LSST Data Management System
Applications Layer
Simulated Data Needs Description:
Simulation Needs for DC3

Draft

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A joint document from the LSST Data Management Team and Image Simulation Team
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1. Introduction

The LSST Data Management System (DMS) is responsible for receiving raw image data and ancillary telemetry from LSST camera/telescope systems, generating transient alerts on a nightly basis, and on a longer term generate photometrically and astrometrically calibrated images and extracted source catalogs. The Applications Layer of the LSST DMS is responsible for developing and implementing software and operations systems for data processing, archiving and distribution.

The LSST Image Simulation (IS) team is responsible for the development of an efficient high fidelity image simulator that includes input source models, an atmospheric model, an optics and control system model of the LSST telescope and camera, a detector model. This image simulator produces example images of requested fidelity and size that support multiple goals of the LSST team. A primary goal of the IS effort is to support the Data Challenges (DC) that are needed to guide the development of the DM system. This document specifically addresses the request by DM for DC3.

The framework and algorithm performance of Applications software subsystems and modules will be tested using a combination of "precursor" image data of the sky taken with other wide-field imaging systems (e.g. CFHT Legacy Survey data) and simulated images and source catalogs designed to represent the features of the LSST observing system and operational modes.

This document describes general characteristics of simulated LSST data that are needed to support development and testing of elements of the LSST Data Management Systems Applications Layer, and specifically for the third Data Challenge (DC3) in the LSST R&D period.

Section 2 contains a summary of the DC3 Applications tasks that require the use of simulated data, and thus that define the drivers for the simulations described in this document. Section 3 of this document contains a matrix of different simulation properties, the requirements on the composition of the simulation, the primary customers (Applications personnel) of each particular simulation property, the motivation and/or rational for the property, open questions or comments about the property, and finally the need-by date to support DC3 development. Section 4 contains a hierarchy for describing simulations that will be referred to later in the document, and in future versions. Section 5 contains a description of the image and catalog simulations that will be required specifically for DC3.

Section 6 and 7 contain a selection of attributes and parameters relevant to current and future Applications development that will eventually need to be represented in simulated Image, Catalog and accompanying ancillary data. While only a subset of these is required for DC3 simulations, a more complete listing is provided here for informational purposes.

2 DC3 Applications Development Objectives

The table below contains a subset of the DMS Applications development tasks for DC3 that will require access to simulated LSST image and catalog data. This is not a comprehensive listing of DC3 objectives, but rather the subset that drive the definition of simulated data needs.

At the highest level, the Applications development during DC3 focuses on four key areas: 1) extension of the Nightly Pipeline functionality and 2) development of the first release of the Data Release Pipeline, 3) development of the first release of Science Data Quality Analysis system in support of the Pipeline activities, and 4) continuation of scaled tests of queries on the source and object databases that are produced by the Nightly and Data Release Pipelines. The table below is organized along these four key areas.

A number of the DC3 development activities will make use of precursor image and catalog data sets (e.g. CFHT Legacy Survey). These are not included in this listing.

Table 1 - DC3 Tasks Requiring Simulated Data

Ref	Category	Task	Lead	Sims
1	Nightly PL	PSF generation	Lupton/Becker	Image
2	Nightly PL	Source classification (point/not-point)	Lupton/Becker	Image
3	Data Relase PL	Image Coaddition: resampling, stacking and combining	Owen/Connolly	Image
4	Data Release PL	Template Image Generation for image differencing	Connolly/Owen	Image
5	Data Release PL	Deep Source Detection on coadded images	Lupton/Becker	Image
6	Data Release PL	PSF-fit photometry	Becker/Lupton	Image
7	Data Release PL	Confused source deblending	Becker/Lupton	Image
8	Data Release PL	Multifit galaxy shape and photometry characterization	Wittman	Image
9	Data Release PL	Extended source photometry framework (Gaussian approx)	Becker/Lupton	Image
10	Data Release PL	Photometric Calibration: time dependence, simulated PL algorithms	Axelrod	Cat
11	Data Release PL	Astrometric calibration: Low order term determination	Monet	Cat

3 Simulation Needs by Property

LSST DMS Applications developers working on aspects of the DC3 task have supplied a description of the properties of simulated image and catalog data that they require to implement and test their subsystems and modules. These are summarized in tables 2 and 3 below.

