The Large Synoptic Survey Telescope

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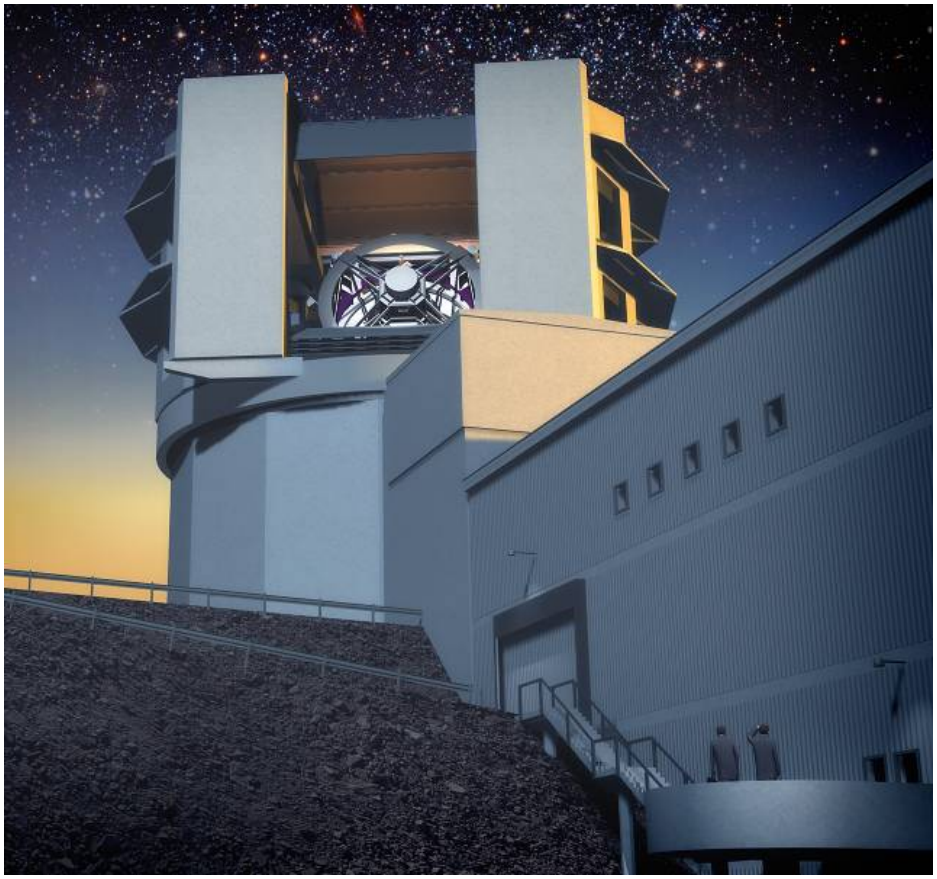


LSST in a Nutshell

Large Synoptic Survey Telescope

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.

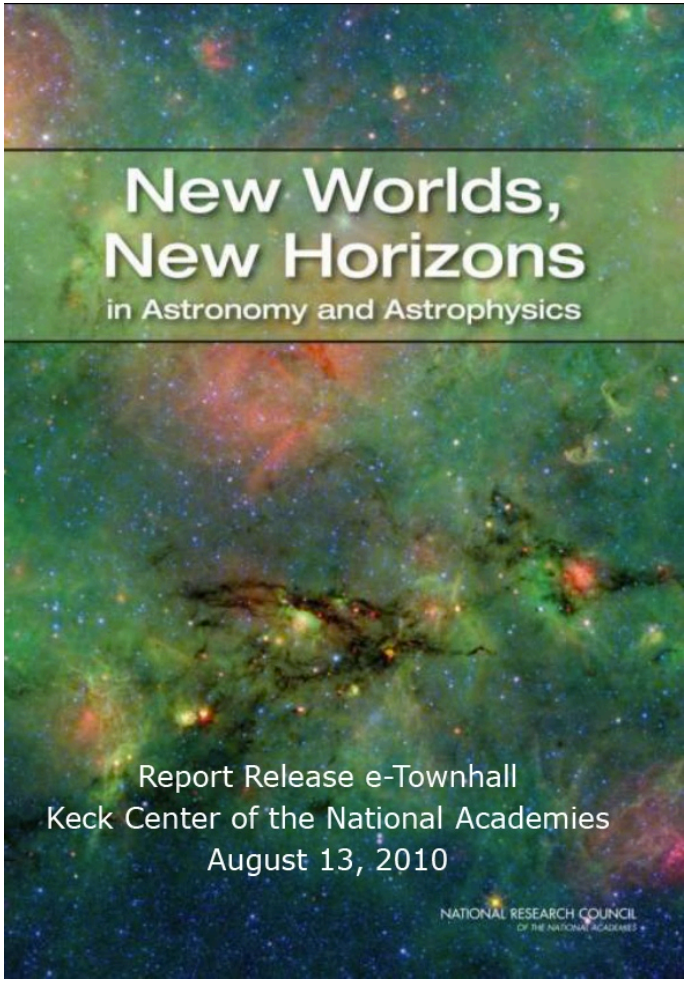
The LSST will enable a wide variety of complementary scientific investigations, utilizing a common database and alert stream. These range from searches for small bodies in the Solar System to precision astrometry of the outer regions of the Galaxy to systematic monitoring for transient phenomena in the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

Highest Ranked Project in 2010 Decadal Survey

LSST
Large Synoptic Survey Telescope

LSST ranked as the highest priority large ground-based facility for the next decade.

"The top rank accorded to LSST is a result of (1) its compelling science case and capacity to address so many of the science goals of this survey and (2) its readiness for submission to the MREFC process as informed by its technical maturity…"



LSST is a Public/Private, Interagency Project

Large Synoptic Survey Telescope

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.
- Executed by the Association of Universities for Research in Astronomy (AURA) through Cooperative Agreement.

