DANIEL K. INOUYE SOLAR TELESCOPE (DKIST) $0

Appropriated and Requested MREFC Funds for the Daniel K. Inouye Solar Telescope
(Dollars in Millions)

	Prior Years[1]	FY 2018	FY 2019	FY 2020 Actual	FY 2021 Estimate	FY 2022 Request	Total Project Cost
Previous Authorized Total Project Cost	$308.00	$20.00	$16.13	-	-	-	$344.13
Increase in Authorized Total Project Cost (COVID-19)	-	-	-	9.40	9.50	-	18.90
Current Authorized Total Project Cost	**$308.00**	**$20.00**	**$16.13**	**$9.40**	**$9.50**	**-**	**$363.03**

[1]Includes $146.0 million of ARRA funding.

Brief Description

No funding is requested in FY 2022 for construction of DKIST. The planned 11-year MREFC funding profile for DKIST construction represented an NSB-authorized Total Project Cost (TPC) of $344.13 million, with FY 2019 as the final year of funding. The award authorization was then increased by $9.40 million (to $353.53 million) in FY 2020, and again by $9.50 million (to $363.03 million) in FY 2021 to allow for NSF-held management reserve for the construction project. This reserve is being awarded to the project in accordance with NSF procedures only as specific costs related to the impacts of COVID-19 are realized. Completion of construction atop Haleakalā on Maui, Hawai'i, originally scheduled before the end of FY 2020, is delayed by the impacts of COVID-19 into the fall of 2021. See the Project Status section for further details on COVID-19 impacts.

DKIST is a four-meter solar telescope designed to enable observations and ongoing measurements of solar magnetic fields. The four-meter mirror (the largest of any solar telescope in the world) is accompanied by a cutting-edge instrument suite for both imaging and spectropolarimetry.

When completed, DKIST will be the world's most powerful solar observatory, poised to answer fundamental questions in solar physics by providing transformative improvements over current ground-based facilities. The relevance of DKIST's science drivers was reaffirmed by the National Academies of Sciences, Engineering, and Medicine 2010 Astronomy and Astrophysics decadal survey: *New Worlds, New Horizons in Astronomy and Astrophysics*[1] as well as the 2012 Solar and Space Physics decadal survey: *Solar and Space Physics: A Science for a Technological Society*.[2] DKIST will play an important role in enhancing the "fundamental understanding of space weather and its drivers," an objective called out in the National Space Weather Strategy[3] and associated National Space Weather Action Plan,[4] both of which were released by the National Science and Technology Council in October 2015. An update to the National Space Weather Strategy has been developed through the Space Weather Operations, Research, and Mitigation Working Group of the National Science and Technology Council and was informed by community input. This update, entitled *National Space Weather Strategy and Action Plan,* was released in March 2019.[5]

Scientific Purpose

DKIST will enable the study of magnetohydrodynamic phenomena in the solar photosphere, chromosphere, and corona at unprecedented spatial, temporal, and wavelength resolution to gain information on the creation, interaction, and ultimate annihilation of solar magnetic fields. Determining the role of magnetic

[1] www.nap.edu/catalog/12951/new-worlds-new-horizons-in-astronomy-and-astrophysics
[2] www.nap.edu/catalog/13060/solar-and-space-physics-a-science-for-a-technological-society
[3] www.obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/final_nationalspaceweatherstrategy_20151028.pdf
[4] www.obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/final_nationalspaceweatheractionplan_20151028.pdf
[5] www.trumpwhitehouse.archives.gov/wp-content/uploads/2019/03/National-Space-Weather-Strategy-and-Action-Plan-2019.pdf

fields in the outer regions of the Sun is crucial to understanding the solar dynamo, solar variability, and solar activity. Solar activity drives the constant solar wind, as well as eruption events such as flares and coronal mass ejections. These phenomena, collectively known as "space weather," can affect civil life on Earth and may impact the terrestrial climate.

Baseline History

Beginning in 2001, NSF provided funds to the National Solar Observatory (NSO) for an eight-year development and design program for DKIST and its initial complement of instruments through the Division of Astronomical Sciences (AST) in MPS and through the Division of Atmospheric and Geospace Sciences (AGS) in GEO. The current design, cost, schedule, and risk were scrutinized in an NSF-conducted Preliminary Design Review held in October-November 2006.

