VERA C. RUBIN OBSERVATORY (RUBIN OBSERVATORY) $7,610,000

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] Estimate	FY 2024 Request[2]	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
Preliminary Estimate of Future COVID-19 Impact	-	-	-	-	35.39	15.00	7.61	58.00
American Rescue Plan	-	-	-	30.00	-	-	-	30.00
Estimate after Rebaseline	**$331.72**	**$48.82**	**$56.35**	**$70.75**	**$40.75**	**$15.00**	**$7.61**	**$571.00**

[1] In December 2021, based on the recent re-baseline of the Rubin construction project, NSB authorized a new Total Project Cost of $571.0 million.

[2] The FY 2023 appropriation, together with the FY 2024 Request, are based on the current best estimate of the total funding needed to address COVID-19 impacts. The COVID-19 situation continues to evolve, and ongoing schedule and cost impacts may lead to revisions of this funding plan.

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, FY 2024 represents the eleventh year of support for the construction project, originally planned to last 99 months. The original NSB-authorized Total Project Cost (TPC) was $473.0 million for NSF's contribution to Rubin Observatory, which is a joint project of NSF and DOE. Delays due to the COVID-19 pandemic have now shifted the expected project completion to late 2024. The FY 2024 NSF request for Rubin Observatory is $7.61 million. This request is based on the re-baselined plan to complete construction given the approximately 27-month-delay and the revised TPC of $571.0 million[1] approved by the NSB in December 2021. The impacts of COVID-19 are described in more detail in the Project Status section.

Future 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 the Gemini Observatory.

Baseline History

Rubin Observatory is a joint NSF and DOE project to build an instrument that was ranked as the top 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*.[2]

[1] NSF intends to draw upon multiple funding sources to cover the additional costs. NSF reprogrammed $10.0 million from FY 2020 funds within the MREFC account, originally intended for the Antarctic Infrastructure Modernization for Science project which did not need all its appropriated funds in FY 2020 because of the COVID-19 pandemic. In FY 2021, NSF allocated an additional $30.0 million from the American Rescue Plan appropriation to cover pandemic-related costs; these funds were carried over and used in FY 2022. The remaining funds needed to complete the Rubin construction project are requested in the FY 2023 and FY 2024 appropriations.

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

Prior to NSF's construction award, NSF, DOE, and private partners invested over $130.0 million in Rubin Observatory-related work, of which about 70 percent supported design and development. About 30 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 M1M3 mirror and cell are completed and have been safely transported to the summit of Cerro Pachón. 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 has been executing 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 caused significant additional delays later in FY 2021, the telescope mount's major structure is now complete. Dome installation is nearly complete, despite the earlier delays caused by weather and realization of other known risks. Commissioning activities for the Auxiliary Telescope, which will be used for calibration purposes, are proceeding well. In 2023, DOE's completed camera will be shipped to Chile for installation and integration on the telescope. NSF- and DOE-supported activities remain tightly coordinated, both at the project level and among agency program officers.

Summary of COVID-19 Impacts

- In March 2020, the project suspended all construction activity on the summit while most work on data management was able to continue through telework. Other remote activities have prioritized tasks that will help recover schedule as on-site work resumes.
- Summit construction activity began a slow ramp-up on September 28, 2020. Fortunately, no significant damage resulted from site exposure to the elements during Chilean winter storms, while summit construction was paused. Key contractors gradually returned to the summit over several months. The dome is now substantially closed. In January 2021, work on the TMA, which is on the critical path, resumed successfully, and March 2, 2021 marked the spectacular installation of the TMA's top-end assembly.
- In FY 2020, NSF authorized $10.0 million in NSF-held management reserve for any urgently required expenses necessitated by COVID-19, such as ramping down and ramping up activity on the summit, protecting exposed equipment from the elements, mitigating potential damage to sensitive equipment during the Chilean winter, and direct expenses for new procedures and protocols required for COVID-19.
- TMA work paused again for five months while some subcontractors awaited the cancellation of Chilean COVID-19 quarantines that prevented their return to the summit. The current schedule remains tentative and is subject to potential additional delays as the global pandemic continues.
- In FY 2021, the NSB authorized $12.0 million in NSF-held management reserve to sustain the

project while the re-baseline review was conducted. The amount was based on an NSF analysis of anticipated construction costs related to COVID delays and availability of authorized management reserve.

- In December 2021, the NSB authorized a new TPC of $571.0 million, based on the re-baselined plan for the construction project, including an additional $98.0 million for realized and potential impacts caused by the COVID-19 pandemic and new data security requirements identified since project initiation. The estimated cost took into account a projected 22-month schedule delay and estimated remaining uncertainty in COVID-19-induced schedule delay (currently an additional 5 months). This action also moves the anticipated final year of MREFC funding to FY 2024.
- NSF's re-baseline process is expected to be completed in FY 2023.

Meeting Intellectual Community Needs

The site on Cerro Pachón, Chile, was selected for 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 Rubin Observatory's 10-year survey. Rubin Observatory will collect about 20 terabytes of multi-color imaging data every night[3] 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 the sky accessible from Cerro Pachón will 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)[4] and Potentially Hazardous Asteroids (PHAs)[4] have been refined by the Rubin Observatory project members,[5] as well as by external studies, including an independent Jet Propulsion Laboratory study[6] 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. However, the Rubin Observatory project expects to create a science-ready database of enormous utility throughout astrophysics research and education. 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 astrophysics community as for educators and the public.

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

[4] 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.

