VERA C. RUBIN OBSERVATORY (RUBIN OBSERVATORY) $40,750,000

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

	Prior Years	FY 2018	FY 2019	FY 2020	FY 2021 Estimate	FY 2022 Request	FY 2023 Estimate	Total Project Cost
Previous Authorized Total Project Cost	$273.92	$57.80	$48.82	$46.35	$40.75	$5.36	-	$473.00
Increase in Authorized Total Project Cost (COVID-19)	-	-	-	10.00	-	-	-	10.00
Preliminary Estimate of Future COVID-19 Impact	-	-	-	-	-	35.39	15.00	50.39
Estimate prior to Rebaseline	**$273.92**	**$57.80**	**$48.82**	**$56.35**	**$40.75**	**$40.75**	**$15.00**	**$533.39**

Brief Description

The FY 2022 NSF Request for Vera C. Rubin Observatory is $40.75 million. Begun in August 2014, FY 2022 represents the ninth year of support for a construction project originally planned for nine years. 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 the Department of Energy (DOE). To meet unforeseen COVID-19 related expenses, the NSF Acting Director increased the award authorization by $10.0 million (up to $483.0 million) in FY 2020 to provide an NSF-held management reserve for the near-term impacts on the construction project.[1] In FY 2020, NSF shifted the final year of construction out by one year due to COVID-19. The FY 2022 Request is the best current estimate of the project need in FY 2022 given the anticipated approximately 16-month-delay and the authorization of management reserve in FY 2020; it is based on a preliminary estimate of overall project need increasing to $533.39 million. The project is currently being re-baselined to account for the impacts of COVID-19, and NSF anticipates presenting the NSB with a recommendation for authorization of a new TPC by the end of CY 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. See the NOIRLab narrative in the Facilities Section for further details.

Scientific Purpose

Vera C. Rubin Observatory will comprise an 8.4-meter wide-field optical telescope located in Chile, a 3.2-gigapixel camera supplied by 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. Rubin Observatory's initial 10-year survey has a cadence that will enable repeat observation of each survey field approximately twice weekly. The requirements for 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.

[1] The $10.0 million in management reserve was reprogrammed from FY 2020 funds within the MREFC account, originally intended for the Antarctic Infrastructure Modernization for Science project; that project did not need all its appropriated funds in FY 2020 because of the COVID-19 pandemic.

By satisfying the requirements defined by these key investigations, Rubin Observatory's initial Legacy Survey of Space and Time (LSST) will result in a comprehensive data set that will enable a broad range of fundamental astrophysical studies by the entire research community on these and other topics. Thus, 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

Rubin Observatory is a joint NSF and 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*.[2]

Prior to NSF's construction award, NSF, DOE, and private (non-federal) partners invested over $130.0 million in Rubin Observatory-related work. About 70 percent supported design and development. 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, 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 approval process and making an award in the last quarter of FY 2014.

Project Status

NSF's construction award was issued in August 2014. As of January 2021, the project's NSF-funded scope is 87 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 moved into the completed base facility. Dome installation was progressing well prior to the onset of the COVID-19 pandemic, despite significant delays caused by weather and realization of other known risks. The project had been executing activities to minimize the impact of delays on the integrated project schedule. Installation of the telescope mount assembly (TMA) on the summit had also been progressing well prior to the impacts of the COVID-19 pandemic on construction. The Auxiliary Telescope, which will be used for calibration purposes, had also seen excellent progress with its commissioning activities. NSF- and DOE-supported activities remain tightly coordinated, both at the project level and among agency program officers.

<u>Summary of COVID-19 Impacts</u>

- 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 the recent 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 MA work will soon pause

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

again for two months while some subcontractors wait for the cancellation of Chilean COVID-19 quarantines, which currently prevent their return to the summit. The current schedule remains tentative and is subject to potential additional delays as the global pandemic continues.

- 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, potential damage to sensitive equipment during the Chilean winter, and direct expenses for new procedures and protocols required for COVID-19.
- Current projections for a potential re-baselining of the construction project include an additional ~$50 million for other potential impacts caused by the COVID-19 pandemic and are based on the estimated cost of a projected 16-month schedule delay. This would also move the final year of MREFC funding to FY 2023. A rigorous re-baseline, including a joint agency-led review by a panel of external experts, of the Rubin Observatory Construction Project is expected in FY 2021, now that site construction has resumed. The re-baseline process will result in a revised estimate of the TPC.

Meeting Intellectual Community Needs

While the COVID-19 pandemic forced a suspension of summit construction activity of Vera C. Rubin Observatory, the project maintained regular inspections of the site. This photo was taken during the inspection conducted on June 9, 2020. *Credit: Rubin Observatory/AURA/NSF.*

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 ten-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, as well as find new moving objects and better characterize those already known. Estimates of Rubin Observatory's ability to locate NEOs[4] and Potentially Hazardous Asteroids (PHAs)[4] have been refined by Rubin 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).

