U.S. DEPARTMENT OF ENERGY | Office of Science

Office of Project Assessment
CD-3 Review Report on the

Large Synoptic Survey Telescope Camera (LSSTCam) Project

at SLAC National Accelerator Laboratory

August 2015

EXECUTIVE SUMMARY

A Department of Energy/Office of Science (DOE/SC) review of the Large Synoptic Survey Telescope Camera (LSSTCam) project was conducted on August 4-6, 2015 at the Brookhaven National Laboratory (BNL). The review was conducted by the Office of Project Assessment (OPA), and chaired by Kurt Fisher. The purpose of the review was to evaluate the LSSTCam project's readiness to proceed with CD-3, Approve Start of Construction.

In general, the Committee was of the opinion that the LSSTCam team is well managed and can effectively deliver on the construction phase tasks as well as manage the procurements, the interfaces, and the risks. BNL was chose to host the review since BNL is responsible for a significant amount of scope and the use of a cleanroom, which the Committee found the cleanroom to be well developed as well as the associated processes. Overall, the Committee supported LSSTCam proceeding to CD-3.

Sensors, Electronics, Control System, and Data Acquisition

The two vendors producing first article sensors have experienced separate challenges, delivery is delayed by about two months, the vendors are not certain of the root cause of the problem and diagnosis at the two vendor facilities continues. The project has specific mitigations to address the yield issue. Regardless of the difficulties, the Committee encouraged the project to pursue a two-vendor approach. The sensors, electronics, and software team assembled for this project is exceptional. The team clearly possesses the necessary expertise to adapt to or overcome challenges. The number of charge-couple device (CCD) spares seems inadequate and could limit the flexibility of the project. The team needs to continue to work with the Observatory to develop a calibration plan. The project should consider additional sky testing with testing of astronomical performance parameters before the commissioning camera and deployment.

Optics, Mechanics, Cryostat, and Integration & Testing

The camera body is 4 months behind schedule, but the team added another engineer and plans to be back on schedule by June 2016. Integration and test planning for the camera is well advanced. Regarding the filter Exchange Mechanism, the team has done an excellent job considering failure modes, interlocks, and installation process for filter loader. Refrigeration contamination has yet to be resolved and poses a high risk since plugged refrigerant lines require removal from the camera, which take approximately three weeks. The final design review (FDR) for science raft was completed in May 2015 and corner raft FDR is scheduled for November 2015.

Environment, Safety and Health (ES&H)

The Environmental, Safety and Health (ES&H) program covering all project phases is sound and maturing as project progresses. Furthermore, the ES&H requirements are well integrated. As the LSSTCam project progresses, safety procedures that meet SLAC requirements will be developed for camera construction and operations in Chile. While comprehensive oversight and training approach is planned for integration and testing (I&T) operations at SLAC, challenges remain in effectively managing ES&H for subsystems personnel.

Cost and Schedule

The assessment of residual exposure of risks appears, in some cases, to be optimistic; however, the risk assessment process appears to be thorough and risk management is very active. This should provide a good means to assess cost and schedule risk exposure as well as the estimate-at-complete (EAC). Cost contingency is $31.3 million and the project's cost risk assessment includes $19.7 million from a bottom-up and $9.3 million Monte Carlo (at an 80% confidence level), which leaves $3.8 million for unknowns. Schedule appears well integrated with the LSST overall project schedule. The critical path runs through raft electronics board (REB) development, sensor raft assembly, and integration. Although the schedule contingency to CD-4 milestone is 24 months, the schedule contingency on the LSSTCam being ready for the NSF Operational Readiness Review is 13 months.

Management

The LSST Camera project team is expert and very capable. The team is well managed and can effectively deliver on the construction tasks, manage procurements, interfaces, and risks. Current overall design is at 80% with 100% final design planned in FY 2016. The baseline plan currently has one sensor vendor for the second lot, but procurement is flexible to accommodate two vendors, which appears to be a sound mitigation strategy. Five major procurements ($>200K) remain, with a total value of roughly $18.5 million. The project has identified $6.4 million of scope contingency and approximately $30 million of scope enhancements.

Key Recommendations

- Analyze and document the number of sensor and raft spares required for a high probability of successfully populating the focal plane array.
- Review the optical vendor plans for handling and shipping blanks and lenses
- Use a coarse electrically grounded screen at the ion pump port into the cryostat.
- Develop camera and telescope safety interface provisions prior to early operations.

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1. INTRODUCTION

A ground-based, next-generation "Stage-IV" dark energy project received approval of Critical Decision-0 (CD-0), Approve Mission Need, on June 20, 2011. As detailed in the approved Mission Need Statement (MNS), this project is for the support of a new, next-generation, state-of-the-art, ground-based dark energy experiment. The scientific goal for the Department of Energy (DOE) High Energy Physics (HEP) program is to determine the nature of dark energy, which is causing the acceleration of the expansion of the universe. To date, there are no compelling theoretical explanations for the origin of the dark energy, so future progress will be driven by increasingly more precise observational measurements.

The alternative selection to respond to this Mission Need is for DOE to provide the camera and associated systems for the Large Synoptic Survey Telescope (LSST), which will generate the necessary data to enable the key "Mission-Level Assumptions" as envisioned in the MNS. The CD-1, Approve Alternative Selection and Cost Range, was approved on April 12, 2012, by the Director of the Office of Science with a cost range of $120 million to $175 million. The LSST camera (LSSTCam) will become part of a unique wide-field, ground-based telescope that will provide deep images of the southern half of the sky every few nights and will address a broad range of astronomical topics with an emphasis on enabling precision studies of the nature of dark energy using forefront experimental techniques including weak gravitational lensing. LSST was recommended by the National Research Council's (NRC) Astronomy and Astrophysics Decadal Survey (Astro2010) in their 2010 report as the highest-priority ground-based initiative.

The construction and operation of the LSST observatory, to be located in Chile atop the El Penon peak, is a partnership between the DOE/HEP Office, the National Science Foundation (NSF), Division of Astronomical Sciences (AST), and the privately-funded LSST Corporation, a non-profit entity located in Tucson, Arizona, which acts as a conduit for contributions from private institutions and foreign partners. NSF is the lead agency and is responsible for the site preparation and telescope facility, the data management system, and education and outreach. DOE/HEP is responsible for the design, fabrication, testing, and delivery of the three-billion pixel optical camera, together with its associated instrumentation.

DOE/HEP named the SLAC National Accelerator Laboratory (SLAC) as the lead contractor to manage the LSSTCam Major Item of Equipment (MIE) project. LSSTCam will design, fabricate, and laboratory-test an integrated camera system prior to delivery for installation onto the LSST telescope in Chile. The camera, as an integrated functional system, will be assembled and completed at SLAC.