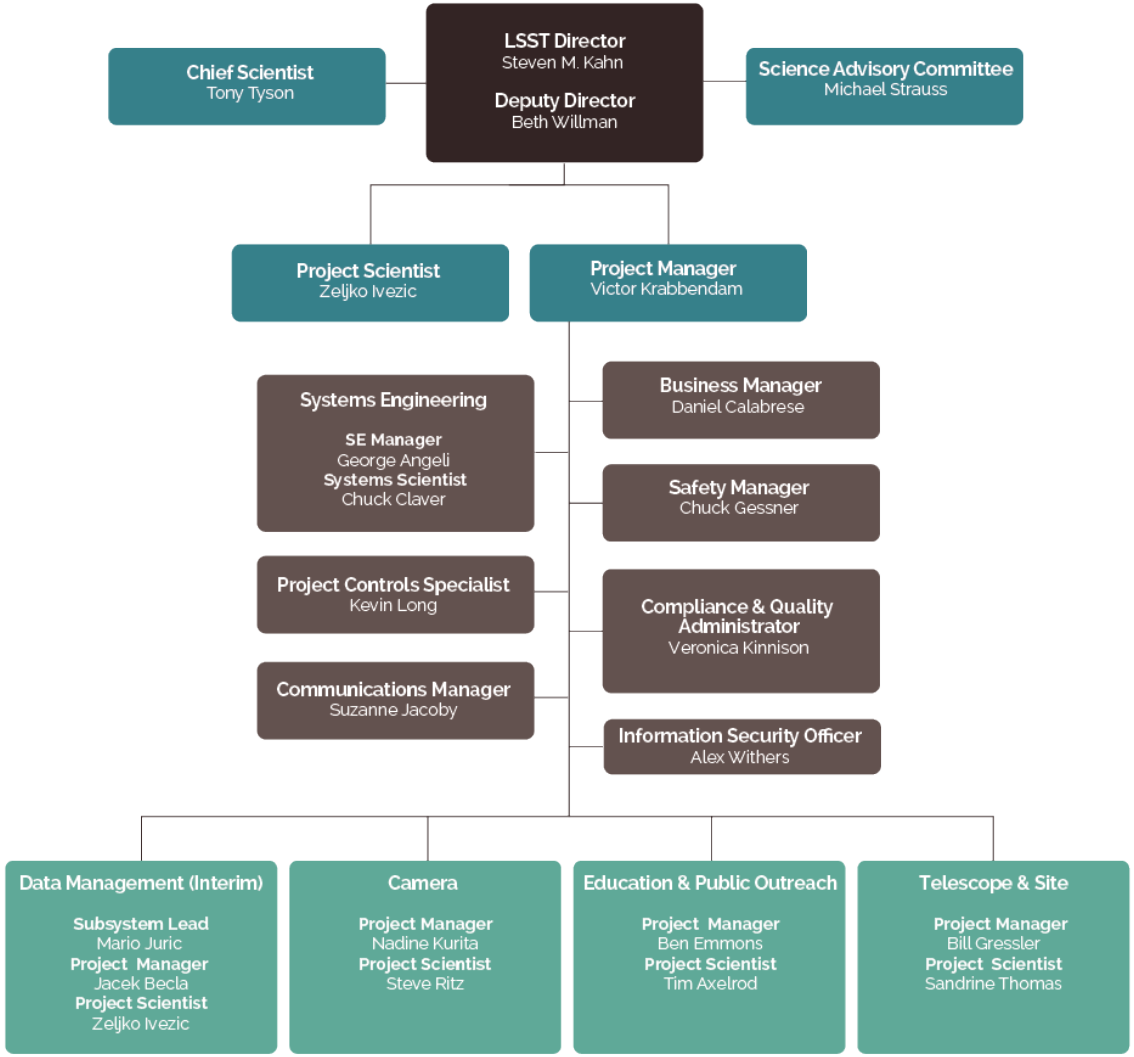
The Department of Energy:

- 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.

LSST Technical Organization Chart



Four Science Themes Define the Science Requirements

Large Synoptic Survey Telescope

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.

The Science Requirements are Captured in the SRD

Large Synoptic Survey Telescope

Formally adopted in July, 2011, and unchanged since that time.

Modification requires the approval of the LSST Corporation Board.

Includes a minimum specification, design specification, and stretch goals for all key parameters of the survey.

LARGE SYNOPTIC SURVEY TELESCOPE

Large Synoptic Survey Telescope (LSST)

Science Requirements Document

Željko Ivezić and the LSST Science Collaboration

LPM-17

July 6, 2011

Summary of High Level Requirements

Large Synoptic Survey Telescope

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

Approval Status: NSF

Large Synoptic Survey Telescope

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.

Approval Status: DOE

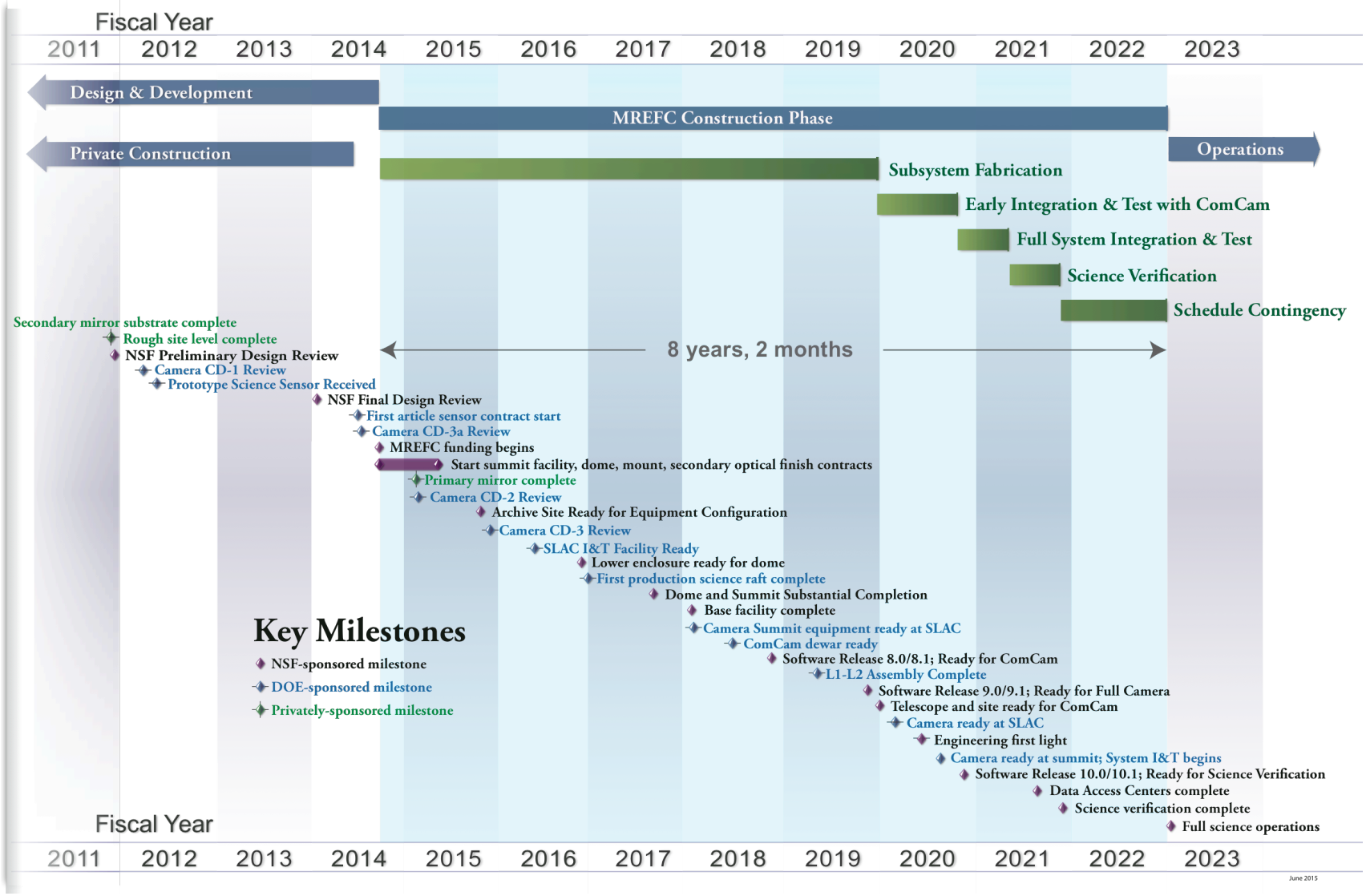
DOE approval on construction/fabrication projects proceeds via a series of steps called *Critical Decisions*.

