VERA C. RUBIN OBSERVATORY (RUBIN OBSERVATORY) $0

Appropriated and Requested MREFC Funds for
Vera C. Rubin Observatory
(Dollars in Millions)

	Prior Years	FY 2019	FY 2020	FY 2021[1]	FY 2022	FY 2023[2]	FY 2024 Request[2]	FY 2025 Request	Total Project
Previous Authorized Total Project Cost	$331.72	$48.82	$46.35	$40.75	$5.36	-	-	-	$473.00
Current Authorized Total Project Cost (COVID-19)	-	-	10.00	-	-	-	-	-	10.00
COVID-19 Impacts	-	-	-	-	35.39	15.00	7.61	-	58.00
American Rescue Plan	-	-	-	30.00	-	-	-	-	30.00
Revised Total Project Cost	**$331.72**	**$48.82**	**$56.35**	**$70.75**	**$40.75**	**$15.00**	**$7.61**	**-**	**$571.00**

[1] A new Total Project Cost of $571.0 million was authorized.

[2] Funds from the FY 2023 appropriation, together with the FY 2024 Request, represent the current best estimate for addressing the remaining COVID-19 impacts.

Brief Description

Vera C. Rubin Observatory will comprise an 8.4-meter wide-field optical telescope located on Cerro Pachón in northern Chile, a 3.2-gigapixel camera supplied by the Department of Energy (DOE), and an advanced data management system. Taken together, these components are designed to carry out a deep survey of nearly half of the sky that will enable a broad range of fundamental astrophysical studies by the research community. Begun in August 2014, the construction project, which was originally planned to last 99 months, is receiving the eleventh year of support in FY 2024. Delays due to the COVID-19 pandemic have now shifted the expected project completion to 2025. The original authorized Total Project Cost (TPC) for NSF's contribution to Rubin Observatory was $473.0 million. In December 2021, a new TPC of $571.0 million was authorized to implement the project's re-baseline in response to the delays and other impacts from the global COVID-19 pandemic. No additional MREFC funding is anticipated for FY 2025.

Operations of Rubin Observatory will be fully integrated into NSF's National Optical-Infrared Astronomy Research Laboratory (NOIRLab), which launched at the start of FY 2020 (Rubin Observatory construction is a stand-alone project outside NOIRLab). NOIRLab also includes the Mid-Scale Observatories, the Community Science & Data Center, and Gemini Observatory. Additional information can be found in the NOIRLab narrative within the Federally Funded Research and Development Centers (FFRDCs) section of this chapter.

Baseline History

Rubin Observatory is a joint NSF and DOE project to build an instrument that the top-ranked large ground-based astrophysics 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 partners invested over $130 million in Rubin Observatory-related work, of which about 70 percent supported design and development. About 30

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

percent, from 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, including the NSF Preliminary Design Review and a subsequent cost estimation review, to determine the project baseline. 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 design and approval process in late FY 2014.

Project Status

NSF's construction award was issued in August 2014. The primary telescope building, mirror cell lift, and mirror coating plant construction have been completed. The secondary mirror (M2) has been successfully coated at the summit facility, and staff have moved into the completed base facility in La Serena, Chile. Following the onset of COVID-19, the project executed activities to minimize the impact of delays on the integrated project schedule. Installation of the telescope mount assembly (TMA) on the summit resumed in January 2021. While a resurgence of COVID-19 in Chile later in FY 2021 caused significant additional delays, the TMA is now substantially complete. The primary-tertiary (M1M3) mirror cell and commissioning camera were installed on the TMA along with the M1M3 and M2 mirror surrogates for dynamic testing. Dome installation is nearly complete, despite earlier delays caused by weather and realization of other known risks. Commissioning activities for the Auxiliary Telescope (AuxTel), which will be used for calibration purposes, are proceeding well, and AuxTel is being used to commission and exercise the entire data management system. In spring of 2024, DOE's completed camera will be shipped to Chile for installation and integration on the telescope. First light through the entire telescope and camera system is expected early in 2025. NSF- and DOE-supported activities remain tightly coordinated, both at the project level and among agency program officers.

Subsequent to the authorization in December 2021 of a project re-baseline due to COVID impacts, the project realized additional COVID-induced schedule delays when several international contractors were unable to send crews to Chile as planned. COVID impacts on the supply chain and global shipping times and costs also impacted the project cost and schedule. However, since these post-re-baseline possibilities were anticipated, their additional impacts were factored into the re-baselined TPC of $571.0 million. Any potential ongoing COVID-induced cost impacts will be reviewed, considered, and awarded as appropriate in FY 2024, and are expected to remain within the revised TPC.

