Large Synoptic Survey Telescope (LSST)

LSST System Requirements (LSR)

Charles F. Claver and the LSST Systems Engineering Integrated Project Team

LSE-29 (rel5.1)

Latest Revision: September 7, 2018

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## Change Record

<table>
<thead>
<tr>
<th>Release</th>
<th>Date</th>
<th>Description</th>
<th>Owner name</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>5/18/2010</td>
<td>Initial version</td>
<td>Charles F. Claver and the LSST Systems Engineering Group</td>
</tr>
<tr>
<td>1.4</td>
<td>3/23/2011</td>
<td>Initial version placed under change control by CCB. This is baselined as version 1.4 in the SysArch model.</td>
<td>Charles F. Claver and the LSST Systems Engineering Group</td>
</tr>
<tr>
<td>2.0</td>
<td>10/08/2013</td>
<td>Incorporates LCR-148, LCR-153 (amended by the 10/08/2013 CCB meeting minutes), and LCR-144 (amended by the 10/02/2013 meeting minutes)</td>
<td>Brian Selvy and the LSST Systems Engineering Integrated Product Team</td>
</tr>
<tr>
<td>3.0</td>
<td>3/11/2015</td>
<td>Incorporates LCRs 141, 182, and 253. LCR-141 flows down SRD text edit to clarify the intent of photometry requirements. LCR-182 adds a minimum exposure time specification. Changes related to LCR-253 provide consistency throughout throughput flowdown chain.</td>
<td>C. Claver and the LSST Systems Engineering Integrated Product Team</td>
</tr>
<tr>
<td>3.1</td>
<td>8/4/2016</td>
<td>Implementation of LCR-584. Add requirements that provide the flow down logic for advanced publication of the expected scheduler.</td>
<td>C. Claver (LCR), B. Selvy (SysML), Robert McKercher (DocuShare)</td>
</tr>
<tr>
<td>4.0</td>
<td>2017-09-19</td>
<td>Implementation of LCR-687. Added requirement for alternate visit. LCR-REQ-0120</td>
<td>George Angeli (LCR), Kathryn Wesson (SysML), R. McKercher (DocuShare)</td>
</tr>
<tr>
<td>4.1</td>
<td>2017-09-21</td>
<td>Editorial correction and new format from software transition. No content change. Still release 4.0.</td>
<td>K. Wessen</td>
</tr>
<tr>
<td>5.0</td>
<td>2018-06-26</td>
<td>Implementation of LCR-1309 to address the DM processing of special data.</td>
<td>T. Jenness, M. Graham</td>
</tr>
<tr>
<td>5.1</td>
<td>2018-09-07</td>
<td>Implementation of LCR-1302 modifying LSR-REQ-0034.</td>
<td>W. O'Mullane (LCR), R. Carlson (SysML)</td>
</tr>
</tbody>
</table>

Latest document version generated from model version #1099.
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The LSST System Requirements (LSR)

This document is referenced to the LSST System Requirements v2.0 baseline dated 10/08/2013 in the SysML based SysArch Enterprise Architect Database. The XML file of this baseline is DocuShare handle LSE-52.

Project Background:

The LSST is a large-aperture, wide-field, ground-based telescope that will survey the visible sky every few nights in six photometric bands. The 10-year survey will produce a database suitable for answering a wide range of pressing questions in astrophysics, cosmology, and fundamental physics. LSST is designed to be a public facility. The images, alerts, and resulting catalogs will be made available to a broad community with no proprietary period. A sophisticated data management system will provide easy access to these data, enabling simple queries from individual users (both professionals and laypersons), as well as computationally intensive scientific investigations that utilize the entire dataset.

Document Scope:

This LSST System Requirements (LSR) document provides a comprehensive definition of the highest level of LSST Observatory system requirements. Contents of the document are generated out of the SysML based LSST System Architecture model (see Claver et al, 2010). It is derived from the LSST Science Requirements Document [LSST LPM-17] that describes the scientific motivations for the project, the survey capabilities and the reference science missions used to develop detailed scientific specifications for the LSST survey. This document builds on those to fully describe the specific nature of the LSST survey, final data products, and derived system functions and specifications that must be met in the execution of the LSST project.

These requirements cover the following areas:

- Adopted survey performance parameters from the SRD table and Technical requirements extracted from the SRD text,
- Required system capabilities for
  1) Optical configuration
  2) Data collection functions and performance
  3) Data processing functions and performance
  4) Archiving and services functions and performance
- Survey operation and administration functions

Reference Documents:

- The LSST Science Requirements Document (v5.1.3), document LPM-17
- The Observatory System Specifications, document LSE-30
Definition of Terms:

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 of the system or subsystem itself possesses.
The LSST System Requirements (LSR)

1 Survey Design Specifications

1.1 Survey Design Specifications

ID: LSR-REQ-0080

Requirement: The LSST system shall be designed such that the system achieves a survey with the following scientific and performance requirements.

Discussion: The LSST SRD specifies a suite of requirements for the scientific performance of the survey with minimum, design, and stretch goals. For the purpose of establishing the system design and flow down to lower level requirements a single value for each parameter for these requirements is defined here. The requirements that follow establish which specific value for each of the SRD performance parameters has been adopted, from within the SRD-defined ranges for the system design.

Further additional requirements and parameters have been pulled out of the body text in the SRD as identified requirements.

In nearly all cases the SRD design specification has been adopted for each parameter. It is explicitly noted where the design specification has not been adopted.

1.2 Filter Set Characteristics

1.2.1 Filter Set Characteristics

ID: LSR-REQ-0081

Requirement: The LSST survey shall provide imaging in 6 spectral bandpasses that are defined in the following requirements for the Filter Complement and the Filter Bandpass Performance.

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
<th>Unit</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>The ugrizy filter set is based on the filters from the SDSS with the addition of the y-band, These provide roughly uniform sampling of the optical spectrum from 320-1000nm.</td>
<td>ugrizy</td>
<td>unitless</td>
<td>FC</td>
</tr>
</tbody>
</table>

1.2.1.1 Filter Complement

ID: LSR-REQ-0082

Requirement: The filter set to be used during the lifetime of the survey shall comprise a complement of least 6 filters, FC, providing uniform sampling across the optical spectrum. The active complement shall be changeable within TDFMax hours.

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
<th>Unit</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>The ugrizy filter set is based on the filters from the SDSS with the addition of the y-band, These provide roughly uniform</td>
<td>ugrizy</td>
<td>unitless</td>
<td>FC</td>
</tr>
</tbody>
</table>
### 1.2.1.2 Filter Complement Swap Time

**ID:** LSR-REQ-0103  
**Requirement:** The active complement shall be changeable within \( TDF_{\text{Max}} \) hours.

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
<th>Unit</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>This is the time allowed for swapping out any filter in the internal complement of ( n_{\text{Filters}} ) filters (those available on a nightly basis) for another filter from the full complement ( FC ).</td>
<td>8</td>
<td>hour</td>
<td>( TDF_{\text{max}} )</td>
</tr>
</tbody>
</table>

### 1.2.1.3 Night Filter Availability

**ID:** LSR-REQ-0083  
**Requirement:** The number of filters available for use in the course of a night shall be at least \( N_{\text{Filters}} \), with no more than \( TF_{\text{Max}} \) seconds required to change the active filter.

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
<th>Unit</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>The number of filters available on a nightly basis within the required change time.</td>
<td>5</td>
<td>integer</td>
<td>( N_{\text{Filters}} )</td>
</tr>
<tr>
<td>The total time allowed to change the selected internal filter. This time includes any time needed to configure the LSST hardware to execute the change and then return to normal operations.</td>
<td>120</td>
<td>minute</td>
<td>( TF_{\text{Max}} )</td>
</tr>
</tbody>
</table>

### 1.2.1.4 Filter Bandpass Performance

**ID:** LSR-REQ-0084  
**Requirement:** The filter bandpasses shall have a maximum out of band leakage in any 10nm interval of no more than \( F_{\text{Leak}} \) relative to the peak filter response more than one FWHM from the filter center wavelength, with the total integrated leak outside the first 0.1% response points no more than \( F_{\text{LeakTot}} \) relative to the total transmission.

**Discussion:** The rationale is that this form of a requirement moves the max out of band leakage out to beyond the foot of the filter response, and avoids the computational problem with the original spec. Furthermore this form does not leave a gap between the 0.1% response and the FWHM point since the integrated out-of-band is maintained to the first 0.1%, which controls the overall foot.

**Issue:** This requirement deviates from what is in the SRD. It is not possible to meet the requirement as stated in the SRD. A change request to the SRD is pending to rectify the differences here.
The maximum out of band leakage in any 10nm interval relative to the peak filter response outside first instance of reaching 0.1% relative response.

The integrated leak is measured from 300-1200nm.

