Overview of LSST Tools and Simulations

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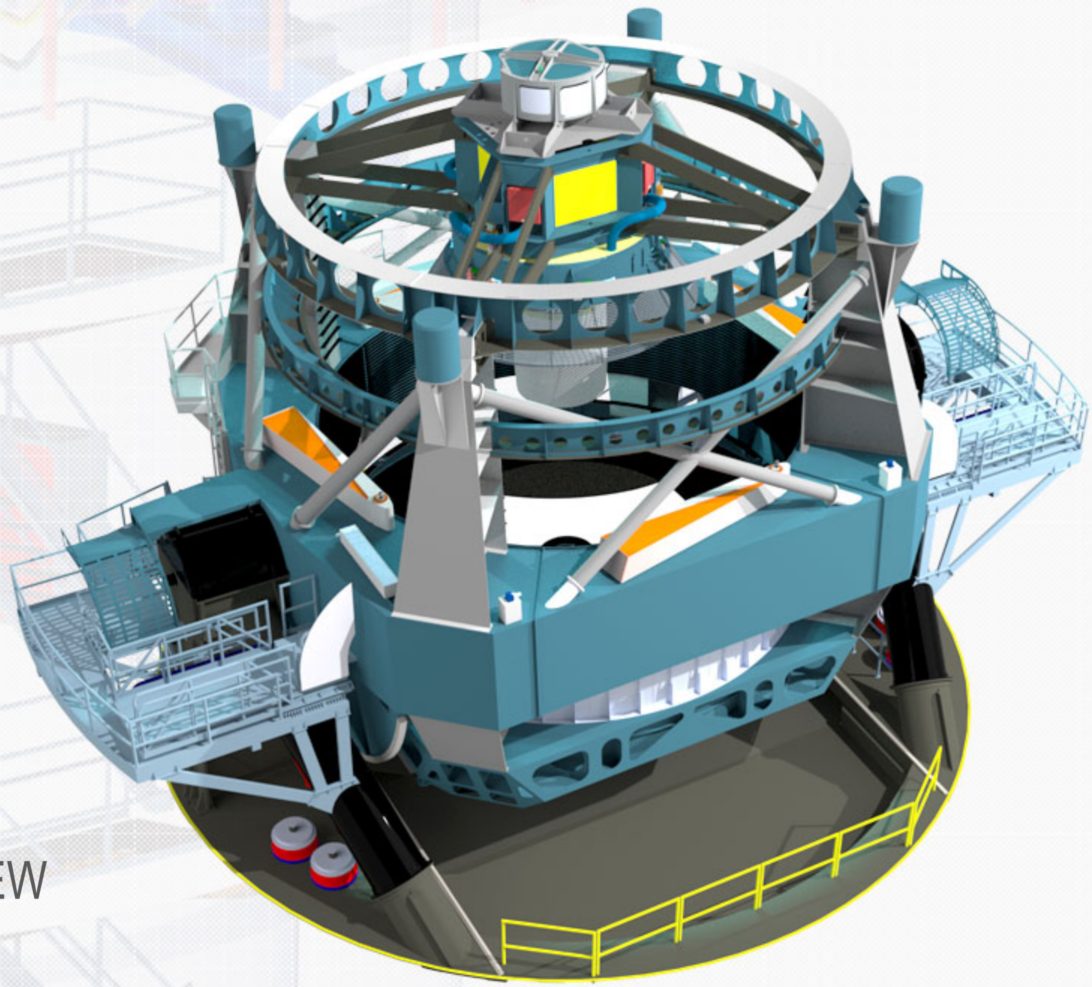
22nd October 2013



