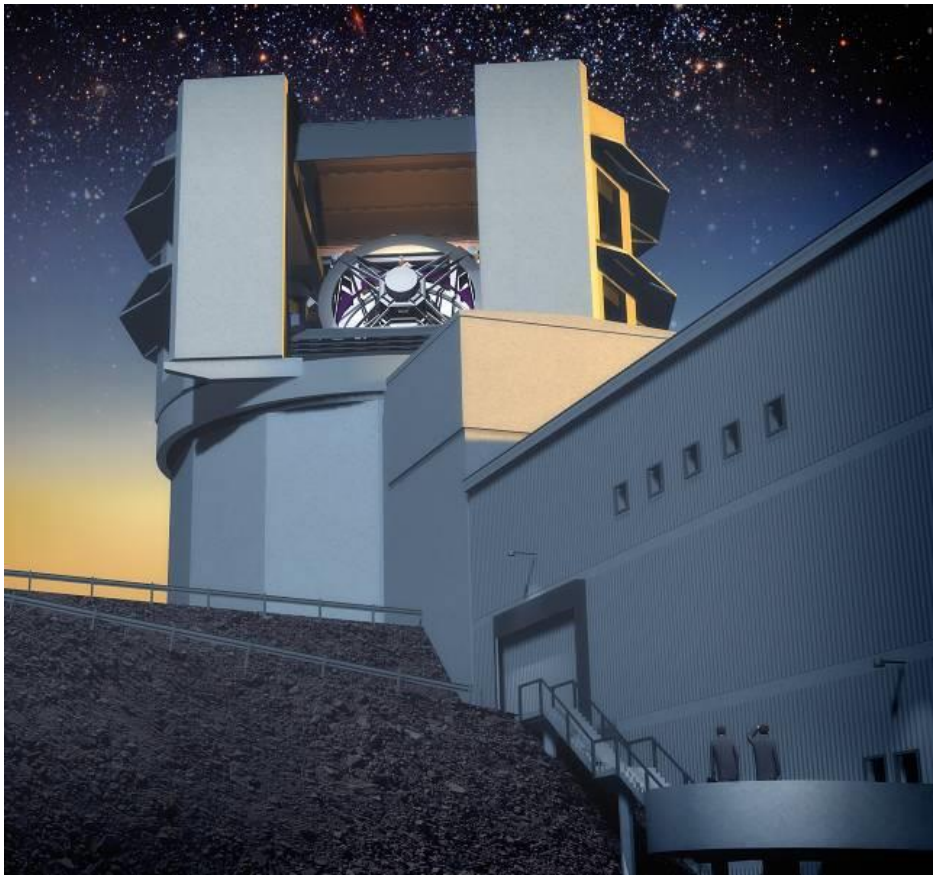
The Large Synoptic Survey Telescope: Status Update

Steven M. Kahn

LSST Director

Mid-Decadal Review Committee
December 13, 2015



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.

Decadal Survey Endorsement of LSST

"LSST is proposed as an 8.4-meter telescope to be sited in Chile. It is specially designed to produce excellent images over a very wide 3.5-degree field of view. It will image the sky repeatedly in six colors in the visible band (0.3 to 1.0 micrometer). Over its lifetime of 10 years, it will observe each region of the sky 1,000 separate times. The 1,000 separate images will be used to make a "cosmic movie" to search for objects that move or whose brightness varies. By adding these images, it will also produce a very deep map of roughly half of the entire sky."

"The technical risk of LSST as determined by the survey's cost appraisal and technical evaluation (CATE) process was rated as medium low. The committee did identify additional risk with establishing data management and archiving software environments adequate to achieving the science goals and engaging the astronomical community."

"The appraised construction cost is $465 million with a time to completion of 112 months. The committee recommends that LSST be started as soon as possible, with, as proposed by the project, two-thirds of the construction costs borne by NSF through its MREFC line and a quarter by DOE using Major Item of Equipment (MIE) funds."

"The estimated operations cost is $42 million per year over its 10-year lifetime, of which roughly $28 million is proposed to be borne by the U.S. agencies—the committee recommends two-thirds of the federal share of operations costs be borne by NSF and one-third by DOE."

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

Data Products and Services Provided by LSST

Nightly (Level 1)

- 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.

Annual DRs (Level 2)

- 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.

Added Value (Level 3)

- 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.

