavelength of the z-band lower envelope.	933.5	nanometre	z_lowerRed(0)
The in-band red limit for the z-band filter response normalization.	908.5	nanometre	z_InBandRed
The in-band blue limit for the z-band filter response normalization.	833.0	nanometre	z_InBandBlue
The blue side zero response wavelength of the z-band lower envelope.	808.0	nanometre	z_lowerBlue(0)

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Description	Value	Unit	Name
The blue side 97% response wavelength of the z-band lower envelope.	832.25	nanometre	z_lowerBlue(0.97)
The blue side zero response wavelength of the z-band upper envelope.	803.0	nanometre	z_upperBlue(0)
The blue side 103% response wavelength of the z-band upper envelope.	828.75	nanometre	z_upperBlue(1.03)
The red side 103% response wavelength of the z-band upper envelope.	912.75	nanometre	z_upperRed(1.03)
The red side zero response wavelength of the z-band upper envelope.	938.5	nanometre	z_upperRed(0)

1.2.8.1 z-band not to exceed envelope

ID: CAM-REQ-0117

Specification: Over the wavelength range defined by the upper envelope - excluding the in-band range, 30% (by wavelength) of the area weighted average u-band filter response with may lie outside the nominal upper and lower envelope, but shall lie completely within the minimum and maximum envelopes defined below.

Discussion: Specific instances of non-compliance to this specification will be evaluated by the project to assess acceptability.

Description	Value	Unit	Name
The blue side zero response wavelength of the z-band minimum envelope.	811.0	nanometre	z_minBlue(0)
The blue side 97% response wavelength of the z-band minimum envelope.	832.25	nanometre	z_minBlue(0.97)
The red side zero response wavelength of the z-band minimum envelope.	930.5	nanometre	z_minred(0)
The red side 97% response wavelength of the z-band minimum envelope.	909.25	nanometre	z_minred(0.97)
The blue side zero response wavelength of the z-band maximum envelope.	800.0	nanometre	z_maxBlue(0)
The blue side 103% response wavelength of the z-band	825.75	nanometre	z_maxBlue(1.03)

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Description	Value	Unit	Name
maximum envelope.			
The red side 103% response wavelength of the z-band maximum envelope.	915.75	nanometre	z_maxRed(1.03)

1.2.9 y-band Response

ID: CAM-REQ-0015

Specification: The area weighted mean y-band filter response normalized to the in-band average (as measured between **y_inBandBlue** and **y_inBandRed**) shall lie between the upper and lower envelopes defined in the tables below.

Description	Value	Unit	Name
The in-band blue limit for the y-band filter response normalization.	938.5	nanometre	y_InBandBlue
The in-band red limit for the y-band filter response normalization.	1069.25	nanometre	y_InBandRed
The blue side zero response wavelength of the y-band lower envelope.	913.5	nanometre	y_lowerBlue(0)
The blue side 97% response wavelength of the y-band lower envelope.	937.75	nanometre	y_lowerBlue(0.97)
The red side 97% response wavelength of the y-band lower envelope.	1070.0	nanometre	y_lowerRed(0.97)
The red side zero response wavelength of the y-band lower envelope.	1070.0	nanometre	y_lowerRed(0)
The red side zero response wavelength of the y-band upper envelope.	1201.0	nanometre	y_upperRed(0)
The red side 103% response wavelength of the y-band upper envelope.	1201.0	nanometre	y_upperRed(1.03)
The blue side 103% response wavelength of the y-band upper envelope.	934.25	nanometre	y_upperBlue(1.03)
The blue side zero response wavelength of the y-band upper envelope.	908.5	nanometre	y_upperBlue(0)

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1.2.9.1 *y-band not to exceed envelope*

ID: CAM-REQ-0118

Specification: Over the wavelength range defined by the upper envelope - excluding the in-band range, 30% (by wavelength) of the area weighted average u-band filter response with may lie outside the nominal upper and lower envelope, but shall lie completely within the minimum and maximum envelopes defined below.

Discussion: Specific instances of non-compliance to this specification will be evaluated by the project to assess acceptability.

Description	Value	Unit	Name
The blue side zero response wavelength of the y-band minimum envelope.	916.5	nanometre	y_minBlue(0)
The red side zero response wavelength of the y-band minimum envelope.	1070.0	nanometre	y_minRed(0)
The red side 97% response wavelength of the y-band minimum envelope.	1070.0	nanometre	y_minRed(0.97)
The blue side 97% response wavelength of the y-band minimum envelope.	937.75	nanometre	y_minBlue(0.97)
The blue side zero response wavelength of the y-band maximum envelope.	905.5	nanometre	y_maxBlue(0)
The red side zero response wavelength of the y-band maximum envelope.	1201.0	nanometre	y_maxRed(0)
The red side 103% response wavelength of the y-band maximum envelope.	1201.0	nanometre	y_maxRed(1.03)
The blue side 103% response wavelength of the y-band maximum envelope.	931.25	nanometre	y_maxBlue(1.03)

1.3 Dynamic Range

ID: CAM-REQ-0016

Specification: The LSST Camera system shall have a single exposure unsaturated dynamic range of at least **[camDynamicRange]** above the 5-sigma point source r-band limiting magnitude in a standard 15 second exposure.

Discussion: This requirement is referenced to the fiducial conditions (defined in the LSR requirement LSR-REQ-0089) used to define the limiting magnitude requirements.

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Description	Value	Unit	Name
The camera minimum dynamic range in a single 15 second exposure.	8	AB magnitude	camDynamicRange

1.4 Image bits per pixel

ID: CAM-REQ-0017

Specification: The imaging system shall acquire science data with a significance of **[campixelBitDepth]** bits per pixel.

Description	Value	Unit	Name
Bits per pixel	18	integer	CamPixelBitDepth

1.5 Camera max image quality error

ID: CAM-REQ-0018

Specification: The maximum delivered image quality error for the camera shall be less than [**CameraImageQuality**] FWHM.

Discussion: This is the total image quality error allocation to the camera, from all sources.

Description	Value	Unit	Name
Image quality error (FWHM)	0.30	arcsecFWHM	CameraImageQuality

1.6 Image Ellipticity

ID: CAM-REQ-0125

NOTE: Ellipticity is a full-system requirement that, in principle, involves interactions among subsystems, so it is not easily factorized. Therefore, LSST has chosen to manage the ellipticity requirement at the observatory level, with the subsystems reporting the relevant performance best estimates to LSST System Engineering, which updates the end-to-end ellipticity analysis and tracks the performance against the requirement. This plan is documented in System Engineering Document-16234 ("LSST Integrated Model for Image Performance Simulations"). Note that several Camera requirements (e.g., those related to focal-plane flatness) that flow from the image quality requirement also support ellipticity performance.