Table 2 - Simulated Image Data Properties

Image Sim property	Requirement	Customers	Motivation	Questions/comments
Size (focal plane)	3 adjacent rafts (9 CCDs within each raft)	Becker, Monet	Sample range of optical distortions. Isoplanatic seeing patch.	Need to justify size better
Source density	2 density levels for stars and galaxies (average density and 4x average density)	Becker	Source detection/extraction as function of crowding	Need science driver
Source spatial distribution	Appropriate clustering for galaxies and appropriate densities for stars. Use Galactic stellar model	Becker, Monet	Astrometric grid	What about clustering ?
Source types & shapes	Stars & galaxies (range of galaxy shapes and galaxy/star ratios vs. depth)	Becker, Wittman	Source detection/extraction as a function of shape	What range of galaxy shapes is needed ?
Atmospheric Seeing (PSF size & shape)	3 values (0.4, 0.8, 1.2arcsec FWHM)	Becker, Wittman	Source detection/extraction under realistic PSF variations	Are three PSF sizes enough for Wittman, provided galaxy shape variations are large (he asked for a lot of PSF variations: 200)?
Airmass	3 airmasses (1,1.5,2)	Becker	Source matching with differential refraction ?	
Source brightness distribution (S/N)	Galactic stellar model, Cosmological model	Monet, Becker	Astrometric grid, source detection	
Image Distortions (across focal plane)		Becker, Monet, Wittman	Detection, astrometry, weak lensing	Tied into size but need estimate of distortion parameters and ranges expected
filters	1: r-band	Becker, Wittman	Source detection/extraction vs. filter properties	Need 2 filters to examine color effects.
Depth	2 (one at full year depth and the rest at 15sec). Full CRONOS.92 cadence.	Becker Monet	Template for image subtraction and sampling of other parameters. Astrometric solution including parallax and proper motion.	What is the minimal sampling to determine astrometric errors?
Background (level and spatial variation)	2 (bright, dark)		Detection	
Variability (intrinsic)	10% of sources variable across images	Becker	Source detection/extraction vs. S/N ?	What variation amplitudes are needed ? Is a 10% variable source fraction realistic ? Isn't this a parameter for the catalogs and source matching across time/filters ?

Notes for Table 2:

(1) Source density: realistic values at r<28th magnitude and 4x this nominal value. Source densities to be specified via realistic luminosity functions of stars and galaxies appropriate for the field locations.

(2) Clustering: Galaxies will have appropriate 2 point correlation statistics, Stars will have stellar densities appropriate for galactic coordinates (but no clustering)

(3) Sizes and shapes of galaxies: will be defined from distributions derived from simulations. For DC3 the simulations will be base on Sersic profiles.

(4) Source brightness: will be defined in the input catalogs

(5) Atmospheric absorption: will be based on MODTRAN4 realizations of the atmosphere for a given telescope pointing. Initially, model absorption spectra will be input as a text file (associated with the catalog input data) and applied to the source SEDs within the image simulator. The absorption spectra will be output as part of the catalog simulations.

(6) Variability: Initial variability will be based on an rms sampling of the sources.

(7) World Coordinate System: A basic WCS will be defined within the header of the CCD images. This, together with the input catalog shall be sufficient to solve for a full WCS solution.

Table 3 - Simulated Catalog Data Properties

Catalog Sim property	Requirement	Customers	Motivation	Questions/comments
Astrometry (RA, DEC, PM, Parallax)	Randomly distributed positions, PM (stars). Galactic stellar model	KT, Monet	Database population and source to object matching. Astrometric solution.	What range in PM is required ? What range in posn. error is required ?
Number of objects	Sources: 5E9 galaxies, 1E10 stars Objects: 5E8 galaxies, 1E9 stars	KT	Data volume and scalability tests	
Source types & shapes	Stars & galaxies (realistic range of galaxy shapes and galaxy/star ratios vs. depth)	KT	Source identification / classification vs. type	
Photometry	Fluxes and noise estimate over expected range. Depth = 26 mag	KT, Monet	Test averaging over low SNR data. Astrometric solution.	Is averaging over time or source type ?
Variability (intrinsic)	Realistic sampling of variability	KT	Source matching across images. Limits.	What variation amplitudes are needed ? Is a 10% variable source fraction realistic (see above).
Filters	2 or more with some sources missing from one filter set	KT	Source matching across filters when overlap is incomplete	
Scenes	10% of sky covering a variety of astrophysical scenes	KT	Source identification / classification over variety of densities (clustering)	

Note: both Source (nightly differences) and Object (associations) catalogs are required for DC3 with the assumption that there are a factor of ~10 more sources than objects.

