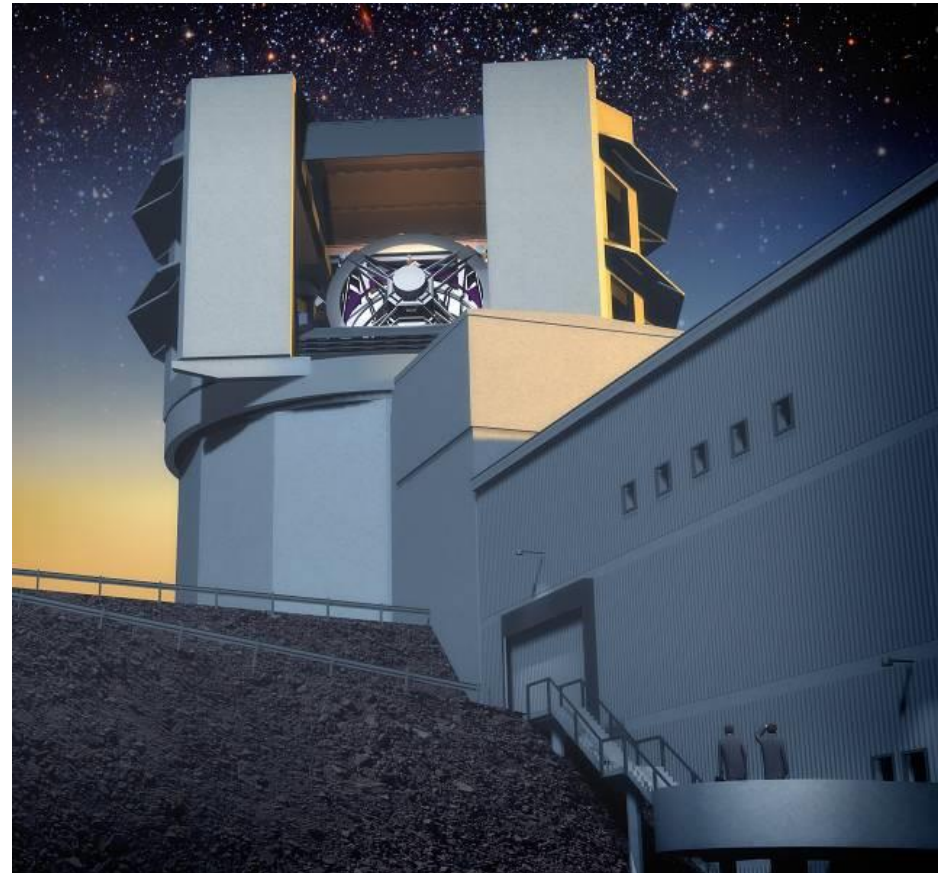


The Large Synoptic Survey Telescope: Status Update

Steven M. Kahn

LSST Director

CAA Meeting – March 31, 2015



- 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 detected 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.

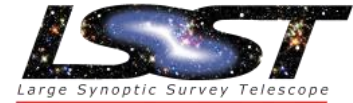
“LSST is proposed as an 8.4-meter telescope to be sited in Chile. It is specially designed to produce excellent images over a very wide 3.5-degree field of view. It will image the sky repeatedly in six colors in the visible band (0.3 to 1.0 micrometer). Over its lifetime of 10 years, it will observe 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.”

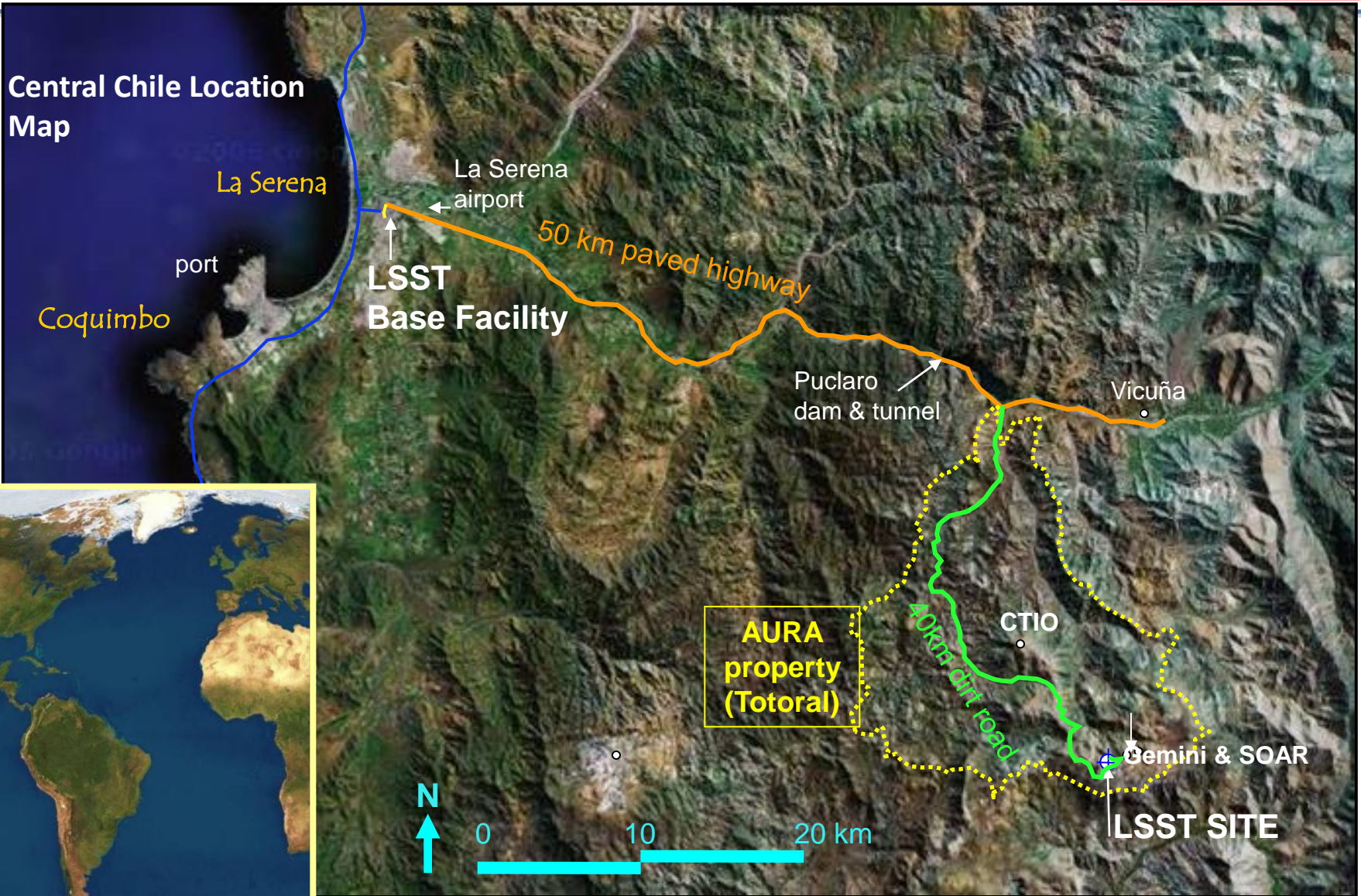
Summary of High Level Requirements



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

- Construction: \$473M (NSF) + \$168 (DOE) + \$40M (Private)
[Including Contingency: 21% (NSF), 31% (DOE)]
- Operations: \$37M per year (2013 USD)
[50% NSF, 25% DOE, 25% Foreign Partners]
- Duration of Construction: 8/1/14 – 9/30/22
[98 months]

