Large Synoptic Survey Telescope	Document # **LCA-48-J**	LSST Camera APPROVED Effective Date 24 Jan 2019
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Document Title

Camera Specification

Purpose

This document collects the requirements for the Camera

Definitions

References

Change Log

Effective Date	Revision A
13-Oct-11	Finalized and presented at CD-1. Subsequently reformatted and reviewed for release under LCN-1012.

Effective Date	Revision B
12-Mar-14	This version is a snapshot of the in-process document to show the current status. This includes approved LCN-1032, 1034, 1072 and -1033. This includes refinements to the Guider and Wavefront Sensor ICDs.
21-Jul-14	Added LCN-1090
11-Sep-14	LCN-1071 contains the details of the changes to this specification. Added LCN-1083, -1075, -1103, -1091, -1074, -1105, -1096, -1095, -1077 and -1079.
27-Oct-14	Released per LCN-1071.

Effective Date	Revision C
5-Mar-15	Incorporated LCN-1101
5-Mar-15	Incorporated LCN-1151
5-Mar-15	Incorporated LCN-1171
16-Apr-15	Incorporated LCN-1244
	Incorporated LCN-1316, LCN-1302
	Incorporated LCN-1303
	Incorporated LCN-1293
	Incorporated LCN-1356
	Incorporated LCN-1281
	Incorporated LCN-1102, LCN-1320
15-Jul-15	Incorporated LCN-1360
28-Jul-15	Released per LCN-1334
Effective Date	**Revision D**
16-Oct-15	Incorporated LCN-1346
12-Nov-15	Released per LCN-1447
Effective Date	**Revision E**
8-Aug-16	Released per LCN-1623
Effective Date	**Revision F**
28-Sep-16	Released per LCN-1633
Effective Date	**Revision G**
11-Nov-16	Released per LCN-1360
Effective Date	**Revision H**
12-Dec-16	Updated non-controlled performance estimates and added waivers
12-Dec-17	Added waivers LCN-834, 867, 898 and 1140
14-Feb-18	Incorporated LCN-1446 (Guider ICD (LSE-66) changes per LCR-360, LCR-1003 and LCR-1206)
	Released per LCN-1446.
Effective Date	**Revision I**
16-Feb-18	Revised to capture redline changes from LCN-1803 on mass and moment of inertia
16-Feb-18	LCN-1803 Redline changes: Changed C-230, Center of gravity spec from 1350 to 1500 mm; changed C-234, Moment of inertia spec from 3500 to 4700 (waiver)

16-Feb-18	Changes implemented in LCN-1848: C-054, -089, and 287, changed position of L3, filter, and detector plane; C-002, -003, clarified that adjustment range applies around nominal position defined in previouse revision of spec
9-Mar-18	Released per LCN-1898.
Effective Date	**Revision J**
24-Jan-19	Revised to capture changes to C-139, C-246, and added new requirement C-431 per LCN-2263

#	Predecessor/ Traceability	Requirement Title	Requirement	Comments	Status	Status description/comments	Flowdown Analysis (Validation)	Verification Method	Phase	Verification Test
		1. Camera Performance Requirements								
		1.1 Image Quality								
C-044	CAM-REQ-0018	Camera max image quality error	The maximum delivered image quality error for the camera shall be less than 0.30 arc-seconds FWHM	This is the total image quality error allocation to the camera, from all sources	Complete		LCA-17	Test/Analysis	1	I&T: Analysis
C-049	C-044	I.Q. error due to optical fab errors	Maximum image quality error due to optical fabrication errors = 0.055 arc-seconds		Complete		LCA-17	SS Verif	2	Opt: null test
C-047	C-044	I.Q. error due to Raft Sensor Assembly manufacturing, assembly errors	Maximum image quality error due to RSA manufacturing and assembly errors =0.242 arc-seconds		Complete		LCA-17	Test/Analysis	2	I&T: Metrology; I&T BOT
C-053	C-044	Assembly and alignment error	Maximum image quality error due to assembly and alignment errors = 0.088 arc-seconds		Complete		LCA-17	Test/Analysis	2	I&T: Metrology, I&T: Survey and Alignment
C-048	C-044	I.Q. error due to gravity-induced motion	Maximum image quality error due to gravity-induced motion = 0.062 arc-seconds		Complete		LCA-17	Test/Analysis	2	I&T: Survey and Alignment; I&T: Metrology
C-051	C-044	I.Q. error due to thermally-induced motions	Maximum image quality error due to thermally-induced motions = 0.039 arc-seconds		Complete		LCA-17	Test/Analysis	2	I&T: Cryostat Functional Test, I&T: Camera Functional Test
C-050	C-044	I.Q. error due to pressure-induced motions	Maximum image quality error due to pressure-induced motions = 0.034 arc-seconds		Complete		LCA-17	SS Verif	2	Opt: analysis
C-052	C-044	I.Q. error due to vibration	Maximum image quality error due to all sources of vibration = 0.061 arc-seconds		Complete		LCA-17	Test/Analysis	2	I&T: System Dynamics Test
		1.3 Camera Throughput								
		1.3.1 Camera Optical Throughput								
			The optical hardware throughput integral is defined as: $\int_{\lambda=300}^{1200} \frac{t_\lambda}{\lambda} d\lambda$ Where t_λ is the camera throughput at the wavelength λ							
C-165	CAM-REQ-0001	Camera u-band throughput	The camera optical hardware throughput in the u-band, averaged over 10 years, shall be greater than 0.065.	For flowdown purposes within the camera, the implied mean fractional throughput when averaged over the u-band upper limit wavelength defined in table 1 on sheet “filter definition” should be greater than 22.5%	Complete		LCA-18	Test	2	I&T: CCOB
C-162	CAM-REQ-0001	Camera g-band throughput	The mean camera optical throughput in the g-band, averaged over 10 years, shall be greater than 0.170.	For flowdown purposes within the camera, the implied mean fractional throughput when averaged over the g-band upper limit wavelength defined in table 1 on sheet “filter definition” should be greater than 45.4%	Complete		LCA-18	Test	2	I&T: CCOB
C-164	CAM-REQ-0001	Camera r-band throughput	The mean camera optical throughput in the r-band , averaged over 10 years, shall be greater than 0.135.	For flowdown purposes within the camera, the implied mean fractional throughput when averaged over the r-band upper limit wavelength defined in table 1 on sheet “filter definition” should be greater than 49.1%	Complete		LCA-18	Test	2	I&T: CCOB
C-163	CAM-REQ-0001	Camera i-band throughput	The mean camera optical throughput in the i-band, averaged over 10 years, shall be greater than 0.097.	For flowdown purposes within the camera, the implied mean fractional throughput when averaged over the i-band upper limit wavelength defined in table 1 on sheet “filter definition” should be greater than 46.3%	Complete		LCA-18	Test	2	I&T: CCOB
C-167	CAM-REQ-0001	Camera z-band throughput	The mean camera optical throughput in the z-band, averaged over 10 years, shall be greater than 0.065.	For flowdown purposes within the camera, the implied mean fractional throughput when averaged over the z-band upper limit wavelength defined in table 1 on sheet “filter definition” should be greater than 42.1%	Complete		LCA-18	Test	2	I&T: CCOB
C-166	CAM-REQ-0001	Camera y-band throughput	The mean camera optical throughput in the y-band, averaged over 10 years, shall be greater than 0.024.	For flowdown purposes within the camera, the implied mean fractional throughput when averaged over the y-band upper limit wavelength defined in table 1 on sheet “filter definition” should be greater than 12.6%	Complete		LCA-18	Test	2	I&T: CCOB
		1.3.2 Camera Effective Area								

	#	Predecessor/ Traceability	Requirement Title	Requirement	Comments	Status	Status description/comments	Flowdown Analysis (Validation)	Verification Method	Phase	Verification Test
238	C-238	CAM-REQ-0003	Detector plane central fill factor	The CCD device fill factor within the central circle (diameter of 634.17 mm) shall be at least 85 percent.	The central area is defined as a circle with the center at the geometric center of the detector plane	Complete			Analysis	2	I&T: Survey and Alignment; I&T: Metrology
239	C-239	CAM-REQ-0004	Detector plane fill factor	The fill factor of active pixels in the area covered by science grade imaging devices shall be at least 90 percent		Complete			SS Verif	2	Srft: Inspection
			1.3.3 Other Throughput Parameters								
170	C-170	CAM-REQ-0005	Detector plane allowable dead pixels	The maximum percent of pixels on the detector plane within the central circle (diameter of 634.17 mm) that do not meet their requirements shall be less than 2% at delivery, with an additional loss of no more than 2% averaged over the 10-year survey lifetime	This includes pixels in otherwise live detectors that do not meet spec, and includes dead pixels, hot pixels, dead columns, and dead segments/amplifiers.	Complete			Test	3	I&T: BOT; I&T: CCOB
133	C-133	CAM-REQ-0079	Camera unplanned downtime	The Camera shall be designed to facilitate unplanned repair activities expected not to exceed 10 days per year.	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.	Complete			Analysis	2	I&T: Ops Plan analysis
205	C-205	CAM-REQ-0077	Camera planned downtime	The camera shall contribute no more than 7 days of observatory downtime due to maintenance requirements		Complete			Analysis	2	I&T: Ops Plan analysis
			1.4 System Noise								
			1.4.1 Electronic noise								
036	C-036	CAM-REQ-0020	Camera electronic noise	The electronic noise from the LSST Camera system shall contribute no more than 9 electrons per exposure to each pixel in the data from the science sensor array	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...	Complete			Test	1	I&T: BOT
			1.4.2 Stray and Scattered Light								
041	C-041	CAM-REQ-0034	Reflective surfaces	All components with a direct view of the field of view of the internal light cone as defined in LCA-10333 shall either be shielded by light baffles, treated/shaped to minimize scattering, or coated flat black. Paint with a BRDF (Bidirectional reflectance distribution function) equal to or lower than the BRDF of LORD Aeroglaze Z306 coating is acceptable.		Complete			Inspection	2	Subsystem: Inspection
043	C-043		Shutter Leakage	When exposed to diffuse light, the closed camera shutter shall attenuate the light flux by 10,000 when averaged over any square centimeter as measured at the CCD surface.		Complete			SS Verif	2	Shut: Shutter light test
113	C-113	CAM-REQ-0033	Lens maximum reflectance	The reflection at any location on L1, L2 or L3 shall be less than 2% at all wavelengths between 300-1100nm over the following angles of incidence: L1 Surface 1 air side angle of incidence on air side of 6.5-17.8° and angle of exitance on glass side of 4.5-12.1° L1 Surface 2 air side angle of incidence on glass side of 8.0-15.6° and angle of exitance on air side of 11.7-23.2° L2 Surface 1 air side angle of incidence on air side of 10.3-31.4° and angle of exitance on glass side of 7.0-20.9° L2 Surface 2 air side angle of incidence on glass side of 5.1-15.7° and angle of exitance on air side of 7.5-23.3° L3 Surface 1 air side angle of incidence on air side of 11.7-25.4 and angle of exitance on glass side of 8.0-17.1° L3 Surface 2 air side angle of incidence on glass side of 5.4-20.3° and angle of exitance on air side of 8.0-30.4°	Note that this is not averaged over the beam footprint	Complete			SS Verif	2	Opt: lens acceptance testing
261	C-261	CAM-REQ-0035	Baffling	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		Complete			Test/Analysis	2	I&T: CCOB
			1.5 Spatial Throughput Variations								
020	C-020	CAM-REQ-0036	Camera QE variation	The minimum QE specifications for each band shall be satisfied by each individual sensor when averaged over the active area for that sensor		Complete			SS Verif	2	