1.7 Camera lifetime

ID: CAM-REQ-0019

Specification: The camera and all subsystems and components shall be designed to operate for at least [**CamLifetime**].

Discussion: This includes the observatory lifetime plus additional time for camera integration, test, and observatory commissioning.

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Description	Value	Unit	Name
Camera lifetime	15	year	CamLifetime

1.8 Total system read noise

ID: CAM-REQ-0020

Specification: The electronic noise from the LSST Camera system shall contribute no more than **camSysNoise** per exposure to each pixel in the data from the science sensor array.

Discussion: This top level noise budget includes all sources internal to the camera system that contribute to the base noise in each pixel, including readout noise, residual noise from dark current, additional noise in the electronics, etc... The camera read noise requirement per exposure is derived from the OSS requirement of 12.7e- per visit and the standard definition of two exposures per visit.

Description	Value	Unit	Name
Camera read noise per exposure	9	electron	iCamReadNoise

1.9 Detector pixel pitch

ID: CAM-REQ-0021

Specification: The detector nominal pixel pitch shall be [**PixelPitch**].

Discussion: This corresponds to (0.2 arc-second) sampling.

Description	Value	Unit	Name
Nominal pixel pitch	10	micrometre	PixelPitch

1.10 Radioactive background

ID: CAM-REQ-0022

Specification: The Camera subsystem shall have a project-reviewed radioactive material test plan.

Discussion: The Camera must develop a radioactive material test plan that defines testing approaches that are reasonable such that the camera subsystem can achieve a radiation level that is "As Low as Reasonably Achievable" (ALARA). The test plan must specify testing of critical components and subsystems assemblies to ensure that their contributions are well below the level of artifacts caused by cosmic radiation. Critical components and sub-assemblies, as well as test success criteria, will be determined by the camera subsystem team taking into consideration the distance between the components and sensors, shielding, component mass, and primary material of the component. A project-reviewed radioactive material test plan means that the Camera subsystem test plan must be placed under the Camera subsystem's change control; initial baselining and any subsequent updates must include review and input from the LSST Project Systems Engineering (PSE) office.

The contents of this document are subject to configuration control and may not be changed, altered, or their provisions waived without prior approval.

1.11 Electromagnetic Emissions

ID: CAM-REQ-0023

Specification: The camera shall not emit electromagnetic radiation that significantly interferes with itself (as defined by meeting its performance specifications) or the operation of other observatory subsystems. Off-the-shelf electronics devices shall be compliant with FCC part 15 Class B standards or shall have shielding or other mitigation. Custom designed camera electronics shall take advantage of all reasonable good practices in design and fabrication to minimize interference.

1.12 Electromagnetic Susceptibility

ID: CAM-REQ-0024

Specification:The camera shall not be susceptible to electromagnetic emissions from itself or other elements in the observatory. Off-the-shelf electronics devices shall be compliant with FCC part 15 Class A standards or shall have shielding or other mitigation. Custom designed camera electronics shall take advantage of all reasonable good practices in design and fabrication to minimize susceptibility.

1.13 Light Emissions

ID: CAM-REQ-0025

Specification: Light sources within the camera shall not escape out of the camera or cause camera performance to go out of specification.

1.14 Astrometric Requirements

ID: CAM-REQ-0129

Discussion: There are no astrometric requirements on the camera. Modeling at the observatory level has shown that astrometry can be realized by the existing algorithms without placing constraints on focal plane stability.

1.15 Crosstalk

1.15.1 Crosstalk within a raft

ID: CAM-REQ-0097

Specification: The crosstalk between any two electronic channels within a raft shall not exceed **[withinRaftCrosstalk]**.

Description	Value	Unit	Name
Maximum crosstalk on a raft	0.002	TBD	withinRaftCrosstalk

1.15.2 Crosstalk between rafts

ID: CAM-REQ-0098

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Specification: The crosstalk between any two electronic channels on different rafts shall not exceed **[betweenRaftCrosstalk]** with a goal of **[betweenRaftCrosstalkGoal]**.

Discussion: If this requirement is not met, it may occur that the crosstalk correction applied by the Camera on behalf of DM is not able to meet the performance goal for Alert Production. This is tracked as a DM risk, where the risk response may require the development of a crosstalk correction stage for Alert Production, with an impact on the alert latency. It is also tracked in the Camera risk list, where the response may include action to remediate the crosstalk itself, or the collection of additional laboratory or other data characterizing the actual crosstalk, to enable its successful correction in DM.

Description	Value	Unit	Name
Between raft crosstalk	0.0001	TBD	betweenRaftCrosstalk
Goal for crosstalk between rafts	2.5e-5	TBD	betweenRaftCrosstalkGoal

1.15.3 Raft to Raft crosstalk count

ID: CAM-REQ-0099

Specification: For a single camera science raft there shall be no more than **[maxCrosstalkCount]** amplifiers on other science rafts that each contribute crosstalk greater than **[betweenRaftCrosstalkLimit]** to any pixel on that single raft.

Discussion: If this requirement is not met, it may occur that the crosstalk correction applied by the Camera on behalf of DM is not able to meet the performance goal for Alert Production. This is tracked as a DM risk, where the risk response may require the development of a crosstalk correction stage for Alert Production, with an impact on the alert latency. It is also tracked in the Camera risk list, where the response may include action to remediate the crosstalk itself, or the collection of additional laboratory or other data characterizing the actual crosstalk, to enable its successful correction in DM.

Description	Value	Unit	Name
Crosstalk value below which raft to raft crosstalk can be ignored	0	integer	betweenRaftCrosstalkLimit
Number of amplifiers contributing crosstalk	256	integer	maxCrosstalkCount

1.15.4 Crosstalk stability

ID: CAM-REQ-0100

Specification: The crosstalk from any pixel to any other pixel shall be stable to **[crosstalkStability]** of a full scale pixel over a period of **[crosstalkStabilityDuration]** days or the camera shall provide algorithms and telemetry to enable the reconstruction of the crosstalk to **[crosstalkStability]** of a full scale pixel at any time during that period.

Discussion: If this requirement is not met, it may occur that the crosstalk correction applied by the Camera on behalf of DM is not able to meet the performance goal for Alert Production. This is tracked

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as a DM risk, where the risk response may require the development of a crosstalk correction stage for Alert Production, with an impact on the alert latency. It is also tracked in the Camera risk list, where the response may include action to remediate the crosstalk itself, or the collection of additional laboratory or other data characterizing the actual crosstalk, to enable its successful correction in DM.