LSST Will be Sited in Central Chile



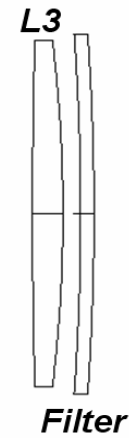
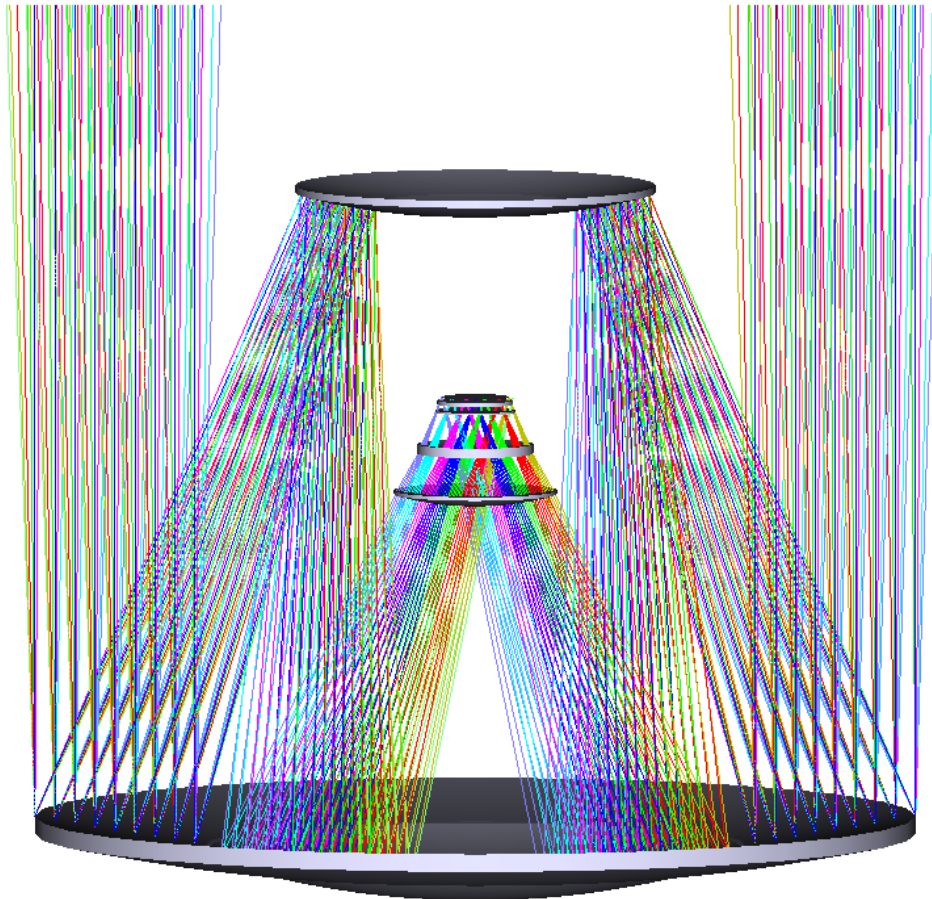
Dome and Facility Design



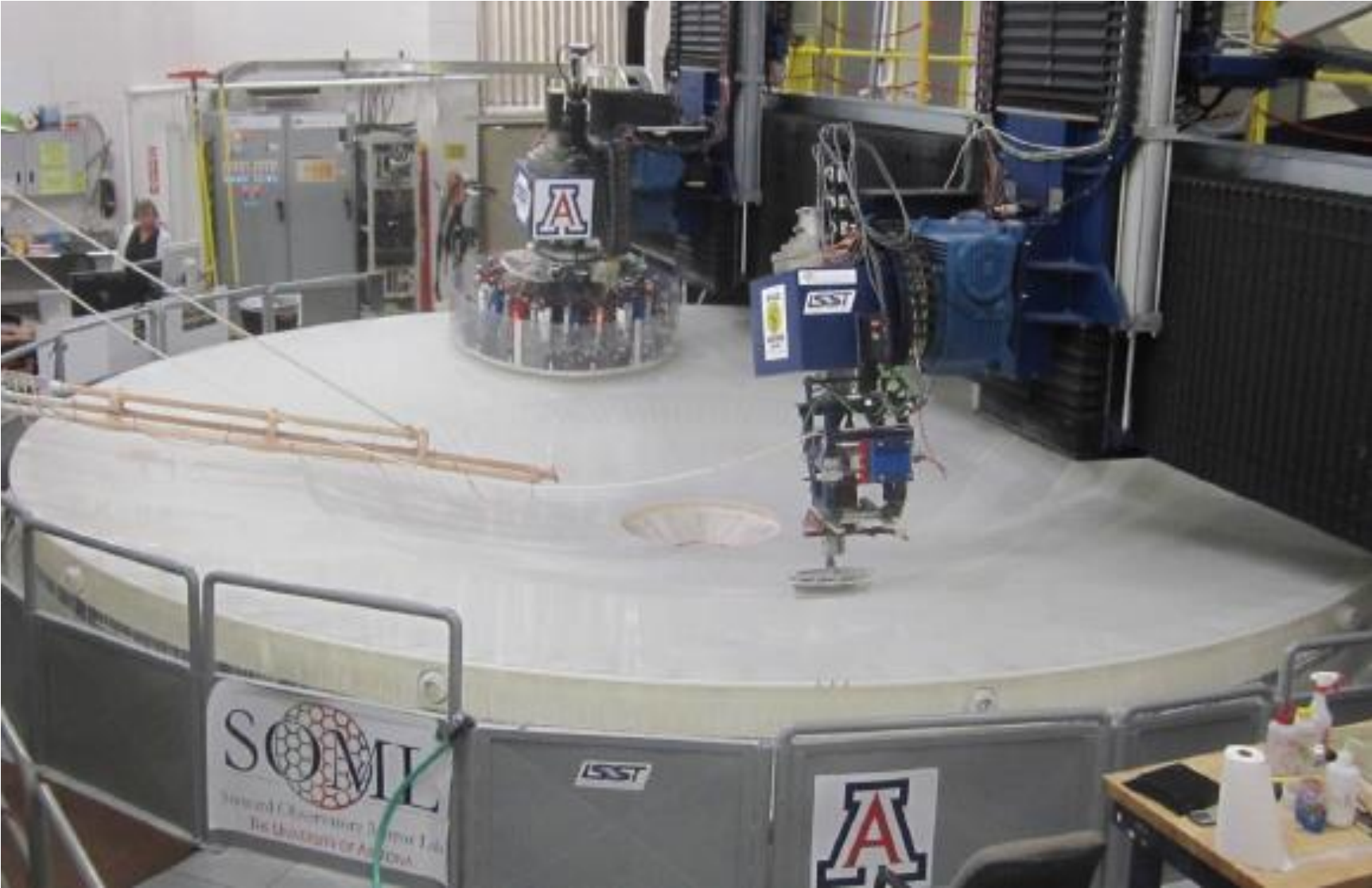
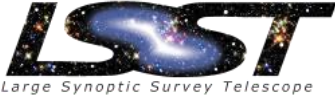
Site has been leveled!