### 1.2.1.5 Filter Temporal Stability

**ID:** LSR-REQ-0085

**Requirement:** The temporal stability of the filter bandpasses shall be sufficiently small such that the required photometric calibration repeatability requirements can be met.

### 1.3 Single Image Performance

#### 1.3.1 Single Image Performance

**ID:** LSR-REQ-0086

**Requirement:** The LSST shall meet the following requirements for a single standard visit (defined by LSR-REQ-0016) performance:

1. Delivered Image Quality
2. Photometric Performance
3. Astrometric Performance
4. Image Depth

**Discussion:** The SRD defines a "single image" as the coaddition of the two exposures in a standard visit (see SRD sections 3.2 and 3.3.2).

#### 1.3.1.1 Delivered Image Quality

**ID:** LSR-REQ-0007

**Requirement:** The design requirement for the image quality requires that, for the median atmospheric seeing, the system contribution to the delivered image quality never exceeds 15% and have the properties specified in the table `imageQuality`.

**Discussion:** The design point specified here deviates from the SRD design requirement due to the conflict between image quality and charge spreading in the thick detectors, needed to achieve the desired z-band and y-band sensitivities. Nevertheless, the adopted base system image quality of 0.4 arcsec FWHM remains within the allowed value set by the SRD minimum specifications. Similarly the minimum specifications for encircled energy have also been adopted.

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
<th>Unit</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>The minimum number of pixels across the FWHM of the</td>
<td>3</td>
<td>pixel</td>
<td>PSFSample</td>
</tr>
</tbody>
</table>
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1.3.1.1.2 Off Zenith Degradation

ID: LSR-REQ-0087

**Requirement:** The system image quality is allowed to degrade as a function of Zenith Distance (angle) at the same rate as the atmospheric turbulent seeing. The canonical dependence on zenith distance is given as $\sec(ZD)^{\text{ImFunc}}$.

**Discussion:** This requirement should be fulfilled irrespective of the airmass, which limits the seeing degradation due to hardware away from the zenith (e.g. due to gravity load). Assuming that the atmospheric seeing increases with airmass, $X$, as $X^{\text{imFunc}}$, the design specification for the allowed image quality budget due to the system is 0.60 arcsec at airmass of 2 and for the median seeing conditions (0.49 arcsec for $X=1.4$) as defined by the attributes `SysIm_60` (equivalent to SXE in SRD) and `SysIm_45` respectively.

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
<th>Unit</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>The limiting RSS image blur that can be exceeded by 10% of the field of view in the first quartile (0.44 arcsec FWHM) atmospheric seeing conditions.</td>
<td>0.43</td>
<td>arcsecFWHM</td>
<td>10%outlierBudget_0.44</td>
</tr>
<tr>
<td>The limiting RSS image blur that can be exceeded by 10% of the field of view in the median (0.60 arcsec FWHM) atmospheric seeing conditions.</td>
<td>0.46</td>
<td>arcsecFWHM</td>
<td>10%outlierBudget_0.60</td>
</tr>
<tr>
<td>The limiting RSS image blur that can be exceeded by 10% of the field of view in the third quartile (0.80 arcsec FWHM) atmospheric seeing conditions.</td>
<td>0.52</td>
<td>arcsecFWHM</td>
<td>10%outlierBudget_0.80</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
<th>Unit</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>The maximum RSS contribution from the LSST system to the atmospheric seeing referenced at zenith distance of 45 degrees or airmass ($\sec(ZD)$) = 1.4.</td>
<td>0.49</td>
<td>arcsecFWHM</td>
<td><code>SysIm_45</code></td>
</tr>
<tr>
<td>The maximum RSS contribution from the LSST system to the atmospheric seeing referenced at zenith distance of 60 degrees or airmass ($\sec(ZD)$) = 2.0.</td>
<td>0.60</td>
<td>arcsecFWHM</td>
<td><code>SysIm_60</code></td>
</tr>
<tr>
<td>The system image budget is allowed to degrade through the three reference zenith distances (zd) as $\sec(zd)^{\text{ImFunc}}$.</td>
<td>0.6</td>
<td>unitless</td>
<td><code>ImFunc</code></td>
</tr>
</tbody>
</table>

1.3.1.2 Delivered Image Ellipticity

ID: LSR-REQ-0092

**Requirement:** The Point spread function ellipticity for bright isolated unresolved sources in images from a single visit shall have the properties specified in the table `imageEllipticity` below.
### Description

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
<th>Unit</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>The fraction of PSF ellipticity measurements allowed to exceed the ellipticity outlier limit for bright isolated non-saturated stars.</td>
<td>5</td>
<td>percent</td>
<td>EF1</td>
</tr>
<tr>
<td>The maximum median raw PSF ellipticity over the full field of view in a single 15 second exposure for bright isolated non-saturated stars.</td>
<td>0.04</td>
<td>unitless</td>
<td>SE1</td>
</tr>
<tr>
<td>The maximum PSF raw ellipticity outlier limit.</td>
<td>0.07</td>
<td>unitless</td>
<td>SE2</td>
</tr>
</tbody>
</table>

#### 1.3.1.3 Filter Depths

**ID:** LSR-REQ-0090

**Requirement:** The single visit depth for unresolved point sources in each of the 6 LSST filters shall meet the specifications in the following table, assuming the reference conditions specified in LSR-REQ-0089 scaled appropriately for each filter.

**Discussion:** A detailed description of the assumed inputs and methods used to calculate the 5-sigma limiting magnitudes are given in Document-8857.

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
<th>Unit</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>g-band point source 5-sigma detection depth median</td>
<td>24.8</td>
<td>AB magnitude</td>
<td>DB1g</td>
</tr>
<tr>
<td>i-band point source 5-sigma detection depth median</td>
<td>23.9</td>
<td>AB magnitude</td>
<td>DB1i</td>
</tr>
<tr>
<td>r-band point source 5-sigma detection depth median</td>
<td>24.4</td>
<td>AB magnitude</td>
<td>DB1r</td>
</tr>
<tr>
<td>u-band point source 5-sigma detection depth median</td>
<td>23.5</td>
<td>AB magnitude</td>
<td>DB1u</td>
</tr>
<tr>
<td>y-band point source 5-sigma detection depth median</td>
<td>22.1</td>
<td>AB magnitude</td>
<td>DB1y</td>
</tr>
<tr>
<td>z-band point source 5-sigma detection depth median</td>
<td>23.3</td>
<td>AB magnitude</td>
<td>DB1z</td>
</tr>
</tbody>
</table>

#### 1.3.1.3.1 r-band Reference Depth

**ID:** LSR-REQ-0089

**Requirement:** The single visit median depth in the r-band for unresolved point sources shall meet the specifications in the following table, assuming the reference conditions specified therein.

**Discussion:** The SNR v1.2 (Document-8857) calculation assumes optimal extraction even for sources near the noise limit. Optimal extraction is applicable to time series photometry, and this is extrapolated to the background limited extreme in all bands but u.
Given the median detection depth for a visit as MVD(i), the distribution of MVD(i) shall have a median r-band 5-sigma limiting magnitude no brighter than D1 for unresolved point sources.

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
<th>Unit</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>The fraction of the images with a median 5-sigma point source detection depth (MVD(i)) brighter than the depth outlier limit (Z1) shall be no more than DF1.</td>
<td>10</td>
<td>percent</td>
<td>DF1</td>
</tr>
<tr>
<td>The reference airmass under which the depth specifications shall be met is refAirmass.</td>
<td>1.0</td>
<td>air mass</td>
<td>refAirmass</td>
</tr>
<tr>
<td>The reference exposure time for which the single image depth specifications shall be met is refExposureTime.</td>
<td>30</td>
<td>second</td>
<td>refExposureTime</td>
</tr>
<tr>
<td>The reference atmospheric seeing for which the depth specifications shall be met is refSeeing as measured in the r-band.</td>
<td>0.7</td>
<td>arcsecFW HM</td>
<td>refSeeing</td>
</tr>
<tr>
<td>The reference sky surface brightness for which the depth specifications shall be met is refSkyBrightness as measured in the r-band.</td>
<td>21</td>
<td>magnitude per arcsecond squared</td>
<td>refSkyBrightness</td>
</tr>
<tr>
<td>The outlier limit for 5-sigma point source detection depth is Z1.</td>
<td>24.4</td>
<td>AB magnitude</td>
<td>Z1</td>
</tr>
</tbody>
</table>

1.3.1.3.2 Depth Variation Over FOV

ID: LSR-REQ-0109

Requirement: An image meeting the median depth defined by the requirement Filter Depths (LSR-REQ-0090) shall meet the specification for depth distribution given in depthVarFOV below.