FINAL DESIGN REVIEW

October 21 - 25, 2013

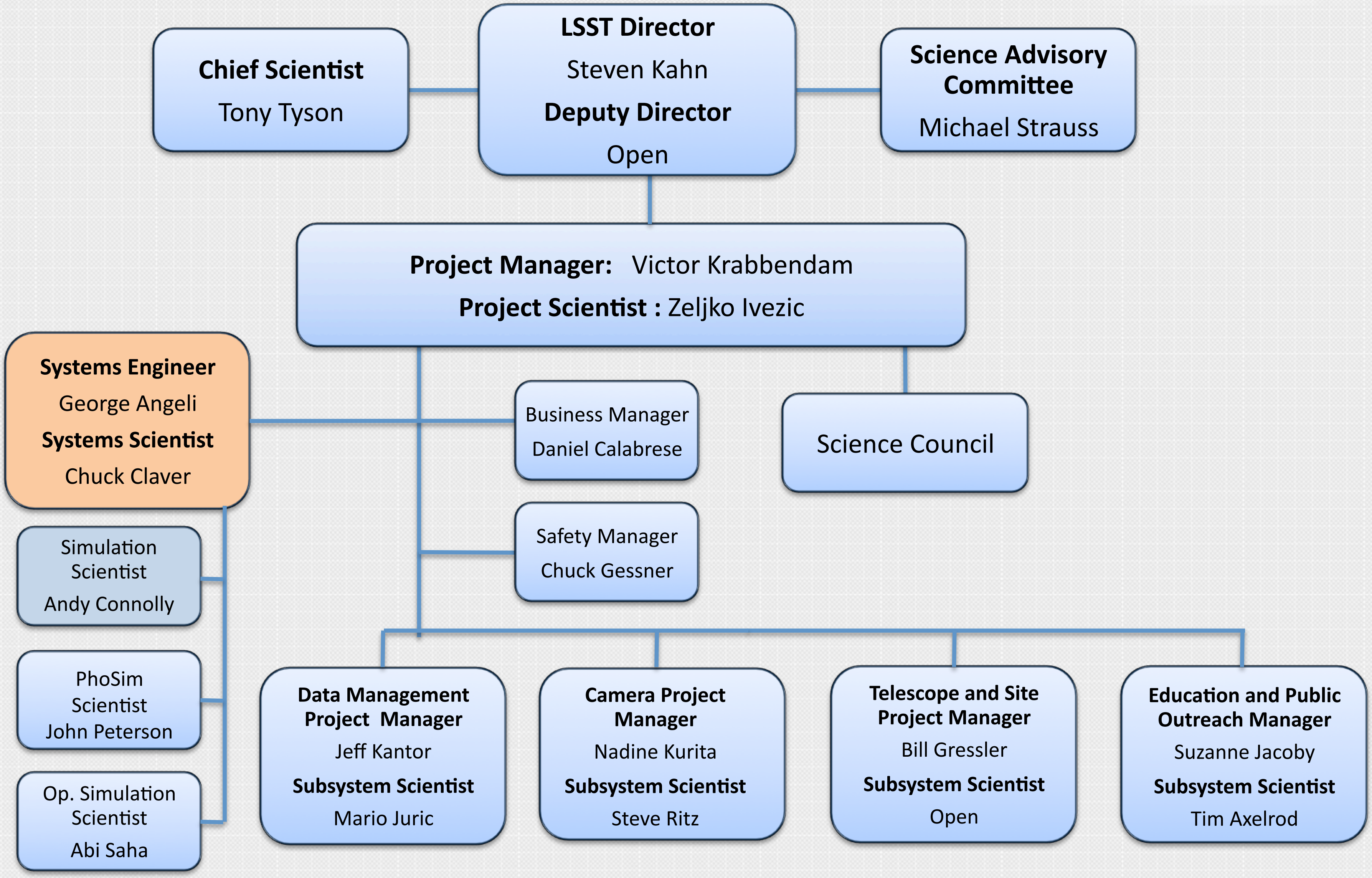
The role of simulations in construction

- Evaluate whether the properties of as-delivered components are sufficient to meet the design and minimum requirements.

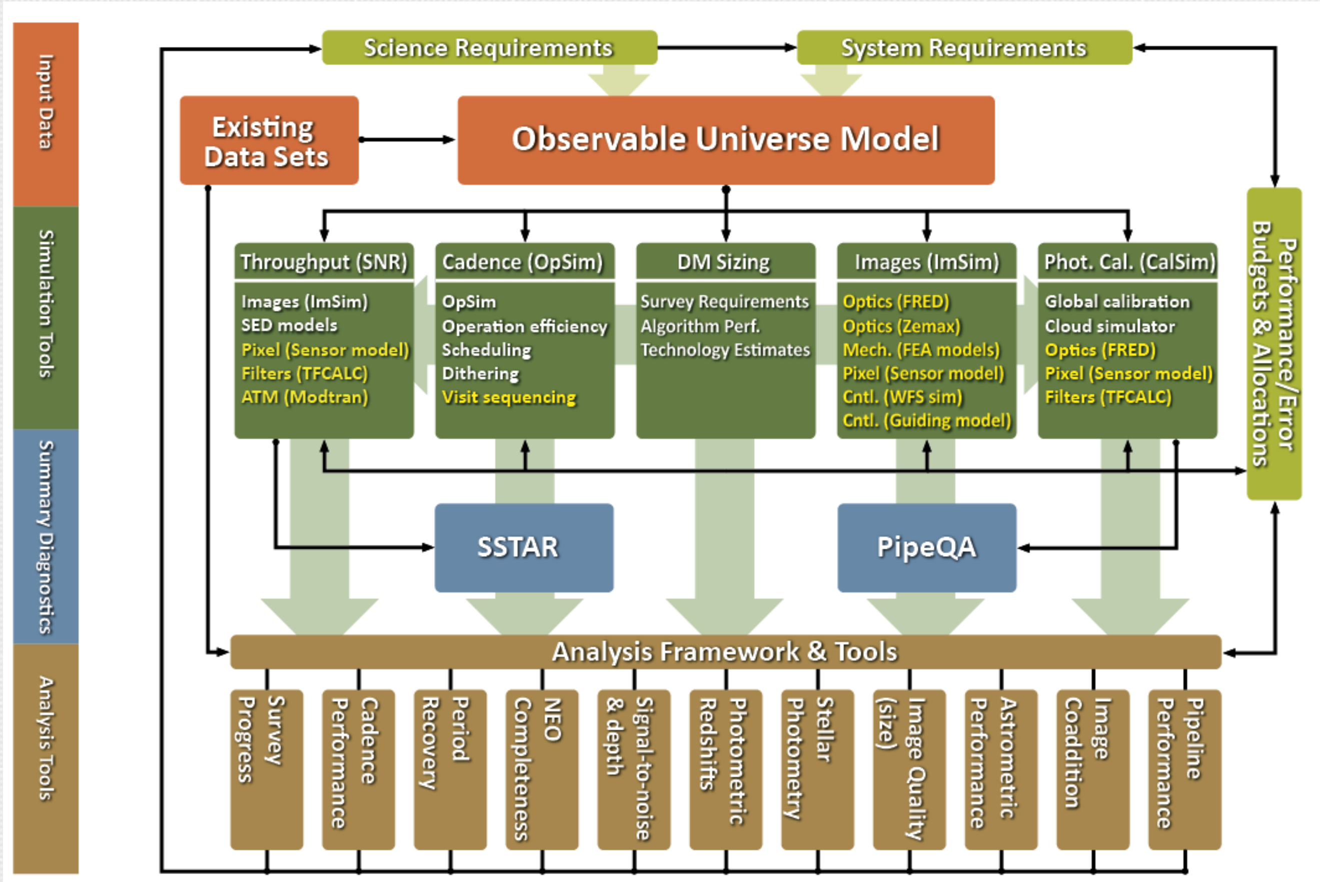
- Perform trade studies to evaluate how design modifications or optimizations impact the overall science performance of the system.