4 General Simulation Description Hierarchy

4.1 Image Data

We describe here a convenient hierarchy for describing and tracking the desired attributes of simulated image data necessary to test the Applications development for LSST DMS. This organization generally approximates the path photons take from the astrophysical setting, through the atmosphere, through the telescope and camera system, and onto the sensors within the camera.

A simulation description begins with the astrophysical scene at a particular time that produces photons. These photons pass through the atmosphere whose transparency and disturbing effects (e.g. seeing, extinction) vary with time (an observation). The photons are imaged by the telescope/camera system that introduces distortion, aberration and scattered light that may vary with telescope attitude and environmental conditions. The photons ultimately impact the focal plan sensor array that has a particular physical configuration (piston offsets, tilts, etc). Each detector in the array imparts its own signature on the resulting image delivered to the DMS according to their physical and electronic characteristics (e.g. QE, bias, dark current, read noise, linearity, responsivity, charge transfer efficiencies, bleed, etc).

A sample of the attributes that may be simulated in each of these hierarchy layers is given in Section 6.

A particular image scene may be observed through a variety of atmospheric conditions, which in turn may be observed by a variety of different telescope configurations. Each of these combinations can be simulated for a variety of focal plane/sensor configurations. The resulting path of simulations can be visualized as a familiar inverted tree structure. The trunk represents the scene at a given time, and then it branches to a set of atmosphere conditions, each of which branches to a set of telescope configurations, which each branch to a set of focal plane/sensor models, etc. Layers to the hierarchy can be added as necessary to accommodate additional specifications such as different times for variable scenes or filter passbands.

Although the combinatorial nature of the tree structure implies a large number of possible simulation configurations, it does not require them. For example, it may be desired to simulate images of a particular scene and atmospheric condition, through a specific telescope model, but with a variety of focal plane/sensor configurations. These simulations are described by a limited number of specific paths through the tree structure.

Based on this hierarchy we define terms that we will use throughout the rest of this document to describe the IS data:

Scene: a set of input catalogs (source brightnesses and positions etc) that describe the astrophysical properties of a data set.
Observation: a single realization of a scene for a given airmass, seeing, rotation angle, atmospheric model and timestamp.
FOV: images and catalogs for all (or a subset of) CCDs within a single LSST field-of-view. All images within a FOV will have the same parameters described by the scene and observation (i.e. a common timestamp and atmosphere, telescope and camera definitions)
Raft: Nine CCDs aligned on the focal plane as defined by the camera specifications
CCD: One CCD as defined by the camera specifications

4.2 Catalog Data

Database scalability tests and astrometric solution tests are the primary drivers for simulated catalog data in DC3. Database scalability tests will focus on high-volume end-user query loads. Astrometric tests will attempt to demonstrate that the solution pipeline can deliver the required accuracy for a realistic telescope model and observing cadence.

Both object and source catalogs are needed to cover the spatial and temporal dimensions of the LSST survey. Simulated object and source catalogs can be generated by ‘observing’ a truth catalog at one or more cadences, or by randomly varying source parameters for each visit.

It will not be possible at this stage to run a full image data simulation for each observation, which would be computationally prohibitive. Instead, object and source data can be statistically drawn from more or less realistic distributions of location, brightness, morphology, and observing conditions.

The spatial distribution of objects in the truth catalog should be as realistic as possible at this stage for both database scalability and astrometric requirements. Realistic distributions of stellar proper motions, parallaxes, and their errors are required in order to simulate a full astrometric solution for the survey.

Realistic distributions of intrinsic source properties such as brightness, morphology, and variability are less crucial at this stage. The primary requirement is that these parameters cover the full range and depth of the LSST survey.

5 Simulation Needs for DC3

DC3 will address, in part, the ability of the data release pipeline to combine images from multiple exposures (coaddition) and to detect and characterize objects from the combined image sets.

Coaddition must be able to combine optimally images of the same objects from different parts of the focal plan taken under potentially different atmospheric conditions. Thus, image simulations must capture in a representative way the effects of aberrations produced by telescope optics, focal plane geometry, and variations in image quality produced by the atmosphere (e.g. atmospheric seeing and differential chromatic refraction).