	#	Predecessor/ Traceability	Requirement Title	Requirement	Comments	Status	Status description/comments	Flowdown Analysis (Validation)	Verification Method	Phase	Verification Test
			1.6 Photometric Req's								
396	C-396	CAM-REQ-0102	Exposure duration knowledge	The exposure duration shall be known to within 2% rms of the actual value for any position on the focal plane for the standard exposure of 15 seconds		Complete			SSVerif	2	Shut: Shutter functional test
023	C-023	CAM-REQ-0040	Filter positioning for photometric precision	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 shall be better than 1.65mm in all camera orientations and after filter changes.		Complete			Test/Analysis	2	I&T: Survey and Alignment
094	C-094	C-023	Filter positioning repeatability	Filters must be placed into the optical beam with a repeatability of filter placement of < 0.1 mm.		Complete		LCA-152	Test	3	I&T: Survey and Alignment
394	C-394	CAM-REQ-0104	12 hour stability	The video channel gain shall be stable to within 1% rms 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 1% rms over a 12-hour observing period		Complete			Test/Analysis	2	I&T: BOT
395	C-395	CAM-REQ-0105	One hour stability	The video channel gain shall be stable to within 0.1% rms 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 0.1% rms over a 1-hour observing period		Complete			Test/Analysis	2	I&T: BOT
032	C-032	CAM-REQ-0103	Detector plane temperature knowledge	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 0.5 degrees Kelvin relative to the temperature at a reference time no more than 30 days in the past. The temperature measurements shall be accurate to within 5 degrees Kelvin on an absolute scale	This requirement does not cover periods that span significant camera maintenance	Complete			SS Verif; Test/Analysis	2	SRft: CCD and raft testing; I&T: Cryostat Functional test
027	C-027	CAM-REQ-0041	Throughput as-built knowledge	The as-built camera throughput shall be measured separately from the telescope with relative accuracy of 0.25% over spatial scales of 1 degree on the focal plane (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)	This is to provide data for use in extraction of dome flat illumination corrections..	Open	Photometric requirements defined in document-9553 are under observatory team review and may be relaxed		Test	3	I&T: CCOB
123	C-123		Detector signal linearity	Maximum deviation of detector response from a linear fit up to full well < 3 % of full well signal		Complete			SS Verif; I&T Test	3	SRft: CCD and raft test; I&T: BOT
009	C-009	CAM-REQ-0037	Exposure duration accuracy	The accuracy of the shutter exposure duration shall be < 50 milli-seconds	The accuracy is the difference between the actual duration and what was requested	Complete			SS Verif	2	Shut: Exposure Trajectory Test
			1.7. Optical Design								
			1.7.1 Filters								
			Filter prescriptions	The prescription of the Filters shall be defined by the following requirements when the telescope is zenith pointed	This prescription is a copy of the prescription called out in the Observatory System Spec (OSS), and defines only nominal values when the telescope is zenith pointed; tolerances on figure and position are derived at a lower level from image quality requirements						
055	C-055	CAM-REQ-0028	Filter 1st surface radius	Filter 1st surface spherical radius = -5632.0 mm		Complete			SS Verif	2	Opt: null test
056	C-056	CAM-REQ-0028	Filter s1 clear aperture	The filter first surface clear aperture diameter shall be at least 756.00 mm		Complete			SS Verif	2	Opt: inspection
411	C-411	CAM-REQ-0028	Filter s2 clear aperture	The filter second surface clear aperture Diameter shall be at least the following: u-filter: 737.00 g-filter: 741.00 r-filter: 745.00 i-filter: 746.00 z-filter: 747.00 y-filter: 748.00		Complete			SS Verif	2	Opt: inspection
057	C-057	CAM-REQ-0028	Filter glass type	Filter glass type: fused silica		Complete			SS Verif	2	Opt: inspection
058	C-058	CAM-REQ-0028	g-filter 2nd surface radius	g-filter 2nd surface spherical radius = -5576.0 mm		Complete			SS Verif	2	Opt: null test
059	C-059	CAM-REQ-0028	g-filter center thickness	g-filter center thickness = 21.50 mm		Complete			SS Verif	2	Opt: null test
060	C-060	CAM-REQ-0028	i-filter 2nd surface radius	i-filter 2nd surface spherical radius = -5623.0 mm		Complete			SS Verif	2	Opt: null test
061	C-061	CAM-REQ-0028	i-filter center thickness	i-filter center thickness = 15.700 mm		Complete			SS Verif	2	Opt: null test
062	C-062	CAM-REQ-0028	r-filter 2nd surface radius	r-filter 2nd surface spherical radius = -5606.0 mm		Complete			SS Verif	2	Opt: null test
063	C-063	CAM-REQ-0028	r-filter center thickness	r-filter center thickness = 17.900 mm		Complete			SS Verif	2	Opt: null test

	#	Predecessor/ Traceability	Requirement Title	Requirement	Comments	Status	Status description/comments	Flowdown Analysis (Validation)	Verification Method	Phase	Verification Test
064	C-064	CAM-REQ-0028	u-filter 2nd surface radius	u-filter 2nd surface spherical radius = -5530.0 mm		Complete			SS Verif	2	Opt: null test
065	C-065	CAM-REQ-0028	u-filter center thickness	u-filter center thickness = 26.600 mm		Complete			SS Verif	2	Opt: null test
066	C-066	CAM-REQ-0028	y-filter 2nd surface radius	y-filter 2nd surface spherical radius = -5640.0 mm		Complete			SS Verif	2	Opt: null test
067	C-067	CAM-REQ-0028	y-filter center thickness	y-filter center thickness =13.600 mm		Complete			SS Verif	2	Opt: null test
068	C-068	CAM-REQ-0028	z-filter 2nd surface radius	z-filter 2nd surface spherical radius = -5632.0 mm		Complete			SS Verif	2	Opt: null test
069	C-069	CAM-REQ-0028	z-filter center thickness	z-filter center thickness = 14.400 mm		Complete			SS Verif	2	Opt: null test
			1.7.2 L1 Lens								
150	C-150	CAM-REQ-0026	L1 lens prescription	The prescription of the L1 lens shall be defined by the following requirements with a pressure differential as defined in LCA-69 with surface 1 at a lower pressure than surface 2.	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	Complete			SS Verif	1	Opt: null test, analysis
070	C-070	CAM-REQ-0026	L1 1st surface radius	L1 1st surface spherical radius = -2824.00 mm		Complete			SS Verif	2	Opt: null test
071	C-071	CAM-REQ-0026	L1 2nd surface radius	L1 2nd surface spherical radius = -5021.00 mm		Complete			SS Verif	2	Opt: null test
072	C-072	CAM-REQ-0026	L1 center thickness	L1 center thickness = 82.23 mm		Complete			SS Verif	2	Opt: null test
073	C-073	CAM-REQ-0026	L1 s1 clear aperture	The L1 first surface clear aperture diameter shall be at least 1550.00 mm		Complete			SS Verif	2	Opt: inspection
410	C-410	CAM-REQ-0026	L1 s2 clear aperture	The L1 second surface clear aperture diameter shall be at least 1523.00 mm		Complete			SS Verif	2	Opt: inspection
075	C-075	CAM-REQ-0026	L1 glass type	L1 glass type: fused silica		Complete			SS Verif	2	Opt: inspection
			1.7.3 L2 Lens								
			L2 lens prescription	The prescription of the L2 lens shall be defined by the following requirements	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						
076	C-076	CAM-REQ-0027	L2 1st surface radius	L2 1st surface spherical radius = flat		Complete			SS Verif	2	Opt: null test
077	C-077	CAM-REQ-0027	L2 2nd surface asphere	L2 2nd surface asphere A6 coefficient = 1.656e-18 mm^-5		Complete			SS Verif	2	Opt: null test
078	C-078	CAM-REQ-0027	L2 2nd surface conic constant	L2 2nd surface conic constant = -1.5700		Complete			SS Verif	2	Opt: null test
079	C-079	CAM-REQ-0027	L2 2nd surface radius	L2 2nd surface spherical radius = -2529.00 mm		Complete			SS Verif	2	Opt: null test
080	C-080	CAM-REQ-0027	L2 center thickness	L2 center thickness = 30.00 mm		Complete			SS Verif	2	Opt: null test
081	C-081	CAM-REQ-0027	L2 s1 clear aperture	The L2 first surface clear aperture diameter shall be at least 1102 mm		Complete			SS Verif	2	Opt: inspection
409	C-409	CAM-REQ-0027	L2 s2 clear aperture	The L2 second surface clear aperture diameter shall be at least 1040 mm		Complete			SS Verif	2	Opt: inspection
083	C-083	CAM-REQ-0027	L2 glass type	L2 glass type: fused silica		Complete			SS Verif	2	Opt: inspection
			1.7.4 L3 Lens								
155	C-155	CAM-REQ-0029	L3 lens prescription	The prescription of the L3 lens shall be defined by the following requirements with a pressure differential as defined in LCA-69 with surface 2 at a lower pressure than surface 1.	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	Complete			SS Verif	1	Opt: null test
084	C-084	CAM-REQ-0029	L3 1st surface radius	L3 1st surface spherical radius = -3169.0 mm		Complete			SS Verif	2	Opt: null test
085	C-085	CAM-REQ-0029	L3 1st surface conic constant	L3 1st surface conic constant = -0.9620		Complete			SS Verif	2	Opt: null test
086	C-086	CAM-REQ-0029	L3 2nd surface radius	L3 2nd surface spherical radius = 13360.0 mm		Complete			SS Verif	2	Opt: null test
087	C-087	CAM-REQ-0029	L3 center thickness	L3 center thickness = 60.00 mm		Complete			SS Verif	2	Opt: null test
088	C-088	CAM-REQ-0029	L3 s1 clear aperture	The L3 first surface clear aperture diameter shall be at least 722.00 mm		Complete			SS Verif	2	Opt: inspection
408	C-408	CAM-REQ-0029	L3 s2 clear aperture radius	The L3 second surface clear aperture diameter shall be at least 722.00 mm		Complete			SS Verif	2	Opt: inspection
090	C-090	CAM-REQ-0029	L3 glass type	L3 glass type: fused silica		Complete			SS Verif	2	Opt: inspection
			1.7.5 Optics Positions								