- 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.

Laying of the First Stone Event on the Summit

Integrated Project Schedule

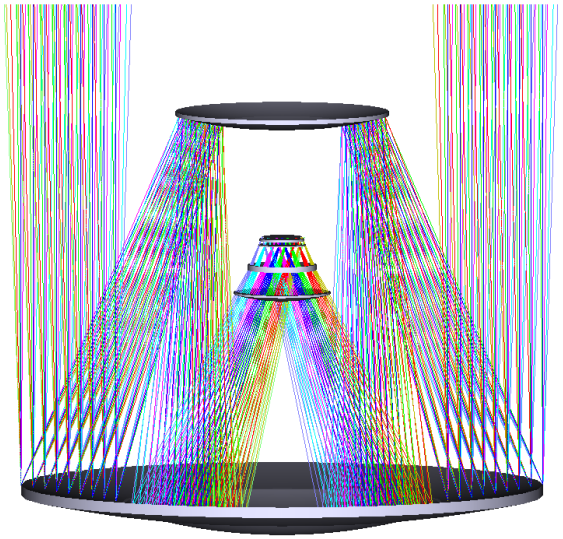
Large Synoptic Survey Telescope

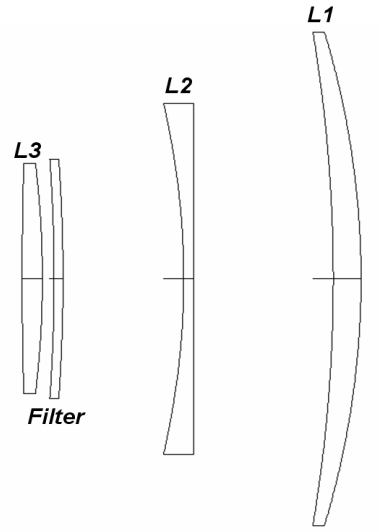


LSST Optical Design

Large Synoptic Survey Telescope

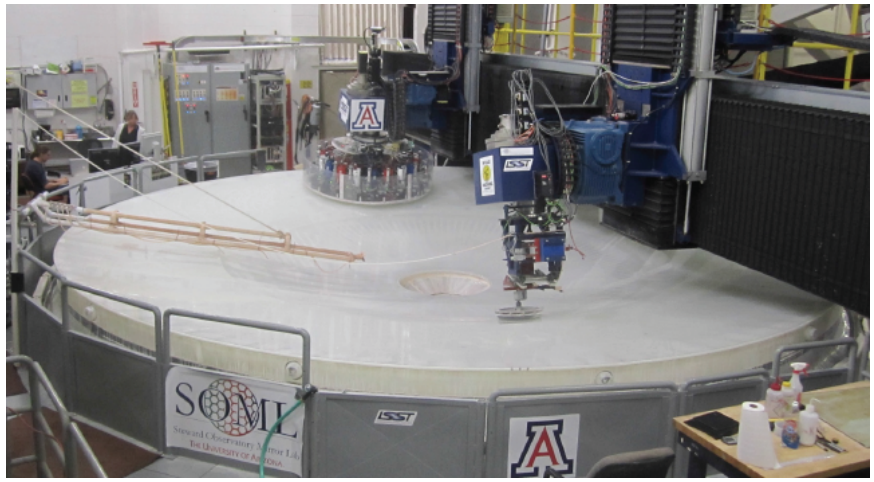
- The LSST incorporates a unique and compact Modified Paul-Baker 3-mirror optical design, with the camera located just below the secondary.
- The design incorporates an 8.4 m primary (M1), a 3.5 m secondary (M2), and a 5.0 m tertiary (M3). M1 and M3 are nearly coplanar, and are fabricated from a single, monolithic substrate.
- The surfaces of all three mirrors, and the six degrees of freedom orientation of the camera, are controlled by an active optics system.
- There are three refractive optics in the camera (L1, L2, L3), plus a filter with very modest optical power.
- The design has been optimized to reduce asphericity in the various elements, and to ease in testing.