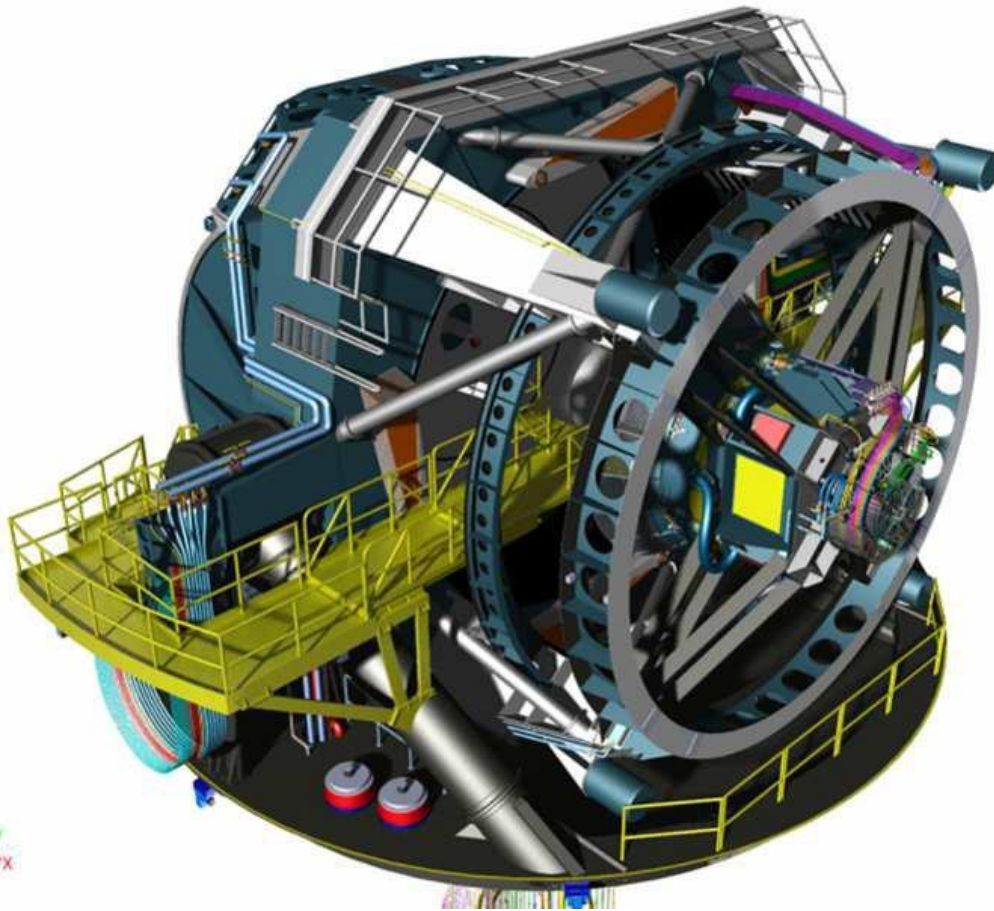
Modified Paul-Baker Optical Design



Primary/Tertiary Fabricated as a Single Monolith

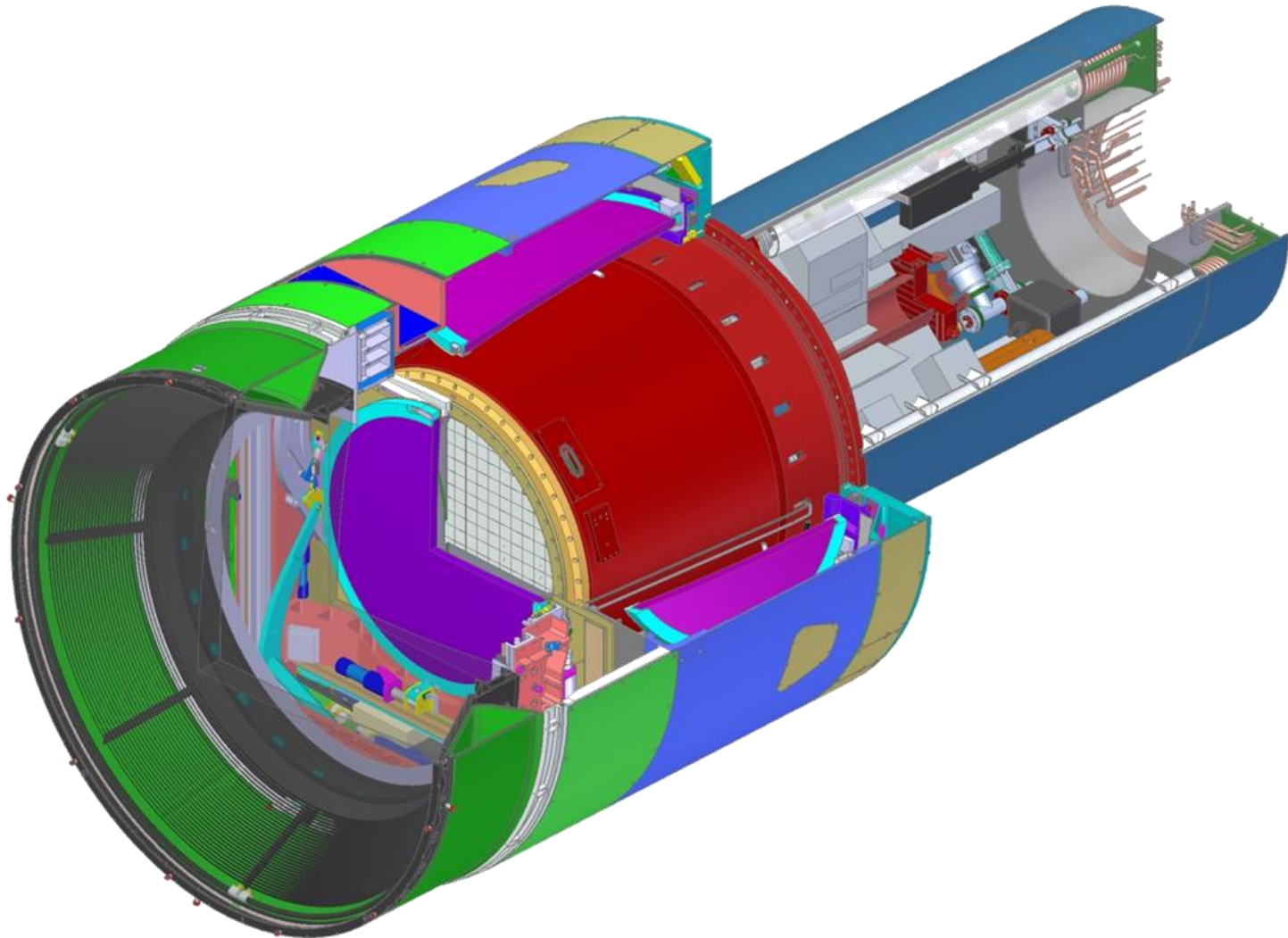


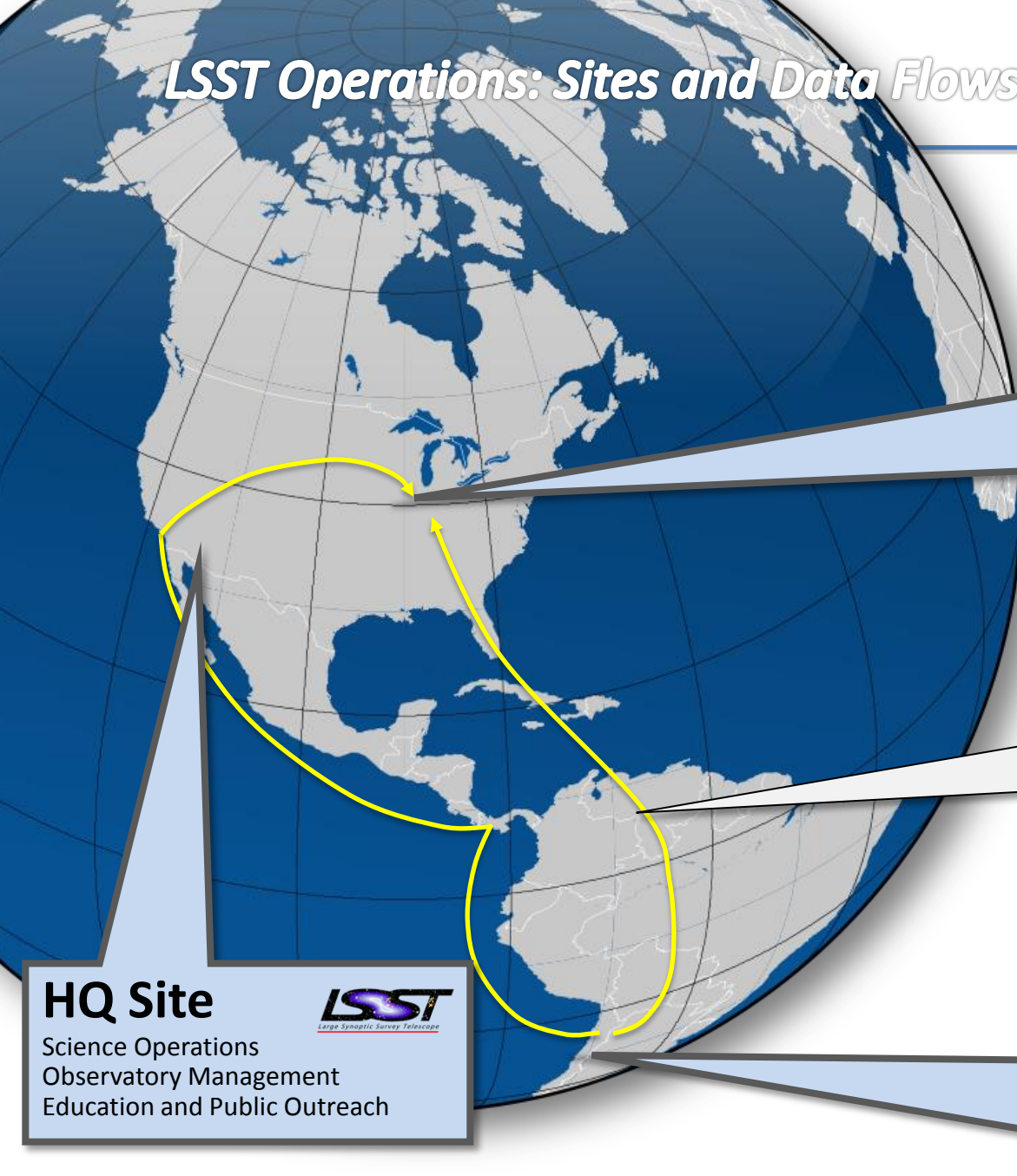
Telescope Mount Enables Fast Slew and Settle



- 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 Gigapixel Camera





Archive Site

Archive Center

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

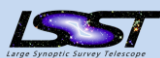
Data Access Center

- Data Access and User Services

Dedicated Long Haul Networks

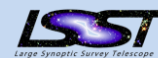
Two redundant 40 Gbit links from La Serena to Champaign, IL (existing fiber)

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

- 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.
- 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.
- 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.