- Verify that the algorithms used in the processing the LSST data are capable of characterizing the astrometric, photometric, and morphological properties at a level of fidelity required by the SRD.

Simulations are managed through systems engineering



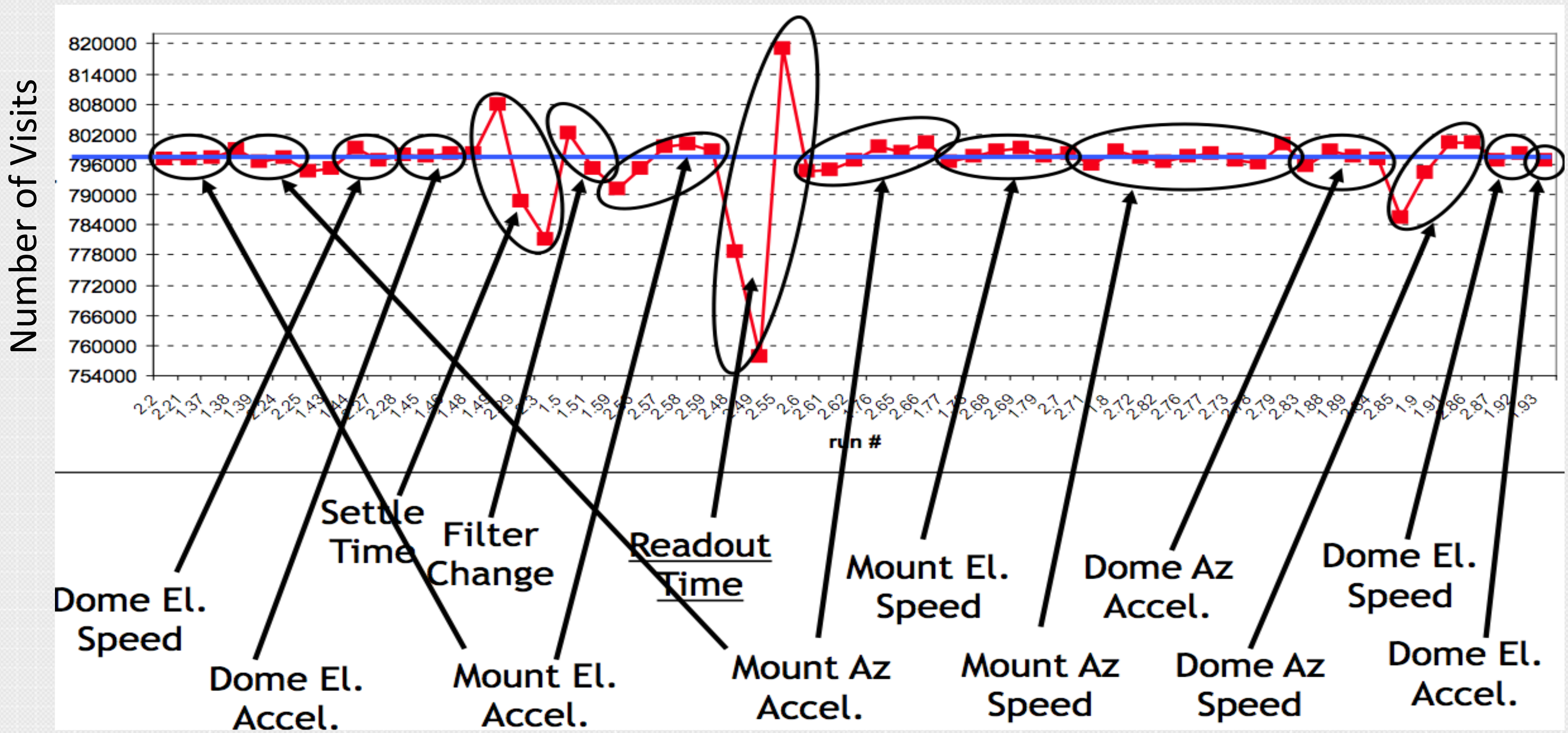
LSST science and engineering tools



All software is version controlled and provenance information is output with the data. Systems are validated through project initiated reviews with external members .