Meeting Intellectual Community Needs

The Rubin Observatory site on Cerro Pachón, Chile, was selected 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 10-year Legacy Survey of Space and Time (LSST). Rubin Observatory will collect about 20 terabytes of multi-color imaging data every night[2] for 10 years, producing a long-lived data set of unprecedented utility. It will produce the widest-field sky images ever and issue alerts for changing and transient objects within 60 seconds of their discovery. Repeated deep imaging of the sky accessible from Cerro Pachón will

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

identify explosive events such as cataclysmic variable stars, supernovae, and the optical counterparts of X-ray flashes, and will find new moving objects and better characterize those already known. Estimates of Rubin Observatory's ability to locate Near Earth Objects (NEOs)[3] and Potentially Hazardous Asteroids (PHAs)[3] have been refined by the project staff[4] as well as by external studies, including an independent Jet Propulsion Laboratory study[5] supported by NASA's Planetary Defense Coordination Office. Assuming other existing NEO efforts continue, at the end of Rubin Observatory's 10-year initial survey the catalogue for objects larger than about 140 meters across should be about 75 percent complete for NEOs (about 80 percent for PHAs). Without Rubin Observatory, the completeness would be about 60 percent for NEOs (about 65 percent for PHAs).

While the facility is under construction, there are no science users. Once operating, the Rubin Observatory expects to create a science-ready database of enormous utility throughout astrophysics research and education. These 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 operations cost 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 astrophysics community and for educators and the public.

Governance Structure and Partnerships

NSF Governance Structure

NSF oversight is provided by a program officer in the MPS Division of Astronomical Sciences (AST) working cooperatively with other NSF staff through the Integrated Project Team, which has members from MPS, Office of International Science and Engineering, BFA, the Office of the General Counsel, and the Office of Legislative and Public Affairs. Within BFA, the Research Infrastructure 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 and commissioning of the camera.

External Governance Structure

The responsible awardee for Rubin Observatory construction is the Association of Universities for Research in Astronomy, Inc. (AURA), a non-profit science management corporation. The Rubin Observatory Project Office is an AURA-managed center for construction, and AURA established a separate management council that oversees it. The 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 Rubin Observatory pre-operations ramp-up activity that began in October 2018 and for coordinating construction activities and pre-operations activities that are executed side-by-side. Pre-operations activities are fully integrated into NOIRLab for which AURA

[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 0.05 au (roughly 7.5 million kilometers) 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

has a separate NOIRLab Management Oversight Council. The NOIRLab management team works with the Rubin Observatory Operations Director to oversee NOIRLab integration activities as Rubin Observatory prepares for operations.

Partnerships and Other Funding Sources

The Rubin Observatory Project is a partnership between NSF and the DOE Office of High Energy Physics, with NSF as the lead agency. Private funding totaling approximately $39 million was critical for reducing risk and beginning the fabrication of the novel primary telescope mirror prior to the initiation of the NSF and DOE construction projects. DOE is providing the world-leading 3.2-gigapixel digital camera and is contributing to design, development, installation, commissioning, operations, and scientific research support. Interagency coordination is accomplished through weekly meetings of the NSF-DOE Joint Oversight Group (JOG) and was formalized through a Memorandum of Understanding signed in July 2012. The JOG coordinates all aspects of activities during all phases of the project. The DOE-funded effort is managed by the SLAC National Accelerator Laboratory.

Cost and Schedule

NSF obligations for design and development are complete at $57.13 million; other contributions came from DOE ($26.0 million) and from private support (approximately $13 million).

In 2013, the FDR panel considered the proposed TPC of $473.0 million to be reasonable and recommended that the project improve its planning of potential descoping options. NSF carried out further cost review prior to making the Construction Stage award. The Project Team performed a Monte Carlo analysis on its resource-loaded integrated master schedule and determined the probability of completing the project within the proposed budget and by the planned survey start date of October 1, 2022, to be over 90 percent. The recent re-baseline confirmed earlier estimates that the COVID-19 pandemic will result in a delay of approximately 30 months in project completion with a cost increase of $98 million above the original TPC of $473.0 million. DOE's baseline cost for the camera was fixed at $168.0 million.[6] The total construction cost also included approximately $39 million from non-federal sources, all of which have been expended.