On June 5, 2014, the Project Management Executive approved, CD-3a, Approve Long Lead Procurement, of the first-lot production sensors for the camera, in the amount not-to-exceed $13 million.

Following a DOE/SC review in November 2014 of the project's readiness to baseline, CD-2, Approve Performance Baseline, was approved on January 7, 2015 with a Total Project Cost (TPC) of $168 million and a Project Completion date of March 2022.

This DOE/SC review of the LSSTCam project, requested by the Associate Director for HEP and conducted by the Office of Project Assessment (OPA), was held at Brookhaven National Laboratory (BNL) on August 4-6, 2015. The purpose of the review was to evaluate the project's readiness for seeking approval of CD-3, Approve Start of Construction. The sections that follow describe the findings, comments, and recommendations resulting from this review.

2. TECHNICAL SYSTEMS EVALUATIONS

2.1 Sensors, Electronics, Control Systems, Data Acquisition

2.1.1 Findings

Sensors

First article sensor delivery for both vendors is delayed with respect to the baseline schedule. Each vendor has experienced production “challenges”. These challenges are different for the two vendors and the underlying causes are not yet completely understood.

The project expects sensor delivery at the rate of 1/week once delivery begins, ramping to 2/week in full production. The testing infrastructure at Brookhaven is designed to cope with this rate. Additional testing effort might be available through French collaborators.

Electro-optical laboratory testing of many prototype sensors has been performed in pace with vendor deliveries. This testing has validated vendor capability claims in all relevant performance areas. Prototype testing is a path-finding activity for the production-level Raft testing and development activity.

Electronics

Raft Readout Board (REB) design and prototype work is near completion. Raft board version 2 meets performance specifications but does not have the final layout. REB3, an almost final design, is now becoming available for test stand studies.

In response to problems with the CABAC clock-generation application specific integrated circuit, the collaboration developed an alternative solution utilizing commercial CCD driver chips. This design is the new baseline.

The corner raft board shares much of the infrastructure of the science raft board. A large fraction of the board layouts are identical at the schematic level but the boards have different form factors.

Power supplies are located on the trunk section of the camera body. There is a detailed power distribution and grounding system design. There is also a plan to monitor the power system including interfaces to the camera control system and hardware and PLC-based interlocks and alarms.

Control Systems and Data Acquisition

The project has developed an integrated testing plan with camera control system software and DAQ hardware incorporated into test stands.

Vertical slice tests were performed in order to establish that the raft electro-optical system meets LSST requirements. The tests to date have not used the Camera Control System (CCS) and have utilized version 2 of the readout boards. These tests have measured levels of crosstalk and characterized noise and gain as a function of temperature and clocking conditions. With one exception (read rate for one sensor type) LSST specifications were met. The LSST team expects that these sensors will meet full specifications when tested with final (shorter) cables.

2.1.2 Comments

Sensors

Sensor production is a continuing concern. The production challenges do not have a well-defined mitigation path for either vendor. The vendors need to solve these problems, but LSST should continue to closely monitor the situation and consider possible mitigation actions.

The Committee encouraged the project to work to improve communications between sensor vendors and LSST. In light of the sensor production challenges, the Committee encouraged the project to continue to pursue a two-vendor approach and study of scientific impact of a heterogeneous focal plane.

The level of CCD spares is inadequate, especially for a homogeneous focal plane. This will limit the overall flexibility of the project.

The science raft production schedule needs to be updated to reflect the correct sensor totals and more realistic first article, lot 1 and lot 2 dates. The total number of sensors to be ordered is unclear.

The project should consider the possible need for raft-level optimization of sensor operating conditions that may mitigate future issues in sensor performance.

Electronics

Science raft and corner raft electronics development is collaborative and effective. Prototypes are available and have been tested. Final designs are nearly complete.

The project should plan a thorough thermal cycling testing plan that verifies the integrity of all electrical connections.

The collaboration presented what appears to be a thorough risk analysis and mitigation plan. The full plan was difficult for us to review in any detail. There are many items in the camera that are not redundant and where confidence in the design relies on a calculated mean time to failure. The Committee urged the collaboration to carefully evaluate and monitor the risk for any such items that can be a single point of failure in the focal plane and electronics.

Control Systems and Data Acquisition

DAQ support is provided by a small but effective team that has leveraged systems developed for other experiments as well technologies developed through the DOE detector R&D program. The DAQ group must support both on-summit and test stand work.

General

The project should consider additional sky testing of the full camera system chain. Astronomical performance parameters such as photometry and astrometry should be characterized before the commissioning camera deployment.

The LSST Camera project should continue to work with the Observatory to maintain and extend what is already a well-documented calibration plan based on production testing findings and Observatory developments. The plan should include any calibrations to be performed by the DAQ system (which is currently limited to crosstalk) as well as expected post-processing.

The sensors, electronics, and software team assembled for this project is exceptional. This team has investigated or is actively pursuing all of the major challenges identified with the project. The team clearly possesses all of the necessary expertise to adapt-to or overcome those challenges. The team is also well prepared, well organized, and extremely professional as evidenced by the level of preparation and detail applied to this review. The Committee enjoyed the frank and open interaction with the presenters and the supporting team members.

2.1.3 Recommendations

1. Analyze and document the number of sensor spares and the associated procurement plan required for a high probability of successfully populating the focal plane array, as well as spare rafts and the commissioning camera.

2. Proceed to CD-3 approval.

2.2 Optics, Mechanics, Cryostat, Integration and Test

The Committee commended the LSST camera team for its excellent work on the design, development, planning, and documentation for the camera system. The team was well prepared for this review, as shown in the very thorough presentations. The LSST camera system is ready for CD-3 approval.

2.2.1 Findings

Camera Body and Shutter

The camera body is currently running four months behind schedule, but the team has added another engineer to help catch up within nine months. The shutter duty cycle is 1,000,000 cycles per year. The project plans to build two shutters, and to swap them for servicing during the annual approximately two week shutdown. The team plans to use camera integration period to develop and document detailed service and maintenance procedures. Some components in the camera are being designed to be serviceable in the telescope.

Filter Exchange Mechanism

The filter exchange mechanism (FEM) system is at FDR. The FEM systems uses a PLC-based control system, which is located in the utility trunk. The FEM is designed for a lifetime of 100,000 cycles, and two units will be built. The FEM will be exchanged out of the camera for servicing during the annual two week observatory shutdown. The FEM filter storage box, loader cart, carousel, and bench stand are at PDR or FDR level. -5C is lowest operating temperature for the FEM (-10C for survival). Operation of the system will be tested at -5C.