Engineering and science are integrated

Run of the Cadence Simulator



The number of visits as a function of engineering properties

This enables sensitivity analyses

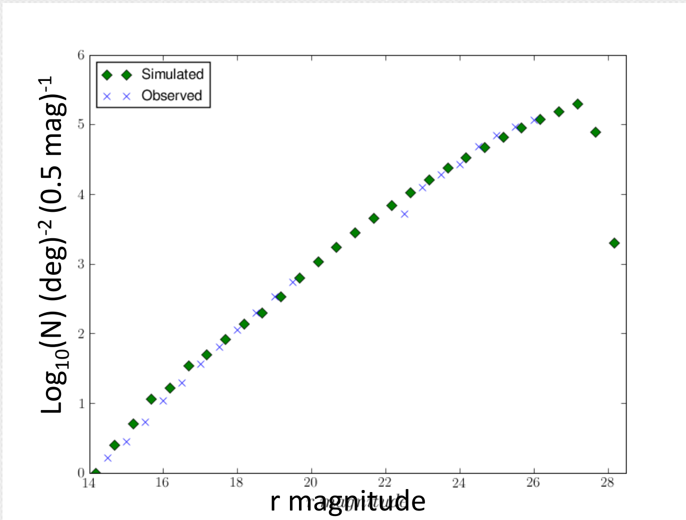
Parameter	Range	Change of # of visits
Readout Time	1 to 4 sec	1.25% per 0.5sec
Settle Time	2.5 to 4 sec	1.1% per 0.5sec
Filter Change	90 to 150 sec	0.15% per 10sec
Mount Elevation Acceleration	1.5 to 5.5 deg/sec^2	0.21% per deg/sec^2
Mount Azimuth Acceleration	4.5 to 9 deg/sec^2	0.15% per deg/sec^2
Dome Azimuth Max Speed	0.5 to 2.5 deg/sec	Asymptote
Mount Azimuth Max Speed	4.5 to 9 deg/sec	Negligible
Mount Elevation Max Speed	2 to 5 deg/sec	Negligible
Dome Azimuth Acceleration	0.25 to 1.25 deg/sec^2	Negligible
Dome Elevation Acceleration	0.6 to 1.15 deg/sec^2	Negligible
Dome Elevation Max Speed	0.75 to 2.75 deg/sec	Negligible

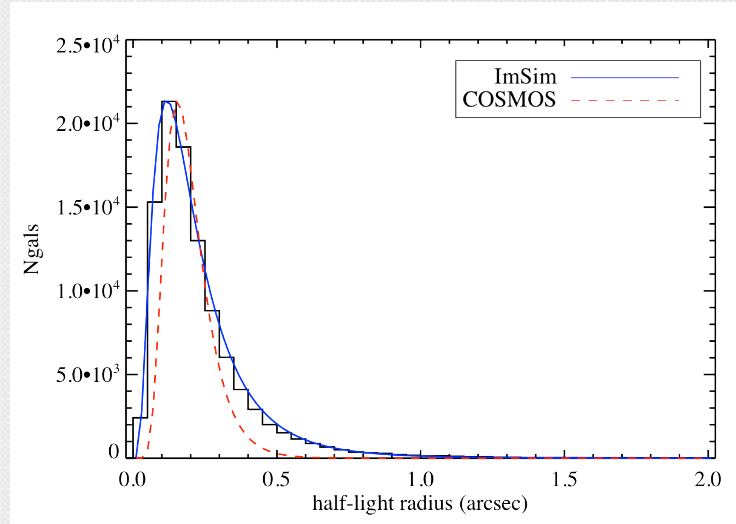
The sensitivity of engineering parameters on number of visits

The LSST universe model (CatSim)

A universal model of the sky

see presentation by Andy Connolly

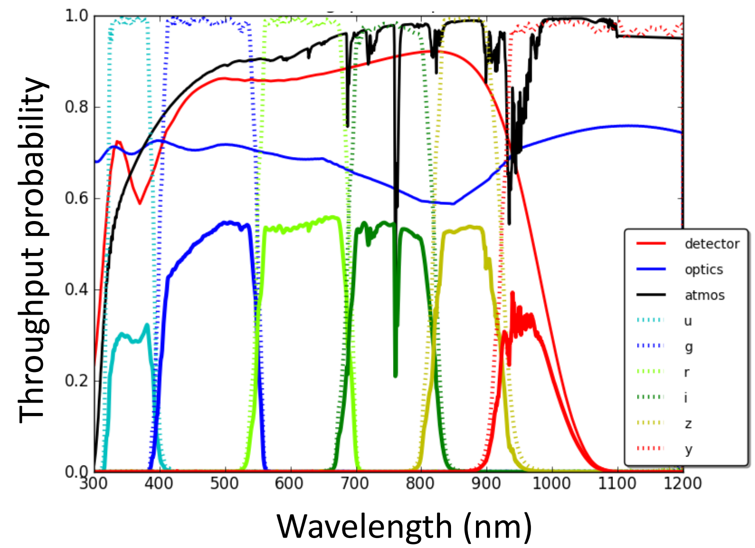


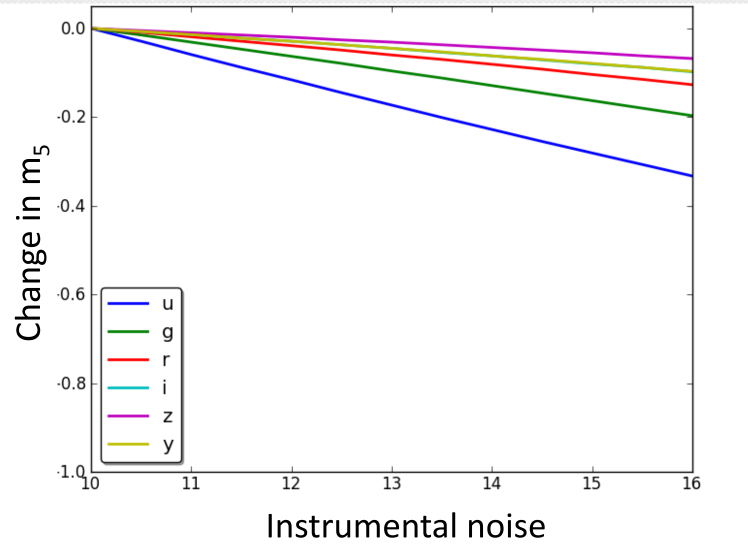


- Extensive use is made of existing ground and space-based data sets to characterize the expected properties of the LSST
- Source counts are based on simulations of the universe matched to observed densities and color of sources. Galaxies reproduce the observed number counts, size distributions, and redshifts.
- Simulations complement the observed data, providing a simplified view of the sky which can be used to evaluate the performance of the LSST system