Discussion: The variations in depth allowed for in this requirement are less stringent than those implied by the variation in image quality. This requirement is meant to allow for variations in sensor sensitivity and effects of vignetting. The intent of this requirement is to restrict using low QE sensors in the focal plane array is met by requiring the camera detectors meet their minimum QE specifications (see OSS-REQ-0256 in the flow down).

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
<th>Unit</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>The maximum area over the 3.5 degree field-of-view with a 5-sigma point source detection brighter than Z2 above the median limiting magnitude for that visit shall be no greater than DF2.</td>
<td>15</td>
<td>percent</td>
<td>DF2</td>
</tr>
</tbody>
</table>
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### 1.3.1.4 Photometric Performance

**ID:** LSR-REQ-0093

**Requirement:** The photometric quality of images from a single visit shall meet the specifications listed in the table **photometricPerformance** below.

**Discussion:** The specifications for photometric repeatability, PA1, PA2 and PF1, applies to the cataloged LSST magnitudes, $m_{\text{std}(\text{catalog})}$ (see SRD eq. 8), for appropriately chosen main sequence stars (e.g. non-variable stars color-selected from the main stellar locus).

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
<th>Unit</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>The allowed 5-sigma detection outlier limit is $Z_2$.</td>
<td>0.2</td>
<td>AB magnitude</td>
<td>$Z_2$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
<th>Unit</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Photometric Performance</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### 1.3.1.4.1 Photometric Performance

- **ID:** LSR-REQ-0093

- **Requirement:** The photometric quality of images from a single visit shall meet the specifications listed in the table **photometricPerformance** below.

- **Discussion:** The specifications for photometric repeatability, PA1, PA2 and PF1, applies to the cataloged LSST magnitudes, $m_{\text{std}(\text{catalog})}$ (see SRD eq. 8), for appropriately chosen main sequence stars (e.g. non-variable stars color-selected from the main stellar locus).

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
<th>Unit</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage of image area that can have ghosts with surface brightness gradient amplitude of more than 1/3 of the sky noise over 1 arcsec.</td>
<td>1</td>
<td>percent</td>
<td>GhostAF</td>
</tr>
<tr>
<td>The RMS photometric repeatability of bright non-saturated unresolved point sources in the $g$, $r$, and $i$ filters.</td>
<td>5</td>
<td>millimagnitude</td>
<td>PA1gri</td>
</tr>
<tr>
<td>The RMS photometric repeatability of bright non-saturated unresolved point sources in the $u$, $z$, and $y$ filters.</td>
<td>7.5</td>
<td>millimagnitude</td>
<td>PA1uzy</td>
</tr>
<tr>
<td>Repeatability outlier limit for isolated bright non-saturated point sources in the $g$, $r$, and $i$ filters.</td>
<td>15</td>
<td>millimagnitude</td>
<td>PA2gri</td>
</tr>
<tr>
<td>Repeatability outlier limit for isolated bright non-saturated point sources in the $u$, $z$, and $y$ filters.</td>
<td>22.5</td>
<td>millimagnitude</td>
<td>PA2uzy</td>
</tr>
<tr>
<td>RMS width of internal photometric zero-point (precision of system uniformity across the sky) for all bands except $u$-band.</td>
<td>10</td>
<td>millimagnitude</td>
<td>PA3</td>
</tr>
<tr>
<td>RMS width of internal photometric zero-point (precision of system uniformity across the sky) in the $u$-band.</td>
<td>20</td>
<td>millimagnitude</td>
<td>PA3u</td>
</tr>
<tr>
<td>Accuracy of absolute band-to-band color zero-point for all colors constructed from any filter pair, excluding the $u$-band.</td>
<td>5</td>
<td>millimagnitude</td>
<td>PA5</td>
</tr>
<tr>
<td>Accuracy of absolute band-to-band color zero-point for colors constructed using the $u$-band.</td>
<td>10</td>
<td>millimagnitude</td>
<td>PA5u</td>
</tr>
<tr>
<td>Accuracy of the transformation of the internal LSST photometry to a physical scale (e.g. AB magnitudes).</td>
<td>10</td>
<td>millimagnitude</td>
<td>PA6</td>
</tr>
</tbody>
</table>
The maximum fraction of isolated non-saturated point source measurements exceeding the outlier limit.

Fraction of zeropoint errors that can exceed the zero point error outlier limit.

The zero point error outlier limit.

The maximum fraction of pixels scientifically unusable per sensor out of the total allowable fraction of sensors meeting this performance.

Maximum RMS of the ratio of the error in integrated flux measurement between bright, isolated, resolved sources less than 10 arcsec in diameter and bright, isolated unresolved point sources.

The maximum error in the precision of the sky brightness determination.

The maximum allowable fraction of sensors with scientifically unusable pixels.

The maximum local significance integrated over the PSF of imperfect crosstalk corrections.

### 1.3.1.5 Astrometric Performance

**ID:** LSR-REQ-0094

**Requirement:** The astrometric quality of images from a single visit shall meet the specifications listed in the table `astrometricPerformance` below.

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
<th>Unit</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median error in absolute position for each axis, RA and DEC, shall be less than AA1.</td>
<td>50 arcsecond</td>
<td>AA1</td>
<td></td>
</tr>
<tr>
<td>RMS difference between separations measured in the r-band and those measured in any other filter.</td>
<td>10 milliarcscond</td>
<td>AB1</td>
<td></td>
</tr>
<tr>
<td>The color difference outlier limit for separations measured relative the r-band filter in any other filter.</td>
<td>20 milliarcscond</td>
<td>AB2</td>
<td></td>
</tr>
<tr>
<td>Fraction of separations measured relative to the r-band that</td>
<td>10 percent</td>
<td>ABF1</td>
<td></td>
</tr>
</tbody>
</table>
### Description

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
<th>Unit</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>can exceed the color difference outlier limit.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 arcminute outlier limit.</td>
<td>20</td>
<td>milliarcsecond</td>
<td>AD1</td>
</tr>
<tr>
<td>20 arcminute outlier limit.</td>
<td>20</td>
<td>milliarcsecond</td>
<td>AD2</td>
</tr>
<tr>
<td>200 arcminute outlier limit.</td>
<td>30</td>
<td>milliarcsecond</td>
<td>AD3</td>
</tr>
<tr>
<td>The maximum fraction of relative astrometric measurements on 5 arcminute scales to exceed 5 arcminute outlier limit.</td>
<td>10</td>
<td>percent</td>
<td>AF1</td>
</tr>
<tr>
<td>The maximum fraction of relative astrometric measurements on 20 arcminute scales to exceed 20 arcminute outlier limit.</td>
<td>10</td>
<td>percent</td>
<td>AF2</td>
</tr>
<tr>
<td>Fraction of relative astrometric measurements on 200 arcminute scales to exceed 200 arcminute outlier limit.</td>
<td>10</td>
<td>percent</td>
<td>AF3</td>
</tr>
<tr>
<td>Median relative astrometric measurement error on 5 arcminute scales shall be less than AM1.</td>
<td>10</td>
<td>milliarcsecond</td>
<td>AM1</td>
</tr>
<tr>
<td>Median relative astrometric measurement error on 20 arcminute scales.</td>
<td>10</td>
<td>milliarcsecond</td>
<td>AM2</td>
</tr>
<tr>
<td>Median relative astrometric measurement error on 200 arcminute scales.</td>
<td>15</td>
<td>milliarcsecond</td>
<td>AM3</td>
</tr>
</tbody>
</table>

### 1.3.1.6 Bright Sources

**ID:** LSR-REQ-0095

**Requirement:** The LSST shall be capable of unsaturated measurements of sources brighter than the nominal 15-second saturation limit by at least brightSource.

**Discussion:** This is not a requirement on the ability to measure saturated sources in standard visits. It is largely a requirement on the capability of the system to acquire and process visits of such duration that an object brightSource brighter than the nominal saturation limit would not be saturated (e.g., to support overlaps with brighter external catalogs).
1.4 Full Survey Performance

1.4.1 Full Survey Performance

ID: LSR-REQ-0096

Requirement: Integrated over all survey observations made over a 10 year period the LSST shall meet all specifications for skyCoverage and overallEllipticityCorrelations.

1.4.1.1 Ellipticity Correlations

ID: LSR-REQ-0097

Requirement: Using the full survey data, the E1 and E2 (see SRD for definitions) distributions averaged over an arbitrary FOV shall have medians less than TE1 for theta ~ 1 arcmin, and less than TE3 for theta < 5 arcmin. No more than TEF % of images shall have these medians for E1 and E2 larger than TE2 for theta ~ 1 arcmin, or larger than TE4 for theta < 5 arcmin.

Discussion: The requirements specified here require the full survey data set to exist before they can be met. Thus these are intended to ensure that the LSST system design enables that these requirements can be met after the 10-year survey. Prior to survey start, they will be verified to the extent possible using simulations incorporating the as-built telescope and camera performance characteristics.