LSST is a Public/Private, Interagency Project

- The National Science Foundation:
  - Telescope and site facility construction, data management system, and education and public outreach.
  - Major Research Equipment and Facility Construction (MREFC). Total not to exceed cost is $473M.
  - Under Cooperative Agreement with the Association of Universities for Research in Astronomy (AURA)
- The Department of Energy:
  - Camera fabrication.
  - 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.
- Private Support:
  - Total Support is ~ $40M.
  - Primary/tertiary mirror, secondary mirror blank, preliminary site preparation, early sensor studies.
  - Responsible organization is the Large Synoptic Survey Telescope Corporation.

Approval Status: NSF

- Successful Final Design Review held in December, 2013.
- Approval by the National Science Board May, 2014.
- Award became official on August 1, exactly one month later than initially planned.

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

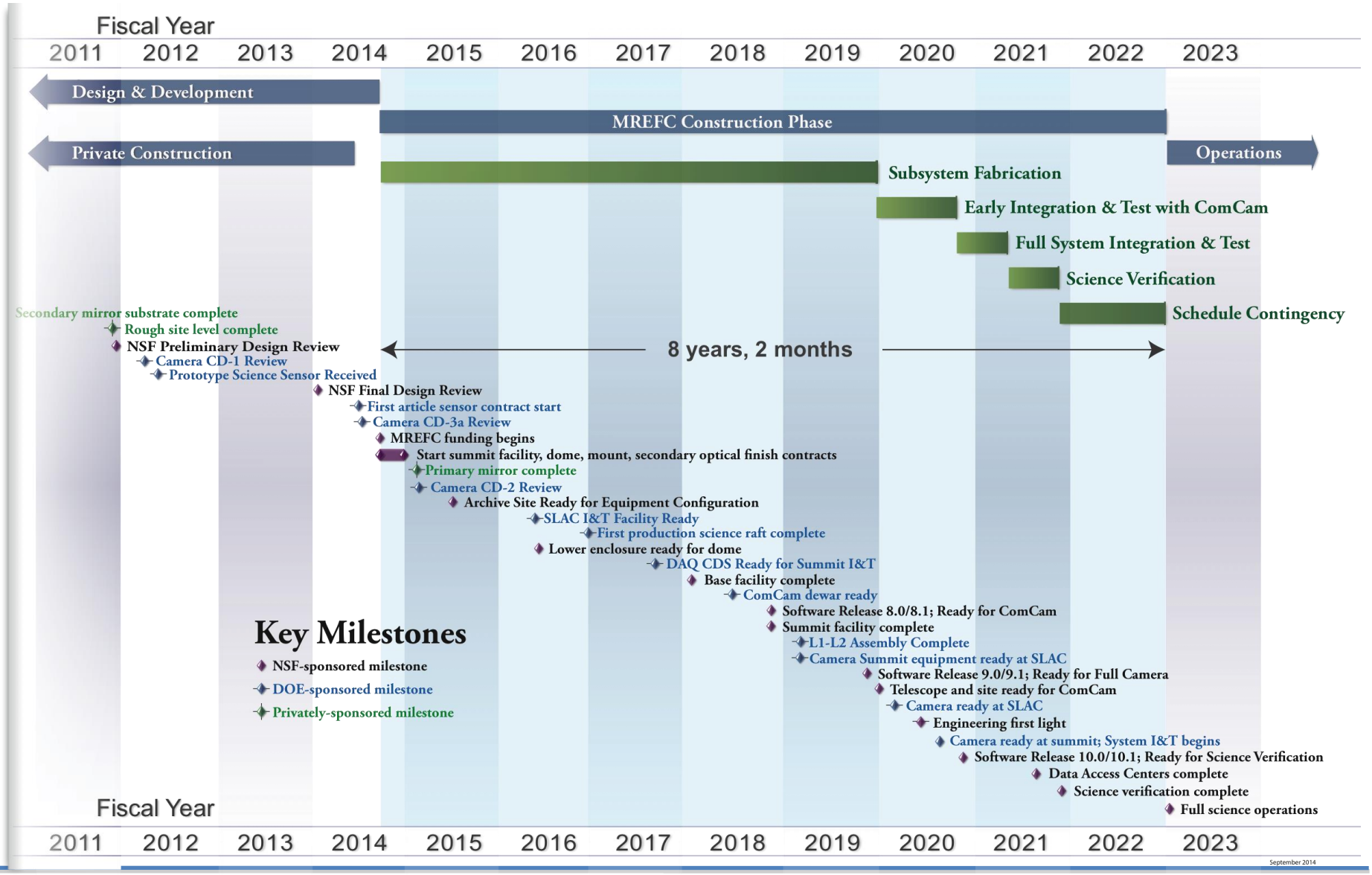
Construction of the highly anticipated Large Synoptic Survey Telescope (LSST) can begin now that the National Science Foundation (NSF) has finalized funding. To be located in Chile, LSST is a proposed 8-meter wide-field survey telescope that will image the entire visible sky approximately twice per week,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

