

LARGE SYNOPTIC SURVEY TELESCOPE (LSST)**\$46,340,000**

The FY 2020 Request for the Large Synoptic Survey Telescope is \$46.34 million. This is the seventh year of support for a nine-year construction project that began in August 2014. The NSB-approved not-to-exceed total project cost is \$473.0 million for NSF’s contribution to the project’s scope.

Appropriated and Requested MREFC Funds for the Large Synoptic Survey Telescope

(Dollars in Millions)

FY 2014 Actual	FY 2015 Actual	FY 2016 Actual	FY 2017 Actual	FY 2018 Actual	FY 2019 Estimate	FY 2020 Request	FY 2021 Estimate	FY 2022 Estimate	Total Project Cost
\$27.50	\$79.64	\$99.67	\$67.12	\$57.80	\$48.82	\$46.34	\$40.75	\$5.36	\$473.00

LSST is located in Chile and, when completed, will be an 8.4-meter wide-field optical telescope designed to carry out surveys of nearly half the sky. The initial 10-year survey has a cadence enabling repeat observation of each survey field approximately twice weekly. The requirements for LSST were set by considering four key science areas:

- the physics of dark energy and dark matter
- a census of small bodies in the Solar System, including potentially hazardous Near-Earth Objects
- the structure and contents of the Milky Way galaxy
- the nature of transient astronomical objects on time scales ranging from seconds to years.

By satisfying the requirements defined by these key investigations, the LSST survey will result in a comprehensive data set that will enable hundreds of fundamental astrophysical studies by the entire research community on these and other topics. Thus, LSST has the potential to advance every field of astronomical study, from the inner Solar System to the large-scale structure of the Universe.

Baseline History

LSST is a joint NSF and Department of Energy (DOE) project to build an instrument that was ranked the top large ground-based astronomy project by the National Academies of Sciences, Engineering, and Medicine 2010 Astronomy and Astrophysics decadal survey: *New Worlds, New Horizons in Astronomy and Astrophysics*.¹

Prior to NSF’s construction award, NSF, DOE, and private (non-federal) partners invested over \$130.0 million in LSST-related work. About 70 percent supported design and development, and about 30 percent, from the non-federal funding, supported casting and polishing of the innovative combined primary-tertiary mirror (M1M3), initial site preparation, and prototype detector creation and evaluation, all of which significantly reduced construction risk.

NSF and DOE conducted a series of reviews in 2011 and 2012 to determine the project baseline, including the NSF Preliminary Design Review and a subsequent cost estimation review. Plans were kept up-to-date to synchronize the DOE and NSF funding profiles as reviews continued, leading to NSF’s Final Design Review (FDR) in December 2013. NSF then carried out a detailed cost analysis prior to following through on its approval process and making an award in the last quarter of FY 2014.

¹ www.nap.edu/catalog/12951/new-worlds-new-horizons-in-astronomy-and-astrophysics

Major Research Equipment and Facilities Construction

Total Funding Requirements for LSST

(Dollars in Millions)