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
<th>Unit</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>The fraction of PSF ellipticity correlation residuals that can exceed the outlier limits on 1 and 5 arcminutes scales, over an arbitrary field, of view shall be no more than</td>
<td>15</td>
<td>percent</td>
<td>TEF</td>
</tr>
<tr>
<td>Median residual PSF ellipticity correlations averaged over an arbitrary field of view for separations less than 1 arcmin shall be no greater than TE1.</td>
<td>2.0e-5</td>
<td>arcminuteSeparationCorrelation</td>
<td>TE1</td>
</tr>
<tr>
<td>Median residual PSF ellipticity correlations averaged over an arbitrary field of view for separations less than 5 arcmin shall be no greater than TE2.</td>
<td>1.0e-7</td>
<td>arcminuteSeparationCorrelation</td>
<td>TE2</td>
</tr>
<tr>
<td>The outlier limit on the PSF ellipticity correlation residuals on 1 arcminute scales shall be no more than TE3.</td>
<td>4.0e-5</td>
<td>arcminuteOutlierLimit</td>
<td>TE3</td>
</tr>
<tr>
<td>The outlier limit on the PSF ellipticity correlation residuals on 5 arcminute scales shall be no more than TE4.</td>
<td>2.0e-7</td>
<td>arcminuteOutlierLimit</td>
<td>TE4</td>
</tr>
</tbody>
</table>

1.4.1.2 Sky Coverage

ID: LSR-REQ-0098

Requirement: Integrated over all survey observations made over a 10 year period the LSST shall meet all specifications for skyCoverage.
### 1.4.1.3 Integrated Astrometric Performance

**ID:** LSR-REQ-0099

**Requirement:** For all observations of unresolved point sources having $r < 24$, after 10 years the astrometric performance shall meet the specifications in the table `astrometricPerf` below.

**Discussion:** These requirements constrain the distribution in time over 10 years such that the parallax factor is even sampled and that the time baseline is sufficient to meet the proper motion performance specification.

| Description                                                                 | Value | Unit           | Name          |
|                                                                             |       |               |               |
| The median parallax uncertainty (sigma) for sources with $r = 24$ or brighter shall be no more than $\text{SiGpar}$. | 3.0   | milliarcsecond | SiGpar        |
| The median parallax uncertainty (sigma) in the y-band shall be no more than $\text{SiGparRed}$. | 6.0   | milliarcsecond | SiGparRed     |
| The median proper motion accuracy per coordinate across the main survey area for sources brighter than $r = 24$ must be at least $\text{SiGpm}$. | 1.0   | milliarcsecond | SiGpm         |

### 1.5 Data Processing and Management

**1.5.1 Data Processing and Management**

**ID:** LSR-REQ-0100
1.5.1.1 Data Processing for Single Visits and Transients

ID: LSR-REQ-0101

**Requirement:** The LSST shall meet the following specification for reporting of data on optical transients detected in single-visit data: OTT1, transN, and transSNR.

**Discussion:** It is unclear whether the SRD specification of transN refers to the number of alerts that can be generated for a single visit (i.e. an instantaneous limit), or the number per visit averaged over time.

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
<th>Unit</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>The latency of reporting optical transients following the completion of readout of the last image of a visit</td>
<td></td>
<td>minute</td>
<td>OTT1</td>
</tr>
<tr>
<td>The minimum number of optical transients for which data can be reported per visit</td>
<td>1.0e4</td>
<td>unitless</td>
<td>transN</td>
</tr>
<tr>
<td>The signal-to-noise ratio in single-visit difference images above which all optical transients are to be reported.</td>
<td>5</td>
<td>float</td>
<td>transSNR</td>
</tr>
</tbody>
</table>

1.5.1.2 Data Release Processing

ID: LSR-REQ-0102

**Requirement:** Specific, fixed "snapshots" of the data (data releases) of the data shall be released to the public periodically, at least every DRT1 years.

**Discussion:** The project is planning on at least two Data Releases in the first year of operations.

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
<th>Unit</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>The minimum interval between standard Data Releases</td>
<td>1</td>
<td>year</td>
<td>DRT1</td>
</tr>
</tbody>
</table>

1.5.1.3 Processing Data from Special Programs

ID: LSR-REQ-0122

**Requirement:** The LSST shall deliver unique and separate data products for visits from Special Programs (e.g., mini-surveys, deep drilling fields), whenever possible. These data products shall be delivered on timescales intermediate to OTT1 and DRT1 when this enables the intended science of the Special Program.

**Discussion:** The term "whenever possible" includes cases where the Data Management System can run original or reconfigured versions of existing pipelines, and excludes cases where the development of new algorithms, or the allocation of significant additional computational resources, are required.

2 System Capabilities

2.1 System Capabilities

ID: LSR-REQ-0001
**Requirement:** In order to perform a survey as defined above and present the data in a scientifically useful manner the LSST Observatory shall be a complete system that:

1. obtains survey data in the form of digital images,
2. processes, calibrates, and archives the images,
3. generates source and object catalogs, and
4. makes all data and data products available to a wide range of users.

**Discussion:** The requirements that define the system capabilities have been organized into 4 groupings that characterize the high level performance and functional requirements that must be met. The 4 groupings include:

1. **The Optical Configuration:** These requirements specify the type of optical design, field of view, effective aperture, and overall system throughput that are derived from the SRD.
2. **Observatory Control Capabilities:** These requirements specify the overall control and administration functions needed to conduct the survey and ensure that the LSST is responsive to the scientific community of its lifetime.
3. **Data Collection:** These requirements specify in broad terms the data collection functions the LSST system must have in order to conduct the specified survey, optimize its operation, and record knowledge of its physical state during routine operation.
4. **Data Products & Processing:** These requirements specify the high-level definition of the LSST data and data quality products to be delivered to the user community and what process must occur to create these products.
5. **Data Archiving and Services:** These requirements define the high-level archiving and data delivery functions that are needed to deliver the LSST data and Data Products to its intended user base. Also included are the definitions of other data processing services that will be provided by the LSST system.

### 2.2 Optical Configuration

#### 2.2.1 Optical Configuration

**ID:** LSR-REQ-0002

**Requirement:** The LSST optical configuration shall be from the anastigmatic class of optical designs meeting the specification given below.

**Discussion:** The anastigmatic design class eliminates 3rd order astigmatism across the field of view.

#### 2.2.1.1 Effective Aperture

**ID:** LSR-REQ-0003

**Requirement:** The on-axis effective light collecting area of the LSST shall be equivalent to a clear unobstructed circular aperture of at least \( \text{effAperture} \).
## 2.2.1.2 Field Of View

**ID:** LSR-REQ-0004  
**Requirement:** The field of view of the LSST optical system shall be at least an angle \( \text{fieldOfView} \) in diameter.  
**Discussion:** The FOV defined here is not meant to be the final effective FOV recorded by the LSST camera. This is meant to be a nominal optical configuration requirement from which the optical design is derived.

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
<th>Unit</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>The diameter of the field of view - equivalent to 9.6 square degrees of sky coverage.</td>
<td>3.5</td>
<td>degree</td>
<td>fieldOfView</td>
</tr>
</tbody>
</table>

## 2.2.1.3 Effective Etendue

**ID:** LSR-REQ-0005  
**Requirement:** The LSST optical system shall have an effective \( \text{étendue} \) (effective collecting \( x \) area of sky recorded in each image integrated over the \( \text{fieldOfView} \)) of at least \( \text{etendueRec} \).  
**Discussion:** The specified value is less than the product of \( \text{effAperture} \) and \( \text{fieldOfView} \) because of vignetting and focal plane fill factor.

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
<th>Unit</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>The effective collecting area integrated over the field of view * field of view area recorded in each image.</td>
<td>280</td>
<td>metre squared degree squared</td>
<td>etendueRec</td>
</tr>
</tbody>
</table>

## 2.2.1.4 Atmospheric Dispersion Correction

**ID:** LSR-REQ-0006  
**Requirement:** An atmospheric dispersion corrector (ADC) is not required in the LSST system design.  
**Discussion:** The project undertook a detailed trade study during the early conceptual phase of the project to determine if an ADC is needed and if it was even feasible to design and build an ADC large enough to accommodate the LSST field of view. This trade study concluded that an ADC was feasible but was not necessary provided that the survey observations were kept below 1.4 airmasses for that science needing the most control of the PSF shape. The minimum survey area is achievable while staying below 1.4 airmasses. (Documentation relating to this study is contained in Collection-894 on the LSST Document Archive).
2.2.1.5  **Stray and Scattered Light**

**ID:** LSR-REQ-0009

**Requirement:** The LSST design shall control the effects of stray and scattered light to the extent necessary to meet the performance in the Survey Specifications.