Description	Value	Unit	Name
Crosstalk stability	1e-5	TBD	crosstalkStability
Interval over which the crosstalk stability requirement is applicable	14	day	crosstalkStabilityDuration

1.15.5 Crosstalk correction extent

ID: CAM-REQ-0101

Specification: The camera shall be capable of applying crosstalk corrections for each raft using all of the amplifiers within that raft.

2 Camera Optical Design

The Camera optical prescription is a direct copy of the observatory prescription specified in the Observatory System Spec (OSS). The Camera optical prescription is given below with details and performance discussed in document LSE-11. The prescription contains parameters to define each surface, their separations, and clear apertures. All parameters follow the sign conventions used by the Zemax raytracing software.

The Camera optical prescription is a direct copy of the observatory prescription specified in the Observatory System Spec (OSS).

The Camera optical prescription is given below with details and performance discussed in document LSE-11. The prescription contains parameters to define each surface, their separations, and clear apertures.

All parameters follow the sign conventions used by the Zemax raytracing software.

2.1 L1 Lens Prescription

ID: CAM-REQ-0026

Specification: The prescription of the L1 lens shall be defined by the following table of parameters.

Discussion: This prescription is a copy of the prescription called out in the Observatory System Spec (OSS), and defines only nominal values; tolerances on figure and position are derived at a lower level from image quality requirements. These tolerances address impacts of gravity and other effects as the camera pointing deviates from zenith.

Description	Value	Unit	Name
The radius of the first surface (s1) of the first lens (L1) shall be **[L1-S1-Radius]**	-2824.0	millimetre	L1-S1-Radius

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Description	Value	Unit	Name
The radius of the second surface (s2) of the first lens (L1) shall be [**L1-S2-Radius].**	-5021.00	millimetre	L1-S2-Radius
The center thickness of the first lens (L1) shall be **[L1CenThick]**	82.23	millimetre	L1CenThick
The first lens (L1) shall be fabricated from **[L1GlassType]**		TBD	L1GlassType
The first surface clear aperture diameter of the first lens (L1) shall be at least [**L1S1OuterCA]**	1550.00	millimetre	L1S1OuterCA
The second surface clear aperture diameter of the first lens (L1) shall be at least [**L1S2OuterCA]**	1523.00	millimetre	L1S2OuterCA

2.2 L2 Lens Prescription

ID: CAM-REQ-0027

Specification: The prescription of the L2 lens shall be defined by the following table of parameters.

Discussion: This prescription is a copy of the prescription called out in the Observatory System Spec (OSS), and defines only nominal values; tolerances on figure and position are derived at a lower level from image quality requirements. These tolerances address impacts of gravity and other effects as the camera pointing deviates from zenith.

Description	Value	Unit	Name
The radius of the first surface (S1) of the second lens (L2) shall be [**L2-S1-Radius]**		TBD	L2-S1-Radius
The second surface 6th order aspheric coefficient on the second lens shall be [**L2-S2-6thAsphere].**	1.656e-18	TBD	L2-S2-6thAsphere
The radius of the second surface (s2) of the second lens (L2) shall be **[L2-S2-Radius].**	-2529.0	millimetre	L2-S2-Radius
The second surface (s2) conic constant on the second lens (L2) shall be **[L2-S2Conic**].		TBD	L2-S2Conic
The center thickness of the second lens (L2) shall be **[L2CenThick].**	30.00	millimetre	L2CenThick
The second lens (L2) shall be fabricated from **[L2GlassType]**		TBD	L2GlassType
The first surface clear aperture diameter of the second lens	1102.00	millimetre	L2S1OuterCA

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Description	Value	Unit	Name
(L2) shall be at least **[L2S1OuterCA].**			
The second surface clear aperture diameter of the second lens (L2) shall be at least **[L2S2OuterCA].**	1040.00	millimetre	L2S2OuterCA

2.3 Filter Prescription

ID: CAM-REQ-0028

Specification: The prescription of the filter substrates shall be defined by the following table of parameters.

Discussion: This prescription is a copy of the prescription called out in the Observatory System Spec (OSS), and defines only nominal values; tolerances on figure and position are derived at a lower level from image quality requirements. These tolerances address impacts of gravity and other effects as the camera pointing deviates from zenith.

Description	Value	Unit	Name
The radius of the first surface (s1) of the filter substrates shall be **filter_s1Radius**	-5632.0	millimetre	filter_s1Radius
The radius of the second surface (s2) of the g-band filter substrate shall be **filter_s2Radius_g**	-5576.0	millimetre	filter_s2Radius_g
The radius of the second surface (s2) of the i-band filter substrate shall be **filter_s2Radius_i**	-5623.0	millimetre	filter_s2Radius_i
The radius of the second surface (s2) of the r-band filter substrate shall be **filter_s2Radius_r**	-5606.0	millimetre	filter_s2Radius_r
The radius of the second surface (s2) of the u-band filter substrate shall be **filter_s2Radius_u**	-5530.0	millimetre	filter_s2Radius_u
The radius of the second surface (s2) of the y-band filter substrate shall be **filter_s2Radius_y**	-5640.0	millimetre	filter_s2Radius_y
The radius of the second surface (s2) of the z-band filter substrate shall be **filter_s2Radius_z**	-5632.0	millimetre	filter_s2Radius_z
The filter shall be fabricated from **filterGlassType**		TBD	filterGlassType
The first surface clear aperture diameter of all filter substrates shall be at least **filterS1OuterCa**	756.00	millimetre	mi
The second surface clear aperture diameter the g-band filter	741.00	millimetre	filterS2OuterCa_g

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Description	Value	Unit	Name
substrate shall be at least **filter2OuterCa_g**			
The second surface clear aperture diameter the i-band filter substrate shall be at least **filterS2OuterCa_i**	746.00	millimetre	filterS2OuterCa_i
The second surface clear aperture diameter the r-band filter substrate shall be at least **filterS2OuterCa_r**	745.00	millimetre	filterS2OuterCa_r
The second surface clear aperture diameter the u-band filter substrate shall be at least **filterS2OuterCa_u**	737.00	millimetre	filterS2OuterCa_u
The second surface clear aperture diameter the y-band filter substrate shall be at least **filterS2OuterCa_y**	748.00	millimetre	filterS2OuterCa_y
The second surface clear aperture diameter the z-band filter substrate shall be at least **filterS2OuterCa_z**	747.00	millimetre	filterS2OuterCa_z
The thicknes of the g-band filter substrate shall be **filterThick_g**	21.50	millimetre	filterThick_g
The thicknes of the i-band filter substrate shall be **filterThick_i**	15.70	millimetre	filterThick_i
The thicknes of the r-band filter substrate shall be **filterThick_r**	17.90	millimetre	filterThick_r
The thicknes of the u-band filter substrate shall be **filterThick_u**	26.60	millimetre	filterThick_u
The thicknes of the y-band filter substrate shall be **filterThick_y**	13.60	millimetre	filterThick_y
The thicknes of the z-band filter substrate shall be **filterThick_z**	14.4	millimetre	filterThick_z

2.4 L3 Lens Prescription

ID: CAM-REQ-0029

Specification: The prescription of the third lens (L3) shall be defined by the following table of parameters.