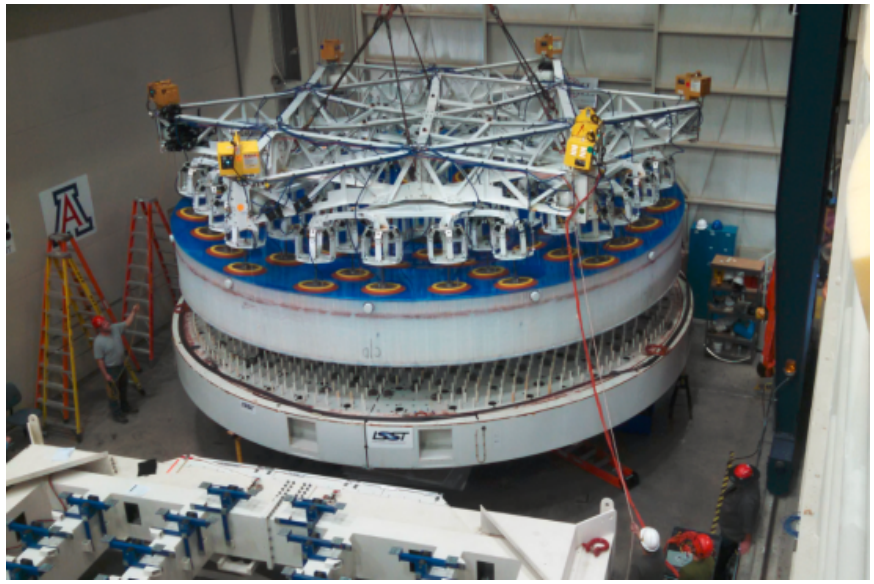




M1/M3 Fabrication

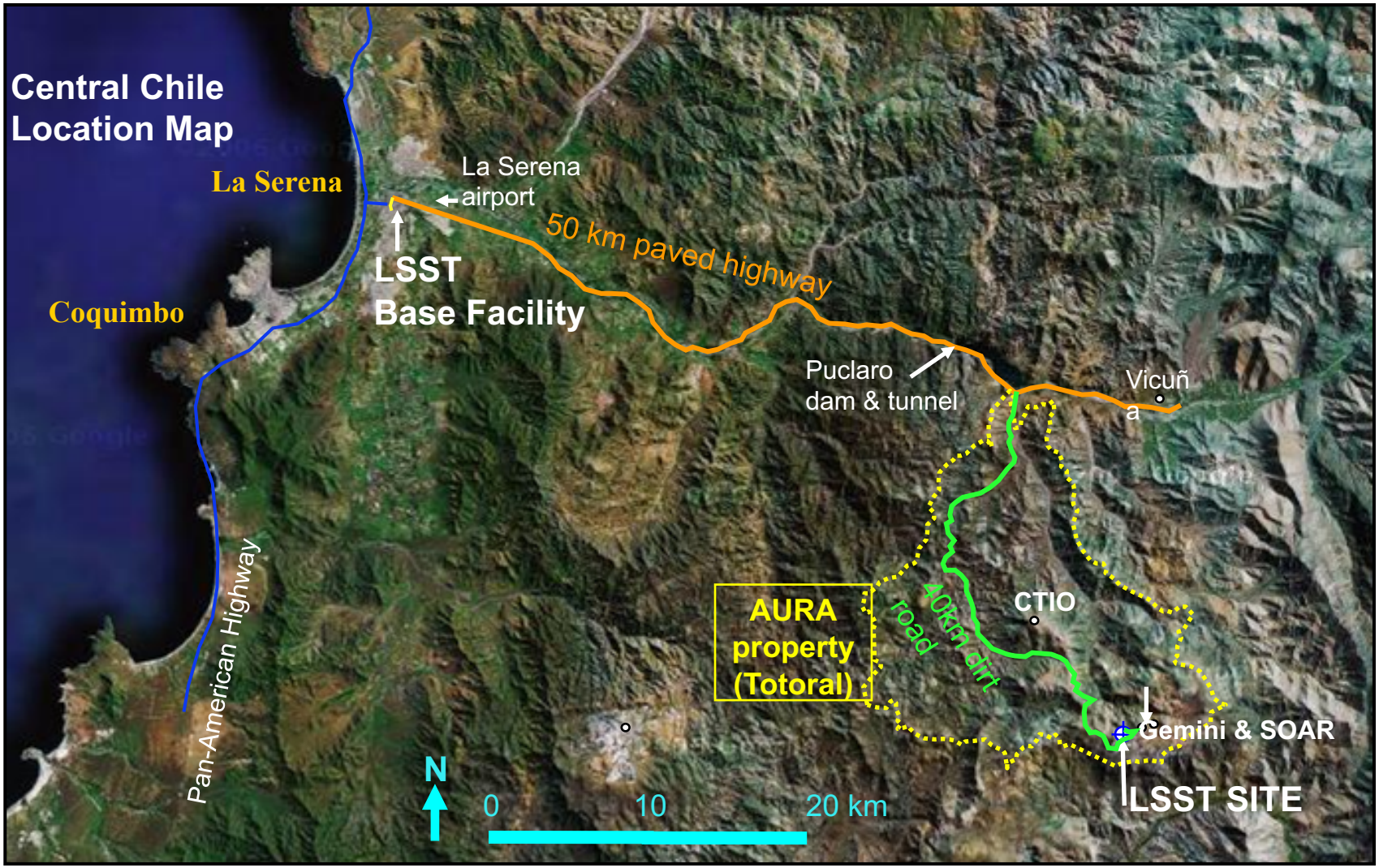
- M1 and M3 are two concentric, monolithic surfaces on one monolithic substrate.
- The combined optic was fabricated by the University of Arizona's Richard M. Caris Mirror Laboratory, and is now complete.
- The substrate material is Ohara E6 borosilicate glass in a honeycomb sandwich configuration.





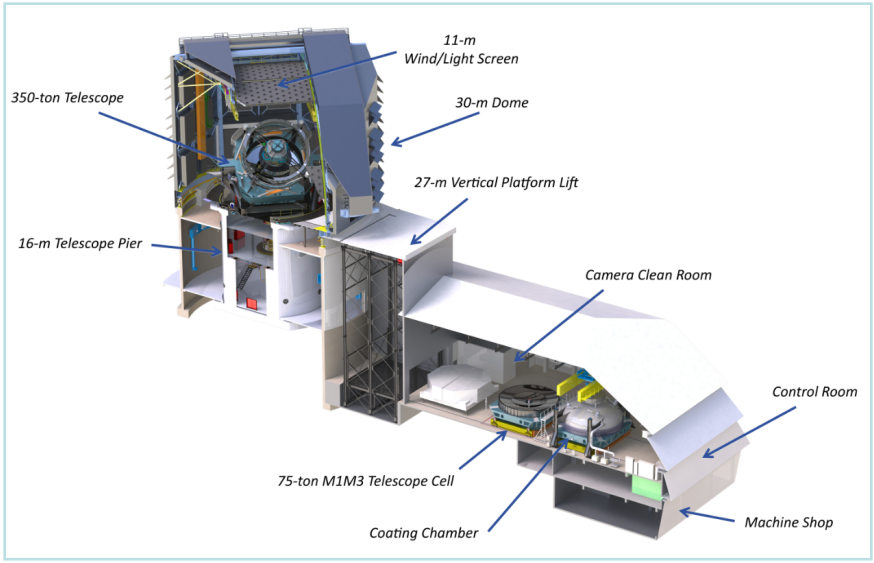
LSST Will be Sited in Central Chile

Large Synoptic Survey Telescope



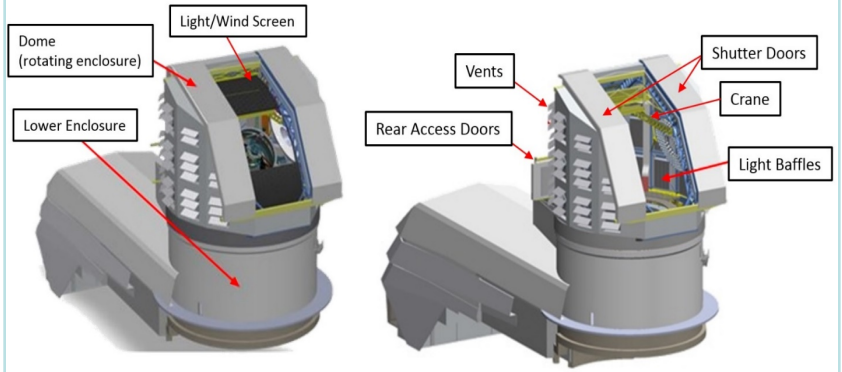
Summit and Base Facilities

- The summit facility construction is being undertaken by Besalco Construcciones, S.A., based on a design by Arcadis-Chile.
- Pflow Industries is producing a custom 80-ton vertical lift platform, designed to transport the mirror assemblies to and from the coating facilities.
- Progress on the summit is well-underway.
- The base facility will integrate and expand existing office space at the AURA property in La Serena. Initial work will begin in late 2016.