The original total project cost to NSF, $297.93 million, was set after a Final Design Review (FDR) in May 2009, which determined that the project was fully prepared to begin construction. The NSB authorized an award for this amount, to be made at the NSF Director's discretion, contingent upon completion of compliance with relevant environmental and cultural/historic statutes. In FY 2009, $153.0 million was appropriated to initiate construction. Funding was provided through a combination of the regular MREFC account appropriation ($7.0 million) and the American Recovery and Reinvestment Act ($146.0 million). Given the timing of the receipt of budget authority and the complexity of project contracting, the entire $153.0 million was carried over from FY 2009 and obligated in FY 2010.

The environmental compliance requirements were completed on November 20, 2009, and the NSF Director signed the Record of Decision authorizing construction in December 2009. The Hawai'i Board of Land and Natural Resources (BLNR) approved the project's application for a Conservation District Use Permit (CDUP) in December 2010. A contested case challenge to the 2010 CDUP issuance delayed site construction until the BLNR ruled in favor of the DKIST project and issued a new CDUP in November 2012. Full access to the site atop Haleakalā followed shortly thereafter. A ground-breaking ceremony kicking off site construction was held on December 1, 2012.

The unexpected length of the delay associated with the environmental compliance process led to a reassessment of the project schedule and total project cost in 2012. An external panel of experts reviewed the revised baseline and recommended increasing the total project cost by approximately $46.20 million. The NSB subsequently considered and authorized a revised total project cost of $344.13 million at its August 2013 meeting.

Project Status

The DKIST project continues to make progress on construction at the summit of Haleakalā on Maui, HI, while remaining in compliance with all local, state, and federal environmental and cultural requirements and dealing with the COVID-19 pandemic. The project management team continues to consult with various stakeholders on a regular basis including the Hawai'i Department of Land and Natural Resources, the Hawai'i Department of Fish and Wildlife, the U.S. Fish and Wildlife Service, the Federal Aviation Administration, the National Park Service, and Native Hawaiian cultural practitioners.

<u>Construction Highlights</u>

- In early FY 2020, the Wave Front Correction (WFC) system was installed and tested on the summit of Haleakalā. The WFC is the heart of the DKIST adaptive optics system that corrects for distortions due to the Earth's atmosphere.
- In FY 2020, the project achieved another Level 1 milestone, first light from the Sun through the entire optical path including the WFC. As part of this first-light initiative, the Visible Broadband Imager

(VBI) instrument recorded the highest resolution images of the Sun ever made.

- In FY 2021, the project completed a periodic recoating of the primary (M1) mirror at the U.S. Air Force's Mirror Coating Facility on the summit of Haleakalā. The M1 was transported back to the DKIST support and operations building where it was reinstalled in the mirror cell assembly and successfully mounted back on the telescope.
- In FY 2021, progress was made on the Cryogenic Near Infrared Spectropolarimeter (Cryo-NIRSP) and Diffraction Limited Near Infrared Spectropolarimeter (DL-NIRSP) instruments despite the pandemic. Components of both instruments were transported to the summit, assembled, installed, and aligned within the DKIST coudé lab in preparation for integration, testing and commissioning.

In February 2020, the DKIST project undertook a re-planning exercise and reconciliation of the work completed through January 2020. As a result, the project management team determined that construction would be ~98 percent complete as of June 30, 2020, the scheduled date for the last major construction milestone (Start of Operations). The delays involved were the result of a variety of factors, including extreme weather events in early 2020 at the construction site, identified operational safety hazards that required mitigations prior to the start of operations, and re-aluminization of the primary mirror necessary to meet coronal scientific performance requirements. In accordance with NSF's Major Facilities Guide, the project management team submitted a request to NSF for a No-Cost Extension (NCE) to move the Start of Operations to September 30, 2020 allowing the completion of site construction activities. In addition, the project management team requested that the project award completion date be amended to December 31, 2020 to allow for the completion of all post-construction closeout activities. At this time, the project requested no new funding and no changes to the Total Project Cost (TPC) of $344.13 million at that time. This NCE was reviewed and approved by NSF. The extension was completely unrelated to any impacts involving the suspension of construction activities due to COVID-19.

