The Large Synoptic Survey Telescope

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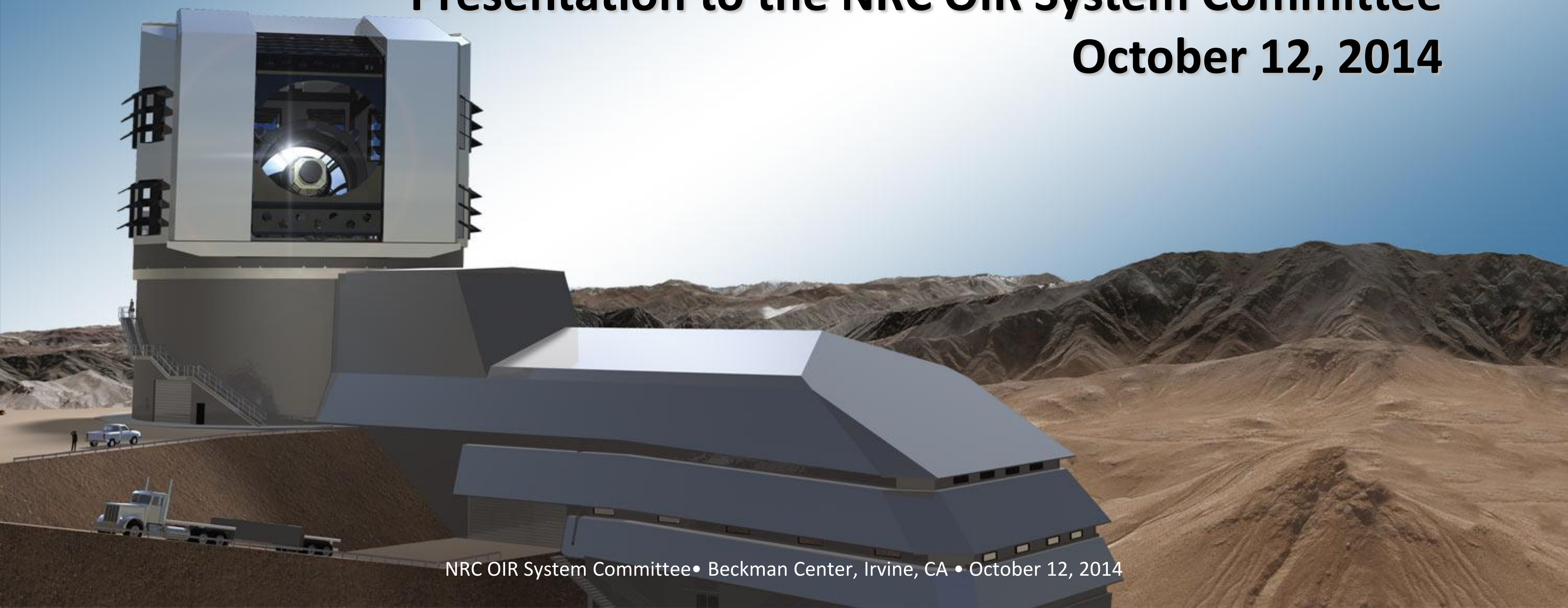
Presentation to the NRC OIR System Committee
October 12, 2014



LSST in a Nutshell

- **The LSST is an integrated survey system designed to conduct a decade-long, deep, wide, fast time-domain survey of the optical sky. It consists of an 8-meter class wide-field ground based telescope, a 3.2 Gpix camera, and an automated data processing system.**

- **Over a decade of operations the LSST survey will acquire, process, and make available a collection of over 5 million images and catalogs with more than 37 billion objects and 7 trillion sources. Tens of billions of time-domain events will be detect and alerted on in real-time.**

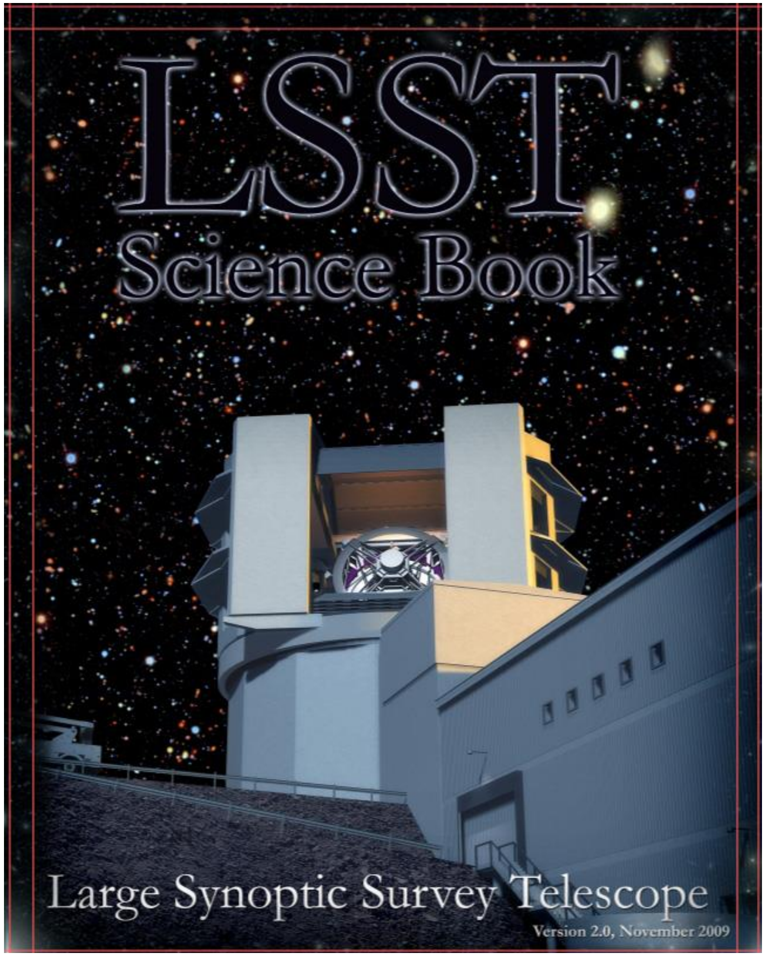
- **The LSST will enable a wide variety of complementary scientific investigations, utilizing a common database and alert stream. These range from searches for small bodies in the Solar System to precision astrometry of the outer regions of the Galaxy to systematic monitoring for transient phenomena in the optical sky. LSST will also provide crucial constraints on our understanding of the nature of dark energy and dark matter.**