Telescope Dome

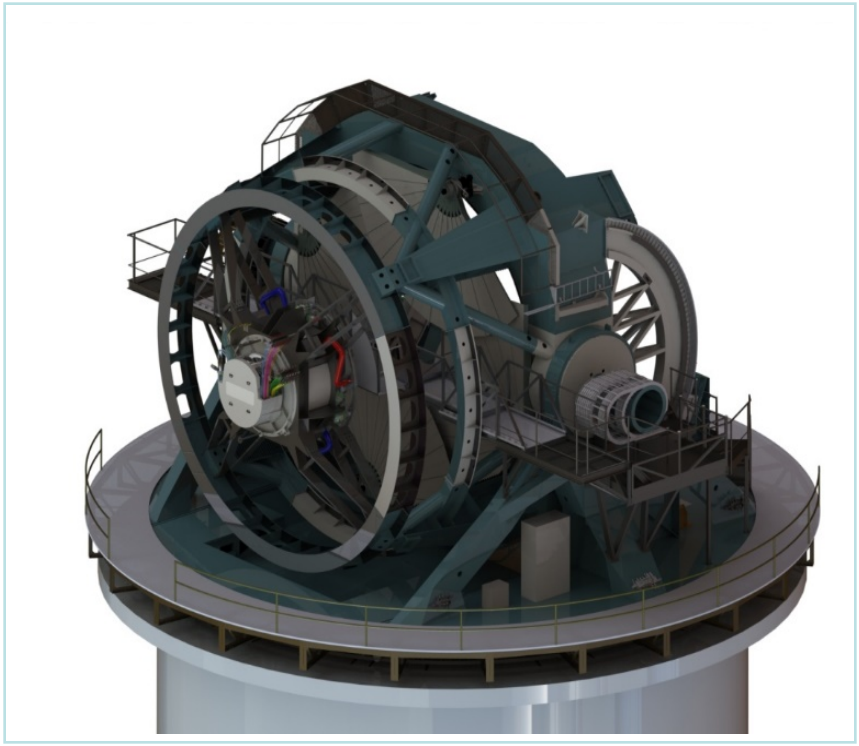
- The dome contract was awarded to European Industrial Engineering (EIE), in Mestre, Italy.
- It is similar to existing EIE VLT dome designs, but includes a separate light/wind screen to suppress stray and scattered light.



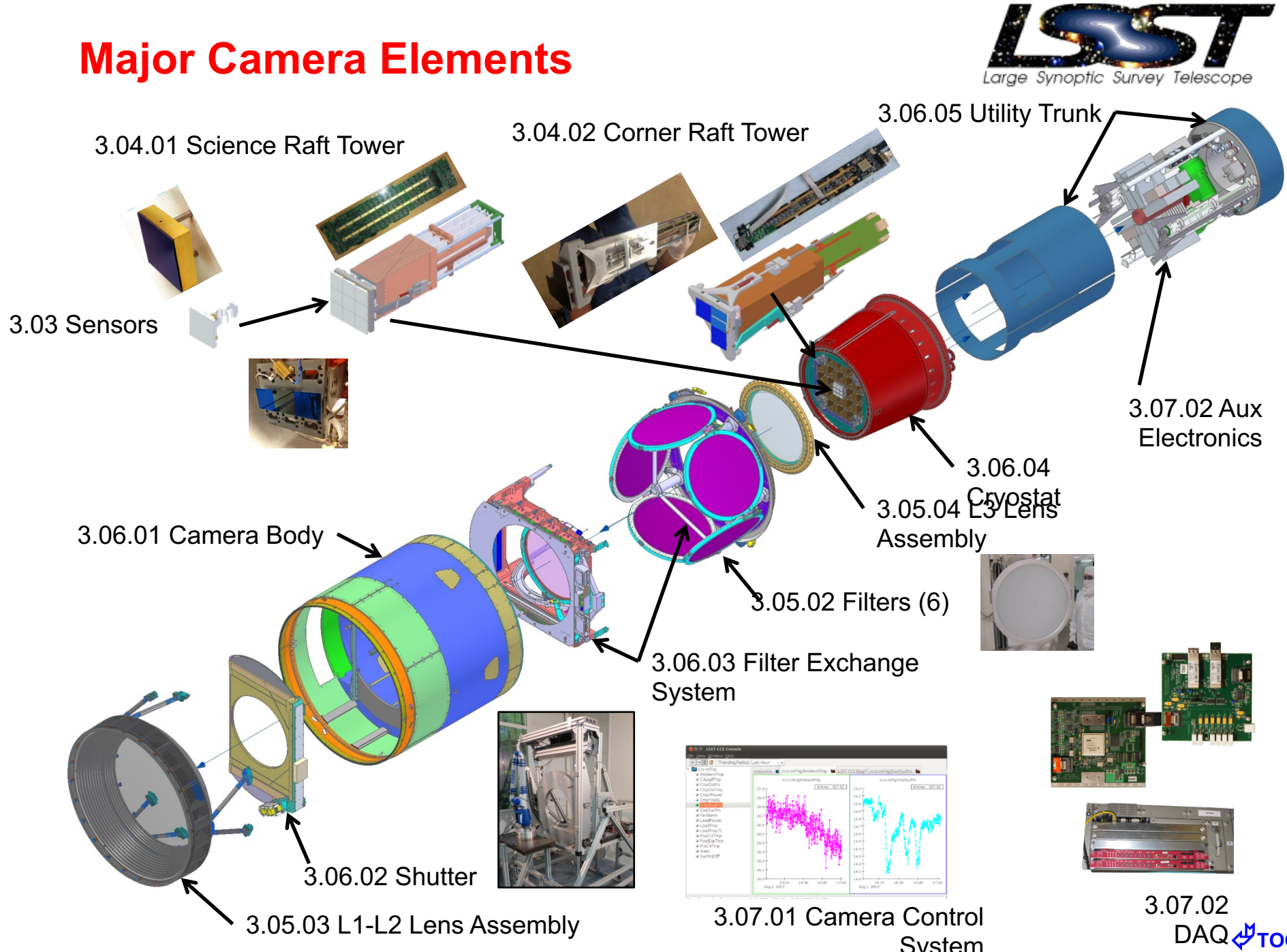
Telescope Mount Assembly

- The telescope mount assembly will be delivered by GHESA Ingenieria y Technologia S.A. and Asturfeito, S.A. in Spain.