Discussion: This prescription is a copy of the prescription called out in the Observatory System Spec (OSS), and defines only nominal values; tolerances on figure and position are derived at a lower level from image quality requirements. These tolerances address impacts of gravity and other effects as the

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camera pointing deviates from zenith.

Description	Value	Unit	Name
The radius of the first surface (s1) of the third lens (L3) shall be **[L3-S1-Radius].**	-3169.0	millimetre	L3-S1-Radius
The first surface (s1) conic constant on the third lens (L3) shall be **[L3-S1Conic]**.		TBD	L3-S1Conic
The radius of the second surface (s2) of the third lens (L3) shall be **[L3-S2-Radius].**	13360.0	millimetre	L3-S2-Radius
The center thickness of the third lens (L3) shall be **[L3CenThick].**	60.00	millimetre	L3CenThick
The third lens (L3) shall be fabricated from **[L3GlassType].**		TBD	L3GlassType
The first surface clear aperture radius of the third lens (L3) shall be at least **[L3S1OuterCA].**	722.00	millimetre	L3S1OuterCA
The second surface clear aperture radius of the third lens (L3) shall be at least **[L3S2OuterCA].**	722.00	millimetre	L3S2OuterCA

2.5 Camera optics spacings

ID: CAM-REQ-0030

Specification: The prescription for the separation of the Camera optical elements shall be defined by the parameters in the table below.

Discussion: This prescription is a copy of the prescription called out in the Observatory System Spec (OSS), and defines only nominal values; tolerances on figure and position are derived at a lower level from image quality requirements.

Description	Value	Unit	Name
The distance from the vertex of the second surface of L1 to the vertex of the first surface of L2 shall be **l1_l2Spacing.**	-412.642	millimetre	l1_l2Spacing
The distance from the vertex of the second surface of L2 to the vertex of the first surface of the filter substrate shall be **L2_filterSpacing.**	-346.95	millimetre	l2_filterSpacing
The distance from the vertex of the second surface of the g-band filter substrate to the vertex of the first surface of L3 shall be **L3_filterSpacing_g.**	-50.50	millimetre	l3_filterSpacing_g

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Description	Value	Unit	Name
The distance from the vertex of the second surface of the i-band filter substrate to the vertex of the first surface of L3 shall be **L3_filterSpacing_i.**	-56.30	millimetre	l3_filterSpacing_i
The distance from the vertex of the second surface of the r-band filter substrate to the vertex of the first surface of L3 shall be **L3_filterSpacing_r.**	-54.10	millimetre	l3_filterSpacing_r
The distance from the vertex of the second surface of the u-band filter substrate to the vertex of the first surface of L3 shall be **L3_filterSpacing_u.**	-45.40	millimetre	l3_filterSpacing_u
The distance from the vertex of the second surface of the y-band filter substrate to the vertex of the first surface of L3 shall be **L3_filterSpacing_y.**	-58.40	millimetre	l3_filterSpacing_y
The distance from the vertex of the second surface of the z-band filter substrate to the vertex of the first surface of L3 shall be **L3_filterSpacing_z.**	-57.60	millimetre	l3_filterSpacing_z
The distance from the vertex of the second surface of L3 to the focal plane array (FPA) shall be **l3_fpaSpacing.**	-28.82	millimetre	l3_fpaSpacing

2.6 Detector plane+L3+Filter gap adjustability to L2

ID: CAM-REQ-0031

Specification: The detector plane + L3 + Filter shall be capable of being adjusted one time by +/- [**DetL3FilterAdjust**] with respect to L2 relative to the nominal spacing of 346.58 mm.

Discussion: This provides compensation for the as-built figure errors in the mirrors. This adjustment essentially redefines the optical spacing defined in CAM-REQ-0030. Thus the tolerance of this adjustment is controlled by the image quality budget.

Description	Value	Unit	Name
L2 to L3+filter+detector plane spacing adjustability	5	millimetre	DetL3FilterAdjust

2.7 Detector plane-L3 gap adjustability

ID: CAM-REQ-0032

Specification: The gap between the detector plane and L3 shall be capable of being adjusted one time by +/- [**Det-L3GapAdjust**] relative to a nominal spacing of -28.5 mm.

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Discussion: This provides compensation for the as-built figure errors in the mirrors.

Description	Value	Unit	Name
Detector plane to L3 spacing adjustability	3.5	millimetre	Det-L3GapAdjust

3 Camera Stray and Scattered Light

3.1 Lens Maximum Reflectance

ID: CAM-REQ-0033

Specification: The reflection at any location in the pupil for any field angle in the 3.5 degree field of view on any transmissive optical surface (not including filters), shall be less than **lensReflection** at all wavelengths between 300-1100nm using the r-band beam angles of incidence defined in LSE-11.

Discussion: These specifications constrain the intensity of the 2-reflection ghost images.

The r-band beam defined in LSE-11 has been designated the nominal beam for use in evaluating the lens reflections. That definition includes the beam angles at both surfaces of each lens.

Description	Value	Unit	Name
The maximum allowable reflection fraction from any lens surface after AR coating.	2	percent	lensReflection

3.2 Reflective surface treatments

ID: CAM-REQ-0034

Specification: Reflective surfaces near the main beam shall either be shielded by light baffles, painted flat black or treated/shaped to minimize scattering.

3.3 Optical Baffling

ID: CAM-REQ-0035

Specification: The camera shall be baffled such that there are no direct specular paths to the focal plane from celestial sources that are outside the nominal field of view

4 Photometric Requirements

4.1 Camera optical throughput variation

ID: CAM-REQ-0036

Specification: When flowing down the throughput requirements to the component level, the Camera shall set a single minimum quantum efficiency (QE) specification, for each filter band, that is to be met

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by each science sensor in the focal plane, averaged over its active area.