Characterization of sources detected on the coadded images is performed on the "stack" of individual exposures covering a particular region of the sky. This is done using the an algorithm that fits source templates simultaneously to the images of the same object in the "stack." Thus, image simulations must capture the effects that result in images of the same object being represented by a variety of PSFs depending on atmospheric conditions, telescope aberrations/distortions and possible sensor effects such as charge transfer efficiency.

It is recognized that it is not practical to generate a completely populated “tree” of simulations, as described in the hierarchy in Section 4. It is sufficient for DC3 needs to sample a relatively small number of simulation branches that are representative of the range of conditions that might be experienced during LSST operations. The goal of DC3 is to demonstrate feasibility of design rather than to exhaustively test all possible conditions.

The delivery of simulated data by the IS team to DM will be in the form of images, associated catalogs and ancillary information that describes the simulations.

Two sets of data will be delivered for DC3. The first of these sets will comprise a series of FOVs with 18 CCDs (corresponding to 3 rafts) to be used in source charcterization. The second data set will amount to a series FOVs with one CCD to be used in image coaddition

Details of these simulations are given below and in Table 2.

5.1 Simulation Configuration and outputs

There are approximately 1200 parameters in the current version of the image simulator. For each delivered FOV the parameters describing the simulation (atmosphere, telescope, camera and detectors etc) will be independent realizations. The values of these parameters will be selected by the IS group from distributions of likely values. The current models of the LSST image simulator (atmosphere, telescope, camera and detectors as of the date of this document) are sufficient for DC3 identified needs. There are parallel efforts to improve these models so, in some cases, new parameters may be added prior to the final delivery of images for DC3.

The DM group can specify parameters that must be held constant or varied for each FOV (e.g. airmass, seeing). For DC3 these parameters and their values are specified in Table 2

The input catalogs and the models used to select photon samples for each source (star or galaxy) remains the primary definition of "truth". This is because all sources that are parameterized (stars, galaxies with Sersic profiles, galaxies from shapelets etc) can be specified exactly from the catalog information. This should be the primary source when comparing the outputs of the DM pipelines.

For each of the simulated FOVs specified by Table 2 the IS group will also generate an "ideal LSST reference image" with all the parameters set to ideal values. Seeing will be set to 0.1 arcsec FWHM. Airmass will be set to 1.0. All parameters of the telescope and camera will be set to nominal values with no perturbations (ideal LSST design optics). All detector chips will be flat with no tip or tilt. The CCDs will be pistoned to best focus for the r band. The atmospheric absorption will be turned off. This "ideal image" will be generated photon by photon as with other simulations. This is not intended to be a prediction of a perfect LSST telescope nor a definition of input truth. It will act as a secondary tool for understanding the nature of the input data.

The ideal reference image is a secondary and practical tool for understanding the nature of the input and for debugging and validation of the Applications algorithms. The total size of the ideal images will be (9 x 3 x 2 x 1 x 1 x 2 = 106 Chips). Producing the ideal images only increases the total DC3 requirement by 11% in size.

5.2 Coaddition and Deep Detection

For testing coaddition and deep detection of sources, image simulations of two r-band scenes are requested, one corresponding to the average detected surface density of stars and galaxies and one 4 times this density. Each scene should be generated for three different seeing conditions, and at least three airmasses per density. This translates into a request for observations of 2 scenes * 3 seeing conditions * 3 airmasses = 27 simulation images or a total of
972 (9 x 3 x 2 x 3 x 3 x 2) CCD sized images.

Ultimately, two observations of each scene/atmosphere/telescope/sensor combination are desired. However, the observations may be delivered in serial, with the first set available for the start of Data Release Pipeline development.

a. Scene description

- Two scenes with source densities corresponding to (1) the average detected star and galaxy densities and (2) 4x this average densities.

- Source populations to include a realistic number, spatial distribution and color distribution of Milky Way stars and background galaxies. The surface density of stars and galaxies will be defined by specified luminosity functions (i.e. number vs. flux density). The luminosity functions should extend to flux levels sufficiently below the expected coadded image detection limit so that the influence of source confusion noise may be sampled. The luminosity functions should be normalized to produce the surface density of stars and galaxies specified above. Galaxies should have a representative distribution of shapes and orientations, but they do not need to simulate weak lensing signatures. Solar system objects and other astrophysical transients not required.
- Realistic sky background levels, but structure not required.
- Sky backgrounds will be defined by the phase and angle to the Moon (with bright and dark skies specified in this manner)
- All images will be simulated in the r band

b. Atmosphere

- Simple, atmospheric model for extinction. The absorption spectrum will be delivered with the simulation data.
- Time and spatially variable PSF. PSF FWHM 0.4, 0.8 and 1.2".