**Discussion:** Stray and scattered light is defined as any light that is not part of the ideal image and includes:

- diffuse scattered light,
- secondary ghost images,
- diffraction, and
- structured glints.

2.2.1.5.1  **Baffling**

**ID:** LSR-REQ-0011

**Requirement:** The LSST optical system shall be baffled as required to ensure that no unwanted specular path can put light onto the LSST focal plane.

2.2.1.6  **Science Instrument**

**ID:** LSR-REQ-0012

**Requirement:** The LSST system shall contain a single science instrument - the Camera.

**Discussion:** By the very nature of conducting a consistent well calibrated survey the LSST will not need to support the multiple instruments often found on classical telescope systems.

2.3  **Observatory Control Capabilities**

2.3.1  **Observatory Control Capabilities**

**ID:** LSR-REQ-0067

**Requirement:** The observatory shall be developed with the necessary control centers to achieve the LSST objectives. This shall include, as a minimum, the capabilities defined here.

2.3.1.1  **Central Administration**

**ID:** LSR-REQ-0068

**Requirement:** A central location shall serve as Project Headquarters for operational coordination and project interfaces to supporting agencies.

**Discussion:** The LSST Observatory will be a distributed set of assets functioning for the specific objectives of executing the survey and serving the raw data and its data products to the public.

2.3.1.2  **Autonomous Operation**

**ID:** LSR-REQ-0072
**Requirement:** The LSST system shall operate in a locally supervised autonomous mode during routine survey data collection and processing, with little human intervention required.

**Discussion:** It is not practical to expect human driven observations to keep pace with the observing cadence dictated by the LSST survey requirements.

### 2.3.1.3 Survey Scheduling

**ID:** LSR-REQ-0062

**Requirement:** The Observatory shall include a dynamic scheduler sufficient to achieve the survey requirements in the presence of changing observing conditions, nightly technical performance, previous survey performance and internal and/or external constraints.

### 2.3.1.4 External Observatory Co-Observing Capability

**ID:** LSR-REQ-0119

**Specification:** LSST Observatory shall enable "co-observing", where an external observatory can anticipate where future observations will be made with reasonable likelihood.

### 2.3.1.5 Scientific Oversight During Data Collection

**ID:** LSR-REQ-0071

**Requirement:** The LSST Observatory shall be developed to allow an observing scientist to have oversight of the Data Collection process. This interaction shall be enabled either locally on the summit or at remote locations. The data provided shall include all observing condition data, telemetry data to assess telescope conditions, and science data quality metrics for evaluation of the data collection process.

**Discussion:** The objective this requirement is to enable the observing scientist to be directly involved in the observing process. Under normal circumstances the observing scientist will not intervene with the autonomous operations (LSR-REQ-0072), but should be allowed to override if anomalous behavior occurs.

### 2.3.1.6 Process Command and Control

**ID:** LSR-REQ-0069

**Requirement:** In addition to the connectivity required for the science data, the observatory shall include the necessary capability to command and control the process from multiple centers and to adjust for changing environmental, technical, and scientific conditions.

### 2.4 Data Collection

#### 2.4.1 Data Collection

**ID:** LSR-REQ-0013

**Requirement:** The LSST shall provide a Data Collection system that is capable of providing all necessary data to meet the SRD survey specifications including science image data and all ancillary data needed to calibrate the survey and to optimize operations.
2.4.1.1 **Science Data**

**ID:** LSR-REQ-0014

**Requirement:** The observatory shall collect science images as a series of "visits", sequenced by an automated system that optimizes the scientific return of the survey according to established priorities, taking into account environmental and sky conditions in the course of each night.

### 2.4.1.1.1 Standard Visit

**ID:** LSR-REQ-0016

**Requirement:** The bulk of the survey shall be performed as sequences of "standard Visits", defined as \( n_{\text{VisitExp}} \) back to back exposures in one of the system spectral bands, each having an exposure time of \( \text{visitExpTime} \).

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
<th>Unit</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>The number of exposures, ( n_{\text{VisitExp}} ), in a standard visit shall be</td>
<td>2</td>
<td>integer</td>
<td>( n_{\text{VisitExp}} )</td>
</tr>
<tr>
<td>The exposure time, ( \text{visitExpTime} ), for single images in a standard visit shall be</td>
<td>15</td>
<td>second</td>
<td>( \text{visitExpTime} )</td>
</tr>
</tbody>
</table>

### 2.4.1.1.2 Non-Standard Visit

**ID:** LSR-REQ-0111

**Requirement:** The LSST shall be capable of obtaining and processing exposures not taken in a standard visit mode including those with a minimum exposure time of \( \text{minExpTime} \).

**Discussion:** Non-standard visits are defined as having a number of exposures per visit and visit exposure time different from the values of \( n_{\text{VisitExp}} \) and/or \( \text{visitExpTime} \) respectively, as specified in LSR-REQ-0016. Non-standard visit exposures may possibly be degraded in some aspects of performance (e.g., cosmic ray rejection on visits consisting of a single exposure), and might be incompatible with difference imaging and alert production (e.g., short exposures in which the PSF is not fully formed).

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
<th>Unit</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>The maximum shortest exposure time of a single exposure is ( \text{minExpTime} ).</td>
<td>1</td>
<td>second</td>
<td>( \text{minExpTime} )</td>
</tr>
<tr>
<td>The goal for the shortest exposure time of a single exposure is ( \text{minExpTimeGoal} ).</td>
<td>0.1</td>
<td>second</td>
<td>( \text{minExpTimeGoal} )</td>
</tr>
</tbody>
</table>

### 2.4.1.1.3 Alternate Standard Visit

**ID:** LSR-REQ-0120

**Specification:** The system shall have the capability to schedule a visit using a single 30-second exposure while maintaining overall system performance in terms of depth and number of visits per unit area on the...
The expectation is that the system can be operated to acquire images with exposure times over a range of exposure times from ~1 to order ~300 seconds. Non-standard visit exposures do not need to be processed with the same latency as those for main survey “standard” visits.

2.4.1.1.4 Data Format
ID: LSR-REQ-0015

Requirement: The LSST survey data shall be collected in the form of pixel addressable digital images that preserve the full information content of the LSST instrument.

2.4.1.2 Photometric Calibration Data
ID: LSR-REQ-0017

Requirement: The LSST shall measure and record data relating to instrumental and atmospheric transmission as necessary to photometrically calibrate the science data, referenced to the top of the Earth’s atmosphere.

2.4.1.3 Engineering Data
ID: LSR-REQ-0018

Requirement: The LSST data collection system shall collect engineering and environmental data necessary to capture the physical state of the observatory, its components, and surrounding environment, during all modes of operation.

2.4.1.4 Ancillary Data
ID: LSR-REQ-0019

Requirement: The LSST system shall measure and record the data required as input to the optimization of the acquisition of survey data as well as record the environmental conditions that existed during each exposure. These data shall include but are not limited to:

1. atmospheric seeing;
2. cloud cover; and
3. meteorological information (temperatures, wind, humidity etc..)

2.5 Data Products and Processing

2.5.1 Data Products and Processing
ID: LSR-REQ-0020

Requirement: The system shall process the raw image data from the camera to produce calibrated images, analyze them to generate source and object catalogs, detect and generate alerts for transient phenomena, and record the quality of the data collected and its processing provenance.

Discussion: The Observatory is expected to process and calibrate the data from the entire focal plane.
While the SRD requirements on image quality and depth are specified as applying only within the nominal 3.5-degree field of view, the data processing is nevertheless expected to strive to maximize the scientific usability of the data outside the nominal field.

### 2.5.1.1 Calibrated Image Production

**ID:** LSR-REQ-0021  
**Requirement:** The LSST data processing system shall process raw image data to produce photometrically and astrometrically calibrated images, both from single visits and from deep coadds.  
**Discussion:** The single-visit and deep-coadd image-level calibrations are a subset of the final catalog-level calibrations, which will be done in later stages of the processing flow (LSR-REQ-0029).

### 2.5.1.2 Catalog Production

**ID:** LSR-REQ-0029  
**Requirement:** The data processing system shall process calibrated image data to produce catalogs with photometrically and astrometrically calibrated sources and objects.  
**Discussion:** "Sources" refer to measured properties from an astrophysical event or object in a single individual visit, whereas "Objects" refer to the inferred properties of the underlying astrophysical phenomenon, given information collected from all visits to date.

### 2.5.1.3 Calibration Data Products

**ID:** LSR-REQ-0030  
**Requirement:** The data processing system shall, from time to time, generate Calibration Data Products, including bias frames and flat fields, as required by the other processing functions.  
**Discussion:** These will typically appear at time scales intermediate to those of the Level 1 and Level 2 Data Products as described below. The Alert Production will require calibration data products of sufficient timeliness and quality to permit instrument signature removal prior to transient detection. These must be updated as often as necessary to meet this need. Data Release Production will require higher-quality calibrations, but the production of these may be done as part of the preparations for each new Data Release, i.e., annually.