Parametric and statistical tools

- Throughput simulations
  - Driven by engineering inputs from the optical design, sensor model, filter design, Modtran
  - Delivers SNR calculations, depths, colors and counts as a function of SED and integration time
- Data sizing models
  - Driven by the universal model, operations simulator, technology predictions, DM projections
  - Enables the trace of the propagation of requirements to final data management outputs (cost, CPUs, disks, etc.).

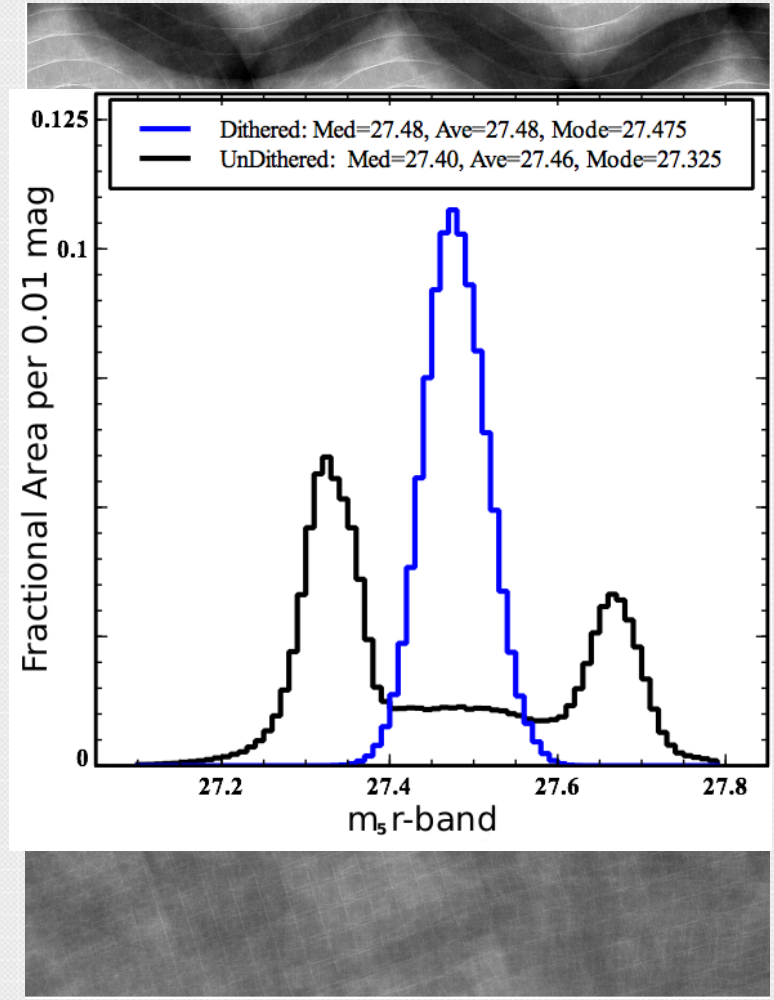




Survey performance tools

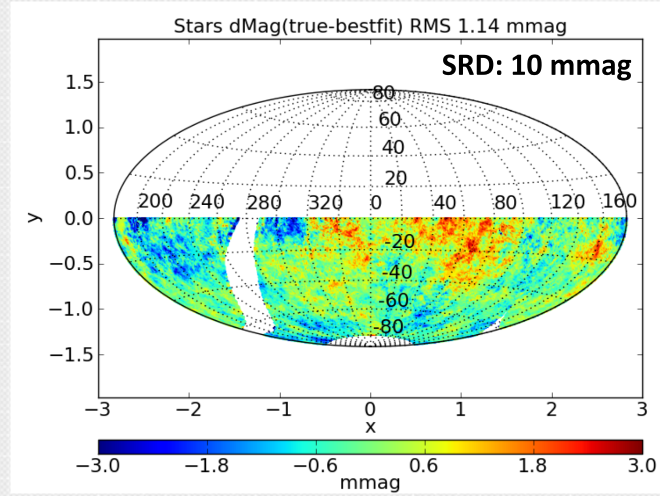
see presentation by Abi Saha

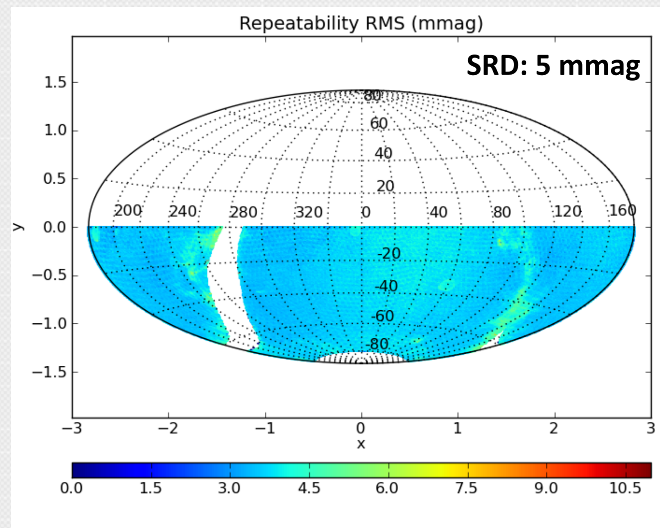
– Operations simulations (OpSim)
  - The constraints on the operations simulator are provided by the astrophysical properties of the site (e.g. sky background, visibility), the engineering models (settle time, read out time), and the science requirements
  - OpSim delivers sequences of observations together with their properties.
  - These outputs drive the sizing models, image simulations, calibration simulations.