Summary of High Level Requirements

Survey Property	Performance
Main Survey Area	18000 sq. deg.
Total visits per sky patch	825
Filter set	6 filters (ugrizy) from 320 to 1050nm
Single visit	2 x 15 second exposures
Single Visit Limiting Magnitude	u = 23.5; g = 24.8; r = 24.4; I = 23.9; z = 23.3; y = 22.1
Photometric calibration	2% absolute, 0.5% repeatability & colors
Median delivered image quality	~ 0.7 arcsec. FWHM
Transient processing latency	60 sec after last visit exposure
Data release	Full reprocessing of survey data annually

The LSST Science Book

- **Contents:**
  - Introduction
  - LSST System Design
  - System Performance
  - Education and Public Outreach
  - The Solar System
  - Stellar Populations
  - Milky Way and Local Volume Structure
  - The Transient and Variable Universe
  - Galaxies
  - Active Galactic Nuclei
  - Supernovae
  - Strong Lenses
  - Large-Scale Structure
  - Weak Lensing
  - Cosmological Physics



Four Key Science Themes Used to Define the Science Requirements

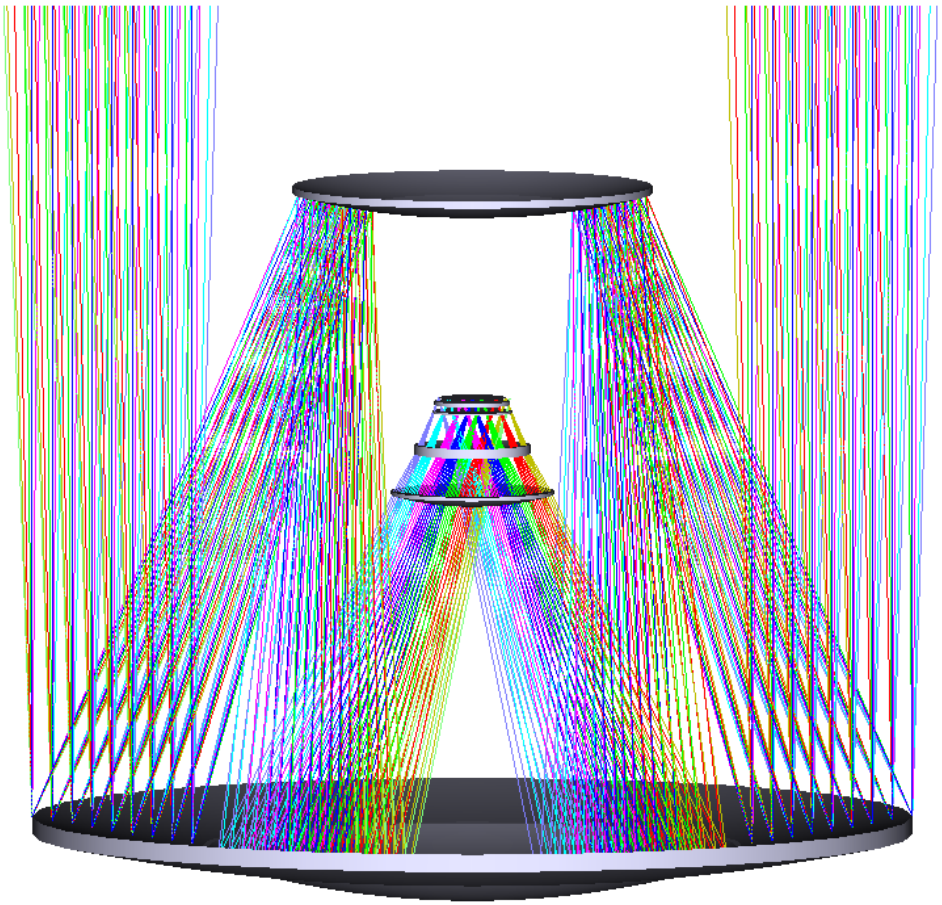
- Taking a census of moving objects in the solar system.
- Mapping the structure and evolution of the Milky Way.
- Exploring the transient optical sky.
- Determining the nature of dark energy and dark matter.

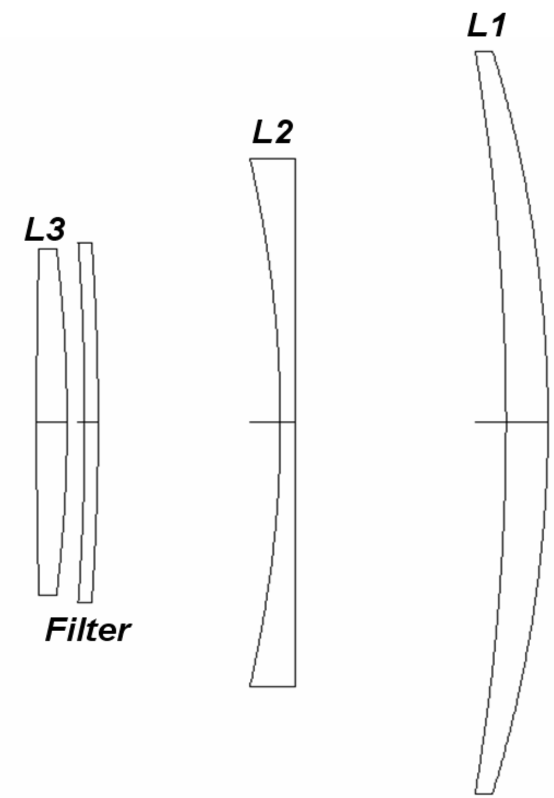
The techniques associated with these four themes stress the system design in complementary ways. By designing the system to to accomplish these specific goals, we ensure that LSST will in fact enable a very broad range of science.