Summary of COVID-19 Impacts

In response to the COVID-19 pandemic and social distancing restrictions imposed by the State of Hawai'i, the DKIST project management team, in consultation with NSO management, began restricting travel in early March 2020, and completely halted site construction on March 17, 2020. This cessation of work put the facility construction and instrument commissioning teams on standby, resulting in an increase in the cost of construction. Since this cost increase was caused by the realization of an unforeseen event beyond the control of the project, it was not an appropriate use of budget contingency and not subject to NSF's No Cost Overrun Policy. On June 22, 2020, the Acting NSF Director authorized an increase of $9.40 million to the DKIST construction award, to be allocated as management reserve for the project.[6]

On June 4, 2020, the DKIST project entered a very limited (Phase 1) restart of site construction activities which entailed two non-overlapping shifts of approximately 20 percent of the construction workforce on site, with the use of personal protective equipment (PPE) and social distancing strictly enforced. In early August 2020, the project entered a modified Phase 1 that allows for two overlapping shifts of approximately 35 personnel per shift. The project management team undertook a re-planning exercise to estimate the impacts of COVID-19 on the remaining scope, cost, and schedule. They submitted a request to NSF for supplemental funding to be drawn from the previously authorized management reserve as needed, in accordance with internal NSF procedures. Following NSF's review and approval of the request, funds were awarded in December 2020 and March 2021, exhausting the initial management reserve.

Continued pandemic impacts were sustained into 2021, further delaying the remaining construction work due to ongoing travel restrictions, labor inefficiencies, and other COVID-related constraints. These constraints have led to further delays in the integration, testing, and commissioning of several key

[6] This initial $9.40 million management reserve was funded by reprogramming FY 2020 appropriated MREFC funds not required for the Antarctic Infrastructure Modernization for Science project.

instruments and supporting systems. A second re-planning exercise by the project, completed in early 2021, identified delays until November/December 2021, leading to additional estimated costs of $9.50 million to complete the project. The NSB authorized $9.50 million in additional NSF-held management reserve in February 2021—for a total of $18.90 million in management reserve and a total award authorization of $363.03 million—along with authorizing a delay in the Start of Operations milestone to the end of CY 2021.

Meeting Intellectual Community Needs

DKIST is under construction so it currently has no scientific users. At the start of operations in 2021, NSO will execute a 12-month DKIST operations commissioning phase (OCP) during which the DKIST staff will begin to execute the DKIST Critical Science Plan (CSP). The CSP has been under development for several years by NSO scientific staff in consultation with the community based DKIST science working group (SWG). On May 14, 2020, NSO issued the first call for DKIST Cycle 1 OCP proposals, which were due August 14, 2020. These proposals have been reviewed for both technical feasibility and scientific merit and prioritized by the external Time Allocation Committee. The original plan was for Cycle 1 observations to begin Fall of 2020; however, this has been delayed due to the impacts of COVID-19, thus the currently accepted projects will be held until the start of operations.

Governance Structure and Partnerships

NSF Governance Structure

NSF oversight is provided by a program officer in AST working cooperatively with staff from MPS, the Office of Budget, Finance, and Award Management (BFA), and the Office of the General Counsel. Within BFA, the Large Facilities Office provides advice to program staff and assists with agency oversight and assurance. Representatives from the above NSF offices comprise the DKIST Integrated Project Team, which meets on a quarterly basis to discuss outstanding project issues. The MPS Facilities Team and NSF's Chief Officer for Research Facilities also provide high-level guidance and oversight support for the project.

External Governance Structure

The National Solar Observatory (NSO) is responsible for managing the construction project. NSF funds NSO operations and DKIST construction via separate cooperative support agreements (CSAs) beneath an overarching cooperative agreement (CA) with the managing organization, the Association of Universities for Research in Astronomy, Inc. (AURA). The current NSO CA covers the DKIST Construction Stage and the achievement of sustainable operations of the completed facility. The NSO associate director for DKIST is a senior NSO scientist who was a leader in the development of the science case and an expert in the field of solar adaptive optics, a critical technology for DKIST. The project manager has extensive experience in large telescope development and implementation, having served as lead telescope engineer for the International Gemini Observatory. Several councils and working groups give input from the solar and space physics communities.