	#	Predecessor/ Traceability	Requirement Title	Requirement	Comments	Status	Status description/comments	Flowdown Analysis (Validation)	Verification Method	Phase	Verification Test
			Camera optical element positions	The nominal position of the camera optical elements shall be defined by the following requirements. Positions refer to the Camera Coordinate System and are nominal values only		Complete					
054	C-054	CAM-REQ-0030	Filter 1st surface Z-position	Filter 1st surface Z-position = 871.823 mm in the Camera Coordinate System	tolerances defined by the image quality budget	Complete	LCN-1898		Inspection	2	I&T: Survey and Alignment
074	C-074	CAM-REQ-0030	L1 first surface Z-position	L1 first surface Z-position = 0 mm in the Camera Coordinate System	tolerances defined by the image quality budget	Complete			Inspection	2	I&T: Survey and Alignment
082	C-082	CAM-REQ-0030	L2 first surface Z-position	L2 first surface Z-position = 494.872 mm in the Camera Coordinate System	tolerances defined by the image quality budget	Complete			Inspection	2	I&T: Survey and Alignment
089	C-089	CAM-REQ-0030	L3 first surface Z-position	L3 first surface Z-position = 943.823 mm in the Camera Coordinate System	tolerances defined by the image quality budget	Complete	LCN-1898		Inspection	2	I&T: Survey and Alignment
002	C-002	CAM-REQ-0031	Detector plane+L3+Filter gap adjustability to L1	the detector plane + L3 + Filter shall be capable of being adjusted one time by +/- 5 mm with respect to L1, relative to a nominal L2 to filter gap of 346.58	this provides compensation for the as-built figure errors in the mirrors	Complete	LCN-1898		Demonstration	2	I&T: Survey and Alignment
003	C-003	CAM-REQ-0032	Detector plane-L3 gap adjustability	The gap between the detector plane and L3 shall be capable of being adjusted one time by +/- 3.5 mm, relative to the nominal gap of 28.50	this provides compensation for the as-built figure errors in the mirrors	Complete	LCN-1898		Demonstration	2	I&T: Survey and Alignment
287	C-287	CAM-REQ-0030	Detector Plane Position	The detector plane Z-position = 1032.644 in the Camera Coordinate System	tolerances defined by the image quality budget	Complete	LCN-1898		Inspection	2	I&T: Survey and Alignment
			1.8 Filters								
				LSST Beam Definition at filter	This is based on the r-band beam						
			Surface 1 incidence angles	The angles of incidence at surface 1 are 13.8 to 23.0° degrees on the air side and the angles of exitance are 9.4 to 15.6° on the glass side				LSE-11			
			Surface 2 incidence angles	The angles of incidence at surface 2 are 9.5 to 15.6° degrees on the glass side and the angles of exitance are 13.9 to 23.1° on the air side				LSE-11			
			Beam footprint	The beam footprint for filter evaluation at surface 1 is 114.8 x 67.3 (ODxID,mm) and at surface 2 is 104.5 x 61.1 (ODxID,mm)				LSE-11			
250	C-250	CAM-REQ-0009, CAM-REQ-0109	In-band Ripple	The in-band filter response at each location on the filter within the filter clear aperture when illuminated by the LSST beam shall have peak-to-valley ripple of no more than +/3% relative to the in-band mean response when evaluated over the band defined in Table 1 adjusted by the measured band shift allowed by C-252.	The LSST beam is defined above	Complete			SS Verif	2	Opt: filter acceptance test
252	C-252	CAM-REQ-0008, CAM-REQ-0109	Filter Response Uniformity	The wavelength of the blue and red 50% response points of the normalized response function at each location on the filter within the filter clear aperture when illuminated by the LSST beam shall not deviate by more than 1.5% for g,r,i,z, and y-bands and 2.5% for u-band from that of the area weighted normalized mean response function.	The area weighted mean response is defined on sheet “area weighted response” and the LSST beam is defined above	Complete			SS Verif	2	Opt: filter acceptance test
095	C-095	CAM-REQ-0110, CAM-REQ-0109	Band-pass leakage, incremental	The average leakage in any 10nm segment between 300-1200nm excluding the region one FWHM below the filter band central wavelength to one FWHM above the filter band central wavelength shall be no more than 0.01%. Up to 5% of the 10nm interval 1 FWHM from central wavelength (between 300nm and 1200nm) may be greater than 0.01% of Peak transmission but no more than 0.1% of Peak transmission. This applies when illuminated by the LSST beam defined above	For Leakage that occurs in the wavelength region beyond 1050 nm the response of 100 micron thick silicon at -100 C can be multiplied against the filter response in the leak evaluation.	Complete			SS Verif	2	Opt: filter acceptance test
096	C-096	CAM-REQ-0110, CAM-REQ-0109	Band-pass leakage, total	The integrated transmission over all wavelengths between 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 0.03%. This applies when illuminated by the LSST beam defined above	For Leakage that occurs in the wavelength region beyond 1050 nm the response of 100 micron thick silicon at -100 C can be multiplied against the filter response in the leak evaluation.	Complete			SS Verif	2	Opt: filter acceptance test
413	C-413	CAM-REQ-0010, CAM-REQ-0011, CAM-REQ-0012, CAM-REQ-0013, CAM-REQ-0014, CAM-REQ-0015, CAM-REQ-0113, CAM-REQ-0114, CAM-REQ-0115, CAM-REQ-0116, CAM-REQ-0117, CAM-REQ-0118, CAM-REQ-0109	Filter shape	The normalized area weighted mean response function for each filter shall lie within the upper and lower trapezoids defined in table 2 on sheet “filter definition”. Over the wavelength range defined by the upper envelope (excluding the pass band defined in table 1 on sheet “filter definition”), 30% by wavelength of the area weighted average for each filter may lie outside the nominal upper and lower envelope, but shall lie completely within the minimum and maximum envelopes defined in table 3 on sheet “filter definition”	The normalized area weighted mean response is defined on sheet “area weighted response” and the LSST beam is defined above Specific instances of non-compliance to this specification will be evaluated by the project to assess acceptability	Complete			SS Verif	2	Opt: filter acceptance test

	#	Predecessor/ Traceability	Requirement Title	Requirement	Comments	Status	Status description/comments	Flowdown Analysis (Validation)	Verification Method	Phase	Verification Test
			1.9 Detector Pitch								
045	C-045	CAM-REQ-0021	Detector pixel pitch	Detector nominal pixel pitch shall be 10 microns	This corresponds to (0.2 arc-second) sampling	Complete			SS Verif	2	SRft: Inspection
			1.10 Bits per pixel								
215	C-215	CAM-REQ-0017	Image bits per pixel	The imaging system shall acquire science data with a significance of 18 bits per pixel		Complete			Test	2	I&T: Cryostat Functional Test
			1.11. Guiding Requirements								
259	C-259	CAM-REQ-0043	Guide sensors	The camera shall provide guide sensors to support telescope guiding		Complete			Inspection	1	I&T: Cryostat Functional Test
271	C-271	CA-TS-GDR-ICD-0003	Number of sensors	The camera shall provide 8 sensors		Complete			Inspection	1	I&T: Cryostat Functional Test
309	C-309	CA-TS-GDR-ICD-0003	Sensor area	The guide sensors shall have a minimum area of 1612.9 mm^2	This is the same area specified for the science sensors	Complete			SS Verif	2	CRft: Inspection
310	C-310	CA-TS-GDR-ICD-0004	Windows per sensor	The camera shall provide the capability to read out 1 window in each of the guide sensors		Complete			Test	2	I&T: Cryostat Functional Test
311	C-311	CA-TS-GDR-ICD-0005	Pixel size	The nominal guide sensor pixel size shall be 10 microns		Complete			SS Verif	1	CRft: Inspection
272	C-272	CA-TS-GDR-ICD-0015	Read Noise	The camera read noise shall be less than 9 electrons for data from the ROI acquired at the nominal integration time of 50 msec. This specification includes dark current.	The goal is a read noise less than 7 electrons.	Complete			Test	2	I&T: BOT
378	C-378	CA-TS-GDR-ICD-0034, CA-TS-GDR-ICD-0038	Integration time	The camera shall support integration time (single value shared by all sensors) of 5 milliseconds to 200 milliseconds. The nominal integration time is 50 milliseconds.	The telescope will provide the integration time in msec.	Complete			Test	2	I&T: Camera Functional Test
273	C-273	CA-TS-GDR-ICD-0013	ROI readout rate	The camera shall deliver the ROI data at rate no slower than 9Hz for integration times of 50 msec and ROI dimensions of 50 x 50 pixels		Complete			Test	2	I&T: Cryostat Functional Test
288	C-288	CA-TS-GDR-ICD-0053	Full guide sensor data delivery	The Camera shall transport guide image data as defined in LSE-68 when the full guide sensors are read out in the same manner as science sensors are read out.		Complete			Demonstration	1	I&T: Cryostat Functional Test
380	C-380	CA-TS-GDR-ICD-0035	Readout start	The camera shall coordinate the start time of the ROI integration to be no later than 10 msec after the start of an exposure	This will provide one or two dark ROI images before the ROI is exposed to light	Complete			Test	2	I&T: Camera Functional Test
381	C-381	CA-TS-GDR-ICD-0037	Data delivery	Guide data delivery shall continue until total closure of the shutter		Complete			Test	3	I&T: Camera Functional Test
278	C-278	CA-TS-GDR-ICD-0036	Integration synchronization	The start of integration for all ROIs shall be synchronized to 1 msec		Complete			Analysis	3	I&T: Cryostat Functional Test
275	C-275	CA-TS-GDR-ICD-0009	Delivery latency	The latency from the end of the sensor readout to the delivery of image and metadata shall be < 1msec for ROI sizes of 50 by 50 pixels		Complete			Test	3	I&T: Cryostat Functional Test
281	C-281	CA-TS-GDR-ICD-0006	ROI Dimensions	The camera shall accommodate ROI dimensions from 10 by 10 to 400 by 400 physical pixels (no binning) using the data interface defined in this ICD, or full CCD (using the LSE-68 data interface). The nominal ROI dimensions will be 50 by 50 physical pixels.	The Region of Interest does not need to be square. Any ROI larger than the maximum will be read out as the full CCD.	Complete			Test	3	I&T: Cryostat Functional Test
379	C-379	CA-TS-GDR-ICD-0033	ROI locations	The camera shall be capable of reading out ROIs that cross segment boundaries	The ROI will not cross the boundary that separates segments 1-8 from segments 9-16.	Complete			Test	3	I&T: Cryostat Functional Test
428	C-428	CA-TS-GDR-ICD-0042	Binning	The camera shall support binning factors of 1 to 3. The single binning factor will be used for all sensors.	Discussion: A binning factor of 1 means no binning is performed. A binning factor of 2 means that the electrons from a 2 by 2 pixel groups are combined and sampled by the A/D, resulting in a single A/D sample for the four pixels.	Complete			Test	3	Crft
284	C-284	CA-TS-GDR-ICD-0025	Diagnostic mode	The camera shall implement a diagnostic mode that will provide access to and control of the guide sensor data collection parameters through a camera provided control panel that allows at a minimum changes of integration time, binning, ROI dimensions and ROI locations in accordance with CA-TS-GDR-ICD-0006.	When in diagnostic mode, the ROI dimensions cannot be larger than 400x400 while using the guider data transport interface defined within this ICD. However, there is access provided to the entire guide chip with a 15 second integration through the LSE-68 data transport interface.	Complete			Test	3	I&T: Cryostat Functional Test
285	C-285	CA-TS-GDR-ICD-0017	Z axis position	Each guide sensor shall have 95% of its active area contained in a vertical band that is +/- 30 microns to a plane defined by the science sensors for all operational conditions		Complete			Test	2	I&T: Metrology