LSST Will be Sited in Central Chile

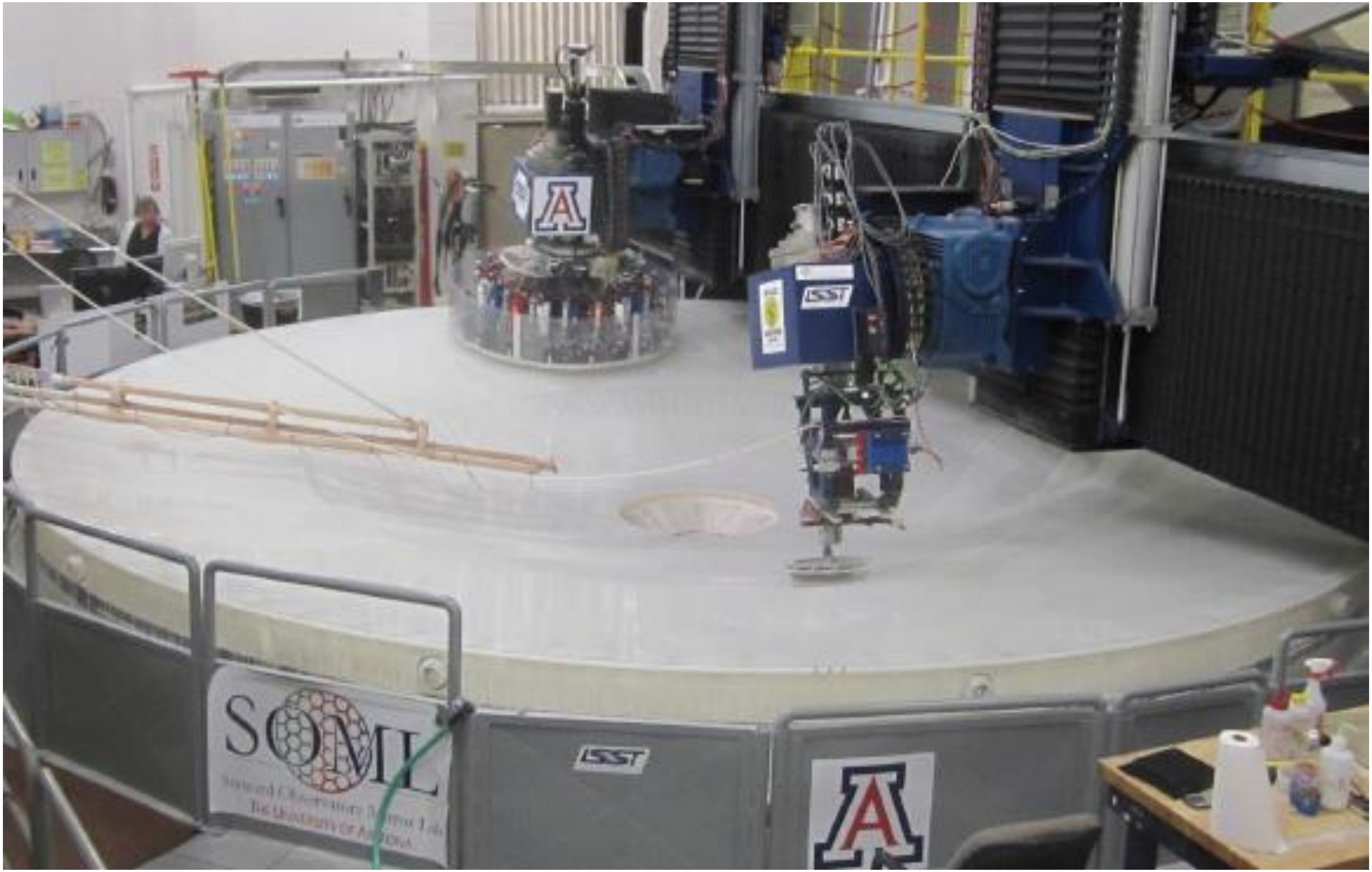
Dome and Facility Design

Modified Paul-Baker Optical Design

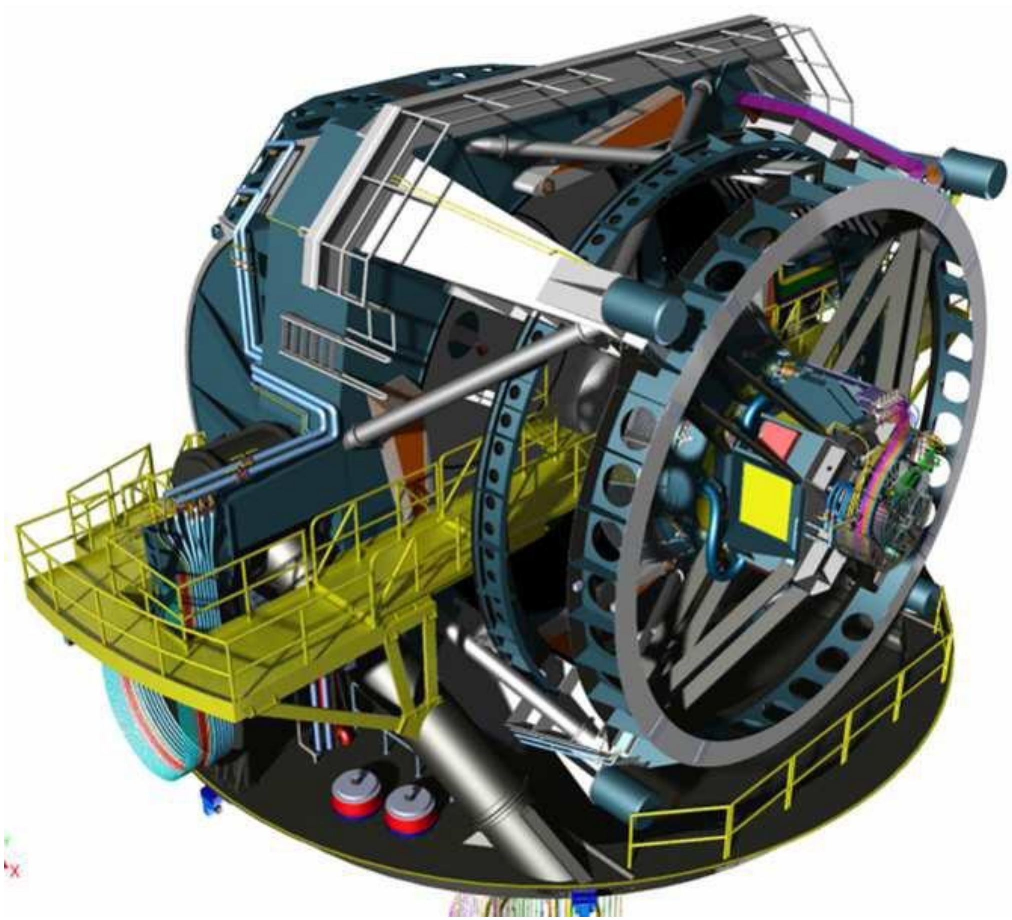




Primary/Tertiary Fabricated as a Single Monolith

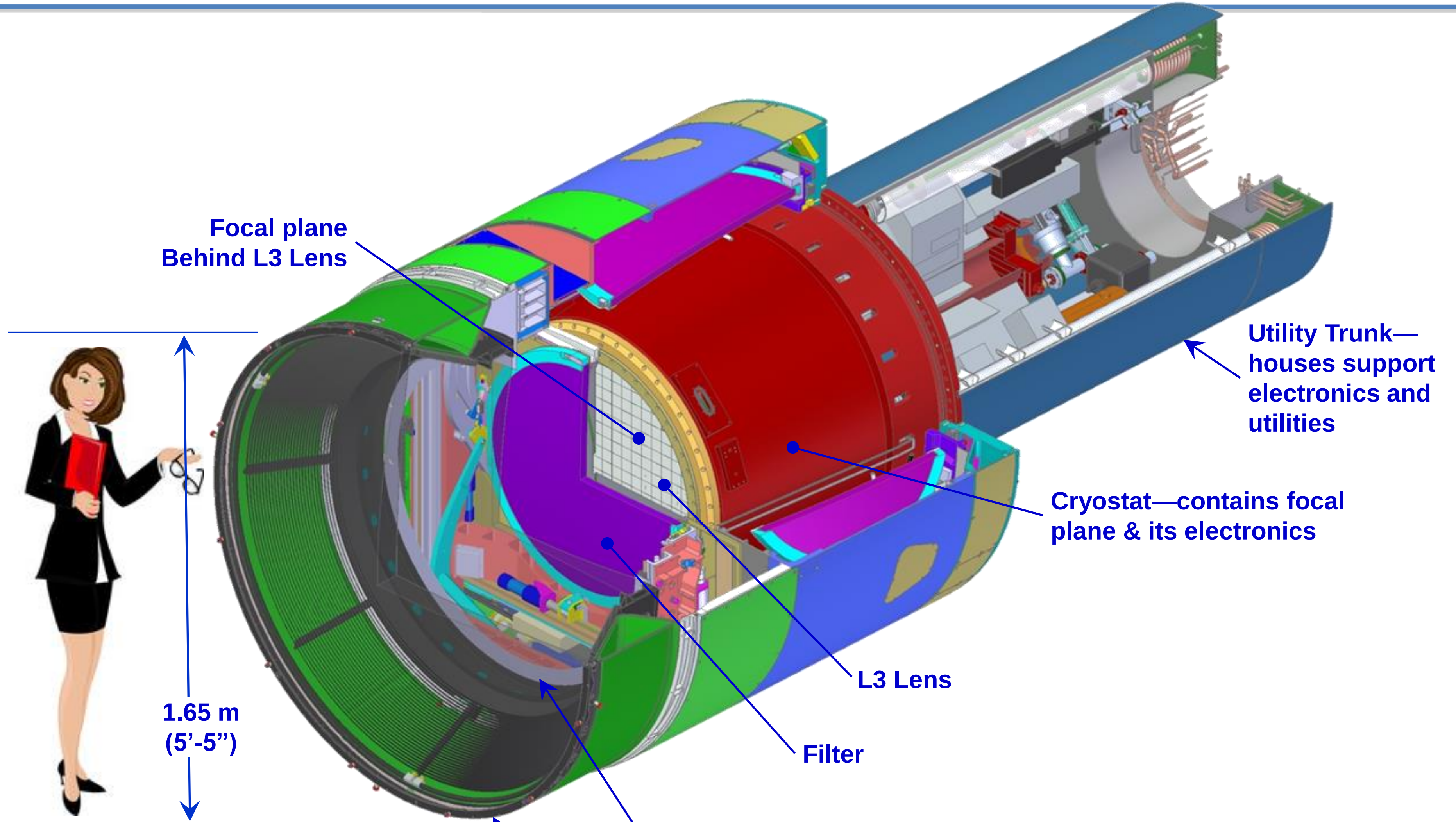


Telescope Mount Enables Fast Slew and Settle



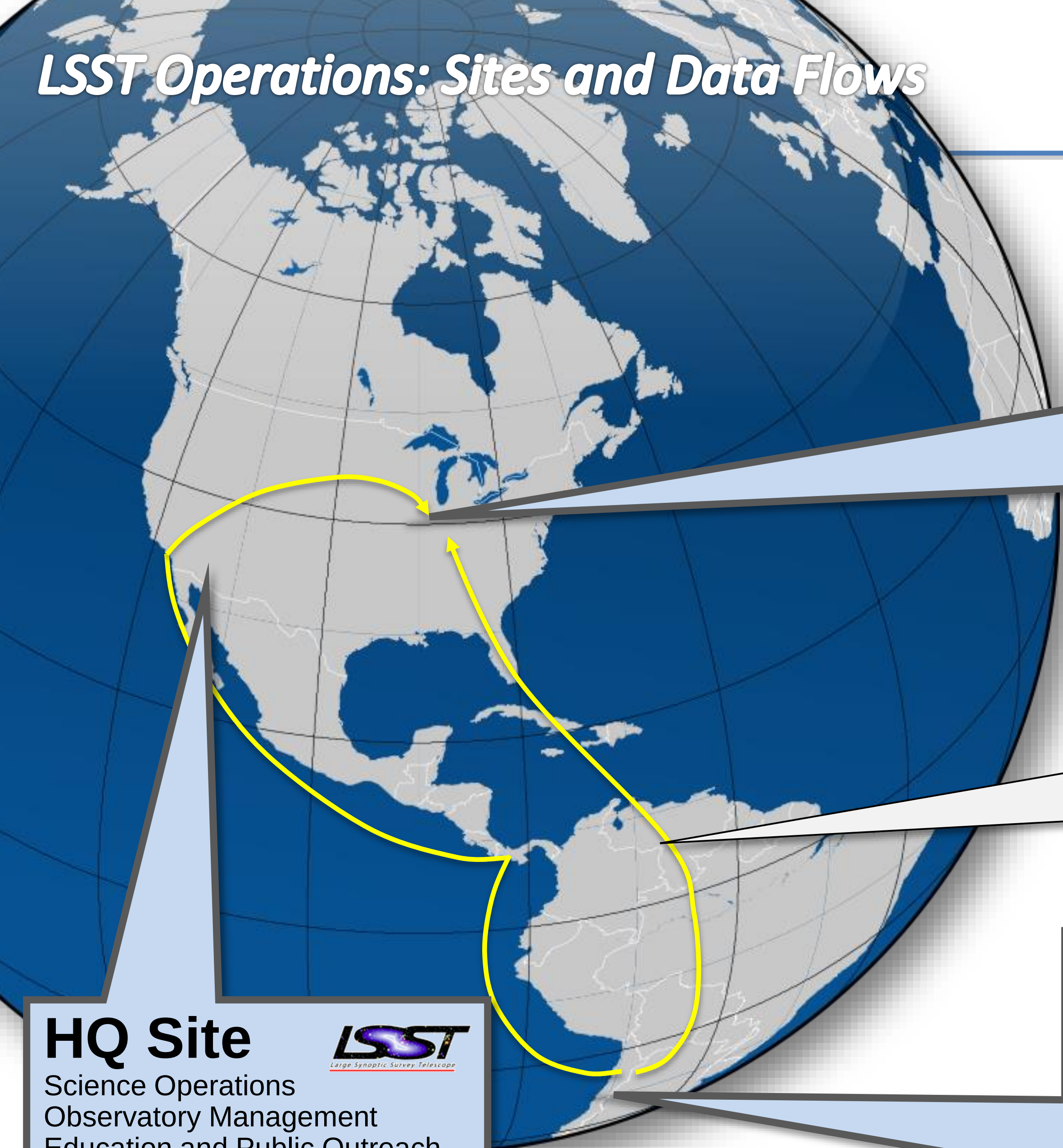
- **Points to new positions in the sky every 39 seconds**
- **Tracks during exposures and slews 3.5° to adjacent fields in ~ 4 seconds**