Partnerships and Other Funding Sources

The DKIST project is a collaboration of scientists and engineers at more than 20 U.S. and international organizations. Other partners include the U.S. Air Force Office of Scientific Research (AFOSR) and groups in Germany, the United Kingdom, and Italy. Some partnership activities include:

- The U.S. Air Force (USAF) replaced the aluminizing chamber at their Advanced Electro-Optical System telescope on Maui and sized it to accommodate the DKIST primary mirror. An Interagency Agreement for use of the Mirror Coating Facility (MCF) was signed by NSF and USAF in FY 2017. This eliminates the need to build a dedicated aluminizing chamber for DKIST.
- Leibniz-Institut für Sonnenphysik (KIS; Freiburg, Germany) is constructing a narrow-band instrument named the Visible Tunable Filter (VTF) as an in-kind contribution.

- Queens University Belfast (Northern Ireland) is leading a consortium of institutions from the United Kingdom that will supply high-speed visible cameras to feed the DKIST instruments.

Discussions of other possible contributions for second-generation instruments, algorithm development, coordinated observations, and student exchange are ongoing.

Cost and Schedule

The original risk adjusted TPC was established following the Final Design Review. A revised project baseline review was held in October 2012, and NSB authorized a new baseline in August 2013. Funding is derived from American Recovery and Reinvestment Act (ARRA) appropriations ($146.0 million) and regular appropriations from the MREFC account ($198.13 million). A Monte Carlo analysis of the risk-adjusted project end date at the time of the project re-baseline indicated an 80 percent confidence level for successful completion by the end of June 2020. The project was on track for a FY 2020 end date within the authorized funding level of $344.13 million. However, the construction end date has now shifted into 2021 and may require up to $18.90 million in management reserve due to the impacts of COVID-19, increasing the authorized Total Project Cost to $363.03 million.

Total Funding Requirements for DKIST

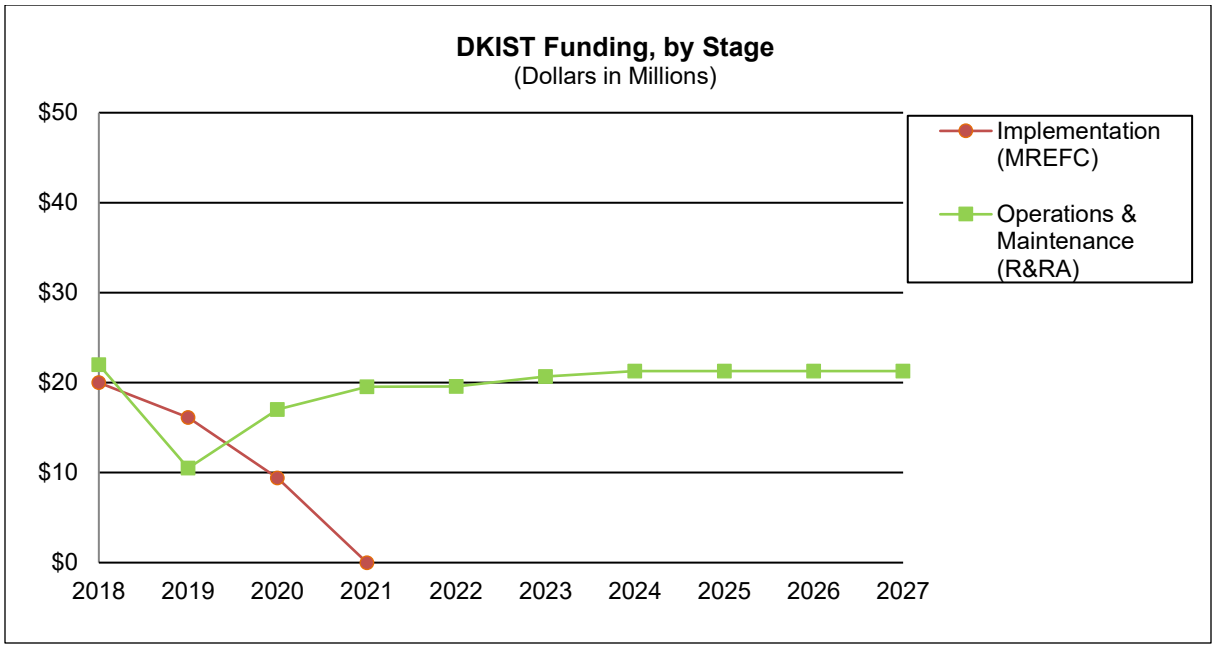
(Dollars in Millions)