Discussion: This is understood to implement the throughput variation requirements in Table 7 of the Science Requirements Document, LPM-17 and OSS-REQ-0256.

4.2 Exposure duration accuracy

ID: CAM-REQ-0037

Specification: The accuracy of the shutter exposure duration shall be <[**ExposureDurationAccuracy**].

Discussion: The accuracy is the difference between the actual duration and what was requested.

Description	Value	Unit	Name
Exposure duration accuracy	50	TBD	ExposureDurationAccuracy

4.3 Exposure duration knowledge

ID: CAM-REQ-0102

Specification: The exposure duration shall be known to within [**ExposureDurationKnowledge**] of the actual value for any position on the focal plane for the standard exposure of 15 seconds.

Description	Value	Unit	Name
Exposure duration knowledge	2	percent	exposureDurationKnowledge

4.4 Filter positioning for photometric precision

ID: CAM-REQ-0040

Specification: The light impinging on a particular pixel passes through a circle approximately 100mm in diameter on the surface of the filter. The knowledge of position of the center of that circle on a specific filter for any pixel on the best fit detector plane between any two camera orientations shall be better than **[FilterPosKnowledge],** including effects of filter changes.

Discussion: This requirement, coupled with the filter response uniformity requirement (CAM-REQ-0008) satisfies the OSS requirement OSS-REQ-0331 per the analysis in LSE-180. This does not include changes to the incoming light angles due to hexapod driven changes to camera position.

Description	Value	Unit	Name
Filter position knowledge	1.65	millimetre	FilterPosKnowledge

4.5 Throughput as-built knowledge

ID: CAM-REQ-0041

Specification: The as-built camera throughput shall be measured separately from the telescope with relative accuracy of **[ThroughputOverFOV]** over spatial scales of 1 degree on the focal plane

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(approximately the size of a raft) for light at a fixed angle of incidence and in LSST griz bands. The angular dependence of the throughput shall be measured over the range 14-26 degrees for at least one point on the focal plane. (TBR)

Discussion: This is to provide data for use in extraction of dome flat illumination corrections.

Description	Value	Unit	Name
Throughput as built knowledge relative accuracy	0.25	percent	ThroughputOverFOV

4.6 Long term gain stability

ID: CAM-REQ-0104

Specification: The video channel gain shall be stable to within [**12HourGainStability]** over a 12-hour observing period. Alternatively appropriate algorithms and telemetry data shall be provided to enable reconstruction of changes in video channel gain to within [**12HourGainStability]** over a 12-hour observing period.

Description	Value	Unit	Name
Gain stability over 12 hours	1	TBD	12HourGainStability

4.7 Short term gain stability

ID: CAM-REQ-0105

Specification: The video channel gain shall be stable to within [**1HourGainStability]** over a 1-hour observing period. Alternatively appropriate algorithms and telemetry data shall be provided to enable reconstruction of changes in video channel gain to within [**1HourGainStability]** over a 1-hour observing period.

Description	Value	Unit	Name
Gain stability over 1 hour	0.1	TBD	1HourGainStability

4.8 CCD temperature knowledge

ID: CAM-REQ-0103

Specification: The camera shall provide sufficient telemetry and models to enable reconstruction of the temperature at any point on the active portion of the sensor surface to an accuracy of **[TempRelAccuracy]** Kelvin relative to the temperature at a reference time no more than **[TempRefInterval]** (TBR) in the past. The temperature measurements shall be accurate to within **[TempAbsAccuracy]** Kelvin on an absolute scale.

Discussion: This requirement does not cover periods that span significant camera maintenance.

Description	Value	Unit	Name
Absolute accuracy of the temperature measurement	5	degree	TempAbsAccuracy

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Description	Value	Unit	Name
Time interval between reference narrowband calibration and the time of the image for which the temperature is measured	30	day	TempRefInterval
Relative accuracy (precision)	0.5	degree	TempRelAccuracy

5 Guiding

5.1 Guide Sensors

ID: CAM-REQ-0043

Specification: The camera shall provide guide sensors to support telescope guiding.

Discussion: The requirements for these guide sensors are in the Camera to Telescope Guiding ICD (LSE-66).

6 Wavefront Sensing

6.1 Wavefront Sensor Data

ID: CAM-REQ-0044

Specification: For the purposes of archiving and buffering the wavefront sensor imaging data shall be treated the same as science image data.

6.2 Wavefront Sensors

ID: CAM-REQ-0045

Specification: The camera shall provide 4 wavefront sensors located near the corners of the inscribed square to the 3.5 degree FOV.

Discussion: The wavefront sensor requirements are in the Camera to Telescope Wavefront Sensing ICD (LSE-67).

7 Camera Operations

7.1 Camera command and telemetry

7.1.1 Commanding from OCS

ID: CAM-REQ-0046

Specification: The camera shall support commands from the OCS to power-up and initialize the camera, to change filters and to take exposures.

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Discussion: The full list of commands is defined in the OCS to Camera ICD. (LSE-71).

7.1.2 Camera telemetry transfer method

ID: CAM-REQ-0047

Specification: The camera shall publish telemetry using the Observatory specified protocol as defined in the OCS Architecture and Protocol ICD (LSE-70).

7.1.3 Camera meta-data availability

ID: CAM-REQ-0048

Specification: The camera telemetry shall include all required information (metadata) needed for the scientific analysis of the survey data.

Discussion: This includes metadata to maintain the required photometric precision and accuracy during operations between daily and periodic calibration.

7.1.4 Camera State Notification

ID: CAM-REQ-0049

Specification: The camera shall report any changes in its major internal state.

7.1.5 Camera Status

ID: CAM-REQ-0050

Specification: The Camera shall assess and report an overall hardware health status for major camera components.

Discussion: The primary purpose of these status indicators is for the OCS to be able to orchestrate normal operations and handle out of normal conditions.

7.2 Exposure Control Operations

7.2.1 Visit timing

ID: CAM-REQ-0051

Specification: The total elapsed time for a Standard Visit (2 x 15 sec exposures) or Alternate Standard Visit (1x30-second exposure), from the command to begin the first exposure to the end of the last exposure when the shutter is fully closed, shall be no more than visitDuration.

Discussion: The end point of the visit is defined when the shutter is fully closed on the last exposure of a standard visit and does not include the readout time. This is because the readout of the last exposure is done while the system is being re-pointed to the next field location.

The baseline sequence for a Standard Visit (2x15 second exposure) is 1 sec open shutter; 14 sec integration; 1 sec close shutter; 2 sec pixel readout 1 sec shutter open; 14 sec integration; 1 sec shutter close.