Approval Status: DOE

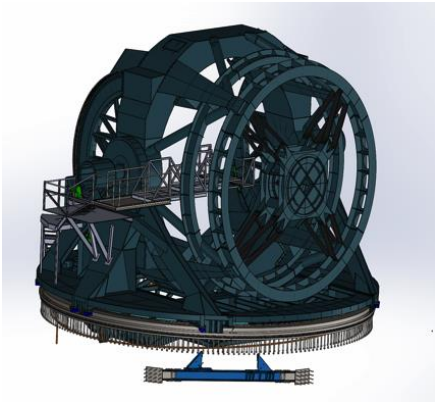
- DOE approval on construction/fabrication projects proceeds via a series of steps called *Critical Decisions*.
  - CD-0 is a statement of "Mission Need". Granted for LSST in March, 2011.
  - CD-1 is a selection of the alternative strategy to meet this need. At this stage a cost range is also established. Granted for the LSST Camera in April, 2012.
  - CD-2 is the approval of the *baseline plan*, which includes the funding profile through completion. Granted for the LSST Camera in January, 2015.
  - CD-3 is the authority to begin the fabrication. For long-lead items, this can be granted in phases. We received CD-3a authority to procure the camera sensors in July, 2014. The full CD-3 approval was granted at the end of August, 2015.
  - CD-4 marks the completion of the project.

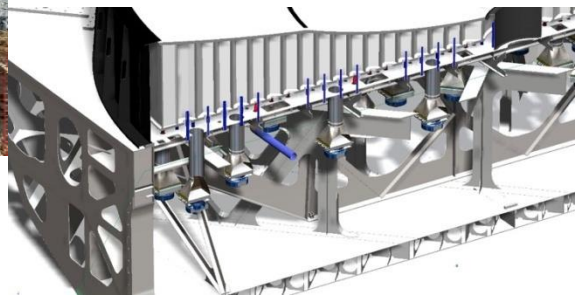
Integrated Project Schedule



Telescope and Site Highlights / Status

- Telescope Team is entering the most intense period
  - Major Subsystems reaching fabrication readiness milestones
  - Fixed Price design efforts still need requirement management
  - In-house Fabrication work producing piece parts





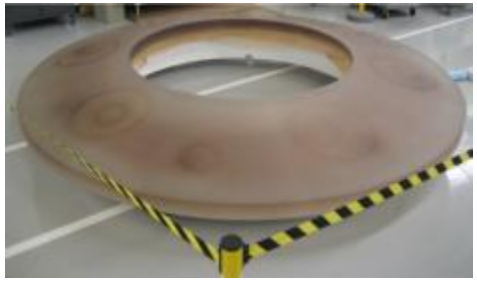
Laying of the First Stone Event on the Summit

Current Status of the Summit Facility Construction

M1M3 safely placed into storage; M2 safely removed from storage

- M1M3 successfully delivered to Tucson airport on May 20th

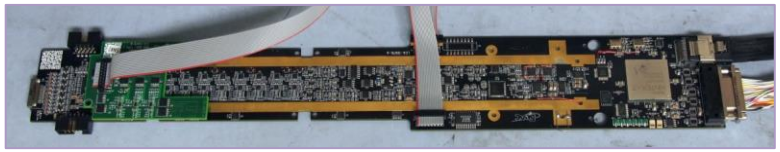
- M2 successfully unpacked and positioned for processing on August 25th



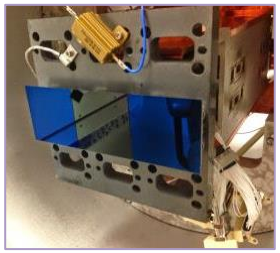
Most Camera Subsystems Have Been Prototyped