### 2.5.1.4 Optical Transient Alert Production

**ID:** LSR-REQ-0022  
**Requirement:** The LSST data processing system shall process raw image data to detect optical transients and generate alerts to the astronomical community based on these detections.

#### 2.5.1.4.1 Optical Transient Event Detection

**ID:** LSR-REQ-0023  
**Requirement:** Transient events above one or more thresholds shall be detected in acquired raw images, and their detection and associated parameters shall be archived and made available for future transient
classification.

**Discussion:** SRD flow down for transient detection is described in LSR-REQ-101.

### 2.5.1.4.2 Optical Transient Event Classification

**ID:** LSR-REQ-0024

**Requirement:** The data processing for Optical Transient Alert production shall differentiate between moving objects and other types of optical transients and shall reject cosmic rays and other non-astrophysical sources of transients, to the extent practicable. Cosmic-ray rejection will primarily be based on the use of exposure pairs. If a detected transient can be associated with a previously observed object, the processing shall include a calculation of the probability that the object is variable, based on prior observations.

**Discussion:** It is not possible to differentiate between moving objects and other types of optical transients in all cases. For slowly moving objects, we can do so only to the extent that the catalog of moving objects is complete, and this will never be 100%. At the beginning of the survey, it will be very incomplete, unless we are able to initialize it based on a precursor survey.

### 2.5.1.4.3 Optical Transient Alert Generation

**ID:** LSR-REQ-0027

**Requirement:** Transient alerts shall be generated based on detected transients, and made available to external consumers. Alerts shall include measurements of position, flux, size and shape, using appropriate weighting functions, as well as prior variability information and data from the same night, if available. Prior variability information shall include, at minimum, low-order light-curve moments and the above assessment of the probability that the object is variable.

**Discussion:** Alerts should ideally include the full light curves in all available bands as well.

#### 2.5.1.4.3.1 Transient Filtering

**ID:** LSR-REQ-0025

**Requirement:** Given an alert-detection algorithm chosen to meet LSR-REQ-0027, the algorithm shall be applied and the alert transmitted within the specified latency for at least a fraction $OTR_1$ of instances where the image data contains a transient detectable by the algorithm. The remaining transients so detectable must still be identified and recorded at the next processing opportunity.

**Discussion:** This requirement is on the production system given a particular algorithm and covers both detection and latency. This requirement constrains the reliability and timeliness of application of the algorithm and the alert publication. It does not constrain either the completeness or purity of the transient identifications themselves. It is unspecified whether the "next processing opportunity" is a fault-tolerance fallback or the daily reprocessing at the Archive.

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
<th>Unit</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fraction of detectable alerts for which an alert is actually transmitted within latency $OTT_1$ (see LSR-REQ-0101).</td>
<td>98</td>
<td>percent</td>
<td>$OTR_1$</td>
</tr>
</tbody>
</table>
2.5.1.4.3.1.1  Predefined Transient Filters

ID: LSR-REQ-0026

**Requirement:** Pre-defined filters optimized for traditionally popular transients shall be made available. It shall be possible for the project to add new pre-defined filters as the survey progresses.

**Discussion:** The list of pre-defined filters, by way of example, should include ones for supernovae and microlensed sources.

2.6  Science Data Products

2.6.1  Science Data Products

ID: LSR-REQ-0031

**Discussion:** The requirements that follow govern the content and organization of the data products to be delivered by the LSST Observatory and the need to support the 4 primary science missions of the LSST.

2.6.1.1  Organization of Data Products

ID: LSR-REQ-0032

**Requirement:** The LSST data processing system shall provide the means for organizing the production of three classes of science data products: Prompt Products (nightly cadence, formerly known as Level 1), Data Release Products (yearly data release cadence, formerly known as Level 2), and User Generated Products (formerly known as Level 3). The science goals of Special Programs may require that their processed data products be made available in an additional fourth class, and possibly with intermediate timescales. LSST should also provide a means for this processing.

2.6.1.1.1  Level 1 Data Products

ID: LSR-REQ-0033

**Requirement:** The LSST Observatory shall produce Level 1 Data Products as the result of processing of the stream of image data from the Data Collection system during the course of normal observing.

**Discussion:** Level 1 data products are intended to enable time-domain science use cases requiring timely alerting and follow-up.

2.6.1.1.1.1  Level 1 Scientific Content

ID: LSR-REQ-0110

**Requirement:** The Level 1 data products shall include:

- Raw Science Images
- Calibrated Science Images (trimmed, de-biased, flattened, etc.)
- Difference Images
- Image Metadata/Catalog
- DIA Source Catalog
- DIA Forced Source Catalog
- DIA Object Catalog
- Solar System Orbit Catalog
- Transient Alerts
- Nightly Data Quality Summary Report
- Nightly Data Management System Performance Report

**Discussion:** Level 1 products are generated by pipeline processing the stream of data from the camera system during normal observing. Level 1 data products are therefore continuously generated and/or updated every observing night. This process is of necessity highly automated, and must proceed with absolutely minimal human interaction. In addition to science data products, a number of Level 1 SDQA data products are generated to assess quality and to provide feedback to the Observatory Control System. The abbreviation "DIA" stands for "Difference Imaging Analysis".

### 2.6.1.1.2 Level 1 Data Product Availability

**ID:** LSR-REQ-0104

**Requirement:** All Level 1 Data Products except Transient Alerts & Solar System Objects shall be produced and made publicly available within time L1PublicT of the acquisition of the corresponding raw images.

**Discussion:** The exceptions for Transient Alerts and Solar System Objects are defined in requirements LSR-REQ-0117 and LSR-REQ-0118, respectively.

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
<th>Unit</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum time from the acquisition of science data to the public release of associated Level 1 Data Products (except alerts)</td>
<td>24</td>
<td>hour</td>
<td>L1PublicT</td>
</tr>
</tbody>
</table>

#### 2.6.1.1.2.1 Level 1 Data Product Availability for Solar System Objects

**ID:** LSR-REQ-0118

**Requirement:** Solar System Objects shall be made publicly available within L1PublicT of successful moving source linkage and orbit computation.

**Discussion:** It takes multiple visits to the same Solar System Object in order to successfully link moving sources and compute their orbital parameters. As such, the time in which Solar System Objects can be made publicly available is dependent upon the time it takes to obtain these multiple visit images.

#### 2.6.1.1.2.2 Level 1 Data Product Availability for Transient Alerts

**ID:** LSR-REQ-0117

**Requirement:** Transient Alerts shall be produced and made publicly available within time OTT1 of the
acquisition of the corresponding raw images.

**Discussion:** OTT1 is the SRD (LPM-17) latency requirement and is defined in SRD section 3.4. LSR requirement LSR-REQ-0101 defines the design value to be used for design purposes.

### 2.6.1.1.3 Calibration, Engineering, Ancillary, and Provenance Data

**ID:** LSR-REQ-0034

**Requirement:** The Level 1 Data Products shall include all collected calibration, engineering, and ancillary data, as well as all processing history and provenance required to understand how the Level 1 Data Products were generated and to allow their reproduction from the raw input data.

### 2.6.1.1.4 Science Data Quality Monitoring

**ID:** LSR-REQ-0035

**Requirement:** Level 1 Data Product production shall include the production of sufficient Science Data Quality Assessment (SDQA) data, in a manner which supports feedback of observatory and observing conditions to the Observatory Control System, and alerts to observatory operators when poor quality data are detected.

### 2.6.1.1.5 Science Data Quality Archiving

**ID:** LSR-REQ-0105

**Requirement:** SDQA data produced shall be archived in association with the corresponding raw image data.

### 2.6.1.2 Level 2 Data Products

**ID:** LSR-REQ-0036

**Requirement:** The LSST shall produce a set of Level 2 Data Products as the result of periodic processing of the entire archive of raw image data from the Data Collection system.

#### 2.6.1.2.1 Level 2 Scientific Content

**ID:** LSR-REQ-0037

**Requirement:** The Level 2 Data Products in a Data Release shall include:

- images, corrected for instrumental artifacts and photometrically and astrometrically calibrated,
- measurements of the properties (positions, fluxes, shapes, motions) of all detected objects, including those below single visit sensitivity limit;
- astrometric and photometric calibration of the object catalog,
- photometrically calibrated light curves for all detected objects,
- orbital parameters for Solar System Objects (see discussion in LSR-REQ-0024),
- characterization of objects based on their static properties and time-domain behavior, and
- deep co-added images of the full survey area on the sky.

**Discussion:** The determination of motions for objects below the single-visit sensitivity limit will be constrained by the data and by computational limits, and may have limited precision or be possible only in a limited part of parameter space. The intent is to provide sufficient capability to support the planned TNO/KBO science.