Optics

The L1 and L2 lens systems completed their 90% FDR in July 2015, with 100% FDR planned for August 2015. The filter FDR was held in June 2015. The L3 assembly (cryostat window) has passed PDR, the L3 design has been re-analyzed and signed-off according to LLNL safety standards, and the L3 FDR is planned for late 2015. Two vendors have been identified to provide the lens (L1, L2, and L3) broad-band anti-reflection (BBAR) coatings; multiple vendors have been identified to provide the filter coatings. The filter fabrication first article will be for the r-band. All filter coatings will first be demonstrated on witness samples. No spare optical substrates are planned to be procured for any of the camera optics. The L3 BBAR coatings are water-proof (to survive possible condensation on this element).

Cryostat and Refrigeration Systems

The cryostat is at FDR, the refrigeration system is at PDR with FDR 10 months out, and the utility trunk design is still pre-PDR. The vacuum and contamination control systems have completed FDR. All mitigated risks are now ranked as minor or insignificant; however, contamination recovery of the refrigeration lines is still carried as a high risk. Plugged refrigerant lines require removal from the camera for repair (and approximately three weeks to replace). The cryostat can meet its requirements with one (of 6) cryogenic refrigerators off-line. The team has hired an industry expert (from Polycold), with deep experience resolving contamination issues, to help close out the contamination issues. Development of the cryogenic refrigeration system has been ongoing for 6 years, starting with technology transfer from industry to SLAC. Multiple prototypes have been completed and will continue to be used to demonstrate planned risk mitigations.

Science and Corner Rafts

The science raft system FDR was completed in May 2015, while the corner raft FDR is scheduled for November 2015. CD-2 concerns about risk of stiction in the kinematic mounting interface have been retired. Science rafts are developed and fabricated by the Brookhaven National Laboratory (BNL) while the corner rafts are being developed at Harvard.

Integration and Test

The Integration and Test (I&T) FDR is scheduled for January/February 2016. The budget for I&T is approximately $12 million. The new camera integration cleanroom at SLAC was completed in June 2015. Camera assembly is scheduled to start in May 2018 and to be ready for shipping in January 2020.

2.2.2 Comments

Camera Body and Shutter

It was not clear in the review presentations that all of the camera in-telescope serviceable components were attached with captured fasteners.

Filter Exchange Mechanism

There are tight tolerances on filter positon repeatability in the camera. It might be useful to have fiducial marks on the filter frames to allow repeatable alignment of filters with frames. The team has done an excellent job considering failure modes, interlocks, and installation process for filter loader.

Optics

The Committee did not see plans for shipping of the L1 and L2 blanks to outside vendors for generating, or shipping of the polished L1 and L2 lenses to outside vendors for BBAR coating.

Cryostat and Refrigeration Systems

There is no internal protection of the cryostat volume from the (3) exposed ion pumps from possible plasma discharge under poor vacuum conditions. Unshielded ion pumps have discharged plasma into detector cryostats previously (resulting in loss of detectors). The prototyping and development of the cryogenic system has been ongoing for six years. The advances in the last year have made significant progress. The move of the cryogenic compressors on to the TMA (telescope) keel beam has several benefits, and results in a smaller and simpler refrigeration system. The revised design allowing the exchange of the refrigerator filter assemblies makes maintenance much easier. Quantitative measures for maximum moisture content in the refrigerant charging gas mixture should be considered.

Science and Corner Rafts

The cleanroom and associated processes for science raft production at BNL appeared to be well developed. However, during our visit, cleanroom personnel were observed wearing but not using their face masks. An ESD monitoring system would improve understanding of ESD properties of materials and processes in the cleanrooms.

Integration and Test

Integration and test planning for the camera is well advanced. The use of the e-travelers at BNL and SLAC should provide continuity in the camera hardware build. The camera integration frame design (with rotator) is currently unpowered and will require a crane to re-position the camera during integration. In the integration frame, the camera can be rotated about two different points, neither of which is located near the camera center of gravity. It was not entirely clear to the Committee that the stitched focal plane flatness measurement system could distinguish between errors in the focal plane and in the measurement system.

2.2.3 Recommendations

Camera Body and Shutter

3. Using captured fasteners on the on-telescope serviceable camera components wherever possible.

Optics

4. Review the Ball/AOS plans for handling and shipping lens blanks and finished lenses to mitigate risks during shipping between vendors (shock and vibration hazards).

Cryostat and Refrigeration Systems

5. Use coarse and electrically grounded screens at the ion pump ports into the cryostat.

Science and Corner Rafts

6. Procure electro-static discharge (ESD) event monitoring systems for the camera cleanroom facilities (e.g. the "EM Aware" product from 3M). See http://documents.staticcontrol.com/pdf/EMAwareTNG.pdf

Integration and Test

7. Consider revising the design of the camera integration frame to avoid unbalanced conditions.

8. Consider motorizing the camera integration frame to improve safety and ease of use.

3. ENVIRONMENT, SAFTEY and HEALTH

3.1 Findings and Comments

The LSSTCam project continues to maintain an effective, comprehensive, and mature ES&H program that is integrated and managed within the LSSTCam project structure ensuring that adequate systems and processes are in place to mitigate all of the hazards identified ensuring delivery of the project in a safe and environmentally sound matter as the project progresses. Strong management commitment to ES&H is evident throughout all phases of the project. Camera Safety Officer (CSO) duties have been successfully transitioned with the recent retirement of the former CSO. The current CSO has served to support the project prior to assuming the safety officer role, and is very knowledgeable of the project operations and associated ES&H considerations. The LSST Executive Safety Council remains active and has scheduled a camera safety review for the coming weeks (previous reviews have examined telescope and observatory safety issues).

A safety systems engineering approach is utilized as a basis for estimating risk of mishaps associated with hazards of the project. Personnel and equipment safety protection is addressed in the camera hazard list. A Camera Protection System (CPS) provides for independent back-up of the Camera Control System for greater assurance of protection. Technical management control plans covering various aspects (e.g., contamination control, electro-static discharge control) are integrated with the requirements coming from the Camera Hardware Protection Plan (LCA-139) and flowed into camera specifications. It should be noted that critical systems and components used for active protection against potential mishaps as delineated in the camera protection protocols require specific maintenance, testing, and calibration for optimal and expected performance.