c. Telescope configuration

- Single distortion and aberration model, flexure is optional.
- 3 different airmasses for each seeing (secZ = 1.0, 1.5 and 2.0)
- Representative dithering for each observation of a given scene.

d. Sensor configuration

- Single focal plane model, CCD piston and tilt are optional.
- Cosmic ray strikes/trails.
- Images may be delivered with instrumental signatures "removed". However, image noise should be representative of noise produced by sensor effects, such as bias, read noise, responsivity, etc. If images are simulated with instrumental signatures, then correction images must be supplied.

e. Image Area

- Each simulation should cover at least 3 contiguous rafts. Multiple, contiguous raft images will enable testing of CCD and raft edge effects.

f. Ancillary Information

- Input “truth” catalog of source information, including galaxy shapes, used to generate scenes
- Atmospheric absorption spectrum.
- Simulation input parameters
- Instrumental signature correction frames, if necessary.
- A WCS in the FITS header sufficient to derive the WCS in the DM pipelines.

g. Need by Dates

- A test set of images (10% of the total data volume) will be delivered 11/1/08 for validation of the data structure. Upon acceptance the large scale simulations will be initiated.
- Initial set of 27 CCD images and ancillary information, as specified above, required for the start of DC3 Data Release Pipeline development. 12/1/08.
- Two additional observations of each scene/telescope/atmosphere/sensor combinations by start of DC3 testing 3/1/09.

5.3 Source Characterization

For testing of the source characterization algorithms, one r-band image scene containing stars and galaxies of a variety of morphologies and sizes, but imaged with a large number of delivered PSFs is required. The PSFs should correspond to seeing FWHM values ranging from 0.4” to 1.8” in increments of 0.1”. The delivered PSF may be constant across the image. The simulations should be generated for at least two different airmasses, and at least three different observations of a given scene, so that a representative range of field (and therefore PSF) rotations may be sampled. This translates into a request for 1 scene * 15 seeing FWHM * 2 airmasses * 3 observations = 90 images. The simulated images should cover the area of one CCD detector. The input catalog of stars and galaxies (including shapes) should also be provided.

Note that the single image scene simulation used for testing source characterization may be a subset of one of the scenes simulated for testing of coaddition/deep detection.

a. Scene description

- One scene with a source density corresponding to r=28 for realistic luminosity functions of stars and galaxies. This can be the same scene described in 5.1.
- Source populations to include a realistic number, spatial and color distribution of Milky Way stars and background galaxies. The surface density of stars and galaxies will be defined by specified luminosity functions (i.e. number vs. flux density). The luminosity functions should extend to flux levels sufficiently below the expected coadded image detection limit so that the influence of source confusion noise may be sampled. Galaxies should have a representative distribution of shapes and orientations, but they do not need to simulate weak lensing signatures. Solar system objects and other astrophysical transients not required.
- Realistic sky background levels, but structure not required.
- Sky backgrounds will be defined by the phase and angle to the Moon (with bright and dark skies specified in this manner)
- All images will be simulated in the r band

b. Atmosphere

- Simple, atmospheric model for extinction. The absorption spectrum will be delivered with the simulation data.
- Time and spatially varying PSF FWHM ranging from 0.4"-1.8", in 0.1" increments.

c. Telescope configuration

- PSF may be isoplanatic. PSF model should be specified. If non-isoplanatic simulation model is used, variation across focal plane must be specified.
- Representative dithering for each observation of a given scene.

d. Sensor configuration

- Single CCD, so piston is not applicable. CCD tilt is optional.
- Cosmic ray strikes/trails.
- Images may be delivered with instrumental signatures "removed". However, image noise should be representative of noise produced by sensor

effects, such as bias, read noise, responsivity, etc. If images are simulated with instrumental signatures, then correction images must be supplied.

e. Image Area
- Each simulation should cover at least the area of one CCD in a raft.

f. Ancillary Information
- Input "truth" catalog of source information, including galaxy shapes, used to generate scenes
- Atmospheric absorption spectrum.
- Simulation input parameters
- Instrumental signature correction frames, if necessary.
- A WCS in the FITS header sufficient to derive the WCS in the DM pipelines.

g. Need by Dates

- Initial set of 15 images and ancillary information, as specified above, spanning the required range of seeing FWHM at one airmass, required for the start of DC3 Data Release Pipeline development. 12/1/08.
- Remaining observations of the scene delivered in phases, with all delivered by start of DC3 testing 3/1/09.