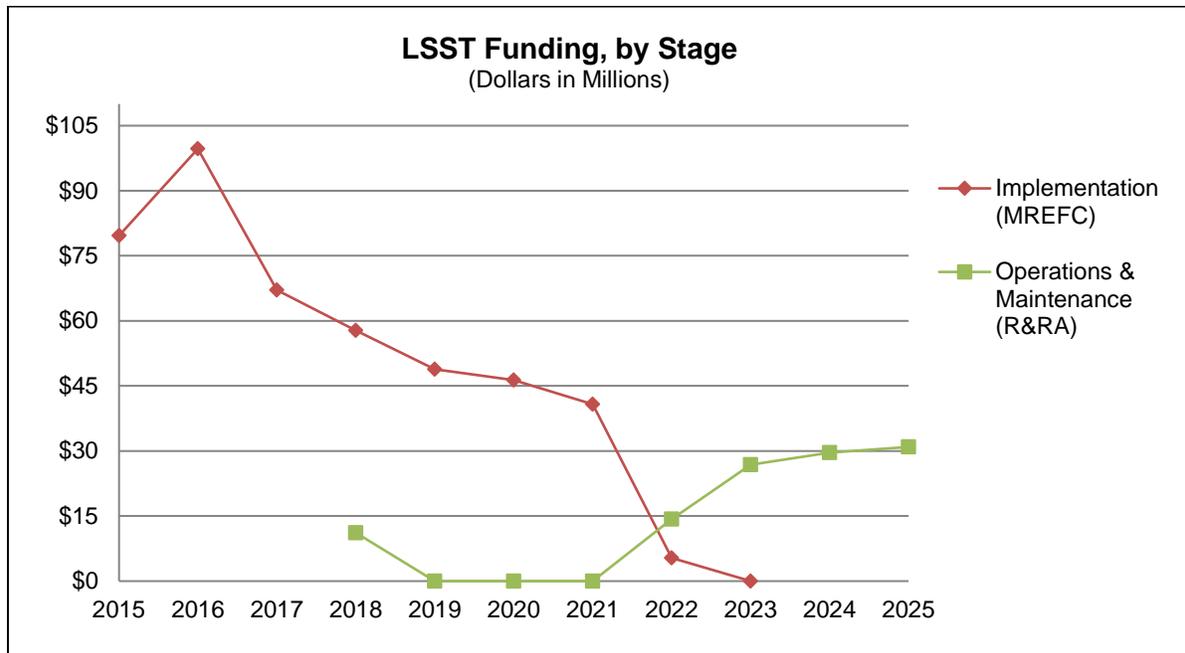
	Prior Years	FY 2018 Actual ¹	FY 2019 Estimate	FY 2020 Request	ESTIMATES ²					
					FY 2021	FY 2022	FY 2023	FY 2024	FY 2025	
<i>R&RA:</i>										
Development & Design	\$57.13	-	-	-	-	-	-	-	-	-
Operations & Maintenance ³		11.10	-	-	-	14.32	26.85	29.64	30.93	
Subtotal, R&RA	\$57.13	\$11.10	-	-	-	\$14.32	\$26.85	\$29.64	\$30.93	
<i>MREFC:</i>										
Implementation ⁴	273.93	57.80	48.82	46.34	40.75	5.36	-	-	-	
Subtotal, MREFC	\$273.93	\$57.80	\$48.82	\$46.34	\$40.75	\$5.36	-	-	-	
TOTAL REQUIREMENTS	\$331.06	\$68.90	\$48.82	\$46.34	\$40.75	\$19.68	\$26.85	\$29.64	\$30.93	

¹ FY 2018 obligations for Operations & Maintenance are intended to cover pre-operations costs for the first three years of the pre-operations ramp up, FY 2019-FY 2021.

² Outyear funding estimates are for planning purposes only.

³ Operations & Maintenance funding represents NSF support only and amounts to about 49 percent of the operations cost. Other support from DOE and non-federal contributors provides the balance.

⁴ Includes \$4.74 million carried forward into FY 2019.



LSST Science Plan

The site on Cerro Pachón, Chile, was selected for LSST because of the excellent sky transparency and image quality, dark skies, small fraction of cloudy nights, and the geological characteristics that enable the rapid telescope motions required to carry out the LSST survey. LSST will collect nearly 40 terabytes of multi-color imaging data every night for 10 years, producing a long-lived data set of unprecedented utility. It will produce the deepest, widest-field sky image ever and issue alerts for changing and transient objects within 60 seconds of their discovery. Repeated deep imaging of every part of the accessible sky will turn up explosive events such as cataclysmic variable stars, supernovae, and the optical counterparts of X-ray flashes, as well as finding moving objects and better characterizing those already known. Estimates of

LSST's ability to locate Near-Earth Objects (NEOs) and Potentially Hazardous Asteroids (PHAs) have been refined by LSST project members², as well as by external studies, including an independent Jet Propulsion Laboratory study³ supported by NASA's Planetary Defense Coordination Office. Assuming other existing NEO efforts continue, at the end of LSST's 10-year prime mission, the catalogue for objects larger than about 140 meters across should be about 75 percent complete for NEOs (about 80 percent for PHAs). Without LSST the completeness would be about 60 percent for NEOs (about 65 percent for PHAs).