Calibration and source simulations

- Calibration simulations take data from the universal model, the observation sequences, engineering designs for the vignetting, illumination correction, scattered light (FRED), atmosphere, and sky background
- Observations are generated (with the expected signal and noise) covering large sequences of observations.
- A calibration solver performs a self-calibration process, producing calibrated magnitudes, patch zeropoints.
- The results have been used to refine the flowdown from SRD to system design

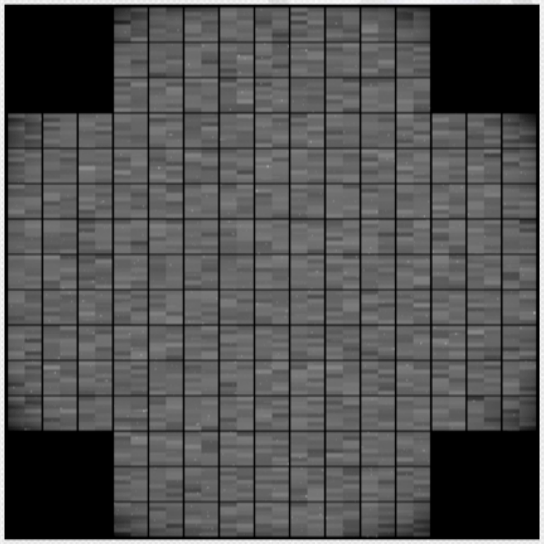


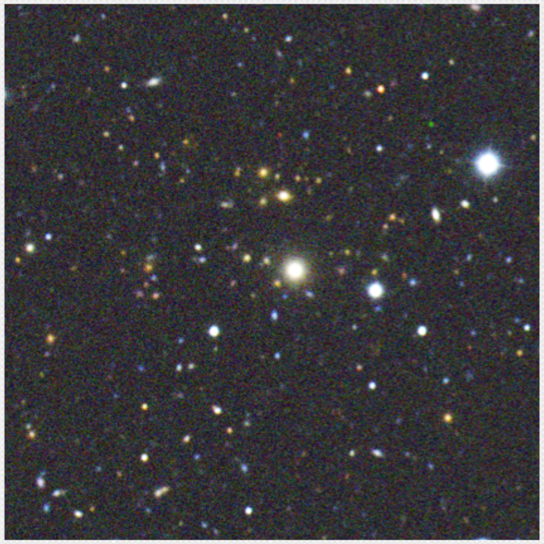


see presentation by Tim Axelrod

Image generation and data challenges (PhoSim)

- For image simulations, LSST telescope and camera optical designs are integrated with outputs from OpSim and the universal model to generate representative
- Supplementing observational data sets, the images (and reference catalogs) enable end-to-end comparisons that test the performance of the DM pipelines with realistic source densities, and data footprints
- Large scale runs (7TB of images touching 5×10^9 sources) test the robustness and scalability of algorithms.
- Small scale runs test sensitivity of algorithms/analyses to individual components or sub-components