	Prior Years	FY 2020 Actual	FY 2021 Estimate	FY 2022 Request	ESTIMATES[1] FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
R&RA:									
Development & Design	$20.41	-	-	-	-	-	-	-	-
Operations & Maintenance[2]		17.01	19.54	19.58	20.68	21.30	21.30	21.30	21.30
ARRA	3.10	-	-	-	-	-	-	-	-
Subtotal, R&RA	$23.51	$17.01	$19.54	$19.58	$20.68	$21.30	$21.30	$21.30	$21.30
MREFC:									
Implementation[3]	$198.13	$9.40	$9.50	-	-	-	-	-	-
ARRA	146.00	-	-	-	-	-	-	-	-
Subtotal, MREFC	$344.13	$9.40	$9.50	-	-	-	-	-	-
TOTAL REQUIREMENTS	**$367.64**	**$26.41**	**$29.04**	**$19.58**	**$20.68**	**$21.30**	**$21.30**	**$21.30**	**$21.30**

[1] Outyear funding estimates for O&M are for planning purposes only. The current cooperative agreement ends September 2024.

[2] The FY 2021 Estimate includes $2.0 million to another awardee for cultural mitigation activities as agreed to during the compliance process.

[3] Includes $9.40 million carried forward into FY 2021.



Future Operations Costs

DKIST operations are funded through R&RA. The projected outyear funding profile for operations has increased from prior estimates based on the results of a comprehensive external mid-term review of the NSO Long-Range Plan for 2020-2024, which were presented to the NSB in February 2020. The anticipated lifetime of the facility is at least two Hale Cycles (i.e., two 22-year solar cycles) and will not exceed fifty years, after which the facility is scheduled to be decommissioned.

Reviews

- Management, Cost, and Schedule reviews: DKIST scope, schedule, budget estimate, and risk-adjusted total project cost were scrutinized and validated at the Preliminary Design and Final Design Reviews.
- Programmatic Review: A comprehensive external panel review of construction progress took place April 8-10, 2019 in Boulder, CO. In addition to an assessment of the project's status against the Project Execution Plan, the review focused on establishing the criteria for project close-out and acceptance. The panel's final report was submitted to NSF and the results reviewed by NSF and transmitted to the project management team. NSF continues to work with the management team to address any outstanding recommendations.
- Earned Value Management (EVM) System Surveillance: In conjunction with the external panel review described above, a surveillance of the project's EVM system was conducted on April 10-11, 2019. This surveillance provided an updated assessment of the project's previously validated EVM system. The final assessment report was submitted to NSF and transmitted to the project. NSF continues to work with the project to address any outstanding recommendations.
- Final Construction Review: An external final construction review of the DKIST Project was scheduled to take place on Maui, Hawai'i in April 2020. The review, which was to include an in-person site visit for the review panelists, has been postponed due to the COVID-19 pandemic. NSF plans to conduct this review in Q4 of FY 2021. Because of continued travel restrictions, it is likely that this final construction review will be held virtually.