LSST data will be widely accessible, and discovery opportunities will be available to K-12 students as easily as to professional astronomers. An innovative citizen science program will involve people of all ages in LSST discoveries. More than half of the cost during operations is for data management, including user-friendly interfaces tailored for the different anticipated communities. The survey strategy makes the same data set usable for almost all of the astronomy community as well as for educators and the general public. The primary data archive is planned to be located at the National Center for Supercomputing Applications in Illinois.

Management and Oversight

- **NSF Structure:** NSF oversight is handled by a program officer in the MPS Division of Astronomical Sciences (AST) working cooperatively with NSF staff through the Integrated Project Team with members from MPS, BFA, the Office of General Counsel, the Office of Legislative and Public Affairs, OISE, and the Office of the Director. Within BFA, the Large Facilities Office provides advice to program staff and assists with agency oversight and assurance. The NSF program officer works closely with counterparts in the DOE Office of High Energy Physics, who have oversight responsibility for the LSST camera sub-project. Interagency coordination is accomplished through weekly meetings of a Joint Oversight Group and was formalized through a Memorandum of Understanding signed in July 2012.
- **External Structure:** The responsible awardee for LSST construction is the Association of Universities for Research in Astronomy, Inc. (AURA), a non-profit science management corporation consisting of 46 U.S. member institutions and 4 international affiliates as of February 28. AURA works closely with the LSST Corporation (LSSTC), which initiated LSST development and remains responsible for privately raised funding. AURA and LSSTC established the LSST Project Office as an AURA-managed center for construction; this office is overseen by the AURA Management Council for LSST. The LSST project director and the LSST project manager are experienced in large facility construction and operation and are appointed by AURA, with the approval of NSF and DOE. AURA is also the responsible awardee for LSST pre-operations ramp-up activity that began in October 2018. AURA is responsible for coordinating construction activities and pre-operations activities that execute side-by-side.

Reviews

Technical Reviews: Reviews were conducted throughout the development and design phase, culminating in NSF's FDR in December 2013, with DOE involvement. All major sub-systems undergo regular system-level design reviews organized by the LSST Project Office with external participants.

Management, Cost, and Schedule Reviews: Cost, schedule, and risk are also scrutinized by the technical reviews. During construction, NSF and DOE hold regular joint progress reviews. The most recent reviews are summarized below:

- A successful data management-focused review took place in July 2017, providing support for significant use of cost contingency. The third joint agency progress review occurred in September 2017 and was successful. The latest joint agency progress review occurred in July/August 2018 and was also

² <https://doi.org/10.1016/j.icarus.2017.11.033>

³ <https://arxiv.org/abs/1705.06209>

successful.

- Follow-up Earned Value Management surveillance reviews coincided with the 2017 and 2018 annual progress reviews.
- In January 2017, DOE and NSF held a joint external agency review of the project's plans for commissioning and transition to early operations. NSF and DOE followed up this review in August 2018 with another in-depth review of the project's advanced plans for commissioning as a significant extension of the annual progress review. The review panel praised the state of LSST commissioning plans.
- In December 2017, NSF and DOE held a joint review of the project's proposal for operations of the full ten-year survey, plus an additional four years of pre-operations ramp up and two years of post-survey activity. The review was successful, and NSF and DOE began initial funding of early pre-operations activity in FY 2019 (with NSF forward-funding from FY 2018 for the period FY 2019-FY 2021).

Project Status

NSF's construction award was issued in August 2014. As of January 2019, the project's MREFC scope is 66 percent complete. The primary telescope building has been completed, and dome installation and mirror cell lift construction are underway in earnest. About \$100 million worth of components were successfully shipped or preparing for shipment to the site in 2018. The Auxiliary Telescope, used for calibration purposes, is being installed and commissioned. Progress on the LSST base facility located in La Serena, Chile, is progressing with no new risks that cannot be mitigated through the allocation of additional available contingency and is set to be completed in early to mid-year 2019. NSF- and DOE-supported activities remain tightly coordinated, both at the project level and between agency program officers.

Cost and Schedule

The FDR panel found the NSF Total Project Cost (TPC) of \$473.0 million to be reasonable and justifiable, and they also recommended that the project introduce possible additional descoping options. NSF carried out further cost review prior to making the award. The LSST Project established a joint cost and schedule Monte Carlo (MC) method through their Project Management Control System and showed that the computed TPC corresponds to a better than 90 percent chance that the final cost of the current construction scope will fall within the NSB-approved funding cap and by the planned survey start date. This result was finalized in April 2015 and incorporated into the associated cooperative support agreement. In addition to NSF's contribution, DOE's baseline for the camera was fixed at \$168.0 million. Construction also includes approximately \$39 million from non-federal sources, all of which has been expended.

