

VERA C. RUBIN OBSERVATORY**\$40,750,000**

The FY 2021 Request for the Vera C. Rubin Observatory is \$40.75 million. This is the eighth year of support for a nine-year construction project that began in August 2014. The NSB authorized award is \$473.0 million for NS’s contribution.

Appropriated and Requested MREFC Funds for the Vera C. Rubin Observatory

(Dollars in Millions)

FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020 Request	FY 2021 Request	FY 2022 Estimate	FY 2023 Estimate	Total Project Cost
\$27.50	\$79.64	\$99.67	\$67.12	\$57.80	\$48.82	\$46.34	\$40.75	\$5.36	-	\$473.00

Prior to the FY 2021 Request, this project had been called the Large Synoptic Survey Telescope. Following the passage of the Vera C. Rubin Observatory Designation Act (P.L. 116-97), the facility is now named the Vera C. Rubin Observatory. The facility’s new name honors Dr. Rubin, an American astronomer who made a concerted effort to improve diversity in astronomy and whose pioneering studies of galactic rotation rates provided important evidence for the wide-spread existence of dark matter, one of the key science areas for the project. The Vera C. Rubin Observatory will be comprised of an 8.4-meter wide-field optical telescope in Chile with a 3.2 giga-pixel camera and an advanced data management system, which together are designed to carry out a deep survey of nearly half of the sky. The Rubin Observatory’s initial 10-year survey has a cadence enabling repeat observation of each survey field approximately twice weekly. The requirements for the Vera C. Rubin Observatory and the survey 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 (NEOs);
- the structure and contents of the Milky Way Galaxy; and
- the nature of transient astronomical objects on time scales ranging from seconds to years.

By satisfying the requirements defined by these key investigations, the Vera C. Rubin Observatory’s initial 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, the Vera C. Rubin Observatory 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

The Vera C. Rubin Observatory is a joint NSF and Department of Energy (DOE) project to build an instrument that was ranked as the top large ground-based astronomy project recommended 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 Vera C. Rubin Observatory-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.

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

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 completing its approval process and making an award in the last quarter of FY 2014.

Total Funding Requirements for the Vera C. Rubin Observatory

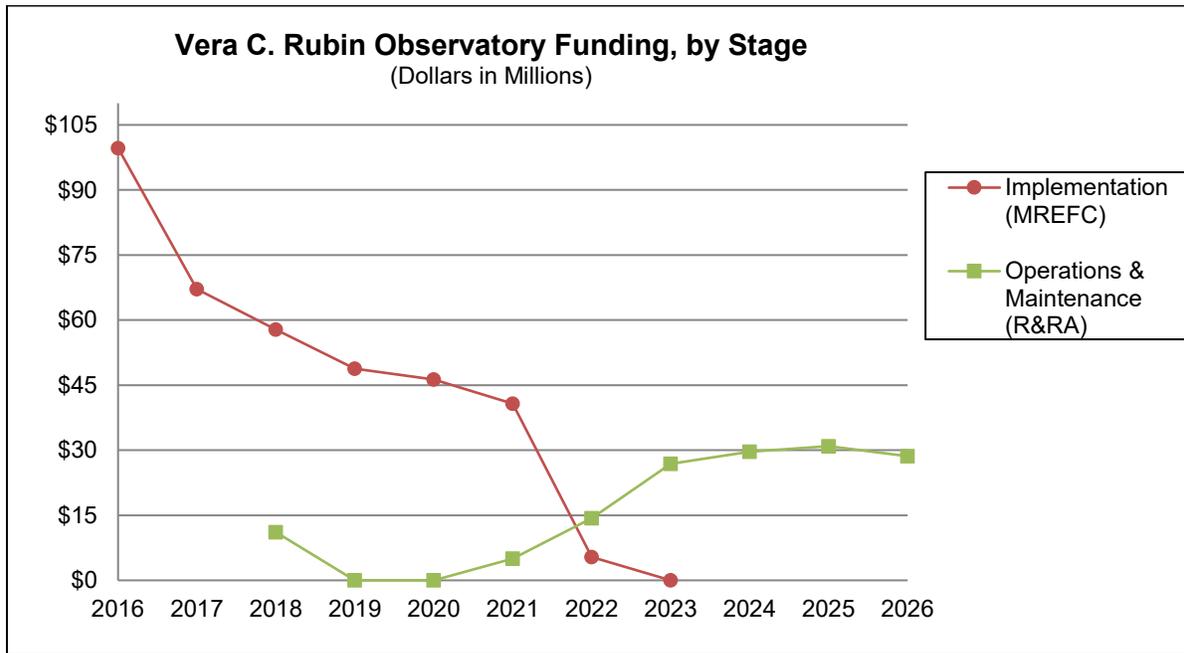
(Dollars in Millions)