Note that the requirement to provide light curves for "all" detected objects implies the provision of forced photometry, for the evaluation of light curves below the single-visit sensitivity limit.

Examples of characterization of objects include star-galaxy separation, or assessment whether an object is variable or not (see section 3.5 of the SRD).

### 2.6.1.2.2 Production in Data Releases

**ID:** LSR-REQ-0038

**Requirement:** All Level 2 Data Products shall be produced in the context of Data Releases. These Data Releases shall be produced at intervals no less than the Survey Specification for standardized data release interval - DRT1 (see LSR-REQ-0102).

**Discussion:** Data Releases will be performed more frequently during the first year of the survey.

### 2.6.1.2.3 Calibration, Engineering, Ancillary, and Provenance Data

**ID:** LSR-REQ-0039

**Requirement:** A release of Level 2 Data Products shall include a consistent set of all necessary calibration, engineering, and ancillary data, and all processing history and provenance, required to understand how Level 2 data products were generated, and allow their reproduction from the raw input data.

### 2.6.1.2.4 Data Quality Monitoring

**ID:** LSR-REQ-0040

**Requirement:** Level 2 Data Product production shall include the production and publication of sufficient SDQA data to allow the determination of the scientific usability of the data products and the assessment of the large-scale progress of the survey.

### 2.6.1.3 Level 3 Data Products

**ID:** LSR-REQ-0041

**Specification:** The LSST Observatory shall support Level 3 Data Products that are the result of processing based on Level 1 and Level 2 Data Products, of a nature specified by users (by the provision of code and/or processing configuration data).

**Discussion:** There will be technical limits on DM's ability to meet this requirement, such as cases where an intensive amount of additional computational resources is required, because only ~10% of the total computational system is allocated for user processing.
2.6.1.1.3.1 Level 3 Data Processing

ID: LSR-REQ-0106

**Specification:** The LSST Observatory shall provide software, services, and hardware resources to enable the production and storage of Level 3 Data Products. It shall be possible to produce Level 3 Data Products using LSST computing resources or elsewhere, and bring them into federation with Level 1 and 2 Data Products at the LSST data center.

**Discussion:** Level 3 Data Products are the result of processing that utilizes Level 1 and Level 2 Data Products, of a nature specified by users (by the provision of code and/or processing configuration data).

2.6.1.1.3.2 Level 3 Data Product Federation

ID: LSR-REQ-0107

**Specification:** The manner of production of Level 3 Data Products shall facilitate their federation with related Level 1 and Level 2 Data Products, when archived.

**Discussion:** The LSST project may, over time, promote selected Level 3 Data Products and their production to Level 2 or Level 1, subject to scientific justification and the availability of resources, and with the agreement of their originators.

2.6.1.1.4 Data Products for Special Programs

ID: LSR-REQ-0121

**Specification:** The LSST Observatory shall produce unique and separate Data Products as the result of processing data from Special Programs whenever possible, on a timescale that enables the intended science goals of the Special Program. The cumulative size of the online Special Programs data products shall be no more than ~10% of the size of the DRP data products from the most recent data release.

**Discussion:** As discussed in Section 1.5.1.3, the term "whenever possible" includes cases where the Data Management System can run original or reconfigured versions of existing pipelines, and excludes cases where the development of new algorithms, or the allocation of significant additional computational resources, are required. The cumulative size of the Special Programs data products is capped at ~10% of the most recent DR because this matches the expected fractional survey area of Special Programs compared to the main survey.

2.6.1.2 Science Flowdown

ID: LSR-REQ-0042

**Requirement:** The LSST Observatory shall produce the data products necessary to support the 4 primary science missions listed below.

**Discussion:** The 4 key science drivers listed below are meant to exercise the extremes of capability phase space, thereby enabling a broad range of parallel scientific research. Additionally, the repeating of these key science drivers from the SRD support the traceability of more detailed requirements at the OSS level.
2.6.1.2.1  Data Products for Dark Energy/Matter Science
ID: LSR-REQ-0043

Requirement: The LSST Observatory shall provide the necessary data products to support the Constraining Dark Energy and Dark Matter science as described in the LSST SRD.

2.6.1.2.2  Data Products for Solar System Science
ID: LSR-REQ-0044

Requirement: The LSST Observatory shall produce the necessary data products to support the Taking an Inventory of the Solar System science case described in the LSST SRD.

2.6.1.2.3  Data Products for the Transient Sky
ID: LSR-REQ-0045

Requirement: The LSST Observatory shall produce the necessary data products to support the Exploring the Transient Sky science case described in the LSST SRD.

2.6.1.2.4  Data Products for Milky Way Science
ID: LSR-REQ-0046

Requirement: The LSST observatory shall produce the necessary data products needed to support the Mapping the Milky Way science case described in the LSST SRD.

2.7  Data Archiving & Services

2.7.1  Data Archiving & Services
ID: LSR-REQ-0047

Requirement: The LSST shall archive all image, catalog, engineering, calibration, and environmental data collected during the course of the survey, and shall make this data available for analysis and distribution.

2.7.1.1  Raw Image Data Archiving
ID: LSR-REQ-0048

Requirement: The LSST system shall archive all raw science and calibration image data, collected in the course of the survey as well as data collected during engineering and calibration operations, as well as all wavefront sensor data. It shall also permit the archiving of such diagnostic image data as may be needed to support the commissioning, calibration, and maintenance of the observatory.

2.7.1.2  Meta Data Archiving
ID: LSR-REQ-0108

Requirement: The LSST system shall archive sufficient information to permit the reliable and reproducible retrieval of calibrated image data.

Discussion: Calibrated image data must be available to retrieve, but may be reconstructed on demand as
an alternative to its direct archiving (see LSR-REQ-0049).

2.7.1.3 Data Product Archiving

ID: LSR-REQ-0049

Requirement: The LSST system shall archive all generated Level 1, Level 2, and Calibration Data Products, or provide services to reconstruct any given data product on demand. When regenerated on-demand, the Data Products shall be scientifically equivalent – i.e. at a level of precision sufficient to reproduce the primary and derived attributes well within their formal uncertainties.

Discussion: Floating-point operations can return slightly different results on different hardware and guaranteeing absolute bitwise reproducibility across generations of hardware platforms is infeasible. These differences are typically in the least significant bit(s) that are already dominated by numerical or measurement noise. Thus the scientific impact is minimal, if at all existent.

Nevertheless, whenever viable algorithmic alternatives exist they will be preferred to those that are potentially hardware dependent, indeterministic, or numerically unstable.

2.7.1.3.1 Level 3 Data Product Archiving

ID: LSR-REQ-0050

Specification: Level 3 Data Products shall be archived, subject to project approval, based on user applications. An administrative mechanism shall be established to allocate a certain fraction of project resources for this purpose and to allocate that fraction to approved user requests based on their assessed usefulness to the project and the achievement of its science goals, and their value to the LSST user community.

2.7.1.4 Engineering and Environmental Data Archiving

ID: LSR-REQ-0051

Requirement: The LSST system shall archive all ancillary (e.g. engineering and environmental) data collected by the observatory.

2.7.1.5 Public Data Release

ID: LSR-REQ-0052

Requirement: The LSST System shall provide open access to all LSST Level 1 and Level 2 Data Products, in accordance with LSST Corporation Board approved policies. This shall include access to all engineering, environmental, and ancillary data required for scientific interpretation of the Data Products.

Discussion: Level 3 Data Products may or may not be available for open access, depending on agreements with their creator. Whether the creator is willing to accept open access is a criterion that may be used to determine how the project’s resources for Level 3 Data Product archiving and service are allocated.

The LSST Corporation reserves the right to retain confidential business records, proposals, personnel files, medical records, or other confidential documents, obtained from others.
2.7.1.5.1 No Proprietary Period

ID: LSR-REQ-0059

Requirement: The raw survey data and processed data products shall be released as Open Data and Open Source to the US, Chile, and foreign partners without any proprietary period (via MOU as per LSST Board policy).

Discussion: A necessary step in releasing the processed data is to perform Science Data Quality Analysis (SDQA). If intermediate data products or products that have not undergone quality assessment are made available, they will be clearly marked and documented as such.

2.7.1.5.2 Data Distribution

ID: LSR-REQ-0053

Requirement: The LSST shall permit and facilitate the bulk distribution of its public data to remote sites or users wishing to consume or host it, subject to the availability of resources and the data access policy from LSR-REQ-0052.

Discussion: This requirement is not intended to create an open-ended obligation to add bandwidth for data distribution. In cases where remote sites wish to host a large amount of LSST public data, it is anticipated that some cost-recovery arrangement may be needed to support the installation of additional data distribution capacity.

