

DANIEL K. INOUYE SOLAR TELESCOPE (DKIST)

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No funding is requested in FY 2021 for construction of NSF’s Daniel K. Inouye Solar Telescope. FY 2019 represented the final year in an 11-year funding profile within an NSB approved not-to-exceed total project cost of \$344.13 million. Completion of construction atop Haleakalā on Maui, Hawai‘i is planned for no later than June 2020. This narrative provides an update on the project’s status.

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

	Prior Years	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021 Request ¹	Total Project Cost
MREFC Approp.	\$122.00	\$20.00	\$20.00	\$20.00	\$16.13	-	-	\$198.13
ARRA MREFC Appropriation	146.00	-	-	-	-	-	-	146.00
Total	\$268.00	\$20.00	\$20.00	\$20.00	\$16.13	-	-	\$344.13

¹ FY 2019 was the final year for MREFC funding for DKIST construction. The project is currently on track to complete construction in 2020 within the Total Project Cost cap.

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. DKIST will enable the study of magnetic phenomena in the solar photosphere, chromosphere, and corona. Determining the role of magnetic fields in the outer regions of the Sun is crucial to understanding the solar dynamo, solar variability, and solar activity including flares and coronal mass ejections. Solar activity can affect civil life on Earth through phenomena generally described as space weather and may impact the terrestrial climate. 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* and associated *National Space Weather Action Plan* 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 2019.³



The DKIST telescope enclosure and Support and Operations building at the site on Haleakalā, Maui, HI. Credit: David Boboltz, NSF.

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.whitehouse.gov/wp-content/uploads/2019/03/National-Space-Weather-Strategy-and-Action-Plan-2019.pdf

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 in GEO. The current design, cost, schedule, and risk were scrutinized in an NSF-conducted Preliminary Design Review 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 approved an award for this amount 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 MREFC account (\$7.0 million) and the American Recovery and Reinvestment Act (ARRA) account (\$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 on 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 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.

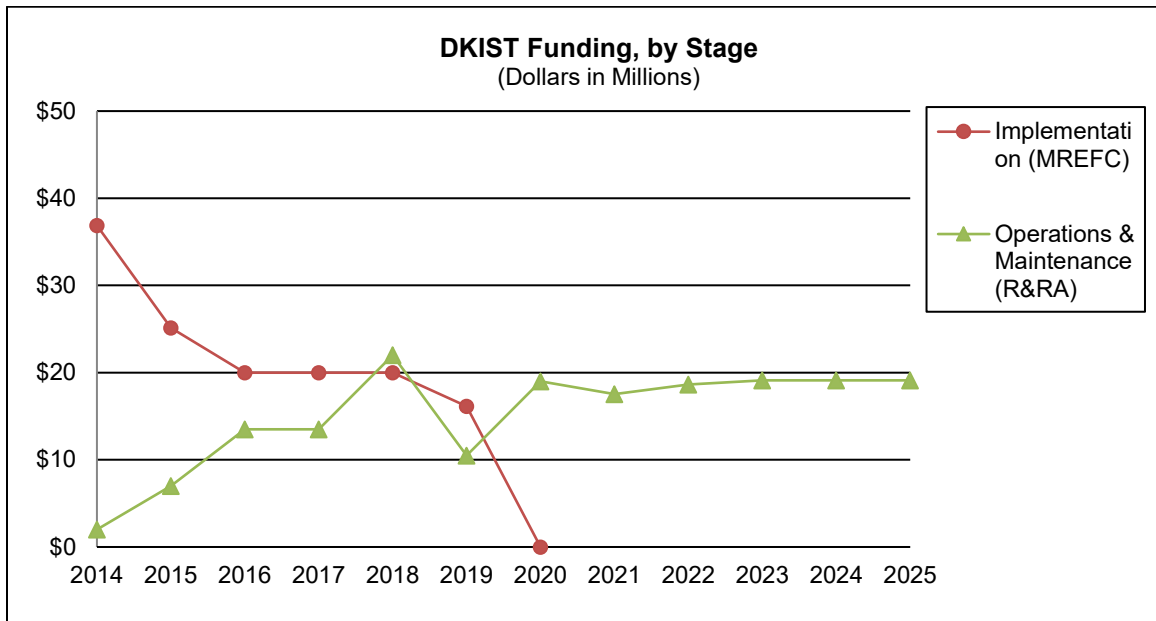
Total Funding Requirements for DKIST

(Dollars in Millions)