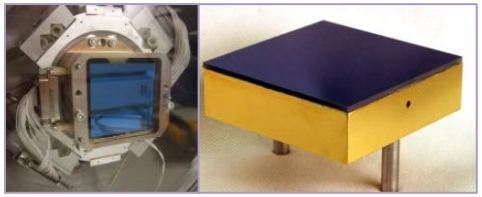
Large Synoptic Survey Telescope

Raft Tower



Corner Raft Electronic Board

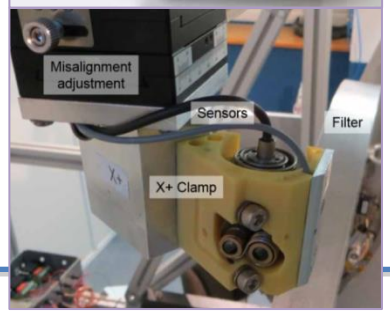


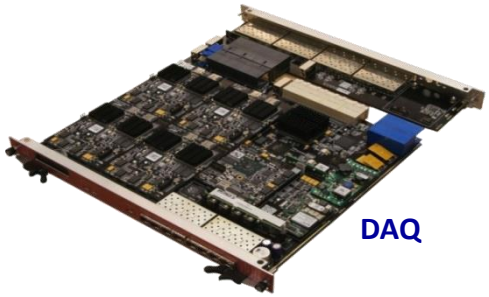


Prototype sensors

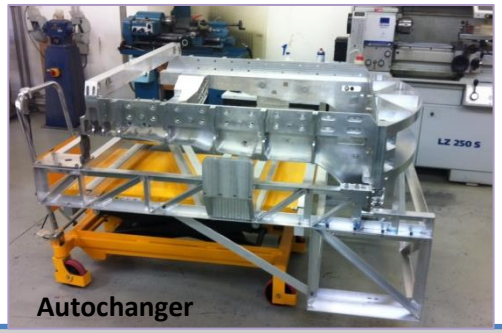
Refrigeration

Carousel Clamps



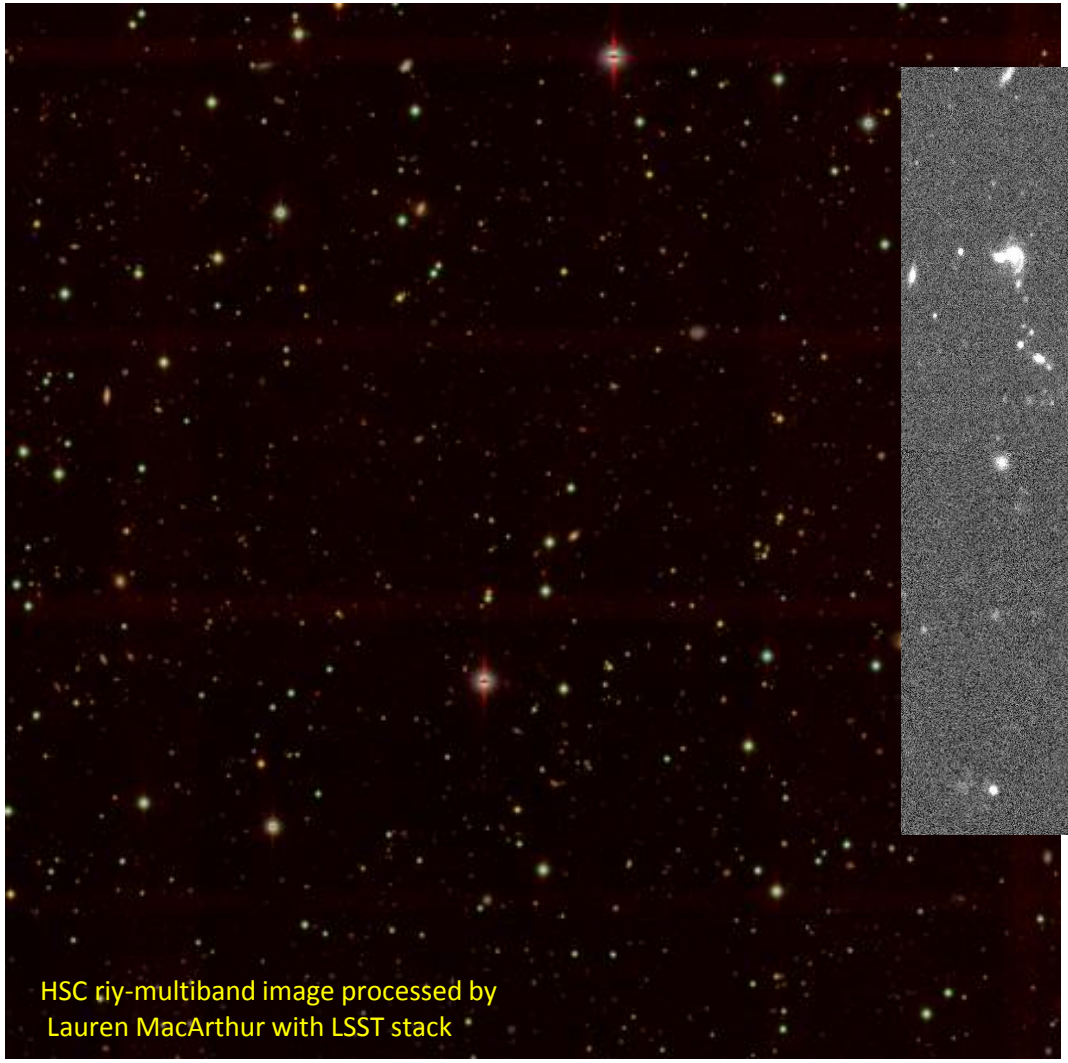


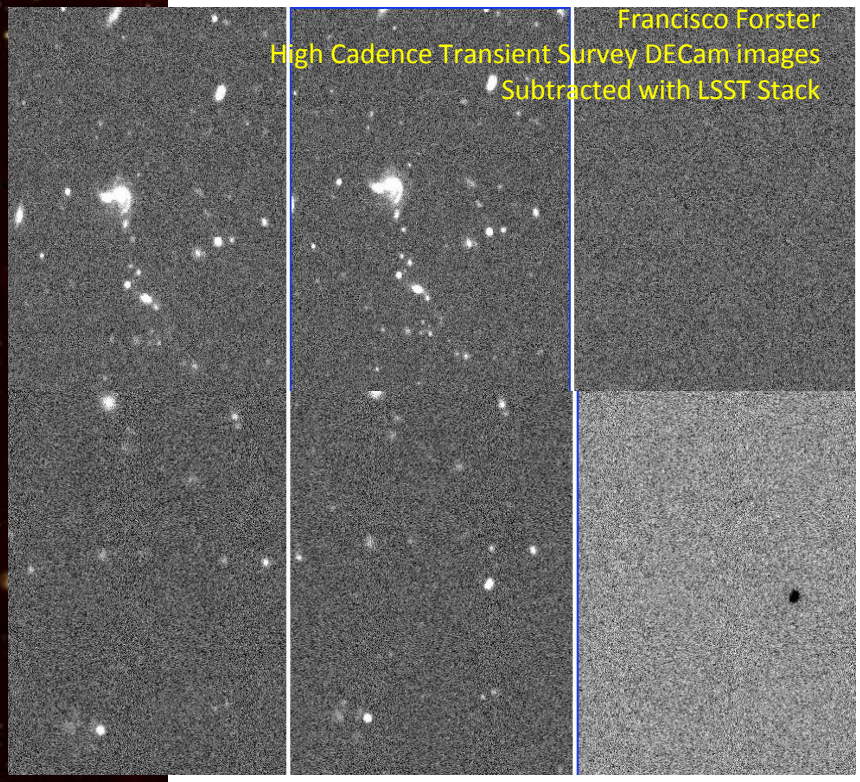
DAQ



Filter Exchange System

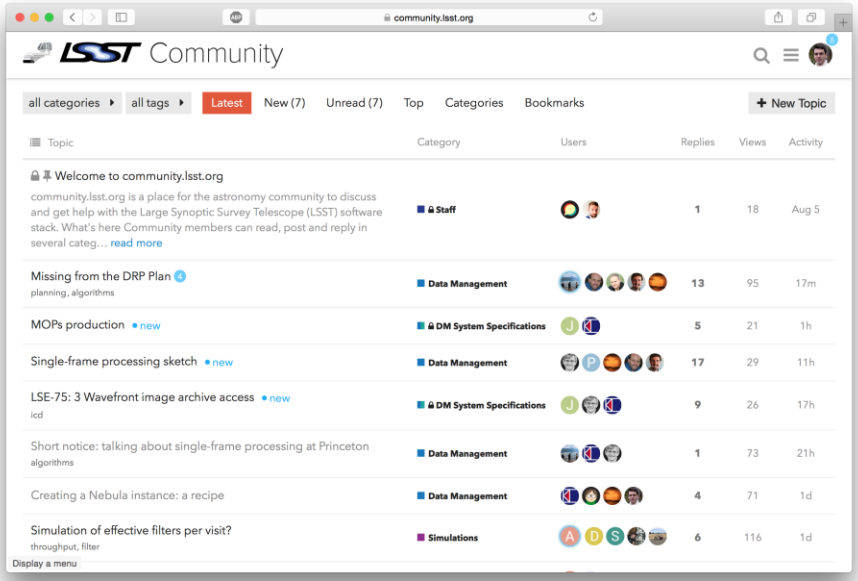
Data Management Software in Use on Precursor Datasets





Community Engagement – Project Communication

- Key project information, including software and simulations, at www.lsst.org
- DPS Town Hall in November 2015, AAS Town Hall in January 2016
- Weekly email – Anyone can subscribe
- Email exploder anyone can subscribe to [soon]



http://community.lsst.org

Reporting Time-domain Events

- For every source detected in a difference image, LSST will emit an "Event Alert" within 60 seconds of observation. **The primary use case is to enable real-time recognition and follow-up of transients of special interest.**

- Each alert will include the following:
  - Alert and database ID: IDs uniquely identifying this alert.
  - The photometric, astrometric, and shape characterization of the detected source