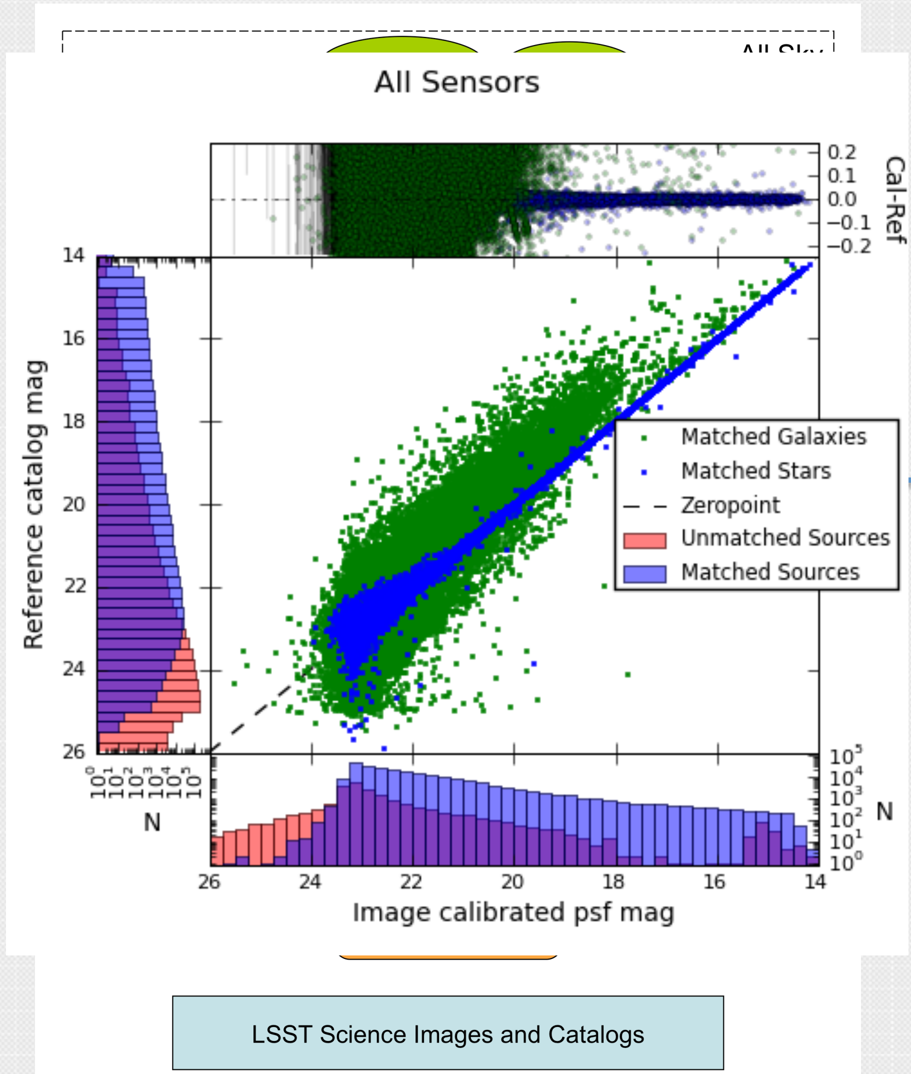




See presentation by John Peterson

An end-to-end integrated simulation framework

OpSim



CatSim

PhoSim

Science to Simulation Requirements

- Science requirements are described in the science requirements document (Ivezic et al 2011) and associated flow down documents
- Requirements on the simulations are set such that the simulation fidelity is sufficient to distinguish between **design** and **minimum** requirements in the SRD
- These requirements are described in the simulation requirements document (Connolly et al 2013)
- Validation is undertaken using existing observations, as-delivered components, and against validated reference implementations

Development through construction

LSST Simulation Software Development Roadmap

Release	**Simulation System**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**
Elapsed time (years)		**1**	**2**	**3**	**4**	**5**	**6**
Finish Date		**8/31/2014**	**8/31/2015**	**8/31/2016**	**8/31/2017**	**8/31/2018**	**8/31/2019**
Year during which work is done		FY14	FY15	FY16	FY17	FY18	FY19
Release Highlights		Completion of V3 for OpSim;Perturbation model; Parameter audit	Metric framework for Opsim; Parameter database; Stellar variability model for LSST; Wavefront sensor simulation	Completion of scheduler simulation and logic; Cloud model and scattered light; Ghosts and glints	Telescope scheduler; Coating non uniformities; Calibration telescope simulation	Dithering and scheduler efficiencies; Flat field and calibration simulations	Delivery of validated telescope scheduler; Delivery of catalog and image simulation and large scale image and catalog generation
Metrics and Logic	**Opsim**		Deliver Metric framework		Calibration telescope scheduling		
Site and Parameters	**OpSim**			Updated sky and cloud model			
Scheduler/Simulator	**OpSim**	Delivery of v3.0 simulator		Delivery of completed cadence simulator	Implementation of scheduler		Deliver validated scheduler
Data Challenges	**OpSim**	Cadence studies and workshop	Cadence evaluation data challenge (10 yr simulations)	Dithering strategy data challenge		Report on efficiency of scheduler	
Framework	**CatSim**		Delivery of framework for catalog support	Analytic model for calibration telescope		Large scale simulation tests and runs for calibration simulations	
Catalogs: Galaxies, Stars, Asteroids	**CatSim**	Delivery of morphological model	Delivery of stellar variability model	Delivery of cosmology models with lensing/LSS	Deliver update asteroid model		
Site and Parameters	**CatSim**		Deliver LSST parameter database	Delivery of sky and cloud model			
Data Challenges	**CatSim**		Morphology and shape measurement data challenge		Full sky data challenge for calibration	Alert generation data challenge	
Atmosphere	**PhoSim**			Deliver updated atmosphere model			Update of atmosphere from commissioning data
Telescope/optical model	**PhoSim**	Deliver perturbation model	Wavefront sensor simulations	Scattered light model	Simulated flat field and monochromatic flats		Update of optical model based on telescope performance
Sensor	**PhoSim**			Deliver updated sensor model and validation			
Site and Parameters	**PhoSim**	Parameter audit for simulations	Update Cosmic Ray morphologies			Update of site parameterization	
Framework	**PhoSim**			Simulate full sensor test bed		Large scale simulation tests and runs	
Data Challenges	**PhoSim**		2000 focal planes (13TB): multifit challenge	17000 focal planes (110TB): difference images and coaddition	25000 focal planes (165TB): blending, coaddition, and ghosting	25000 focal planes (165TB): calibration, difference images, and multifit	

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Start of the scheduler development

ComCam delivery

Sensor Science Raft

Summary

- The LSST has a broad range of simulation and modeling tools

  - Engineering tools (Zemax, FRED, CFD) have been extensively used in the design of the telescope system.

  - A broad range of system simulation tools (integrating the astrophysical and engineering properties of the system) are available that enable parametric and Monte-Carlo simulations of the end-to-end performance of the system.

  - Development of these tools is integrated with the construction requirements of the project (including the development of the data management, testing of the camera and sensors, and the commissioning tasks required by the LSST).