- The compact design provides a stiff structure, necessary to achieve the short slew and settling time allocation of < 4 s for a 3.5 degree slew.



Major Camera Elements



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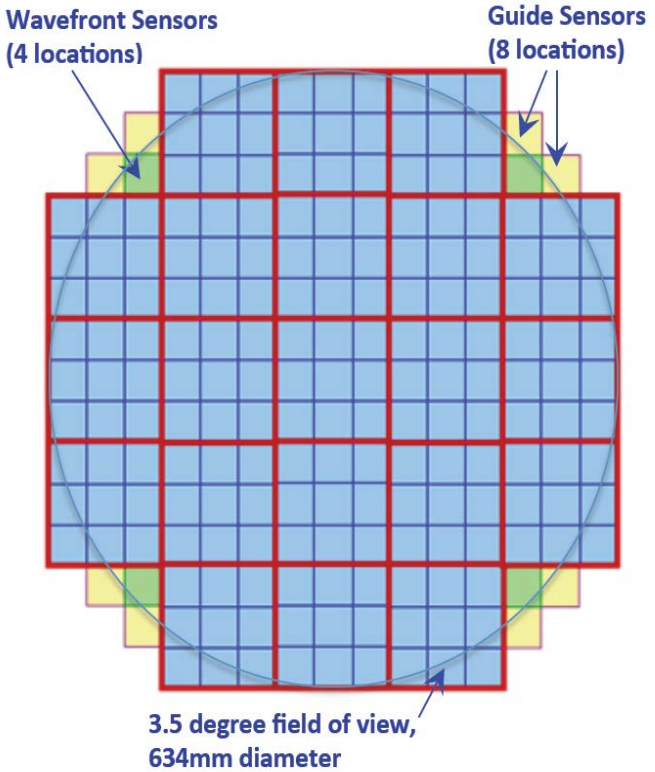
Focal Plane Layout

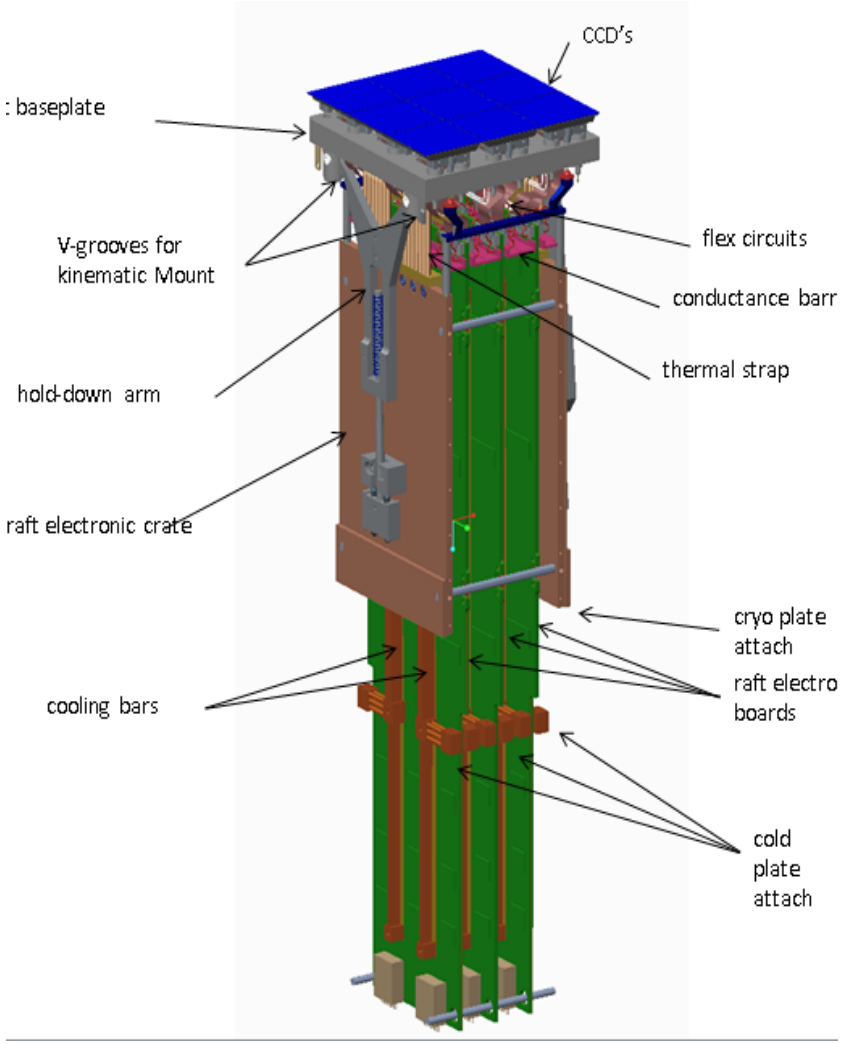
Large Synoptic Survey Telescope

- The LSST camera contains a 3.2 gigapixel focal plane array comprised of 189 4K x 4K CCD sensors, with 10 micron pixels.
- The sensors are deep depletion, back-illuminated devices with a highly segmented architecture, that enables the entire array to be read out in 2 s.
- The sensors are grouped into 3 x 3 arrays, called “rafts”, each with its own dedicated electronics boards, which fit within the footprint of the sensors.
- At the edges of the field, are corner rafts, containing a set of wavefront sensors and two guide sensors.
- Two vendors are under contract to produce sensors, e2v Corporation in the UK, and the Imaging Technology Laboratory at the University of Arizona in the US.