3.2 Billion Pixel Camera



Camera ¾ Section

LSST Operations: Sites and Data Flows



Archive Site

NCSA

Archive Center

Alert Production
Data Release Production
Calibration Products Production
EPO Infrastructure
Long-term Storage (copy 2)

Data Access Center

Data Access and User Services

Dedicated Long Haul Networks

Two redundant 40 Gbit links from La Serena to Champaign, IL (existing fiber)

HQ Site

Science Operations
Observatory Management
Education and Public Outreach

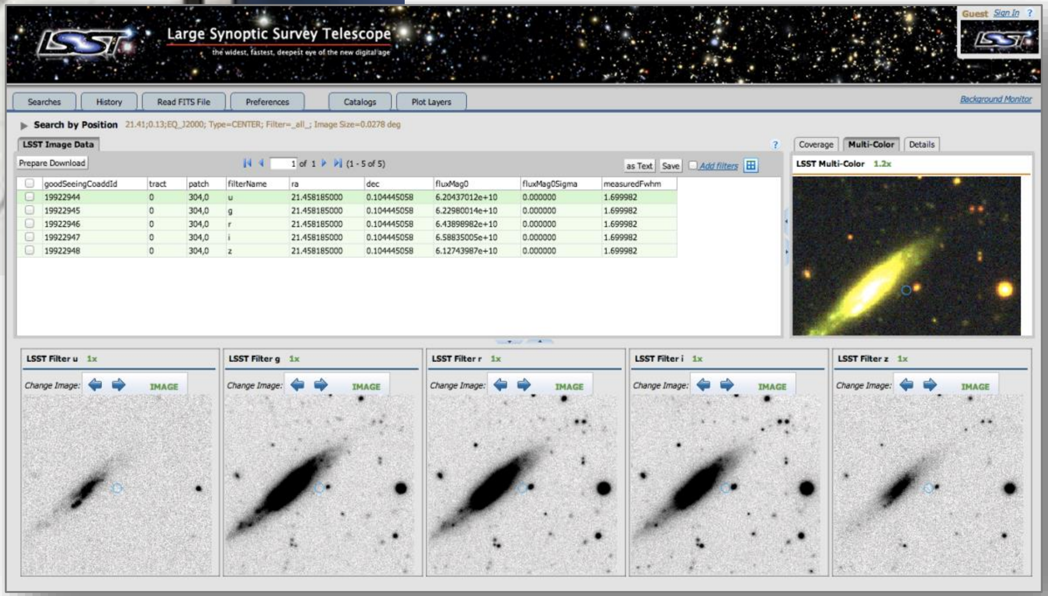
Summit and Base Sites

Telescope and Camera
Data Acquisition
Crosstalk Correction
Long-term storage (copy 1)
Chilean Data Access Center

Ultimate LSST Deliverable: Reduced Data Products

*A petascale supercomputing system at the **LSST Archive** (at NCSA) will process the raw data, generating reduced image products, time-domain alerts, and catalogs.*

__Data Access Centers__ in the U.S. and Chile will provide end-user analysis capabilities and serve the data products to LSST users.