  - 30x30 pixel (on average) cut-out of the difference image (FITS)
  - 30x30 pixel (on average) cut-out of the template image (FITS)
  - The time series (up to a year) of all previous detections of this source
  - Various summary statistics ("features") computed of the time series

- **The goal 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 (thus introducing extra latency)**

LSST Alert Rates

- The alerts will be transmitted over the Internet in VOEvent format using standard IVOA protocols.

- Based on models of the rates of observed asteroids as well as stellar variability (dominant sources of event alerts), **we expect a high rate of alerts, approaching 10 million per night**.

- Consequences:
  - A typical LSST user will not have sufficient bandwidth to receive this full stream.
  - LSST will not have enough outgoing bandwidth to transmit a full stream to everyone; data size and bandwidth in the current baseline allow for transmission of ~three copies of the full data stream.

LSST Alert Filtering Service

- Most end-users will **not** be interested in reception of the full stream, but **only a subset that matches their scientific interest** (e.g., potential SNe candidates, variable stars, or moving objects).

- To support selecting such subsets of alert candidates, **LSST will provide an alert filtering service**. This service will let astronomers create simple *filters* that limit which alerts are ultimately forwarded to them.

- These user defined filters will be possible to specify using an SQL-like declarative language, or short snippets of (likely Python) code.

- **This is the Level 1 analog of querying the database in Level 2**, a service we also provide. The (significantly smaller) returned subset will then be transmitted to the end-user for analysis.

Example of a User-Defined Filter

```
# Keep only never-before-seen events within two
# effective radii of a galaxy. This is for illustration
# only; the exact methods/members/APIs may change.

def filter(alert):
    if len(alert.sources) > 1:
        return False
    nn = alert.diaobject.nearest_neighbors[0]
    if not nn.flags.GALAXY:
        return False
    return nn.dist < 2. * nn.Re
```

The user will subscribe to the alert stream by specifying a filtering function such as the one shown above. Once specified, only the alerts for which the function returns True will be forwarded to the user's VOEvent client.