	Prior Years	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	ESTIMATES¹				
					FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
<i>R&RA:</i>									
Development & Design	\$20.41	-	-	-	-	-	-	-	-
Operations & Maintenance ²		10.50	-	17.54	18.08	18.62	19.13	19.13	19.13
ARRA	3.10	-	-	-	-	-	-	-	-
Subtotal, R&RA	\$23.51	\$10.50	-	\$17.54	\$18.08	\$18.62	\$19.13	\$19.13	\$19.13
<i>MREFC:</i>									
Implementation	182.00	16.13	-	-	-	-	-	-	-
ARRA	146.00	-	-	-	-	-	-	-	-
Subtotal, MREFC	\$328.00	\$16.13	-	-	-	-	-	-	-
TOTAL REQUIREMENTS	\$351.51	\$26.63	-	\$17.54	\$18.08	\$18.62	\$19.13	\$19.13	\$19.13

¹ FY 2019 includes \$2.0 million to another awardee for cultural mitigation activities as agreed to during the compliance process. Excluded is \$8.0 million of 2019 O&M costs obligated in FY 2018.

² Outyear O&M funding estimates are for planning purposes only. The current cooperative agreement ends September 2024.



The DKIST project is a collaboration of scientists and engineers at more than 20 U.S. and international organizations. Other partners include the Air Force Office of Scientific Research and international 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 the U.S. Air Force 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.