Education and Public Outreach

- Key Goals:
  - Broadening Participation to Include a Large, Diverse Audience
  - Addressing National Priorities in STEM Education and Science Literacy
  - Leveraging Emerging Trends in Free-Choice Learning and Social Networking
  - Incorporating Evidence-based Evaluation of Participant Outcomes

- LSST EPO will have a dynamic public web presence as well as a physical presence in classrooms and science centers promoting engagement in the research process.

- LSST EPO Integrates Education & Research
  - Citizen science extends goals of LSST
  - Education research possible from tracking registered users
  - EPO participants gain awareness, engagement, understanding

- Sustainable Partnerships with Institutional Member EPO programs and other organizations for dissemination, leveraging, and implementation.

LSST is a Public/Private, Interagency Project

- **The National Science Foundation:**
  - Support for the telescope and site facility construction, the data management system, and the education and public outreach components.
  - Funded under the Major Research Equipment and Facility Construction (MREFC) line. Total not to exceed cost is $473M.
  - Prime contractor for this effort is the Associated Universities for Research in Astronomy (AURA), which also manages the National Optical Astronomy Observatory (NOAO), the Space Telescope Science Institute (STScI), and other facilities.

- **The Department of Energy:**
  - Support for the camera fabrication.
  - Funded as a Major Item of Equipment (MIE), through the Office of High Energy Physics in the Office of Science. Total projected cost is $168M.
  - SLAC National Accelerator Laboratory is the lead DOE lab for the LSSTcam project.

- **Private Support:**
  - Key donors include the Lisa and Charles Simonyi Fund for Arts and Sciences, Bill Gates, Richard Caris, the W.M. Keck Foundation, Research Corporation for Science Advancement, Wayne Rosing and Dorothy Largay, Eric and Wendy Schmidt, and Edgar Smith.
  - Total Support is ~ $40M.
  - Funded development of the primary/tertiary mirror, the secondary mirror blank, preliminary site preparation, as well as early sensor studies and some data management activities.
  - Responsible organization is the Large Synoptic Survey Telescope Corporation.

NSF MREFC Approval

National Science Foundation
WHERE DISCOVERIES BEGIN

Press Release 14-095

TAKING ASTRONOMY TO THE NEXT LEVEL

Large Synoptic Survey Telescope gets funding to begin construction

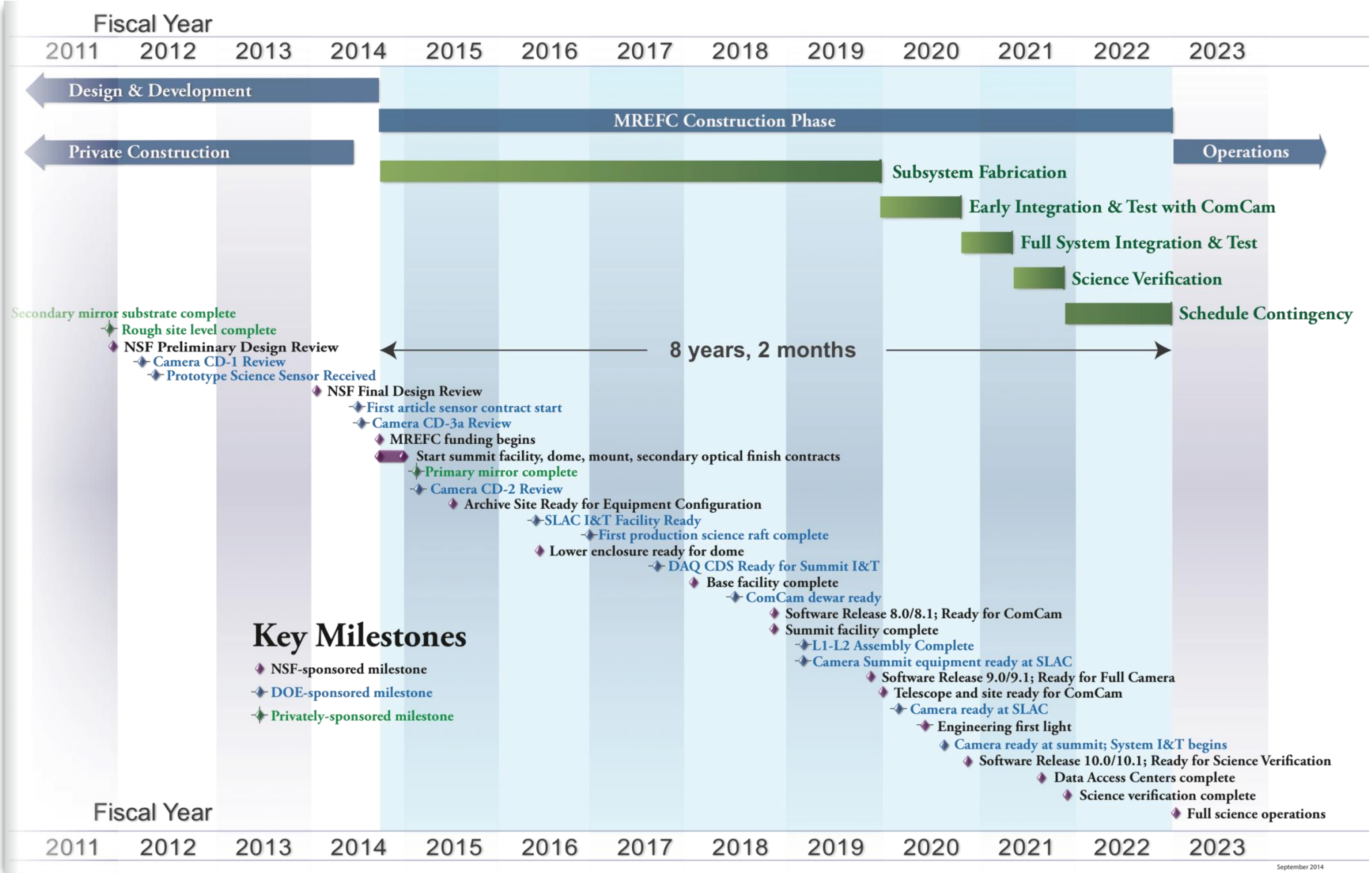
LSST was the highest-ranked ground-based large initiative in NAS' 2010 decadal survey.
Credit and Larger Version

August 7, 2014

Construction of the highly anticipated Large Synoptic Survey Telescope (LSST) can begin now that the National Science Foundation (NSF) has finalized funding. To be located in Chile, LSST is a proposed 8-meter wide-field survey telescope that will image the entire visible sky approximately twice per week, providing an unprecedented amount of information while transforming the emerging discipline of data-enabled science.