A safety management structure for future camera and non-camera operations in Chile has been developed in close coordinated among the various partners (LSST, SLAC, and Observatory safety personnel). Safety procedures for future camera operations in Chile will be developed by SLAC with partner input and concurrence. Observatory work to take place on the summit will be governed by the LSST Summit Site Health and Environmental Plan (draft LPM-114), and any specific safety, health, and environmental plans pertaining to work on the summit will be in conformance with relevant U.S. and Chilean regulations and best practices. Effective implementation of the overall safety management program for the work on the summit will need to take advantage of the current close coordination among the LSST Safety Program Manager, the Camera Safety Officer, and the Observatory Safety Manager (addressing non-camera hazards). It is still clear that as this project evolves, safety program coverage between the camera and non-camera observatory issues will require further discussion and definition. Working through the interface of the camera and non-camera safety programs during incorporation of the commissioning camera on the summit site will assist in providing clarification for future operations.

Integration and testing (I&T) operations to be conducted at SLAC will address safety and equipment protection. The CSO, in conjunction with I&T facility staff, has developed a comprehensive clean room access training addressing all pertinent safety and equipment protection considerations. All personnel accessing the clean room will be required to complete this prior to entry. The CSO will conduct a prior safety review of eTraveler documentation for I&T operations. In addition, daily tailgate operational and safety planning sessions will be performed by camera management representatives and work release will be formally given by the clean room manager prior to work commencing. Overall authorization and qualification for job-specific work performed by I&T collaborators at SLAC will be granted by line management. While a comprehensive safety oversight and training approach is planned for I&T operations at SLAC, challenges remain in managing ES&H for subsystems personnel.

A recommendation from CD-2, "*Obtain external expertise to perform a comprehensive safety evaluation of the L3 lens assembly…*" was successfully addressed prior to the CD-3 review. Specifically, Lawrence Livermore National Laboratory (LLNL) conducted a mechanical engineering review for the L3 lens assembly that serves as window and vacuum barrier for a cryostat containing the cooled detector array. All safety factors (thermal, pressure, seismic) evaluated met the LLNL general-purpose and rare-event requirements as documented in mechanical engineering safety note (MESN14-000018-AA). The safety note was also reviewed and approved by SLAC's Pressure System Safety Engineer, and the safety note covers the requirements of the SLAC ES&H Manual Chapter 14—Pressure Safety. This issue is considered closed.

3.2 Recommendations

9. Ensure adequate oversight and assistance is provided to supervisory staff establishing qualifications and authorization basis for external personnel working on I&T operations at SLAC.

10. Verify an integrated configuration management system is established and implemented for critical safety systems (e.g., oxygen deficiency monitors, other sensors, interlocks) that support the Camera Hardware Protection Protocols (LCA-140) prior to commencing early operations.

11. Refine camera and non-camera interface ES&H program provisions prior to commencing early operations.

4. COST and SCHEDULE

4.1 Findings

PROJECT STATUS (as of June 2015)		
Project Type	MIE	
CD-0	Planned:	Actual: 06/20/2011
CD-1	Planned: Mar 2012	Actual: 04/11/2012
CD-2	Planned: Jan 2015	Actual: 01/07/2015
CD-3a	Planned: Jul 2014	Actual: 06/5/2014
CD-3	Planned: Jan 2016	Actual: TBD
CD-4	Planned: Mar 2022	Actual: TBD
TPC Percent Complete	Planned: 32.9%	Actual: 31.7%
TPC Cost to Date	$41.7M	
TPC Committed to Date	$60.8M	
TPC	$168.0M	
TEC	$150.3M	
Contingency Cost (w/Mgmt Reserve)	$31.3M	33% on work to go (EAC)
Contingency Schedule on CD-4	24 months	44% on work to go
CPI Cumulative	1.03	
SPI Cumulative	0.97	

The project presented the funding profile (Appendix F). For FY 2016-FY 2018, the project assumes a 6 month CR with 1/12 funding of current year per month. The project has planned for carryover funds into each year to ensure continued momentum.

The LSST project includes 9 CAMs managing 53 control accounts at WBS L2 and L3.

The cost/schedule plan presented includes budget/schedule to achieve the Objective KPP's. The PEP specifically excludes shipping to and installing the camera in Chile. The schedule is integrated with the LSST overall schedule (milestone graphic, Appendix E).

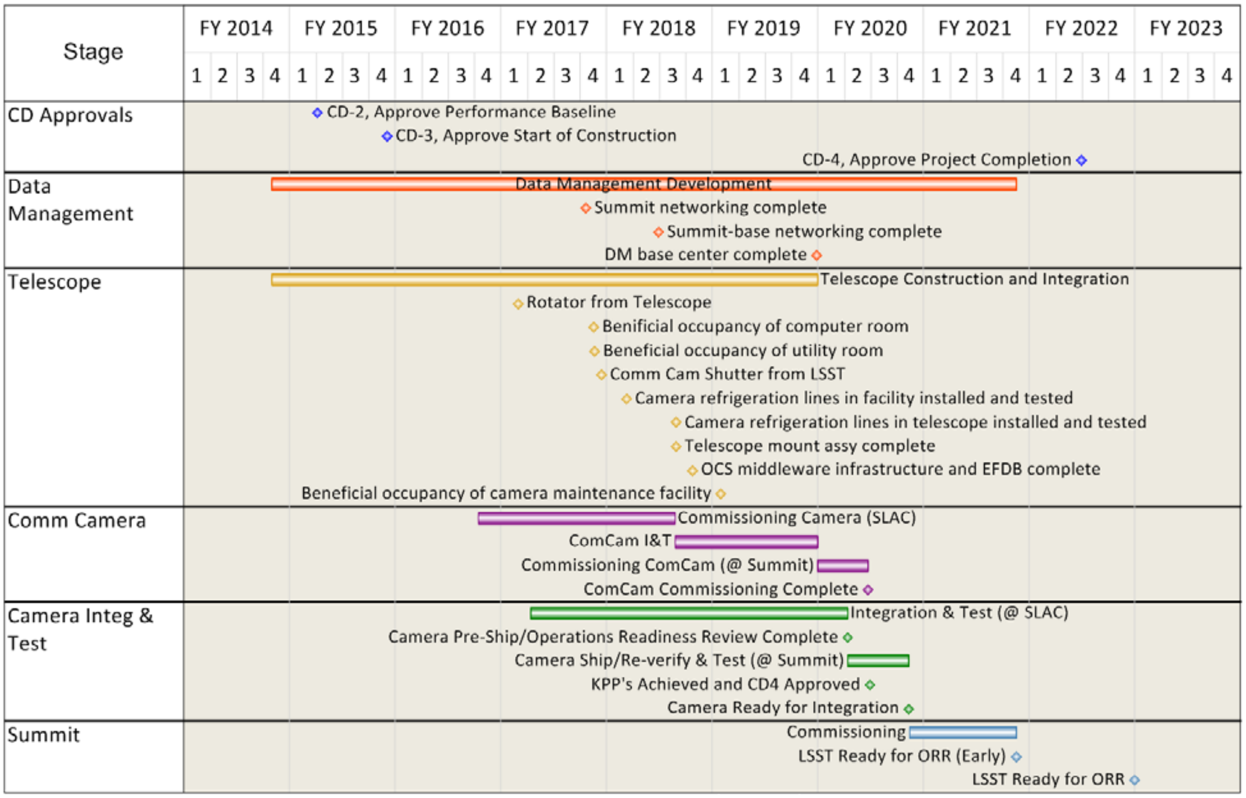
In-kind contributions have been identified and estimates prepared; these activities are represented at zero cost in the resource-loaded schedule (RLS). Risks for not meeting these commitments are in the risk register. Adding these activities to the project budget or finding replacement resources is not considered a high risk and contingency is identified to mitigate the risk. In-kind contributions are not subject to earned value management and are managed through milestone monitoring.