[5] www.doi.org/10.1016/j.icarus.2017.11.033

[6] www.arxiv.org/abs/1705.06209

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, 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 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 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 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 (D&D) are complete at $57.13 million; other contributions to D&D 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. As described more fully above, it is expected that the COVID-19 pandemic will impose a delay of approximately 27 months in project completion with a cost increase that is currently estimated to be approximately $98 million above the original TPC of $473.0 million. DOE's baseline cost for the camera was fixed at $168.0 million.[7] The total construction cost also included approximately $39 million from non-federal sources, all of which have been expended.

The FY 2024 NSF Request level for Rubin Observatory will enable the construction project to account for the impacts of COVID-19 and continue progress to completion in 2024. It is based on the re-baselined plan, incorporating the funding needed to address the delays due to COVID-19. The COVID-19 situation continues to evolve, and ongoing schedule and cost impacts may lead to revisions.

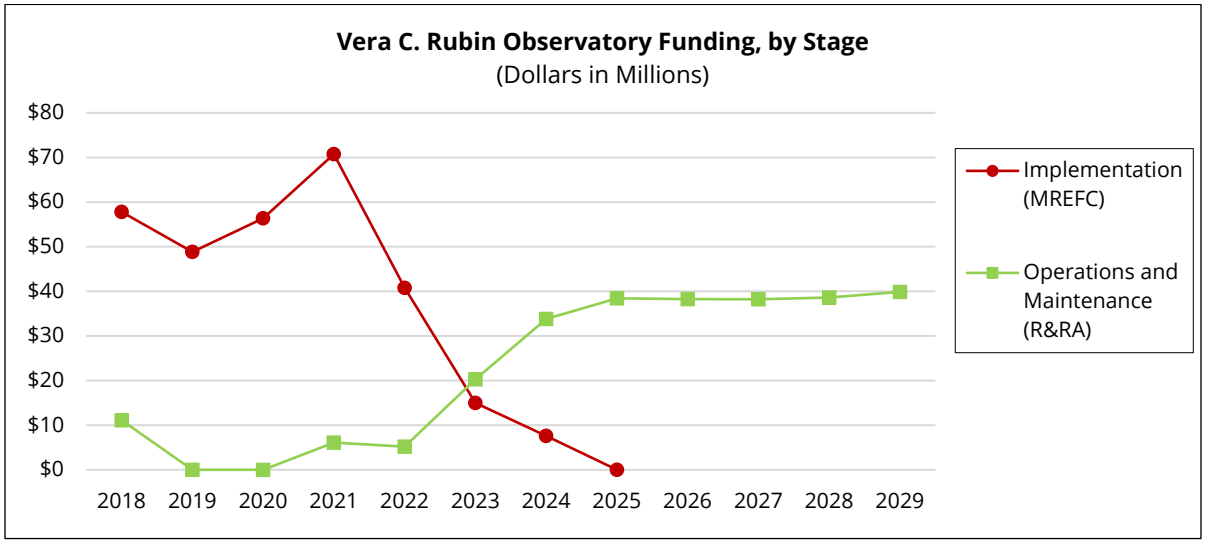
Total Funding Requirements for Vera C. Rubin Observatory

(Dollars in Millions)

	Prior Years	FY 2022 Actual	FY 2023 Estimate	FY 2024 Request	ESTIMATES[1] FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
R&RA:									
Development & Design	$57.13	-	-	-	-	-	-	-	-
Operations & Maintenance		5.20	22.10	33.80	38.45	38.25	38.22	38.63	39.88
Subtotal, R&RA	$57.13	$5.20	$22.10	$33.80	$38.45	$38.25	$38.22	$38.63	$39.88
MREFC:									
Implementation[2]	507.64	40.75	15.00	7.61	-	-	-	-	-
Subtotal, MREFC	$507.64	$40.75	$15.00	$7.61	-	-	-	-	-
TOTAL REQUIREMENTS	**$564.77**	**$45.95**	**$37.10**	**$41.41**	**$38.45**	**$38.25**	**$38.22**	**$38.63**	**$39.88**

[1] Outyear funding estimates are for planning purposes only. A new cooperative support agreement for O&M is anticipated in FY 2023. 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.

[2] Prior Years implementation includes $30.0 million of ARP funding provided to Rubin in FY 2021 that was carried forward into FY 2022.



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

Future Operations Costs

The total annual operations cost for Rubin Observatory is currently estimated to be about $72.0 million in the first full year of operations (FY 2025), and NSF and DOE are partnering on 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 funding 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 contributions mitigates the risk of future funding for operations being inadequate, 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.

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.

- A joint agency-led review of the project re-baseline request was held June 15-17, 2021. The review looked at the Project's performance to date and the execution plan, including technical scope, cost, schedule, and the safety and risk management plans. The reviewers endorsed the re-baseline request and recommended revisions to document costs in greater detail and to update the request following a more certain restart of TMA work on the summit.
- An EVMS surveillance review of the re-baseline request coincided with the re-baseline review and focused on the impacts of the COVID-19 pandemic. The review team identified several items to improve in the re-baseline request to assure confidence in the revised TPC.
- The seventh joint agency progress review occurred in October 2021 with a positive outcome. The review was comprehensive but with particular focus on the work remaining, the readiness of the project team for the re-baselined activities, the on-going 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 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.

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 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 commissioning sequencing will mitigate the remaining risks associated with DM. Commissioning plans overall have strategies to mitigate technical risks as the entire system is assembled and integrated over the final two years.

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: Y. AlSayyad/Rubin Obs./NSF/AURA.