	#	Predecessor/ Traceability	Requirement Title	Requirement	Comments	Status	Status description/comments	Flowdown Analysis (Validation)	Verification Method	Phase	Verification Test
286	C-286	CA-TS-GDR-ICD-0018	Z axis stability	The maximum z-axis variation of any position on the guide sensor relative to the best fit science detector plane shall be less than 2.5 microns within a 15 second exposure.		Complete			Analysis	2	
314	C-314	CA-TS-GDR-ICD-0019	XY plane stability	The guide sensors x,y position relative to the neighboring science sensors shall be stable to within 0.5 micron during each 15 second exposure		Complete			Analysis	2	
315	C-315	CA-TS-GDR-ICD-0039	Region of interest	The camera shall use the Region of Interest (ROI) specified by the telescope as the location of the ROI (in pixels), the dimensions of the ROI (pixels), the integration time and the binning factor.	See LSE-71 for the definition of the initGuider command containing these parameters.	Complete			Test	2	I&T: Cryostat Functional Test
316	C-316	CA-TS-GDR-ICD-0021	ROI definition lead time	The camera shall be able to process the ROI definition and prepare for ROI readout when that definition is provided at least 200 msec before the start of the exposure		Complete			Test	3	I&T: Cryostat Functional Test
327	C-327	CA-TS-GDR-ICD-0021, CA-TS-GDR-ICD-0040	Guider control parameters	The camera shall accept the guider control parameters from the OCS as defined in LSE-71, initGuider command.		Complete			Test	2	I&T: Cryostat Functional Test
328	C-328	CA-TS-GDR-ICD-0022	ROI delivery	The camera shall read out the unique region of interest for each guide sensor and provide that data to the TCS		Complete			Test	2	I&T: Cryostat Functional Test
330	C-330	CA-TS-GDR-ICD-0026	Guider data format	The guider data shall be provided in an ordered pixel image format		Complete			Test	3	I&T: Cryostat Functional Test
331	C-331	CA-TS-GDR-ICD-0026	Bit depth	The guider data shall be represented in at least 18 bits		Complete			Test	2	I&T: Cryostat Functional Test
429	C-429	CA-TS-GDR-ICD-0046	Guider data pixel packing	The 18 bit pixel samples shall be delivered by the camera as signed (two's complement) 32-bit values, with an endianness matching the consumes machine.		Complete			Demonstration	3	DAQ: functional testing
430	C-430	CA-TS-GDR-ICD-0045	Guider data layout	The camera DAQ API shall define the ROI pixel data layout		Complete			Demonstration	3	DAQ: functional testing
334	C-334	CA-TS-GDR-ICD-0029	Time tag	The camera shall provide sufficient time information with the data from each guide sensor to allow the reconstruction of the image generation start/stop times to within 1 msec.		Complete			Test	2	I&T: Cryostat Functional Test
382	C-382	CA-TS-GDR-ICD-0041, CA-TS-GDR-ICD-0027, CA-TS-GDR-ICD-0047, CA-TS-GDR-ICD-0049, CA-TS-GDR-ICD-0030, CA-TS-GDR-ICD-0028	Metadata	The metadata that accompanies the guide image shall include a spatial identifier per CA-TS-GDR-ICD-0047, a unique identifier per CA-TS-GDR-ICD-0028, firmware and software versioning per CA-TS-GDR-ICD-0049, binning factor per CA-TS-GDR-ICD-0041, image location per CA-TS-GDR-ICD-0030 and all parameters controlled by the diagnostic mode	This includes binning level. Unbinned operation is indicated as binning level = 1	Complete			Demonstration	2	I&T: Cryostat Functional Test
336	C-336	CA-TS-GDR-ICD-0031	Registration	The calibration data shall include the transformations of guide sensor pixel location (row, column) to (X,Y) science focal plane coordinates for each guide sensor	This is expected to be provided as part of the camera calibration data.	Complete			Test	3	I&T: Cryostat Functional Test
427	C-427	CA-TS-GDR-ICD-0050, CA-TS-GDR-ICD-0060, CA-TS-GDR-ICD-0061, CA-TS-GDR-ICD-0062, CA-TS-GDR-ICD-0063, CA-TS-GDR-ICD-0064, CA-TS-GDR-ICD-0048	Guider interface	The camera shall provide a software interface for guider data delivery as defined in LSE-66, requirements CA-TS-GDR-ICD-0050, CA-TS-GDR-ICD-0060, CA-TS-GDR-ICD-0061, CA-TS-GDR-ICD-0062, CA-TS-GDR-ICD-0063, CA-TS-GDR-ICD-0064 and CA-TS-GDR-0048	These libraries will be in C++, and will include sharable images and necessary include (header) files.	Complete			Test	3	DAQ: functional testing
			1.12. Wavefront Sensing Requirements		Questions to Vincent						
178	C-178	C-214	Readout time	The wavefront data readout time shall not be greater than 2 seconds		Complete			Test	2	I&T: Cryostat Functional Test
304	C-304	CA-TS-WFS-ICD-0004	Data latency	The wavefront data shall be transmitted to the Telescope and Site subsystem within 3 seconds after the beginning of the readout		Complete			Test	2	I&T: Cryostat Functional Test
181	C-181	CA-TS-WFS-ICD-0006	Pixel dimensions	The wavefront detectors shall have a pixel pitch of 10 microns	This is equivalent to 0.2 arcsec sampling	Complete			SS Verif	2	CRft: Inspection
240	C-240	CA-TS-WFS-ICD-0003	Bit depth	The wavefront data shall be represented in 18 bits		Complete			Test	2	I&T: Cryostat Functional Test

	#	Predecessor/ Traceability	Requirement Title	Requirement	Comments	Status	Status description/comments	Flowdown Analysis (Validation)	Verification Method	Phase	Verification Test
268	C-268	CA-TS-WFS-ICD-0006	Detector area	Each wavefront detector shall have an active area of at least 720 sq mm.	Each wavefront sensor is composed of two detectors, each of which is a nominal 2Kx4K	Complete			SS Verif	2	CRft: Inspection
200	C-200	CA-TS-WFS-ICD-0007	WFS focus displacement	The wavefront detectors within a wavefront sensor shall be offset each other by a nominal offset of 3.0 mm.	The vertical height specification pertains to the distribution of pixels about the “center of mass” of the pixel distribution of each wavefront detector. The placement of the wavefront detectors with respect to the best fit plane is defined in C-417, with one surface intra-focal and one extra-focal. The target offset will be the same for all 4 sensors.	Complete			Test	2	I&T: Metrology
416	C-416	CA-TS-WFS-ICD-0017	WFS Z direction separation error	The z direction separation between the two wavefront detectors shall have an error of +/- 0.1 mm.		Complete			Test	2	I&T: Metrology
417	C-417	CA-TS-WFS-ICD-0018	WFS Z direction pixel location	The average of the z locations of all the pixels of the two wavefront detectors of the wavefront sensor shall be within +/-25 microns of the best fit detector plane over all operating conditions	This tolerance is split between the corner raft and I&T.	Open			Test	2	I&T: Metrology
305	C-305	CA-TS-WFS-ICD-0008	WFS focus variation	The z direction surface of each wavefront detector shall be contained within +/- 15 microns of its nominal position and shall have 95 percent of the sensor area contained within +/- 5 microns of the best fit plane for that half wavefront sensor		Open			Test	2	I&T: Metrology
308	C-308	CA-TS-WFS-ICD-0011	WFS placement stability	The position of each wavefront detector shall be stable to 0.5 microns in plane with respect to adjacent science sensors over the full range of operating conditions and orientations within a 15 second exposure		Complete			Analysis	2	
212	C-212	CAM-REQ-0045	Wavefront sensor position	The camera shall provide 4 wavefront sensors located near the corners of the inscribe square to the 3.5 degree FOV.		Complete			Inspection	2	I&T: Cryostat Functional Test
179	C-179	CA-TS-WFS-ICD-0013	Readout noise	Wavefront detector readout noise shall be less than 10 electrons in a 15 second exposure		Complete			Test	3	I&T: BOT
415	C-415	CA-TS-WFS-ICD-0015	WFS Crosstalk Correction	The camera shall, upon request, apply crosstalk-correction to the wavefront sensor data. The correction shall be applied independently to each wavefront sensor.	The method for selecting raw or crosstalk corrected data is defined in LSE-68. This requirement does not call for crosstalk correction that takes into account the data from any other wavefront or science sensors.	Complete			Test	2	I&T: Cryostat Functional Test
213	C-213	CAM-REQ-0044	Wavefront sensor data	For the purposes of archiving and buffering the wavefront sensor imaging data shall be treated the same as science image data.		Complete			Demonstration	1	I&T: Cryostat Functional Test
302	C-302	CA-TS-WFS-ICD-0001	Wavefront data exchange	The camera subsystem shall directly provide to the Telescope and Site Subsystem wavefront data from each of the 4 locations of the inscribed square of the LSST’s minimal 3.5 degree field-of-view	The wavefront data is normally also provided to Data Management for archiving and analysis	Complete			Demonstration	1	I&T: Cryostat Functional Test
418	C-418	CA-TS-WFS-ICD-0019	WFS Performance consistency with science sensors	Except for the read noise defined in C-179, the wavefront sensors shall be consistent with the science sensor performance requirements		Complete			SS Verif	2	CRft:Test
			1.13.Crosstalk Requirements								
376	C-376	CAM-REQ-0097	Intra raft cross-talk	The pixel to pixel crosstalk within a single raft shall be less than 0.002		Complete			Test	1	I&T: BOT
377	C-377	CAM-REQ-0098	Inter raft cross-talk	The raft to raft crosstalk shall be less than 0.0001, with a goal of 2.5e-5		Complete			Test	1	I&T: BOT
391	C-391	CAM-REQ-0099	Crosstalk extent	For all pixels on a science raft, the camera shall have no more than 256 amplifiers on other rafts that each contribute crosstalk greater than 1e-5		Complete			Test	1	I&T: BOT
392	C-392	CAM-REQ-0100	Crosstalk stability	The crosstalk from any pixel to any other pixel shall be stable to 1e-5 of a full scale pixel over a period of 14 days or the camera shall provide algorithms and telemetry to enable the reconstruction of the crosstalk to 1e-5 of a full scale pixel at any time during that period		Complete			Test	1	I&T: BOT
393	C-393	CAM-REQ-0101	Crosstalk correction extent	The camera shall be capable of applying crosstalk corrections for each raft using all of the amplifiers within that raft.		Complete			Test	1	I&T: BOT
			2 Camera Operations								