BNL and LLNL receive project funding directly from DOE-OHEP at the direction of the SLAC project manager. Transfer of actual cost and other performance data monthly is via electronic file from the other partner labs to SLAC. Recommendations from prior DOE reviews have been addressed and all are closed.

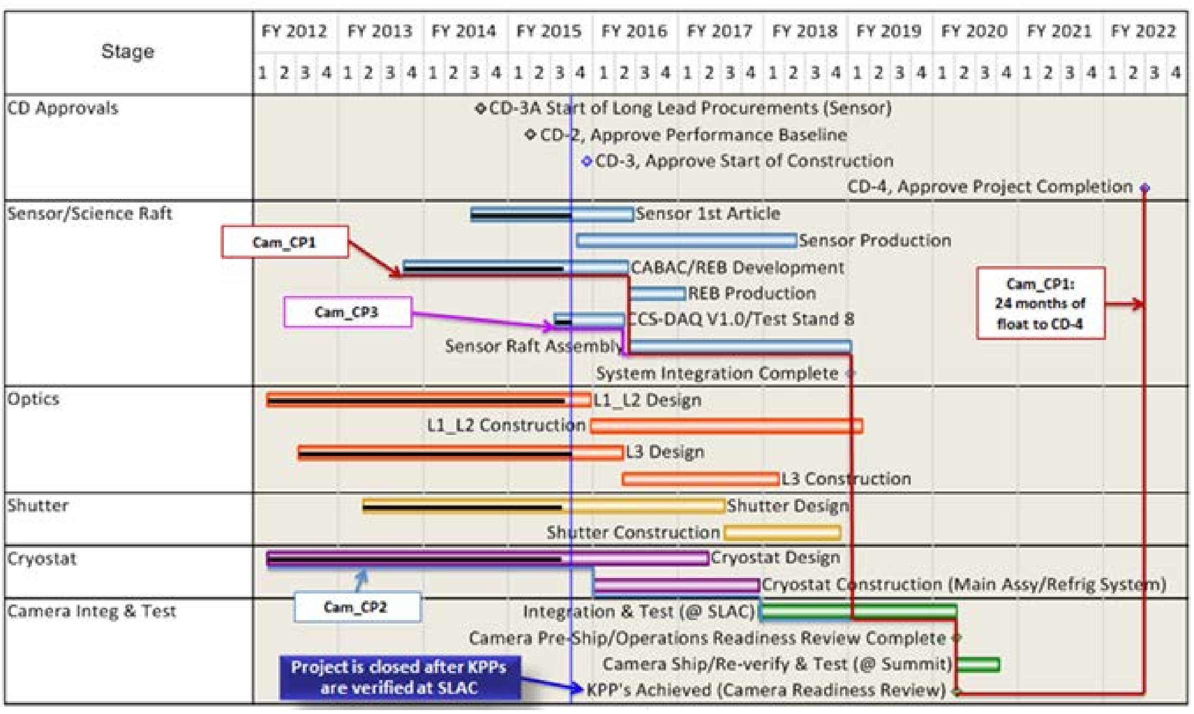
Cost/Schedule Performance

The project established the performance measurement baseline in November 2014 at a PMB cost of $134,628,718 and has been using earned value management since December 2014. The present PMB at WBS L2 is shown in the table below.

PMB data from P6 and Cobra has 6095 activities including 1581 milestones. Major milestones are shown in the graphic below.



The critical path to the KPPs achieved is through REB Development and Qualification, Sensor Raft Assembly, Integration & Test at SLAC (CAM CP1 shown below).



Cost and schedule estimates for work to go where contracts are not in place are mainly based on CD-2 estimates from November 2014. The project intends to update the estimated cost to complete annually.

The monthly report process, including variance reports, are being generated monthly in accordance with the SLAC certified EVMS. A log of VAR corrective actions was presented showing all variances since start of reporting EVM, statusing on a regular basis, and tracking to closure where appropriate. The project has processed 11 BCRs through June 2015 adding $611,607 to the PMB cost. Several of the changes were to incorporate actual contract prices into the PMB.

The project uses a Pending BCR log process to understand what changes are in progress. Where appropriate, these are added to the ETC monthly to create a new EAC. The EAC process as presented uses a CAM-estimated and PM-approved EAC, and compares it to calculated EACs that use two different methodologies.

Sensor production began in May 2014 and it will take 4.5 years to produce all the sensors, roughly one year per lot. Both sensor vendors for the first article (20 units) have experienced some schedule difficulties, currently about two months behind schedule. However, they plan to recover this schedule during the first Lot (45 units) within eight months.

Electronic tools known as the Hammer and the eCam book are used by the CAMs and project managers to view and report project performance, write variance reports, process and document Baseline Change Requests, and substantiate and process Estimates to Complete.

The project has identified $6.4 million of scope contingency (described in LCA-276) and approximately $30 million of scope enhancements (LCA-396), along with decision dates, which are indicated on the master schedule as milestones.

Risks and Contingency

The project currently has 317 total risks identified, of which 139 have been closed. Of the 178 active risks, the project has 4 high, 17 moderate, 115 minor, and 42 insignificant risks remaining. 22 risks have been added and 39 risks have been closed since CD-2. Most technical design risks are assessed to be reduced to minor post-mitigation. Higher risks are reviewed and updated monthly by the project team, and the Monte Carlo analysis is run quarterly to assess required budget and schedule reserve for risks.