The baseline sequence for an Alternate Standard Visit (1x30 second exposure) is 1 sec open shutter, 29

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second integration, 1 sec close shutter.

The expectation is that the system can be operated to acquire images with exposure times over a range of exposures times from ~1 to of order ~300 seconds. Non-standard visit exposures do not need to be processed with the same latency as those for main survey "standard" visits.

Description	Value	Unit	Name
Visit duration, not counting readout of the second exposure	34	second	CamVisitTiming

7.2.2 Bias/zero exposures

ID: CAM-REQ-0052

Specification: The camera shall be able to perform bias/zero exposures.

Discussion: These exposures are taken without any CCD integration time. Otherwise the CCDs are prepared for an exposure as usual. At the time the shutter would normally open, the CCD readout will start.

7.2.3 Closed-shutter integration

ID: CAM-REQ-0053

Specification: The camera shall be able to perform exposures without opening the shutter

7.2.4 Max exposure duration

ID: CAM-REQ-0054

Specification: The camera shall be capable of exposures longer than the nominal duration of 15 seconds, but single image specifications need not be met.

7.2.5 Min exposure duration

ID: CAM-REQ-0055

Specification: The camera shall be able to obtain a single exposure with an effective minimum exposure time of no more than **minExpTime**, with a goal of an effective minimum exposure time of **minExpTimeGoal**.

Discussion: The camera thermal stability may be affected if the duty cycle differs from the standard 15 second cadence. If the exposure time is shortened from the 15 second nominal, the spacing between successive exposures might need to be extended to maintain the average readout rate consistent with a 15 second exposure. If the exposure is lengthened from the 15 second nominal, the thermal stability may also be affected, which may affect photometric accuracy. In addition, as the exposure time uncertainty is essentially a fixed amount of time, shorter exposures will have proportionally larger fractional uncertainty.

Description	Value	Unit	Name
Minimum exposure time	1	second	minExpTime

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Description	Value	Unit	Name
Minimum exposure time goal	0.1	second	minExpTimeGoal

7.2.6 Filterless Images

ID: CAM-REQ-0130

Specification: The camera shall be capable of exposures with no filter in the optical path.

Discussion: The camera will use a unique filter id in the setFilter command to identify the no filter case and to set the no filter configuration.

7.3 Science data read-out

ID: CAM-REQ-0122

Discussion: The science data read-out requirements defined below are refined in the DM to Camera ICD (LSE-68).

7.3.1 Science Image Identifier

ID: CAM-REQ-0056

Specification: The camera shall deliver each image with a unique identifier per device per exposure.

7.3.2 Cross-talk corrected image data

ID: CAM-REQ-0057

Specification: The camera shall provide cross-talk corrected science pixel data to client subscribers.

Discussion: The DM will provide the cross-talk coefficients and correction algorithm as defined in the DM to Camera ICD (LSE-68).

7.3.3 Persistence of raw data

ID: CAM-REQ-0059

Specification: The camera shall maintain the capability to persist the raw pixel data captured during [**CamPersist**] 24 hour cycles of normal science observing and calibration operations. This is [**CamPersistImages**] based on the minimum number of raw science exposures acquired over a sustained period [**nRawExpNightWinterAvg**] and the minimum number of calibrations that can be acquired per day under normal operations [**nCalibExpDay**]. The data shall include science and wavefront sensor data for all observations and full-frame guider data from calibration operations.

Discussion: For image rates above the normal levels the persistence time will be shortened.

Description	Value	Unit	Name
Science data buffer capability	10	day	CamPersist
Minimum number of calibration exposures able to be	450	integer	nCalibExpDay

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Description	Value	Unit	Name
acquired per day under normal operation shall be at least **nCalibExpDay**.			
The minimum number of raw science exposures acquired over a sustained period [nRawExpNightWinterAvg]	24100	integer	CamPersistImages
Minimum number of raw science exposures required to be supported by the LSST Observatory over a sustained period (as during the weeks around the winter solstice)	1960	integer	nRawExpNightWinterAvg

7.3.4 Raw Image Data

ID: CAM-REQ-0058

Specification: The camera shall provide raw science pixel data in response to a request for one or more specific images.

7.3.5 Raw data buffer readout

ID: CAM-REQ-0060

Specification: The camera shall be able to transmit a backlog of accumulated raw data in parallel with normal observing operations and the transmittal of new data, at a rate of **playbackImagesPerDay** images in **playbackInterval.**

Discussion: This rate is equivalent to playback of at least 2 days of stored data in a day. The playback interval allows for up to 4 hours of maintenance per day on observatory subsystems that would prevent stored data transmission.

Description	Value	Unit	Name
playback images per day	4820	integer	playbackImagesPerDay
The playback interval allows for up to 4 hours of maintenance per day on observatory subsystems that would prevent stored data transmission.	20	hour	playbackInterval

7.3.6 Wavefront data to DM

ID: CAM-REQ-0061

Specification: The camera shall provide wave front data to DM.

7.4 Time Reference

7.4.1 Timestamp Accuracy and Precision

ID: CAM-REQ-0111

The contents of this document are subject to configuration control and may not be changed, altered, or their provisions waived without prior approval.

Specification: Computer clocks used to produce timestamps shall be synchronized with an observatory master clock to a precision of **[timestampPrecision]** and an accuracy of **[timestampAccuracy]**, as given in the table below. This requirement shall apply separately to each computer clock.

Discussion: The purpose of time synchronization is to ensure that timestamps recorded in the database are meaningful regardless of which computer generated the timestamp. To achieve this, an observatory master clock is distributed to all computer hosts that generate timestamps recorded in LSST telemetry. Current protocols (PTP and NTPv4) allow system clocks to be synchronized well within the requirement. Timestamps are used to record both internal and external events as observatory telemetry. The relationship between the timestamp and the actual physical event, expressed as latency/jitter, depends on both the computer and the hardware (mechanical, electrical, etc.). It is the responsibility of individual hardware design teams to determine the relevance of latency/jitter. When cross subsystem dependencies on timestamps exist, additional requirements can be documented in ICDs. The term "precision" is to be interpreted as a one-sigma statistical measure, and the term "accuracy" as a statistically determined mean measurement.

Description	Value	Unit	Name
Computer clock timestamp accuracy	0.010	second	timestampAccuracy
Computer clock timestamp precision	0.001	second	timestampPrecision

7.5 Filter Operations

ID: CAM-REQ-0120

7.5.1 Filter swap in place

ID: CAM-REQ-0066

Specification: The internal filter complement of the camera shall be reconfigurable without requiring the removal of the camera from the telescope.