LSST was the highest-ranked ground-based large initiative in the 2010 National Academy of Sciences decadal survey in astronomy and astrophysics. The project is a partnership among NSF, the Department of Energy (DOE) and a number of private contributors. Additionally, researchers from around the world, not only the United States and Chile, will provide operational support to facilitate LSST's mission.

Integrated Project Schedule



Data Products and Services Provided by LSST

- A stream of ~10 million time-domain events per night, detected and transmitted to event distribution networks within 60 seconds of observation.
- A catalog of orbits for ~6 million bodies in the Solar System.

Nightly (Level 1)

- A catalog of ~37 billion objects (20B galaxies, 17B stars), ~7 trillion single-epoch detections (“sources”), and ~30 trillion forced sources, produced annually, accessible through online databases.
- Deep co-added images.

Annual DRs (Level 2)

- Services and computing resources at the Data Access Centers to enable user-specified custom processing and analysis.
- Software and APIs enabling development of analysis codes.

Added Value (Level 3)

More Information: ***Section 3.3, LSST Overview Paper***; *http://ls.st/op*

High Data Quality

- **System designed for maximum data quality**
  - Nightly full system calibration
  - Real time correction for atmosphere transmission
  - CCD detector and camera ghosting artifacts known and included in event detection algorithm
  - Full pixel data distribution used in detection significance
  - Automated data quality assessment at multiple levels
- **Designed to enable use cases requiring rapid detection and follow-up**
  - Will subtract each incoming image against a deep template constructed from prior observations of the same spot, and detect sources on the difference image
  - New PSF objects appearing between 15 sec exposures can yield ~30 sec time resolution
  - Significant sources defined in *full context* of known imaging artifacts and measured noise
  - Below, this will be called "*detection*" or "*detected sources*"
  - Goal: object detections in alerts and catalogs will be real, not system artifacts
- **Position, flux, and shape will be measured for each detection**
  - Shape measurement will include characterization of trailing (assisting detection of NEOs)

*More Information: **LSST Data Products Definition Document**; http://ls.st/dpdd*

(note: this document is updated approximately annually)

Nightly Level 1 Processing (Near Real-time)

- Designed to enable use cases requiring rapid detection and follow-up
  - Will subtract each incoming image against a deep template constructed from prior observations of the same spot, and detect sources on the difference image
- Position, flux, and shape will be measured for each detection
  - Shape measurement will include characterization of trailing (assisting detection of NEOs)
- Each detection will be positionally associated with sources previously detected in the same location
  - Enables user-end construction of light curves and object classification
  - Simple variability characterization will be provided as well (moments, period estimate, etc.)
- Each detection will be characterized for the likelihood of being spurious
  - E.g. using machine learning techniques (such as Bloom et al. 2011)
  - We *do not* plan to pre-filter the alert stream, unless overwhelmed by false detection
- Each detection will be cross-matched to deep LSST ("Level 2") catalogs, including the catalog of known Solar System objects.
- This information will be transmitted to alert networks, stored in the database for later querying, and fed to the orbit linking code to identify new asteroids.

More Information: ***LSST Data Products Definition Document****;* *http://ls.st/dpdd*
(note: this document is updated approximately annually)

Time Domain Event Alerts

- For each detection, LSST plans to emit an "Event Alert" within 60 seconds of the end of observation (defined as the end of image readout from the LSST Camera).
- The objective is to transmit nearly everything LSST knows about any given event, enabling downstream classification and decision making *without* the need to call back into LSST databases (latency minimization).
- Each alert "packet" will include:
  - All measurements performed on the detected source
  - All measurements of sources previously detected at the same position
  - Variability characterization (light curve moments, period estimate, etc.)
  - Identification and orbit characterization, if associated with a known minor planet
  - IDs of (and distance to) nearby objects in LSST Level 2 (deep) catalogs
  - Postage stamps (cutouts) of the difference and template image (FITS)
  - Metadata

More Information: ***LSST Data Products Definition Document (DPDD)****;* *http://ls.st/dpdd*

(note: this document is updated approximately annually)

LSST Services in Support of Level 1

More Information: **LSST DPDD;** http://ls.st/dpdd

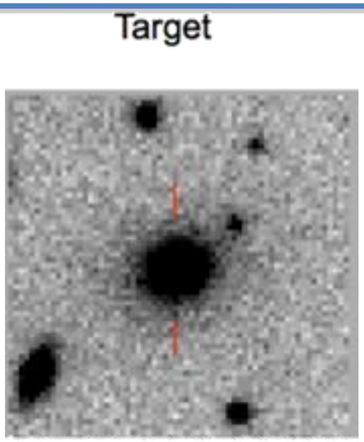
- **Forced Photometry ("Precovery") Service**
  - **Automatically perform and make available forced photometry at the position of all newly detected sources, on imaging acquired over the preceding 30 days**
  - **On request, for a limited number of positions perform and make available forced photometry on *all* imaging overlapping that position**
  - **Turnaround on a ~day timescale.**

- **Alert generation service**
  - **Package and transmit all alerts to community-supported alert distribution networks**