The project has $32.8 million cost contingency against the PMB as of June 2015. There is $31.2 million (33% contingency) on the work remaining for the EAC. Bottom-up cost contingency is calculated as part of the estimating process at the activity level, and is $19.7 million. Risk contingency as determined by a Monte Carlo analysis is $9.3 million at an 80% confidence level; this leaves $3.8 million for unknown unknowns on the PMB.

Schedule contingency on the LSSTCam being ready for the NSF Operational Readiness Review is 14 months. The schedule contingency on the KPPs achieved and CD-4 milestone is 24 months.

Procurement

53% of the overall $62.37 million in procurements have been awarded. These costs came in under the estimated cost. Five major ($>200K) procurements remain with a total value of approximately 18.5M with approximately 10M of smaller procurements to be executed. The project has high confidence these awards will be within the project's estimated cost. The five large procurements are:

- Sensor sub-contract, procurement process starting and expected to be leveraged off existing sub-contracts (i.e., Terms and Conditions and technical requirements are expected to be the same)
- Science raft baseplate, first article with option for fabrication is starting
- Filter coating procurement, RFP preparation is starting and will include a witness sample initial phase with option for production coating
- Filter optical fabrication, RFP is planned for later this calendar year
- Broad-Band Anti-Reflection coating, RFP contract to be executed after the currently ongoing witness sample demonstration

4.2 Comments

There is a very strong management and project controls team working on the project. The CAMs appear to have embraced earned value management as a tool for monitoring and tracking performance on the project and understanding how to take action. The electronic tools (the Hammer and the eCAM book) used by the project for cost/schedule performance management and reporting appear easy for CAMS and project managers to use and provide drill down to lower levels of the project for analysis and corrective action.

The project team has a real and substantive EAC process. CAMs are expected to perform to their baseline CA cost unless agreed to by the PM in a substantiated EAC submittal and approved by the PM. This should over the lifetime of the project provide a good means to assess the available budget reserve.

Risk management is very active and thorough in the project including regular risk review board meetings, monthly updates to the risk registry, and quarterly assessment with the Monte Carlo analysis. This should provide a good means to assess cost and schedule risk exposure in conjunction with the EAC analysis. However, the assessment of residual exposure of risks, as represented in the risk registry, appears in some cases to be optimistic.

Regarding current performance issues, schedule delays of approximately one month overall on project performance to date appear to be related to lower than expected staffing levels. The project believes the staffing issues are resolved and will be able to catch up. This was tracked in the corrective action log and closed in July. Concerns about the schedule delays of the 2 sensor vendors were presented, showing approximately two months delay, but an expectation that the vendors will be able to meet present milestones. Sensor delivery delay is the highest project risk; the project has done a good job of developing mitigation strategies to utilize sensors from multiple vendors and expect to have an early understanding of this risk mitigation strategy by November when a study on the full impact of a heterogeneous focal plane is due.

Since present cost and schedule estimates for work to go are based mainly on estimates performed almost a year ago, the annual estimate to complete process should be performed to assure continued confidence in the base plan for cost and schedule. This should include review of the activity-level bottom-up contingency assessment. The project should also review the laboratory labor estimates for work to go to validate the level is sufficient.

4.3 Recommendation

12. This project is ready to proceed to CD-3.

5. PROJECT MANAGEMENT

5.1 Findings

Scope and KPPs have not changed since CD-2 approval. The new camera will support during operations the observations of 18,000 sq. degrees with up to 825 visits per patch of sky in 6 filters (ugrizy) from 320 to 1050nm. A typical observation will consist of a pair of 15 second exposures.

The objective instrument KPP will provide 21 science rafts and 4 corner rafts totaling to 3.2 billion pixels. The threshold KPP on the number of pixels was set by defining the minimum needed to meet the requirements of a stage IV DE project. The difference between threshold and objective corresponds to roughly 4 rafts of pixels.

A CD-3a for long lead procurements was approved for $13 million in June 2014.

Current overall design is at 80% with 100% design planned in FY 2016. A Final Design Review by NSF was successfully completed in December 2013, and a Camera Final Design Review was successfully conducted by an external review panel in June 2015.

The project has developed response documents for all previous reviews and tracks the recommendations.

Internal and external interface control documents are complete and in configuration control.

Prototyping for multiple components has been successfully completed to reduce project risk.

Current staffing is at 47 with peak staffing of 55 projected in FY 2016. The ramp up in staffing is due to engineers, technicians, and designers needed to finalize drawings and manufacturing documents.

Two vendors are currently under contract to produce the sensor first articles (20 units) and first lot (45 units). The second lot award scheduled for December 2015 will be based on vendor performance. The baseline plan currently has one vendor, but procurement is flexible to accommodate two vendors.

The two sensor vendors are both currently behind baseline schedule (approximately two months). The project is working with the vendors to minimize schedule delay by having weekly teleconferences, site visits, and additional face-to-face meetings.

The project has identified $7 million in descoping options with decision dates ranging from now to 2019. There are $30 million in scope enhancements, which have target decision dates ranging from November 2015 to 2020.

The MIE project ends with KPPs verified at SLAC, and shipment to Chile is included in scope enhancement, funds permitting.

The overall LSST project has weekly meetings with all the major contributors.

Five large procurements >$200K still remain and 53% of total ($62.4 million) anticipated awards have either been placed or an option is available. Major procurements remaining (in FY 2016 unless noted): Sensor second Lot (third and final lot in FY 2017), Grid Metrology & Machining, L1-L2 Coating, L3 Flat & Lens Assembly, and Filter Fabrication.

317 total risks have been identified with 178 risks that are currently active and being managed.

The project has 14 months of schedule contingency relative to the overall LSST project milestones (14 months to the LSST project pre-ship review, 23 days to the LSST project early pre-ship review). The schedule contingency to CD-4 from early delivery is 24 months.

5.2 Comments

The LSST Camera project team is expert and very capable. The team is well managed and can effectively deliver on the construction phase tasks, manage the procurements, interfaces, and risks. The management structure and resources are in place to successfully deliver the project within the cost and schedule.

The LSST Camera management team and the broad based collaboration of institutions are communicating and functioning well together.

Key staff and members of the management team have been working effectively together for a number of years.

The majority of the final design has been successfully reviewed and appears substantially complete to start construction. The LSST Camera design including interfaces with the telescope facility are sufficiently complete to start the fabrication. The Camera Design supports the Key Performance Parameters, which have technical flow-down from the Mission Need Statement supporting a Stage IV dark energy experimental objective.