[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 a distance of 0.05 au (roughly 4,650,000 miles) 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

While the facility is under construction, there are currently no science users. However, the Rubin Observatory project expects to create a science-ready database of enormous utility throughout astronomy 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 astronomy community as well as 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 having members from MPS, OISE, Office of Budget, Finance and Award Management (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.

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 this Project Office. 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 is responsible for coordinating construction activities and pre-operations activities that are executed side-by-side. Pre-operations activity is fully integrated into NOIRLab for which AURA has a separate NOIRLab Management Oversight Council. The NOIRLab Directorate 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 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, non-federal support ($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 16 months in project completion with a cost increase above the original $473.0 million that is currently estimated to be approximately $60 million. DOE's baseline cost for the camera was fixed at $168.0 million.[7] The total construction also included approximately $39 million from non-federal sources, all of which have been expended.

The FY 2022 NSF Request level for Rubin Observatory will enable the construction project to account for the impacts of COVID-19 and continue progress throughout FY 2022. The FY 2023 level is based on the current best estimate of the total funding needed to address the delays due to COVID-19 and is expected to be updated and fully described as part of the FY 2023 Congressional Request.

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

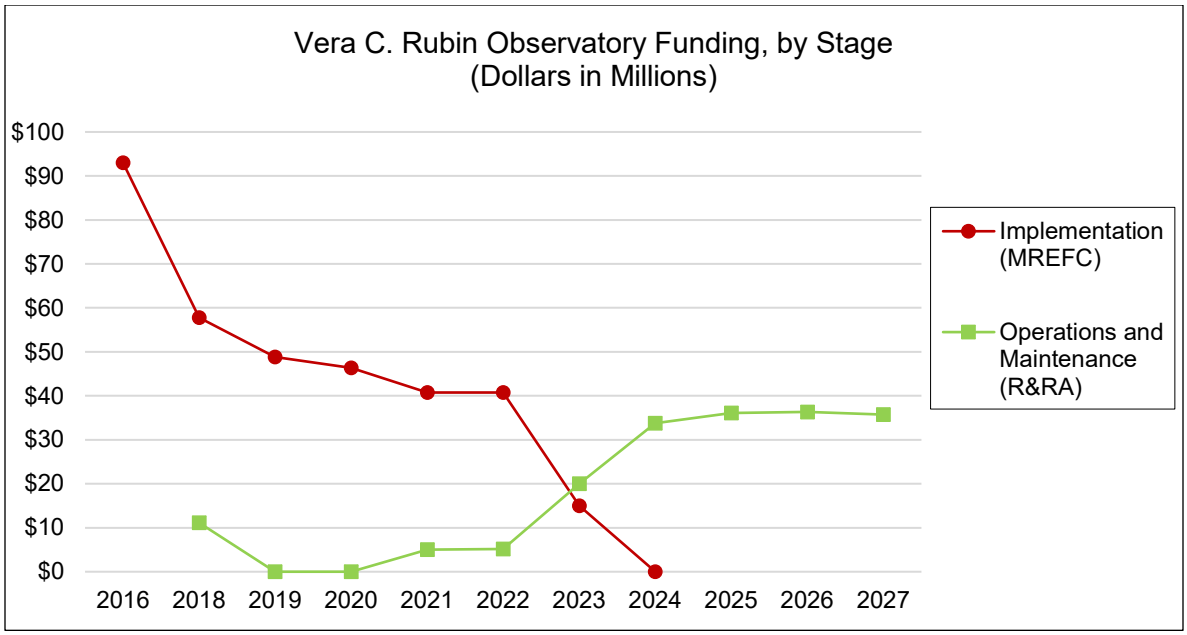
					ESTIMATES[1]				
	Cumulative Prior Years	FY 2020 Actual	FY 2021 Estimate	FY 2022 Request	FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
R&RA:									
Development & Design	$57.13	-	-	-	-	-	-	-	-
Operations & Maintenance[2]		0.01	5.00	5.20	19.98	33.80	36.09	36.34	35.71
Subtotal, R&RA	$57.13	$0.01	$5.00	$5.20	$19.98	$33.80	$36.09	$36.34	$35.71
MREFC:									
Implementation[3]	$380.55	$56.34	$40.75	$40.75	$15.00	-	-	-	-
Subtotal, MREFC	$380.55	$56.34	$40.75	$40.75	$15.00	-	-	-	-
TOTAL REQUIREMENTS	**$437.68**	**$56.35**	**$45.75**	**$45.95**	**$34.98**	**$33.80**	**$36.09**	**$36.34**	**$35.71**

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

[2] This represents NSF support only and amounts to about 50 percent of the total operations cost. DOE and non-federal contributors provide the balance.