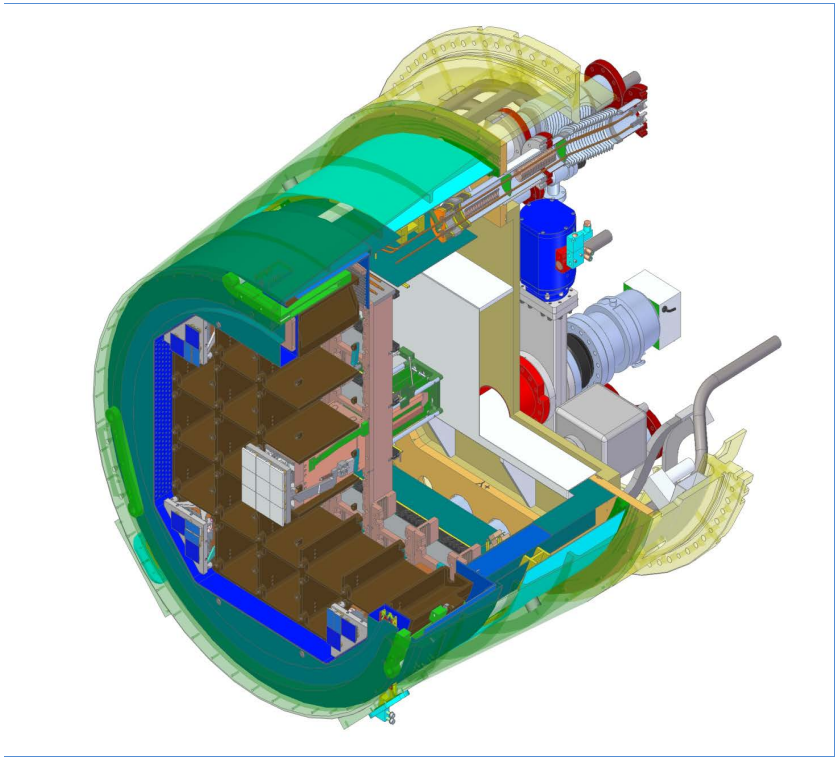
The Science Raft Subsystem

- The science raft tower module is the modular building block of the camera focal plane.
- It consists of three major assemblies: The raft-sensor assembly (RSA), the raft electronics crate (REC), and the raft electronics board (REB).
- All components of the RTM are contained within the camera cryostat vacuum space. The RSA and REC are maintained at an operating temperature ~ -100^{o} C. The REBs operate at a warmer temperature.
- The science raft tower modules are being constructed and tested at Brookhaven National Laboratory.



Camera Cryostat

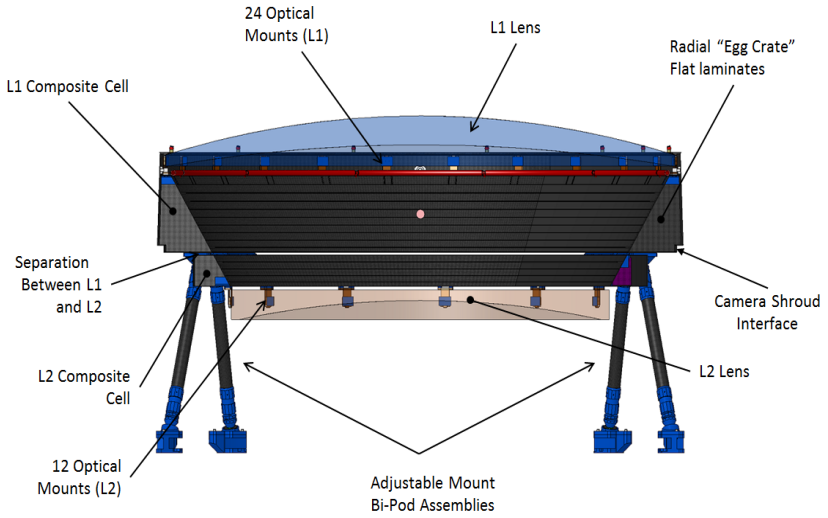
- The camera cryostat assembly structurally supports, thermally controls, and provides the contamination free environment that houses the science and corner raft towers comprising the focal plane array.
- The rafts are kinematically mounted to a Cesic grid manufactured by ECM GmbH in Germany. The grid and grid flexures provide mechanical isolation and minimize gravity and thermally-induced distortions.
- Heat generated by the sensors and electronics is removed by by a cryoplate, operating at -130^{o} C, and cold plate, operating at -40^{o} C.
- The cryostate housing, and its L3 entrance window, comprise a vacuum vessel operating at < 10^{-6} Torr.
- The camera cryostat will be assembled and tested at SLAC National Accelerator Laboratory.



Refractive Optics and Filters

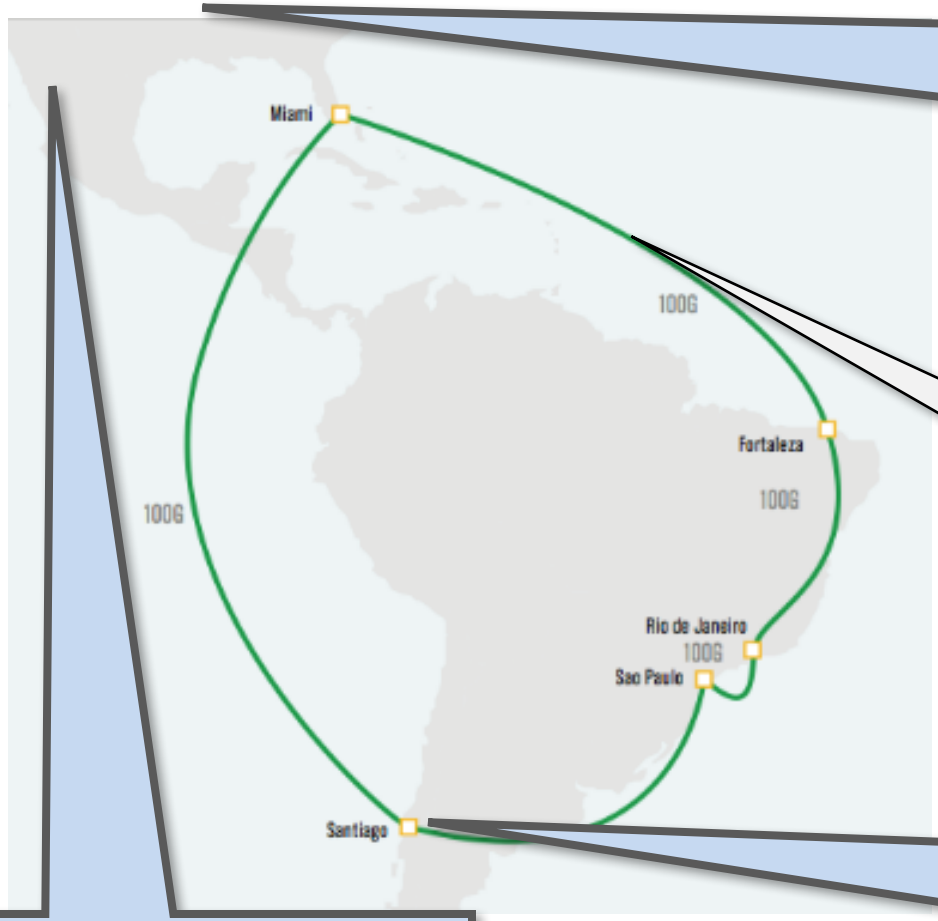
Large Synoptic Survey Telescope

- The camera refractive optics system consists of three fused silica lenses with clear apertures of 1.550 m, 1.102 m, and 0.722m (L1, L2, and L3, respectively).
- L1 and L2 are integrated into a single assembly. The prime contractor for that work is Ball Aerospace.
- L3 is the entrance window the cryostat. It is being produced by Thales/SESO in France.
- The filters consist of multi-layer dielectric interference coatings deposited on fused silica substrates. The substrates are curved, so that the chief ray is normal to the front surface at all points in the field. The filter coatings will be produced by Materion.
- The development of the LSST camera optics systems is being led by Lawrence Livermore National Laboratory.