Nightly
(Level 1)

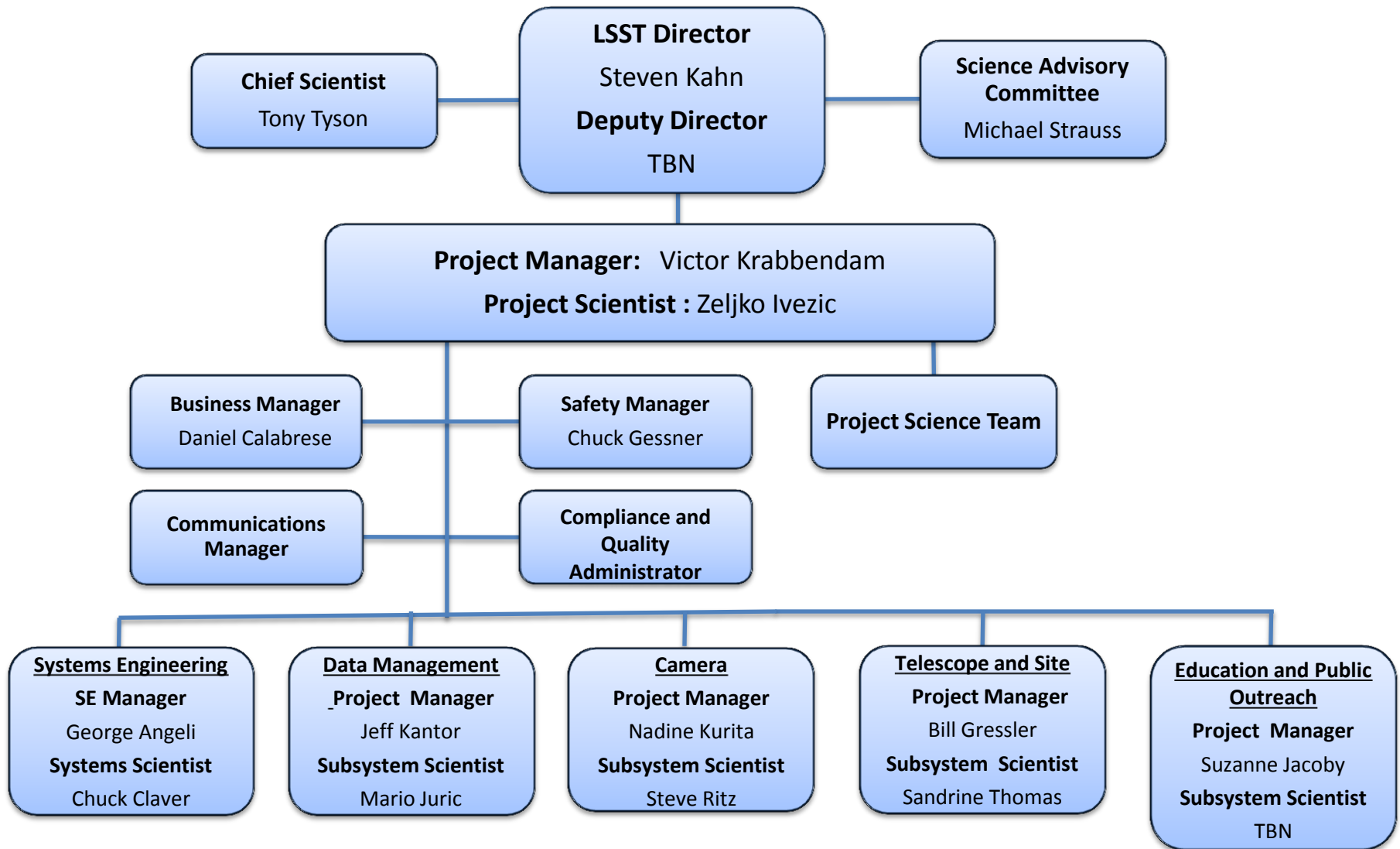
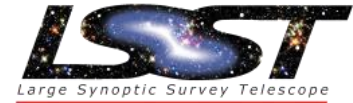
Annual DRs
(Level 2)

Added Value
(Level 3)

- 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.

- 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.

The LSST Technical Organization Chart



- 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.



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

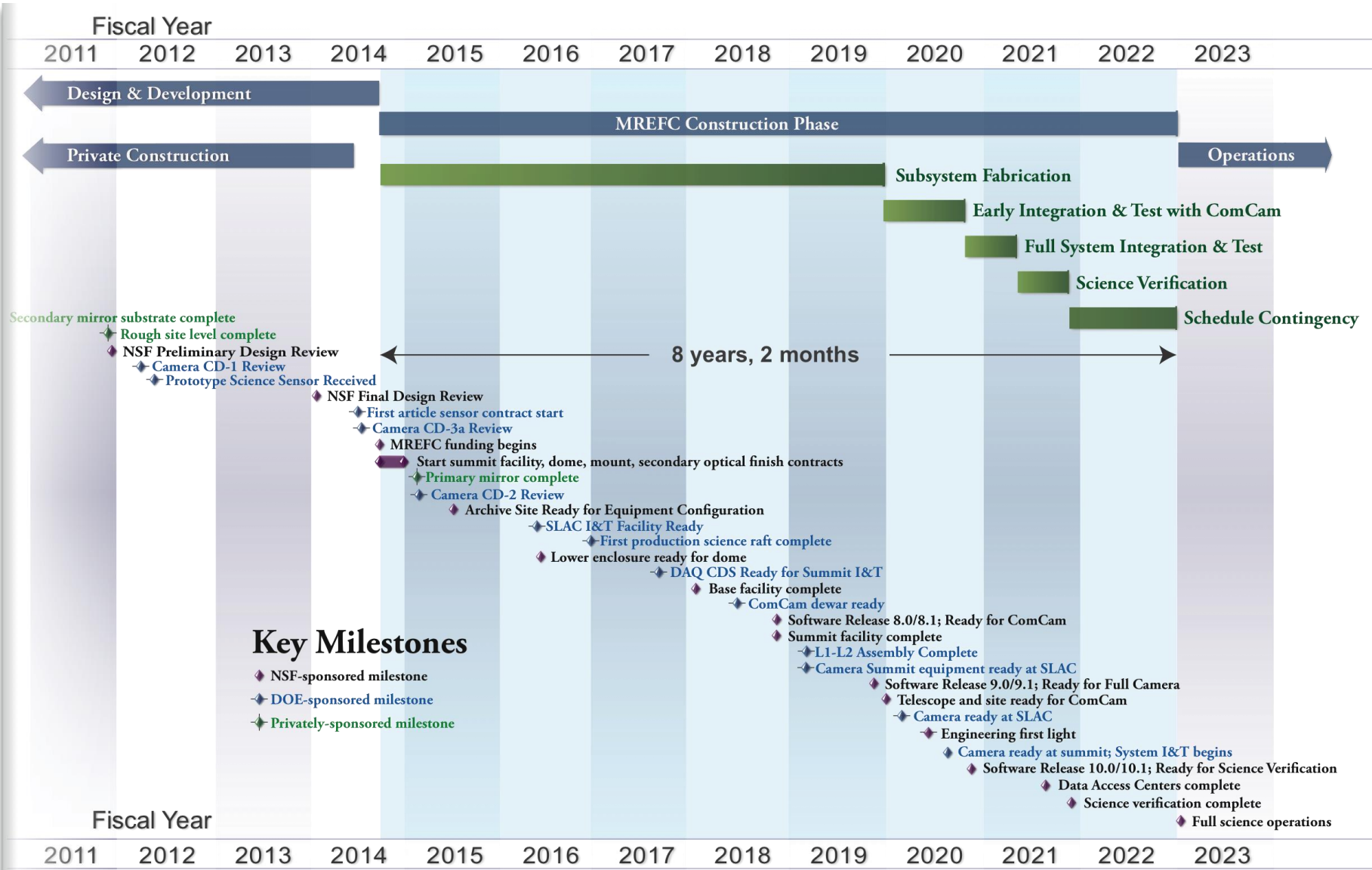
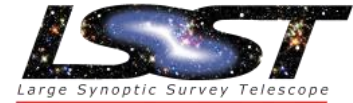
August 7, 2014

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.