5.3 DC3 Catalog Needs

a. Scalability

The desire is to construct catalogs at 10% scale of first data release (DR1), covering 10% of the sky. The simulated object catalog should contain 9 billion stars, 5 billion galaxies. The simulated source catalog should be 10 times as large, with 95 billion stars and 56 billion galaxies. A source/object ratio of 10 is determined how?

b. Spatial and Velocity Distributions

Coverage of the full range of expected source densities on the sky can be achieved by simulating a 36 degree swath in Galactic longitude that covers the full range of Galactic latitude. Is it necessary to include stellar and galaxy clusters to probe the highest densities?

Astrometric tests require the stars to be distributed on the sky and in velocity space following a realistic Galaxy model. Proper motions have to be specified to an accuracy of 0.1 mas/yr in order to study streaming motions in the Galactic halo. Galaxy and quasar positions and magnitudes are needed as a rigid reference frame.

c. Cadence

A full cadence simulation is not required for database scalability tests but, the relative distribution of source/object numbers should be realistic. Astrometric tests do require a realistic cadence (e.g. CRONOS.92) with roughly 200 visits/object in order to determine stellar parallaxes and proper motions. It may be necessary to ignore other source parameters and include only astrometric parameters at high temporal resolution.

c. Depth

The depth of the source catalog should be similar to the expected coadd detection limit of 26th mag.

d. Realistic Object Parameters

The distributions of the following object parameters need to be realistic.

-RA, Dec.
-mag, magErr
-classification (star/galaxy)
-variability
-parallax
-proper motion

e. Realistic Source Parameters

The distributions of the following source parameters need to be realistic.

-RA,Dec.
-objectId
-modelMag: variability can be random
-SNR
-filter-ID

f. Other Object and Source Parameters

Full database scalability tests require 316 columns of data per object entry and 62 per source. However, typical queries search on only 6 columns, so perhaps the full set of columns is not necessary? Except for the parameters listed above, parameter values can be randomly distributed.

6 Appendix: Definition of Simulation Functionality required by DM

We define a set of attributes required by the Data Management group. These attributes are not specific to the DC3 simulations and are expected to grow with the continued development of the image simulations and pipeline development.

6.1 The Astrophysical Scene

a. Source types
   i. Stars (flux, color, spatial distribution)
   ii. Galaxies (flux, color, spatial distribution, morphology, lensing)
   iii. Solar system objects (flux, color, orbits)

b. Astrophysical Backgrounds
   i. Diffuse components (levels, temporal variations, spatial variations)

c. Transients / time variations
   i. Proper motions (stars, solar system objects)
   ii. Parallax
   iii. Intrinsic Flux variability (periodic, random, decay; AGN, stars, GRBs,SNe)

6.2 Atmosphere Description

a. Transparency
   i. Grey clouds (variations with time & pointing)
   ii. Non-grey clouds (variations with time & pointing)

b. Seeing (variations with time, across focal plane)

c. Foregrounds

i. Airglow (fringing), Zodiacal light
ii. Moonlight
iii. Clouds

d. Distortions (differential refraction)

6.3 Telescope Configuration

a. Field Distortions (variations across focal plane and telescope pointing)
b. PRF (variations across focal plane, diffraction)
c. Bandpass (out of band leaks)
d. Scattered light
   i. Internal scattered light
   ii. Ghosts
   iii. Fringing (filter)
e. Pointing error
f. Tracking (jitter)

6.4 Focal Plane/Sensor Configuration

a. Alignment
   i. CCD height
   ii. CCD tilt
b. Bias (overscan)
c. Dark current
d. Responsivity
e. Linearity
f. Pixel bleed
g. Charge transfer
h. Electronic ghosting
i. Cosmic ray profiles
j. Latent images

6.5 Catalogs

a. Source types
   i. Stars (flux, color, spatial distribution)

ii. Galaxies (flux, color, spatial distribution, morphology, lensing)
iii. Solar system objects (flux, color, orbits)

b. Photometry (depth, error distribution)

c. Astrometry (proper motion, parallax, error distribution)

d. Morphology (type/shape classification, error distribution)

e. General

i. Areal coverage
ii. Size (data volume)