2.7.1.5.3 Data Product Access Interface

ID: LSR-REQ-0054

Requirement: The LSST shall provide access to all its public data products through an interface that utilizes, to the maximum practicable extent, community-based standards such as those for pixel-based images (e.g. FITS), as well as those being developed by the Virtual Observatory (VO) community, and that facilitates user data analysis and the production of Level 3 and other user-defined data products at LSST-provided facilities and at remote sites.

2.7.1.6 Community Computing Services

ID: LSR-REQ-0055

Requirement: The LSST shall provide and maintain an amount of computing capacity equivalent to at least userComputingFraction of the total LSST data processing capacity (computing and storage) for the purpose of scientific analysis of LSST data and the production of Level 3 Data Products by external users.

Discussion: The detailed scope of this service is to be determined based on a representative set of system queries and analyses assembled from community input and based on MOUs with other organizations willing to serve part of the public access distribution.

The fraction set by this requirement refers only to project funded resources. The LSST Observatory expects and will facilitate community use of grid, peta-scale computing centers, etc.
### 2.7.1.7 Data Curation

**ID:** LSR-REQ-0056

**Requirement:** The LSST Observatory shall develop a data curation plan that is consistent with developing community standards (e.g. Open Archival Information System - OAIS, or the NSF DataNet Initiative) to the extent allowed by project budgets and schedules.

**Discussion:** It is important that all archival data products generated by the LSST Observatory be managed to ensure their long-term usability. This includes not only the preservation of the data itself, but the additional information required to make it understandable by scientific users.

### 3 Survey Operation & Administration

#### 3.1 Survey Operation & Administration

**ID:** LSR-REQ-0057

**Requirement:** The Observatory shall be designed and developed to efficiently manage the execution of the survey.

**Discussion:** The LSST Observatory will be a comprehensive project to capture, process, archive, and serve data.

##### 3.1.1 Operational Safety

**ID:** LSR-REQ-0058

**Requirement:** The LSST shall be designed, constructed, and operated so that the safety of personnel, followed by safety of equipment, and then the integrity of the data are preserved.

**Discussion:** The detailed safety requirements and applicable external codes are documented in the Observatory System Specifications Document.

##### 3.1.2 Science Priorities and Survey Monitoring

**ID:** LSR-REQ-0070

**Requirement:** The LSST project shall monitor the scientific and technical progress of the survey, communicate with the scientific user community and establish survey priorities, and adjust the survey design as needed to accomplish its goals given these priorities and achieved performance.

#### 3.1.2.1 Science Objectives Definition

**ID:** LSR-REQ-0063

**Requirement:** The Observatory system shall provide the ability to define a set of scientific objectives and
associated performance metrics, which shall be used to assess and control the sequence of observations to optimally satisfy these objectives.

**Discussion:** The reference survey can be accomplished with many different observing cadences or sequences that impact the scientific reach of the accumulated data.

### 3.1.2.2 Adjustment of Survey Priorities

**ID:** LSR-REQ-0064

**Requirement:** The operation of the LSST Observatory shall allow for periodic adjustment of the survey priorities based on community input.

**Discussion:** This requirement is intended to ensure that the survey priorities and scheduling can be adapted to address any changes in the scientific landscape that can occur on a 10-year timescale. It is intended that these adjustments be assessed on relatively long time scales (e.g. every 6 months).

### 3.1.2.3 Survey Performance Reviews

**ID:** LSR-REQ-0065

**Requirement:** The Observatory shall have the ability to provide periodic status reports on the progress of the survey to allow both operations staff and the community to assess the survey progress.

### 3.1.2.4 Survey Performance Evaluation

**ID:** LSR-REQ-0066

**Requirement:** The Project shall create the necessary survey performance evaluation tools to predict the final results of the ten year survey based on the actual survey completed to date, assess the impacts of survey strategy changes resulting from changes in scientific priorities, and support the planning of the survey on a variety of time scales, from nightly through the entire 10 year duration.

### 3.1.3 Overall Operational Efficiency

**ID:** LSR-REQ-0073

**Requirement:** The LSST system shall meet the Survey Design Specifications for number of visits and area coverage, including the constraints of weather, system dynamics, scheduled maintenance, and unscheduled down time.

**Discussion:** The specifications for the allowed allocations to each of the terms for non-observable time are contained in the companion document *the Observatory System Specifications* (document LSE-30).

### 3.1.3.1 Survey Time Allocation

**ID:** LSR-REQ-0075

**Requirement:** The LSST Survey performance requirements shall be met utilizing approximately 90% of the historically available observing time, leaving the remaining time available for yet to be defined special programs (e.g. targeted deep drilling programs or Targets Of Opportunity - TOO).
3.1.3.2  System Operational Lifetime

ID: LSR-REQ-0076

Requirement: The LSST system shall meet all its requirements and specifications over the full duration of the 10 year survey.

3.1.3.2.1 Preventive Maintenance

ID: LSR-REQ-0077

Requirement: The LSST system shall prepare a maintenance and reliability plan to ensure LSR-REQ-0076 (above) is met with an optimum balance between preventive maintenance and replacement strategies.

Discussion: Preventive maintenance implies servicing, repairing, and replacing components and subsystems based on their expected lifetime, as opposed to their failure.

3.1.3.3 Graceful Degradation

ID: LSR-REQ-0074

Requirement: The LSST system will be designed so that its performance degrades gracefully in the presence of adverse environmental and/or operating conditions.

3.1.4 LSST Broader Impacts

ID: LSR-REQ-0061

Specification: The LSST Observatory shall include an Education and Public Outreach program that supports Federal "Broader Impacts" requirements encompassing "the potential to benefit society and contribute to the achievement of specific, desired societal outcomes".

Discussion: The National Science Foundation supports programs based both on intellectual merit and broader impacts. The National Science Board strives for all American citizens to have the basic scientific, technological, and mathematical knowledge to make informed personal choices, to be educated voters, and to thrive in the increasingly technological global marketplace. The National Research Council, through its development of Science Education standards, addresses the critical issues of STEM Education, U.S. competitiveness and workforce preparation.

3.1.4.1 EPO Users

ID: LSR-REQ-0112

Specification: LSST-EPO shall be user-centered, building learning experiences to meet the needs of specific audiences while proactively engaging diverse learners and those who are traditionally underrepresented in STEM fields.

Discussion: The audience for LSST EPO is potentially quite large, being any non-science user with an internet connection. It is necessary to prioritize and target specific settings and user groups to maximize the impact of the system. Increasing diversity in the STEM workforce is essential to sustained national prosperity. The specific audiences are defined in the derived OSS requirements (OSS-REQ-0356, OSS-REQ-0357, OSS-REQ-0358).
3.1.4.2   EPO Products, Tools, and Interfaces

ID: LSR-REQ-0113

Specification: LSST EPO shall provide access to LSST data through tools, interfaces, and learning experiences that are designed to engage communities with different levels of knowledge, experience and skills.

Discussion: Astronomy is known to be an entryway to science for everyone, not just those who end up in STEM careers. Engaging learners in authentic science experiences is the best way for them to learn and gain an understanding of science topics and the research process. Boundaries between learning environments are becoming less defined, as learners become more self-directed and lifelong learning is recognized for its value. LSST EPO products, tools, and interfaces, which are to be innovative and user-friendy, can be used in multiple settings; for example, citizen science projects can take place online, incorporated into classroom settings, and introduced in informal science settings through a kiosk or interactive planetarium show.

3.1.4.3   EPO User Impacts

ID: LSR-REQ-0114

Specification: LSST EPO shall conduct an evidence-based evaluation program that measures (user-centered) performance metrics as well as outcomes defined as demonstrated changes in understanding, appreciation, skills, knowledge, or awareness.

Discussion: It is important to use, identify, and share evidence based approaches to program development and evaluation for maximum impact as described in the OMB STEM Strategic Plan.

3.1.4.4   EPO Longevity

ID: LSR-REQ-0115

Specification: The LSST EPO plan shall be agile and remain relevant and effective for the full survey duration, making adjustments that reflect technology trends and educational priorities.

Discussion: In addition to using flexible interface designs and elastic computing resources, it will be necessary to build strong partnerships with external organizations to maximize the longevity of the system.

3.1.4.5   EPO Fully Integrated

ID: LSR-REQ-0116

Specification: LSST EPO shall be fully integrated into the design of LSST so that effort can be shared and leveraged during construction. Additionally, Citizen Science results that extend the science goals of LSST shall be made available to science users during operations.

Discussion: The LSST EPO subsystem is not an add-on to the observatory conceptually or functionally. The science and education goals have been developed in tandem as has the implementation of the system to support those goals. Big Understandings of the EPO learning activities are aligned with the LSST science mission and the DM/EPO interface allows for both transfer of data to the EPO system and the return of
EPO-generated results that can be integrated with science data products for the community. In this way the education and science from LSST are collaboratively maximized.