As of September 2018, the project had allocated 53 percent of the total contingency to the baseline, and \$38.40 million of contingency remains. One recent change was for a 2.5-month schedule shift of the project finish date. The early finish is now in January 2022, reducing schedule contingency to 8.5 months, down from the starting contingency of 13 months. The 2018 annual integrated MC analysis was completed and indicates an 88 percent confidence that the project will be completed within the TPC of \$473.0 million and a 90 percent confidence that the project will be completed by August 2022, one month ahead of the defined period of performance for construction. At the same time NSF and DOE work closely with the project to monitor and consider remaining descoping and deferral options.

Risks

Technical: Much of the technical risk was retired during development and design. Since full construction began, no new major risks have appeared, and small, realized risks have been mitigated by use of cost and schedule contingency, including float internal to sub-projects. The Data Management (DM) construction effort has been identified as a risk and re-planning has been completed. Implementation of the recommendations of the July 2017 DM review, including the release of cost and schedule contingency, has been completed. Careful planning to stage DM deliverables in coordination with commissioning sequencing

will mitigate those risks associated with DM. Commissioning plans overall have pathfinders to mitigate technical risks as the entire system is assembled and integrated over the next two years.

Environmental and Cultural Compliance: Environmental and cultural impact mitigation continues as planned with no unforeseen issues.

Site: The possible site risk due to local geological anomalies, noted in previous requests, was realized during excavation. Since this risk was localized and anticipated, it was successfully handled. Site disruptions from geological events and extreme weather remain as possible risks with appropriate mitigation plans.

Environmental Health and Safety: The LSST project has a full-time head of safety with experience in AURA operations, which has a long history of an excellent safety record in Chile. Both the summit and base sites have on-site safety supervisors employed by LSST to monitor contractor and project activities. All safety plans are fully compliant with applicable standards from U.S., Chilean, and participating institutions, and are updated regularly. External reviews have given the project high marks for its safety culture.

Partnership Risk: Significant attention has been paid to partnership risk, and that risk has been mitigated by careful coordination and unified project structures. The LSST project director oversees the entire project. A single project manager, agreed to by both NSF and DOE, manages the complete work breakdown structure elements. Budgetary management details are clearly set out between the project director, the project manager, the project's Change Control Board, the AURA Management Council for LSST, and the agencies' program officers, grants officers, and financial managers.

Operations Costs

Operation costs are funded within R&RA. NSF is planning to support approximately half of operations funding with the balance coming from the DOE and non-federal, primarily international contributors. Operations costs are planning estimates based on the most recently available data. The overall 10-year operations cost estimate to NSF remains unchanged at \$310.0 million (then-year U.S. dollars). The final full operations costs and the amount required from non-federal contributors will be determined through a review, approval, and award process that began with the project's submission of a formal proposal for the full LSST survey operations, including pre- and post-survey activities, in August 2017 and initial external panel review in December 2017. An additional proposal for the first three years of pre-operations ramp-up was received in May 2018 and covered costs through FY 2021. This proposal was reviewed and awarded in FY 2018 using FY 2018 R&RA funds to cover the entire proposed period. Additional O&M funds are not anticipated to be required in FY 2019 - 2021. The NSB is expected to review a request to authorize an operations award in FY 2020 or FY 2021, which will fund operations beginning in FY 2022.

Major Research Equipment and Facilities Construction

In their joint memorandum of understanding, NSF and DOE agreed to fund operations, increasing agency support and revising the operations plans, as appropriate. AST is planning to provide approximately half of the original estimated steady-state amount, as well as operations ramp-up support, with the DOE Office of High Energy Physics providing one quarter, plus installation and commissioning support additional to the project construction cost. The project team has already established firm agreements to fund about half of the remaining one quarter with contributions from non-federal entities. Negotiations continue with potential partners to fund the remaining balance.



LSST from Gemini South at Sunset, August 2018. *Credit: Gianluca Lombardi*