#	Predecessor/ Traceability	Requirement Title	Requirement	Comments	Status	Status description/comments	Flowdown Analysis (Validation)	Verification Method	Phase	Verification Test
		2.1 General Operations								
C-136	CAM-REQ-0046, OCS-CA-CMD-ICD-0004	Commanding from OCS	The camera shall support commands from the OCS to power-up and initialize the camera, to change filters and to take exposures using the Command/Action/Response (CAR) model as detailed in LSE-70 "LSST Observatory Control System Communication Architecture and Protocol"	Calibration is expected to be a subset of this set of commands	Complete			Test	1	I&T: Camera Functional Test
C-320	OCS-CA-CMD-ICD-0020	Concurrent commands	The Camera shall be able to receive and act on the following commands at any time, including when executing any command and in any state: abort, stop. Upon completion, the stop command returns the Camera to a well defined state while the final state after an abort is not defined. The Camera shall reject all other commands unless in the ready state. See LSE-71 (OCS-Camera ICD).	The intention of these commands is to allow for either rapid or emergency stop. A rapid stop might correspond to wind speed exceeding some threshold whereas an emergency stop might correspond to an earthquake trigger.	Complete			Test	2	I&T: Camera Functional Test
C-317	OCS-CA-CMD-ICD-0024	Interface to OCS	The camera shall instantiate a standard OCS publish/subscribe interface as defined in LSE-70 "LSST Observatory Control System Communication Architecture and Protocol"		Complete			Test	2	I&T: Camera Functional Test
C-195	CAM-REQ-0072	Camera Power Up	Upon activation, the camera shall be ready for communication with the OCS without further human intervention. This activation process shall take less than one (1) minute	This does not place any requirements the subsystem in terms of being ready to take data. For example, the Camera cool down (which requires activation) will take considerable longer than 1 minute. This assumes a warm restart or activation with the appropriate computers up and running.	Complete			Test	2	I&T: Camera Functional Test
C-319	OCS-CA-CMD-ICD-0005, CA-DM-CON-ICD-0005, OCS-CA-CMD-ICD-0006, OCS-CA-CMD-ICD-0025, OCS-CA-CMD-ICD-0022, OCS-CA-CMD-ICD-0008, OCS-CA-CMD-ICD-0007, OCS-CA-CMD-ICD-0010, OCS-CA-CMD-ICD-0026, OCS-CA-CMD-ICD-0027, OCS-CA-CMD-ICD-0028, OCS-CA-CMD-ICD-0029	CCS command set	The camera shall respond to the commend set defined in LSE-71 "OCS Command Dictionary for the Camera"		Complete			Test	2	I&T: Camera Functional Test
C-297	CAM-REQ-0073	Camera initialization	The camera at power up shall be initialized into a known safe state without human intervention		Complete			Demonstration	2	I&T: Camera Functional Test
C-224	CAM-REQ-0075, OCS-CA-CMD-ICD-0016	Engineering and maintenance	The camera shall support operations necessary for engineering and maintenance		Complete			Demonstration	2	I&T: Camera Functional Test
C-260	CAM-REQ-0076	Remote operations	The camera shall be remotely operable from any of the LSST Facilities or other Project designated site	This remote access is subject to cyber security policies and restrictions as well as personnel and hardware safety	Complete			Demonstration	2	I&T: Camera Functional Test
C-207	CAM-REQ-0074	Stand alone operations	The camera shall maintain technical health, safety and status without any other subsystem operational		Complete			Demonstration	2	I&T: Camera Functional Test
C-298	CAM-REQ-0078	Maintenance recommendations	The camera team shall provide a preventive maintenance program to the Observatory		Complete			Inspection	2	I&T: Camera Functional Test
C-173	CAM-REQ-0080	Number of shutter actuations	The Camera shall be capable of 1000000 total number of shutter actuations per year		Complete	Our number is higher than the OSS. Check the level of margin is acceptable		SS Verif	2	CBM: Analysis-cyclic
		2.2 Camera Exposure Control								
C-214	CAM-REQ-0051	Visit timing	The camera shall complete each visit (not including the readout of the last exposure in the visit) within 34 seconds	This requirement is based on two 15 second exposures per visit.	Complete			Test	1	I&T: Camera Functional Test

	#	Predecessor/ Traceability	Requirement Title	Requirement	Comments	Status	Status description/comments	Flowdown Analysis (Validation)	Verification Method	Phase	Verification Test
016	C-016	CAM-REQ-0055	Min exposure duration	The camera shall be able to obtain a single exposure with an effective minimum exposure time of no more than 1 second, with a goal of an effective minimum exposure time of 0.1 second	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	Complete			Test	2	I&T: Camera Functional Test
146	C-146	CAM-REQ-0053	Closed-shutter exposures	The camera shall be able to perform exposures without opening the shutter		Complete			Test	2	I&T: Camera Functional Test
174	C-174	CAM-REQ-0054	Maximum exposure duration	The camera shall be capable of exposures longer than the nominal duration of 15 seconds, but single image specifications need not be met.		Complete			Test	2	I&T: Camera Functional Test
175	C-175	CAM-REQ-0052	Bias/zero exposures	The camera shall be able to perform a zero duration exposure	Discussion: This captures bias or zero frames for calibration. In this case the CCDs are read out immediately after preparation for the exposure without any integration	Complete			Test	2	I&T: Camera Functional Test
			2.3 Filter operations								
004	C-004	CAM-REQ-0067	Filter complement	The camera shall accommodate 5 filters on board the camera at any time	this presumes that a filter swap-out for a spare filter requires a daytime access	Complete			Test	1	I&T: Camera Functional Test
216	C-216	CAM-REQ-0066	Filter swap in place	The internal filter complement of the camera shall be reconfigurable without requiring the removal of the camera from the telescope.		Complete			Test	2	I&T: Camera Functional Test
005	C-005	CAM-REQ-0068	Filter exchange duration	The camera shall require less than 90 seconds to change between any two filters that are resident inside the camera	this duration covers all required camera operations, but does not include any additional telescope or OCS times	Complete			Test	2	I&T: Camera Functional Test
008	C-008	CAM-REQ-0070	Number of filter exchanges	The auto changer shall be designed for at least 70,000 changes.	70,000 changes [(1 self-check + 10 cal + 10 ops)/night x 300 nights + 4 swap-outs/month x 12 months] x 10 years	Complete	Reconcile with OSS spec. Ours is higher		SS Verif	2	Exch: Test/analysis
006	C-006	CAM-REQ-0069	Filter swap-out duration	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 1.5 hours after safe access to the Camera has been established	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 calibration	Complete			Test	2	I&T: Camera Functional Test
176	C-176	CAM-REQ-0071	Number of filter swap-outs	The Camera shall be capable of 3000 total number of manual filter changes during its lifetime	This allows one every 2 days during operations (365.25/2*10=1822 changes) and leaves over 1000 changes for I&T and commissioning.	Complete			SS Verif	2	Exch: Test/analysis
431	C-431	CAM-REQ-0130	Filterless Images	The camera shall be capable of exposures with no filter in the optical path.	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.	Complete			SS Verif		Exch: Test
			2.4 Telemetry/health								
247	C-247	CAM-REQ-0047	Camera telemetry	The camera shall publish telemetry using the Observatory specified protocol as defined in LSE-70 "LSST Observatory Control System Communication Architecture and Protocol"		Complete			Demonstration	1	I&T: Camera Functional Test
318	C-318	OCS-CA-CMD-ICD-0003, OCS-CA-CMD-ICD-0019, CA-DM-CON-ICD-0007	Other Observatory subsystem telemetry	The camera shall be capable of obtaining telemetry from other Observatory subsystems either by subscription or direct query of the EFD	Discussion: The OCS provided methods will be in the SAL and the CCS will use them.	Complete			Demonstration	2	I&T: Camera Functional Test
373	C-373	CA-DM-CON-ICD-0002	Telemetry list	The telemetry to be provided by the camera shall be defined in the Camera Telemetry and Event List (LSE-165).	This dictionary will be developed during the detail design phase	Complete			Analysis	2	I&T: Camera Functional Test
426	C-426	OCS-CA-CMD-ICD-0018	tlm time tags	The camera telemetry shall include time-stamp fields that support both scientific and engineering analysis of the state of the camera during operation.		Complete			Demonstration	2	I&T: Camera Functional Test
144	C-144	CAM-REQ-0048	Camera meta-data availability	The camera telemetry shall include all required information (metadata) needed for the scientific analysis of the survey data.	This data is defined in the Control System Interface between Data Management and Camera (LSE-69)	Complete			Analysis	2	I&T: Camera Functional Test

	#	Predecessor/ Traceability	Requirement Title	Requirement	Comments	Status	Status description/comments	Flowdown Analysis (Validation)	Verification Method	Phase	Verification Test
209	C-209	CAM-REQ-0049, CA-DM-CON-ICD-0018, OCS-CA-CMD-ICD-0021	Camera State Notification	The Camera shall publish events whenever change of state happens, including camera conditions that limit or prevent operations. In particular, the camera shall publish the following events: • startIntegration • startReadout • endReadout • startShutterOpen • endShutterClose	Events are distinguished from regular telemetry in that they may be used to trigger decisions and sequences within the OCS. Events are the primary means to rapidly communicate changes in the state of a subsystem, triggered by commands, by internal Camera behavior, or when a monitored value exceeds the limits defined in the Camera alarms configuration table.	Complete			Demonstration	2	I&T: Camera Functional Test
225	C-225	C-209	Filter in use status	The camera shall positively identify the filter that is currently in position for use		Complete			Test	3	I&T: Camera Functional Test
210	C-210	CAM-REQ-0050	Camera Status	The Camera shall assess and report an overall hardware health status for major camera components.	The primary purpose of these status indicators is for the OCS to be able to orchestrate normal operations and handle out of normal conditions.	Complete			Test	2	I&T: Camera Functional Test
321	C-321	CAM-REQ-0050, OCS-CA-CMD-ICD-0021	Alarm publication	The camera shall publish alarms whenever a monitored value exceeds the limits defined for the current configuration		Complete			Test	2	I&T: Camera Functional Test
206	C-206	CAM-REQ-0082	Baseline performance	The camera shall provide the initial baseline performance as determined during acceptance testing and system integration and test	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.	Complete			Analysis	2	I&T: Report
421	C-421	CA-DM-CON-ICD-0003	Alert processing telemetry latency	Camera telemetry data specified as required for DM's Alert Production, enumerated in document LSE-130 , concerning times through the end of the readout of an image shall be published via the OCS middleware within 300 msec of the conclusion of readout. The Camera should generally publish this data within time 300 msec of its acquisition.	The latter condition expresses the desire that Data Management not receive all Conditions data as a lump delivery at the end of readout.	Complete			Test	2	I&T: Camera Functional Test
422	C-422	CA-DM-CON-ICD-0004	Alert processing telemetry latency	All Camera Conditions telemetry data required by DM shall be published through the OCS middleware within 10 seconds of its measurement time	The “measurement time” is meant to be a wall clock time for an underlying physical measurement or equivalent, determined in a way that is reasonable for the telemetry data in question. This is the same time that is referenced in LSE-71, requirement OCS-CA-DMC-ICD-0018.	Complete			Test	2	I&T: Camera Functional Test
299	C-299	CAM-REQ-0083	Telemetry analysis	The camera shall provide trend analysis specific to the camera design using the provided toolkit		Complete			Analysis	2	I&T: Camera Functional Test
		2.5 Time Reference									
137	C-137	CAM-REQ-0111	Time synchroniization	Computer clocks used to produce timestamps shall be synchronized to an observatory master clock.		Complete			Analysis	2	I&T: Camera Functional Test
222	C-222	CAM-REQ-0111	Time stamp precision	Camera time stamps shall have a precision of at most (worst) 1ms.		Complete			SS Verif	2	CCS:Test
223	C-223	CAM-REQ-0111	Time stamp accuracy	Timestamps shall have an absolute accuracy of 10 ms or better.		Complete			SS Verif	2	CCS:Test
		2.6 Science Data Read-Out									
374	C-374	CA-TS-WFS-ICD-0016, CA-DM-CON-ICD-0011, CA-DM-CON-ICD-0014, CA-DM-CON-ICD-0015, CA-DM-CON-ICD-0016	Interface to DM	The science data, guider data and wavefront data shall be provided to DM as defined in the Data Acquisition Interface between Data Management and Camera (LSE-68)		Complete			Demonstration	1	I&T: Camera Functional Test
419	C-419	CA-DM-CON-ICD-0017	Data Management load on image data interfaces	The Camera shall provide to DM two concurrent accesses to the camera CCD data. Each access shall have communication channel bandwidth sufficient to retrieve the science data at the science CCD readout rate.		Complete			SS Verif	2	DAQ: Test
420	C-420	CA-DM-CON-ICD-0017	Concurrent access capability	The camera shall have the capability to divide each access to the camera CCD data into at least 63 requests for data with the data volume limited to the size of a science image.		Complete			SS Verif	2	DAQ:Demonstration