	Cumulative Prior Years	FY 2019 Actual	FY 2020 Request	FY 2021 Request	ESTIMATES ¹				
					FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
R&RA:									
Development & Design	\$57.13	-	-	-	-	-	-	-	-
Operations & Maintenance ²		-	-	5.00	14.32	26.85	29.64	30.93	28.62
Subtotal, R&RA	\$57.13	-	-	\$5.00	\$14.32	\$26.85	\$29.64	\$30.93	\$28.62
MREFC:									
Implementation ³	331.73	48.82	46.34	40.75	5.36	-	-	-	-
Subtotal, MREFC	\$331.73	\$48.82	\$46.34	\$40.75	\$5.36	-	-	-	-
TOTAL	\$388.86	\$48.82	\$46.34	\$45.75	\$19.68	\$26.85	\$29.64	\$30.93	\$28.62

¹ Outyear funding estimates are for planning purposes only and represent preliminary estimates. A new cooperative agreement for O&M of the Vera C. Rubin Observatory for FY 2022-FY 2026 is anticipated in FY 2021

² O&M funding represents NSF support only and amounts to about 50 percent of the total operations cost. Support from DOE and non-federal contributors provides the balance.

³ Includes \$82,943 carried forward into FY 2020.



Vera C. Rubin Observatory Science Plan

The site on Cerro Pachón, Chile, was selected for the Vera C. Rubin Observatory 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 Vera C. Rubin Observatory's ten-year survey. The Rubin Observatory will collect about 20 terabytes of multi-color imaging data every night² for 10 years, producing a long-lived data set of unprecedented utility. It will produce the 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 the Vera C. Rubin Observatory's ability to locate NEOs³ and Potentially Hazardous Asteroids (PHAs)³ have been refined by Observatory project members,⁴ as well as by external studies, including an independent Jet Propulsion Laboratory study⁵ supported by NASA's Planetary Defense Coordination Office. Assuming other existing NEO efforts continue, at the end of the Vera C. Rubin Observatory'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 the Vera C. Rubin Observatory, the completeness would be about 60 percent for NEOs (about 65 percent for PHAs).

The Vera C. Rubin Observatory's 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 Rubin Observatory discoveries. About half the cost during operations is for data management, including the development of user-friendly interfaces tailored for the different anticipated communities. The survey strategy makes the same data set usable for the astronomy community as well as for educators and the general public.

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, OISE, BFA, the Office of General Counsel, the Office of Legislative and Public Affairs, 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 MPS Facilities team and NSF's Chief Officer for Research Facilities also provide high-level guidance and oversight support for the project. The NSF program officer works closely with counterparts in the DOE Office of High Energy Physics, who have oversight responsibility for the construction of the camera. 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 the Vera C. Rubin Observatory construction is the Association of Universities for Research in Astronomy, Inc. (AURA), a non-profit science management corporation. The Vera C. Rubin Observatory Project Office is an AURA-managed center for construction, and AURA established a separate management council that oversees this Project Office. The Observatory's project director and 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 the

² See Ivezić et al. (2019), *The Astrophysical Journal*, 873, 111.

³ NEOs are objects that come within 1.3 astronomical units (au, the distance from Earth to Sun) of the Sun, which means they come near Earth's orbit. PHAs are defined as objects that come within a distance of 0.05 au (roughly 4,650,000 miles) of Earth and are larger than roughly 140 meters in diameter.

⁴ www.doi.org/10.1016/j.icarus.2017.11.033

⁵ www.arxiv.org/abs/1705.06209

Vera C. Rubin Observatory pre-operations ramp-up activity that began in October 2018. AURA is responsible for coordinating construction activities and pre-operations activities that are executed side-by-side.

Reviews

Technical Reviews: Stage-gate reviews were conducted throughout the Design Stage, culminating in NSF's FDR in December 2013, with DOE involvement. All major subsystems have undergone regular system-level reviews organized by the Vera C. Rubin Observatory Project Office during Design and Construction.

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

- The fifth joint agency progress review occurred in August 2019 and was successful.
- An Earned Value Management System (EVMS) surveillance review coincided with the 2019 annual progress review and is used to evaluate the project's alignment with Government Accountability Office (GAO) good practices on schedule. This review determined that the Vera C. Rubin Observatory EVMS continues to meet both the intent of the American National Standards Institute/Electronic Industries Alliance standard, EIA-748-C, Earned Value Management Systems (EVMS) guidelines and NSF requirements for EVMS, and there were no findings or corrective actions.
- 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 activity 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 providing \$11.10 million in FY 2018 for the period FY 2019–FY 2021). An additional \$5.0 million is requested for FY 2021 to cover NSF's increased costs associated with the revised co-funding model with DOE, as described in the Future Operations Costs section below.