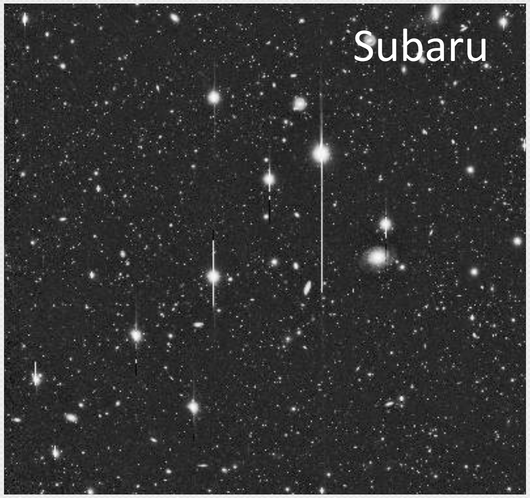
Backup Slides

The tools provide a range of fidelities

- Engineering design tools
  - Zemax, FRED, FEA, CFD, Filters, Camera thermal and compensation models
  - Detailed design tools but not coupled to the astrophysics of the sky
- Parametric and statistical tools
  - Sizing models, throughput and signal-to-noise generation, pipeQA
  - Efficiently characterize source properties as a function of the system
- Survey performance tools
  - Characterize the general survey properties using outputs from the design tools and the science requirements (e.g. SSTAR)
- Catalog and image modeling tools
  - CatSim, PhoSim, precursor data
  - End-to-end evaluation of the performance to the LSST (including data management and the impact of the as-delivered sub components)
- Validated through project initiated reviews with external members

Data driven models of the universe

Analyses based on precursor data



- Extensive use is made of existing ground and space-based data sets to characterize the expected properties of the LSST and the data management frameworks (e.g. SDSS, CFHTLS, Suprimecam, COSMOS)
- Existing data sets capture the complexity of the data including the impact of the atmosphere, source variability, source density and variations in morphology.
- Existing data sets do not, however, provide "truth-tables" nor do they enable the impact of individual subsystems to be evaluated

Walkthrough of a simulation requirement

- Astrometric requirements
  - The SRD states that the rms of the astrometric distance distribution of pairs of stars should not exceed

Goal	5 arcmin	20 arcmin	200 arcmin
Minimum	20 mas	20 mas	30mas
Design	10 mas	10 mas	15 mas

  - The fidelity of the simulator shall be sufficient that it can differentiate between the minimum and the design specification
  - For this requirement specified by an rms uncertainty we define a requirement that the variance in the simulated positions should be <30% of the variance in the design specification and less than 3.3mas (3σ for the bounds).

Walkthrough of a simulation requirement

- Astrometric requirements
  - For a single sensor 30% of the design variance corresponds to an rms uncertainty of 5.5 mas, 3σ corresponds to **3.3mas**
  - Distributing this uncertainty to the atmospheric image quality (0.60 arcsec) and instrumental (0.4 arcsec) components of the system gives

Goals	astrometric	positional
Atmosphere	2.75 mas	0.14 microns
Instrument	1.89 mas	0.09 microns

  - Validation will be undertaken using sources where photon noise is subdominant. For r < 18., the astrometric variance is 1.1 mas

Walkthrough of simulation requirements

- Density of extragalactic sources
  - LSST sizing models defines the compute and storage requirements for the LSST project (LSE-81 and LSE-82)
  - Requirements from LSE-81 are that the density of galaxies be known to an uncertainty of <30%.
  - Cumulative galaxy counts scale as

$$N(m)= 1.66 \times 10^{0.31(i-25)+5} \text{ degree}^{-2}$$

  - The sample variance on the estimates of faint galaxy counts are 10% at i = 26.8 (5σ point source)
  - This defines a minimum specification on characterizing the density of galaxies of 10%

Core Simulation Requirements

Description	Requirement
Simulated source types	stars, galaxies, solar system sources
Source number densities	10/20% of observed densities
Sizes and ellipticities	<20% of nominal N_{eff}
Source color distribution	-0.4 < g-r < 1.7 and 2% photometry
Catalog astrometric uncertainties	<1 mas
Simulated image integration times	5-40 seconds
Image astrometric (optical model)	<1.89 mas
Image astrometry (atmospheric model)	<2.75 mas
Image ellipticities (atmospheric model)	<0.0033
Image ellipticities (optical model)	<0.0033
Image photometricity	<1.7 mmag

Simulation Reviews and Workshops

- Simulation Requirements Document
  - Reviewed August 2013
- Operations Simulation
  - Workshop July 2013
  - Review scheduled January 2104
- Photon Simulations
  - Reviewed August 2013
- Catalog Simulations
  - Reviewed August 2013
- Calibration Simulations
  - Reviewed July 2013

Project resources in construction

LSST Simulation Development			
Simulation System	**Project FTEs**	**Off-Project FTEs**	**Total FTEs**
Systems Engineering	**1.5**		**1.5**
OpSim	**2.5**	**1**	**3.5**
CatSim	**2**		**2**
PhoSim	**2**	**1**	**3**
Framework and user support		**2**	**2**
			12

Response to simulations review

- Tier 1 RFAs
  - Provide a summary-level description of the current limitations
    - PhoSim Limitation Statement
    - CatSim Limitation Statement
- Tier 2 RFAs
  - Working group on technical aspects of the simulator
    - Working group (internal and external) being constructed
  - Development plan tied to project requirements
    - Construction development plan is in place
- Tier 3 RFA
  - Check the dependence on the number of layers in the atmospheric perturbations simulations
    - In progress
  - Complete ZEMAX-PhoSim comparisons for all filter configurations
    - In progress

Response to simulations review

- Recommendations and Findings
  - An increase in the developer and user base
    - A reorganization of all simulations into a common system for development (opsim, phosim, catsim, and computational framework) has been implemented with an associated increase in resources
    - Implementation of a cross-simulation regular technical meeting