	#	Predecessor/ Traceability	Requirement Title	Requirement	Comments	Status	Status description/comments	Flowdown Analysis (Validation)	Verification Method	Phase	Verification Test
217	C-217	CAM-REQ-0056	Science image delivery	The camera shall deliver each image with a unique identifier per device per exposure		Complete			Test	2	I&T: Camera Functional Test
218	C-218	CAM-REQ-0058	Raw Image Data	The camera shall provide raw pixel data in response to a request for one or more specific images		Complete			Demonstration	1	I&T: Camera Functional Test
219	C-219	CAM-REQ-0057	Cross-talk corrected image data	The camera shall provide cross-talk corrected pixel data to client subscribers		Complete			Test	1	I&T: Camera Functional Test
139	C-139	CAM-REQ-0059	Persistence of raw data	The camera shall persist 24100 images, the data shall include science and wavefront sensor data for all observations and full-frame guider data from calibration operations.	The 24100 images is based on the minimum number of raw science exposures (1960 exposures) and the minumum number of calibrations that can be aquired per day under normal operations (450 calibrations) over a 10 day to 24 hour cycle. For image rates above the normal levels the persistence time will be shortened.	Complete			SS Verif	2	DAQ:Demonstration
246	C-246	CAM-REQ-0060	Raw data buffer readout	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 4820 images in 20 hours.		Complete			SS Verif	2	DAQ:Demonstration
			2.7 Wavefront Data Read-out								
145	C-145	CAM-REQ-0061	Wavefront data to DM	The camera shall provide wave front data to DM		Complete			Test	1	I&T: Cryostat Functional Test
414	C-414	CA-TS-WFS-ICD-0002	WFS readout simultaneity	The camera shall perform the readout of the wavefront sensors in synchronization with the science sensors	The motivation for this requirement is to ensure that any crosstalk between the science and wavefront sensors occurs in a known and stable pattern. Note that the control interface provided by the camera to the OCS permits independent selection of whether the science array and the wavefront array will be read out; if both are selected, this requirement ensures that their readout is synchronized.	Complete			Analysis	2	I&T: Cryostat Functional Test
			2.8 Reliability, maintainability								
001	C-001	CAM-REQ-0019	Camera lifetime	The camera and all subsystems and components shall be designed to operate for at least 15 years	this includes the observatory lifetime plus additional time for camera integration, test, and observatory commissioning	Complete			Analysis	2	I&T: Ops Plan analysis
			3. Thermal Requirements								
134	C-134	CA-TS-MEC-ICD-0017	Camera body temperature control	The camera shall be able to change the average temperature across the surfaces of the camera body and L1 lens at a maximum rate-of-change of 0.2 C/hr, allowing it to follow the dome air ambient temperature within +/- 1 C	For this, both the L1-S1 convection interface and the back flange conduction interface to the rotator should be considered adiabatic; this assumes that dome air is pre-cooled during the day and that rate-of-change is driven by operational constraints of ramping the L1 lens during daytime operations without suitable time for direct cooling.	Complete			Test	2	I&T: Camera Functional Test
326	C-326	CA-TS-MEC-ICD-0018	Utility Trunk heat load	The camera shall release no more than 200W heat load in the telescope top end plenum during observing operations		Complete			Test	2	I&T: Camera Functional Test
390	C-390	CA-TS-FAC-ICD-0054, CA-TS-UTI-ICD-0008	Refrigerant line temperatures	During normal operations, the supply and return refrigerant temperatures shall not deviate from the current dome air temperature by more than -15 C to + 4 C, given a chilled water temperature range of -5 to -10 C below ambient dome temperature.		Complete		LCA-69	Test/Analysis	2	I&T: Camera Functional Test
034	C-034		Detector plane max temperature spatial variation	The temperature of detectors shall vary < 10 degrees C spatially across the detector plane		Complete			Test	3	I&T: Cryostat Functional Test
035	C-035	C-394, C-395	Detector temperature stability	Detector temperatures shall remain stable to <= +/- 0.25 degrees C over an observing run lasting no more than 12 hours.		Complete			Test	2	I&T: Cryostat Functional Test
189	C-189		Temperature status	Temperature measurements shall be provided to the OCS	Those measurements will be defined in the telemetry dictionary (LSE-74)	Complete			Demonstration	3	I&T: Cryostat Functional Test
368	C-368		Detector plane design temperature	The camera detector plane design temperature shall be -100 deg C.		Complete			Demonstration	1	I&T: Cryostat Functional Test
369	C-369		Back end electronics design temperature	The camera back end electronics design temperature shall be -40 deg C		Complete			Demonstration	1	I&T: Cryostat Functional Test
389	C-389		Temperature rate of change	Items within the cryostat shall survive a temperature rate of change of +/- 30 deg C per hour		Complete		LCA-69	SS Verif	2	SS functional testing and analysis

	#	Predecessor/ Traceability	Requirement Title	Requirement	Comments	Status	Status description/comments	Flowdown Analysis (Validation)	Verification Method	Phase	Verification Test
398	C-398		Camera Turn-on	The camera shall be capable of powering on and establishing communications with the OCS when the dome temperature is between -10 and +30 deg C.		Complete		LCA-69	Test/Analysis	2	I&T: Camera Functional Test
407	C-407	CA-TS-MEC-ICD-0045	Utility trunk outer temperature	During observing operations, the camera utility trunk outer surfaces shall follow the air temperature inside the top end assembly to +/- 5 Deg C. This applies during a maximum rate-of-change of the top end assembly temperature of 1 Deg C per hour.	This applies only when the temperature of plenum air supplied by the telescope meets CA-TS-MEC-ICD-0046 (within +/- 2 degrees of dome air ambient) and glycol is supplied to the camera per LSE-64	Complete			Test	2	I&T: Camera Functional Test
			4.Safety Requirements								
296	C-296	CAM-REQ-0081	Safety System	The camera shall implement a non-software based safety system in areas where injury or harm to personnel and or equipment can occur		Complete	Covered in the Hardware Protection Plan (LCA-139)		Test	2	I&T: Camera Functional Test
			5. Plans and Standards								
190	C-190		Contamination control	The camera components shall be compliant with the Camera Contamination Control Plan (LCA-279)		Complete			Audit	3	
262	C-262		Grounding and Shielding Plan	The camera components shall be compliant with the Grounding and Shielding Plan (LCA-278)		Complete			Audit	3	
375	C-375	C-296	Hardware Protection	The camera shall be compliant with the Camera Hardware Protection Plan (LCA-139)		Complete			Audit	2	was a comment in the review. Where are the protection plan requirements?
			6. Misc…								
159	C-159	CAM-REQ-0016	Camera dynamic range	The camera shall have a unsaturated dynamic range of at least 8 magnitudes above the 5-sigma r-band limiting magnitude in a standard 15 second exposure.	This requirement is referenced to the fiducial conditions used to define the limiting magnitude requirements.	Complete			Test/Analysis	2	I&T: BOT
132	C-132	CAM-REQ-0022	Charged particle background	The camera shall comply with the materials selection and testing defined in the Radioactive Test Plan (LCA-10776).		Complete			Audit	3	Subsystem Test
291	C-291	CAM-REQ-0023	EMI	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.		Complete			Inspection	2	I&T: Camera Functional Test
292	C-292	CAM-REQ-0024	EM susceptibility	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.		Complete			Inspection	2	I&T: Camera Functional Test
293	C-293	CAM-REQ-0025	Light Emissions	Light sources within the camera shall not escape out of the camera or cause camera performance to go out of specification		Complete			Analysis	2	I&T: Camera Functional Test
226	C-226	CA-TS-MEC-ICD-0001	Camera envelope	The camera assembly shall stay within the envelope described in LSE-18 sheets 1 and 2. (See the Camera Opto-Mechanical Definition Drawing LCA-126)		Complete			Test/Analysis	1	I&T: Survey and Alignment
322	C-322	CA-TS-MEC-ICD-0004	Camera mechanical interface	The camera shall provide a mounting flange which includes all features, dimensions, and tolerances defined in LSE-18 sheet 2 Section C-C. This shall include access for installing and torqueing the outer bolt circle of interface fasteners. (See the Camera Opto-Mechanical Definition Drawing LCA-126)		Complete			SS Verif	1	CBM: Dimensional measurement
323	C-323	CA-TS-MEC-ICD-0002	Retroreflectors	The camera shall provide the number of sphere mounted retroreflectors (SMR's) at the locations and with the dimensions described in LSE-18 sheet 4. (See the Camera Opto-Mechanical Definition Drawing LCA-126)		Complete			Inspection	2	I&T: Survey and Alignment
325	C-325	CA-TS-MEC-ICD-0016	Retroreflector visibility	Lines-of-sight for at least 6 of the SMR's specified in C-323 shall be visible during the installation/removal of the camera with the L1 lens cap installed.		Complete			Inspection	2	I&T: Survey and Alignment