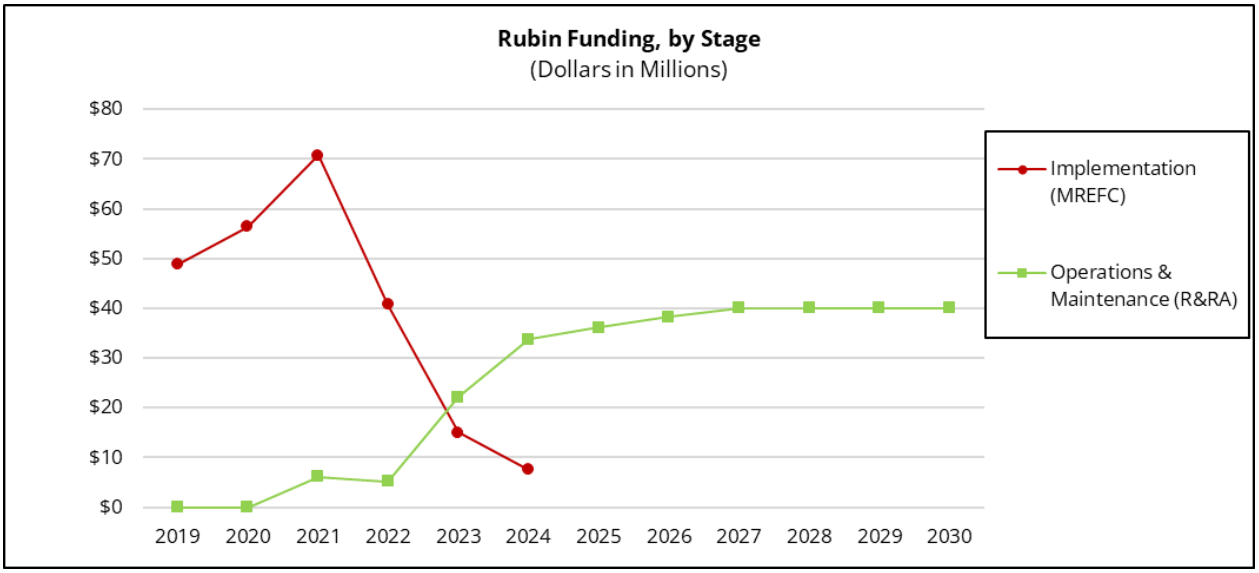
The final year of MREFC funding for Rubin Observatory presented in the FY 2024 Request will enable the construction project to account for the impacts of COVID-19 and continue progress to completion in 2025. Lingering impacts due to the pandemic may lead to revisions to schedule and cost, although no further impacts are currently foreseen.

[6] Any COVID-related changes in the DOE camera costs are outside the scope of the NSF Request.

Total Funding Requirements for Vera C. Rubin Observatory
(Dollars in Millions)

					ESTIMATES[1]				
	Prior Years	FY 2023	FY 2024 Request	FY 2025 Request	FY 2026	FY 2027	FY 2028	FY 2029	FY 2030
R&RA:									
Development & Design	$57.13	-	-	-	-	-	-	-	-
Operations & Maintenance		22.10	33.80	36.09	38.25	40.00	40.00	40.00	40.00
Subtotal, R&RA	$57.13	$22.10	$33.80	$36.09	$38.25	$40.00	$40.00	$40.00	$40.00
MREFC:									
Implementation	548.39	15.00	7.61	-	-	-	-	-	-
Subtotal, MREFC	$548.39	$15.00	$7.61	-	-	-	-	-	-
TOTAL REQUIREMENTS	**$605.52**	**$37.10**	**$41.41**	**$36.09**	**$38.25**	**$40.00**	**$40.00**	**$40.00**	**$40.00**

[1] Outyear funding estimates are for planning purposes only. The current cooperative agreement ends on September 30, 2027. These values represent NSF support only, and amount to about 50 percent of the total operations cost. DOE provides the balance of the funding required, while non-federal contributors will also provide some in-kind contributions.



Future Operations Costs

The total annual operations cost for Rubin Observatory is currently estimated to be about $72 million in the first year of full operations, and NSF and DOE are sharing equally in supporting observatory operations. The full operations cost estimates through FY 2027 were determined through a review, approval, and award process, which was completed in late FY 2022.

Initial pre-operations funding began with NSF providing $11.10 million in FY 2018 for the period FY 2019–FY 2021, with an additional $6.09 million awarded in FY 2021 to cover the COVID-19 delays through FY 2022. The balance of Rubin Observatory pre-operations and full operations support for the period FY 2023–FY 2027 is currently being funded as part of the NOIRLab-wide operations plan.