LSST Operations: Sites and Data Flows

Large Synoptic Survey Telescope



Archive Site

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)

Summit and Base Sites

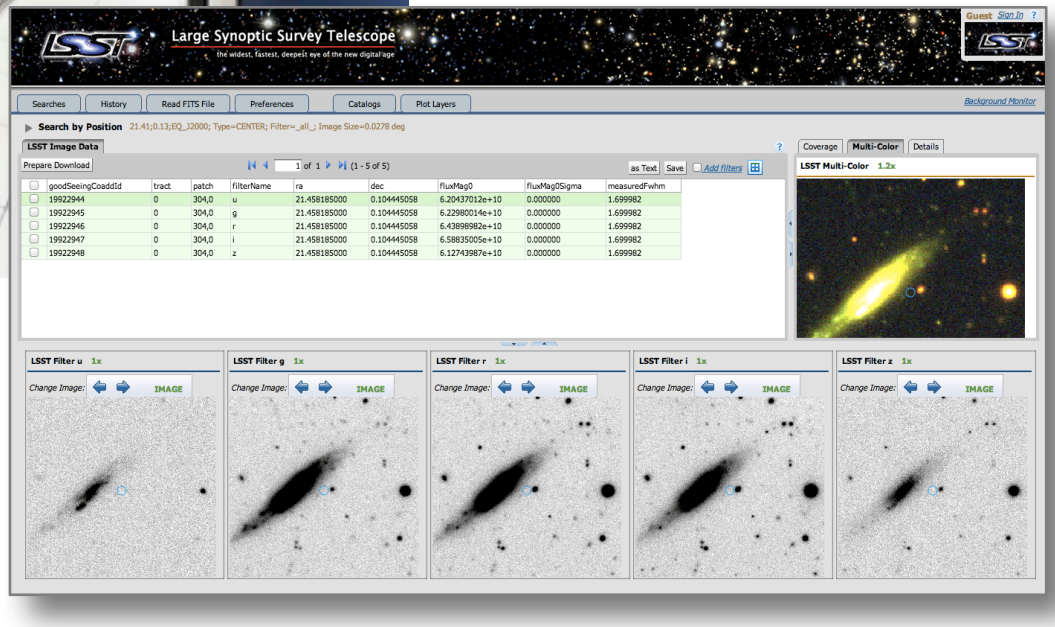
Telescope and Camera
Data Acquisition
Crosstalk Correction
Long-term storage (copy 1)
Chilean Data Access Center

HQ Site

Science Operations
Observatory Management
Education and Public Outreach

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.*

Data Products and Services Provided by LSST

Large Synoptic Survey Telescope

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.

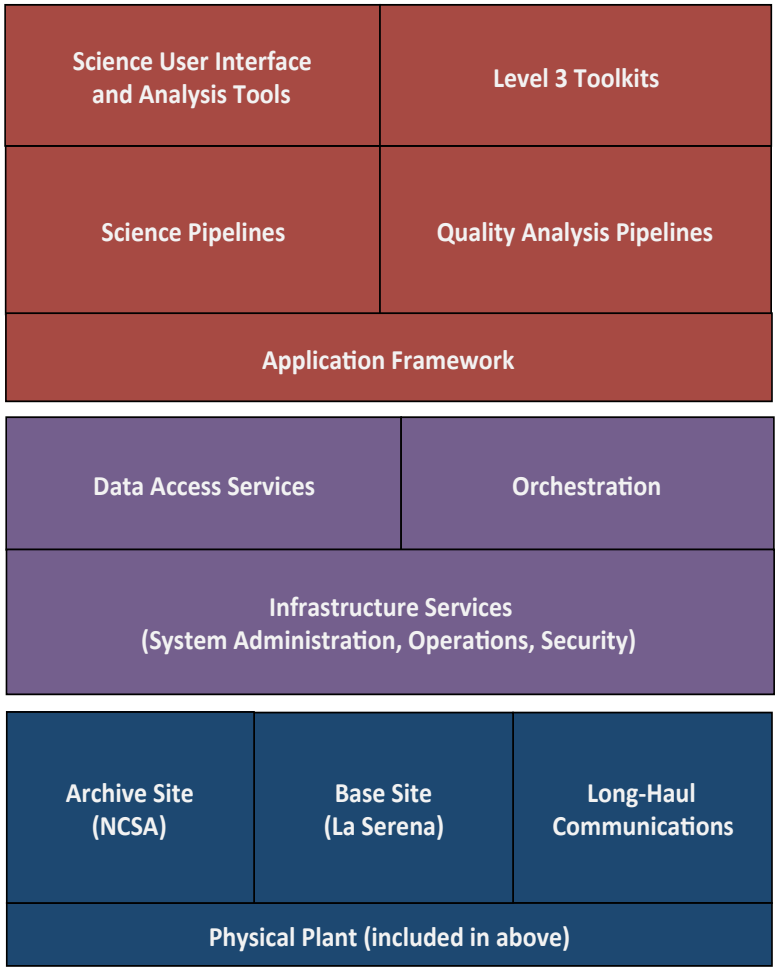
Added Value (Level 3)

- 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.

Data Management System Structure

- The LSST DM system is conceptually divided into three layers:
  - Infrastructure: computing, storage, and networking hardware and system software.
  - Middleware: distributed processing, data access, the user interace, and system operations services.
  - Applications: data pipelines and products, science data archives.

- Physically, the DM system components will span four key facilities on three continents: the base facility in La Serena, the central archive facility at NCSA in Illinois, and a satellite data processing center at CC-IN2P3 in Lyons, France.



Education and Public Outreach

Large Synoptic Survey Telescope

- 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.

Summary

Large Synoptic Survey Telescope

- LSST is a highly complex system, which is pushing the state-of-the art in many technical areas.
- We have assembled an outstanding distributed team to accomplish this work, and a set of high quality vendors around the world to implement our designs.
- The project is on track to achieve first light in 2020, and to formally begin the decade of operations on October 1, 2022.
- This will be a world-unique facility that will make fundamental discoveries in a wide range of disparate fields.