	#	Predecessor/ Traceability	Requirement Title	Requirement	Comments	Status	Status description/comments	Flowdown Analysis (Validation)	Verification Method	Phase	Verification Test
423	C-423	CA-DM-CON-ICD-0001	Provide Camera design, assembly, and laboratory test data	The Camera shall provide to DM design, assembly, and laboratory test information, as specified in section 2.1 of document LSE-130.	The method(s) of delivery will be specified in LSE-130	Complete			Audit	3	N/A
363	C-363		Observatory network	The camera shall use the LSST Observatory Network as defined in LSE-78		Complete			SS Verif	2	CCS, DAQ: Demonstration
			7. Mass Properties								
227	C-227	CA-TS-MEC-ICD-0011	Camera weight	The maximum weight of the camera components mounted on the telescope shall be 3060 kg	Includes all on-telescope camera hardware during normal operations	Complete			Test	1	I&T: Mass Properties Measurement
229	C-229	CA-TS-MEC-ICD-0030	Camera and Servicing equipment weight	The maximum weight of the camera components mounted on the telescope and all servicing equipment mounted to the Camera on its front end shall be 3810 kg	This includes a filter manual changer, L1 lens cap, lift frame, and any other servicing equipment supported by the Camera	Complete			Test	2	I&T: Mass Properties Measurement
324	C-324	CA-TS-MEC-ICD-0012	Operational mass variations	During operation, the allowed change of the camera mass shall be no more than 30.6 kg	This budget is meant to cover the change of filters in the filter carousel. This implies that the c.g. stays within the range stated in requirement CA-C-230 Camera Center of Gravity	Complete			Test	2	I&T: Mass Properties Measurement
230	C-230	CA-TS-MEC-ICD-0013	Center of gravity	The center-of-gravity along the Z-axis of the camera assembly shall be >1500 mm from the origin of the CCS		Complete	LCN-1848		Test	1	I&T: Mass Properties Measurement
231	C-231	CA-TS-MEC-ICD-0032	Radial CG	The center of gravity (CG) of the camera assembly must be within 10 mm, radially, of the CCS Z-axis	This applies while taking an image and not during a filter change or servicing and maintenance	Complete			Test	1	I&T: Mass Properties Measurement
234	C-234	CA-TS-MEC-ICD-0014	Moments of inertia	During normal operations, the mass moments of inertia of the camera assembly shall not exceed: Ixx = 4700 kg-m^2, Iyy = 4700 kg-m^2, Izz = 1000 kg-m^2, around the camera center-of-gravity		Complete	LCN-1848		Test/Analysis	2	I&T: Mass Properties Measurement
			8. Power								
235	C-235	CA-TS-UTI-ICD-0037	On-telescope power	The on-telescope power consumption shall comply with the Utilities and Services Interface between the Camera and Telescope (LSE-64)		Complete			Test	2	I&T: Camera Functional Test
371	C-371	CA-TS-FAC-ICD-0044, CA-TS-FAC-ICD-0039	Off-telescope power	The off-telescope power consumption shall comply with the Summit Facility Interface between the Camera and Telescope (LSE-65)		Complete			SS Verif	2	DAQ, CCS, Cryo: Test/Analysis
			9. Mechanical Specifications								
249	C-249	CA-TS-MEC-ICD-0015	Natural frequency	Neither the camera nor any camera component with mass over 153 kg shall have natural frequencies less than 24 Hz when the camera is mounted on a fixed base with interface features as defined in C-322		Complete			Test	2	I&T: System Dynamics Test
412	C-412	CA-TS-MEC-ICD-0053	Camera Induced Vibrations	The Camera shall not impart vibrations on the Telescope that will degrade the image quality more than 20 mili-Arcsec	The methodology for determining the Camera Induced Vibrations on the Telescope are defined in Document-16171.	Complete			Analysis	2	I&T: System Dynamics Test
			10. Environmental Specs								
			10.1 On telescope environments		These environments cover the components of the camera that are mounted on the telescope						
337	C-337	CAM-REQ-0084, CAM-REQ-0085	Working temperature range	The Camera Assembly shall meet all requirements over the temperature range from -5 deg C to +30 deg C.	The expected operational range is from -3 deg C to +25 deg C. As defined in LCA-69 the camera has margin against the specified operational range	Complete		LCA-69	Test/Analysis	2	I&T: Camera Functional Test
339	C-339	CAM-REQ-0086	Survival temperature range	The on-telescope portions of thecamera shall survive while off or in any on state when exposed to the survival temperature range as low as -10 deg C or as high as ~~35~~ 30 deg C	Applies with the camera off, in any state of operation, and be able to transition between any state	Complete		LCA-69	Test/Analysis	2	I&T: Camera Functional Test
340	C-340	CAM-REQ-0084	Operational temperature rate of change	The on-telescope portions of the camera shall meet all requirements when exposed to a temperature rate of change of 0.7 deg C per hour		Complete		LCA-69	Test/Analysis	2	I&T: Camera Functional Test
341	C-341	CAM-REQ-0085	Marginal temperature rate of change	The on-telescope portions of the camera shall operate when exposed to a temperature rate of change up to 2 deg C per hour but need not meet performance requirements		Complete		LCA-69	Test/Analysis	2	I&T: Camera Functional Test
343	C-343	CAM-REQ-0084	Operational wind speed	The on-telescope portions of the camera shall meet all requirements when exposed to a wind speed up to 12 m/sec		Complete		LCA-69	SS Verif	2	Opt, CBM: Analysis
344	C-344	CAM-REQ-0085	Marginal wind speed	The on-telescope portions of the camera shall operate when exposed to wind speeds up to 20 m/sec but need not meet performance requirements		Complete		LCA-69	SS Verif	2	Opt, CBM: Analysis

	#	Predecessor/ Traceability	Requirement Title	Requirement	Comments	Status	Status description/comments	Flowdown Analysis (Validation)	Verification Method	Phase	Verification Test
345	C-345	CAM-REQ-0086	Survival wind speed	The on-telescope portions of the camera shall survive while off or in any on state when exposed to wind speeds up to 25 m/sec either sustained or in a 10-second gust		Complete		LCA-69	SS Verif	2	Opt, CBM: Analysis
346	C-346	CAM-REQ-0084, CA-TS-FAC-ICD-0022	Operational humidity	The on-telescope portions of the camera shall meet all requirements when exposed to relative humidities between 30% and 90%		Complete		LCA-69	Analysis	2	I&T: Camera Functional Test
347	C-347	CAM-REQ-0086, CA-TS-FAC-ICD-0022	Survival humidity	The on-telescope portions of the camera shall survive when off or in any on state when exposed to relative humidities between 30% and 100%	Applies with the camera off or on in any state or transition	Complete		LCA-69	Analysis	2	I&T: Camera Functional Test
349	C-349	CAM-REQ-0084	Operational barometric pressure	The camera shall meet all requirements when exposed to the operational barometric pressure range of 72.5 kPa to 77.5 kPa	Applies to range of expected barometric pressure on the summit	Complete		LCA-69	SS Verif	2	SS testing and analysis
362	C-362		Marginal barometric pressure	The camera shall operate when exposed to the marginal barometric pressure range of 72.5 kPa to 104 kPa but need not meet performance requirements	Includes maximum expected barometric pressure at sea level	Complete		LCA-69	SS Verif	2	SS testing and analysis
352	C-352		Operational loads	The camera shall perform within specification while subject to any of the operational load cases listed in Table 1 of the LSST Camera Environmental Specification (LCA-68).	These load cases define the range of observing orientations over which it must meet all requirements	Complete		LCA-68	Analysis	2	I&T: Camera Functional Test
397	C-397		Survival barometric pressure	The camera shall survive the pressure range from 71 kPa to 104 kPa		Complete		LCA-69	SS Verif	2	SS testing and analysis
354	C-354	CA-TS-MEC-ICD-0009	Camera re-pointing accelerations	The camera shall fully function, but not necessarily meet all performance requirements when subjected to the Re-Pointing load cases listed in Table 2 of the LSST Camera Environmental Specification (LCA-68).	Re-pointing load cases bound the peak accelerations due to rotations of the telescope, for all possible camera orientations	Complete		LCA-68	SS Verif	2	SS testing and analysis
355	C-355	CA-TS-MEC-ICD-0007, CA-TS-MEC-ICD-0008	Filter exchange re-pointing accelerations	The camera shall be capable of exchanging an on-board filter while exposed to the re-pointing load cases defined in Table 2 of the LSST Camera Environmental Specification (LCA-68) with the x-axis horizontal to within +/- 2 degrees.	This includes all operations of exchange system components during a filter exchange. The load cases in Table 2 bound the tolerance on the x-axis position	Complete		LCA-68	SS Verif	2	CBM: Exch System functional test
356	C-356	CAM-REQ-0106, CAM-REQ-0107, CAM-REQ-0108, CA-TS-MEC-ICD-0010, CA-TS-MEC-ICD-0028, CA-TS-MEC-ICD-0029	Seismic accelerations	The camera shall be designed to survive the seismic requirements and load cases definitions described in Table 5 of the LSST Camera Loads Specification (LCA-68)	Applies with the camera in any operational mode or standard orientation as well as at all stages of integration; see LCA-68 for waivers for specific transient or temporary configurations	Complete		LCA-68	SS Verif	2	SS functional testing and analysis
357	C-357		Integration and handling accelerations	The camera shall be capable of surviving crane lift and handling loads listed in Table 3 of the LSST Camera Environmental Specification (LCA-68), when supported from their normal mount points and from any auxiliary handling or support points or in alternate orientations.	This includes when supported from their normal mount points and any auxiliary support points or alternate orientations and when the cryostat is evacuated and cold	Complete		LCA-68	SS Verif	2	SS functional testing and analysis
			10.2 Off-telescope environments		These environments cover the components of the camera that are not mounted on the telescope						
386	C-386		Step change in air temperature	Camera components shall survive an external air temperature step change of +/- 15 degC		Complete		LCA-69	Analysis	2	SS functional testing and analysis
385	C-385		Control room working temperature	Camera components in the control room shall meet all requirements over the temperature range from +19 deg C to +23 deg C.		Complete		LCA-69	SS Inspection	2	SS functional testing and analysis
360	C-360	CA-TS-FAC-ICD-0042	Utility room working temperature	Camera components in the utility room shall meet all requirements over the temperature range from +0 deg C to +25 deg C.		Complete		LCA-69	SS Test	2	Cryo: Refrig System functional test
387	C-387		Control room survival temperature	Camera components in the control room shall survive the temperature range from -15 deg C to +40 deg C.		Complete		LCA-69	SS Inspection	2	SS functional testing and analysis
388	C-388		Utility room survival temperature	Camera components in the utility room shall survive the temperature range from -15 deg C to +40 deg C.		Complete		LCA-69	SS Test	2	Cryo: Refrig System functional test
383	C-383		Utility room humidity	Camera components in the utility room shall meet performance requirements over a humidity range of 20 to 90%		Complete		LCA-69	SS Test	2	Cryo: Refrig System functional test
384	C-384		Computer room humidity	Camera components in the computer room shall meet performance over a humidity range of 30 to 60%		Complete		LCA-69	SS Inspection	2	SS functional testing and analysis
			10.3 Transportation environments		This covers the transportation environments that are applicable to all camera components						
359	C-359	CAM-REQ-0087	Transport temperature range	During transport, the camera shall survive the transportation temperature range of -15 degC to 40 degC	Applies with the camera off and in its shipping container	Complete		LCA-69	Analysis	2	I&T: Shipping Analysis
361	C-361	CAM-REQ-0087	Transport wind speed	During transport, the camera shall survive a maximum wind speed of 45 m/sec	Applies with the camera off and in its shipping container	Complete		LCA-69	Analysis	2	I&T: Shipping Analysis
	C-348	CAM-REQ-0087	Transport humidity	During transport, the camera shall survive the transport relative humidity range of 10% to 100% at the exterior of the shipping container	Applies with the camera off and in its shipping container	Complete		LCA-69	Analysis	2	I&T: Shipping Analysis