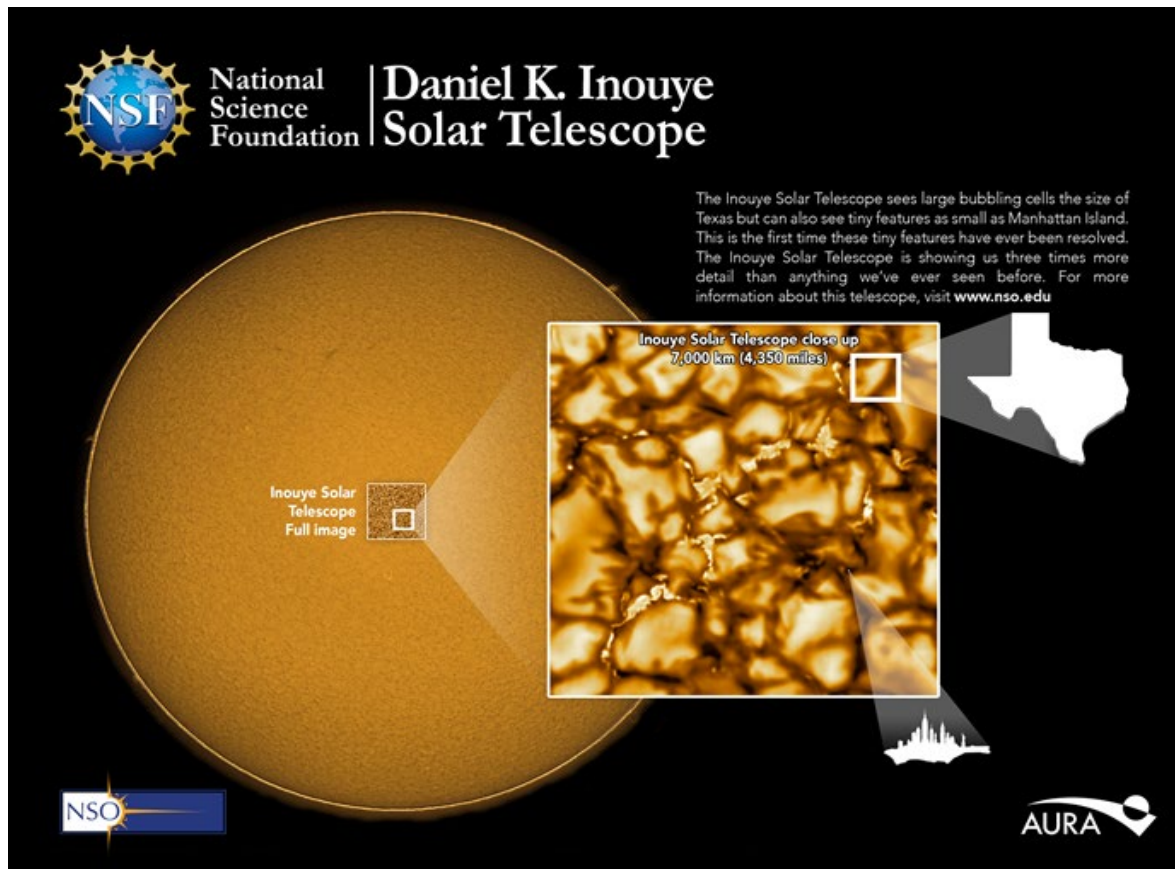
Management and Oversight

- **NSF Structure:** NSF oversight is handled by a program officer in AST working cooperatively with staff from MPS, the Office of Budget, Finance, and Award Management (BFA), the Office of the General Counsel (OGC), and the Office of Legislative and Public Affairs. Within BFA, the Large Facilities Office (LFO) 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.
- **External Structure:** NSO conducts the construction project. NSF funds NSO operations and maintenance (O&M) and DKIST design and 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 DKIST CSA for construction expires June 30, 2020. In 2015, the NSO CA and O&M CSA were renewed through the end of FY 2024. This period covers the DKIST construction phase and the achievement of sustainable operations of the completed facility. The DKIST director 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 experience in large telescope development, having served as lead telescope engineer for the Gemini Telescopes project. Several councils and working groups give input from the solar and space physics communities.

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 programmatic review of the DKIST MREFC construction project 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. NSF continues to work with the project to address any outstanding recommendations.
- Earned Value Management (EVM) System Surveillance: In conjunction with the programmatic review described above, a one-day 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.



NSF's DKIST images the sun in more detail than ever seen before. The telescope can image a region of the sun 38,000km wide. Close up, these images show large cell-like structures hundreds of kilometers across and, for the first time, the smallest features ever seen on the solar surface, some as small as 30km. Credit: NSO/NSF/AURA.

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. The project 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 Hawai'i cultural practitioners.

Construction highlights

- In early FY 2019, DKIST achieved its first images of star light and completed its first pointing model using a temporary Nighttime Acquisition Telescope mounted at the telescope prime focus.
- In FY 2019, the project continued to implement the critical integration, testing, and commissioning (IT&C) phase of construction.
- Fabrication of the first of the DKIST instruments, the visible broadband imager (VBI), was completed and the VBI installed in the DKIST coudé laboratory on the summit in FY 2019.
- In early FY 2020, the Wave Front Correction (WFC) system was installed and tested on the summit of Haleakala. 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, i.e., first light on the Sun through the entire optical path including the WFC. As part of this first-light initiative, the VBI instrument recorded the highest resolution images of the Sun ever made.

In FY 2020 the project will continue to work through the final stages of IT&C and the integration of the remaining first-light instruments. By Q4 of FY 2020, it is expected that DKIST will have achieved its final Level 1 milestone—Start of Operations.

Cost and Schedule

The original baseline not-to-exceed, risk-adjusted cost was established following FDR. As noted above, a revised project baseline review was held in October 2012; NSB approved the new baseline in August 2013. Total project cost of \$344.13 million is derived from ARRA (\$146.0 million) and annual appropriations in 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 June 2020 at an 80 percent confidence level for successful completion. The project is currently on track for a FY 2020 end date within the authorized funding level of \$344.13 million.

Risks

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

Technical: Most of the remaining technical risks are relatively low because of the long development and design phase. The CSA between NSF and AURA identifies four facility-class instruments to be delivered by the DKIST project at the end of the MREFC construction phase. The Project is on track to deliver those four instruments. The VTF is a fifth instrument and is an in-kind contribution from the German KIS 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.

Major Research Equipment and Facilities Construction

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 Hawai'ian 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. On March 27, 2019, NSF received approval from the State of Hawai'i Division of Forestry and Wildlife for early termination of its environmental obligations as outlined in the Habitat Conservation Plan (HCP) and Incidental Take License (ITL). Remaining environmental and cultural compliance risks are very low.

Environmental Health and Safety: NSO has a well-developed safety program engendered in the DKIST project. The DKIST project has developed a site safety plan and conducts annual external safety reviews. In addition, safety updates are provided to NSF by the project on a monthly basis and DKIST project safety is one of the topics covered in the annual external program reviews.

Operations Costs

DKIST operations are funded through R&RA. In FY 2021, the projected budget is \$17.54 million for DKIST operations. FY 2020 was the final year of the 10-year award for cultural mitigation activities.