The project interfaces appear well defined and mature at this stage of the project.

The risk register appears to be robust and significant risks are actively being managed and mitigated. The remaining project risks appear to be manageable and sufficient cost contingency is available to handle the projected residual risks.

The calculated schedule contingency of 8.5 months (80% CL) from the risk analysis is optimistic for a project of this duration and with scope elements such as procurement of state-of-the-art sensors, but the 24 month schedule contingency to CD-4 is more than adequate. The 14 month schedule contingency to the LSST project pre-ship review milestone is tight, but appears to be doable.

There appear to be adequate resources to complete, manage, and track the remaining open procurements. Milestones for reviews of major items of procurement exist and these reviews are being performed. Where possible the major procurement reviews (especially sensor) would benefit by including non-advocate reviewers.

The camera utilizes 189 science sensors, 201 sensors in all including wavefront and guide sensors (different type). First article procurement is underway for the science sensors with two vendors. Both vendors have been having schedule and technology difficulties as they approach delivery.

The baseline plan currently has one sensor vendor for the second lot, but procurement is flexible to accommodate two vendors if necessary. The pending BCR to incorporate a second vendor for lot 2 appears to be a sound mitigation strategy and a good use of contingency.

The project has begun to plan the transition to operations; the project should ensure coordination and planning in order to retain key individuals.

The documentation required by DOE Order 413.3B for CD-3 is complete. The team has responded to prior DOE IPR recommendations and is ready for immediate CD-3 approval.

5.3 Recommendation

13. Proceed to CD-3.

Appendix A Charge Memo

DOE F 1325.8
(08-93)

United States Government **Department of Energy**

memorandum

DATE: JUN 2 4 2015

REPLY TO
ATTN OF: Jim Siegrist, Office of High Energy Physics, SC-25

SUBJECT: DEPARTMENT OF ENERGY (DOE) CD-3 REVIEW OF THE LARGE SYNOPTIC SURVEY TELESCOPE (LSST) CAMERA PROJECT

TO: Stephen Meador, Director, Office of Project Assessment, SC-28

I request that your Office organize and conduct for the Office of High Energy Physics (HEP) an Office of Science Independent Project Review (IPR) of the LSSTCAM Major Item of Equipment (MIE) project on August 4 - 6, 2015 at the Brookhaven National Laboratory in Upton, New York. The purpose of this review is to evaluate the project's readiness for seeking approval of Critical Decision (CD) – 3, *Approve Start of Construction.*

The construction and operation of the LSST Observatory facility atop El Penon in Chile is a joint initiative of the National Science Foundation (NSF) Division of Astronomy, the DOE Office of High Energy Physics, and the privately funded LSST Corporation, a non-profit entity located in Tucson, AZ. LSST is designed to provide unprecedented ground-based survey capabilities of various cosmic phenomena; LSST will address the fundamental questions raised by the discovery of the "dark universe" by providing precise characterization of the dark energy and dark matter through studies of multiple phenomena in a deep survey of southern half of the sky. NSF is responsible for the site preparation and construction of the Telescope and support facilities (with a not-to-exceed project cost of $473M); DOE is responsible for the LSST Camera design, fabrication, test, and delivery of the Camera to the observatory site.

The project received CD-2, *Approve Performance Baseline*, on January 7, 2015, with a Total Project Cost (TPC) of $168 million. In June 2014, post CD-1, the project had received CD-3A, *Approve Long Lead Procurement*, for the production sensors at a not-to-exceed cost of $13M.

In carrying out its charge, the review committee should respond to the following questions:

1. Design: Is the LSST Camera final design, including the interfaces with the telescope facility, substantially complete to start the fabrication (a.k.a. construction) phase? Does the Camera design support meeting the Key Performance Parameters (KPPs) as described in the approved Project Execution Plan (PEP) to achieve DOE Dark Energy Stage IV, and NSF, science objectives?

2. Management: Is the project being properly managed at this stage? Is there a capable team in place, and required resources identified, to effectively manage the construction phase including all the procurements, major interfaces, and risks to ensure successful delivery of the project?

3. Performance: Is the project performance to-date in line with the approved Performance Baseline and are variances being effectively managed?

4. ES&H: Are ES&H systems and processes in place to support mitigation of all the hazards identified and to ensure delivery of the project in a safe and environmentally sound manner?

5. Has the project met all the CD-3 prerequisites, responded to prior DOE IPR recommendations, and is it ready for CD-3 approval?

The Office of High Energy Physics Program Manager for Instrumentation, Helmut Marsiske, will work with you, as necessary, to plan and carry out this review. I would appreciate receiving your committee's report within 30 days of the review's conclusion.

James Siegrist
Associate Director of Science
for High Energy Physics

cc:
K. Fisher, SC-28
H. Marsiske, SC-25.2
M. Procario, SC-25.2
K. Turner, SC-25.1
P. Golan, SSO
H. Joma, SSO
C. Kao, SLAC
S. Kahn, SLAC
N. Kurita, SLAC
D. MacFarlane, SLAC

Appendix B Review Committee

DOE/SC (CD-3) Review of the
Large Synoptic Survey Telescope Camera (LSSTCam) Project
August 4-6, 2015

Kurt Fisher, DOE/SC, Chairperson

SC1
Sensors, Electronics, Control Systems and DAQ (WBS 3.03/3.04/3.05)

* Ron Lipton, FNAL
Rachel Dudik, USNO
Steve Holland, LBNL

SC2
Optics, Mechanics, Cryostat, I&T (WBS 3.04/3.05/3.06/3.08)

* Bruce Bigelow, Carnegie
Greg Derylo, FNAL
Steve Smee, Johns Hopkins University
Joe Preble, TJNAF

SC3
Environment, Safety and Health

* Jack Salazar, LBNL

SC4
Cost and Schedule

* Elaine McCluskey, FNAL
Brian Huizenga, DOE/AMP
Tim Maier, DOE/SC

SC5
Management

* Mike Levi, LBNL
Jerry Kao, DOE/CH

Observers

Michael Procario, DOE/SC
Helmut Marsiske, DOE/SC
Hanley Lee, DOE/SSO
Hannibal Joma, DOE/SSO
Nigel Sharp, NSF

LEGEND

SC Subcommittee
* Chairperson
[ ] Part-Time Sub Committee Member

Count: 14 (excluding observers)

Appendix C Review Agenda

DOE/SC (CD-3) Review of the
Large Synoptic Survey Telescope Camera (LSSTCam) Project
August 4-6, 2015