- 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 is expected at the end of August, 2015.
 - CD-4 marks the completion of the project.

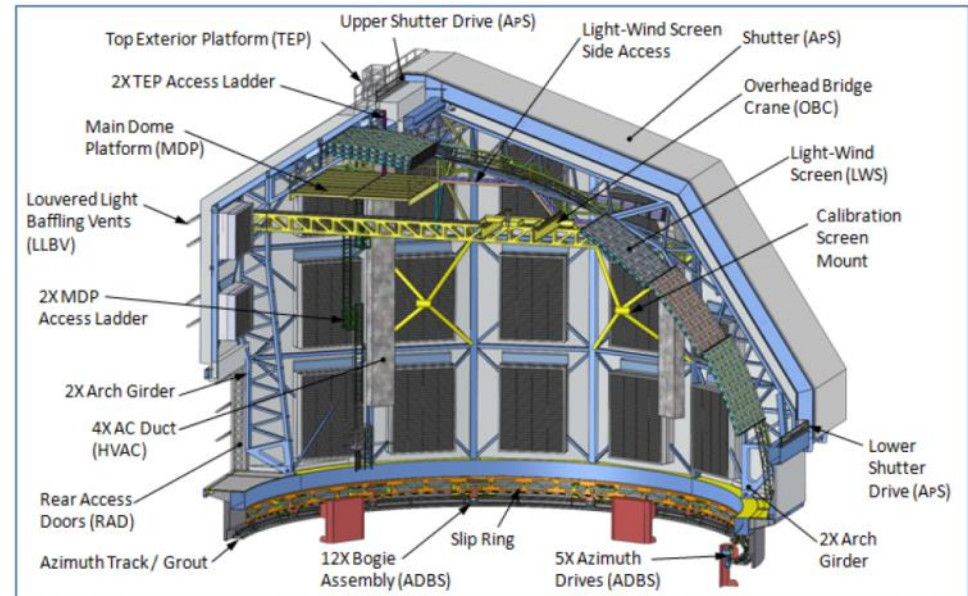
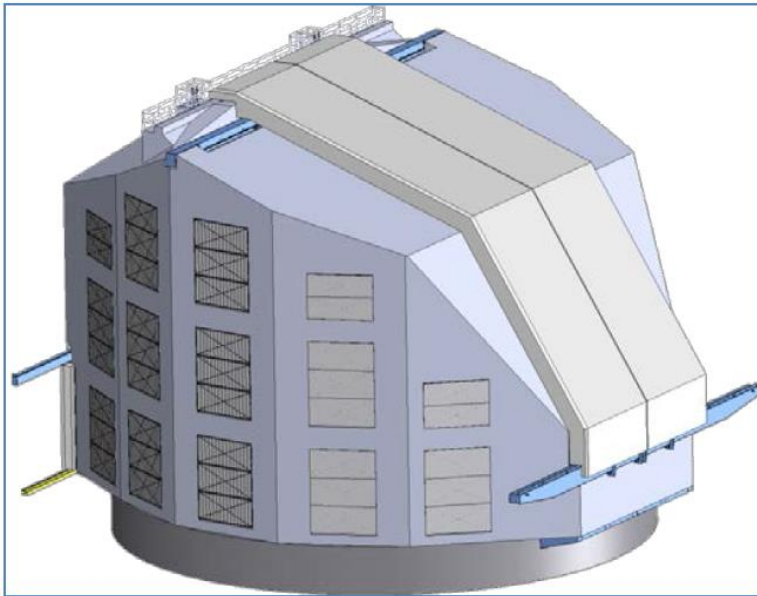
Integrated Project Schedule



Besalco Construcciones, S.A., summit mobilization has begun



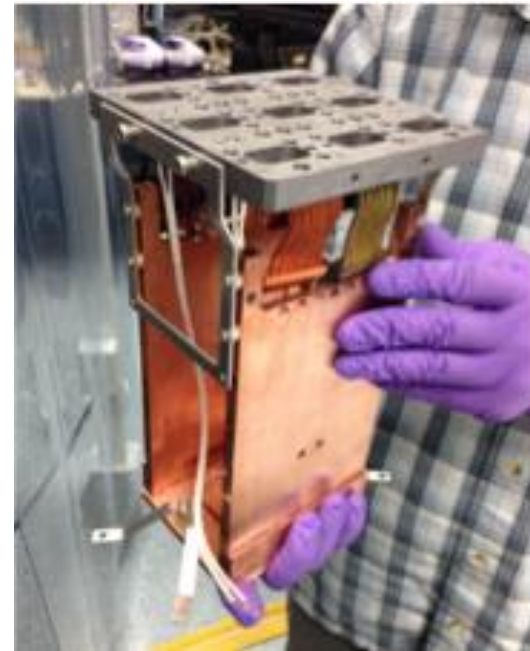
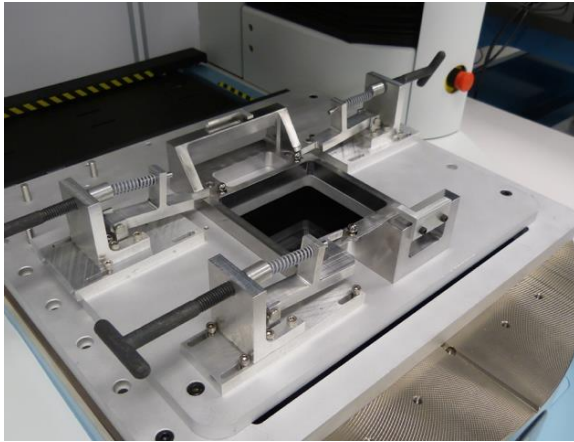
LSST Dome Contract Initiated