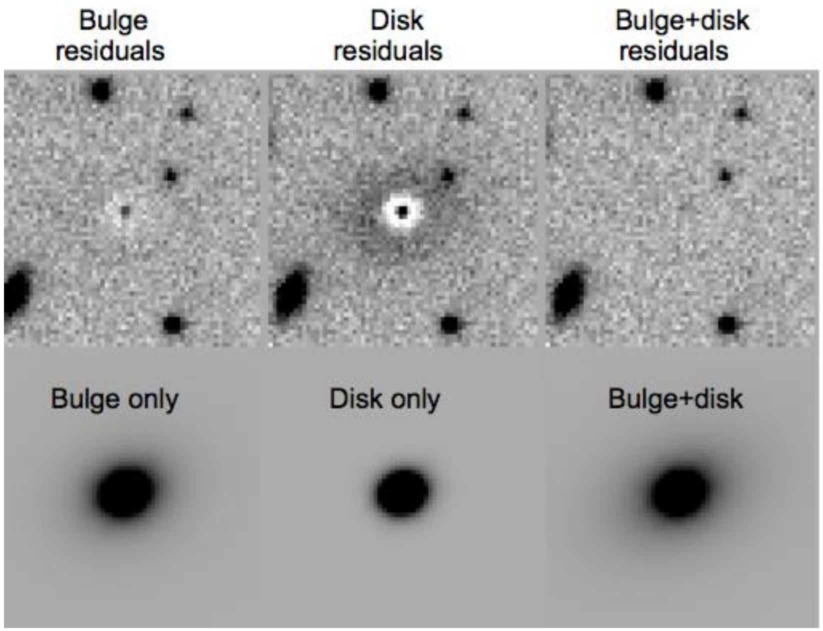
- **Limited end-user alert stream subscription and filtering service**
  - **Individuals will be able to subscribe to receive a small (~20) number of alerts per visit, filtered based on user-specified criteria**
  - **Limited functionality: no classification, not planning to cross-matching to external catalogs, etc.**
  - **We expect the community will provide sophisticated event brokers with classification engines, cross-match capabilities to other catalogs, etc.**

LSST Catalog Contents (Level 2)

- **Object characterization (models):**
  - **Moving Point Source model**
  - **Double Sérsic model (bulge+disk)**
    - Maximum likelihood peak
    - Samples of the posterior (hundreds)
- **Object characterization (non-parametric):**
  - **Centroid: (α, δ), per band**
  - **Adaptive moments and ellipticity measures (per band)**
  - **Aperture fluxes and Petrosian and Kron fluxes and radii (per band)**
- **Colors:**
  - **Seeing-independent measure of object color**
- **Variability statistics:**
  - **Period, low-order light-curve moments, etc.**



LSST Science Book, Fig. 9.3



Some Comments Regarding the OIR System Committee Charge

- LSST was designed to enable a broad set of astronomical and cosmological investigations by providing a large number of multicolor imaging observations for every part of the southern sky.

- Much of the science that will be conducted with this facility can be carried out using the LSST data alone. For most classes of sources, LSST will increase the sample size by factors ~ a hundred, thereby facilitating a wide variety of statistical analyses that could not have been performed previously.

- Nevertheless, it is clear that LSST science will be significantly enhanced through coordinated observations with other facilities. These include:
  - Spectroscopic observations for more precise object characterization and classification, and for calibration of multicolor indices.
  - Multiwavelength observations (radio, IR, X-ray, γ-ray).
  - Time-domain follow-up with increased capability beyond what LSST can provide on its own.

- At present, there is not an obvious mechanism to ensure that the desired observing time will be made available, given the very wide range of facilities that might be involved, and the shear volume of data that LSST will produce. Working through individual proposals to time allocation committees may not be the most effective route. It is very timely that your Committee is exploring such questions now, while we still have a chance to explore new strategies before the flood of LSST data begins.

Some Comments Regarding the OIR System Committee Charge

- As detailed earlier, the LSST Project will provide the basic generic data processing to characterize detected sources in terms of their colors, shapes, time variability, and motion on the sky.

- However, many scientific analyses will require a large suite of additional software to manipulate the data extracted from the LSST catalogs. We call this "Level 3" software. It is not provided by the Project, because it is specific to particular scientific investigations, and there are scientific judgments to be made as to how it is constructed and implemented.

- A significant amount of preparation will be required to ensure that the required Level 3 software is developed in time. To facilitate this, we have encouraged the formation of science collaborations in the relevant fields. Some of the collaborations have been very active in laying out roadmaps for where they will need to be. Others are just beginning that process. Their progress has been hampered by a lack of adequate funding for this kind of work from traditional sources, a problem that could possibly be addressed by your Committee.

Some Comments Regarding the OIR System Committee Charge

- The collaborative nature of much of LSST science could actually simplify some of the complexity involved in trying to facilitate corollary observations.

- If the collaborations represent a large enough segment of the interested community, their memberships may include individuals with access to many of the desired observing facilities. It may matter less who is the PI for a particular set of observations, than that those observations are obtained and made available to the collaboration. In this sense, a larger segment of the community can benefit from the existence of observing resources, whether or not they have individual access to them.

- I am personally in favor of thinking of the entire observing complex as a system, and mapping out the process of optimizing broad scientific investigations using LSST data to that system, using systems engineering-like processes.

- It is difficult to discuss this coherently in the abstract. I think we must charge our existing collaborations to develop some quantitative "use cases" to work this out. They can provide answers to questions like:
  - How large is the sample that will be acquired by LSST?
  - What fraction of that sample must be followed up spectroscopically? With multiwavelength facilities?
  - What are the instrumental requirements for that followup? What facilities can provide it?
  - For time-critical followup, what timescales are required? Will the rate of occurrence be high enough for scheduled observing time, or will ToO's be required?

Summary

- **LSST will enable a new paradigm for a broad range of scientific investigations in astronomy and cosmology by facilitating the acquisition of very large samples of sources with well-measured properties.**

- **Although many of these investigations can be performed with LSST data alone, the science will clearly be enhanced significantly through the provision of corollary observations with a wide array of other facilities. Coordinating the use of such facilities in an optimal way remains a challenge.**

- **The optimization of LSST science will require a significant amount of preparatory work by the community in advance of data taking. This can be facilitated through the formation of collaborations in particular science disciplines. Some of these collaborations are already quite active – others less so – but in all cases, their work has been hampered by a lack of adequate funding channels.**

- **The collaborative nature of LSST science may have impact on the provision of corollary observations, if the collaborations acquire a large enough footprint on the relevant science community.**

End of Presentation