7.5.2 Filter complement

ID: CAM-REQ-0067

Specification: The camera shall accommodate [**NumFilters**] filters on board the camera at any time.

Discussion: This presumes that a filter swap-out for a spare filter requires a daytime access.

Description	Value	Unit	Name
Number of on-board filters	5	integer	NumFilters

7.5.3 Filter exchange duration

ID: CAM-REQ-0068

Specification: The camera shall require less than [**FilterchangeDuration**] to change between any two filters that are resident inside the camera.

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Discussion: This duration covers all required camera operations, but does not include any additional telescope or OCS times.

Description	Value	Unit	Name
Maximum filter change duration	90	second	FilterChangeDuration

7.5.4 Filter swap-out duration

ID: CAM-REQ-0069

Specification: The Camera shall allow for swapping out any of the on-board filters for a new filter during the day, with a total time to swap out the filter of [**FilterSwapOutDuration**] after safe access to the Camera has been established.

Discussion: This duration covers all required camera operations and verification tests, but does not include any additional telescope time needed to access the camera or recover.

Description	Value	Unit	Name
Maximum filter swap duration	1.5	hour	FilterSwapOutDuration

7.5.5 Number of filter exchanges

ID: CAM-REQ-0070

Specification: the Camera shall be capable of a total of **[dailyFiltChanges]** plus **[nightlyFiltChanges]** filter changes per day during its design lifetime.

Description	Value	Unit	Name
Daily filter changes	8	integer	dailyFiltChanges
Nightly filter changes	4	integer	nightlyFiltChanges

7.5.6 Number of filter swap-outs

ID: CAM-REQ-0071

Specification: For design purposes the number of monthly filter swaps shall be at least **[monthlyFiltSwaps]**.

Description	Value	Unit	Name
Minimum number of manual filter swaps per month	2	integer	monthlyFiltSwaps

7.6 Camera Power-on

ID: CAM-REQ-0072

The contents of this document are subject to configuration control and may not be changed, altered, or their provisions waived without prior approval.

Specification: Upon activation, the camera shall be able to initialize itself and be ready for communication with the OCS without further human intervention. This activation process shall take less than **[CamActivationTime]**.

Discussion: This does not place any requirements the camera in terms of being ready to take data. For example, the Camera cool down (which requires activation) will take considerable longer than the specified activation time.

This requirement assumes a warm restart or activation with the appropriate computer(s) up and running.

Description	Value	Unit	Name
Camera activation time	1	minute	CamActivationTime

7.7 Camera Initialization

ID: CAM-REQ-0073

Specification: The camera at power up shall be initialized into a known safe state without human intervention.

7.8 Camera Stand-alone Operations

ID: CAM-REQ-0074

Specification: The camera shall maintain technical health, safety and status without any other observatory subsystem operational.

7.9 Camera Engineering and Maintenance

ID: CAM-REQ-0075

Specification: The camera shall provide access to lower level functionality and telemetry to support engineering and maintenance operations.

7.10 Remote Operation Capabilities

ID: CAM-REQ-0076

Specification: The camera shall be remotely operable from any of the LSST Facilities or other Project designated site (e.g. SLAC for camera troubleshooting), subject to cyber security policy. A local operator shall be always available to regain local control when conditions or safety considerations merit.

Discussion: This provides the opportunity to establish a single operations center for the various functions of Data Management. Note that cyber security policies must be enforced.

7.11 Camera Scheduled Maintenance

ID: CAM-REQ-0077

The contents of this document are subject to configuration control and may not be changed, altered, or their provisions waived without prior approval.

Specification: The camera shall contribute no more than [**CamMaintenanceTime**] of observatory downtime per year due to planned maintenance requirements.

Description	Value	Unit	Name
Maximum scheduled maintenance per year	7	day	CamMaintenanceTime

7.12 Maintenance Recommendations

ID: CAM-REQ-0078

Specification: The camera team shall provide a preventive maintenance plan to the Observatory.

7.13 Camera Unscheduled Downtime

ID: CAM-REQ-0079

Specification: The Camera shall be designed to facilitate unplanned repair activities expected not to exceed **CamDowntime** days per year.

Discussion: This requirement does not invoke the need to verify by reliability analysis. Verification is by analysis that identifies likely hardware failures and identifies mitigations to minimize downtime caused by those failures.

Description	Value	Unit	Name
Unplanned downtime per year	10	day	CamDowntime

7.14 Number of shutter actuations

ID: CAM-REQ-0080

Specification: The camera shall be designed for **nRawExpYear** shutter actuations per year.

Discussion: Includes science and calibration exposures as defined in OSS-REQ-0190 and -0323.

Description	Value	Unit	Name
Minimum number of raw science exposures required to be supported by the LSST Observatory over the course of a single year	750000	integer	nRawExpYear

7.15 Safety System

ID: CAM-REQ-0081

Specification: The camera shall implement a non-software based safety system in areas where injury or harm to personnel and or equipment can occur.

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7.16 Baseline Performance

ID: CAM-REQ-0082

Specification: The camera shall provide the initial baseline performance as determined during acceptance testing and system integration and test.

Discussion: The baseline analysis is a deliverable of the subsystem and will be part of the acceptance process. It is expected that over time the observatory staff will modify and add to the analysis as knowledge of the subsystems improves.

7.17 Trend analysis

ID: CAM-REQ-0083

Specification: The camera shall provide a telemetry trend analysis specific to the camera design using the provided toolkit

Discussion: It is expected that over time the observatory staff will modify and add to the analysis as knowledge of the subsystems improves.

8 Camera Environmental

8.1 Normal Operations

ID: CAM-REQ-0084

Specification: The camera shall meet performance requirements under normal operating conditions as defined in the table below.

8.2 Marginal Condition Operations

ID: CAM-REQ-0085

Specification: The camera shall operate under marginal operating conditions as defined in the table below, but need not meet specification.

8.3 Survival Condition Operations

ID: CAM-REQ-0086

Specification: The camera shall survive the survival conditions as defined in the table below, but need not be operating.

8.4 Transportation Condition Design

ID: CAM-REQ-0087

Specification: The camera and shipping container shall be designed to withstand the transportation conditions as defined in the table below.