[3] Includes $10.0 million carried forward into FY 2021.

[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 $70 million in the first full year of operations (FY 2025). NSF and DOE are partnering on observatory operations. The final full operations costs will be determined through a review, approval, and award process.

Initial, pre-operations funding began with NSF providing $11.10 million in FY 2018 for the period FY 2019–FY 2021, with an additional $5.0 million requested in FY 2021. An additional $5.20 million is requested in FY 2022 to extend the pre-operations ramp-up activity period necessitated by COVID-19 delays to the construction project. A proposal to fund the balance of Rubin pre-operations and full operations funding for the period FY 2023–FY 2027 is expected from AURA as part of a NOIRLab-wide operations proposal in FY 2022 (see NOIRLab narrative).

In FY 2019, NSF and DOE jointly established a new model for in-kind contributions from international participants. 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.

- In April 2020, NSF and DOE held a joint review of the project's latest pre-operations progress and operations planning for the full ten-year survey, including the remaining years of pre-operations ramp-up activity and two years of post-survey activity. A panel of expert external reviewers concluded that

"the operations team has a strong, appropriate plan for its current phase, and is well on the way to full development of the operations plan." NSF and DOE will continue funding pre-operations ramp-up activity, which began in FY 2019.

- The sixth joint agency progress review occurred in August 2020 with a positive outcome. A significant portion of the review focused on the cost and schedule status immediately prior to the COVID-19 pandemic shutdown of construction activity on the summit, and the review panel judged the project to be on track to finish on time and on budget prior to the shutdown. The balance of the review focused on COVID-19 safety; replanning of the remaining assembly, integration, and commissioning activities; risk management; and technical status.
- An Earned Value Management System (EVMS) surveillance review coincided with the 2020 annual progress review and was used to evaluate the project's alignment with GAO good practices on schedule. This review determined that the Rubin Observatory EVMS continues to meet NSF requirements for EVMS, and there were no required corrective actions.
- A joint agency-led review of the project re-baseline is expected in FY 2021.

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 the 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 next two years.

Site

The possible site risk due to local geological anomalies was realized during excavation and successfully handled. Site disruptions from geological 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. In FY 2020, AURA initiated appropriate safety policies, procedures, and protocols to adapt to working safely in the global COVID-19 pandemic. Such policies are reviewed and adjusted appropriately as conditions in various locations evolve. External reviews have given the project high marks for its safety culture.

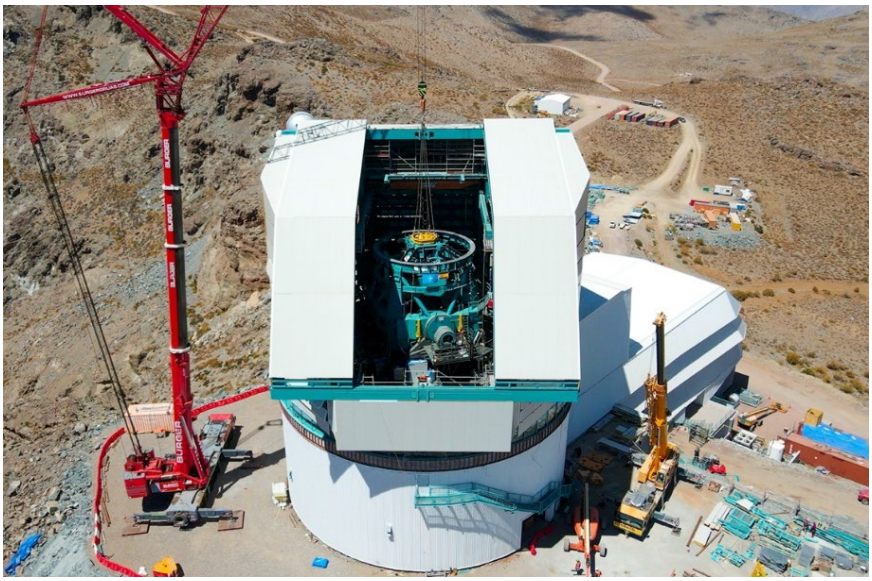
Partnership Risk

Significant attention has been paid to partnership risk, and that risk has been mitigated by careful coordination and unified project 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 on a daily basis. 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 delivery of the NSF construction scope (site, telescope and data management system) and the DOE construction scope (3.2-gigapixel camera). Late delivery of any subsystem could delay project completion. The project management team continually monitors risk of late deliveries and plans mitigation strategies to reduce potential impacts on the overall project cost and schedule.



The Top-End Assembly for the Telescope Mount Assembly (TMA) was lifted by crane into the observatory dome and installed on the TMA on March 2, 2021. The task was completed successfully and was a highly celebrated milestone for Rubin Observatory. *Credit: Rubin Observatory/AURA/NSF.*