Project Status

NSF's construction award was issued in August 2014. As of November 2019, the project's MREFC scope is 76 percent complete. The primary telescope building, mirror cell lift, and mirror coating plant construction have been completed. The M1M3 mirror and cell are completed and have been safely transported to the summit. The secondary mirror (M2) has been successfully coated at the summit facility, and staff have begun moving into the recently completed base facility. Dome installation remains underway despite significant delays. Weather and vendor challenges caused those delays; however, the project has begun planning other activities to minimize the impact of delays on the integrated project schedule. The telescope mount assembly successfully completed factory testing in November 2018, and all parts are now on the summit with installation underway. The Auxiliary Telescope, used for calibration purposes, achieved first light on July 24 with commissioning continuing. NSF- and DOE-supported activities remain tightly coordinated, both at the project level and among agency program officers.

Cost and Schedule

The FDR panel found the NSF Total Project Cost of \$473.0 million to be reasonable and recommended that the project improve their planning of potential descoping options. NSF carried out further cost review prior to making the award. The Vera C. Rubin Observatory Project performed a Monte Carlo simulation analysis on its resource-loaded integrated project schedule, as detailed in its project management control system process, and determined a probability of over 90 percent for completing the project for \$473.0 million and by the planned survey start date of October 1, 2022. This result was finalized in April 2015 and incorporated into the associated cooperative support agreement. In addition to NSF's contribution, DOE's

Major Research Equipment and Facilities Construction

baseline for the camera was fixed at \$168.0 million. Construction also includes approximately \$39 million from non-federal sources, all of which have been expended.

In FY 2019, GAO performed an analysis, published in GAO-19-227, which found that the project schedule did not meet all of GAO's best practices and that the schedule was comprehensive and controlled, but that it was only "partially well-constructed" and "partially credible." NSF and the Vera C. Rubin Observatory project have worked to respond to the GAO findings and recommendations, and GAO has now reported (letter to NSF) that they consider the Vera C. Rubin Observatory project schedule to be well-constructed and credible.

As of November 2019, the project had allocated 70 percent of the total budget contingency to the baseline, and \$25.10 million remains. One recent change was for a 2.5-month schedule shift of the baseline project completion date due to vendor delays, reducing schedule contingency to about 3.5 months. NSF and DOE are working closely with the project to monitor and consider remaining descope and deferral options, to maintain sufficient cost and schedule contingency for proper project management.

Risks

Technical: Much of the technical risk was retired during development and design. Since full construction began, no new major risks have been identified. Realized risks have been mitigated by use of cost and schedule contingency or re-planning by the Vera C. Rubin Observatory Project Office. The Data Management (DM) effort was previously identified as a risk and subsequently re-planned following panel recommendations from the July 2017 DM review, including the release of cost and schedule contingency. Careful planning to stage DM deliverables in coordination with commissioning sequencing will mitigate the remaining 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 Vera C. Rubin Observatory 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 the Observatory 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 Vera C. Rubin Observatory 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, AURA's management council for Vera C. Rubin Observatory construction, and the agencies' program officers, grants officers, and financial managers.

Future Operations Costs

NSF plans to provide approximately half of Vera C. Rubin Observatory operations funding, with support currently expected from within the NSF R&RA account. DOE is partnering with NSF on observatory operations and planning activities are in progress. 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 will be determined through a review, approval, and award process that began with the project's submission of a formal proposal for the Vera C. Rubin Observatory operations, including pre- and post-survey activities, in August 2017 with external panel review in December 2017.

Operations of the Vera C. Rubin Observatory will be fully integrated into NSF's National Optical-Infrared Astronomy Research Laboratory (the Lab), which launched at the start of FY 2020. The Lab also encompasses the Mid-Scale Observatories and Community Science & Data Center, which formerly comprised the National Optical Astronomy Observatory, and the Gemini Observatory. For more details, refer to the corresponding section of the Facilities chapter.

Although it was originally anticipated that international parties would make financial contributions to the Vera C. Rubin Observatory operations, in FY 2019 NSF and DOE jointly modified the original operations funding model into a new model that seeks in-kind contributions from international participants rather than monetary contributions. Nominally, in-kind contributions are expected to benefit U.S. and Chilean scientists and/or offset NSF and DOE operations costs. The specific nature of these in-kind contributions is currently being formulated and negotiated. NSB is expected to review a request to authorize an operations award in FY 2021, which is anticipated to fund operations beginning in FY 2022.



The Vera C. Rubin Observatory during the July 2, 2019 total solar eclipse. Credit: *G. Poczulp. Rubin Observatory/AURA/NSF.*