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351	C-351		Transport pressure rate of change	The camera shall survive a pressure rate of change of +120/-60 kPa/hr	Bounds maximum rate of change in an airplane cargo hold during ascent/descent	Complete		LCA-69	Analysis	2	I&T: Shipping Analysis
358	C-358		Transport accelerations	The camera shall be designed to survive transportation loads listed in Table 4 of the LSST Camera Environmental Specification (LCA-68), or be shipped in special containers and/or transported on “Air-Ride” trucks that include an isolation system.	This may be met with the camera in its shipping container	Complete		LCA-68	Analysis	2	I&T: Shipping Analysis
			11 Ground Support Equipment								
367	C-367		Loads	Lifting and handling fixturing and storage and transport containers shall be designed to safely support all camera hardware when subject to the loads listed in Table 3 of the LSST Camera Environmental Specification (LCA-68).		Complete		LCA-68	Test/Analysis	2	I&T: Fixture Proof Test
			12 Interfaces								
399	C-399	CA-TS-MEC-ICD-0022	Mounting hardware	The camera team shall provide the mounting hardware between the Camera Mounting Flange and the Rotator Mounting Flange as defined in LSE-18 sheet 2. (See the Camera Opto-Mechanical Definition Drawing LCA-126)	The mounting hardware table is in the upper left hand corner of LSE-18 sheet 2.	Complete			Inspection	2	I&T: PSR
400	C-400	CA-TS-MEC-ICD-0025	Optical axis	The as-built best-fit optical axis of the camera during operation shall not deviate more than +/- 600 microns of decenter, +/- 400 microns of piston, and 250 micro-rad of tip/tilt from its nominal position and orientation with respect to the rotator interface datums as defined by LSE-18 sheet 2.		Complete			Test	2	I&T: Survey and Alignment
401	C-401	CA-TS-MEC-ICD-0027	Tip/tilt angle	The camera shall provide the tip/tilt angle of the rotator interface with respect to a coordinate system centered on the best-fit detector plane.		Complete			Test	2	I&T: Survey and Alignment
402	C-402	CA-TS-MEC-ICD-0033	Torque imparted by camera (pinned)	The maximum torque imparted by the camera around the camera Z-axis carried by the telescope hexapod-rotator assembly during servicing and maintenance of the camera with the locking pins engaged shall not exceed 1500 N-m .		Complete			Test/Analysis	2	I&T: Mass Properties Measurement
403	C-403	CA-TS-MEC-ICD-0048	Torque imparted by camera (un-pinned)	With the telescope hexapod and rotator functioning normally, the maximum torque imparted by the camera around the camera Z-axis shall not exceed 500 N-m. This is the maximum allowed torque imparted by the camera while the rotator is rotating or unlocked.	This is equivalent to the maximum torque due to the maximum radial offset of the camera center of gravity (300 N-m), as defined in CA-TS-MEC-ICD-0032, plus safety margin (200 N-m). During any operation, any mass removed should be replaced with a surrogate mass; however, this capability provides flexibility when this is not practical.	Complete			Test/Analysis	2	I&T: Mass Properties Measurement
404	C-404	CA-TS-MEC-ICD-0036	Removal envelopes	The volumes for removal of the camera Auto Changer, Filter Loader, and Shutter shall stay within the lift envelopes defined in LSE-18, sheet 7. (See the Camera Opto-Mechanical Definition Drawing LCA-126)	These requirements are flowed through I&T to the Filter Exchange System and the Shutter through LCA-126	Complete			Analysis	2	I&T: Survey and Alignment
405	C-405	CA-TS-MEC-ICD-0042	L1 lens cap	The camera shall provide a lens cap for L1 for use during maintenance with the following features—fits within the L1 Lens Cap volume defined in LSE-18, sheet 5; capable of being tethered; liftable by a crane; and does not block line-of-sight view cones of SMR’s as defined in CA-TS-MEC-ICD-0002. The lens cap shall be positively secured to the camera so it cannot fall from the camera for all possible orientations of the camera including zenith-pointed.		Complete			SS Inspection	2	SS functional testing and analysis
406	C-406	CA-TS-MEC-ICD-0043	Camera lift frame	The camera shall provide a below-the-hook lift frame to mount/de-mount the camera from the integrating structure while on the floor in the summit facility.		Complete			Demonstration	2	I&T: Fixture Proof Test
424	C-424		Utilities ICD	The camera shall be compliant with the Camera to Telescope Utilities ICD (LSE-64)		Complete			Audit	2	I&T: PSR
425	C-425		Facilities ICD	The camera shall be compliant with the Camera to Telescope Facilities ICD (LSE-65)		Complete			Audit	2	I&T: PSR

Table 4: Sensor QE (Reference LCA-10895)

Wavelength (nm)	QE
1050	0.045
1055	0.034
1060	0.025
1065	0.018
1070	0.013
1075	0.01
1080	7.40E-03
1085	5.15E-03
1090	3.35E-03
1095	2.00E-03
1100	1.07E-03
1105	5.67E-04
1110	4.08E-04
1115	3.04E-04
1120	2.16E-04
1125	1.43E-04
1130	8.62E-05
1135	4.39E-05
1140	1.59E-05
1145	1.91E-06

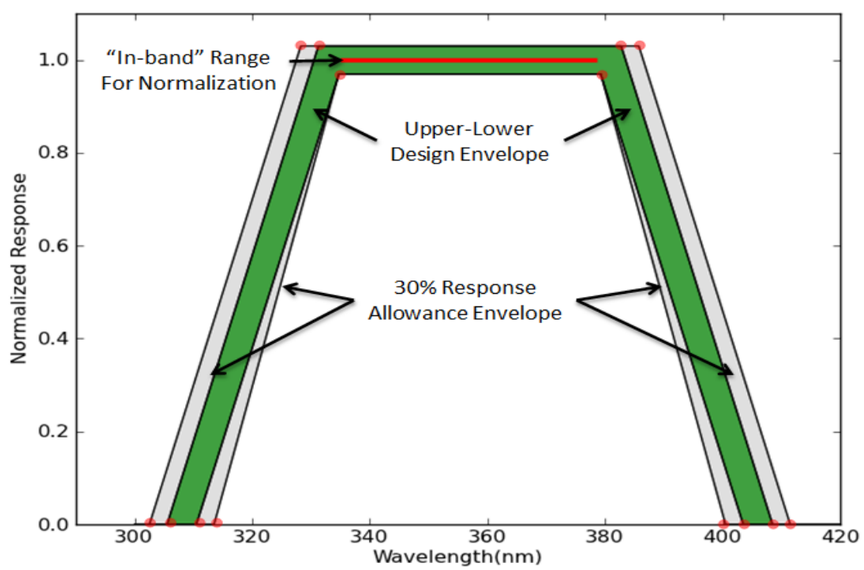

Table 1. Pass Band

In-Band	u	g	r	i	z	y4
Blue Side	335.5	416.5	567	706	833	938.5
Red Side	378.5	537	676	803	908.5	1069.25

Table 2. filter envelope

		Wavelength					
Edge envelope	**Relative transmission**	**u**	**g**	**r**	**i**	**z**	**y4**

blue edge	**Upper 0**	**0**	305.5	386.5	537	676	803	908.5
	Upper Average	**1.03**	331.25	412.25	562.75	701.75	828.75	934.25
red edge	**Upper average**	**1.03**	382.75	541.25	680.25	807.25	912.75	1201
	Upper 0	**0**	408.5	567	706	833	938.5	1201
blue edge	**Lower 0**	**0**	310.5	391.5	542	681	808	913.5
	Lower Average	**0.97**	334.75	415.75	566.25	705.25	832.25	937.75
red edge	**Lower average**	**0.97**	379.25	537.75	676.75	803.75	909.25	1070
	Lower 0	**0**	403.5	562	701	828	933.5	1070

Table 3. Relaxed filter envelope

Edge envelope		**Relative transmission**	**Wavelength** u	g	r	i	z	y4
blue edge	**Upper 0**	**0**	302.5	383.5	534	673	800	905.5
	Upper Average	**1.03**	328.25	409.25	559.75	698.75	825.75	931.25
red edge	**Upper average**	**1.03**	385.75	544.25	683.25	810.25	915.75	1201
	Upper 0	**0**	411.5	570	709	836	941.5	1201
blue edge	**Lower 0**	**0**	313.5	394.5	545	684	811	916.5
	Lower Average	**0.97**	334.75	415.75	566.25	705.25	832.25	937.75
red edge	**Lower average**	**0.97**	379.25	537.75	676.75	803.75	909.25	1070
	Lower 0	**0**	400.5	559	698	825	930.5	1070

This definition of the area weighted function is a guideline, and can be tuned to accommodate the specific witness sample distribution and to accommodate the final filter evaluation and acceptance plans.

Definitions (These definitions apply only to this area weighted response function and may not apply elsewhere):

1. Witness: A coated substrate that may be used to document coating performance
2. Sample: An individual spectral measurement at a single location and angle of incidence.
3. Sample Location: The position of a sample with respect to the filter center and a consistent azimuthal reference, typically given with a radius and an angle.
4. Measurement: A transmission function $T(\lambda)$ that represents the transmission performance for the LSST beam at a location on a filter. This transmission function shall be the mean performance over the annular beam footprint and over the entire angle of incidence range (assuming a radially uniform distribution of incident angles with a range defined in the specification). Each measurement may be the syntheses of many single-point samples (potentially on several witnesses) or a direct measurement on a large sample using a probe beam that simulates the LSST beam footprint and angles of incidence. (See the specification for the beam footprint and angle of incidence range.)
5. Measurement Location. The location of the measurement center with respect to the filter center and a consistent azimuthal reference, typically given with a radius and an angle

The area weighted response function is based on the following conditions:

1. A measurement from the center of the filter shall be included.
2. A measurement from the edge of the filter shall be included (the outer edge of the outermost measurement shall coincide with the clear aperture)
3. All sample locations shall be within the clear aperture
4. Measurement locations shall be as closely spaced radially as possible
5. The measurement set shall be sufficient to characterize radial and azimuthal coating uniformity
6. with measurements $j=1..k_i$ at each radius
7. to be placed on radii r_i, $i=1..N$ (r_i is the distance from the center of the filter to the center of the measurement location), where $r_1=0$, $r_{i+1}>r_i$ and r_N is the radius of the outermost measurement set.

The mean transmission at radius r with an index of i is:

$$T_i(\lambda) = \sum_{j=1}^{k_i} \frac{T_{ij}(\lambda)}{k_i}$$

where $T_{ij}(\lambda)$ is the measurement at radial location i and azimuthal index j.

The area weighted transmission over the filter is:

$$T(\lambda) = \sum_{i=1}^{N-1} a_i \frac{T_{i+1}(\lambda) + T_i(\lambda)}{2}$$

Where:

$$a_i = \frac{r_{i+1}^2 - r_i^2}{{r_N}^2}$$

For example, if the outermost measurement is from a 100mm witness placed with its edge on the clear aperture of 756mm (reference value) r_N would be 328mm.
Example:

$$r_N = \frac{756mm}{2} - \frac{100mm}{2} = 328mm$$

Note: the sum of all weighting factors must be equal to 1.

$$1 = \sum_{i=1}^{N-1} a_i$$

The normalized area weighted transmission over the filter is:

$$S(\lambda) = \frac{T(\lambda)}{\mu_{band}}$$

Where μ_{band} is the mean of $T(\lambda)$ between the two wavelengths that define the filter pass band (see Table 1)