AGENDA

<u>Tuesday, August 4—Brookhaven Center, South Room</u>

8:00 am	DOE Committee Executive Session	Fisher/Marsiske/Joma
9:00 am	Welcome	Lissauer
9:10 am	LSST Status	Kahn
10:05 am	LSSTCam Project Management and Overview	Kurita
11:00 am	**Break**	
11:15 am	LSST Camera Final Design Overview	Nordby
12:10 pm	ES&H	O'Neil
12:30 pm	**Lunch**	
1:30 pm	LSSTCam Science: Scientific Performance	Ritz
2:10 pm	Major Procurements and Risks (Post CD-3)	Riot
2:45 pm	**Break**	
3:00 pm	**Subcommittee Breakout Sessions*—Day 1**	
5:00 pm	DOE Committee Executive Session	
6:00 pm	Adjourn	

<u>Wednesday, August 5, 2015—Bldg. 510, Rm 1-224</u>

8:00 am	Tour (Clean room)—Day 2
9:00 am	**Subcommittee Breakout Sessions***
10:30 am	**Break**
10:45 am	Subcommittee Breakout Sessions
12:00 pm	**Lunch**
1:00 pm	Subcommittee Q/A and Wrap-up
4:00 pm	DOE Committee Executive Session

<u>Thursday, August 6, 2015—Bldg. 510, Rm 1-224</u>

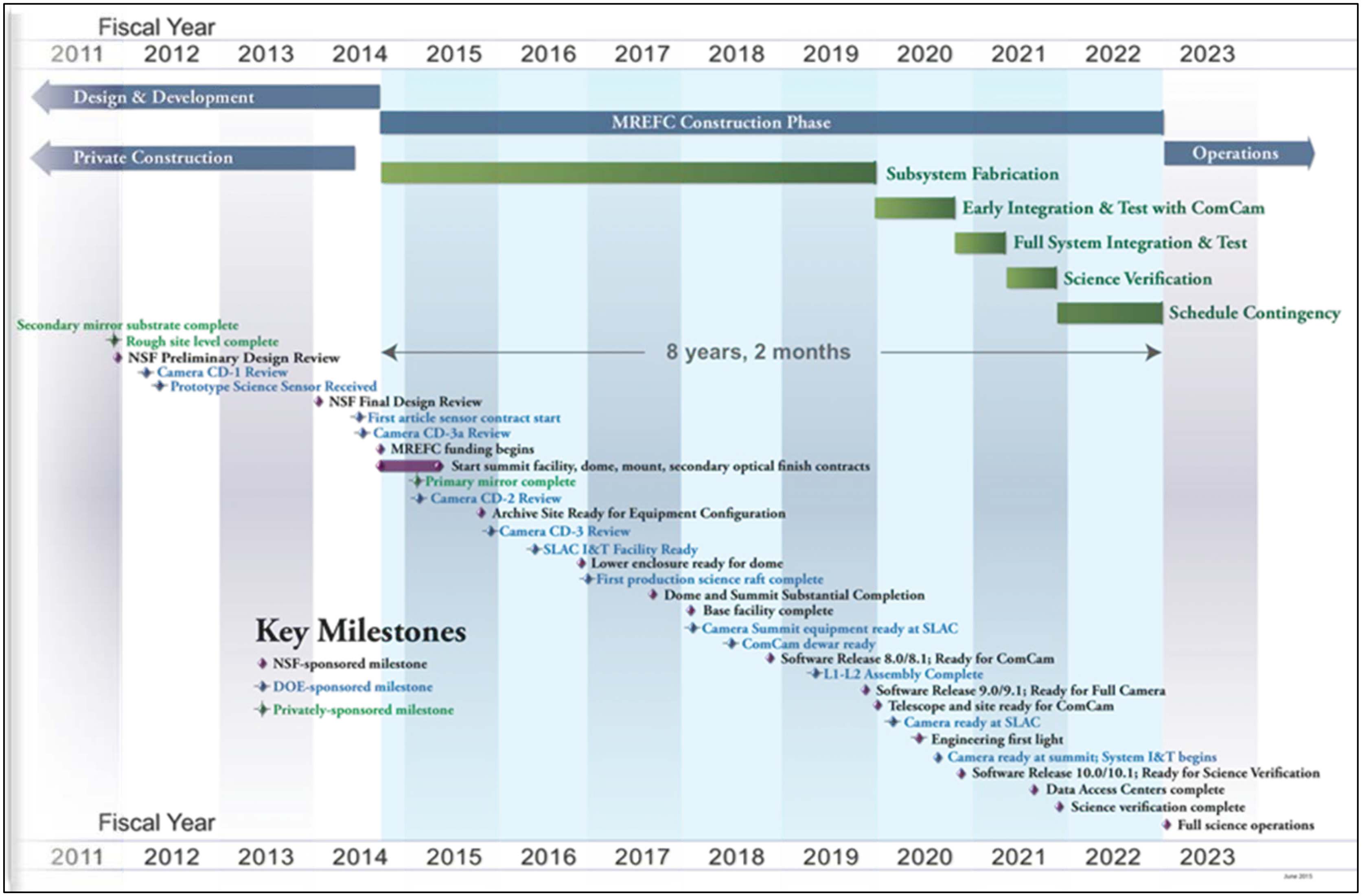
8:00 am	Subcommittee Working Session
11:00 am	DOE Committee Executive Session
12:00 pm	**Lunch**
1:00 pm	*Closeout Presentation*
2:00 pm	Adjourn

**** Topics for all the WBS level 2 technical elements include design (except sensors), major procurements, cost, schedule, risks, mitigations and contingencies.***

Appendix D LSSTCam Cost Table

WBS - Level 2	Total Cost ($K)
WBS 3.01 Management	12,520
WBS 3.02 Systems Integration	8,614
WBS 3.03 Science Sensors	29,649
WBS 3.04 Science and Corner Raft	18,732
WBS 3.05 Optics	25,145
WBS 3.06 Camera Body, Mechanisms, Cryostat	17,587
WBS 3.07 Control System, Data Acquisition System & Auxiliary Electronics	11,094
WBS 3.08 Integration and Test	11,900
Performance Measurement Baseline	**135,240**
Contingency	32,760
Total Project Cost ($)	**168,000**

Appendix E LSSTCam Schedule Chart



Appendix F LSSTCam Funding Table

Fiscal Year	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	Total (M)
OPC	1.9	5.5	8.0	2.3					17.7
TEC				19.7	35.0	40.8	45.0	9.8	150.3
TPC	1.9	5.5	8.0	22.0	35.0	40.8	45.0	9.8	168.0

Appendix G LSSTCam Management Chart