Limitations of the LSST Filtering Service

- The complexity and run time of user defined filters will be limited by available resources and may be throttled depending on load.
- The number of VOEvents transmitted to each user will be limited and dynamically throttled depending on load.
  - E.g., with a maximum of ~20 events per visit per user, we can serve about ~500 simultaneous users at any one time utilizing total bandwidth equivalent to one full stream.
- No information beyond what is contained in the VOEvent packet will be available to user-defined filters (eg., no cross-matches to other catalogs, or other alert streams).
- We will not provide any astrophysical classification (eg., “is the light curve consistent with an RR Lyra?”, or “a Type Ia SN?”).
- **We don’t expect these limitations will generally cause serious hardship. The numbers of alerts returned (>=20,000/night) should be sufficient for rough pre-selection, without rejecting many potentially interesting candidates.**

Public VOEvent Brokers and Networks

- **We also anticipate that advanced, public, filtering services – VOEvent brokers – will be established by the community.**

- Compared to the LSST filtering service, these may provide advanced functionality such cross-correlation of LSST alerts with external catalogs and other alert streams, classification engines, more extensive annotation of alerts, coordination of follow-up groups, and (more generally) incorporation of other contextual information needed to decide on whether a transient is worth following up.

- **Given the current baseline, we have reserved sufficient bandwidth to serve two to three public VOEvent brokers** (exact number is implementation dependent).

- If established, these will further simplify for the end-user the task of winnowing the alert stream to only contain the objects of interest for their science case. Because of their advanced functionality, we expect they will be preferred by the end-users, compared to the more limited LSST filtering service.

- **However, if such public brokering facilities fail to materialize, we expect the filtering service provided by LSST will be sufficient to enable initial Level 1 science.**

Key Functions of LSST Operations

- Schedule and perform the planned observational program.
- Service and maintain the telescope, camera, and support facilities in Chile.
- Perform the full suite of data processing required to produce the LSST Level 1 and Level 2 data products.
- Service and maintain the data archive and data access center facilities in Urbana, La Serena, and Lyon, as well as the network connections between them.
- Carry out investigations to evolve our understanding of both the system performance of LSST and the science coming out of the facility, so as to continue to optimize our operations effort for maximal scientific return.
- Execute our planned education and public outreach programs.
- Manage the effort successfully against the allocated budget and schedule.

Three Sources of Funding

- There are three anticipated sources of funding for LSST Operations: NSF, DOE, and foreign partners, roughly divided as 50%, 25%, and 25%, respectively. (At present, we have agreements signed or in process covering ~ 70% of the desired goal for the foreign partners.)

- For NSF, we will propose that this be managed via cooperative agreement with AURA, as was done in construction.

- For DOE, all operational support will be managed by SLAC, which is the host laboratory for LSST.

- For the foreign partners, the MoU's have been signed with LSSTC, and we expect that LSSTC will collect and administer the funding.

- Therefore, the execution of facility operations for LSST is envisioned as a partnership between these three managing organizations.

Likely Bases of Operations

We anticipate five primary physical locations for LSST operations:

- The summit facility on Cerro Pachon
- The base facility and data processing center in La Serena
- The main data archive facility and data processing center in Urbana
- The satellite data archive facility in Lyon
- The LSST Headquarters facility in Tucson

In addition, there will likely be additional institutional affiliates composed of contributors resident at their home institutions (e.g. SLAC, UW, etc.), interacting remotely with the primary institutional partners

LSST Operations Proposal Team

Co-Leads - B. Willman (LSST/UA) and C. Claver (LSST)

Listed by Domain Expertise

Business Management - D. Calabrese (LSST)

Camera - K. Reil (SLAC)

Costing - K. Long (LSST), C. Petry (LSST)

Data Management Software Engineering and Development - KT Lim (SLAC)

Data Processing and Archiving - D. Petravik (NCSA)

Education and Public Outreach – S. Jacoby (LSST, temporary)

Science Operations - Z. Ivezic (UW), B. Willman

Systems Engineering - B. Selvy (LSST), C. Claver

Technical Writing and Document Preparation Assistance – R. McKercher (LSST)

Telescope and Site – L. Allen (NOAO), C. Claver, S. Thomas (LSST)

Proposal Advice – D. Lehr (AURA Program Manager)

Reports to the LSST Director, S. Kahn (LSST/SLAC).

We anticipate delivering a finished operations proposal to the agencies in Spring 2017.

Summary

- LSST is well underway on its path toward construction, with significant support from both NSF, DOE, and private funding sources.

- The design is largely unchanged since it was presented to the Astro2010 Decadal Survey. The costs have grown to a small extent, but the duration of the construction period has shrunk and the estimates for operations costs have decreased slightly.

- We have established agreements with foreign institutions to help defray operations costs. At present, we have raised ~ 70% of the desired goal.

- Operations planning is well underway. We will submit a proposal for facility operations in Spring 2017.