In FY 2019, NSF and DOE jointly established a new model for in-kind contributions from international participants. The shift from cash to in-kind contributions mitigates the risk of inadequate future funding for operations, at the cost of a larger commitment from the federal agencies. 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 with international participants.

Rubin Observatory is designed to have a 50-year lifetime, and it is likely that it will continue to make important scientific contributions after completion of its initial 10-year survey. The estimated disposition cost is $4.8 million (in current dollars).

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 Rubin Observatory Project Office during Design and Construction.

Management, Cost, and Schedule Reviews

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

- The seventh joint agency progress review occurred in October 2021 with a positive outcome. The review was comprehensive with particular focus on the work remaining, the readiness of the project team for the re-baselined activities, the ongoing COVID-19 response, definition of construction completeness criteria, and the planned transition to operations.
- In February 2022, NSF and DOE held a joint review of the project team's latest operations plan and the five-year proposal (through FY 2027) for pre-operations ramp-up activity and the beginning of survey operations activity. A panel of expert external reviewers commended Rubin Observatory's "strong leadership team" and found the project to be "well on track to be ready for operations in FY 2024."
- The eighth joint agency progress review occurred in September 2022 with a positive outcome. The review was again comprehensive, and it emphasized completion of the work remaining, refinement of the detailed schedule, definition of construction completeness criteria, and the transition to operations.
- A completeness review of the Education and Public Outreach (EPO) component of the construction project was conducted successfully in December 2022. A panel of external experts reviewed the deliverables of the EPO component and found that the activities have been completed according to the specified criteria, and within budget and schedule.
- From February 28 to March 3, 2023, NSF and DOE held a joint review of the project team's latest operations ramp-up activities and plan for survey operations. A panel of expert external reviewers noted Rubin Observatory's "remarkable progress in their organization and planning over the past year,"
- The ninth joint agency progress review of construction occurred from August 22–25, 2023. The review was comprehensive, and it emphasized completion of the work remaining, refinement of the detailed schedule, and the transition to operations. The review report confirmed the expectation of project completion within the NSB-authorized spending authority and provided constructive suggestions for the project team's consideration as it finishes the project.
- The next joint agency review of the project team's operations ramp-up activities and plan for survey operations is scheduled to take place April 2024.

Risks

Technical

Much of the technical risk was retired during development and design and, since full construction began, no new major technical risks have been identified. Realized risks have been mitigated by use of budget and schedule contingency or through re-planning by the Rubin Observatory Project Office. The Data Management (DM) effort was previously identified as a risk and subsequently re-planned following panel recommendations from a July 2017 DM review, including the use of contingencies. Careful planning to stage DM deliverables in coordination with the sequencing of commissioning activities will mitigate the remaining risks associated with DM. The overall commissioning plans have strategies to mitigate technical risks as the entire system is assembled and integrated over the final two years of construction.

Site

The possible site risk due to local geological anomalies was realized during excavation and successfully handled. Site disruptions from geologic events and extreme weather remain as possible risks with appropriate mitigation plans.

Environmental Health and Safety

The 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. In FY 2020, AURA initiated appropriate policies, procedures, and protocols to adapt to working safely in the global COVID-19 pandemic. Such policies are reviewed and adjusted as conditions in various locations evolve. Risks due to currently anticipated COVID-19 conditions are included in the project re-baseline, whereas risks due to unpredictable evolution of COVID-19 conditions are held by the federal agencies.

Partnership Risk

Significant attention has been paid to partnership risk, and that risk has been mitigated by careful coordination and unified project governance and management structures. The 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 and associated work packages daily. Remaining project risks can impact the cost and schedule of each phase of the project. Such risks may affect one or both partner agencies, and the Project Manager carefully manages, coordinates, and mitigates such risks accordingly. 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 Rubin Observatory construction, and the agencies' Program Officers, Grants and Agreements Officer, and AST financial managers.

System Integration Risk

Final delivery of the integrated project will include completion of the NSF construction scope (site, telescope, and data management system) and the DOE construction scope (the 3.2-gigapixel camera). Late delivery of any subsystem could delay project completion. The project management team

continually monitors the risk of late deliveries and plans mitigation strategies to reduce potential impacts on the overall project cost and schedule.

Credit: Rubin Obs/NSF/AURA/B. Stalder.