Discussion: The shipping environment includes the general conditions when equipment is shipped to the

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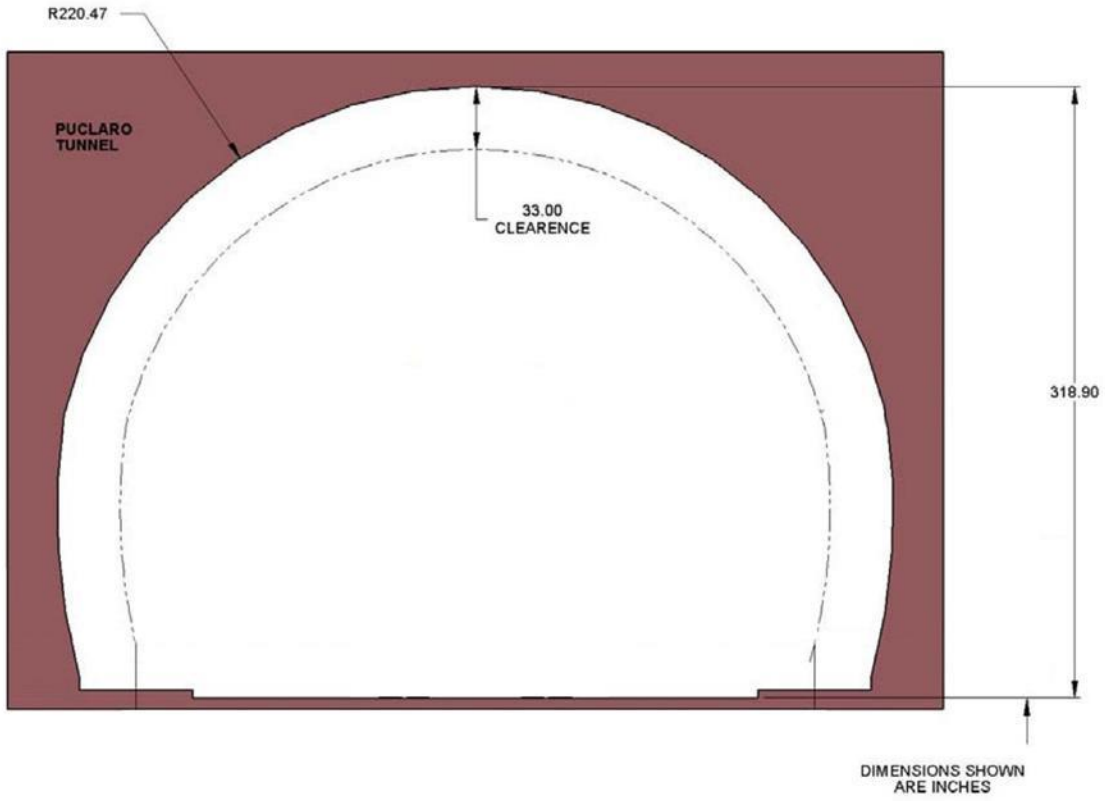
summit. The equipment must remain undamaged after repeated shipments. Delivery is expected to be by plane or boat to Chile and then by road to the summit.

There is a tunnel on the road between the town of La Serena and the summit site on Cerro Pachon called the Puclaro Tunnel. Any equipment will have to pass through that tunnel. Its overall dimensions are given, as defined in Figure 1 below.

Figure 1 - The Puclaro Tunnel and relevant dimensions.



Description	Value	Unit	Name
Wind speed may reach up to 45m/s during transportation to the summit	45	metre per second	Wind Speed
The relative humidity range is from 10% to 100% with condensation for transportation to the summit	10% to 100%	percent	Relative Humidity Range
Pressure will change during transportation to the summit from 1000mbar at sea level down to 750mbar at the summit	1000 to 750	millibar	Pressure
The ambient temperature range or transportation to the summit is	-15C to +40C	degree celsius	Temperature Range

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Description	Value	Unit	Name
Dirt roads will be used during transportation to the summit with grades up to 16%	16	percent	Roads
During transportation to the summit, some roads have vehicle weight restrictions. Gross Vehicle Weight GVW = TBD Weight/axle = TBD	45	tonne	GVW
During transportation, the effective altitude can change between sea level and 3000m.	Sea level to 2700m	metre	Altitude

8.5 Design for Operable-Level Seismic Event

ID: CAM-REQ-0106

Specification: When mounted to the telescope, the Camera shall be designed to operate without any significant damage following an operable-level seismic event, with accelerations as defined in LSE-80, the Camera-Telescope Mechanical ICD, req CA-TS-MEC-ICD-0010. "Significant damage" is defined as any yielding, structural failure, or loss of function that requires more than 40 hours (TBR) to repair after access and initial inspection.

8.6 Design for Recoverable-Level Seismic Event

ID: CAM-REQ-0107

Specification: When mounted to the telescope, the Camera shall be designed to operate without any permanent damage following a recoverable-level seismic event, with accelerations as defined in LSE-80, the Camera-Telescope Mechanical ICD, req CA-TS-MEC-ICD-0028. "Permanent damage" is defined as any damage to optical elements, damage where repair costs are in excess of $4M (TBR), or where repair times are longer than 6 months after access, initial inspection, and damage assessment.

8.7 Design for Survival-Level Seismic Event

ID: CAM-REQ-0108

Specification: When mounted to the telescope, the Camera shall be designed to withstand a survival-level seismic event without catastrophic failure, with accelerations as defined in LSE-80, the Camera-Telescope Mechanical ICD, req CA-TS-MEC-ICD-0029. "Catastrophic failure" is defined as fracture or rupture that allows a significant element to separate and fall, or significantly increases the risk of personnel injury.

Discussion: The return of the Camera (and observatory) to "normal" operations following a "Survival" event will be assessed based on actual damage incurred.

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9 Camera Standards

9.1 Components Standardization Goal

ID: CAM-REQ-0089

Goal: The Camera should be designed to standardize components within the subsystem and with other subsystems when component functional, performance, and operational requirements define overlapping solution spaces.

Discussion: While it is desired to standardize component selection, it is realized that imposing this as a strict requirement is not practical due to a variety of factors, including component requirements that may require selection of unique hardware. However, standardizing components, where practical, supports many project operational goals, including standardization of operational and maintenance procedures. Additionally, standardization reduces the number of unique spares that must be stocked, helping reduce maintenance costs during commissioning and operations. To support the goal of component standardization, it is recommended that the camera subsystem exchange information with the other subsystems on an ongoing basis on their component selection to enable choices to be made informed by what components are already in use. Note: this is a "goal" statement that does not require verification.

9.2 Plans and Standards

ID: CAM-REQ-0119

Specification: The Camera shall develop and document standards and plans for the following:

- Software Standards
- Electrical Standards
- Grounding Plan
- Mechanical Standards

9.3 Safety

ID: CAM-REQ-0093

Specification: The camera shall comply with the LSST Safety Policy (LPM-18) and Hazard Analysis and Safety Practices (LPM-49).

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