M1M3 Fabrication Complete

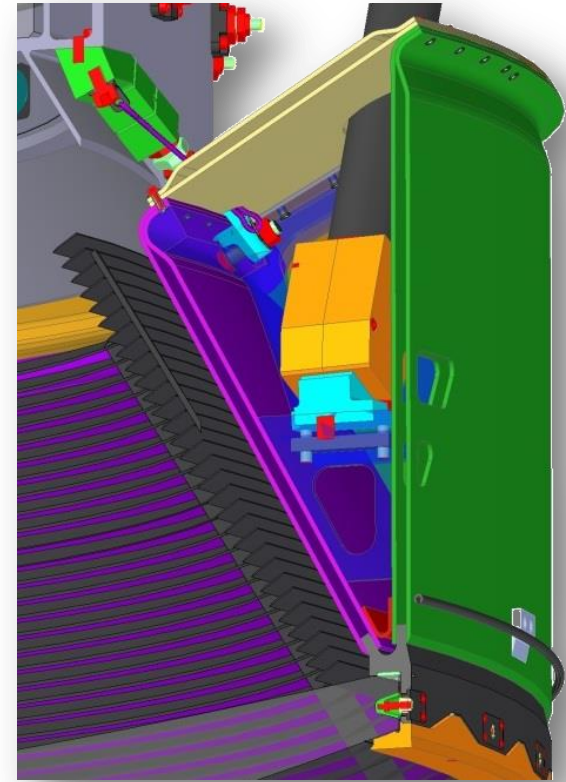
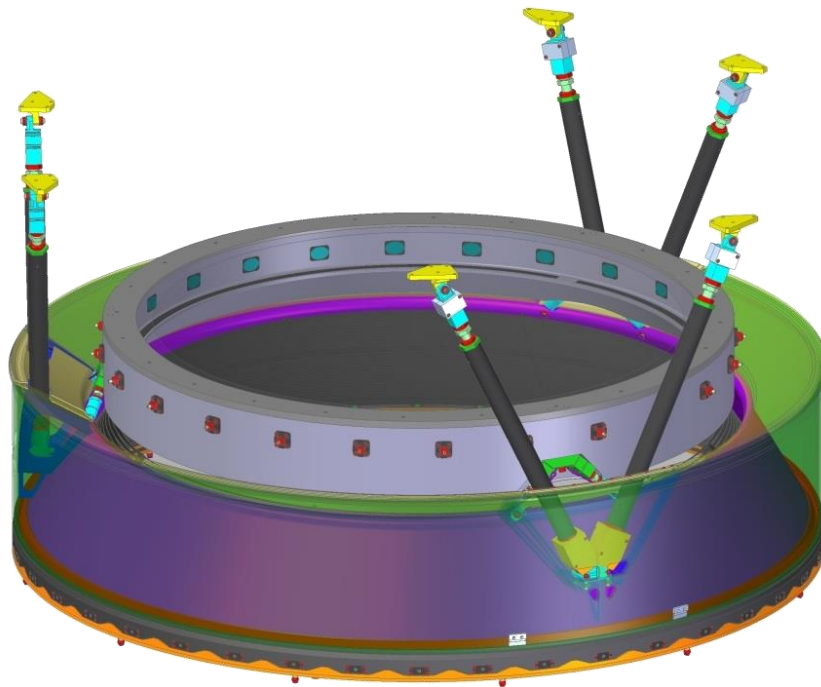


Science Rafts Have Been Prototyped

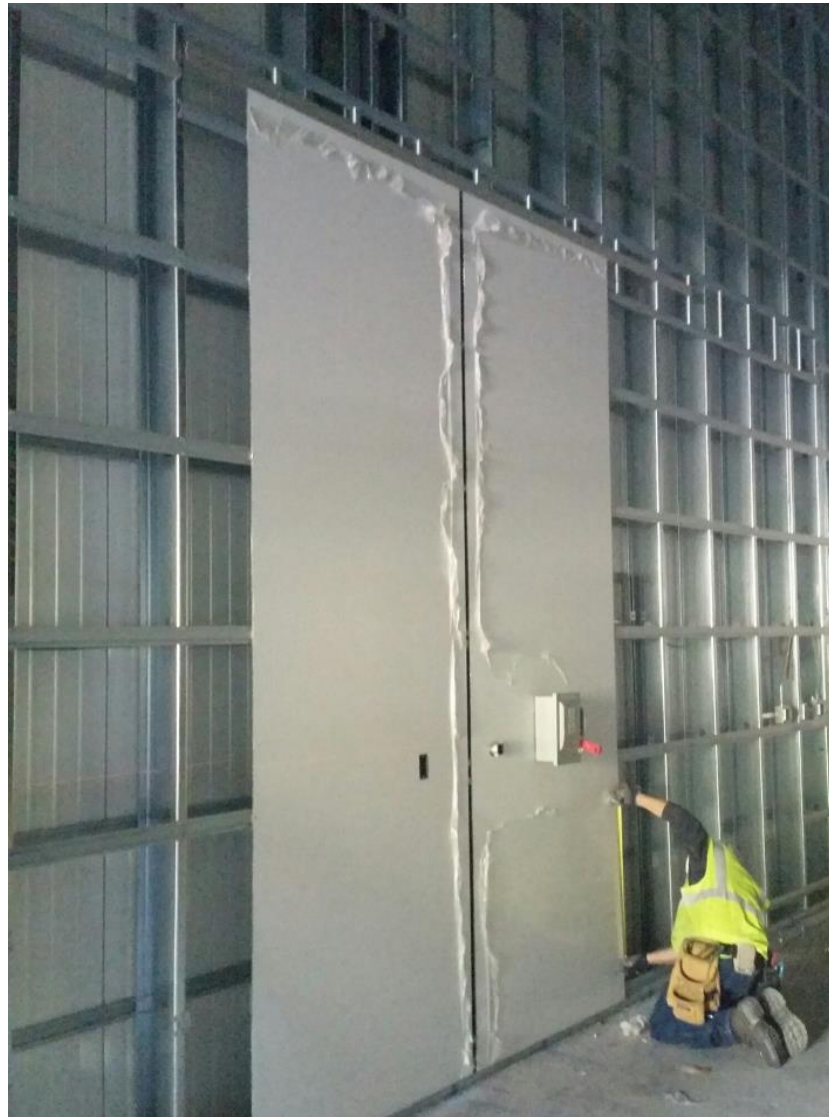


Two Vendors Under
Contract to Produce
Sensor First Articles

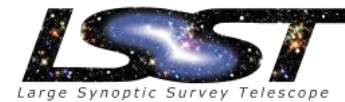
L1-L2 Fabrication Awarded



I&T Facility Construction Started



LSST and the Community: Science Collaborations

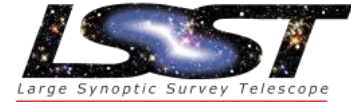


- A set of science collaborations was formed by the project in 2006. The intent was to provide a forum to engage the community in interacting with the project team to refine our understanding of the science opportunities and challenges in each of the main science areas that LSST will address.
- Early on, the project and NOAO exercised leadership roles in establishing criteria for collaboration membership and for collaboration governance.
- The collaborations played an essential part in the drafting of the LSST Science Book in 2009, which was instrumental to our achieving the top ranking by the Decadal Survey Committee in 2010.
- Over time, there has been some evolution in the configuration of the collaborations and their degree of independence from the project. A key development was the formation of the Dark Energy Science Collaboration in 2013, which operates more in the mold of a typical high energy physics collaboration than as a loose confederation of astronomers.
- At this stage, the Project will no longer take any oversight role for the collaborations. They are free to set their own policies for admission, governance, publication, etc. Our only constraint is that they not admit members from foreign institutions that have not yet established partnerships with LSST for a role in operations.