Risks

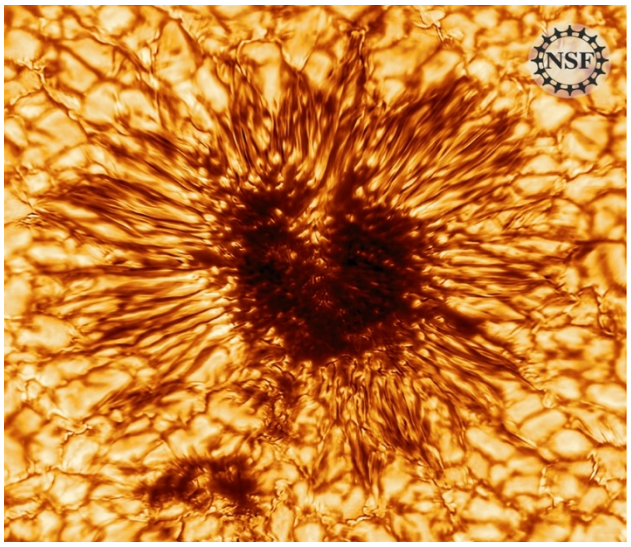
Project management control, interface control, and change controls are in place. The project management team also maintains a risk register that is reviewed and updated monthly.

Technical

Most of the remaining technical risks are relatively low because of the extensive development and design activities prior to construction. The CSA between NSF and AURA identifies four facility-class instruments to be delivered by the Project at the end of the Construction Stage. The Project is on track to deliver those four instruments. The VTF is a fifth instrument and is an in-kind contribution from Germany being designed and developed through a Memorandum of Understanding between AURA and KIS; therefore, the risks for this instrument remain with the German institute. KIS is currently on track to deliver the VTF instrument to DKIST prior to the start of operations.

Environmental and Cultural Compliance

AST, NSF's OGC, and the DKIST project have carefully worked through the applicable statutes, and a cultural monitor has been retained during construction. All required permits are in place and semi-annual consultations with a Native Hawaiian working group continue. Following the November 2012 issuance of the CDUP as mentioned in the Baseline History section above, several challenges to both the CDUP and the University of Hawai'i's Haleakalā Observatory (HO) management plan made their way through the State court system. In October 2016, the Hawai'i Supreme Court ruled against the appellant in both cases, upholding both the project's CDUP and the HO management plan. Due to NSF's robust implementation of its environmental compliance plan, on March 27, 2019, the State of Hawai'i Division of Forestry and Wildlife determined that NSF had met all of its environmental obligations as outlined in the Habitat Conservation Plan (HCP) and Incidental Take License (ITL) and thus approved early termination of the HCP and the ITL. The DKIST Special Use Permit (SUP) for construction and commercial vehicles issued by the National Park Service (NPS) expired June 30, 2020. The NPS issued a letter explaining that DKIST has satisfactorily complied with all the provisions stated in the SUP signed May 10, 2017, and a renewed permit is therefore not required. Remaining environmental and cultural compliance risks are very low.



First DKIST image of a sunspot released December 8, 2020. It represents the highest resolution image of a sunspot ever recorded. The image was taken on January 28, 2020 with a context imager on DKIST. *Credit: NSF, NSO, AURA.*

Environmental Health and Safety

NSO has a well-developed safety program integrated into the DKIST project. The DKIST project management team has developed a site safety plan and conducts annual external safety reviews. In addition, safety updates are provided to NSF monthly, and safety is one of the topics covered in the annual external panel reviews.

COVID-19

The impacts due to COVID-19 continue to manifest as risks to the schedule for the DKIST Start of Operations level-one milestone. As mentioned previously, DKIST construction continues at a reduced staffing level and efficiency for on-site activities. For much of the pandemic, the quarantine requirement

for travelers to the State of Hawai‘i (initially 14 days but reduced to 10 days in December 2020) limited the ability of teams from NSO headquarters, contractors, and instrument partners to complete the remaining integration, testing, and commissioning of the instruments and their supporting optical and thermal systems. However, as of October 15, 2020, the Governor of Hawai‘i implemented the Safe Travels Hawai‘i Program that allows travelers to bypass the quarantine requirement by obtaining a negative result on an approved pre-travel COVID-19 test. Teams from NSO and instrument partners have since been able to travel to Maui to participate in site acceptance testing and science verification activities. The current Start of Operations milestone is projected to be November 2021, which is based on current pandemic projections and the project's experience of working through the first year of pandemic conditions.