- **Supernovae:** [Richard Kessler\(University of Chicago\)](#); [Tom Matheson\(NOAO\)](#);
- **Weak lensing:** [Bhuvnesh Jain\(University of Pennsylvania\)](#); [David Wittman\(University of California Davis\)](#);
- **Active Galactic Nuclei:** [Niel Brandt\(Pennsylvania State University\)](#);
- **Solar System:** [Michael Brown\(Caltech\)](#); [Lynne Jones\(University of Washington\)](#);
- **Galaxies:** [Michael Cooper\(UC Irvine\)](#); [Brant Robertson\(University of Arizona\)](#);
- **Transients/variable stars:** [Ashish Mahabal\(Caltech\)](#); [Lucianne Walkowicz\(Princeton University\)](#);
- **Large-scale structure/baryon oscillations:** [Eric Gawiser\(Rutgers The State University of New Jersey\)](#); [Shirley Ho\(Carnegie Mellon University\)](#);
- **Stars, Milky Way and Local Volume:** [John Bochanski\(Haverford College\)](#); [Nitya Jacob Kallivayalil\(University of Virginia\)](#); [Beth Willman\(Haverford College\)](#);
- **Strong Lensing:** [Phil Marshall\(KIPAC\)](#);
- **Informatics and Statistics:** [Kirk Borne\(George Mason University\)](#);
- **Dark Energy (DESC):** [Bhuvnesh Jain \(University of Pennsylvania\)](#)

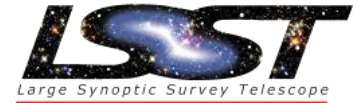
- LSST is essentially a US Project, with the lion's share of support for its construction coming from US federal agencies: the National Science Foundation and the Department of Energy Office of High Energy Physics. It is designed to be a public project, with full access to all data and data products open to the entire American scientific community, as well as the public at large.
- Because the telescope will be sited in Chile, we have entered into an agreement with the Chilean astronomical community to give them full participation in the Project, with equal status and data access as Americans. In addition, a limited number of French scientists (from laboratories associated with IN2P3) have been granted access in view of French contributions to the development of the LSST camera.
- However, we believe that as a *world unique* scientific facility, the scientific exploitation of LSST data would certainly benefit from greater international participation. That has been amply demonstrated by a workshop we held in Cambridge last Fall. Foreign collaborators from Europe and elsewhere bring:
 - New creative ideas for innovative investigations with LSST.
 - Access to corollary facilities that can enhance the science of LSST.
 - Key skills to collaborations that are preparing for some of the more challenging LSST analyses.

Need for Foreign Support of Operations



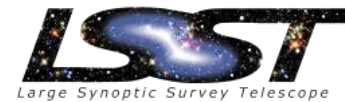
- The construction budget for LSST comes out of the Major Research Equipment and Facility Construction line in the NSF budget, and out of a specific line item for a Major Item of Equipment in the DOE budget.
- These line items cover project construction/fabrication costs only. The money allocated cannot be used for operations or for the conduct of science with the facility.
- Instead, operations funding comes from the Astronomical Sciences division budget at NSF, and from core science funding in HEP at DOE. In both cases, there is significant competition with other projects for those resources, and it is unclear that we will have available the total support we will need to operate LSST.
- Our current estimate for the annual operations costs of LSST is ~ \$37M/yr in 2011 US\$. This covers mountain and base facility operations, as well the costs associated with the data processing and data access performed at NCSA in Illinois. It does not include costs for “doing science” with LSST data. Those will come from the grants programs at the two agencies.
- While we are still several years away from incurring significant operations costs for LSST, it is already clear that we can benefit from additional sources of funding. In particular, we are targeting a number ~ \$10M/yr, again in 2011 US\$.
- We solicited LOIs several years ago, which were meant to demonstrate that we had a good chance of raising this money internationally. That was quite successful, and we are now converting many of those LOIs into real MOUs.

Costs for Participation



- Given our guess as to the size of the relevant user communities for LSST, we have come up with a cost estimate of \$20K per senior scientist per year, as an appropriate amount to charge. (In 2013 USD).
- The charge is only for senior scientists (i.e. permanent personnel). Postdocs (~ two per senior scientist) and graduate students come for free.
- We are looking for the full ten-year commitment for each of these senior scientists, but the payout can be annual at the above rate.
- Funding must begin by 2019. We are willing and able to collect money earlier, if that is more convenient for particular institutes. Such “prefunded” contributions will be placed in escrow in a US bank. If for any reason, the project does not proceed into construction as planned, that money would then be returned to its original contributors.

We are creating partnerships, not selling data!



- We believe that the full exploitation of the scientific content of the LSST database will require the best minds all over the world. We are looking for partners as colleagues to help bring this about. Helping to share in the costs of operating this magnificent facility is a small price to pay for participation in that enterprise.
- It is our intention to treat all foreign partners on the same basis as Americans. There will be no “second class” citizens. We hope to form one world-wide LSST scientific community, with scientific leadership coming from all quarters.
- Nevertheless, we do not want to in any way reduce the opportunity for US investigators to engage with LSST data through the expansion of LSST users. That has some implications for data access. At present, we are planning the construction of two data access centers, one at NCSA and one in La Serena in Chile. These have been sized to handle the expected number (and spectrum) of scientific queries from the US and Chilean communities. If we expand the user base, we will need to expand these facilities (and charge for it), or have international partners build their own data access centers to serve their own communities.
- Rough costs are as follows: \$1500 per year per senior investigator for US-based data access. ~ \$3.5M to set up an independent data access center from scratch, using software from us.

- 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 \sim 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.

- 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?

- 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 are currently establishing partnerships with foreign institutions to help defray operations costs.
- Much of the LSST science can be performed with LSST data alone. However, the provision of follow-up observations with spectroscopic facilities and in other wavelength bands will clearly enhance the scientific return. The collaborations may prove crucial in obtaining the appropriate facility resources.